INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
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Air Infiltration Centre

Air Infiltration Control in Housing
A Guide to International Practice

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Swedish Council for Building Research

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AIR INFILTRATION CONTROL IN HOUSING
A GUIDE TO INTERNATIONAL PRACTICE

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Annex V Air Infiltration Centre

Participants in this task:

Canada, Denmark, Italy, Netherlands,
New Zealand, Norway, Sweden, Switzerland,
United Kingdom and United States of America

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PREFACE

Internal Energy Agency

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialised countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Cooperation and Development (OECD) to administer that agreement. Twenty-one countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the Participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat staff, coordinates the energy research, development, and demonstration programme.

Energy Conservation in Buildings and Community Systems

The International Energy Agency sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, etc. The difference and similarities among these comparisons have told us much about the state of the art in building analysis and have led to further IEA sponsored research.

Annex V Air Infiltration Centre

The IEA Excecutive Committee (Buildings and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous agreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and to increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial ground-work the experts group recommended to their executive the formation of an Air Infiltration Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardization of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and based on a knowledge of work already done to give direction and a firm basis for future research in the Participating Countries.

The participants in this task are Canada, Denmark, Italy, Netherlands, Sweden, Switzerland, United Kingdom and the United States.

New Zeeland and Norway are participants from June 1982.

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PART A

A1 BACKGROUND AND INTRODUCTION

Energy for heating and ventilating buildings constitutes a significant proportion of the total energy consumption by different countries. Traditionally, a building's energy status has been characterized primarily by the k-values – the coefficient of thermal transmittance – of different sections of the building. For this reason, there is a considerable amount known about thermal transmittance and detailed regulations exist in different countries as to how k-values should be calculated and which maximum permissible values are accepted for the different structural components in a building. Energy consumption resulting from transmission through the building envelope is therefore relatively well-defined by the structural component's k-value and the indoor-outdoor temperature difference.

In contrast to thermal transmission far more limited knowledge is available on the subjects of ventilation and airtightness. Standards and regulations are lacking. However, in the research work that has been carried out over recent years, efforts have been made to consider air leakage and ventilation in more detail. This has led, in many respects, to the development of a completely new construction technology in order to save energy. The aim of this construction technology is to make the building envelope so airtight that undesirable air leakage can be minimized and to do so in a safe manner. In the same context, calculation methods have been developed which explain the mechanisms that govern the air leakage in a house. The driving forces for air leakage and ventilation are air pressure differences. These are made up of components from temperature, wind effects and fan effects when mechanical ventilation is used. In addition, the leakage characteristic for the building envelope is difficult to quantify. This means that a sufficiently accurate calculation of energy losses resulting from air leakage and ventilation is relatively complicated. Attention must be paid to attaining an acceptable air quality in dwellings by ensuring that a certain minimum ventilation is maintained independent of the effects of the outdoor climate. This can be achieved with mechanical ventilation or to some extent with controlled natural ventilation. Therefore it is becoming more and more important to consider the interaction between building technology and ventilation technology.

Several new measurement methods have been developed to check the airtightness of a building envelope. Some of these methods can be applied to determining air leakage and ventilation during different climatic conditions. Some methods are suitable for production control, others for research purposes.

It has been considered a matter of urgency to consolidate available research results and other experience in the form of a handbook. This handbook, which forms part of the work of the AIC (Air Infiltration Centre), reviews the state of the art with respect to problems associated with a building's airtightness in the countries which take part in the work within the AIC. General principles, motives, standards, assumptions, climate, energy balance in a house, and common recurring design solutions for both existing and new buildings are treated in the handbook's general section, Part A.

Part B of the handbook contains detailed information about the climate in different countries. It has a main section for each country and each section contains several design examples showing how building structures can be produced to achieve a resonable degree of airtightness. In general, these show examples of good design technology in the respective country.

By tradition, building technology differs from country to country and thus the design and degree of airtightness are also different. In some cases, new building technology is necessary to minimize air leakage. Using other solutions, better airtightness can be achieved with relatively simple measures. Several examples are shown whereby improvements are possible using such simple methods.

Design technology will be affected by new and more stringent requirements for building low-energy, i.e. well-insulated and airtight, houses. The handbook also shows how to satisfy thermal insulation demands while retaining the goal of building problem-free houses with energy demands that are as low as possible.

A2 REASONS FOR ACHIEVING AIRTIGHTNESS IN BUILDINGS

Infiltration and exfiltration of air through a building envelope has become accepted as an intrinsic feature of a building. In residential construction, some regard it as necessary for the proper ventilation and operation of the house. In contrast to this attitude, others suggest that air leakage wastes heat and is detrimental to the performance of the building.

Air infiltration into a building cannot be treated or conditioned, nor can its rate of supply or distribution to the occupied space be controlled. Attempts to do so by intentional pressurization of the building result in a greater waste of energy and promotes increased condensation and thus deterioration of the building fabric. Air leakage through a building envelope, and between building components, can also disrupt the intended operation of heating, ventilating and air conditioning systems and places limitations on the control of noise, fire and smoke (1).

An overview of different ventilation systems for residential buildings is presented in Table A2.1. This table also contains a summary of advantages and disadvantages for each system.

A2.1 Control of air exchange in buildings

Both theoretical calculations and measurements in buildings indicate clearly that there is a connection between the tightness of the building envelope and different types of ventilation system. In the case of natural ventilation, the ventilation is governed to a considerable degree by the climate – wind and temperature – and the size and distribution of leakages. In a multi-storey building with evenly distributed leakages, the ventilation in bottom apartments is often considerable because of the stack effect. On the other hand, the amount of ventilation is often small and inadequate in the highest apartments since the stack effect is negligible in such cases. See Figure A2.1.

The relationship between airtightness, ventilation system and outdoor climate has been studied theoretically by Nylund (2) and others (see also Chapter A7). Figure A2.2 gives an account of results calculated

Table A2.1. Properties of ventilation systems for dwellings.

Ventilation system	Advantages	Disadvantages
Natural ventilation (N).	Simple, low-cost installations. No moving parts in the system. No electricity cost.	Ventilation dependent on many factors: – wind and temperature. Highest ventilation in cold and windy weather. – human behaviour in opening windows or special ventilation provision. – airtightness of the house and leakage distribution. Leaky houses suffer from excess ventilation and draught. In airtight houses there is a risk of insufficient ventilation with, e.g., condensation and air pollution problems as a result. – length of ducts and hight of building. Space-demanding ducting (wide ducts) especially in multi-storey buildings.
Natural controlled ventilation (NC). Automatic control of supply or exhaust air flows due to wind or/and temperature conditions.	Low-cost improvement of N-system.	The effects of such systems on ventilation and energy consumption are yet not sufficiently documented. Problems could arise in controlling air flows and airchange rates especially when driving forces are small and building not airtight. Space-demanding ducting especially in multi-storey buildings.
Mechanical exhaust fan ventilation (E).	Ventilation depends mostly on speed of fan. Depressurization of building which reduces the risk of moisture convection outwards in the constructions. Low-cost mechanical ventilation system. An airtight envelope with properly sized and placed air inlets could provide a well distributed and controlled ventilation. Easy to fit with heat recovery on the exhaust air (e.g. heat pump for hot water production).	A risk of insufficient ventilation in parts of building if leakages are unevenly distributed with big leaks close to the exhaust. Air inlets must be properly sized and placed to reduce the speed of air into conditioned space (draughts). Discomfort caused especially when cold weather. Fan forces are dominating which means that sealing measures only is effective to a certain limit. Ducts must often be cleaned.
Mechanical supply and exhaust fan ventilation (SE).	If airtight building excellent control of ventilation in whole dwelling. Possibilities to treat supply air with preheating and filtering. Supply air could be taken from a place where air pollution is low. Easy to fit with heat recovery.	Expensive installations, especially in existing buildings. Needs a very airtight building to function as intended. Very sensitive to pressure disturbances. Noise from fans could be a problem. Supply air devices must be placed properly to avoid dirt on surfaces caused by the airstream. Ducts must often be cleaned.

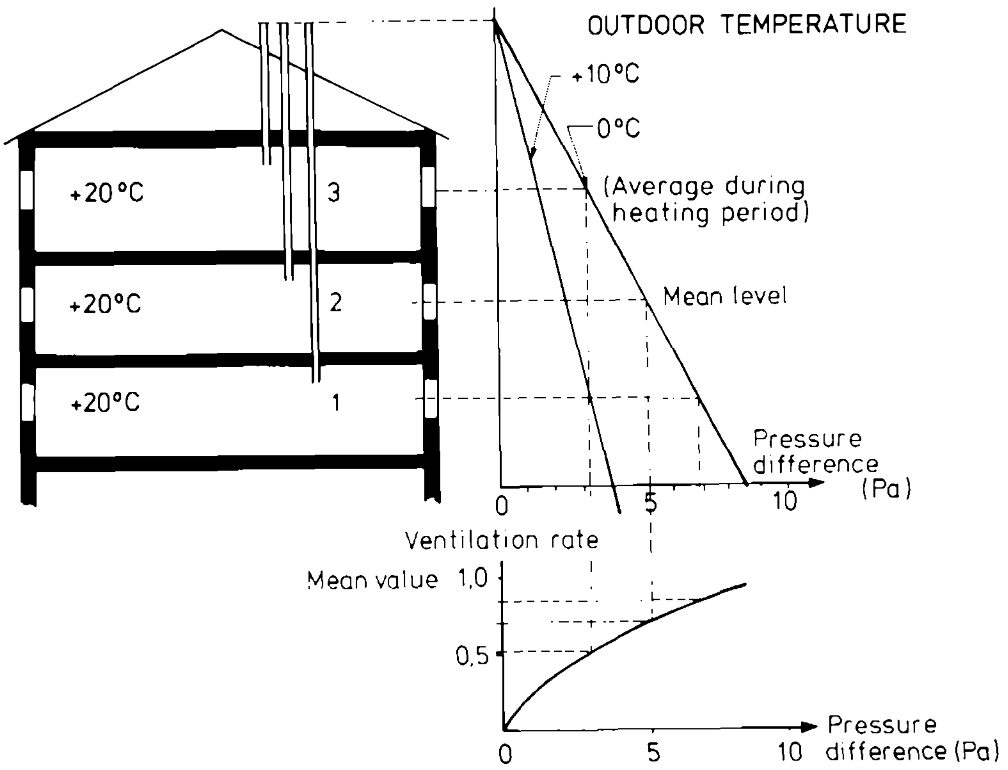


Figure A2.1. Natural ventilation in a multi-storey building due to stack effect. In the bottom apartments the ventilation rate is considerable, often excessive. In the highest apartments, on the other hand, it is often very small and insufficient. In reality the pressure difference is also influenced by wind effect.

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 air changes per hour (ac/h) in still wind conditions and identical indoor and outdoor temperatures. The example illustrates how ventilation is affected by wind speed. 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 (with vents blocked). For airtight houses, e.g. $n_{50} \leq 1.0$ ac/h, the exhaust fan has a dominating effect on ventilation and air infiltration. Air infiltration does not increase until very high wind speeds are in force. In pervious houses, e.g. $n_{50} \geq 5.0$ ac/h, the air leakage increases rapidly with wind speed.

Using the same model, Figure A2.3 shows the calculations of mean annual ventilation in single-family houses with different leakage

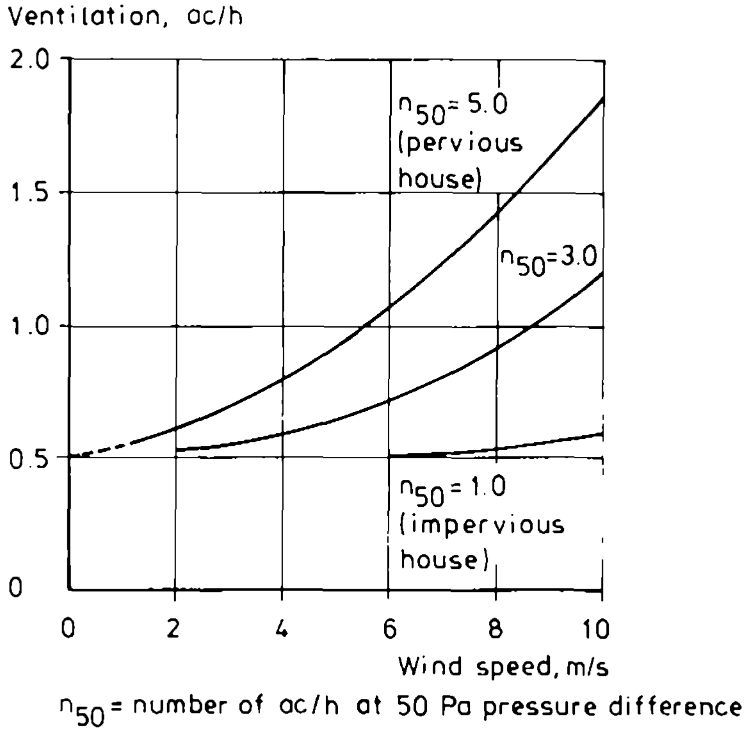


Figure A2.2. Theoretical calculation of air change rate for a one-storey, single-family house with exhaust fan ventilation as a function of wind speed and the house's air change rate determined using the pressure test method. The stack effect is neglected in this example. In impervious houses, $n_{50} = 1.0$*, the ventilation is little affected by wind speed whereas the ventilation in pervious houses,* $n_{50} = 5.0$*, increases rapidly with wind speed.*

factors and ventilation systems. 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 mechanical ventilation systems are adjusted to 0.5 ac/h in still wind conditions and identical indoor and outdoor temperatures. The same figure can be used to calculate energy losses through ventilation using the scale to the right. The results show that in very airtight houses with mechanical exhaust air ventilation, the ventilation is entirely dependent on how the ventilation system is adjusted.

In a house with controlled supply and exhaust ventilation, the rate of ventilation is determined by the fan setting. However, the house still functions as a natural ventilation system, i.e. a balanced system does not affect the pressure state and air leakage can take place unhindered through leaks in the building's envelope. This undesirable, extra air flow is thus determined by the outdoor climate

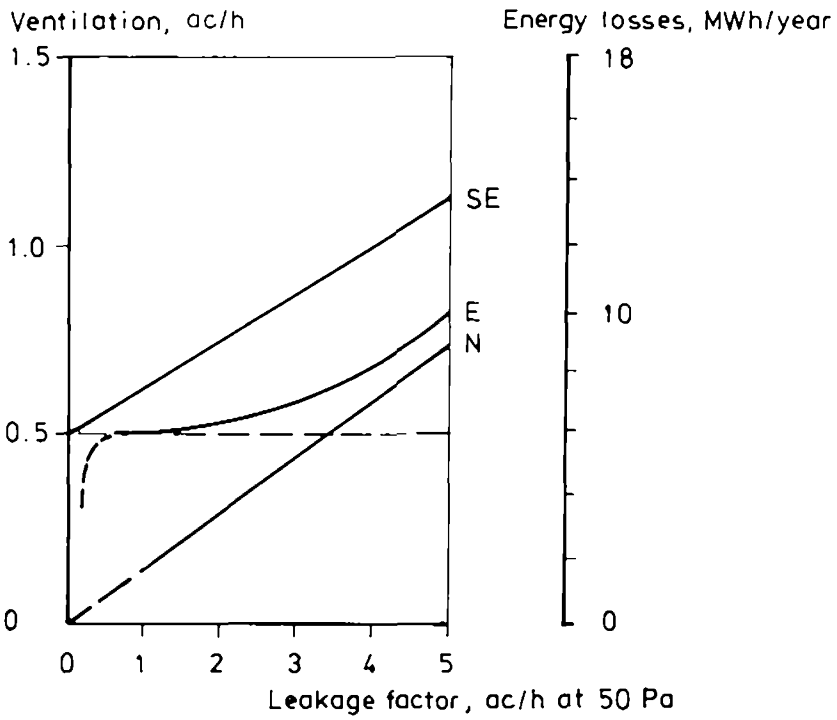


Figure A2.3. *Theoretical calculation of mean annual ventilation for different types of ventilation system in a single-family dwelling as a function of the house's perviousness and from tests using the pressure test method. The scale on the right indicates energy losses in Stockholm's climate caused by ventilation, based on a dormer house with approx. 130 m^2 living area.*

SE = supply and exhaust ventilation system,
E = exhaust fan ventilation system with slot air valves,
N = natural ventilation without air supply devices.

and the size of leaks, and can be shown to be greater than in houses fitted with only exhaust air ventilation. Therefore there is justification for building a tighter house if it is fitted with a mechanical supply and exhaust air system. This becomes even more significant if the house is fitted with a heat recovery system. Obviously, it is only the air which is exhausted through the heat recovery system that can have its heat extracted. Houses with mechanical supply and exhaust air systems fitted with a heat recovery system should be made very airtight if the system is to function as intended, i.e. as a low-energy house.

The examples show that with increasing airtightness undesirable air infiltration and resultant additional heat losses are reduced.

In houses with natural ventilation, it is often assumed that the building is pervious. The ventilation is primarily determined by the outdoor climate and not by the fresh air requirement. This means that if the minimum requirements for air quality are to be maintained for all outdoor climatic conditions, ventilation during the greater part of the year is excessive. Systems for controlled natural ventilation which react to climatic changes by regulating exhaust or supply air flows are under development. Se Figure A2.4. In airtight buildings with natural ventilation systems, ventilation is dependent on human behaviour — opening windows.

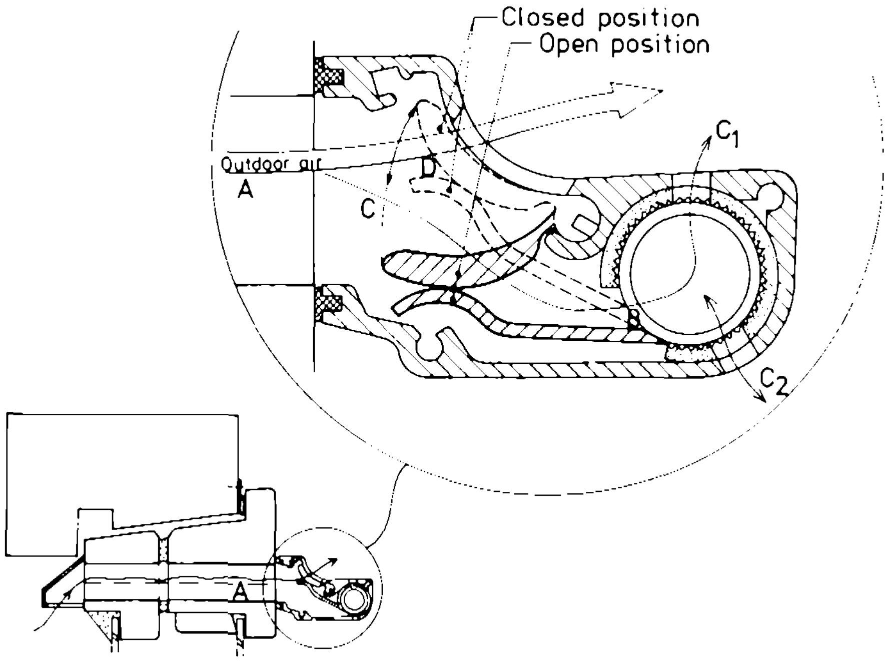


Figure A2.4. Special patented slot air valve "SPAR-VEN" for controlling the amount of supply air in a natural ventilation system.

This ventilator could easily be mounted in the upper casement of a window. Air comes in through drilled holes A in the casement. When colder air, the bimetallic spiral B cools down by the airstream C and the gap D gets smaller. When windy weather the bimetallic spiral cools down even more by the airstreams C, C_1 and C_2 which results in further reduction of the gap. As the air temperature gets higher, the gap is widening in a corresponding way.

Mechanical ventilation systems must be designed correctly. The following Swedish example shows some of the problems (2, 3).

In houses ventilated with an exhaust system, the exhaust air flow is often regulated in Sweden by a centrally positioned control device on the kitchen exhaust. The exhaust air fan is normally fitted in the ventilation duct above the roof. There is seldom an exhaust air device in bedrooms, workrooms, etc. whereas a device is fitted in wet rooms and kitchens. "Tainted air" is extracted via the exhaust air device, while outdoor air enters the house via air supply devices (e.g. slot air valves). These are often positioned above windows in rooms where there are no exhaust air devices (se Figure A2.5).

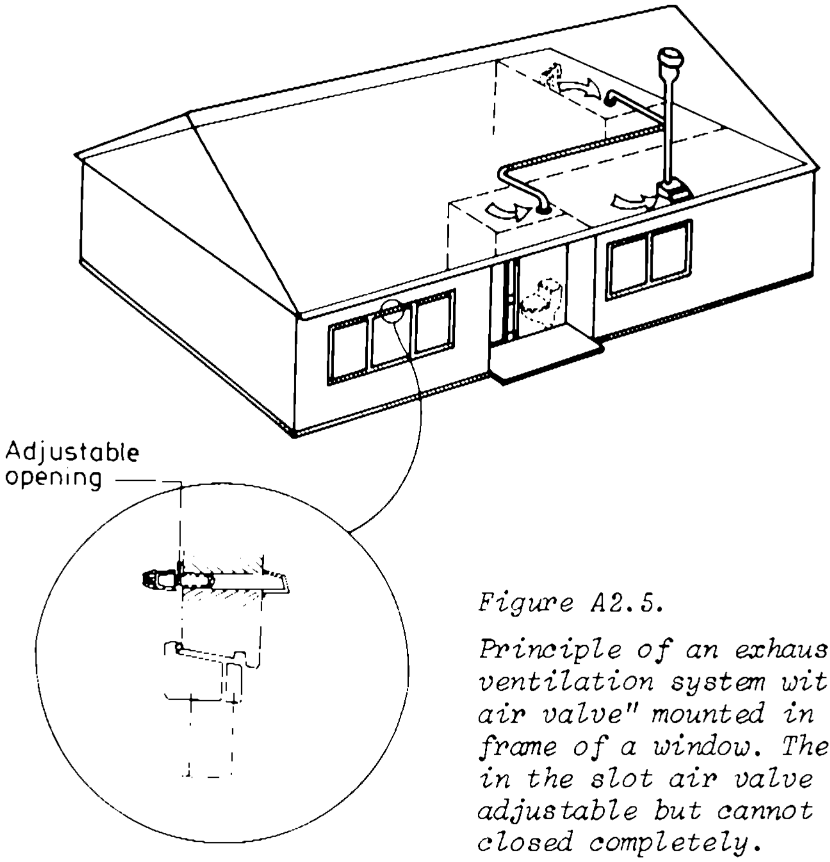


Figure A2.5.

Principle of an exhaust fan ventilation system with a "slot air valve" mounted in the upper frame of a window. The opening in the slot air valve is adjustable but cannot be closed completely.

According to the Swedich Building Code (SBN) the minimum air change rate for the whole house must not be less than 0.35 l/s per m^2 (dm^3/s per m^2) of living area. This corresponds to approximately 0.5 ac/h for the whole house. SBN says nothing about a minimum air change rate for bed- and living rooms, it merely states that "discomfort must not arise".

Tracer gas techniques have been applied to check air change rates in bedrooms occupied for a long period in two detached houses with different airtightness (A and B). The results are summarized in Table A2.2.

In a type A house, the majority of the supply air enters via the slot air valves in the rooms. This means that all rooms are ventilated. In the slightly less tight house, type B, a greater proportion of supply air enters via leaks in the structure. Since these are not evenly distributed throughout the building, there is a risk that individual rooms will be

Table A2.2. Air change rates for different fan settings in a master bedroom with slot air valve open and closed respectively. The door to the master bedroom was closed.

House	Leakage factor ac/h at 50 Pa	Fan setting	Measured air change rate in bedroom dm^3/s (m^3/h)	h^{-1}
A	1.0	Fan set as per SBN (0.35 $l/s\ m^2$) approx. 0.5 ac/h throughout whole house, slot air valve open	8.2 (29.5)	1.0
		Fan set as per SBN (0.35 $l/s\ m^2$) approx. 0.5 ac/h throughout whole house, slot air valve closed	6.0 (21.6)	0.73
B	3.0	Fan set as per SBN (0.35 $l/s\ m^2$) approx. 0.5 ac/h throughout whole house, slot air valve open	5.4 (19.6)	0.66
		Fan set as per SBN (0.35 $l/s\ m^2$) approx. 0.5 ac/h throughout whole house, slot air valve closed	2.3 (8.4)	0.26
		Fan on basic setting approx. 0.25 ac/h throughout whole house, slot air valve open	3.4 (12.2)	0.37
		Fan on basic setting approx. 0.25 ac/h throughout whole house, slot air valve closed	1.4 (5.0)	0.15

NB The slot air valve in house A could not be closed completely whereas it could in house B.

inadequately ventilated even if the house as a whole is well ventilated. Similar results have been found by Blomsterberg (4).

Measurement results show that slot air valves have a decisive effect on a room's air change rate. Therefore it should not be possible to close the slot air valve completely.

Even with the fan setting at the air change rate recommended by SBN, a closed slot air valve in a type B house resulted in a very low air change rate, approx. 2.3 dm^3/s (8.4 m^3/h). Furthermore, the value is less than when the fan is set at its basic setting with the slot air valve open.

The measurements indicate that an airtight house allows more scope for achieving the required ventilation in different rooms than a less airtight house. Uncontrolled leaks in the untight houses with mechanical exhaust ventilation can result in parts of the house being inadequately ventilated. This leads to poor air quality and a risk of moisture problems.

The measurements also indicate that more attention must be paid to the ventilation system during design.

There is a need to study the interaction between building technology and ventilation technology both with regard to new designs and in the case of energy saving measures applied to existing buildings. Tightening measures should not be applied to the extent where the required ventilation is jeopardized.

Air leakage through the building envelope leads to a number of consequences which can be classified under the following headings:

a) efficient energy use

b) comfort and hygiene consequences

c) building design and moisture problems

d) acoustic control.

A2.2 Efficient energy use

From an energy viewpoint, it is important to limit the ventilation to the amount required for maintaining indoor air quality since energy is consumed in heating outdoor air. Energy losses in a building can be described as in Figure A2.6. As can be seen, undesirable ventilation resulting from air infiltration through the building envelope causes additional heat losses.

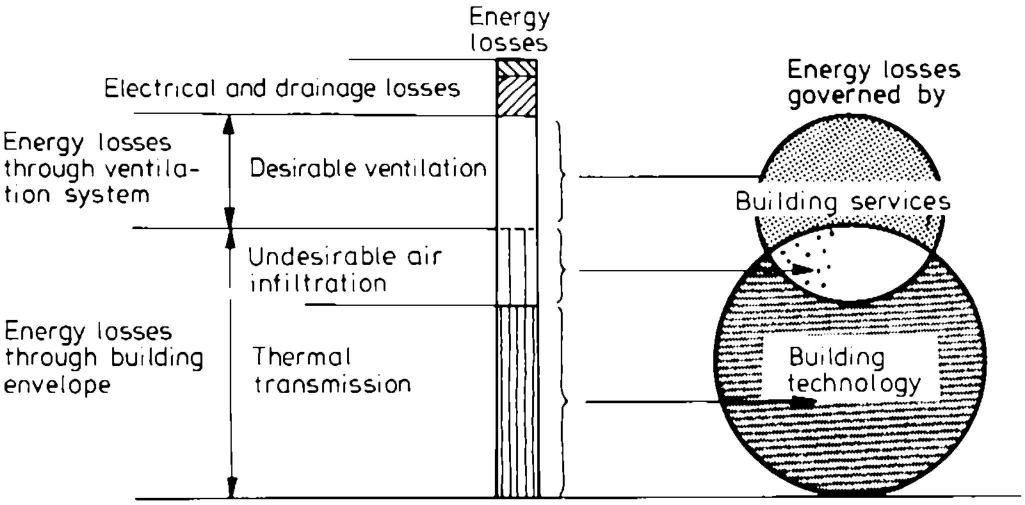


Figure A2.6. Exampele of energy losses due to ventilation and thermal transmission in a dwelling.

The desirable ventilation is primarily governed by the ventilation system while the infiltration depends on the interaction between building services and the building's airtightness. This is often not considered when designing bvildings.

Ventilation energy consumption is clearly illustrated in Chapter A.3. Older houses nearly always have natural ventilation which is dependent to a large extent on the perviousness of the building. To ensure sufficient ventilation for different outdoor climatic conditions, the average ventilation is often excessive. A survey of a relatively large number of houses in Sweden in the early 1970s showed that the average ventilation in single-family houses amounted to 0.7-0.8 air changes per hour (ac/h) (5). These houses had been built without any special regard to airtightness requirements. Sample tests showed that the houses' tightness when pressure testing at a pressure difference of 50 Pa amounted on average to 5 ac/h. There were, however, considerable differences between different houses. Recently built houses in Sweden are more airtight owing to more rigorous requirements which have led to a reduction in infiltration.

Similar results have been recorded in countries such as Canada and Switzerland.

To save energy, many older houses with natural ventilation have been made more airtight. This has led to insufficient ventilation in a number of cases. In turn, this has meant that a significant number of houses suffer from poor air quality and associated moisture problems such as surface condensation on windows. In extreme cases even mould has been observed in certain parts of the dwelling.

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

o Excess ventilation air must be heated to room temperature.

o Leaks can give rise to draughts which must be compensated for by an increase in room temperature which in turn causes increased energy losses.

o Air leakage can cool inner surfaces of parts of the outer structure. The room temperature must therefore be increased to compensate for radiation losses.

o Leaks can also give rise to blow through in mineral wool insulated constructions for example, significantly reducing the insulation effect.

A2.3 Comfort and hygiene consequences

Apart from the effects on energy requirements, uncontrolled air leakage also causes discomfort. A number of investigations agree with Axén and Pettersson's findings (6) that significant deficiencies in insulation and airtightness techniques are evident even in newly built houses, resulting in 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 A2.7 shows a sketch of where sensitive components often occur from the thermal insulation and airtightness aspects.

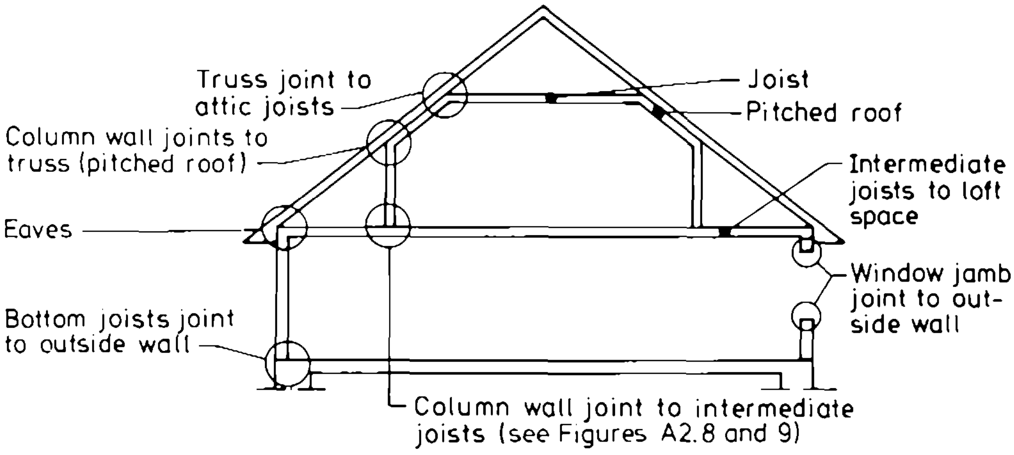


Figure A2.7. The structural sections which often give rise to complaints about draughts. The ways in which airtightness is achieved at joints between different building elements are seldom shown in building documentation.

As can be seen from the figure, leaks often occur at joints. Leakages are often irregular and localized giving rise to a considerable sense of draught in the winter. Draughts from windows and floor are often sensed as being uncomfortable and cold. Leakage at ceiling joints can give rise to floor draughts as a result of cold down draughts at external walls which then flow across the floor.

EXAMPLE OF CONSEQUENCES OF BAD DESIGN AND WORKMANSHIP

A particularly difficult item of construction in a dormer single-family dwelling is where the column wall is joined to the intermediate joists (7). Figure A2.8 shows an illustration of this common type of joint. The figure also shows a reconstruction of the normal method of connection in a group of buildings. Figure A2.9 shows a thermogram from floor level inside the column wall for the construction shown in Figure A2.8. These figures show that there is 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.

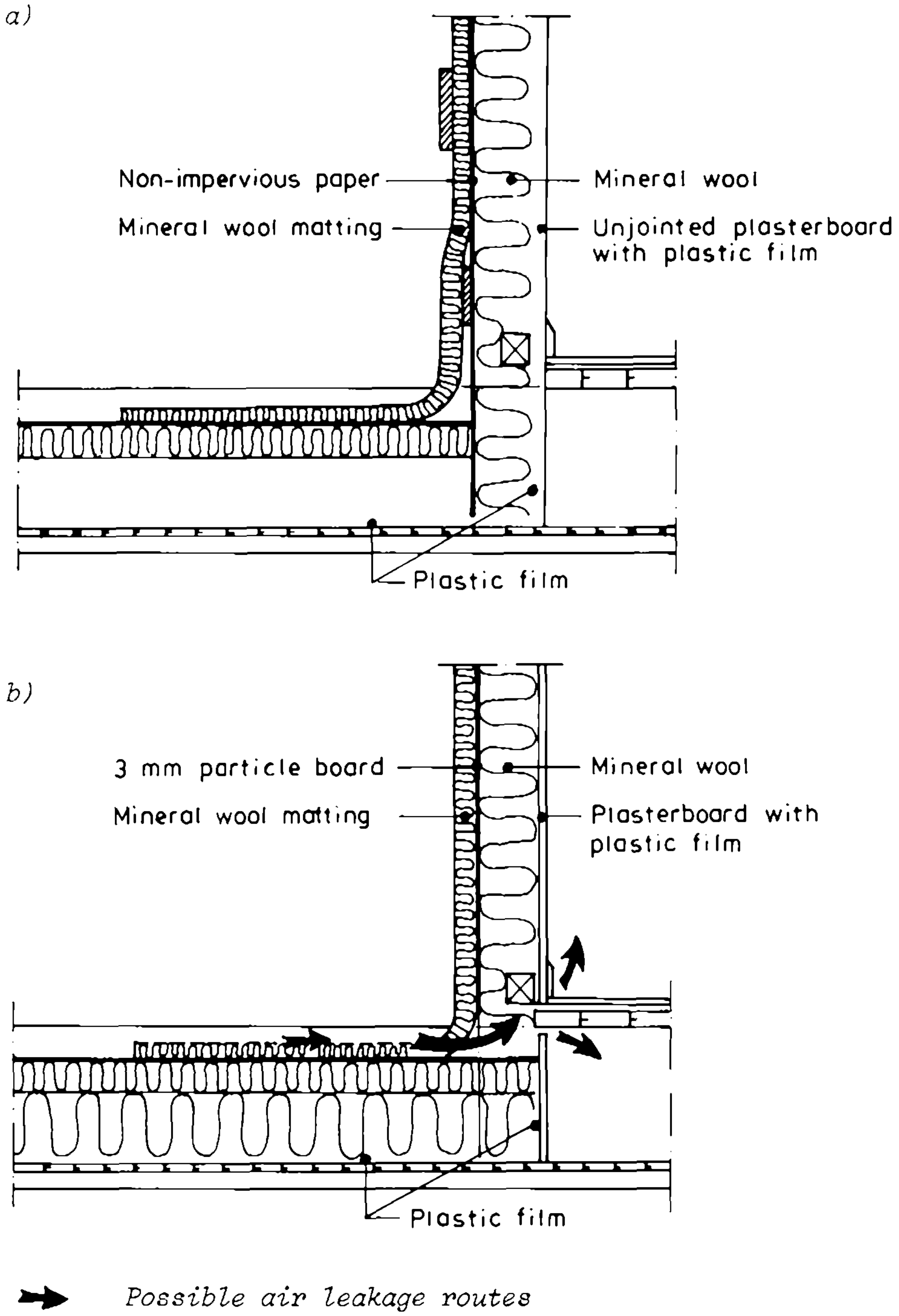


Figure A2.8.

a) An example of common drawing documentation showing how the joint between support wall and intermediate joists is to be carried out in a dormer house. Keeping 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.

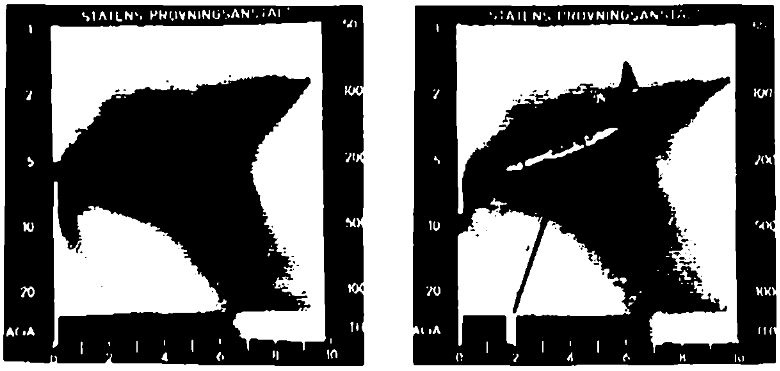


Figure A2.9.

Thermogram from the floor level inside the column wall in the construction in Figure A2.8. The figure to the left is a grey tone photograph and the one to the right an isoterm photograph. When the thermophotography was carried out the outdoor temperature was -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. This is an 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. Deficiences in airtightness and in filling with thermal insulation have therefore caused discomfort. Discomfort is increased by "unrestricted blow through" in the intermediate joists.

A certain minimum ventilation is required to achieve the desired air quality in a building. The ventilation system in the building must produce the required ventilation whether the system is naturally ventilated or fan-assisted. Apart from ventilation to provide air of good quality, additional air is sometimes required for combustion in certain heating devices.

The required ventilation depends on the amount of air pollution that is present. Apart from indoor pollutants the outdoor air quality is also important: air often contains high concentrations of pollutants, especially in urban areas. The highest concentrations usually occur at ground (street) level where the internal negative pressure is also highest owing to the stack effect. The most polluted air could then enter the building via leaks at ground level. By making buildings airtight, air could be brought in where the concentration of pollutants is at the lowest (at the roof). Cleaning incoming air with different kinds of filters is then also a possibility.

Indoor air pollutants are, for example, odours from humans and animals, tobacco smoke, oxides of nitrogen, carbon dioxide, carbon monoxide, formaldehyde, hydrocarbons and particulate matter. Ionizing radiation from radon and radon decay products can be a problem in buildings built on radioactive ground or made of certain materials.

Formaldehyde, as well as radon, presents a particular problem in many houses. Formaldehyde is emitted from glues used in chipboards, for example, and urea-formaldehyde (UF) foam is sometimes used for thermal insulation. In the United States, the Consumers' Product Safety Commission has prohibited the use of UF foam and are discussing prohibiting the use of formaldehyde in chipboards.

The problem of indoor pollutants is further described by Lindvall and Månsson (8). This paper is a result of the work on minimum ventilation rates in IEA annex IX.

Regulations on minimum ventilation and maximum concentrations of different pollutants indoors in different countries are given in Chapter A5.

A2.4 Building design and moisture problems

Traditionally, buildings were primarily constructed to provide adequate protection against wind and rain. This means that great attention was paid to windows, doors, walls and joints between wall sections to ensure wind protection and rain rejection. The outside roof is intended to provide adequate protection against precipitation and wind to a certain extent. Thus not too much attention was paid to building tight roof joists structures. Canadian studies (9) show that a considerable amount of air leakage goes through the roof joist structure. To a great extent this is caused by the large number of penetrations in the vapour barrier for service ducts and pipes in certain types of buildings, see Figure A2.10 and (10). In timber houses, air leakage also depends on the fact that air-vapour barriers are fitted after the erection of internal load bearing walls. This means that there are ducts and openings from lower floors up to the loft. Because of the pressure differences which often occur in houses with natural ventilation, air transport during the winter often takes place from warm areas to the loft space. Condensation is therefore formed against the cold inside of the roof during the winter. In

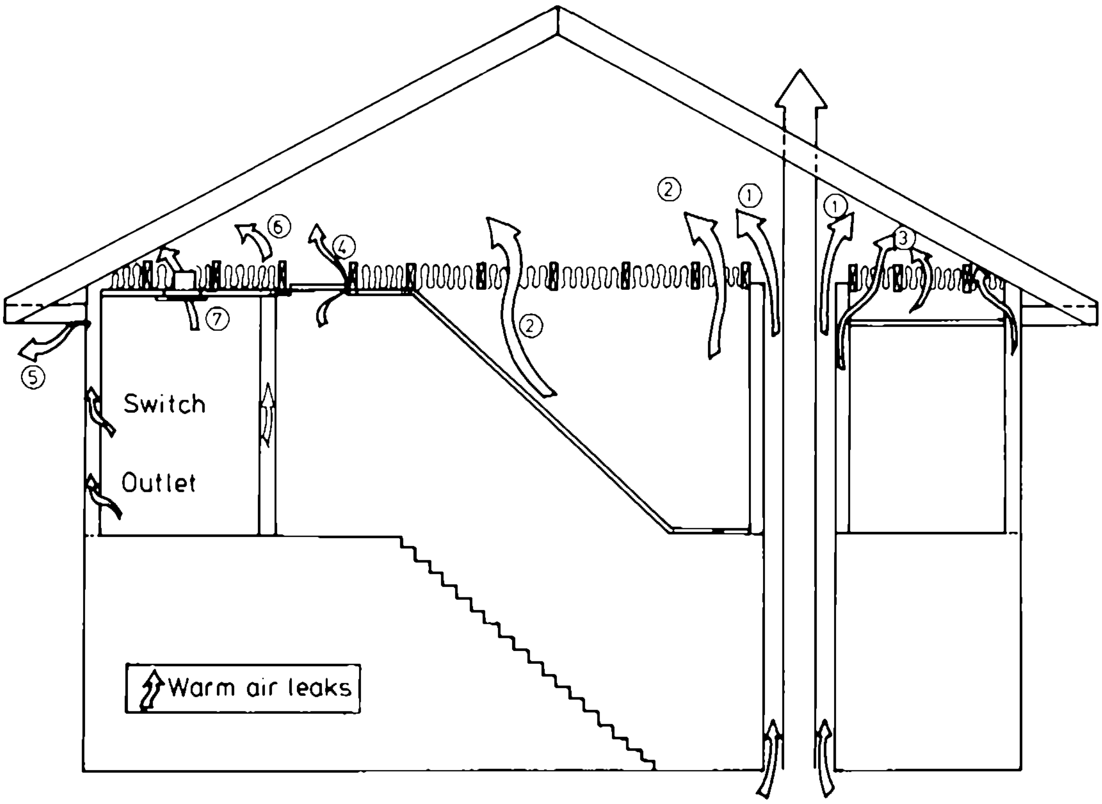


Figure A2.10. Common air exfiltration paths from the living space at the upper portions of the house: (1) around flue and plumbing stack, (2) through the insulation, (3) above dropped ceilings, (4) around entries, (5) penetrations in outer walls and eaves, (6) leakage up through interior walls and electrical systems and (7) recessed lights.

extreme cases, severe ice formation can occur and this is referred to in a Canadian investigation (11). Moisture problems, primarily in horizontal roofs, are common in countries such as Denmark and Sweden where the cause is often called "moisture convection", i.e. warm, moist air leaking through gaps from the inside to the outside. The actual leakages need not be particularly large for the consequences to be severe, see Figure A2.11.

There have been frequent examples of such damage when covering the ceiling with wood on the upper floor of dormer houses. Mould and, in particularly bad cases, rot has occurred. Figure A2.12 shows damage caused by moisture on an external panel. Even relatively good ventilation of the loft and the pitched roof has not prevented condensation damage. This is another reason why it is important to build airtight houses. All parts should be designed with good airtightness in mind.

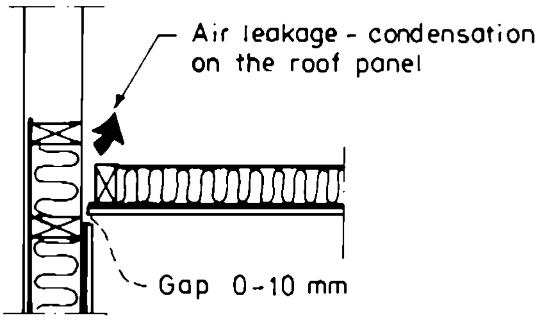


Figure A2.11. A common method of jointing between an outside wall and a truss in a dormer house. As a result of tolerances applied during building work, smaller gaps in the actual joint are not uncommon. Under certain conditions an internal overpressure sometimes occurs at the roof in upper floors of dormer houses. When there are gaps, air can leak through and cause moisture damage. It has been shown that gaps with a width of a few mm are sufficient to cause damage.

Figure A2.12. 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 A2.11. Experience has shown that it is not possible to avoid damage by improving ventilation of the attic. Only by making joints airtight is it possible to eliminate moisture accumulation and the consequent risk of mould and rot damage.

Problems with moisture convection also depend on the design of the ventilation system. The above-mentioned problems are primarily associated with natural ventilation. In the case of exhaust air ventilation with supply air coming through slot air valves and/or leakages there is normally a negative pressure in the house. This usually means that air leaks in through the entire building envelope. The risk of moisture problems as described above is very small in this case.

In houses with balanced ventilation employing both mechanical supply and exhaust air, it is more difficult to determine the pressure conditions in the house. Less well-balanced systems can result in positive or negative pressure indoors. Wind and stack effects can also influence the pressure difference. Experience in Sweden has shown that systems are often balanced so that there is a small positive pressure inside the house quite simply to avoid draughts through leakages. The resultant air transport can lead to severe condensation problems. There are several examples of resultant moisture damage to walls and windows. In certain circumstances, the problems can be quite simply eliminated by rebalancing the ventilation system so that there is a small negative pressure instead. It is difficult, however, to maintain such a small pressure difference bearing in mind the way filters etc. get clogged up. The best way to control these moisture problems is to build the house as airtight as possible so that extra air leakage is minimized.

Air leakage through different wall and joist structures can also drastically affect the thermal insulation characteristics of the construction.

Figure A2.13 illustrates the effect of air penetrating a wood-frame wall with mineral wool insulation according to Bankvall (12). A comparatively insignificant amount of air penetration can almost nullify the effect of, for example, an increase in insulation thickness.

Heat losses caused by blow through are usually large enough to dominate over the effects of other inadequacies in the form of badly fitting insulation and built-in cracks and gaps. Extensive blow through is normally caused by large localized leakage.

The problems are often closely associated with a building's wind protection. Mineral wool insulation which functions well demands that air must be prevented both from passing straight through the insulation layer and from entering the insulation and moving within it.

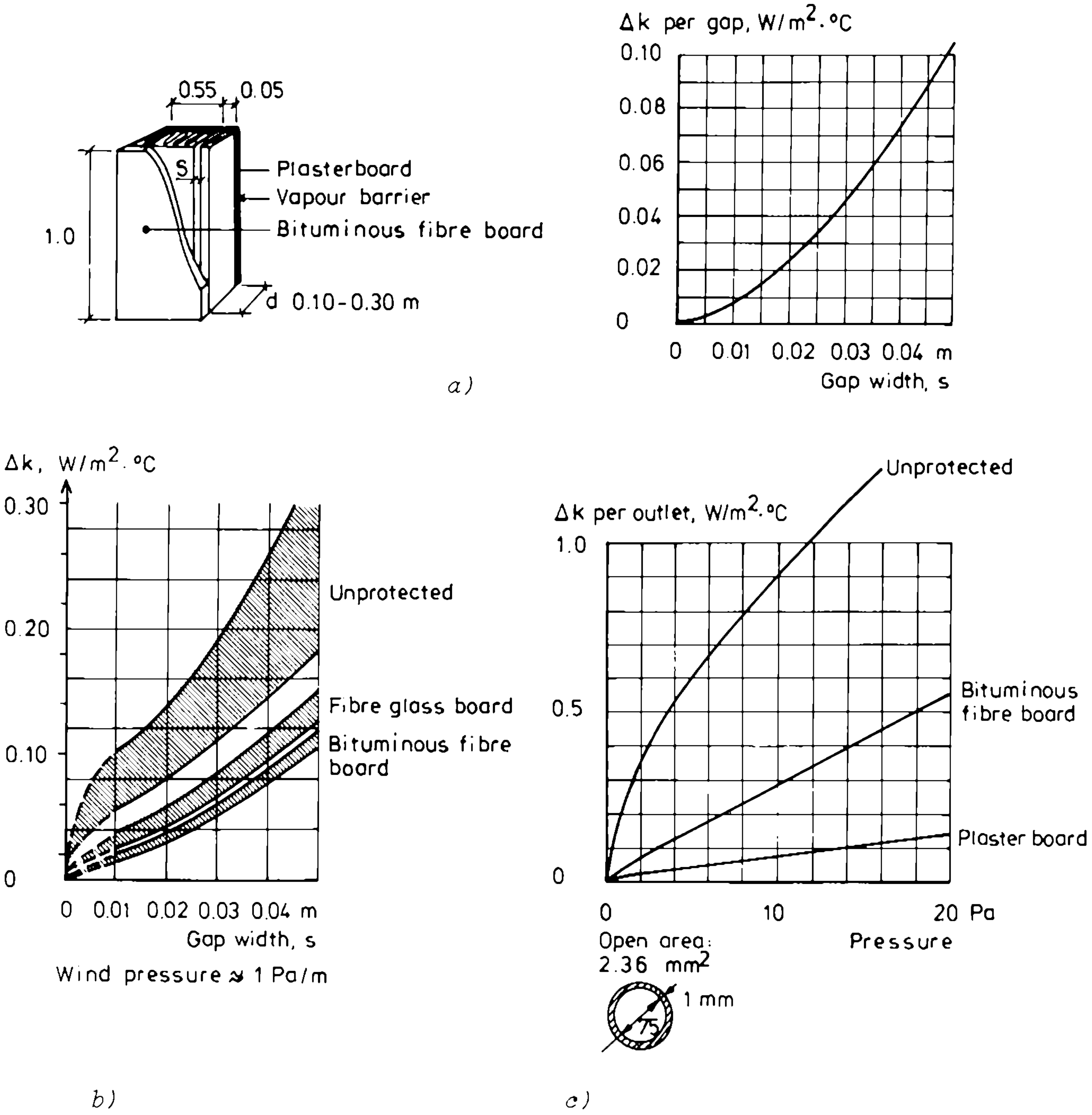


Figure A2.13.

Air movement in or through a stud wall affects its thermal insulation. The figure illustrates the increase of the heat flow expressed with increasing k-value (U-value), Δk (12).

Figure a) shows the influence of an air gap, s, between the mineral wool slab and the wood stud in a well wind-protected wall.

Figure b) shows the influence of wind on a wall with an air gap between mineral wool and stud when the wall has different wind-protections. It is an important increase of the heat flow when the wall is unprotected and has an air gap between insulation and wood studs.

Figure c) shows the influence of an air stream through the wall on the heat transfer coefficient. The air penetration is caused by bad workmanship with the vapour barrier and the internal cladding in connection to an electrical outlet or bad design of the outlet.

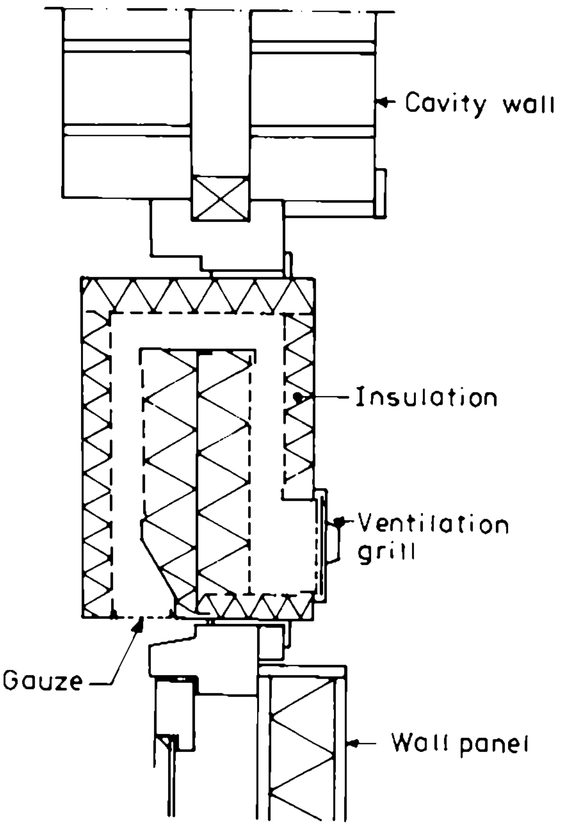
An airtight structure prevents the former and a carefully considered wind barrier prevents the latter.

A2.5 Acoustic control

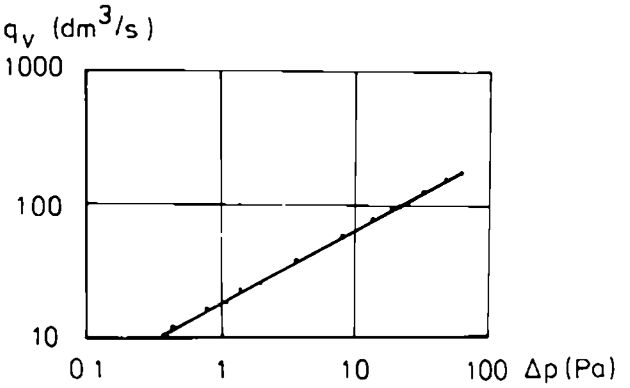
Airtight houses attenuate external noise much better than leaky houses. To start with, make sure that windows and connections are satisfactorily airtight thus providing better sound insulation. The problem is greatest in the vicinity of noisy traffic areas where building techniques could be used to cut down the sound level. Airtight houses contribute considerably to reducing the noise.

Supply air devices in walls could be a source of discomfort since they reduce sound insulation of a wall. However, different noise-reducing supply air devices are available. Figure A2.14 shows two examples of how the problem could be solved (13). Noise-reducing effect and leakage curves are shown for both examples.

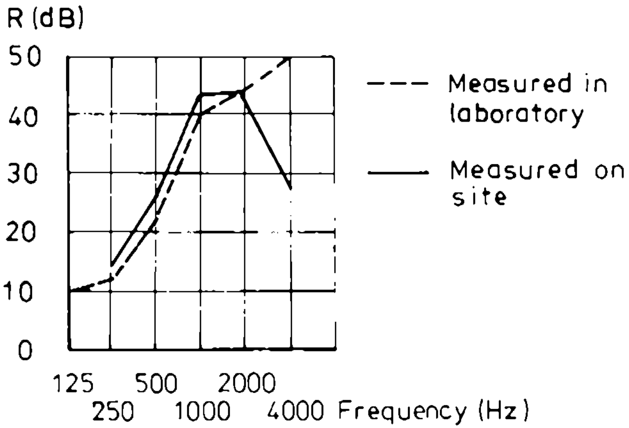
Internal noise, for example from fans, can be more obvious in airtight buildings.



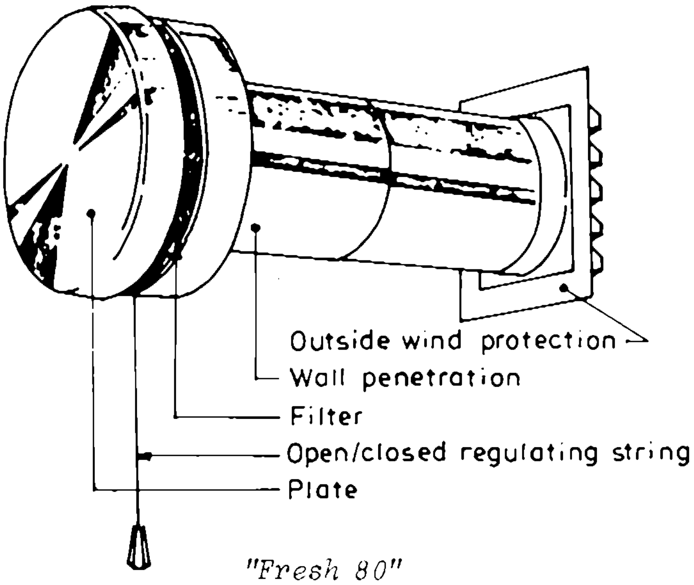
"Sound attenuator"



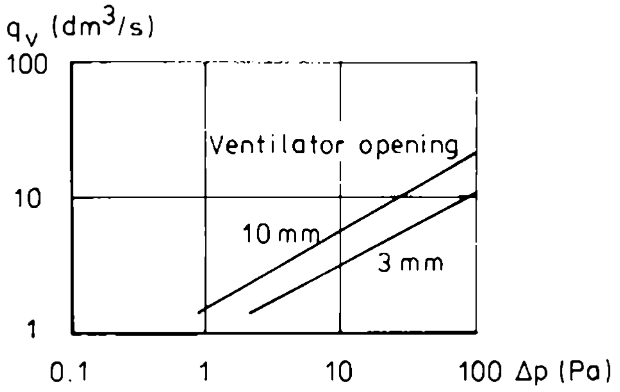
Flow rate, q_v, versus pressure difference, Δp



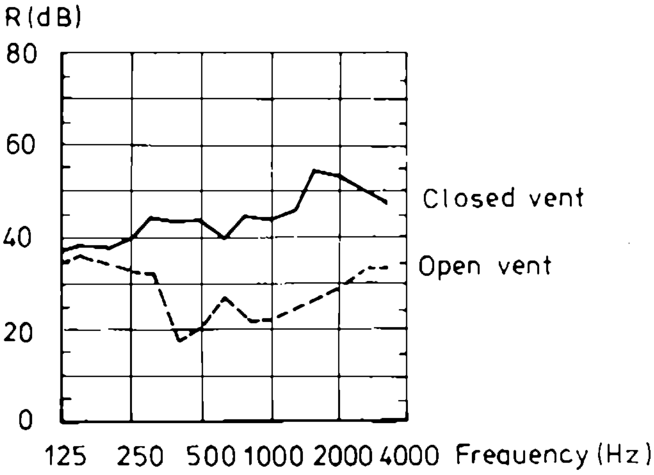
Measured sound insulation, R(dB)



"Fresh 80"



Flow rate, q_v, versus pressure difference, Δp



Measured sound insulation, R(dB)

Figure A2.14.

Two examples of supply air devices with noise reducing properties. The "sound attenuator" is from the Netherlands and the "Fresh 80" is from Sweden.

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A3 AIRTIGHTNESS AND ENERGY BALANCES

As indicated in Chapter A2, the airtightness of the building envelope affects the ventilation rate and thereby the energy consumption of a building.

This chapter contains an overview of levels of airtightness and examples of energy balances for dwellings in seven countries connected to the Air Infiltration Centre.

A3.1 Airtightness

As a measure of the airtightness of building envelopes in different countries, results from the pressurization test method is shown. This method is further described in Chapter A11. Results shown are not fully comparable since the procedure differs somewhat between countries. This is also shown in Chapter A11 (Table A11.1). When comparing these results two important differences should be noted:

1) Canada includes the basement in house volume even though it is not heated, while the rest of the countries use heated volume.

2) When pressure testing a building in Canada, Norway or Sweden the ventilation system is sealed off to get the leakage of the envelope. The United States, United Kingdom and The Netherlands prefer not to make any modifications to the dwelling. Values for the Swiss house are given both with and without blocked vents.

Sweden, Norway and the United States (ASTM) have standards for the pressurization test method, while Canada has a draft standard and The Netherlands standard are under preparation. The method is used by contractors, consultants, etc., in Sweden and Norway as a control of the airtightness of new houses. It also has a widespread use in Canada and the United States, especially when retrofitting older buildings. Below, examples of results from pressurization tests are shown for each country. In cases like Switzerland and United Kingdom very few measurements have been made and so the results are not claimed to be representative of buildings in these countries.

CANADA

A recent study of the airtightness of 176 residences in Saskatoon, Saskatchewan, tested by the pressurization method showed the results according to Figure A3.1 (1).

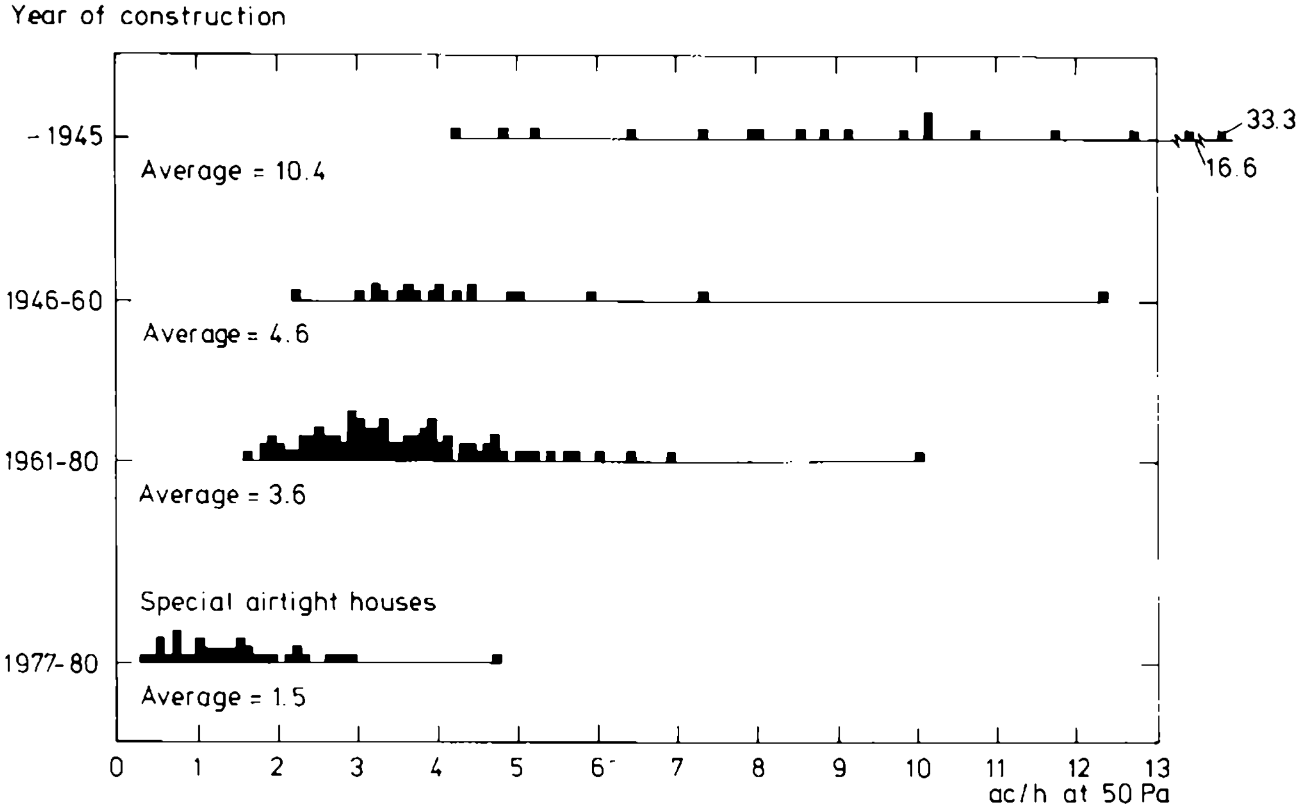


Figure A3.1. Pressure test results for Saskatoon house sample.

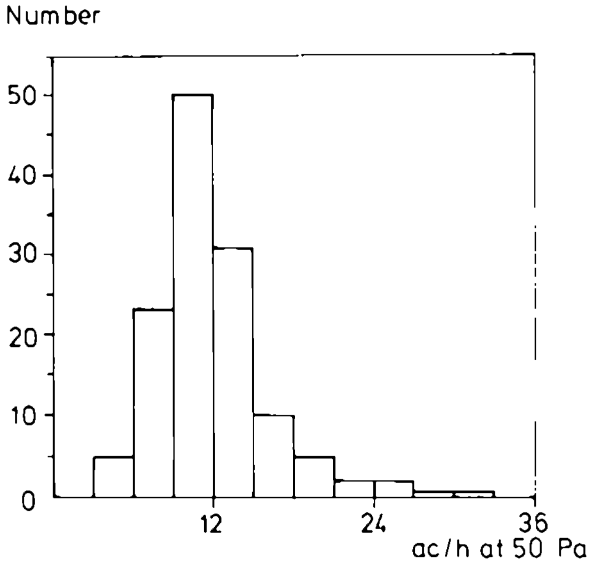
The houses have been divided in groups according to age to illustrate different techniques used in sealing buildings.

Prior to 1945, vapour barriers in sheet form were not used in houses. Following 1945, vapour barriers in the form of waxed paper were introduced. From 1960 onward, the use of polyethylene sheets for vapour barriers became a common practice in Canada.

An earlier investigation of houses in Ottawa (2) showed greater air leakage values than in the Saskatoon sample, which is not totally unexpected owing to differences in climate.

NETHERLANDS

130 Dutch dwellings have been pressurized by Bouwfonds Nederlandse Gemeenten, Amersfoort, with results as in Figure A3.2.



Number = 130

Average = 12

Standard deviation = 4.6

Figure A3.2. Distribution of air leakage for 130 dwellings in The Netherlands.

NORWAY

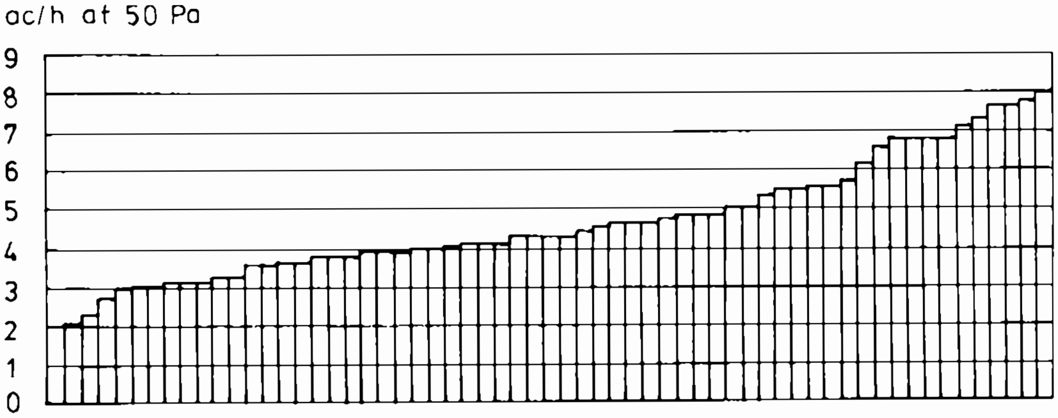
The Norwegian Building Research Institute have pressurized 61 detached houses and 34 flats (3). The result is shown in Figure A3.3. The tested dwellings were randomly chosen from four areas in Norway.

Most of the detached houses had basements with brickwalls of lightweight concrete and one or two floors of conventional wood-frame construction. All of them were built in the period 1974-1978.

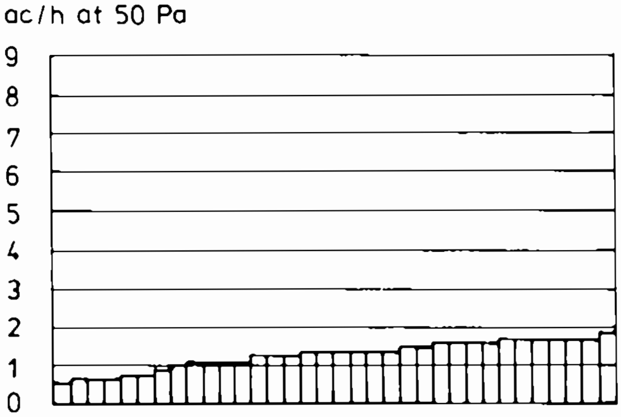
The block of flats were mainly of concrete construction with facade walls of conventional wood-frame construction. The apartments were built in 1971 and 1976.

SWEDEN

Since the end of the 1970s, a great number of Swedish houses have been pressurized using the pressure test method. The method is now used as a routine check on new dwellings. The selected investigation (4) includes 68 detached houses and 23 multi-family houses. It can be seen from this investigation, that the leakiness of the houses are decreasing with year of construction, see Figure A3.4a. The relatively big leakiness of the houses built before 1920 could, apart from their age, depend on the fact that most of these houses had match-boarding walls (17 of 23) which in Figure A3.4b are shown to be leaky.



DETACHED HOUSES *Number = 61*
Average = 4.7
Standard deviation = 1.5



FLATS
Number = 34
Average = 1.3
Standard deviation = 0.4

Figure A3.3. Results from airtightness measurements in some Norwegian detached houses and block of flats.

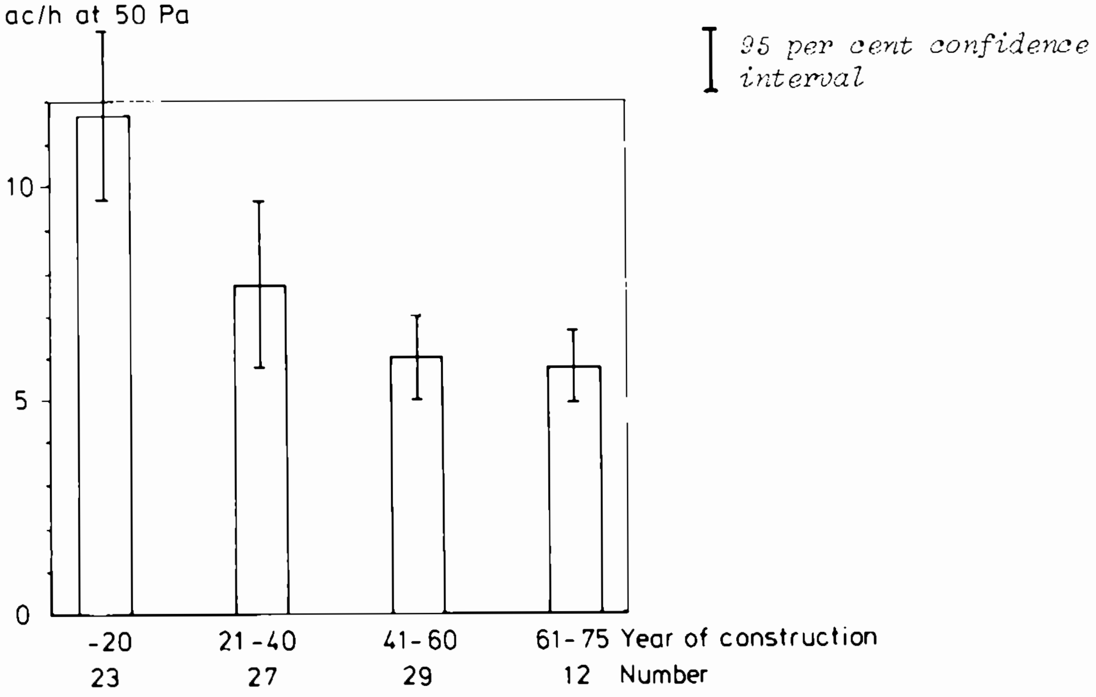


Figure A3.4a. Breakdown by year of construction.

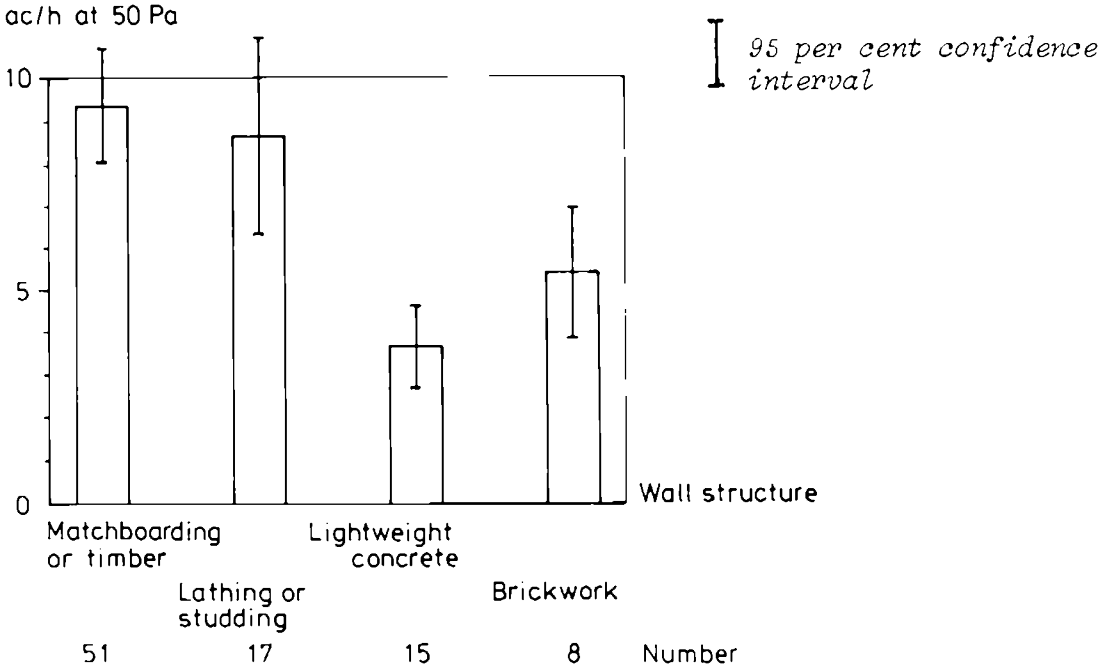


Figure A3.4b. *Breakdown by type of external wall structure.*

Figure A3.4. *Results from pressure tests of Swedish dwellings. The mean value obtained from the pressure tests was 8.0 ac/h for all houses. For the single-family houses the mean value was 8.5 ac/h and for the block of flats 6.3 ac/h. The investigation comprised 68 small houses and 23 multi-family houses.*

SWITZERLAND

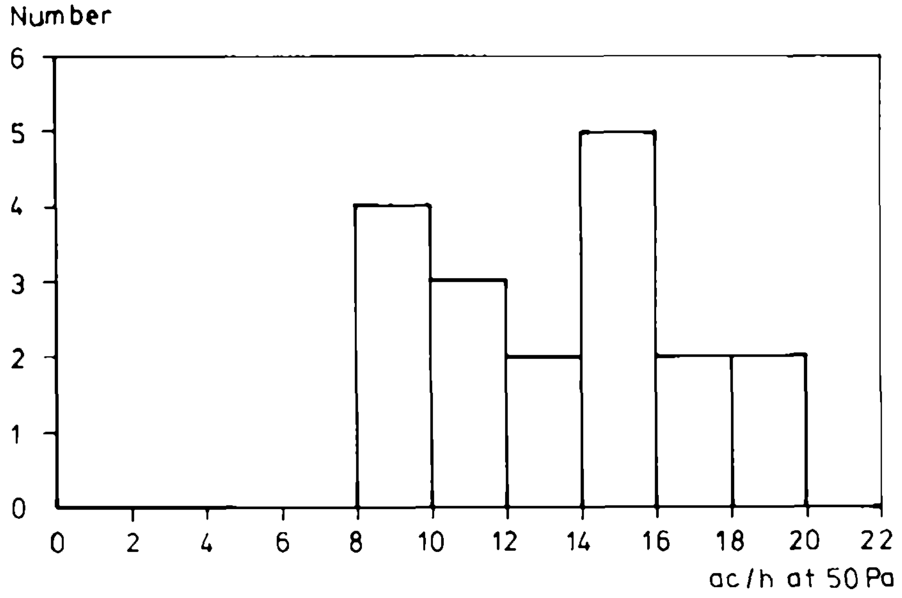
Only one measurement has been made by EMPA in a detached house which is later described in Section A3.2. The results are shown in Table A3.1.

UNITED KINGDOM

19 dwellings in the United Kingdom built within the last twenty years and covering a range of construction types have been tested by the British Research Establishment (5). Mean value for the airtightness of the houses at 50 Pa was 13.9 ac/h, see Figure A3.5.

UNITED STATES

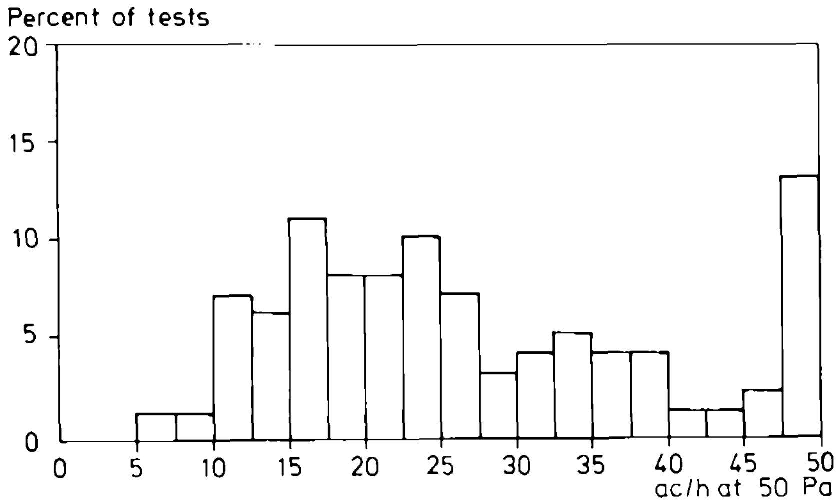
A great number of houses have been pressurized using the "Blower door" approach. Figure A3.6 shows airtightness results from an investigation where 204 detached houses spread out over the United States have been measured (6).



Number of houses = 19

Average = 13.9

Figure A3.5. Distribution of whole house leakage rates in 19 dwellings in the United Kingdom.



Number of tests = 204

Average = 22.52

Standard deviation = 39.31

Figure A3.6. Air change rates at 50 Pa for dwellings in the United States (CSA/NBS Weatherization Demonstration).

Table A3.1. Pressurized house in Maugwil, Switzerland.
C and n refer to the constants in the equation $q = C \cdot \Delta p^n$ (see Chapter A7).

Notes	Volume m^3	Floor area m^2	C	n	ac/h at 50 Pa
Only chimney sealed	435	190	0.0157	0.67	1.77
All vents and stack sealed	413	180	0.00663	0.81	1.37

A3.2 Energy balances

When analysing a building's energy demand for heating and ventilation, it is interesting to study the total energy balance of the building. This gives some idea of the magnitude of the different energy losses and gains.

The basic material used to produce each country's energy balances in this chapter varies considerably. This is because there is no standard method of collecting the data and in some cases the magnitudes of certain factors are as yet unknown. It may also be difficult to compare information because of the differences in heating devices and types of energy and the distribution of factors such as hot water and domestic electricity consumption, body heat, insolation, etc. In countries such as the United States, the energy required for air conditioning during the summer is a significant factor in many regions.

Some examples of energy balances from different countries are given in this chapter despite the number of objections which could be put forward. Interesting data for houses and energy balances are presented in Tables A3.2 and A3.3. The material has been compiled in ways which differ so much that comparatively lengthy comments are required for the energy balances presented for respective countries.

COMMENTS TO THE ENERGY BALANCES IN TABLE A3.2

The energy balances are sometimes calculated sometimes measured. In most cases the total purchased energy is measured and the distribution

Table A3.2. Energy balances for single-family houses in different countries in GJ/year for the whole year. (Heating season for United States and The Netherlands.)

Note: 1 GJ = 0.278 MWh.

Country	Year of construction	Floor Area/ volume	Energy losses					Energy supply						Purchased energy
			Transm.	Vent.	Waste water	Other	Total	Heating	Hot water	Dom. electricity	Body heat	Solar gain	Total	
CANADA (Ottawa)	1970	200[3] / 500[3]	113.4	23.7	16.2	58.0[1]	211.3	137.5	39.2	21.6	2.9	10.1	211.3	198.3
	1980	"-	65.5	16.6	16.2	50.0[1]	148.3	74.5	39.2	21.6	2.9	10.1	148.3	135.3
NETHERLANDS (Schipluiden)	1970	120/ 330	85.7	40.0	4.0	26.6[2]	156.3	122.9	7.2	7.2	5.0	14.0	156.3	137.3
	1980	"-	68.2	27.8	4.0	20.2[2]	120.2	86.8	7.2	7.2	5.0	14.0	120.2	101.2
NORWAY (Oslo)	1970	100/ 240	46.8	18.0	10.8[5]	10.8[5]	86.4	43.2	10.8	18.0	3.6	10.8	86.4	72.0
	1980	"-	32.4	14.4	10.8[5]	10.8[5]	68.4	26.3	10.8	18.0	3.6	9.7	68.4	55.1
SWEDEN (Stockholm)	1970	130/ 320	61.9	36.0	12.6	3.6	114.1	66.6	16.2	14.4	5.4	11.5	114.1	97.2
	1980	"-	46.8	18.4	12.6	3.6	81.4	33.8	16.2	14.4	5.4	11.5	81.4	64.4
SWITZERLAND (Zürich)	1970	220[3] / 500[3]	83.9	28.1	10.8	41.7[6]	164.5	119.5	11.5	15.1	3.3	15.1	164.5	146.1
	1980	"-	54.7	20.9	10.8	22.0[6]	108.4	66.6	11.5	15.1	3.3	11.9	108.4	93.2
UNITED KINGDOM	1970	96/ 240	63.3	16.2	14.8	36.4	130.7	85.3	16.9	12.2	4.0	12.3	130.7	114.4
	1980	"-	35.3	18.3	14.8	23.0	91.4	47.2	16.9	12.2	4.0	11.1	91.4	76.3
UNITED STATES (New Jersey)	1970	150/ 360	70.9	25.9	11.5	29.6[1]	137.9	86.1	14.4[4]	14.4	5.0	18.0	137.9	114.9
	1980	"-	53.3	19.4	11.5	16.6[1]	100.8	52.2	13.7[4]	14.4	5.0	15.5	100.8	67.3

1 Refers to flue losses from both space heating and hot water heating.
2 Flue losses from gas heating.
3 Incl. basement.
4 Values not fully compared with other countries since United States differentiates between summer and winter energy balances. This is a winter energy balance (6 months).
5 Mainly electricity during summer.
6 Flue and heating distribution losses, electricity losses in summer.

Table A3.3. Some typical data for the single-family houses for which the energy balance has been calculated.

Country	Year of construction	Mean internal temp. °C	Thermal transmittance, k-value, W/m² K				Assumed seasonal ventilation ac/h	Heat loss coefficient W/K	Heating system (see note number)
			External walls	Roof	Floor	Windows			
Canada	1970	22	0.57	0.52		3.0	0.4	257	3
	1980	22	0.29	0.20		2.8	0.3	154	3
Netherlands	1970	18	1.04	1.16		3 (6)	1.3	350	1
	1980	17	0.63	0.7	1.7	3 (6)	1.1	290	1
Norway	1970	20	0.4	0.35	0.35	3.0	0.6	205	2
	1980	20	0.25	0.23	0.23	2.1	0.5	146	2
Sweden	1970	20	0.40	0.35	0.40	3.0	0.7	253	2
	1980	20	0.30	0.20	0.30	2.0	0.5	173	2
Switzerland	1970	20	0.9	0.8	1.2	3.1	1.0	385	1
	1980	20	0.5	0.4	0.77	2.0	0.75	261	1
United Kingdom	1970	18	1.5	0.5	0.6	3.5	1		1
	1980	19.5	0.5	0.3	0.6	2.1	1		1
United States	1970	20	0.51	0.47		4.5	0.8		3
	1980	20	0.38	0.28		3.0	0.6		3

1 Natural gas or oil fired boiler with hot water radiator panels.
2 Electric radiator panels.
3 Natural gas forced air.

of the different items is based on calculations with certain probable assumptions (see also Chapter A7). The normal method is as follows:

- o *Transmissions losses through the building represent calculated heat losses for the heating season.*
- o *Ventilation losses represent heat losses through ventilation during the heating season. The average ventilation rate for the period is normally assumed.*
- o *The waste water losses represent the amount of energy used in heating the water that is not useful heat input during the heating season.*
- o *Other losses are calculated differently in different countries and for different heating systems. In electrically heated buildings the losses represent only domestic energy used which is not a useful heat input during heating season. In buildings with other heating systems the other losses also include flue losses from space heating or/and hot water heating.*
- o *Heating supply represents total energy input to the heating system.*
- o *The hot water value is the energy supply for hot water for the whole year except for the United States and The Netherlands which only includes energy consumption during the heating season.*
- o *Energy supply for domestic electricity is normally the domestic electricity load for the whole year. (Heating season for the United States and The Netherlands.)*
- o *The body heat value is the useful energy supplied during the heating season.*
- o *The solar heat gain value is the useful energy supplied during the heating season.*
- o *The purchased energy is the total energy supplied minus the body heat and solar heat gain.*

Energy balances and some basic data for the houses are presented for each country as follows.

CANADA

The house chosen is the following:

Type	Bungalow with full basement. 200 m^2 (total floor area including basement)
Location	Ottawa, Ontario

Annual heating degree days (reference 18°C)	4673°C-days[x]
Space heating system	Natural gas forced air seasonal efficiency = 0.65
Domestic hot water system	Natural gas, seasonal efficiency = 0.55

For new low energy houses (sometimes referred to as "super-insulated houses"), the heat loss coefficient is typically reduced to about 60-80 W/K. This is achieved with high levels of insulation (k-values of approximately 0.1, 0.15, 0.2 and 0.6 W/m^2 K for ceilings, walls, basement walls and basement floors respectively) very airtight construction (<1.0 ac/h at 50 Pa pressure difference), and use of windows (typically triple glazed) located primarily on the south, and air to air heat exchangers to supply ventilation air. With such a design, the space heating requirement is reduced to approximately 15 GJ/yr (4.1 MWh/yr) in an Ottawa location.

Figure A3.7a. Canadian dwelling.

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[x] For method of calculating degree days, see Section A6.2 and Table A6.1.

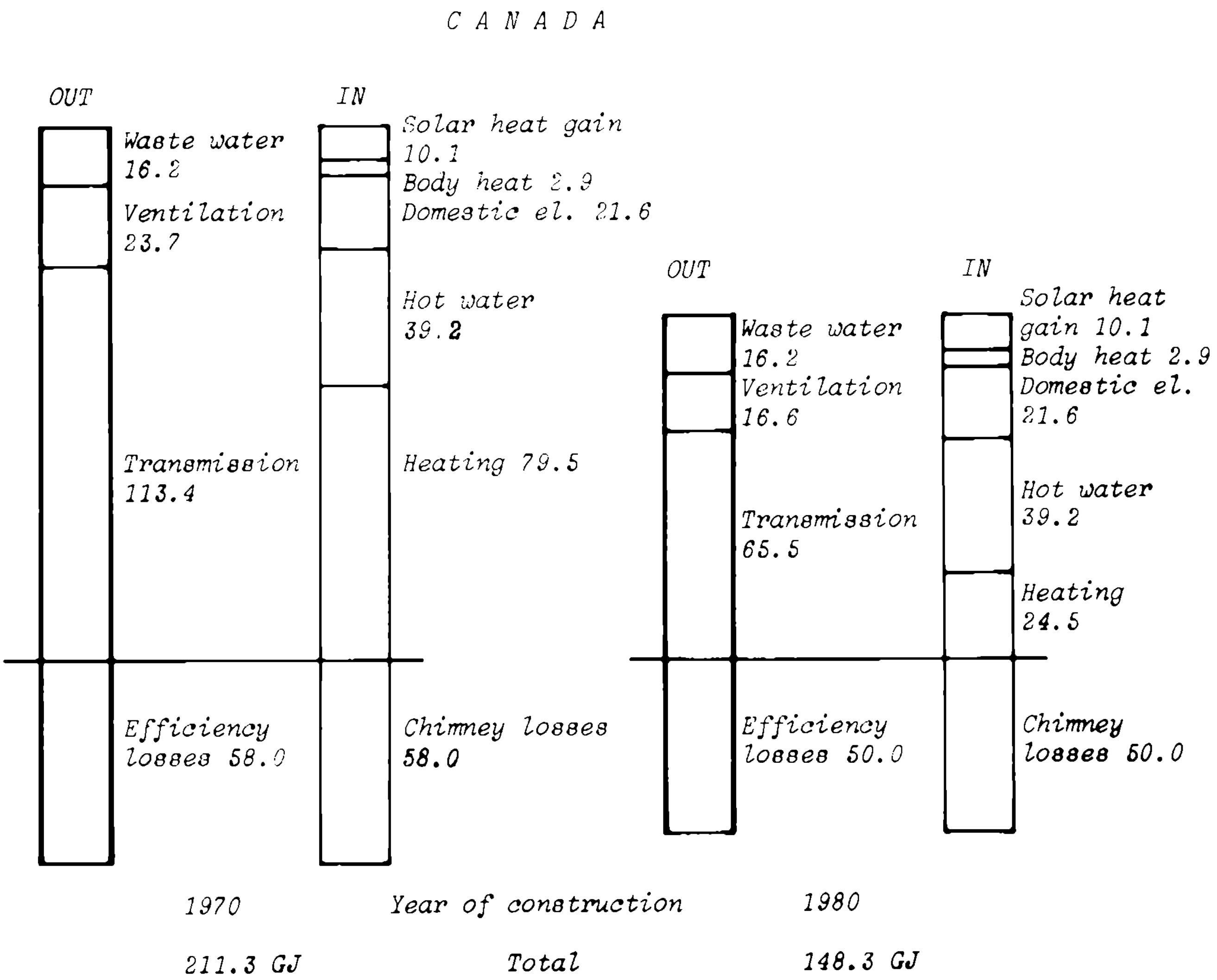


Figure A3.7b. Energy balances for a typical Canadian dwelling.

THE NETHERLANDS

For a single-family house the energy balance has been calculated both for the 1970 house and for the 1980 house. The specifications are listed in Table A3.3 and the design is shown in Figure A3.8b. The energy balances are calculated for the heating season, which in The Netherlands is about 200 days (from mid September to the beginning of April).

Some further details of the house are given below:

Type	Typical terraced house with living area also in the loft
Location	Schipluiden

Space heating system	Natural gas with hot water radiator panels Seasonal efficiency of the boiler ~0.75
Domestic hot water system	Natural gas fired geyser Seasonal efficiency of the geyser ~0.80

Mean gas consumption for heating, hot water and cooking, in Rotterdam is:

Flat with one room heated	1500 m^3 gas/year
Flat with central heating	3000 m^3
Single-family house: (small)	3300 m^3
(small, new)	5000 m^3
(big)	5000 m^3

Note: 1 m^3 gas = 35.2 MJ.

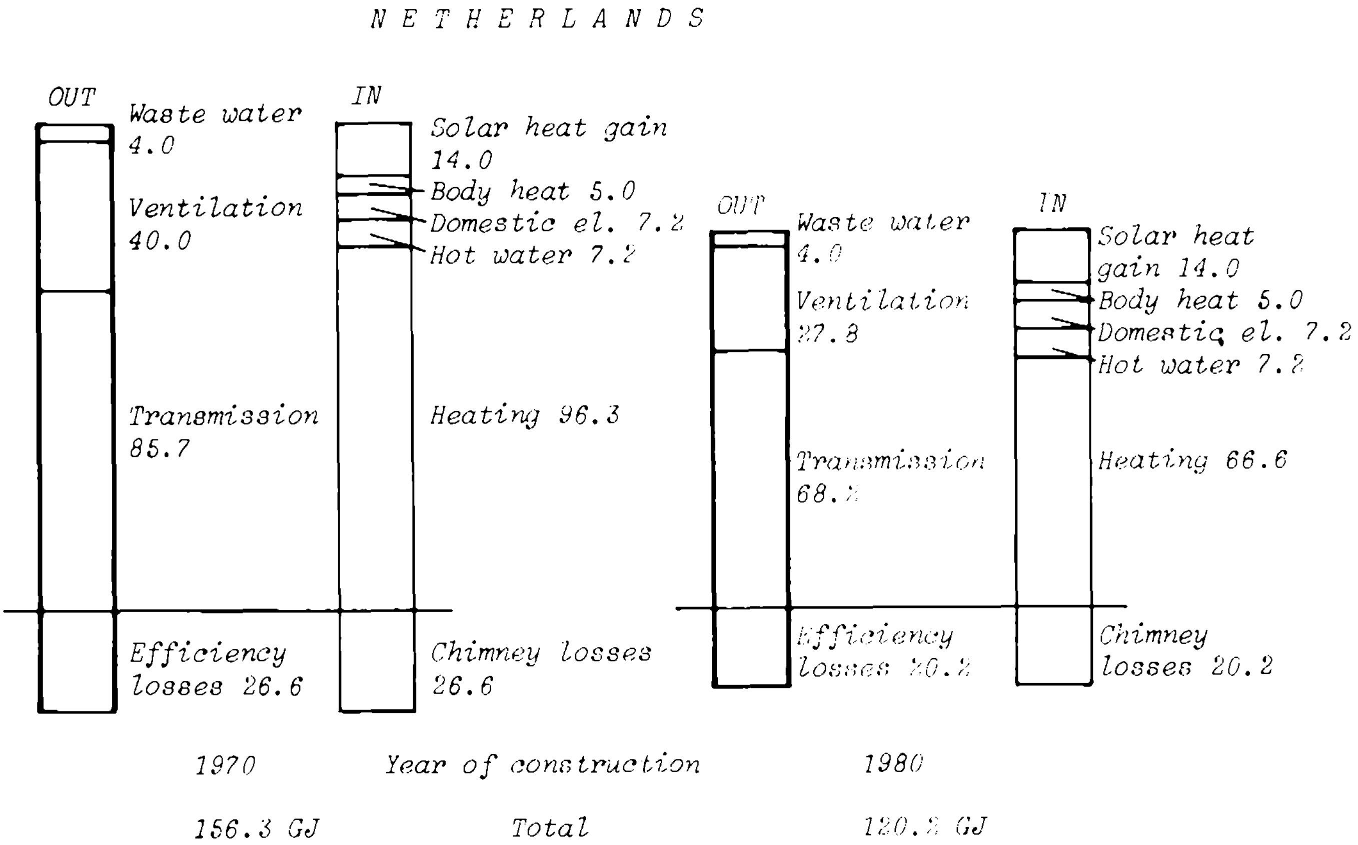
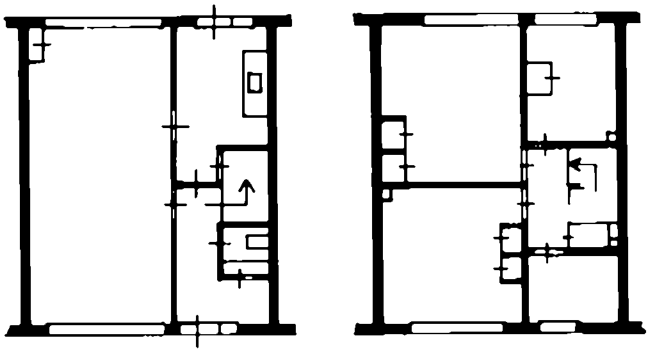
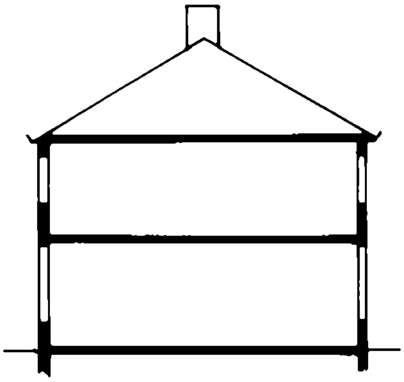


Figure A3.8a. Energy balances for a dwelling (terrace house) in The Netherlands.

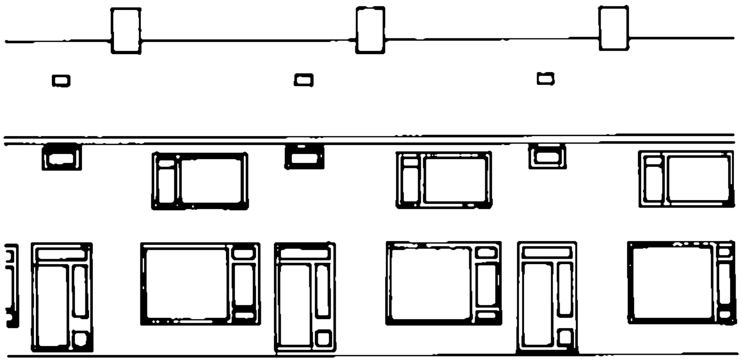


Ground floor

First floor



Cross section



Front façade

Scale 1:200

Rear façade

Figure A3.8b. Single-family house (terrace house) in The Netherlands.

NORWAY

The house chosen is the following:

Type	Bungalow with full unheated basement. 100 m^2 living area (not including basement)
Location	Oslo
Annual heating degree days (reference 17°C)	3774°C-days
Space heating system	Electric resistance heating
Domestic hot water system	Electric

The energy balance for houses built in the period, 1960-1975 is based on numerous measurements of energy consumptions made by the Norwegian Building Research Institute. The houses have a living area of approximately 100 m^2, and they are located in the Oslo area (Oslo's climate is close to the average of the country). In most cases only the total energy consumption is measured. The distribution on the different items in the balance is based on calculations and some detailed studies.

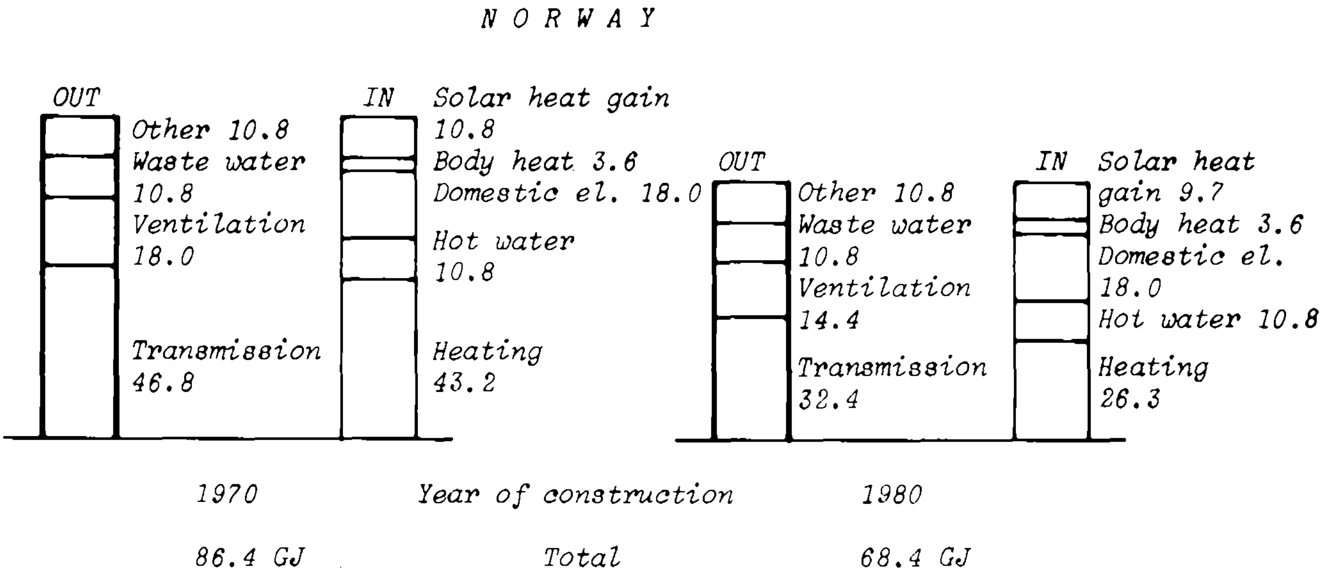


Figure A3.9a. Energy balances for a Norwegian dwelling.

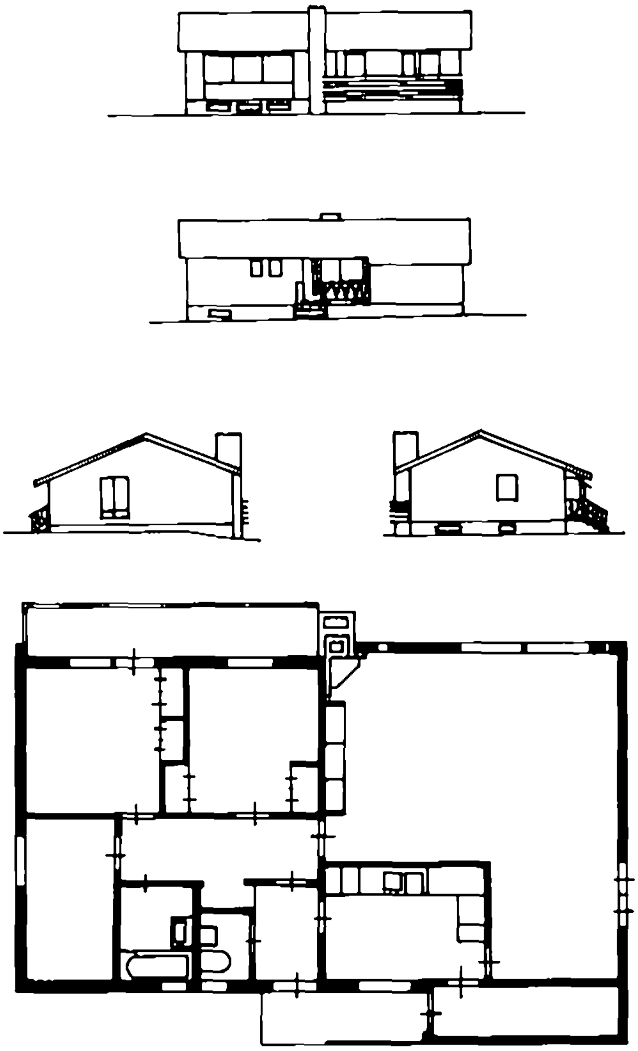


Figure A3.9b. Drawing of the dwelling.

The energy balance for the houses built in 1980 is based on calculations and extensive measurements on a few houses.

The energy balances are net energy consumptions, i.e. consumptions of electrically heated houses. Most houses in Norway are electrically heated with a wood stove or a kerosene burner as a backup system.

Indoor temperature is normally 20°C.

SWEDEN

The energy balance for houses built during the early 1970s is based on investigations into the total energy consumption of 5500 electrically heated houses in Stockholm (7). The typical design of the houses is shown in Figure A3.10b. The total purchased energy is well known. The distribution of the different items in the energy

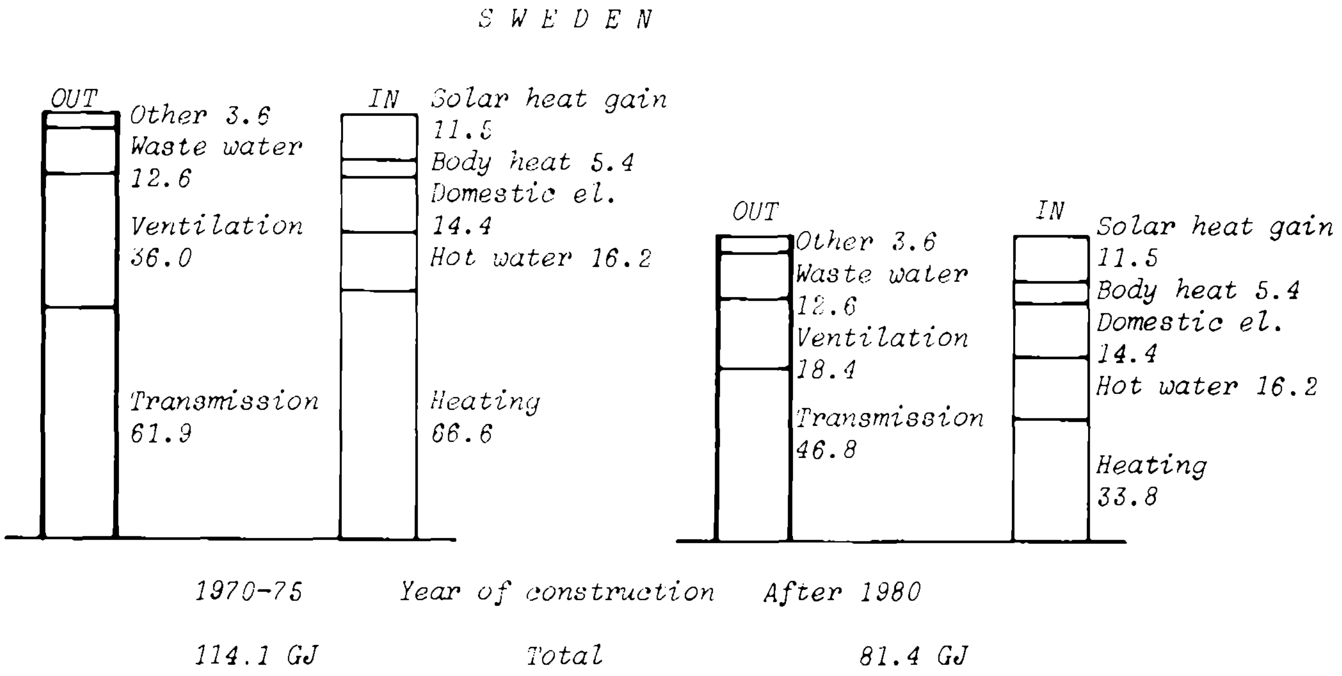


Figure A3.10a. Energy balances for Swedish dwellings.

balances is, however, based on calculations of certain probable assumptions. Ventilation losses are based on tracer gas measurements in a small number of houses. The average air change rate in these amounted however to 0.7-0.8 ac/h. These values have been used in calculations. This results in ventilation losses amounting to a significant proportion of the total energy loss.

The energy balance for newer houses is based on measurements taken in a small number of houses (8). The total purchased energy consumed was carefully measured. Ventilation losses were determined by using tracer gas and pressure test methods.

The new houses have a very airtight envelope. This means that ventilation can be kept almost constant throughout the year by using an exhaust fan. Thus ventilation losses are comparatively well documented in the energy balance presented.

Energy balances for the Swedish houses refer to net energy since they are electrically heated. There are no real efficiency losses within the actual houses. Approximately 50 per cent of Swedish single-family dwellings built during the 1970s have electrical heating.

The indoor temperature is normally +20°C.

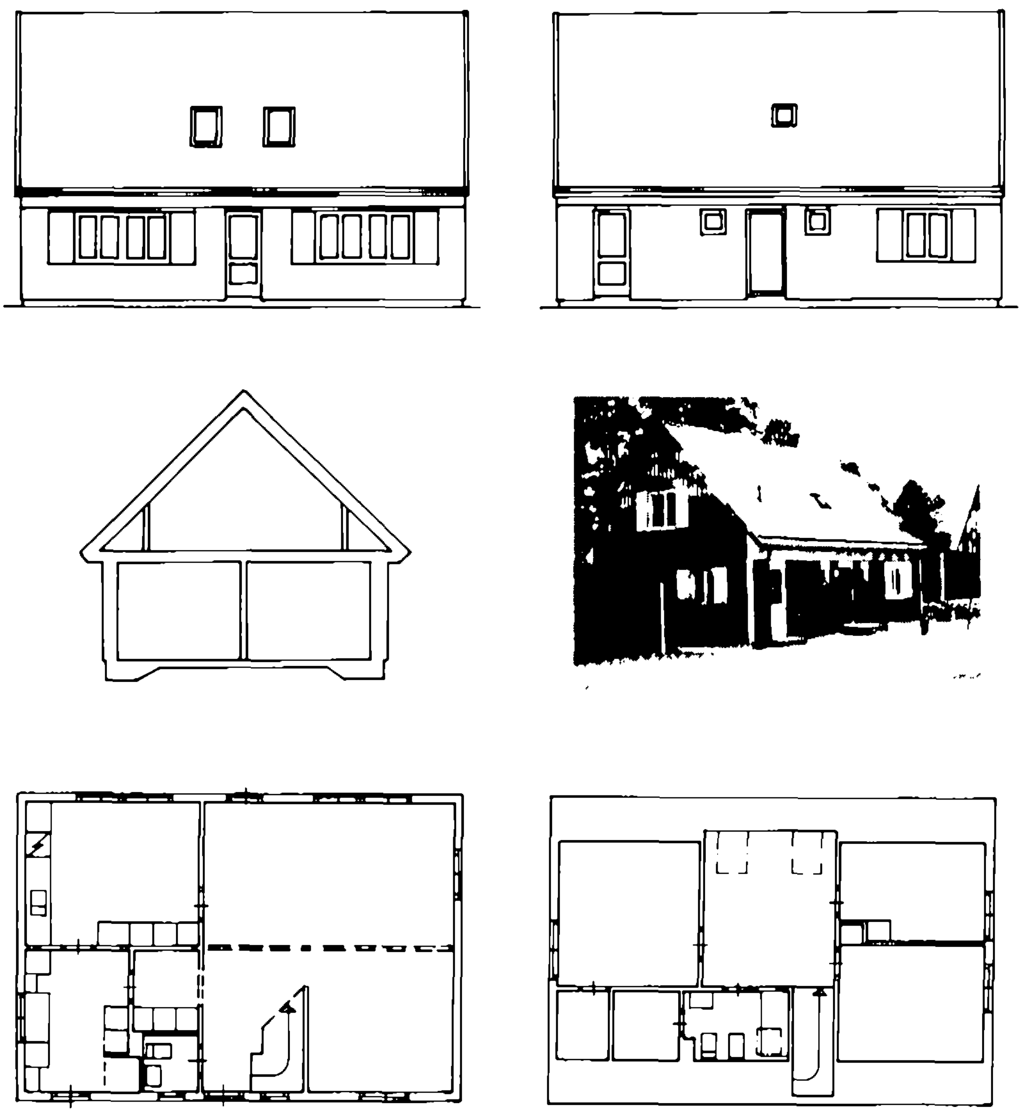


Figure A3.10b. Elevations and plans for a single-family house in Sweden in wood-frame construction. The living area is approx. 130 m^2.

SWITZERLAND

The energy balances for Swiss single-family houses are calculated with the aid of assumed values for both the older and the newer houses. The energy balances are calculated for relatively large houses.

The main features of the house are as follows:

Type	Light-weight construction house with concrete basement; 2 main floors, basement partially heated (220 m^2 floor area including basement)

SWITZERLAND

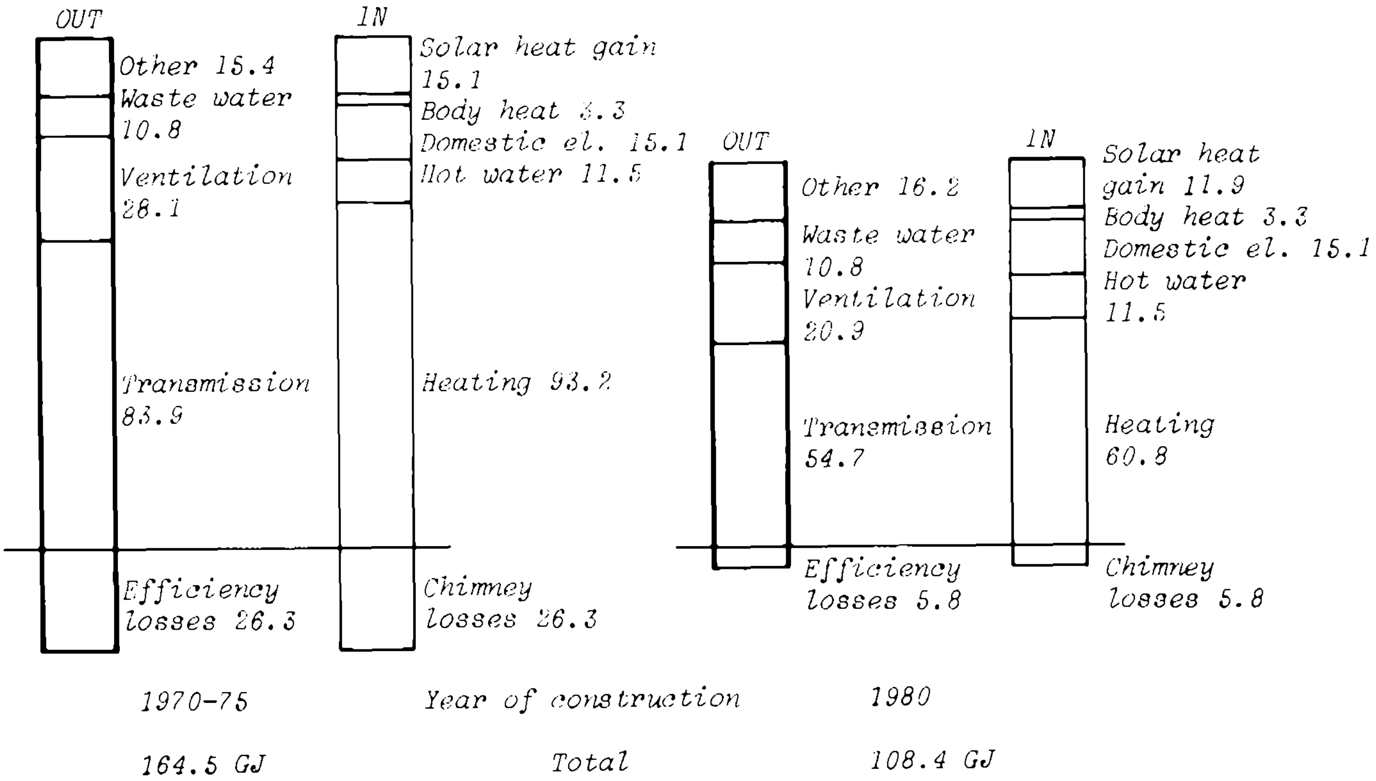
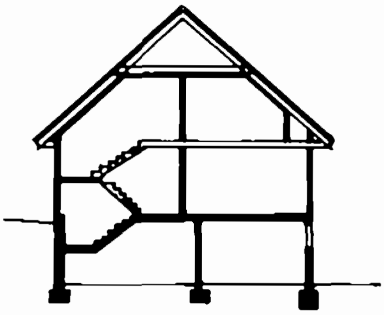


Figure A3.11a. Energy balance for a big Swiss dwelling.

Location	Zürich (similar climate to nearly 90 per cent of the Swiss houses)
Heat loss coefficient	1970-construction: 385 W/K 1980-construction: 261 W/K

For both cases (1970-house and 1980-house) the dimensions of the house are the same. Differences are caused by the increasing trend to conserve energy and the corresponding regulations. They are indicated in the tables and in the following short comments:

- lower k-values for 1980
- reduced chimney losses by a furnace, which has well adjusted design date and a better control
- a change of whole-year hot water production by an oil-furnace to production by electric heat
- a certain reduction of the mean air change rate.



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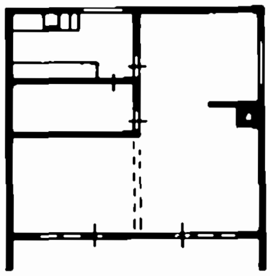
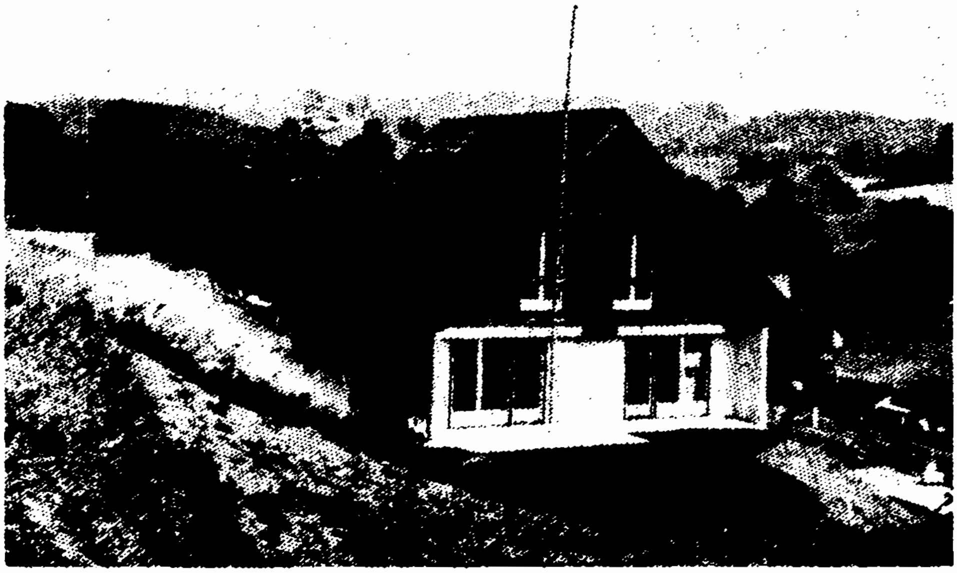


Ground floor



View of test building from the West

Figure A3.11b. Illustration of dwelling.

UNITED KINGDOM

The enclosed energy balances for a detached, single-family house in the United Kingdom have been calculated for the whole year. The standard heating season in the United Kingdom is 212 days and there is no space heating outside this 212 day heating season. Air conditioning is never used in domestic houses. Two standards of insulation are considered.

CASE ONE - Typical United Kingdom house (1970)

Low standard of insulation: 260 mm cavity brick wall plastered internally; single glazed windows in wooden frames with lightweight curtains; tiles on battens; roofing felt and rafters, with roof space and 50 mm mineral fibre insulation laid between joists on 10 mm aluminium foil backed plasterboard ceiling; solid floor in contact with the earth.

CASE TWO - Well-insulated United Kingdom house (1980)

High standard of insulation: 260 mm cavity brick wall plastered internally, cavity insulated with expanded polystyrene 50 mm; double glazing in wooden frames with heavyweight curtains; tiles on battens; roofing felt and rafter, with roof space and 100 mm mineral fibre insulation laid between joists on 10 mm aluminium foil backed plasterboard ceiling; solid floor in contact with the earth.

Mean external temperature = $7^{\circ}C$ (212 days are typical United Kingdom heating season).

Mean internal temperatures	CASE ONE	$18^{\circ}C$
	CASE TWO	$19.5^{\circ}C$.

The energy balances also include efficiency losses based on an assumed efficiency of 65 per cent.

Comments to the calculated energy balances for the United Kingdom

- The transmission losses represent the heating losses through transmission for the 212-day period.
- The ventilation losses represent the heating losses through ventilation for the 212-day period. Ventilation losses is not considered important in the summer, so the United Kingdom differs in this respect from countries which may include the extra air conditioning needed in the summer because of ventilation as an energy loss.
- The waste water losses represent the amount of energy used in heating the water that is not a useful heat input.
- Other losses include flue losses from gas heating and domestic energy used which is not a useful heat input.
- The total is the sum of the above losses.
- The heating value is the energy input to the heating system before the flue losses and efficiency factors have been removed.
- The hot water value is the domestic hot water load for the period given.
- The domestic electricity value is the domestic electricity load for the period given.

- The body heat value is the useful energy supplied during the 212-day period. This, like the ventilation losses, differs from countries which include the extra air conditioning needed in the summer because of body heat as an energy loss here.
- The solar gains value is the useful energy supplied during the 212-day period. Again, this differs from countries which count the solar gains as a loss in the summer.
- The heat total is the sum of the above energy supplies.
- The purchased energy is the total energy supplied minus the body heat and solar gains values.

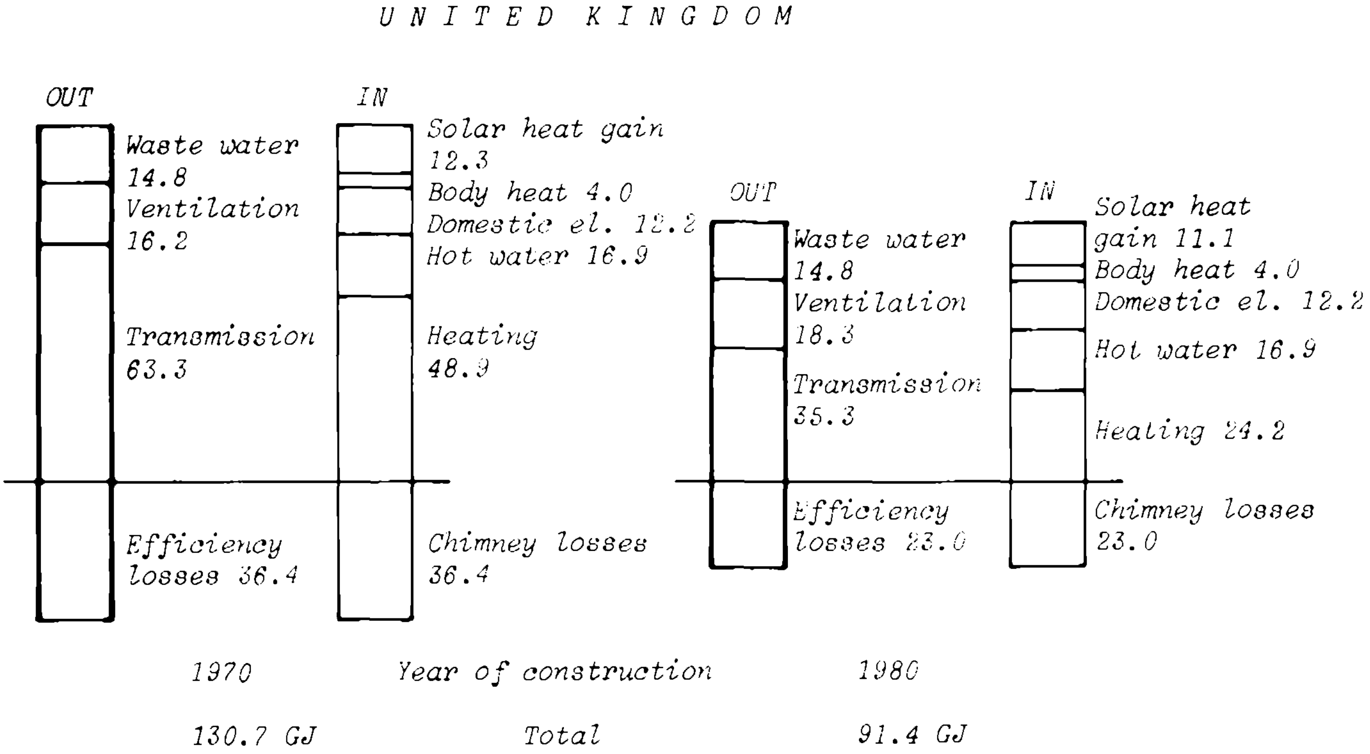


Figure A3.12. Energy balances for a dwelling in the United Kingdom.

UNITED STATES

The examples presented here represent the energy consumed for a typical wood-frame detached house over one heating season. The calculations apply to the Ranch or Split-Level styles as shown in Figure B3.1 in Part B of the United States. The size was chosen as 150 m^2. The climate is chosen as 2800 degree days Celsius (New Jersey climate). Changes from 1970 to 1980 include mineral wool wall insulation increased from 6.5 cm to 9 cm, ceiling insulation increased from 9 cm to 14 cm, improved envelope tightness to decrease the average air infiltration rate from 0.8 to 0.6 ac/h, improved insulation on the water heater and the addition of double glazed windows. The furnace seasonal efficiency is assumed to be 70 per cent in 1970 and 75 per cent in 1980. For both cases the amounts of energy used for appliances and lighting are based upon field studies for four occupant houses.

The values of energy used per square metre of dwelling per degree day are consistent with data from field studies where good construction practices have been employed.

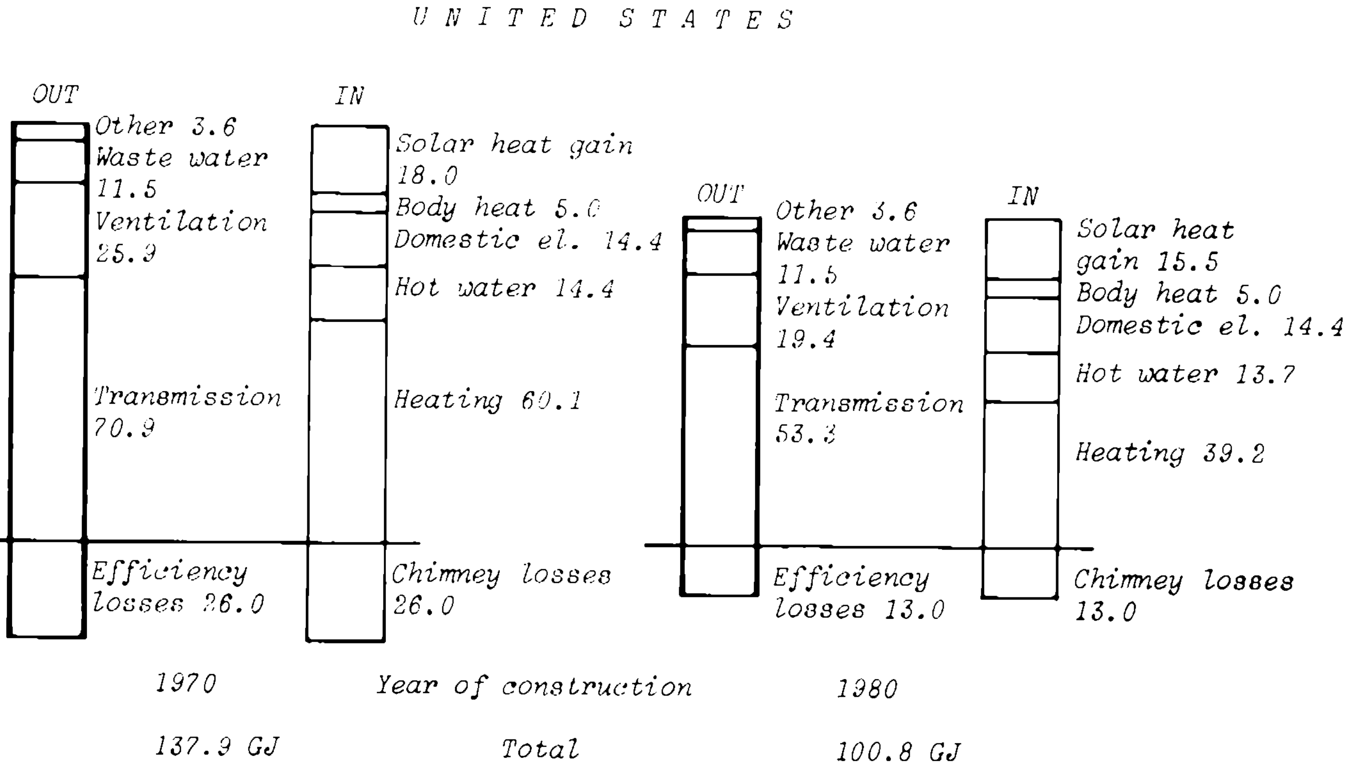


Figure A3.13. Energy balances for a single-family house in United States (New Jersey) for 6 months heating season.

A3.3 References

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(8) Elmroth, A. & Lögdberg, A., Well Insulated Airtight Buildings. Energy Consumption, Indoor Climate, Ventilation and Air Infiltration. Paper to the 8th CIB Congress. Oslo 1980.

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A4 PRINCIPLES FOR AIRTIGHTNESS

The incentives for building airtight houses vary from country to country. The main reasons for variations are differences in climate, building traditions and standards.

This chapter describes the different principles for achieving as tight houses as are technically possible. Examples are given of the interaction between the execution of joints and leakage between them.

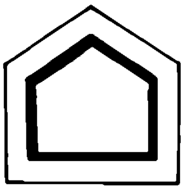
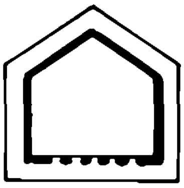
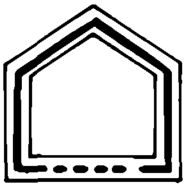
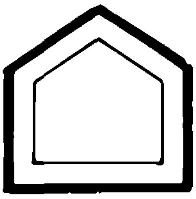
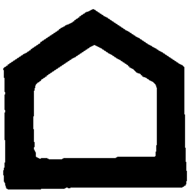
Applications of the principles are given in the design solutions in Chapter A9 and in Part B. Ways to improve the airtightness in existing buildings are given in Chapter A10.

In order to build well-sealed houses, a thorough system of how airtightness can be achieved facilitates practical work. Great importance must be attached to the design of the different structural parts and the penetrations for services – electricity, water, heating and ventilation.

Depending on material and design, there are a number of alternatives available to ensure airtightness. Table A4.1 indicates suggested principles. The air sealing method selected should be carried out as consistently as possible over the whole of the external structure of the building. This means that not only should the walls and ceilings follow the principle but that the air sealing must be carried out consistently even at joints, connections, etc.

Table A4.1 indicates the advantages and disadvantages of the different principles. Further comments are necessary. The table mentions airtightness and windtightness. Airtightness means the property of preventing air from penetrating through the shell. Windtightness means 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 consequently a well-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 wind protection, for example rigid mineral wool slabs fitted in a certain way, cannot be used to fulfil airtightness requirements.

Table A4.1. The main principles for the design and positioning of air sealing layers in constructions (primarily for new buildings).

	Construction principle	Advantages	Disadvantages
a)	Internal airtight cladding (e.g. plasterboard) 	Uses common sheet material properties Can be checked and rectified relatively easily	The sheet lies unprotected Risk of puncturing and damages The joints must be sealed carefully even against floors and roofs. Sensitive to movement and subsequent crack formation
b)	Airtight vapour barrier (e.g. plastic film, paper, metal foil) 	Air/vapour barrier Large size film sheets can be used, with few joints as a result	Certain difficult constructional problems Accuracy required at joints
c)	Drawn in airtight vapour barrier (e.g. plastic film, paper, metal foil) 	The sealing layer is protected against damage Electrical installations possible without the sealing layer being damaged Good prospects of achieving a high level of airtightness	The effects of "supplementary insulation" from carpentry and furnishing, on moisture conditions in the sealing layer, in particular at thermal bridges, are unknown Requires a double wooden frame
d)	Airtight wind barrier (e.g. paper, sheet material) 	Easy to apply The wind protection's air sealing properties can be used	Significant risk that vapour resistance 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 resistance of the material Stringent airtightness requirements in internal vapour barriers
e)	Homogeneous airtight structures (e.g. cellular concrete, concrete, brick) 	Simple design Electrical cables can be positioned in the material without jeopardizing airtightness	Connection details to other building material must be solved separately Stringent requirements on joint sealing material between building elements

A4.1 Further comments on the design principles in Table A4.1

a) INTERNAL AIRTIGHT CLADDING

This method could be applied to timber or steel building technology. It is based on the fact that common internal slab covering is often airtight. Examples of such slab materials are plasterboard, certain types of particle board and plywood. If airtightness is to be achieved, certain measures must be taken to seal all joints between slabs and at joints. There is also the risk of damage resulting from movement in the structure causing crack formation. It would appear that the disadvantages are so significant that the principle has not so far been applied to any great extent.

b) AIRTIGHT VAPOUR BARRIER

This method is based on the internal vapour barrier being airtight. In several timber and steel structures, a vapour barrier is necessary during the winter time. This barrier is normally a special quality of paper, aluminium foil or plastic film. All these materials are sufficiently airtight and large sizes can be obtained, thus limiting the number of joints. Also the materials are thin, making overlap jointing easy. Consequently, good airtightness is easy to achieve. This is also desirable from a vapour barrier point of view. The disadvantage is that the material is relatively easy to damage during the building stage and so the installer of electrical or HVAC services can make unacceptable holes in the material. Careful planning is therefore required, as are detailed instruction of how holes for different services are to be made. The principle is often applied to steel and timber building technology.

c) DRAWN-IN AIRTIGHT VAPOUR BARRIER

This method is based on the same criteria as principle b). It can be applied to timber and steel structures which have a very thick layer of insulation. A smaller part – usually less than one-third of the thickness – can usually be placed between the sealing layer and the internal cladding in such constructions. Consequently the air/vapour barrier is better protected against damage. Electrical cables can all be laid between the sealing layer and the cladding. These are good conditions for maintaining permanent airtightness. Attention must be paid to moisture, particularly at joints and outer corners where the thermal insulation function runs the risk of being reduced by the formation of condensation and bad performance. There is also a certain risk that moisture damage can arise in damp areas. A relative humidity indoors of more than 50 per cent in winter can result in a relative humidity higher than 80 per cent inside the vapour barrier, which may present a risk of mould in a wood frame structure. The method has been applied to a limited extent to date.

d) AIRTIGHT WIND BARRIER

The principle can be applied to timber and steel structures since they are provided with an airtight wind barrier. Wind barriers of paper or sheet material sealed at joints can be used. There are often good chances of applying a wind barrier without too many holes for services and the wind barrier can often pass unbroken past wall and joist joints. Among the disadvantages is that the question of moisture must be carefully considered. An airtight layer is often relatively tight against water vapour and thus it is necessary to ensure that the vapour barrier has a considerably greater resistance to water vapour diffusion than the airtight wind barrier. Particular attention should be paid to air leakage since an internal excess pressure can lead to moisture damage through moisture convection. From this point of view an underpressure indoors is preferred in dwellings even with balanced ventilation. There is also a risk that the airtight wind barrier might be damaged during the building phase.

An airtight wind barrier can, however, be an excellent complement to a vapour and airtight internal layer. The principle of relying entirely on the wind barrier as the building's effective air seal has been applied to a limited extent because of the risk of moisture. However, an airtight wind barrier is a common complement to an airtight vapour barrier. It is easier to form connecting parts.

e) HOMOGENEOUS AIRTIGHT STRUCTURES

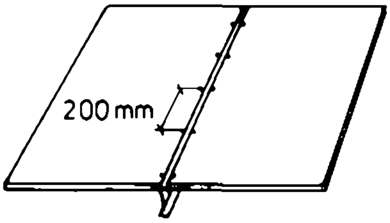
This principle can be applied to structures of homogeneous brickwork and also when different types of concrete elements are used. Most brickwork structures are sufficiently airtight if coated internally and externally with plaster. They have the added advantage that different pipes and cables can be laid in the structure without jeopardizing airtightness. It is therefore relatively easy to achieve good airtightness in such structures. In cases of bad foundations, cracks can occur that can lead to air leakage. At joints and connections, it is necessary to use carefully considered solutions. Particular attention should be paid to the fact that joint sealing materials often have a limited service life. Joints must therefore be designed so that the joint seal can be maintained and replaced as required. The principle of using homogeneous materials' air sealing properties has a widespread application.

A4.2 Planning for airtightness

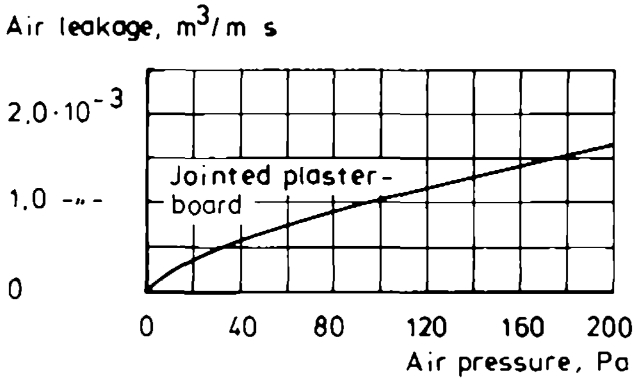
The construction of well-sealed buildings with minimum air infiltration demands new, more stringent, planning requirements. It is very important for the complete sealing function to be carefully stated in design documentation. It is also important, during planning work, to indicate an accaptable work 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-sealed and insulated house, careful choice of the correct materials and proper material handling is necessary. Materials are discussed in Chapter A8.

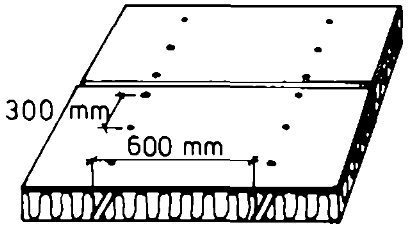
Experience from building airtight houses in Sweden shows that the additional cost of achieving an airtight house can be limited through carefully executed planning. The prime requisite is a knowledge of how airtightness is to be achieved. There are examples of solutions which, in production, do not have any measurable additional costs but which are still very airtight.

The following examples show air leakage in different joints. Figure A4.1 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 $(0.3-1)\cdot 10^{-3}$ m^3/m^2s (1-4 m^3/m^2h) 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.

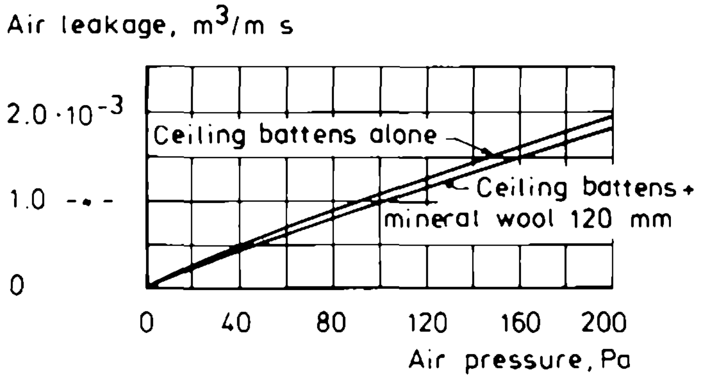


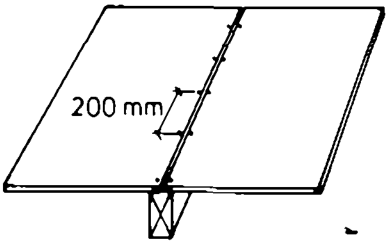
13 mm plasterboard with plastic film joint along a steel beam





13 mm plasterboard (ceiling batten) with film joint along steel beams





13 mm bituminous board, nails carefully positioned 200 mm apart

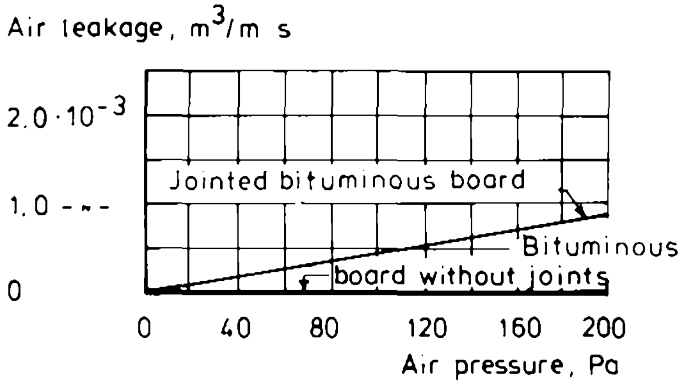


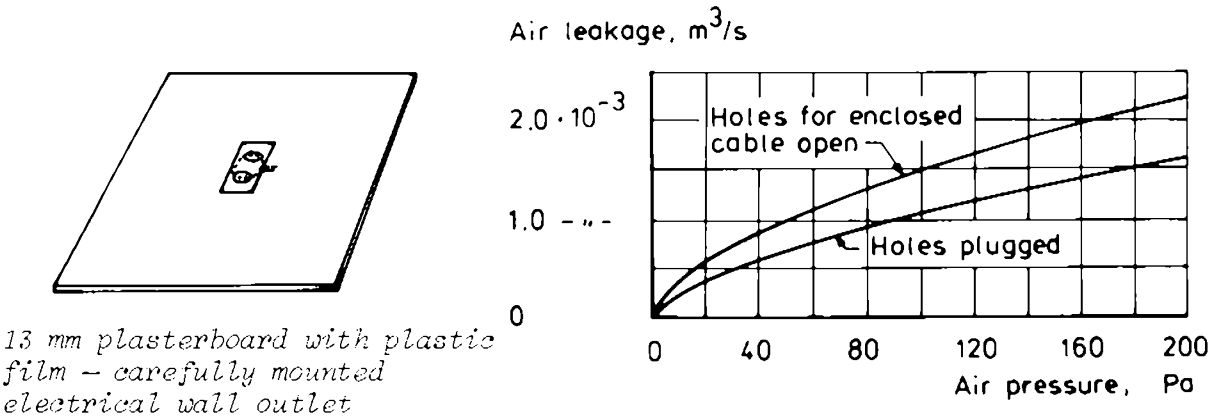
Figure A4.1.

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 film 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 bituminous boards carefully nailed to a wooden beam. Despite the sheet being almost impervious a leakage of almost 0.3·10^{-3} m^3/m s (1 m^3/m h) was measured with a pressure difference of 50 Pa. Bearing in mind normal movements in sheet materials and nails, airtightness cannot be achieved without the further sealing of joints.

Similarly, Figure A4.2 shows results of air leakage measured at an electrical junction box fitted in plasterboard. In this case, the air leakage amounted to $(0.5-1)\cdot 10^{-3}$ m^3/s ($2-4$ 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 the air change in the order of 0.5 ac/h measured at a pressure difference of 50 Pa. Careful sealing is essential if the fitting of electrical connections is unavoidable in external walls and routes through sealing layers. Air movement caused by pervious service routes can also lead to a reduction in thermal insulation properties and can also cause draughts.



13 mm plasterboard with plastic film – carefully mounted electrical wall outlet

Figure A4.2.

Air leakage measured when an electrical wall outlet 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.

The following points help to achieve good, permanent airtightness.

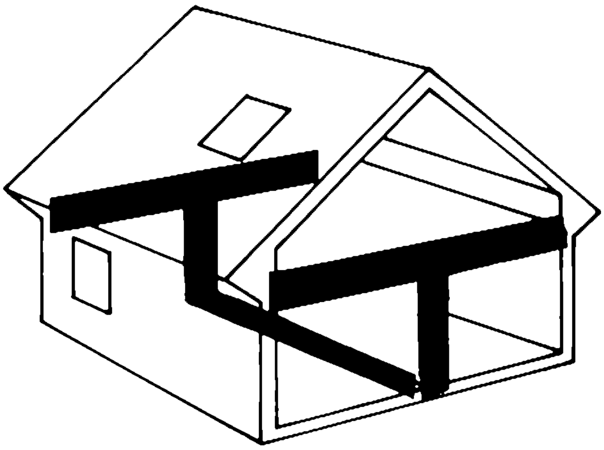
- Carefully plan and show the systems for airtightness and how airtightness is achieved in detail on drawings.
- Try to get all air sealing layers in the same plane throughout the structure.
- Where possible, avoid design and installation-dependent penetrations in the sealing layer.
- Sealing work must be easy to carry out.
- Use only material with documented durability and make sure that material with a limited service life can be easily replaced.

EXAMPLE OF THE USE OF VAPOUR BARRIERS FOR AIR SEALING

This example illustrates how planning for airtightness can use the vapour barrier as the air sealing layer in timber structures. The work can be carried out in stages and is shown in the following figures. The example shows a site-built detached house. The construction details are shown in Chapter A9 and in Part B.

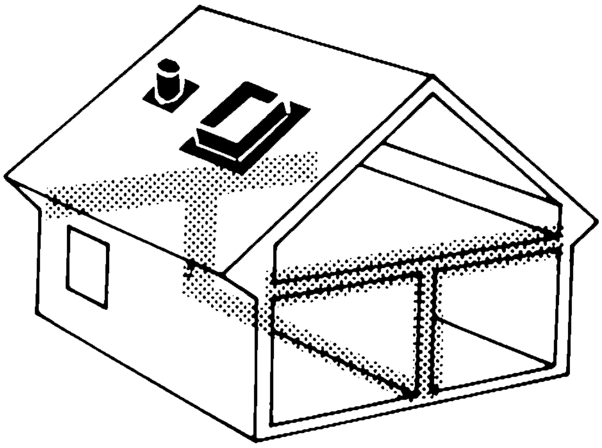
Stage 1

The sealing work is prepared as early as the framework erection by placing strips of plastic film between supporting structural timber. Jointing and overlapping against these strips can be done later and a continuous sealing layer is possible.



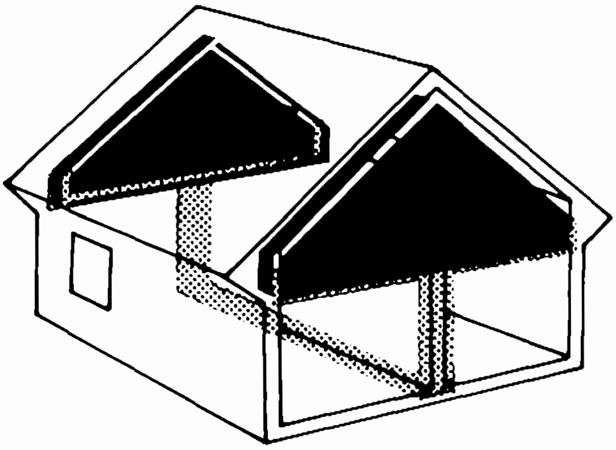
Stage 2

Special sealing measures are taken for different types of penetrations. There are different methods for electrical cables, ventilation ducts, drain pipes, etc. A common factor in all these methods is that they provide an airtight connection and/or joint against the ordinary plastic film.



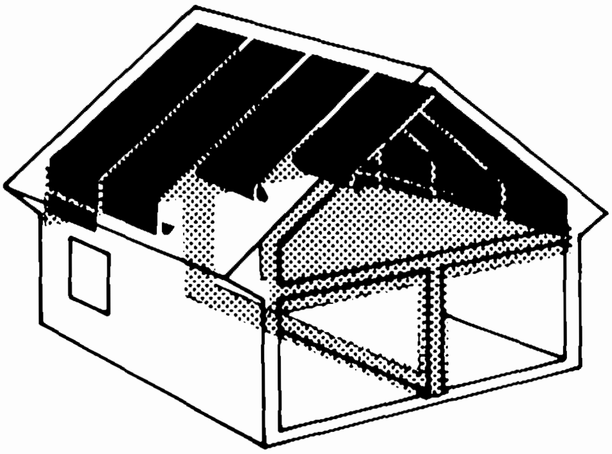
Stage 3

Plastic film is fitted to the gable walls of the building's upper floor. The film is fitted so that there is an overlap against walls and roof. Large size sheets of plastic are recommended.



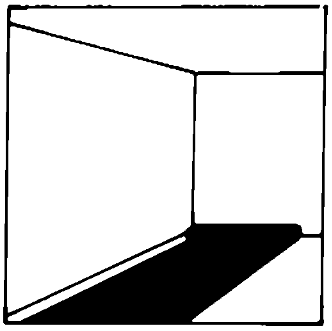
Stage 4

Plastic film is fitted to the wall and roof structure in the upper floor. A suitable size of plastic film which covers the area between roof trusses and provides sufficient overlap is used.

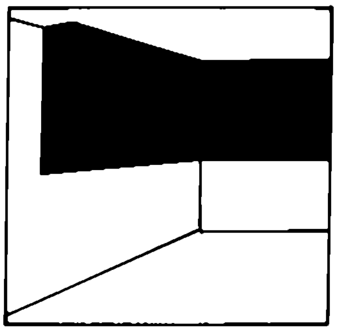


Stage 5

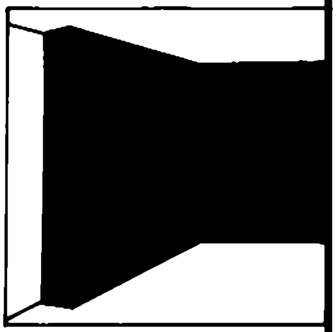
Plastic film is fitted to the walls in the bottom floor. A suitable size of plastic film where the width is equal to the wall height plus overlap is used. The plastic film is rolled out along the length of the outer wall and is then fitted. Very few joints are required. Overlap and clamped joints are possible both at the corner of the ceiling and the floor.



Roll out around outer wall



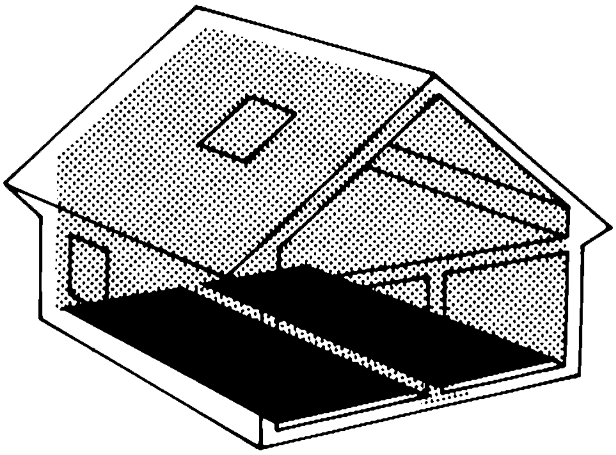
Lift up, fold the little flap against the ceiling, fasten in under the flap



Fold down the large flap and fasten the film

Stage 6

Finally, the plastic film is laid out on the floor. A certain amount of thermal insulation can be laid on top without risk of moisture damage.



A4.3 Reference

Carlsson, B., Elmroth, A. & Engvall, P.-Å., Airtightness and thermal insulation. Building design solutions. (Swedish Council for Building Research.) D37:1980. Stockholm 1980.

A5 REGULATIONS AND REQUIREMENTS

This section summarizes current requirements and standards for buildings in different countries with regard to airtightness, minimum ventilation and maximum coefficient of thermal transmittance. This is an outline summary of the requirements demanded of buildings and building sections with the aim of constructing low-energy buildings and providing a good indoor climate.

In some countries there are several institutions that compile standards (e.g. United States and United Kingdom). This makes comprehensive comparison difficult particularly with respect to ventilation. There is also a number of manuals which, in certain cases, form practices and assume the character of a standard. Local stringent requirements are not uncommon in the United States. The basis for specific requirements and their validity vary between different countries.

Table A5.1 gives a summary of different functional requirements in different countries. These requirements, which are normally valid only for new houses, are exemplified in the following section.

Table A5.1. Requirements and recommendations

	Canada	Netherlands	Norway	Sweden	Switzerland	United Kingdom	United States
Codes or standards:[5]	Residential standards[4]	Building regulations	BF	SBN	STA[4]	Building Regulations[3]	ASHRAE[4]
Airtightness:							
components	W+D	W	R	R	W+D	N	N
whole building	N[6]	N	R	R	N	N	N
Min. ventilation							
rate	R	R	N[1]	R	N[1]	N[1]	R
due to combustion	R	R	N	R	R[2]	R	R[7]
k-values, components	R	R	R	R	R	R	R
k_m-values, whole building	N	R[8]	C	C	R	N	C

R = Requirement exists
N = No requirement exists
C = Compensation allowed if total heat loss of building is not increased
W = Requirements only on windows
W+D = Requirements only on windows and doors

1 Recommendations exist for kitchens, bathrooms and toilets.
2 Requirements in some cantons.
3 United Kingdom has different mandatory requirements applying to Inner London, England & Wales, Scotland and Northern Ireland. Building Regulations apply to England and Wales. The requirements in Northern Ireland are generally the same as England and Wales.
4 Model standard for local application.
*5 See **references**.*
6 Recommendations may be introduced in 1982.
7 Local codes apply.
8 Explained in Part B.

For detailed information refer to the respective country's section in Part B and the text of the relevant standard.

A5.1 Airtightness

Currently, Sweden and Norway are the only countries that have recommendations for airtightness for whole buildings. The matter is being discussed in the United States and recommendations will probably be introduced in Canada in 1982.

There are requirements for airtightness of windows and doors in several countries. These are compiled primarily with protection against rain penetration in mind. There exist ISO and ASTM standards or draft standards for classification and test methods for windows and doors regarding air permeability.

Methods for calculating air infiltration and energy losses exist and are reviewed in the Section on calculation methods. As yet the methods are not standardized.

Table A5.2 shows the demands for airtightness for a complete house in Sweden and Norway.

Table A5.2. Acceptable maximum leakage factors (air change rate per hour) for houses at 50 Pa pressure difference as per Test Methods SP 1977:1 or NS8200 (see Chapter A.11).

Type of building	Leakage factor ac/h at 50 Pa	
	Sweden	Norway
Detached and linked houses	3.0	4.0
Other houses, max. 2 floors	2.0[1]	3.0
Houses with 3 or more floors	1.0	1.5

[1] The value applies to the leakage which occurs towards exposed or non-heated areas. It can for example be applied to terraced house apartments with almost tight party walls (e.g. of concrete). It can also be applied to leaky party walls if a correction is made for the leakages. If no special correction has been made for leaky party walls, e.g. a framework structure, a value of 3.0 ac/h is accepted.

A5.2 Minimum ventilation

To ensure good air quality indoors, requirements for minimum ventilation have been introduced for buildings and premises occupied by people. These requirements are formulated in different ways.

A fundamental assumption is that the concentration of injurious and unhygienic pollutants must not exceed specified limits. These requirements have been translated in terms of air changes, air flow and ventilation openings in different ventilation systems.

The requirements differ considerable depending on the usage of the building. Different ventilation systems are required for different buildings. In the case of new houses, there are currently no requirements for the installation of mechanical ventilation. However, it may be necessary to have mechanical ventilation in single-family dwellings if natural ventilation cannot provide sufficient air change rates. The different standards' values for required air changes rates provide guidelines for ventilation.

If mechanical ventilation is to be installed, there are requirements for minimum flow and capacity in many countries. In the case of natural ventilation there are requirements for open ventilator area, openable flaps and air flow.

With energy saving in mind, the minimum ventilation is often the maximum ventilation. In certain cases this has resulted in insufficient ventilation resulting in moisture and mould problems, bad air, etc. A contributory reason for these problems is the inadequate collaboration between installation and building technicians (see Chapter A2).

Table A5.3 shows the maximum indoor concentrations of different pollutants allowed by ASHRAE and others. Most limits given in requirements apply to conditions in buildings for work rather than dwellings. In Sweden, for instance, the National Swedish Committee for Health and Safety at Work decides maximum limits for concentrations for a great number of different pollutants. These limits are referred to in the Swedish Building Code (SBN 1980) where it is stated that ventilation installations is to be dimensioned to keep a concentration level of one-twentieth of the given maximum concentration except for

Table A5.3. Highest permissible concentrations of different pollutants indoors.

Contaminant	Sweden SBN 1980	United States ASHRAE 62-1981
Carbon dioxide		4.5 g/m^3 [1]
Formaldehyde		120 $\mu g/m^3$
Radon	70 Bq/m^3 [4]	0.01 WL[2] (37 Bq/m^3)
Ozone		100 $\mu g/m^3$ [1]
Odour/smoke	see note[3]	subjective evaluation[3]

1 Continous exposure
2 Annual average (WL – Working level)
3 Odours and other contaminants are not allowed to cause hygienic inconvenience to occupants
4 Radon decay products' concentration in new buildings

Further information about air pollution and indoor air quality is presented by IEA Annex IX "Minimum Ventilation Rates".

CO and CO_2 for which one-tenth of the hygienic limit values are accepted. Still, these apply mostly to working conditions. For dwellings, the term "hygienic inconvenience" often occurs as a subjective level in requirements.

Minimum ventilation rates for dwellings according to codes in different countries are shown in Table A5.4. These requirements determine minimum flow of supply outdoor air or capacity of fans if mechanical ventilation is installed.

Apart from these requirements there are special regulations for supply air to combustion and boiler rooms.

Table A5.5 shows requirements on ventilator openings and area of openable windows in dwellings with natural ventilation.

Table A5.4. Requirements for minimum ventilation (and ranges) in dwellings expressed in air changes per hour (ac/h) or volume (dm^3/s, $dm^3/s\ m^2$ floor area or dm^3/s person). Note: 1 dm^3/s = 1 l/s = 0.001 m^3/s.

Country	Code	Whole dwelling	Kitchen	Bathroom & WC	Living room	Bedroom
Canada	Residential Standards 80[1,7]	1 ac/h				
Netherlands	NEN 1087[2]		21-28 dm^3/s[3]	14 dm^3/s[8]	21-42 dm^3/s	1 $dm^3/s\ m^2$
Norway	BF[2]		22 dm^3/s[1]	16 dm^3/s[1]		
Sweden	SBN 1980[2]	0.35 $dm^3/s\ m^2$	10 dm^3/s	10 dm^3/s[6]		
Switzerland	SIA380[2]		22-33 dm^3/s	17 dm^3/s		
United Kingdom	Building Regulations[5,7]		6 ac/h[1] (Scotland only) 1 $dm^3/s\ m^2$ (Inner London)	3 ac/h[1] (not in Inner London)	3-8 dm^3/s pers.[4,1] (Scotland only) 6 dm^3/s person (Inner London)	3-8 dm^3/s pers.[4,1] (Scotland only) 6 dm^3/s person (Inner London)
United States	ASHRAE 62-1981[2] Summary of other codes[2]		50 dm^3/s[1] 3-15 ac/h[1]	25 dm^3/s[1]	5 dm^3/s 0.5-2.0 ac/h[1]	5 dm^3/s 0.5-1.0 ac/h[1]

[1] *Capacity requirements for ventilation installations for intermittent use.*
[2] *Limits for air flow.*
[3] *Depends on room size (> or < 10 m^2 floor area).*
[4] *Depends on room volume per occupant.*
[5] *For England and Wales; Scotland, N Ireland and Inner London differ somewhat. In no case is mechanical ventilation compulsory.*
[6] *One dm^3/s for each m^2 above 5 m^2 should be added.*
[7] *Mechanical ventilation is required only if natural ventilation is not provided.*
[8] *For WC 7 dm^3/s.*

Table A5.5. Requirements for minimum ventilator openings in dwellings with natural ventilation in m^2 or per cent of floor area.

Country	Code	Whole dwelling	Kitchen	Bathroom & WC	Living room	Bedroom	Basement
Canada	Residential Standards 80 (Dwelling units)		0.28 m^2	0.09 m^2	0.28 m^2	0.28 m^2	0.2 %
Netherlands	NPR 1088 (1 m^2 per m^3/s)		0.02/0.03 m^2	0.01 m^2	0.02-0.04 m^2	0.02-0.04 m^2	
Norway	BF		0.02 m^2	0.015 m^2			
Sweden	SBN 1980		0.02 m^2	0.015 m^2			
United Kingdom	Build. Regulations (Build. Regulations England & Wales) (Build. Standards Scotland)		5 %	5 % (>0.1 in Scotland) (0.18 m^2 openable window in Inner London)	5 % (+0.015 m^2 ventilator in Scotland) (+0.002 m^2 permanent vent. in Inner London)	5 % or living room	
United States	Summary of 16 different codes	4-5 %					

NB Apart from these requirements, there are requirements for openable windows or corresponding devices to cope with "extreme cases". Inner London differs somewhat from United Kingdom as a whole, being more detailed than shown above.

A5.3 Thermal insulation

Table A5.6 shows the maximum permissible k-values (U-values) for the envelope of single-family dwellings.

In Sweden and Denmark, the requirements relate to all buildings that are expected to be heated to at least 18°C.

In the United States, the values apply to single-family and two-family dwellings. Apart from the requirements for thermal insulation of external walls being somewhat lower, the figures apply to all dwellings with three floors or less.

In the United Kingdom the values apply to dwellings, in Canada to residential buildings, whereas in Switzerland and the Netherlands the values apply to all new buildings.

The methods of calculating the k-value do not differ significantly between countries. (A method is given in Chapter A7.) In certain cases, somewhat different values are used for surface resistances but these are often compensated for when dimensioning the insulation. The differences which are apparent apply primarily to cold bridges.

Where the requirements and calculations for cold bridges are concerned, timber frame members are not included in the framework's thermal resistance in the United States and Canada hence the values apply to the best case section. Cold bridges at different connections are not considered. These methods of calculation do not encourage energy saving design solutions at connections between building sections. In Sweden and Norway the effect of cold bridges is calculated in the respective building section's thermal resistance. There are special design regulations applicable to connection details. One method of calculating the influence of cold bridges is described in Section A7.2 "Heat Transfer".

Table A5.6. Maximum permitted heat transfer coefficients, k-value, in W/m²K for outer parts of dwellings.
Note: In Canada, Netherlands and United States the requirements often are given as R-values (R ≈ 1/k).

	Canada 1978	Denmark 1979	Netherlands 1978	Norway 1980	Sweden 1980	Switzerland 1980	United Kingdom 1982	United States 1980 ASHRAE
Roof	0.14[1]-0.40	0.20	0.78	0.23	0.17[1]-0.20	0.50	0.35	0.14[1]-0.28
Exposed outside wall	0.27-0.40	0.30-0.40[3]	0.78	0.25	0.25-0.30	0.60	0.60	0.60-1.60[8]
Exposed floor structures	0.21-0.40	0.20	0.78	0.23	0.17-0.20	0.60	0.60	
Floor structure above crawlspace	0.21-0.40	0.30	1.92	0.30	0.30	0.60		0.25-2.00
Floor structure on earth	0.21[2]-0.40	0.30	1.92	0.30	0.30	0.80		0.34-3.33
Floor structure above cellar	0.21-0.40	0.40	1.92	0.30	0.50	0.80		0.25-2.00
Windows	2.2-3.3	2.90	2.80[4]	2.10	2.00	3.30		
Doors	0.7	2.00		2.00	1.00			
Max. window area	15 %	15 %		15 %	15 %[5]		12 %[7]	
U_m-building	-					0.60-0.75[6]		

1 Figures vary depending on climate zones (Sweden) or number of heating degree days (United States, Canada).
2 Perimeter insulation required if floor <600 mm below ground level.
3 Depends on wall density, the higher demand on lightweight walls.
4 Only in living room and kitchen.
5 Of "external" floor area (+3 % of internal floor area). See Part B – Sweden.
6 Values for mean conditions, the lower value for single-family house. For details see Part B – Switzerland.
7 Figure shown is percentage of perimeter wall area (including party walls). Greater percentage is possible by using double or triple glazing.
8 Includes windows and doors.

A5.4 References

CANADA

(1) Residential Standards Canada 1980, Associate Committee on the National Building Code. (National Research Council of Canada, NRC.) Ottawa 1980.

DENMARK

(1) Bygningsreglement 1977 (BR 77). (Boligministeriet.) Copenhagen 1977.

THE NETHERLANDS

(1) NEN 1087, Ventilatie van Woongebouwen. Ventilations in dwellings. Requirements. (Nederlands Normalisatie-Instituut, NNI.) Rijswijk 1975.

(2) NPR 1088, Ventilatie van Woongebouwen, Aanwijzingen voor en vorbeelden van de constructieve uitvoering van ventilatievoorzieningen. Ventilation in dwellings. Indications and examples for constructional performance of ventilation supplies. (NNI.) Rijswijk 1975.

(3) NEN 3661, Ramen, Luchdoorlatendheit, waterdichtheid, stijfheid en sterkte. Windows, air permeability, watertightness, rigidity and strength. Requirements. (NNI.) Rijswijk 1975.

(4) NEN 1068, Thermische isolatie van gebouven. (NNI.) Delft 1981.

(5) Modél Bouw Verordening, 18th Supplement. (Vereniging van Nederlandse Gemeenten.) ś Gravenhage 1981.

NORWAY

(1) Byggeforskrifter av 1969 (BF). (Kommunal og Arbeidsdepartementet.) Chapter on thermal insulation and airtightness, revised 1980.

(2) Riktlinjer för byggnadsbestemmelser rörande inomhusklimat. Guidelines for building regulations concerning indoor climate. (The Nordic Committee on Building Regulations, NKB.) Proposal 800423.

SWEDEN

(1) SBN 1980, Swedish Building Code. (The National Swedish Board of Physical Planning and Building.) Stockholm 1980.

SWITZERLAND

(1) SIA 180. Thermal Protection of Buildings in Winter. (Swiss Association of Engineers and Architects.)

(2) SIA 380.

UNITED KINGDOM

(1) Easiguide to Open Space and Ventilation in Housing. (The National Building Agency, NBA.) 1980.

(2) The Building Regulations 1981 (and subsequent amendments). London.

(3) Building Standards (Scotland). Regulations 1971 (and subsequent amendments).

(4) London Building (constructional). By-Laws 1972 (and subsequent amendments).

(5) BS 5975:1980, Code of Practice for design of buildings: ventilation principles and designing for natural ventilation. (British Standards Institution.) London.

UNITED STATES

(1) ASHRAE Standard 62-1981, Standards for ventilation Requirements for Minimum Acceptable Indoor Air Quality. (ASHRAE.) Atlanta 1981.

(2) ASHRAE Standard 90A, 1980, Energy Conservation in New Building Design, Atlanta 1980.

(3) The BOCA, Basic Energy Conservation Code, 1977. (Building Officials and Code Administrators International, Inc.) Chicago, Ill. 1977.

A6 CLIMATE AND DEGREE DAYS

A6.1 Comparisons of temperatures, wet bulb temperatures and windspeeds

Comparing the interplay between climate and energy consumption in buildings is interesting and contributes to the understanding of which climate factors are relevant to a building's energy consumption.

Investigations in Sweden have shown that houses in cold climates often do not consume more energy than houses in warmer climates, and often consume less. This probably results from better design, building traditions, living habits, etc., in colder climates.

Lately, the effect of different climate factors on energy consumption in buildings has aroused considerable interest. Today there are only indications of what proportions solar, wind, snow, radiation and moisture conditions contribute to the energy balance.

The climate factor most readily used is outdoor temperature. The term "degree-day", described in the next section, is a consequence of this and the term "lowest design outdoor temperature" has come into being. The effect and magnitude of different climate factors depend to a considerable extent on the appearance of the building, its design, topographical location, etc.

To be able to calculate the energy balance accurately, the microclimate and its effects have to be considered. The microclimate is the wind, solar radiation, temperature and moisture conditions which occur around the building. These conditions can vary considerably from those measured at the nearest official meteorological station.

The microclimate at a particular place changes if a building is erected there. What changes occur can be difficult to forecast.

Results from measurements of local climate factors have recently been used when planning and designing new buildings to minimize energy losses due to climatic conditions.

The following is a summarized comparison between temperature, dew point and windspeed for different locations in Europe and North

America. These factors are assumed to have the greatest effect on a house's energy consumption and to be the most significant with respect to ventilation and air leakage in buildings. The air's moisture content — stated as wet bulb temperature — is in many cases the deciding factor for the need for ventilation. Temperature curves are also given to complement the degree-day term often used (see the following section) since this is not altogether clear and can lead to misunderstanding when making basic calculations of a building's energy demand.

Reference should be made to the handbooks given in the literature list for more detailed information on climates in different countries.

Temperature curves in this chapter are based on monthly mean values which in turn are calculated from diurnal mean and diurnal extreme temperatures. Wet bulb temperatures are calculated from table values of relative humidity at the diurnal mean temperature. Graphs of windspeeds are also based on monthly mean values calculated from hourly and diurnal mean values. Information on monthly means of diurnal mean and extreme temperatures, wet bulb temperatures and windspeeds has been assembled from a number of representative sites in countries affiliated to the Air Infiltration Centre (see Figure A6.1). Comprehensive diagrams for places shown in Figure A6.1 are given in Part B for the respective country. Naturally, the climate varies considerably between these places. Even if the selected sites are considered to be representative, there can be significant local variations with respect to wind and temperature conditions and thus the following are examples of the different climates which can occur.

In United States it is particularly difficult to find representative sites because of the size of the country. Almost all types of climate are to be found there — from areas with cold climates and considerable heat demands in the northern parts, to areas with hot climates in the south with almost only cooling demands.

A comparison of the temperature differences between Miami (United States) on the 25th parallel and Luleå (Sweden) on the 65th serves to illustrate the differences which must be considered for heating and cooling demands in buildings (see Figure A6.2).

The sea's moderating effect on air temperatures and both diurnal and seasonal variations is apparent when comparing the climate in

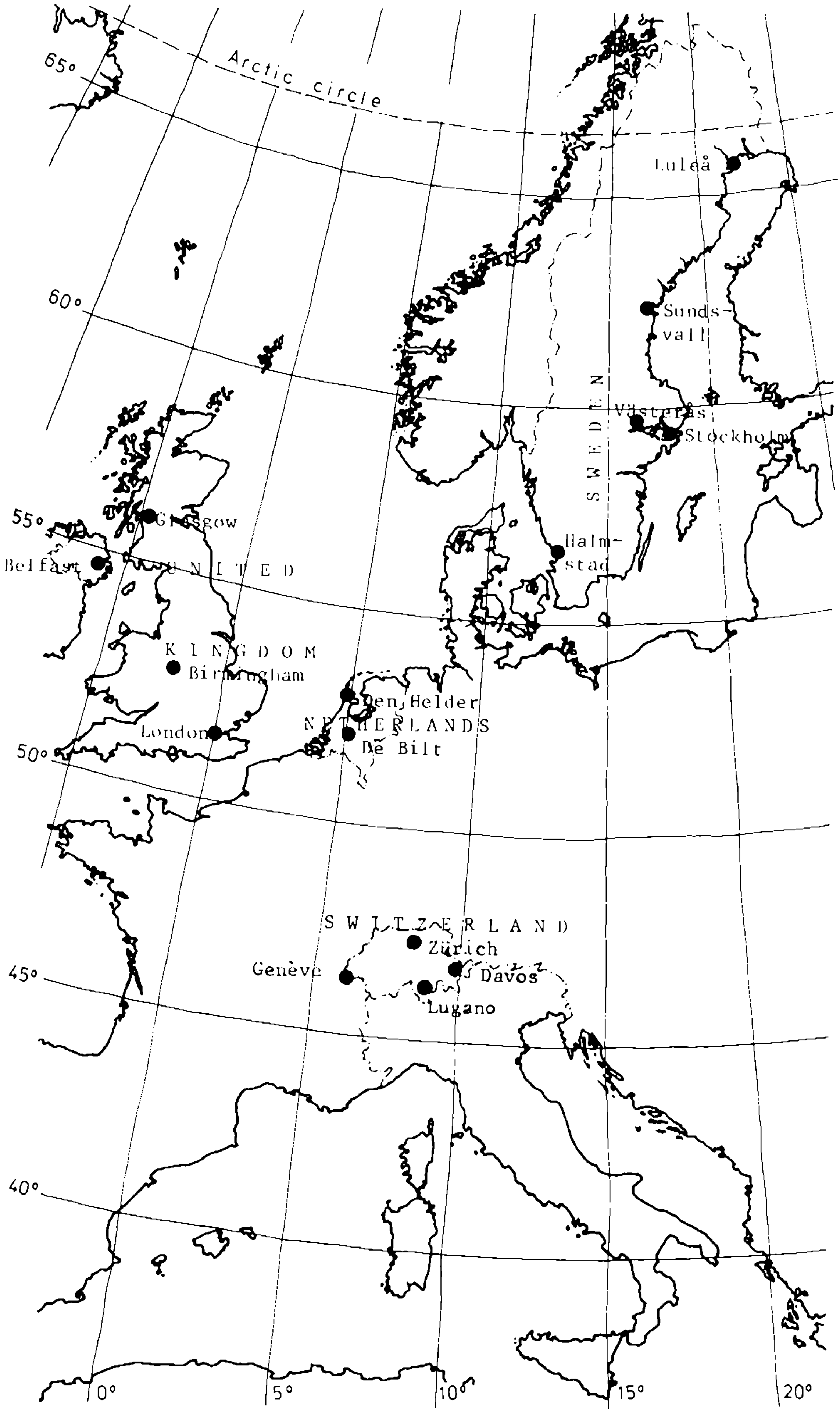

65°
60°
55°
50°
45°
40°
Arctic circle
Luleå
Sundsvall
Västerås
Stockholm
SWEDEN
Halmstad
Glasgow
Belfast
UNITED KINGDOM
Birmingham
London
Den Helder
NETHERLANDS
De Bilt
SWITZERLAND
Zürich
Genève
Davos
Lugano
0°
5°
10°
15°
20°

Figure A6.1a.

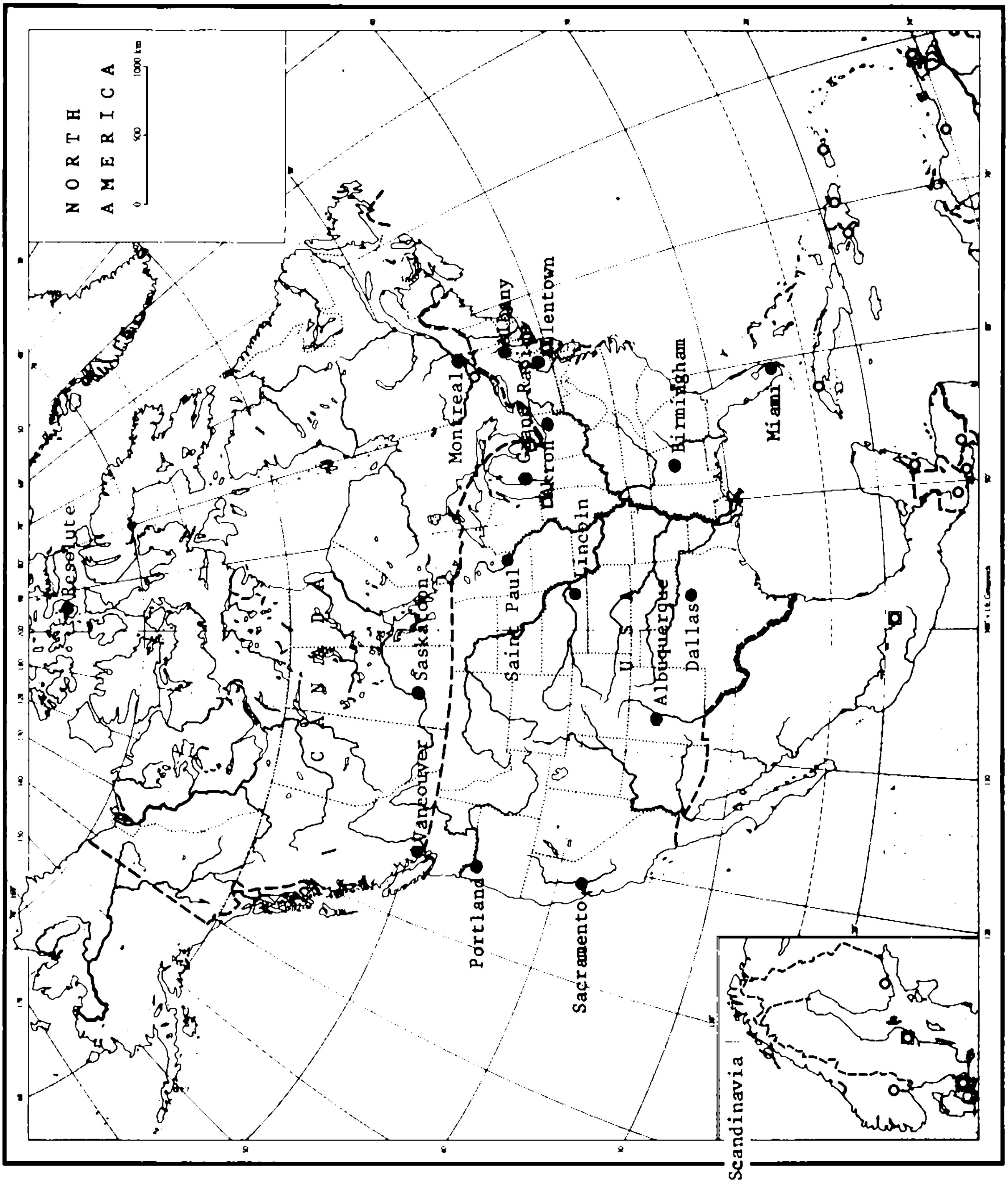
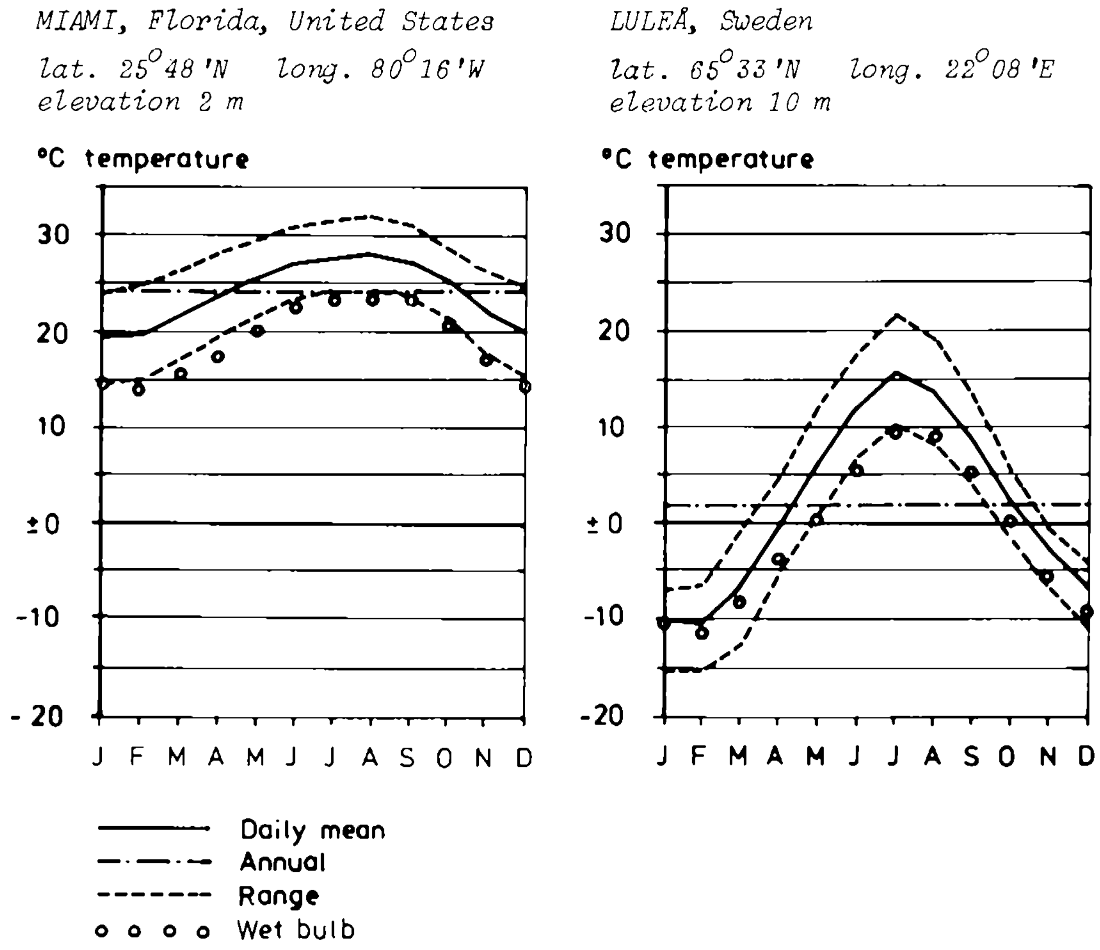


Figure A6.1b.

Figure A6.1a and b.

Overview of places in a) European b) North American countries connected to the Air Infiltration Centre from where climatic data have been collected.



MIAMI, Florida, United States
lat. 25°48'N long. 80°16'W
elevation 2 m

LULEÅ, Sweden
lat. 65°33'N long. 22°08'E
elevation 10 m

Figure A6.2. Example of temperature differences between Miami, United Stated (lat. 25°N) and Luleå, Sweden (lat. 65°N).

Saskatoon, Canada, and Den Helder, The Netherlands, for example (see Figure A6.3).

Figure A6.4 illustrates temperatures for five different locations with approximately the same annual mean temperature but with different yearly amplitudes and monthly variations. Such sites can be found at different latitudes and in different continents. Temperature differences between summer and winter vary depending on distance to the coast, height above sea level, ocean current temperature, etc.

Local windspeeds vary considerably depending on vegetation, buildings, etc. The windspeed measured also varies at different heights above ground level. Windspeeds are normally measured at a height of 10 m above ground level at meteorological stations to avoid "disturbing" effects from buildings, vetegation, etc. Windspeeds which affect low buildings are, on average, probably much less than the windspeeds measured at these stations.

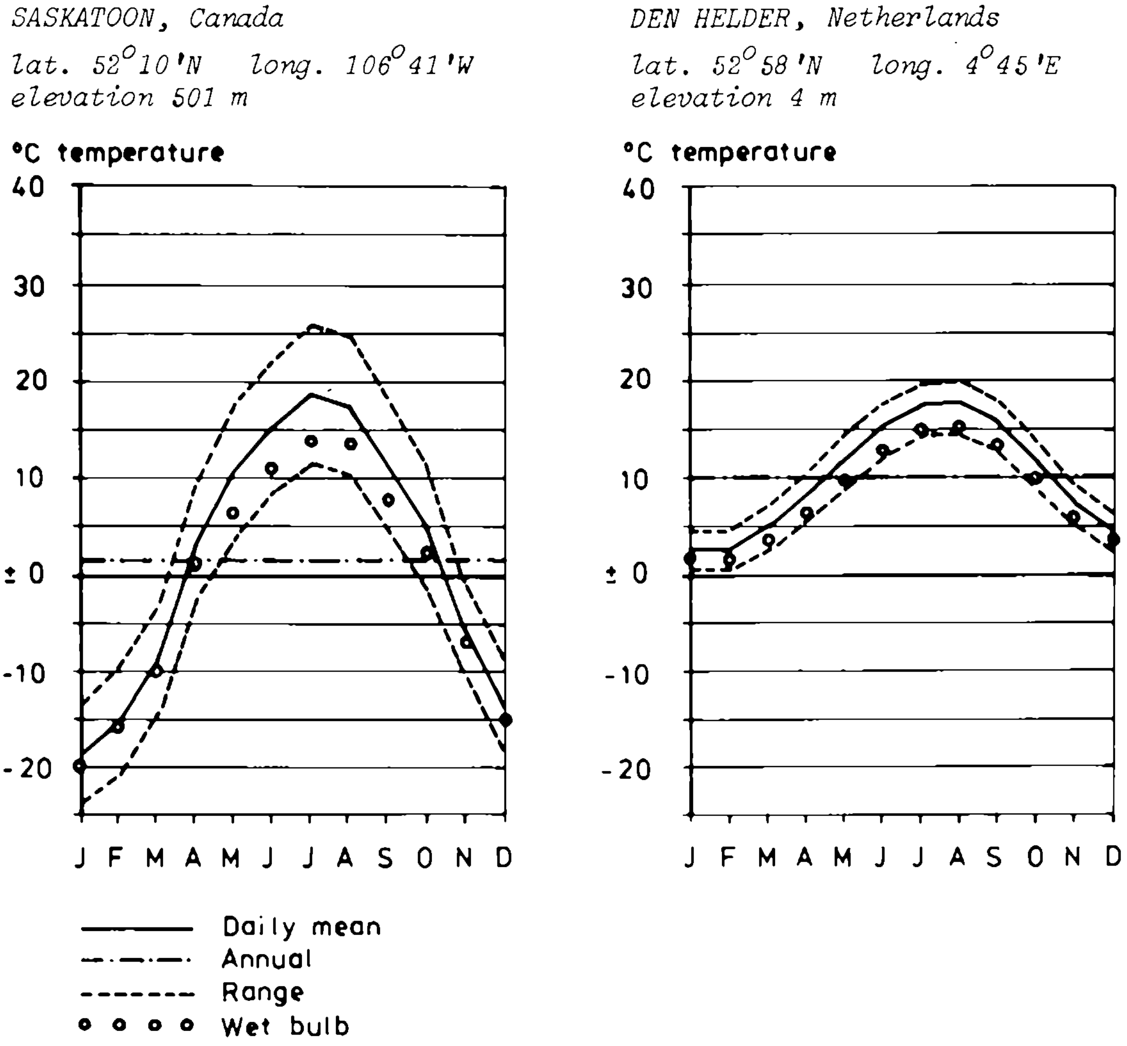
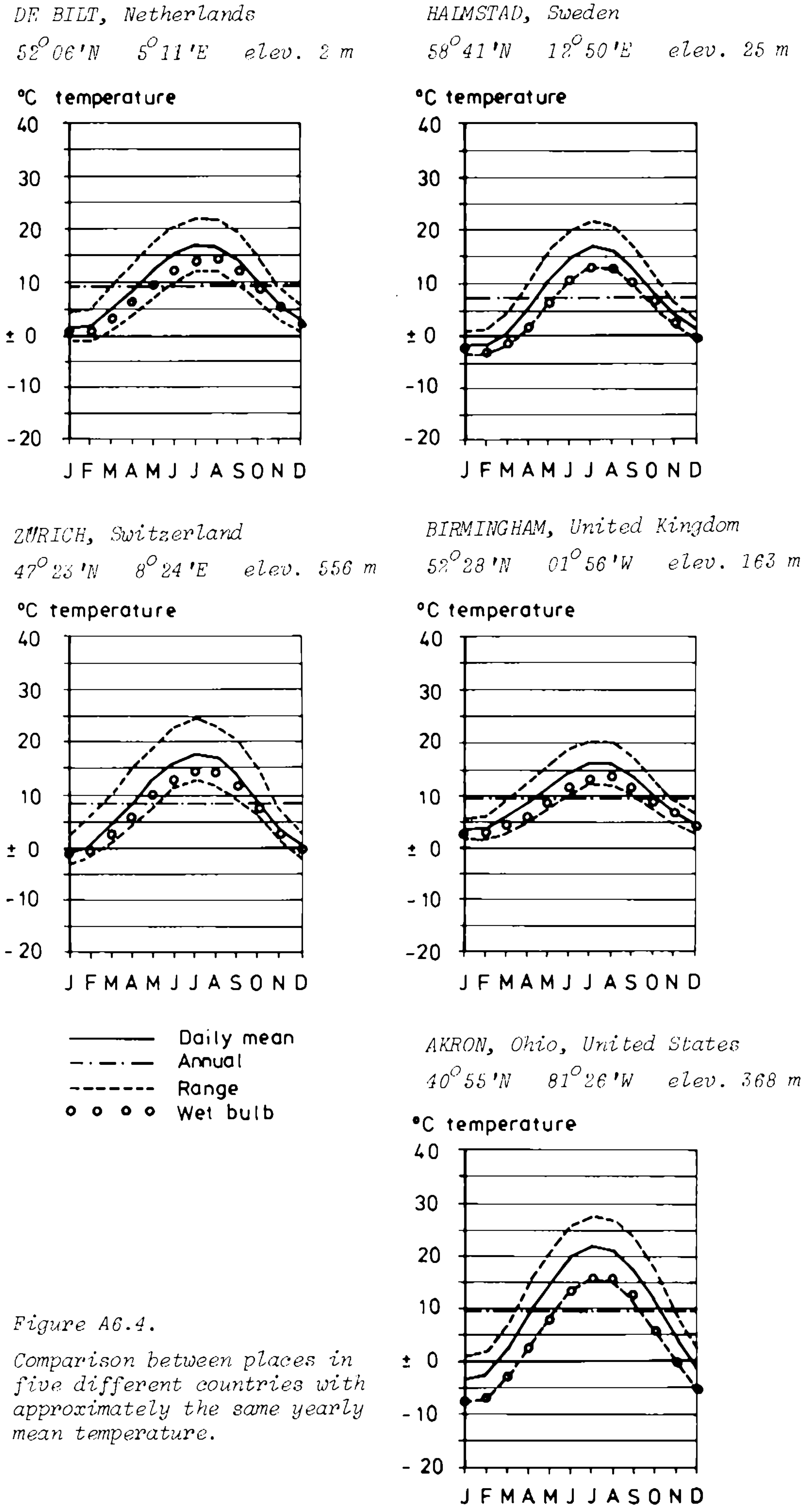


Figure A6.3. Typical inland climate of Saskatoon, Canada, compared with coastal climate of Den Helder, Netherlands. Both cities are situated at latitude 52°N.

Windspeeds also vary a great deal with time, often quite irregularly. The mean windspeed for a respective month often only gives a rough assessment of the actual wind conditions at the site. Figure A6.5 compares windspeeds at two relatively close meteorological stations, De Bilt and Den Helder in The Netherlands. The distance between these meteorological stations is about 100 km. De Bilt is about 50 km from the coast while Den Helder is actually on the coast. The figure shows that the mean windspeed is almost double as much at the coast compared with a bit inland, despite the relatively short distance between the stations.

Air humidity plays a hitherto almost unknown role in a building's energy consumption. In areas with considerable precipitation and



DE BILT, Netherlands
52°06'N 5°11'E elev. 2 m

HALMSTAD, Sweden
58°41'N 12°50'E elev. 25 m

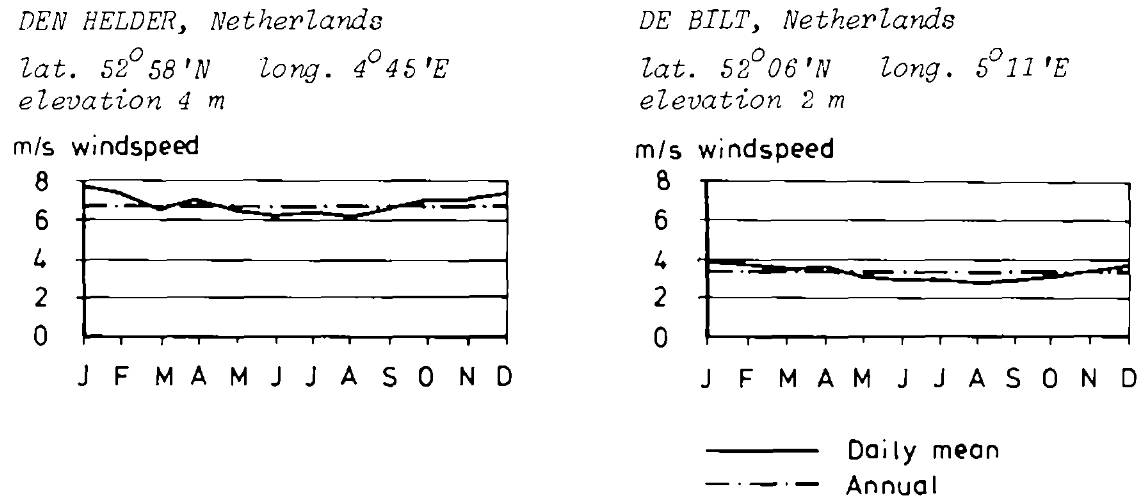
ZÜRICH, Switzerland
47°23'N 8°24'E elev. 556 m

BIRMINGHAM, United Kingdom
52°28'N 01°56'W elev. 163 m

AKRON, Ohio, United States
40°55'N 81°26'W elev. 368 m

Figure A6.4.

Comparison between places in five different countries with approximately the same yearly mean temperature.



DEN HELDER, Netherlands
lat. 52°58'N long. 4°45'E
elevation 4 m

DE BILT, Netherlands
lat. 52°06'N long. 5°11'E
elevation 2 m

Figure A6.5. Windspeeds from De Bilt and Den Helder in The Netherlands. The distance between these stations is approx. 100 kilometres.

along sea coasts, the humidity is greater than inland. Areas with particularly high precipitation are the west coasts of the United Kingdom and Canada, large areas of Switzerland and the eastern part of the United States. Figure A6.6 compares air humidity in Vancouver, Geneva and Albuquerque, where Vancouver and Geneva receive considerable precipitation but Albuquerque is in a semidesert area in New Mexico, United States.

A6.2 Calculating degree days (degree hours)

In simple calculated estimates, a building's energy requirement is assumed to be proportional to the difference in temperature between indoors and outdoors. The number of degree days or degree hours are used to calculate the annual heating requirement. Degree days (DD) are usually calculated from the following equation

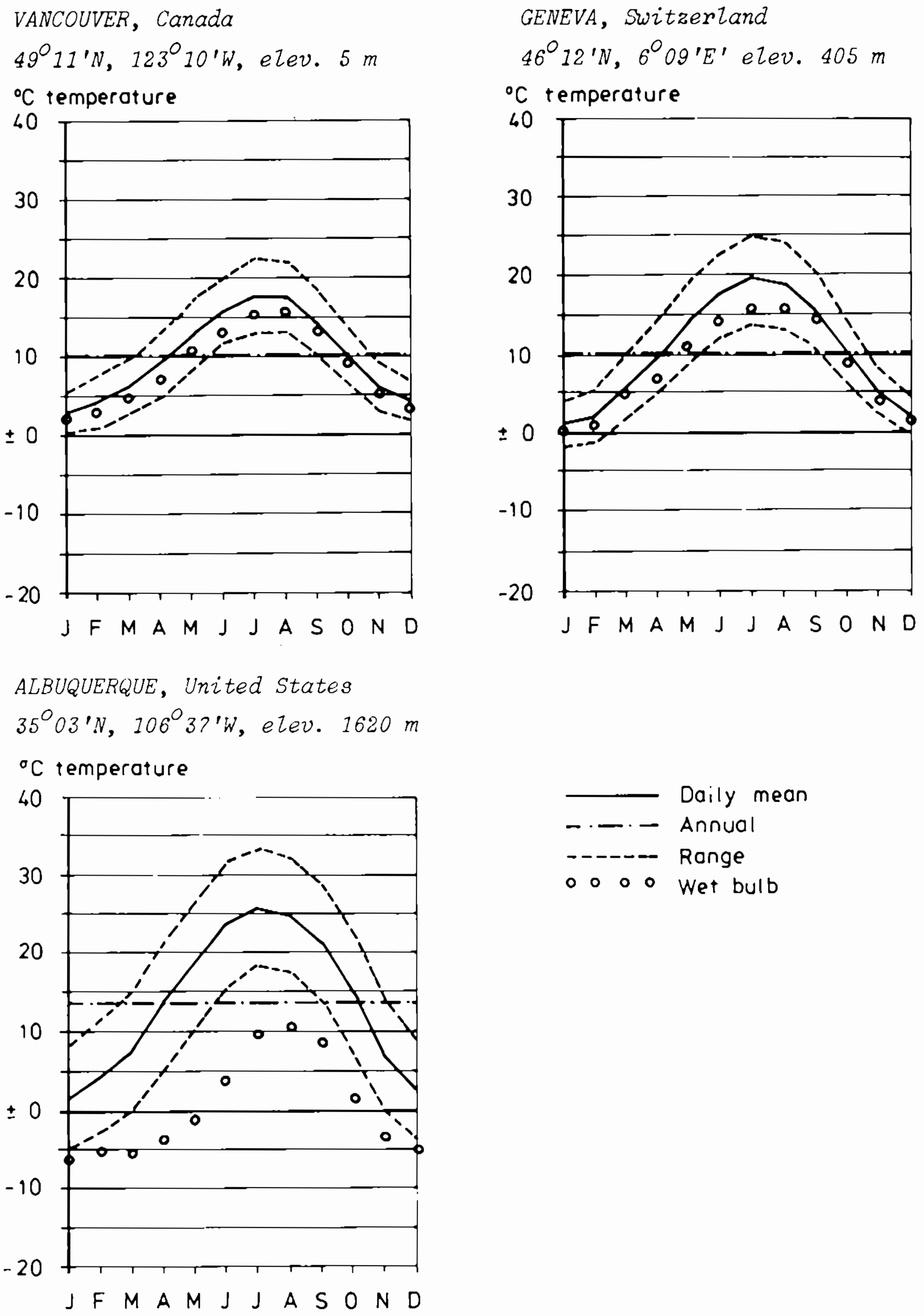
$$DD = \sum_{1}^{n} (t_i - t_o)$$

where t_i = the assumed value of the indoor temperature during the heating season

t_o = the diurnal mean outdoor temperature

n = the number of days (or hours) when heating is required.

As can be seen from the above, only indoor and outdoor temperatures are considered when calculating the number of degree days. Temperature



VANCOUVER, Canada
$49^{o}11'N$, $123^{o}10'W$, elev. 5 m

GENEVA, Switzerland
$46^{o}12'N$, $6^{o}09'E'$ elev. 405 m

ALBUQUERQUE, United States
$35^{o}03'N$, $106^{o}37'W$, elev. 1620 m

Figure A6.6. *Air humidity values for Vancouver (Canada), Geneva (Switzerland) and Albuquerque (United States) expressed as wet bulb temperatures. Wet bulb temperatures should be compared with the daily mean temperatures.*

variations between night and day are not normally considered when the diurnal mean temperature is used. Neither are insolation, radiation, wind precipitation, etc., considered despite the fact that these factors cannot be disregarded when considering a building's energy requirement. For these reasons, the number of degree days can only be used for an approximate calculation of a building's heat requirement. When calculating energy requirements in low-energy buildings, the unqualified use of degree days is not possible.

When calculating degree days, different rules are applied in different countries to consider factors in addition to temperature such as incidental heat gains from persons, domestic equipment, etc. The choice of indoor temperature and the duration of the heating season are the primary factors which vary. A summary of these values and limits is given for different countries in Table A6.1. The table shows clearly the considerable differences in methods of calculation applied in different countries. The normal assumption is that there is a requirement for heat when there is a relatively large difference between indoor and outdoor temperatures.

Table A6.1. Normally used temperatures for calculating heating degree days in different countries. The indoor design temperatures are the expected normal indoor temperatures.

Country	Indoor design temperature ^{o}C	t_i ^{o}C	Limit below which heating is needed ^{o}C	Comments
Canada	21.1	18	18	
Netherlands	20	18	15.5	
Norway	20	20	20	See NS 3031 Table 1
Sweden	20	17	12/10	Start heating season/end heating season
Switzerland	20	20	12	
United Kingdom	18.3	15.5	15.5	Special way of counting when $t_{o_{min}} < 15.5^{o} < t_{o_{max}}$
United States	20	18.3 (65^{o}F)	18.3 (65^{o}F)	

In certain countries (United States, Canada, United Kingdom and Norway), degree days are calculated for all diurnal mean temperatures lower than t_i, i.e. it is assumed that heating is used as soon as the outdoor temperature goes below the indoor temperature. Other countries have a lower heating limit and this also varies between countries and with the time of year in Sweden and Denmark. This is because insolation is greater during the spring than autumn. The heating limit is therefore higher during the autumn than in spring. In the United Kingdom, the number of degree days is corrected in a special way if the outdoor temperature exceeds 15.5°C during a diurnal period, i.e. if $t_{o_{min}} < 15.5 < t_{o_{max}}$.

Since there is no international standard for degree day calculation, degree day values from different countries cannot be compared directly without first having been converted.

Conversion of degree days in °C to °F for the same base temperature is quite easy if the following equation is used

$$DD\ (^{o}C) = DD\ (^{o}F) \cdot 0.556$$

To be able to compare degree days at different base temperatures (heating limits) it is necessary to go back to the monthly mean values or the monthly extreme values in order to avoid excessive deviations in calculations. Such values can be interpreted from diagrams in the previous section for a number of towns in Europe and North America. A rough comparison can be made for optional temperatures in this case. It is also possible to get an idea or the different values possible from applying different methods for degree day calculation.

As can be seen from the above, it is obvious that degree day information from different countries cannot be used for comparative calculations of a building's heat requirement. The more accurate the data required, the more necessary it is to use actual basic data for the different climate factors which affect the result. As was said earlier, when calculating heating requirements for low-energy houses in particular, greater consideration of the climate's effect and incidental heat gains must be made in addition to what is included in the degree day term.

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(3) Degree Days Map from "Community Services Administration Weatherization Demonstration Project Plan", NBSIR 79-1706.

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A7 CALCULATION METHODS

A7.1 Air infiltration

There are several reasons for wishing to calculate the air change rate and undesired ventilation in buildings. One is to enable routine calculations of a house's total energy consumption and thus design the heating installations. Another reason is to evaluate the effects of different types of construction on energy consumption and indoor climate.

Since energy consumption for undesired ventilation is not normally something which can be disregarded in the context of a building's energy losses, the driving forces behind air leakage and their effects must be investigated.

Air infiltration is strongly linked to the weather at the site and the type of ventilation system in the building. However, many factors of house design and location must also be taken into account.

Weather can cause air infiltration by two separate physical mechanisms, wind and temperature-induced convection (stack effect). Unfortunately, these mechanisms do not act independently; i.e. the effects cannot simply be summed. The only statement that is generally valid is that the sum of the separate effects is greater than the actual combined effect. The driving force behind air leakage in buildings is the inside-outside pressure difference caused by these mechanisms.

Wind effects, i.e. the mean wind speed over and around a building, cause a pressure difference between inside and outside. This wind pressure is found to vary over the surface of the building envelope. For every point the pressure caused by wind forces on a building can be expressed as

$$p = p_{ref} + \frac{1}{2} \rho v^2_{ref} C_p \quad \text{(Pa)} \qquad \text{(A7.1)}$$

where p = surface static pressure (Pa)

p_{ref} = reference static pressure (Pa)

C_p = static pressure coefficient

ρ = density of air (kg/m^3) (see Table A7.1)

v_{ref} = wind velocity measured at a height equal to that of the building (m/s).

The wind direction can be an important factor, when calculating air infiltration into a building. A wind approaching perpendicular to the front wall of a building is not necessarily that which results in the highest leakage.

The mean wind speed varies with height, and the vertical profiles of wind velocity vary with the roughness of terrain. Local topographical features such as hills and valleys can greatly influence wind profiles.

Temperature differences between inside and outside cause differences in air density (see Table A7.1). This leads to pressure differences and can be expressed as

$$\Delta p = (\rho_o - \rho_i)\ g\ h \quad \text{(Pa)} \qquad \text{(A7.2)}$$

where ρ = air density (o = outside, i = inside) (kg/m^3)

g = gravitational acceleration (m/s^2)

h = height between inlet and outlet openings (m).

Table A7.1. Variations in air density due to differences in temperature and relative humidity at normal atmospheric pressure (101 325 Pa).

Temperature °C	Relative humidity 0 %	50 %	100 %
-20	1.3950	1.3947	1.3944
-10	1.3419	1.3413	1.3944
0	1.2928	1.2913	1.2898
+10	1.2471	1.2442	1.2413
+20	1.2045	1.1993	1.1940

In buildings where fans create a pressure difference across the building envelope, this pressure difference must be added to the above-named pressure differences.

Since the relationship between the leakage flow and the pressure difference across the building envelope is non-linear, the pressure differences from the different driving forces must be added before the leakage flow at a particular point can be calculated (1), see Figure A7.1.

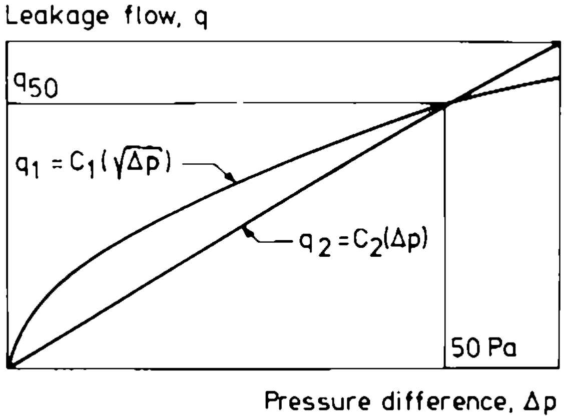

Figure A7.1.

Limiting conditions for the leakage curve between 0 and 50 Pa if the flow at 50 Pa is known.

{After Nylund (1).}

The pressure difference due to the combined effects of wind and stack action is not easy to determine. The resulting interior pressure is based on the fact that the average air flow into and out of the building must be equal. To perform such a calculation, the pressure difference and its distribution over the building envelope as well as the overall leakiness must be known. Often these data are available for general building shapes, which are completely exposed to the wind, rather than the actual building.

The air flow through any kind of opening can be expressed as a function of the pressure across the latter.

$$q = C(\Delta p)^{\beta} \tag{A7.3}$$

where q = volume flow rate of air (m^3/s)

C = air flow coefficient, defined as the volume flow rate of air at a pressure difference of 1 Pa (m^3/s at 1 Pa)

Δp = pressure difference across the opening (Pa)

β = flow exponent, depending on the character of the flow $1/2 \leq \beta \leq 1$

β = 1/2 for pure turbulent flow

β = 1 for pure laminar flow.

This empirical equation has been used for flow through openings with pressure differences in the range of 1 to 100 Pa (2). However, it should be noted that the equation is not dimensionally homogeneous, and it has been argued that a quadratic form of equation is preferable (3). For equilibrium, the inward flow must equal the outward flow. The flow balance equation could be calculated as

$$q_{in} = q_{out} \tag{A7.4}$$

or if mechanical ventilation is separated

$$q_{in} + q_{sv} = q_{out} + q_{ev} \tag{A7.5}$$

where $q_{in} + q_{sv}$ = flow of incoming air by means of infiltration and supply ventilation

$q_{out} + q_{ev}$ = flow of outgoing air through exfiltration and exhaust ventilation.

When there are big differences between indoor and outdoor temperatures, T_i and T_e, the incoming flow could be multiplied by a factor T_i/T_e to compensate for changes in volume. The equations mentioned so far can be considered fundamental physical equations. Values of the constituent parameters are required to solve them. The difficulty lies in finding applicable values for these parameters. Research is in progress in several countries to predict and prepare models for calculating air leakage.

MODELS APPLIED TO FIELD DATA TO INTERPRET AIR INFILTRATION ROLES

The ability to utilize models that describe air infiltration driving forces and thereby predict air infiltration rates is a subject of current research and a task of the Air Infiltration Centre. Factors such as microclimate, differences in wind pressure distribution, location of openings, internal flow resistance certainly complicate this process.

A number of air infiltration models based on the theory outlined in Equations A7.1 to A7.5 have been developed. These range from relatively simple "single-cell" models in which the interior of the building is assumed to be at a single uniform pressure (1, 4-9), to "multi-cell" approaches in which the interior is partitioned into areas of equal pressures interconnected by flow paths (2, 10-15).

The type of model selected will depend very much on the purpose for which it is required. "Single-cell" models may be used to predict whole house air change rates and are therefore useful in energy calculations. However, they give no indication of air movement within a building and cannot be used if internal partitioning results in any significant resistance to air flow. "Multi-cell" models overcome these limitations and, because they can be used to predict internal air movement, are an invaluable aid to indoor air quality studies. Their main disadvantages are that they require a substantial amount of data to describe the internal flow network and that a significant amount of computational effort is often necessary. These disadvantages may be minimized by carefully tailoring the size of the flow network to suit the problem to be solved.

For all models, it is necessary to define the air leakage paths across the building envelope. Depending on the level of detail required, these paths may represent individual leakage components or a combination of components. For each path, the flow coefficient C and the flow exponent β must be specified, as must the surface pressure. Where the quadratic formulation of Equation A7.3 is used (15), the laminar and turbulent components of flow for each path must be given.

The calculation of surface pressure is based on the wind and stack Equations A7.1 and A7.2. The estimation of wind pressure presents particular problems because it is difficult to specify appropriate static wind pressure coefficients. These coefficients are commonly based on the results of wind tunnel tests made on models of isolated buildings and there is some doubt as to the general applicability of these results when applied to dwellings subjected to localized obstructions.

There are several ways in which the flow coefficient C and the flow exponent β may be determined. For example, they may be obtained directly from leakage tests made on individual components or may be based on published values such as those given in the *ASHRAE Fundamentals* (16). Alternatively, it is possible to utilize the leakage characteristics determined from "whole building" pressurization tests. In this instance, the distribution of leakage is based on the leakage area or crack length represented by each leakage path. This method has been used by Sherman & Grimsrud (5) and Warren & Webb (6) as a means to correlate the results of building pressurization tests with air infiltration.

Once the surface pressures and flow parameters have been established, a series of flow equations are developed with unknowns in air flow and internal pressure. These equations are solved by combining them with the flow balance Equations A7.4 and A7.5. At this stage, it is possible to incorporate the effects of purpose-provided openings and chimneys by incorporating suitable orifice flow or duct flow equations. The effect of mechanical ventilation systems may similarly be analysed by specifying appropriate air flow or fan characteristics.

As there is only one internal pressure to determine in "single-cell" models, it is normally possible to solve the flow equations directly. Nylund (1) uses a graphical method of solution in which families of curves are generated as solutions to individual houses, constructed to varying degrees of tightness and having a variety of ventilation systems.

The much increased scale of complexity of "multi-cell" models prevents the use of direct methods of solution. In these instances, numerical methods involving iterative techniques are used.

The theory presented above assumes quasi-steady flow and therefore the influence of turbulent fluctuations on air infiltration is ignored. The results of Grimsrud et al. (17) and Potter (18) show that under certain circumstances this mechanism is significant. Etheridge & Alexander (15) outlines a method to overcome this problem.

Using data on leakiness provided by the pressurization method one can attack the problem of comparing leakiness from one house to the next. Kronvall (19, 20) attempted to make such comparisons for a number of Swedish houses using the parameter q/A (flow/surface area) and then derived a relationship between pressurization tests and natural air infiltration. One factor helping those comparisons was the high degree of similarity of newer Swedish homes as compared to those encountered in the United States. For example, it is important to consider the basis for calculation or representative surface area and how zones communicate.

CRACK AND LEAKAGE BEHAVIOUR

The so-called "crack method" has been used as one means of estimating air infiltration rates. The method emphasizes leakage rates associated with windows and doors which constitute a minor fraction of the overall leakiness in many instances. Furthermore, windows located at the midheight of a single-storey building could, if floor and ceiling are of equal air tightness, be near the neutral zone thereby having less relative influence than a ceiling leak, e.g. around a light fixture or attic trap door.

An improvement to this approach is a catalogue of leakage sites, properly weighted as to importance, so that by appropriate addition of effective leakage areas the overall leakage rate could be estimated. The weighting process, to be accurate, would have to take into account local driving forces and leak location factors. Such catalogues are currently being assembled, making use of information such as that shown in Tables A7.2 and A7.3 (21). The pressurization technique lends itself to gathering such information.

Table A7.2. Infiltration test results, example from literature.

Location of leak	Leakage per item (m^3/h/unit)	Number of units	Average value for 165 m^2 home Total leakage m^3/h	Per cent of total	Cumulative
Soleplate	20.2/ln m crack	53 ln m crack	1070	24.6	24.6
Electrical wall outlets	13.6/outlet	65 outlets	883	20.3	44.9
A/C duct systems	587/system	1 system	587	13.5	58.4
Exterior window	39.5/window	13 windows	513	11.8	70.2
Fireplace	239/fireplace	1 fireplace	239	5.3	75.7
Range vent	226/range vent	1 range vent	226	5.2	80.9
Recessed spot light	56/light	4 lights	226	5.2	86.1
Exterior door	66.7/door	4 doors	200	4.6	90.7
Dryer vent	122/dryer vent	1 dryer vent	122	2.8	93.5
Sliding glass door	74/door	1 door	74	1.7	95.2
Bath vent	56/bath vent	1 bath vent	56	1.3	96.3
Other			152	3.7	100.0
			4348		

Source: Caffey (22).

Table A7.3. Leakage rates of typical houses in Canada.

House type/exterior finish of house	Total leakage in m^3/h at Δp = 70 Pa	Percentage lost		
		Ceiling	Outer walls	Doors/windows
One storey stucco	1160	65	16	20
One storey stucco	1100	57	21	22
One storey brick	2410	16	65	19
One storey brick	2620	34	42	24
Two storey brick	2170	8	77	15
Two storey brick	2240	11	66	23

Source: Tamura (23).

A7.2 Heat transfer

The total heat transport through a building structure varies with time as a result of differing climatic conditions. Certain components of the heat transport also take place in directions other than at right angles to the building structure in question. This applies particularly at corners and joints.

In routine transmission calculations, stationary states and heat transport in one dimension at right angles to the structure are assumed.

The heat transfer ability of a material varies according to temperature difference and moisture content of the material. To be able to compare different materials' heat transfer ability, a material constant, λ-value (k-value in the United Kingdom), is defined as the quantity of heat per unit of time which passes through a square metre of the material which is 1 metre thick and when the temperature difference is 1^oC. The SI unit is W/m K.

This value is measured at 0^oC on one side and $+20^oC$ on the other side under dry conditions. In Sweden, the National Swedish Board of Physical Planning and Building has published values for different building material for practical application. These values have been raised somewhat after comparison with laboratory values bearing in mind the normal moisture content when material is enclosed in a structure and to allow for normal shortcomings in construction work.

A corresponding procedure is applied in a number of countries though assessments as to the amount to be added to laboratory values differ somewhat.

A structure often comprises several layers. A heat transfer coefficient, k-value (U-value in the United Kingdom and the United States) has been introduced to describe a structure's heat transfer properties. This is defined as the quantity of heat which passes through 1 square metre of a structure when the temperature difference is $1^{o}C$.

The SI unit is $W/(m^2\ K)$, i.e. the k-value can be written

$$k = \frac{q}{(t_i - t_o)} \tag{A7.6}$$

where q = heat flow (W/m^2)

t_i = temperature of warm side (^{o}C)

t_o = temperature of cold side (^{o}C).

If room and outdoor temperatures respectively are used, the k-value also includes the thermal resistances of the surfaces. Thermal resistance values vary according to structure and position. Different manuals give different values.

To determine the heat transfer coefficient of a structure comprising several layers, the thermal resistances of the different layers are added.

The thermal resistance of a layer of homogeneous material is calculated from

$$m = d/\lambda \tag{A7.7}$$

where m = thermal resistance of layer $\{(m^2\ K)/W\}$

d = layer thickness (m)

λ = practical value of heat transfer coefficient $\{W/(m\ K)\}$

The total thermal resistance of a structure can thus be written

$$M_{tot} = \frac{1}{k = m_1 + m_2 + m_3 \ldots} \qquad \text{(A7.8)}$$

where m_1, m_2, m_3, etc. are the components resistances of the structure.

The inside and outside surface resistances are included in M_{tot}.

Equation A7.7 is applied when calculating the thermal resistance of homogeneous material. When calculating the thermal resistance of air gaps, e.g. in windows, special consideration must be made of heat transport through convection and radiation. There are special calculation methods for such cases.

THERMAL BRIDGES

Where a layer within a structure is bridged by components of varying thermal resistance, the average thermal resistance may be approximated by

$$m_a = \frac{1}{\frac{p_1}{m_1} + \frac{p_2}{m_2} + \ldots} \qquad \text{(A7.9)}$$

where p_1 and p_2 are the proportional area of each component of the layer and m_1 and m_2 are the thermal resistances of the corresponding components. This approximation is only valid when the highest value of thermal resistance is no more than four times the lowest.

This correction, giving a k-value which is a little too high, is normally used in Scandinavia to calculate the effect of timber frames in mineral wool insulation. This is not the case in the United States and Canada.

There are special calculation methods for calculating energy losses due to cold bridges in construction joints for example. These often assume the use of a computer. The better a low-energy house is built, the more important it is to consider the effect of cold bridges on heat transport.

CALCULATIONS IN DIFFERENT COUNTRIES

The principles and basis for calculating a structure's thermal insulation properties does not vary significantly between different countries. Canada specifies its structures in terms of R-values (M_{tot} in the preceding text) calculated according to the best section. R-values are often quoted in imperial units, i.e. $(ft^2 hr\ ^oF)/Btu$. R in SI units is normally called RSI ($R \cdot 0.176 = RSI$). The R-values of the different insulation thicknesses are often stated individually.

Other countries often give k-values (U-values) in $W/(m^2 \cdot {}^oC)$. Values assumed for surface resistance of boundary surfaces in different structures vary from country to country. Refer to Chapter A5 for information regarding the highest permissible k-values in different countries. Part B gives supplementary information for the respective countries.

A7.3 Energy losses

Energy losses from a building are comprised primarily of transmission, ventilation and drainwater losses. A certain amount of household electricity energy can also be counted as energy losses when used outside the building, e.g. outdoor fans and lighting, or during the warm part of the year when there is no need for heating.

Energy losses from transmission through a building envelope can be written as

$$W_t = \Sigma(k \cdot A)(\overline{\theta}_i - \overline{\theta}_o) \cdot T + \Delta W_t \quad (J) \qquad (A7.10)$$

where k = thermal transmission coefficient of the respective building section ($W/m^2\ K$)

A = area of the respective building section (m^2)

$\overline{\theta}_i$ = average indoor temperature during the heating season (^oC)

$\overline{\theta}_o$ = average outdoor temperature during the heating season (^oC)

T = duration of heating season (s)

ΔW_t = heat transfer through cold bridges (J).

In these calculations, the value of the thermal transmission coefficient for the respective building section is assumed to be the average value for the whole section. In other words, cold bridges in the section have been considered.

The average temperature selected should be the true temperature during the heating season. In certain calculations, the value of the indoor temperature is reduced to compensate for incidental heat gains. In low-energy houses in particular, it is important to use actual temperatures.

It is difficult to define the duration of the heating season. Different practices and methods are applied. As an example, refer to Chapter A6 about degree days. The problem is that the time when actual heating is required depends on factors such as the state of a building's insulation, the amount of waste heat from domestic electricity, incidental heat gains from occupants, the orientation of the building and capacity for short-term heat storage from insolation etc. and the type of climate. In a characteristic inland climate where the transition between summer and winter is rapid and where temperature changes are considerable, the heating season is relatively well-defined. In a maritime climate, defining the duration of the heating season is significantly more difficult.

Consideration of transmission losses through cold bridges in walls and joist structure joints, balconies, corners, foundations, etc., are best calculated using computer programs for multi-dimensional heat flow. As an alternative, standard values for different solutions can be used.

Energy losses for ventilation in a building, including air leakage, are calculated as follows

$$W_i = 3600 \cdot n \cdot V \cdot c \cdot \rho(\bar{\theta}_i - \bar{\theta}_o)\ T \quad (J) \qquad (A7.11)$$

where n = the number of air changes per hour (1/h)

V = the ventilated volume (m^3)

c = the specific heat capacity (J/kg K)

ρ = the density of air (kg/m^3)

$\bar{\theta}_i$ = the average room temperature (^{o}C)

$\bar{\theta}_o$ = the average outdoor temperature during the heating season (^{o}C)

T = the duration of the heating season (s).

As mentioned previously, there are today no really accurate methods for calculating the number of air changes. Thus in consequence, the calculation of ventilation losses is subject to uncertainty.

Until more information on the yearly role of air infiltration and ventilation is available, only estimates are possible. Because of occupant effects these estimates may prove to be quite inadequate (24). Local weather conditions and building location play very important roles with regard to air infiltration severity, e.g. de Gids et al. (25) have documented air leakage influenced by winds of the North Sea.

Drainwater losses are energy losses which arise when water which is heated inside the building runs out through a drain. The size of these losses varies considerable according to occupancy patterns, water usage, etc. It is interesting to note that not only hot water losses but also losses caused by heating cold water as it passes through buildings need to be considered. To a great extent there are no data or calculation methods available to consider such energy losses in detail.

When producing energy balance calculations, it is usual to use standard values for drainwater losses (W_d). The size of these losses is given in Chapter A3.

The percentage of household electricity consumption used for heating a building is usually calculated using standard values. Data for these assumed values are incomplete.

A summation of energy losses for transmission and air changes, together with drainwater losses and "household electricity losses" (W_e) gives the total energy consumption in a building. This gives the "Out" bar in the energy balance and refers to net energy losses, i.e.

$$W_{tot} = W_t + W_i + W_d + W_e \qquad (A7.12)$$

When designing heating installations, the heat demand for the building in question is based on design outdoor conditions. Design for heat losses is usually based on transmission and air change.

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A8 MATERIALS

Demands on building materials vary according to the different requirements and functions of buildings in different countries (indoor climate and energy efficiency for example).

It should be possible to maintain specified requirements for building materials during the life of the building. To ensure that the building functions as designed, materials must be carefully chosen for airtightness and thermal insulation, for example, and their ability to combine with other materials.

Material enclosed in structures should give a satisfactory performance during the life of the building. Material that has not been documented or has inferior durability should be easily accessible for replacement if used.

Materials whose resistance to ageing is of primary importance from a sealing aspect in Sweden include polyurethane foam, EPDM rubber and jointing compounds. The ageing properties of the plastic films used are also of great importance. Another group of materials contains tapes and tape adhesives whose ageing properties are not well documented. These are, however, of lesser importance.

When compared with the expected life of a house, all these materials have been used for a relatively short time. Products are continually being developed and compositions change. The experience gained from the long term use of material, in what can be called natural climates, is thus very limited and test methods for accelerated ageing are inadequately developed. Often only one or two properties are studied in accelerated ageing laboratory tests. Knowledge about newer materials' resistance to ageing is therefore very limited; considerable research is needed. Table A8.1 shows the expected service life of different sealing materials according to investigations by Grunau (1). These indicate that many sealing materials must be used in such a way that resealing is easy.

Gas emissions from different materials must be taken into consideration to provide a good indoor climate. Gases like formaldehyde can cause allergenic reactions. Formaldehyde may be emitted from furniture, chipboard, etc., where urea formaldehyde (UF)

Table A8.1. The expected service life of different sealing materials, 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 {from Ref. (2)}.

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 (2-component)	7	10	5-10
Butyl rubber	13	15	3
Acrylic plastic	13	15	5
Acrylic polymer	7	15	10

glue has been used during manufacture or from insulation using UF foam. Radon gas can be emitted from some building materials, local water, and the ground if it contains uranium. Increasing the concentrations of radon decay products causes an increased risk of lung cancer.

It is also important that materials are given correct descriptions by their manufacturers. Far too many sealing products are sold under anonymous advertising names.

A8.1 Air/vapour barriers

PLASTIC FILMS

Plastic films of different types and qualities are used today both as vapour barriers and for airtightness in houses. Plastic films should be stabilized, especially against oxidative attack and UV radiation. The film used should have sufficient mechanical strength to withstand stresses during construction.

The film should also be transparent to facilitate both inspection of the thermal insulation work and subsequent internal surface erection. In Sweden quality requirements for plastic films are given in Verksnorm 2000 published by the Swedish Plastics Federation (3). The age resistance of a building film is determined by 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 A8.1. 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 therefore recommends that heat reflecting foil of aluminium, for example, be used behind radiators in order to reduce the temperature inside the wall where plastic film is fitted.

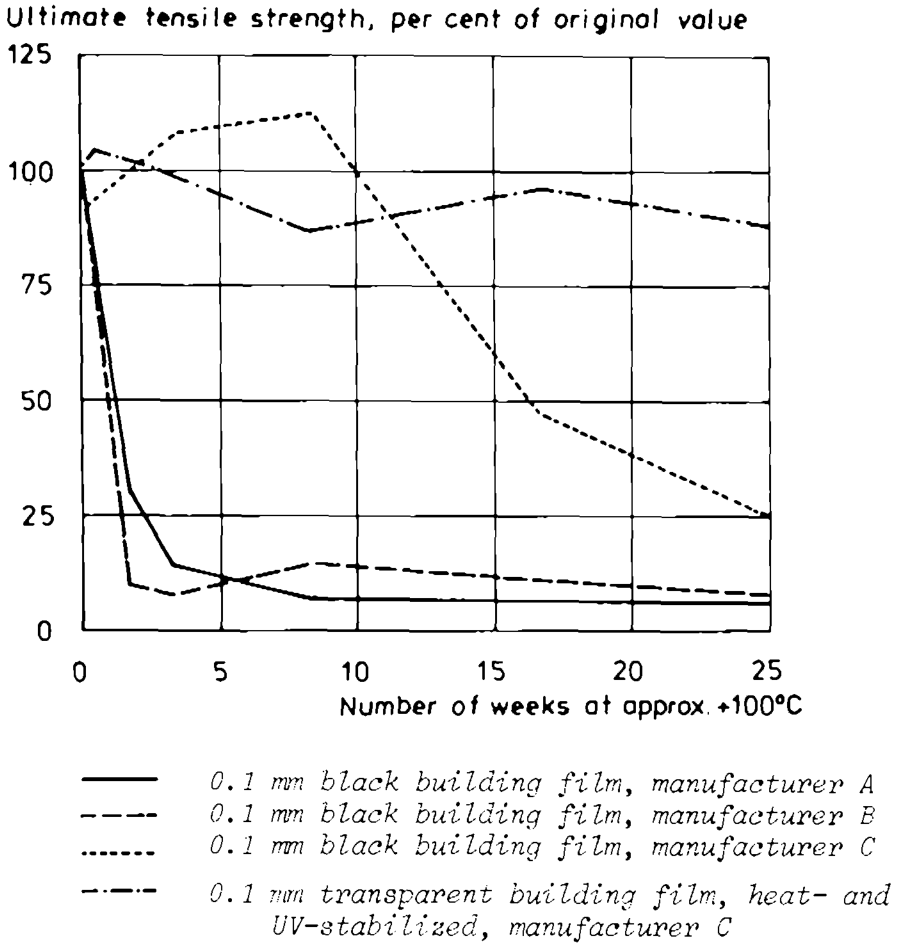

Figure A8.1. An example of a test result on the age resistance of a plastic film. 23 week test at approx. +100°C is assumed to correspond to 40 years at +35°C. The result shows that the plastic film must be heat and UV-stabilized. A black building film gives no guarantee of good age resisting properties (from Ref. (2)).

It should also be noted that fitting polyethylene film with copper staples or non-rust protected steel staples should be avoided since both copper and steel accelerate degradation of the film. Rust-protected steel staples should be used.

The plastic which currently fulfils the requirements for durability in Sweden is 0.2 mm stabilized polyethylene film. Stabilization against UV light and oxidative attack determines the service life of the film. The best quality currently used in Canada has a thickness of 0.15 mm. The thickness of the film determines the mechanical strength which is of importance during erection.

The durability of films of PVC or polypropylene are today unknown owing to lack of test methods.

Jointing and installing plastic film is treated in Chapter A9.

PAPER

Asphalt-impregnated paper (kraft paper) can be used in much the same way as plastic films. Moisture movement is considerable in paper and must be considered when installing paper.

A special system has been developed in Sweden for installing and jointing paper so that it functions as an air/vapour barrier. Special strips of adhesive are used at joints between rolls of paper and are applied with the aid of heat, from an iron for example. This method has also been used to seal plasterboard joints. Good results have been achieved from pressure tests but airtightness durability tests are as yet undocumented.

METAL FOILS

Metal foils of aluminium or copper have a widespread use as vapour barriers in many countries. The foil is often glued on an insulating or sheet material. These materials are very good as vapour barriers. However, both past and present applications of these materials make good airsealing difficult because the use of small sheets has increased the number of joints.

Problems could arise owing to the fact that metal foil conducts electricity. This could be dangerous in connection with electrical installations, expecially for the workers during erection. For this reason, vapour barriers of metal foil are prohibited in walls and ceilings in Sweden.

BOARD MATERIALS

There are many types of board material which in themselves are airtight (e.g. sheets of plaster, wood fibre). Board material with sheets of plastic or aluminium glued to the face is also available.

The greatest problem when using sheet material as a sealing layer is in achieving lasting airtightness at joints. These must be made airtight with the aid of some sort of sealing material and must be able to absorb movements in the sheets resulting from varying moisture conditions and settling of foundations (see following section). When fitting boards and sealing layers internally, there is a considerable risk that these might be punctured when pictures and shelves, for example, are put up on walls.

LOAD-BEARING STRUCTURES

Concrete and aerated cellular concretes are, in themselves, sufficiently airtight. The sealing layer can be combined with the load bearing core in this case. This means that buildings of concrete and aerated concrete can be made very airtight if joints between building elements are made correctly. The airtightness of brick walls depends to a great deal on the workmanship and the mortar. Good adhesion between the mortar and brickwork and adequate filling of joints is a prerequisite for an airtight structure. Brick walls are often plastered on one or two surfaces. The plaster improve the airtightness considerably.

A common denominator for all these structures is their sensivity to crack formation resulting from foundation settling or thermal movement. Considerable air leakage can occur through such cracks.

A8.2 Sealing joints

Even if durable materials are used for sealing joints, the joint could normally be expected to have a shorter service life than adjacent elements. This means that joints should be designed so that they can be easily maintained.

MATERIALS FOR AND PROPERTIES OF WEATHERSTRIPPING

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

The property of primary importance is resilience and this is affected by the following factors which also determine the life of the strip (4)

- temperatures
- variation in moisture or evaporation of plasticizer which gives rise to swelling or shrinkage movements
- chemical action by solvents and detergents
- the action of sunlight and substances contained in the air.

The closing force for strips in windows and doors should not change during service life. The strip should also have good resistance to mechanical action.

Modern weatherstripping is normally manufactured from different types of rubber and plastics. The most common materials are EPDM, silicone and chloroprene rubbers and PVC plastic. Other materials such as textiles and metals have also been used as weatherstripping.

Mouldings which have allowed the least air leakage are different types of tubular and angular strips (see Chapter A9).

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

Heat affects most rubbers and plastics. Temperatures of over $100^{o}C$ for rubbers and over $60^{o}C$ for plastics are in most cases very unsuitable. Even at lower temperatures, temperature has a great effect on the life of the materials. As a rough guide, a $10^{o}C$ rise in temperature doubles the ageing effect. This fact is used to determine the service life of materials in accelerated ageing test.

Note that the same material may be manufactured by different producers and that therefore the quality is not always the same. The proportion of rubber to filler can also vary considerably. A low content of rubber could give the mixture very different properties from those expected from the pure material.

Recent investigations of the service life of EPDM rubber strips, made by the National Testing Institute of Sweden, indicate a widespread range in function in time due to material quality and moulding.

It may be difficult to determine which material a strip is made of. An easy way to find out is to ignite a small piece of the strip. Characteristic reaction for the materials discussed above are given in Table A8.2.

Table A8.2. Characteristic properties on ignition of some materials used for weatherstrips (5).

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

RUBBERS

The rubbers used in weatherstrips are synthetic. Synthetic rubbers such as EPDM, chloroprene and silicone rubber are suitable for outdoor use. The rubber is mixed with filler, plasticizer and vulcanizing agents, extruded through a nozzle and then vulcanized using heat. In this case plasticizers of low volatility should be used. If the rubber strip is under- or overvulcanized, it will age more rapidly than normal.

Ozone attacks all rubbers that have double bonds in the main chain. Of the above-mentioned materials this normally only affects chloroprene. Ozone is formed in the higher air strata and as a result of electrical discharges. Weatherstrips should therefore not be stored in rooms where electric motors are in operation. The action of ozone can be counteracted by the addition of anti-ozonants, i.e. substances which counteract cracking due to ozone.

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

EPDM denotes ethylene propylene dien monomer. It is a characteristic of EPDM that it is wholly resistant to ozone. This is due to the fact that the double bonds necessary for vulcanization are placed in side groups, not in the main molecular chain. Thanks to good resistance to weather, wind, hot water, fumes, acids and alkalis, and excellent resistance to ozone, the material is now used instead of chloroprene for jointing and glazing strips in facades. It is, though, not resistant to oils.

Preliminary results of studies on the ageing effects on EPDM rubber strips by Jergling (6) indicate that ageing effects after about 30 years are more evident in chloroprene strips than in EPDM strips. More recent investigations made by Holmström at the National Testing Institute of Sweden indicate a very widespread service life of EPDM strips due to material quality and moulding (7).

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

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

PLASTICS

The plastics which are mainly used for weatherstrips are different types of polyvinylchloride (PVC). PVC is a thermoplastic material. In order that it should be soft a high proportion of plasticizer must be added. If poor-quality plasticizers are used, the strip may become tacky (dirt is accumulated) and also too hard after a time since the plasticizer will evaporate. There is then a great risk that it will shrink. Shrinkage also occurs because of the release of internal stresses set up during manufacture.

MINERAL WOOL

For a long time, mineral wool (glass fibre and rockwool) 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 woool inside different types of plastic film. Sealing systems have been developed for different purposes. Common products and systems in Sweden are

- *"Sealing fibre"* – used between ground plate and foundation as well as between construction elements. The system comprises mineral wool strips packed in a thin black polyethylene film.
- *"Jointing fibre"* – used between walls and frames. This system comprises one strip with an external transparent polyethylene film coating and one without.
- *Mineral wool packing* – quite often used for sealing joints but its primary function is thermal insulation and it should be supplemented with a rubber strip or jointing compound on ths inside in order to achieve good airtightness.

These systems are illustrated in Chapter A9.

POLYURETHANE FOAM (PUR FOAM)

Polyurethanes are a group of polymers which are produced when isocyanates react with polyalcohols. There are a number of variations. By altering the manufacturing process, expanding polyurethanes with different properties can be produced. The product can be made rigid or soft and 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.

Expanded polyurethanes can be used as thermal insulation material. Excellent thermal insulation can be achieved when the closed cells are filled with freon. This gas diffuses with time and is replaced by air. Combined with a temperature difference over the material or higher temperatures, it can absorb water, which increases the degradation. For both these reasons, 50 µm thick aluminium foil on both sides of polyurethane sheets should be used. This material should not take up structural loads. Polyurethane should not be exposed to daylight.

The material has an 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 PUR foams available today, which are used for air 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, windows, doors, etc. PUR 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 15 times its volume and hardens during contact with moisture in the air or in water. (Polyurethane is a thermosetting plastic.) The foam must have room to expand, otherwise door and window frames may bend and make opening and closing impossible. The hardening of the foam is initiated by the surrounding moisture. The material is almost completely cured after one day.

Polyurethane foam should not be applied if the temperature is below +5°C. The joint width should be greater than 7 mm for the joint to be foamed.

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 1st July 1979, freon was banned in Sweden as a propellant for polyurethane foam by order of the Swedish Products Control Board. Dispensation was granted for foam used for joint sealing in buildings. The isocyanates in the foam can cause allergenic problems and protection of skin and lungs is necessary during application.

Field trials carried out so far on polyurethane foam relate to 2-component foam since single-component foam has not been commercially available for a sufficient length of time. 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.

JOINTING COMPOUNDS

Jointing compound, 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 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, thermo-plastics 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 if these 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 per cent. This is of particular importance for the construction and forming of the joint.

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 (airtightening) 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 A8.1.

Durability and ageing in sealing compounds has also been studied by Burström (8). He treats the fundamental ageing factors' effects 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.

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 to internal joints which primarily have an air sealing function.

A relatively popular butyl-based jointing compound used in Canada for sealing joints in plastic film is known as "Acoustical sealant". It does not solidify and is relatively cheap to buy. The effects of ageing are unknown.

TAPES

With the tape materials currently available, it is inadvisable to use tape in humid or cold conditions. If taping has to be carried out, the building must be covered and heated. Compare with the requirements for heating when 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 in combination with a sealant should be used to achieve airtightness. Taping should only be used as an aid to installation. Experience has shown that taped joints do not provide permanent airtightness even when the work was done well from the beginning. Bearing in mind the difficulties of making joints tight, plastic film work should be planned very carefully and all joints should be indicated on drawings.

There are, however, situations, for example tears in film, where tape is the only practical choice on a building site. Work is currently in progress on producing durable tapes and tape adhesive which can be used with polyethylene film.

A8.3 Thermal insulation

Many different materials are used for thermal insulation. The following gives a summary of the materials used for thermal insulation in buildings. The thermal insulation properties of the different materials are given in Table A8.3.

MINERAL WOOL

Mineral wool (glass fibre or rockwool) is currently a very common thermal insulation material. It is 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 timber frame walls, a relatively pervious mineral wool product is used which, in order to function correctly, must completely fill the space between the containing surface. Gaps and cracks cannot be tolerated since the insulation effect can be severely jeopardized through convection and air movement. Furthermore, mineral wool products of this type require adequate wind protection on external surfaces and an air-sealing layer on the internal surface in order to function as intended (see Chapter A2).

In certain types of timber-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, affixed to the inside of the slabs

Table A8.3. Example of properties of thermal insulating materials according to the National Swedish Board of Physical Planning and Building. Values represent mostly controlled products and normal use above ground as loose batts or filler. Density and thermal conductivity varies depending on material quality, especially for those materials marked with x.

Material	Density kg/m^3	Thermal conductivity for practical use W/m ^{o}C
Glass fibre:		
batts	15	0.045
	20-125	0.040
granulated		0.055
Rockwool:		
batts	20	0.045
	30-160	0.040
granulated		0.055
Polystyrene:		
extruded (with skin and freon)	32	0.035
expanded	15	0.045
	20-30	0.040
Polyurethanes	30-40	0.035^x
UF foam	7-14	0.07^x
Cellulose fibre	30-50	0.065^x
Foamglass	150-200	0.055
Cork	110-200	0.045
Wood chips and shavings	100-220	0.08

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 airsealing layer on the warm side of the insulation, and a facade to protect the mineral wool from direct wind load.

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. "Blown in" mineral wool could also be used as attic insulation. There are also products which are particularly suitable for application to the inside of roofs which will make it possible to carry out the insulation work after the external roof has been erected.

POLYURETHANE FOAM

Polyurethane plastic is available both as sheets and foam. The material is the same as that described in Section A8.2.

UREA FORMALDEHYDE FOAM

This material is used primarily as thermal insulation for injection into older existing walls. It is not airsealing. When curing, water is emitted which must be taken into consideration. It should therefore not be injected between vapour-tight materials. As the water is emitted the material normally shrinks by about 3-10 per cent during the first months. The quality of material is very dependent on the mix which explains the wide variance in shrinkage. This material has been used for a long time in Germany and Sweden.

Owing to formaldehyde emission, the material is prohibited in Canada and the United States. Control of formaldehyde contents takes place in The Netherlands and United Kingdom. The material should not be exposed to sunlight.

POLYSTYRENE

Sheets of primarily expanded and extruded polystyrene cellular plastic are used today for roof, foundation and external wall insulation. Good properties of these materials are, apart from their thermal conductivity, their mechanical strength and insensitivity to moisture.

Owing to low elasticity of the material it is not suitable for use between wood studs. Extruded polystyrene sheets are used in Canada and the United States as thermal insulation on the outside of timber frames in the same way as rigid mineral wool slabs in Sweden. No extra wind protection is then needed.

CORK

Cork is a natural product from the bark of the cork oak. Board is obtained by cooking cork granules at a temperature of 300°C under pressure.

The thermal conductivity of corkboard is somewhat higher than for mineral fibre. As polystyrene sheets, due to its low elasticity, it is not suitable for use between wood studs. It is used especially as roof insulation and insulation of cold storage.

FILLER MATERIAL

Many types of insulation material are used for loose or packed filler in cavities between joists in roof joist structures and gaps in external walls. The following gives a few brief examples of materials available.

Mineral wool in loose form which is sprayed in has already been discussed in this section.

Residual material from forestry work (shavings) is used in countries with extensive wood industries.

Cork granules can be used but are difficult to obtain in some regions.

A cheap filler material used in the United States and Canada is cellulose fibre; old newspapers shredded into small pieces and stabilized against fire. When used in sloping roofs or walls, the fibre settles by about 10 per cent.

Settling can be avoided to a great extent by placing the fibre under pressure which increases the density.

CELLULAR CONCRETE

Cellular concrete is a material which is both load-bearing and thermally insulating. External walls made solely of cellular concrete would have to be very thick to meet Sweden's insulation standards.

Sections known as light elements with polystyrene enclosed in a coating of cellular concrete are, however, used for external walls where the demands for load-bearing are small. The material itself is not sensitive to wind and air movements.

WIND PROTECTION

Insulation material with high air perviousness requires good protection against wind and blow-through to function as intended.

The main purpose of wind protection is to prevent air movements which can impair insulation efficiency in walls and floor structures. Paper or sheet materials are used as wind protection in wooden constructions. Both paper by itself 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 glued to slabs of mineral wool intended for use on walls is positioned so that the mineral wool protects the paper. With this method, the paper is subject to less risk of damage than where loose paper is used and wind protection is improved.

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'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.

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.

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 can often be 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.

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

- a carefully considered constructional design with comprehensive drawings
- 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 protection of insulating material from wind and moisture
- 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.

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A9 BUILDING DESIGN SOLUTIONS OF SPECIAL DETAILS

With regard to airtightness, lightweight types of constructions (wooden constructions, prefabricated lightweight elements, etc.) present many more problems than do massive types of constructions (brick walls, site-mixed concrete, etc.). However, all connections, joints and seams are critical, regardless of the construction style; see Figure A9.1.

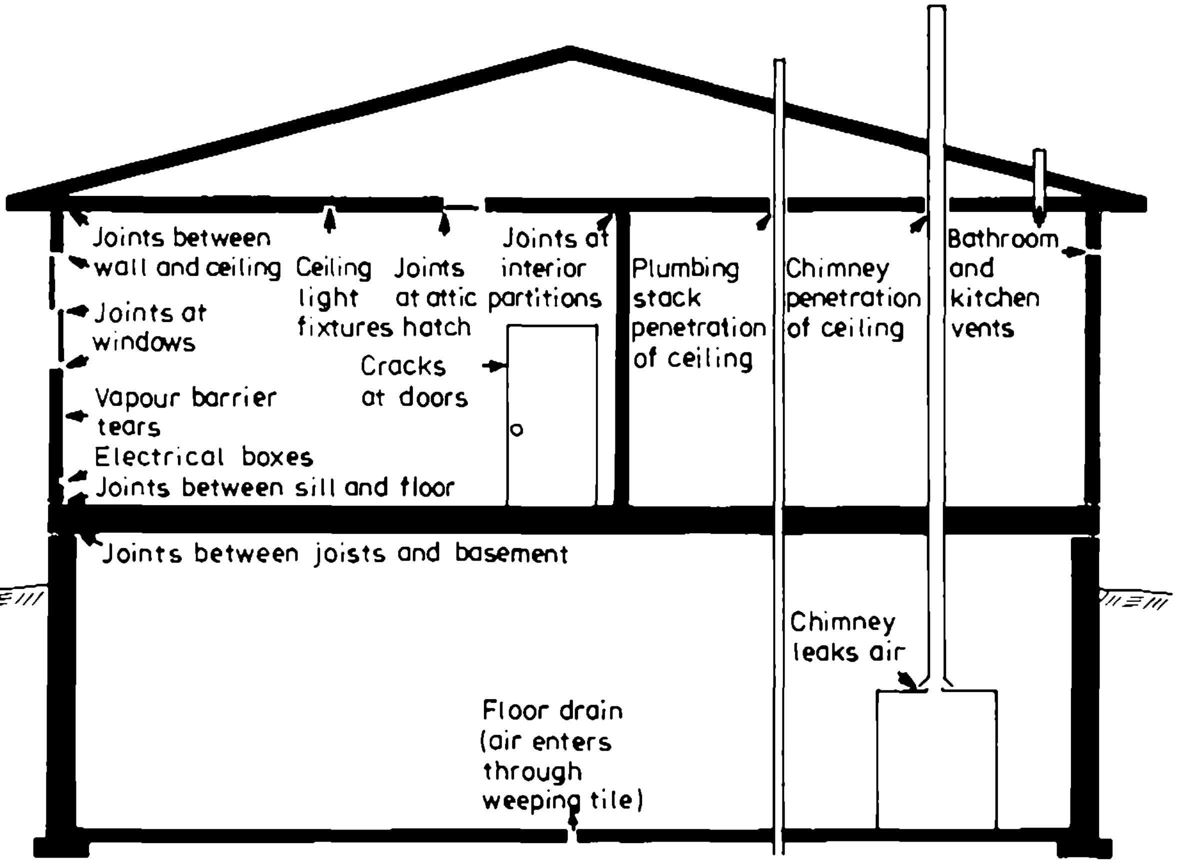

Figure A9.1. Air leakage paths (example from Canada).

It is important to pay attention to the fact that joints can develop as a consequence of strain (deformation) in the construction. Sometimes it is difficult to seal such joints permanently. For this reason, well-fitting joint packings must be used that can fulfil their function even with relative large movements in the construction.[x]

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[x] In this handbook we just describe the constructional problems but not the problems concerning the installations or the user's behaviour (ducted ventilation in toilet/bathroom/kitchen, opened windows, stack effect in chimneys).

A construction must be designed in such a way that satisfactory thermal insulation and airtightness can be achieved. This is especially true in view of present working methods and associated rapid installation rates. It is desirable that well-tried and tested constructions should be used in order to avoid making costly errors.

Certain constructions have been found to have a high frequency of defects. This applies, for instance, to slatted panel constructions. In constructions which incorporate slatted panels in floors and walls (attic walls), it has been found that the vapour barrier is often placed between the slatted panel and the outer skin. With this design there is a risk of air leaking into the construction and spreading along the ducts formed between the boards in the slatted panel. Investigations have shown that the thermal insulation has a more satisfactory performance if the vapour barrier is placed directly against the thermal insulation material.

In single-family houses with a habitable attic storey, air often leaks into the attic wall construction at the corners, particularly if there is a slatted panel on the inside of the thermal insulation. In this type of construction, it is important that junctions at gable walls, ceiling and the floor should be properly sealed. Attic walls should be provided with a satisfactory windproof layer on the outside. The junction with the floor construction must be made with great care. Defects also occur at the juction between the attic wall and the inclined ceiling. Owing to the design, thare are difficulties in ensuring complete airtightness and proper placing of the insulation material at this point.

Leakage of air through improperly sealed joints and junctions often occurs. In designing constructional details of this type, care must be taken to ensure that a sufficient gap is provided, so that effective sealing of the joint can be carried out. It has been found that a joint width of 15 ±5 mm is appropriate.

In sealing joints, the choice of material is of great importance for the performance of the seal. Certain types of material are unsuitable with regard to both performance and workmanship.

Electrical installations and holes for pipes passing through the construction often give rise to problems with regard to the insulation and airtightness performance. Air movements often occur both in the conduits provided for electrical cables, and in the ducts formed between the conduits and the insulation material. Electrical cables laid in the vicinity of the eaves are particularly sensitive. In cases where electrical installations have been placed not in the external wall but in an inner wall, the insulation and airtightness performance has generally been better.

Untrained personnel are sometimes employed for the installation of insulation and joint sealing material. This often gives rise to inferior workmanship owing to lack of knowledge about the performance and properties of the different materials and how to install them properly. Those engaged on insulation and airtightness work must know which are the "sensitive" parts of the construction, and must also know what purpose the different layers of material in the construction perform. Training and information are factors of great importance in this respect.

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 pipes and installations, for instance, electric conduits and holes for pipes through the construction
- unsuitable choice of material
- unsuitable working methods and procedures.

In the following examples of building design solutions of some frequent details are given.

A9.1 Joints between vapour barrier sheets

A major potential leakage area with most vapour barrier installations occurs at the joints between vapour barrier sheets. A number of techniques have been suggested for providing an airtight seal between the sheets. These include:

a) caulking or gluing the sheets together

b) taping the sheets together

c) overlapping the sheets

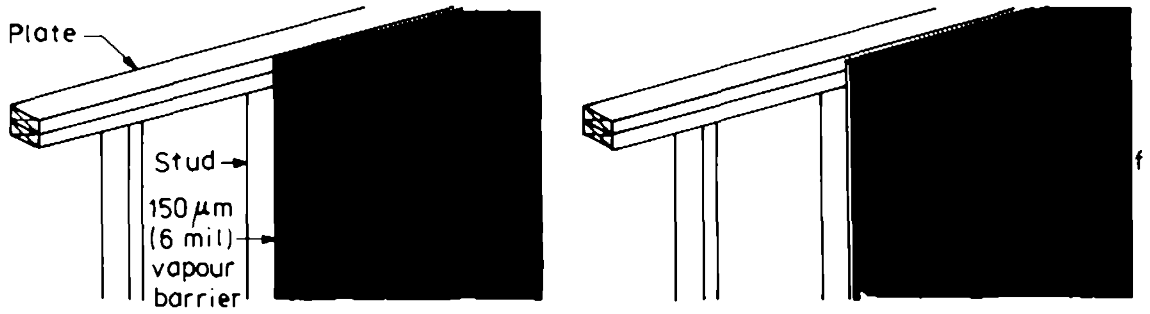
d) providing a double fold seam

e) welding the sheets together.

Bearing in mind the difficulties in making joints airtight, plastic film work should be planned very carefully and all joints should be indicated on the drawings.

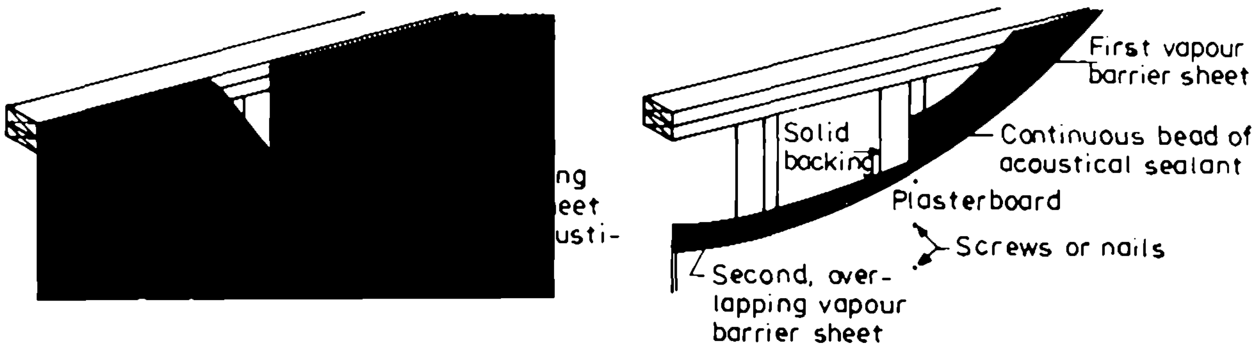
CAULKING OR GLUING THE SHEETS TOGETHER

This method has been popularized in recent Canadian publications (1,2). With this approach, a non-hardening, moderately priced, butyl-based caulking material called "acoustical sealant" is used to join the sheets. The sequence is shown in Figure A9.2. According to this approach there are three essentials needed for a good vapour barrier seal:



a) Staple 150 micrometre (6 mil) vapour barrier to studs and plates

b) Place a bead of acoustical sealant over top of vapour barrier, ensuring that the sealant is continuous and in line with the stud



c) Overlap second vapour barrier sheet (always join the vapour barrier over a solid backing such as a stud)

d) Cover vapour barrier with rigid material (plasterboard, wallboard, etc.)

Figure A9.2. Technique for joining vapour barrier sheets on wall studs (insulation not shown).

a) a solid backing material at the interface between the two sheets

b) a continuous bead of the sealant material

c) a rigid covering material to withstand windforces which can pull the sheets apart.

TAPING THE SHEETS TOGETHER

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.

As yet, insufficient documented experience on joint taping is available. The service life of a taped joint cannot be determined with any confidence. It would appear therefore that, wherever possible, an overlap of at least 200 mm and clamped joints should be used 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 at the beginning.

OVERLAPPING THE SHEETS

This method is described in Ref. (3). With this approach the recommended technique is to overlap the vapour barrier on framing space (usually 400 or 600 mm). No mention is made in the publication of the effectiveness of this technique under field conditions. In Sweden an overlapping of at least 200 mm is recommended and a solid backing material (studs) behind the overlapping (4).

PROVIDING A DOUBLE FOLD SEAM

This technique is shown in Ref. (5) and reproduced in Figure A9.3. No mention is made in the booklet of the effectiveness of the technique under field conditions.

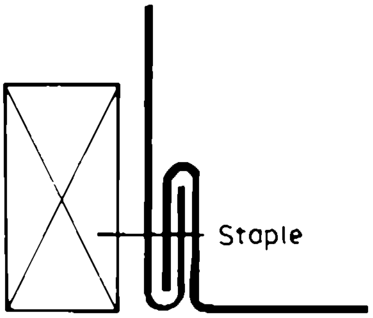


Figure A9.3.

Technique for joining vapour barrier sheets at a corner using a double fold.

WELDING SHEETS TOGETHER

Welding plastic films together is a method that is coming into use in Sweden and Norway. Special equipment has been developed which permits welding in all climates – even in cold or rainy weather. In this method the edges of the plastic films are folded together. With special equipment the films are heated and welded together. (See Figure A9.4.) The method has been used primarily for industrial roofs where extra high demands are made on airtightness to avoid moisture problems. Recently, the method has also been applied to timber house constructions. Welding provides an airtight seam which is considered to be durable.

Figure A9.4.

Technique for welding polyethylene film.

CONCLUSIONS

It appears most desirable to be able to provide a clamped joint wherever there are two vapour barrier sheets to be joined. Glueing, taping, overlapping and double folding can work best only when the joint is firmly clamped. Welding the joints also seems to be a very successful method and further development is taking place.

A9.2 Joint between window (door) frame and wall

There are many different solutions for joints between window or door frames and walls (6,7). Some of these solutions are discussed in the following, and the advantages and disadvantages of the respective methods are given. In this handbook we only describe the problems concerning airtightness and thermal insulation in the joints.

SEALING WITH MINERAL WOOL STRIPS BETWEEN FRAME AND WALL

The joint is covered with a batten and/or adjacent plaster.

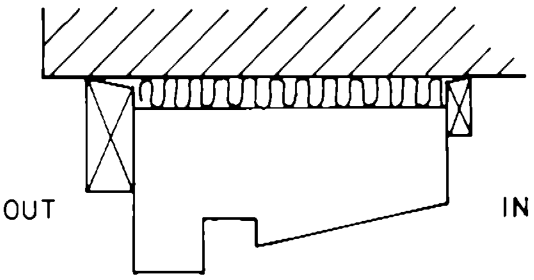


Figure A9.5.
Mineral wool strip sealing.

The joint will be neither air- nor vapour-tight. A certain degree of airtightness can, however, be achieved with caulking, particularly if mineral wool is used. Hard caulking demands extra anchorage of the frame to stop it bulging outwards.

Current Swedish requirements for energy management are usually fulfilled.

The method does have an advantage in that temporary dampness in the joint is not catastrophic since drying out takes place relatively unhindered.

INTERNAL SEALING WITH MASTIC AND MINERAL WOOL CAULKING

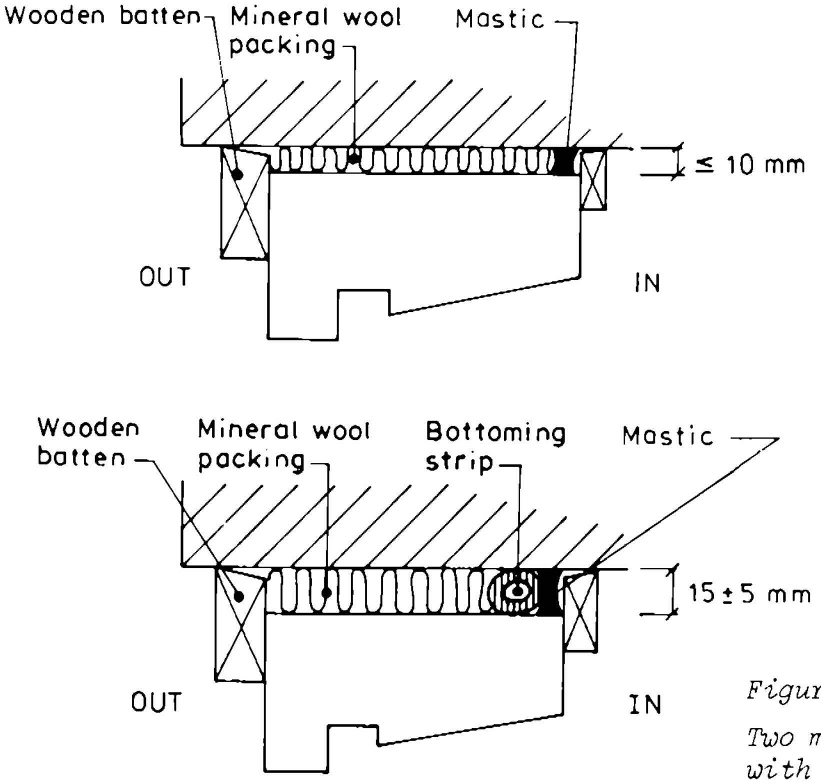


Figure A9.6.
Two methods of jointing with mastic.

To facilitate good sealing, it is recommended that the joint dimension is 15 ±5 mm and the joint is sealed with mastic. The actual airtightness is achieved with the mastic which forms an elastic, tight joint if the correct mastic is used.

The intended purposes of the mastic are diffusion sealing and airtightening. In some cases, the wall's corresponding layers are joined – often an air/vapour barrier. The best method is to bake the film into the joint. Mastic must close tight and adhere well to the wall and frame without separating as a result of movement between the frame and the wall. Particular attention is paid to joints in corners where wedges and attachment devices might remain.

The purpose of the bottoming strip is to provide a rear barrier to the mastic in the joint. The bottoming strip is selected so that it sits tight even if the joint width is 15 + 5 = 20 mm. Two sizes of bottoming strip should be available during installation work.

Caulking is done with mineral wool and is stopped about 15 mm from the edge of the joint. The prime function of caulking is thermal insulation. Correctly applied caulking provides good insulation.

Airtightness is significant in a joint without any other sealing but, when compared with mastic, is of minor importance to the total airtightness.

The inner moulding is used for aesthetic reasons and to cover and protect the mastic.

The outer air gap leads to the outside air. Its most important function is to facilitate drying the air. The outer moulding is intended to provide protection against driving rain.

For the joint to function as intended, it is assumed that stated joint tolerances are maintained.

JOINTING WITH POLYURETHANE FOAM

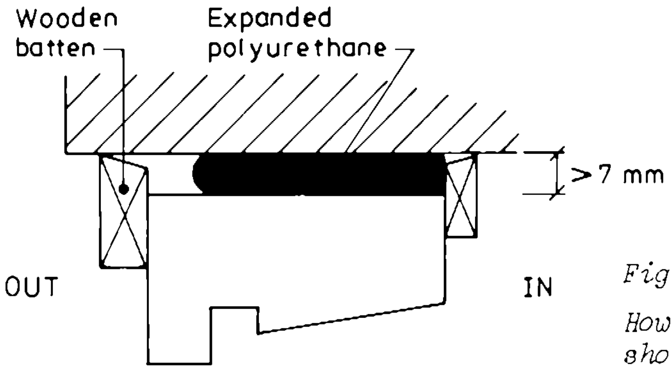


Figure A9.7.
How a polyurethane foam joint should be made.

The joint width should not be less than 7 mm, bearing in mind the application of the foam.

The joint has very good thermal insulation properties compared with frame timber and adjacent wall material. The joint is normally sufficiently diffusiontight and airtight even when joints are relatively wide (>20 mm).

In unfavourable cases, the jointing foam can prolong the drying time of timber that is too moist. Foam should be applied to resonably dry timber.

It is not easy to adjust window frames when foam has been applied.

JOINTING WITH GLASS FIBRE ENCLOSED IN THIN PLASTIC FILM

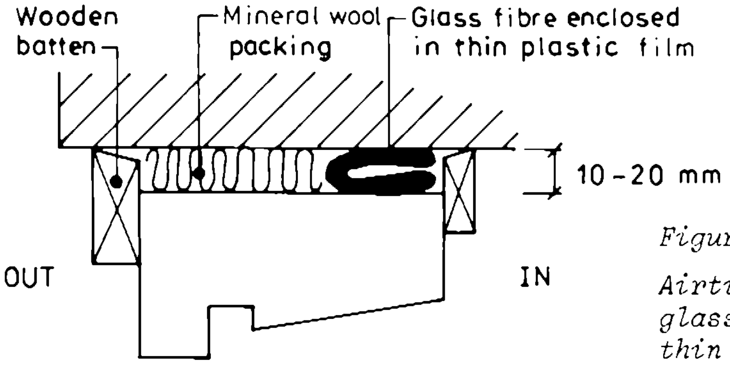


Figure A9.8.

Airtightness achieved with glass fibre enclosed in thin plastic film.

Thermal insulation in joints is provided by mineral wool. The actual airtightness (and diffusion seal) is achieved through the plastic film around the internal mineral wool strip.

Good airtightness is achieved for joints between 10 and 20 mm. Point leakage often occurs at window corners and around wedges.

JOINTING WITH TUBULAR STRIP, ANGULAR STRIP, ETC.

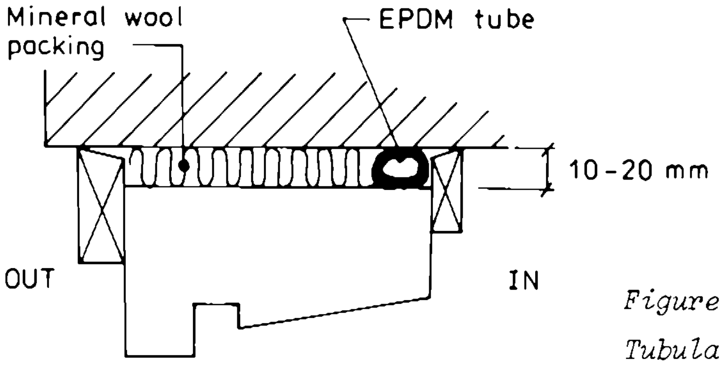


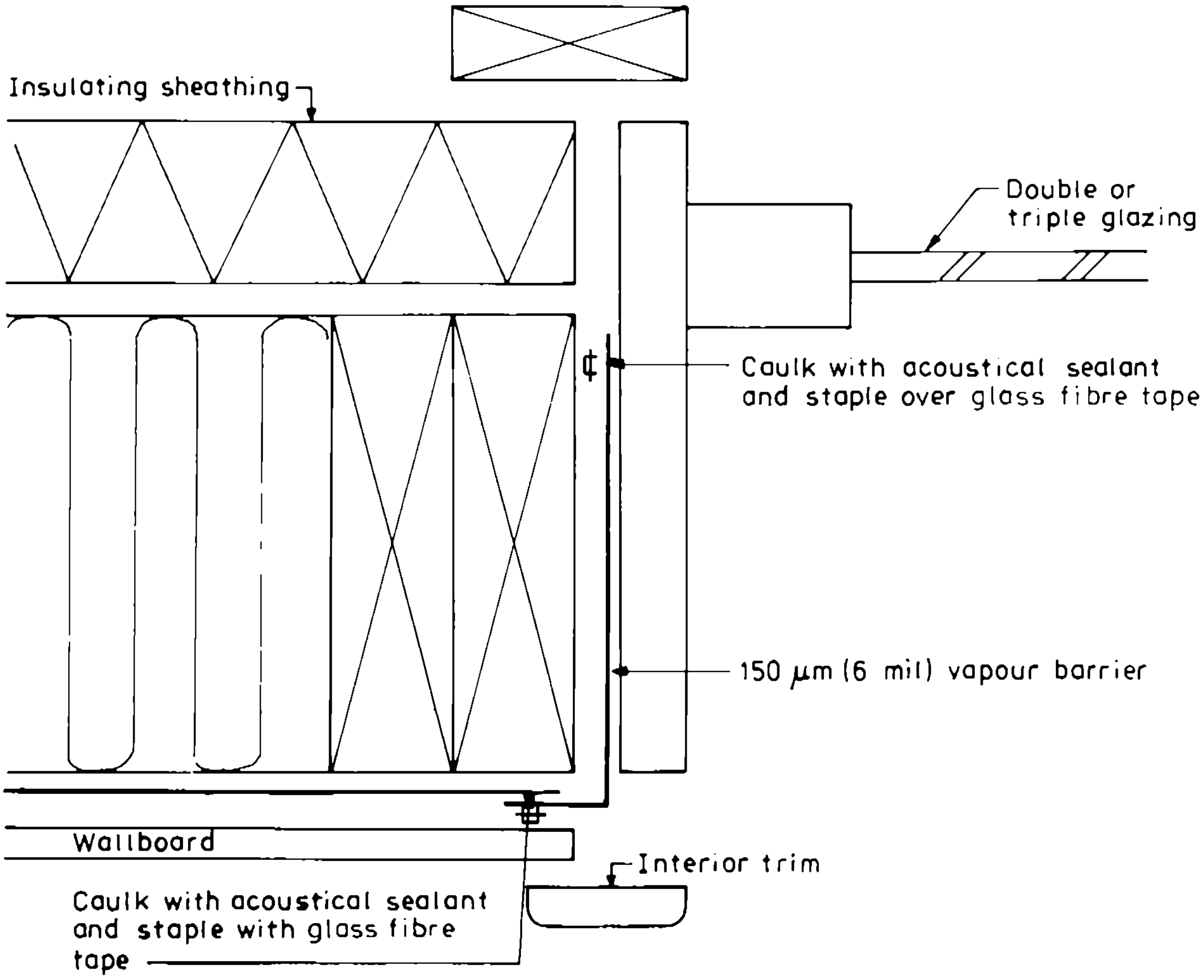
Figure A9.9.

Tubular strip.

Joint sealing between frame and wall by using profiles of EPDM rubber to provide the actual airtightening in the joint. The gap should be between 10 and 20 mm. At least two different moulding sizes are required for installation, bearing in mind different tolerances. To achieve good airtightness, both frame and adjacent wall should be very smooth. The tube should not be stretched too much during installation. Plastic films in timber walls whould be joined to the tubular moulding in the joint. Mineral wool provides thermal insulation in the joint.

JOINTING USING PLASTIC FILM

A technique has been developed in Canada where a plastic film strip is applied to the window frame with staples and using glass fibre tape and mastic. This plastic film strip is joined by overlapping and edge sealing to the plastic film in the wall. It is necessary to fit the plastic strip against the frame before it is installed in the wall. Se Figure A9.10.



Note: Attach vapour barrier strip to window casing before being inserted into rough opening. Allow sufficient material at corners to fold vapour barrier.

Figure A9.10. Air/vapour barrier installation at window (Canadian example).

A9.3 Joint sealing systems at ground plate

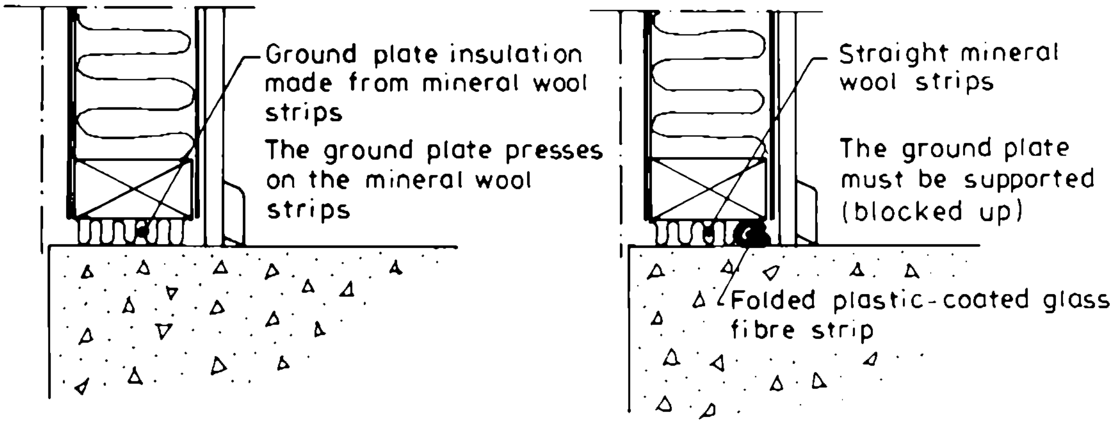
Figure A9.11 illustrates four different methods for sealing at ground plate:

a) ground plate sealing with mineral wool strips

b) ground plate sealing with the joint sealing system "jointing fibre"

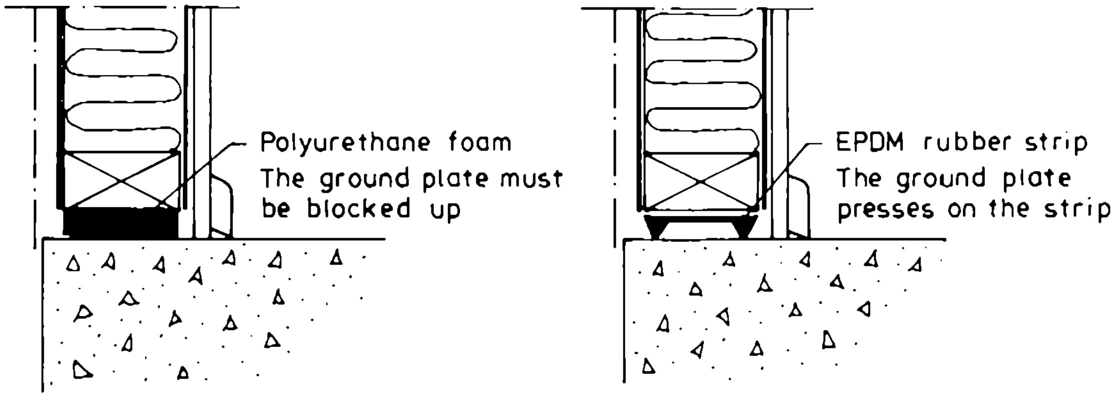
c) ground plate sealing with single-component polyurethane foam

d) ground plate sealing with EPDM rubber strips.



a) Significant risk of air leakage

b) Risk of leakage points around blocks. Exact joint dimensions are necessary for satisfactory function



c) Airtightness is usually good

d) Airtightness is good if the concrete surface is carefully smoothed

Figure A9.11. 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.

METHOD a)

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.

METHOD b)

The jointing fibre system generally provides satisfactory results. In isolated cases a certain amount of air leakage has been observed. It is possible to assume, with good reason, that sealing adjacent to supporting blocks is less satisfactory using this method.

METHOD c)

Polyurethane foam filled joints generally provides satisfactory results. Both sealing and insulating values are normally satisfactory. In a few isolated cases, a blister developed in the material which gave rise to a small amount of air leakage.

METHOD d)

Joint sealing with a double tube EPDM rubber strip normally give satisfactory results. It can be seen that the results are comparable with those of alternative b).

A9.4 Joints between concrete elements

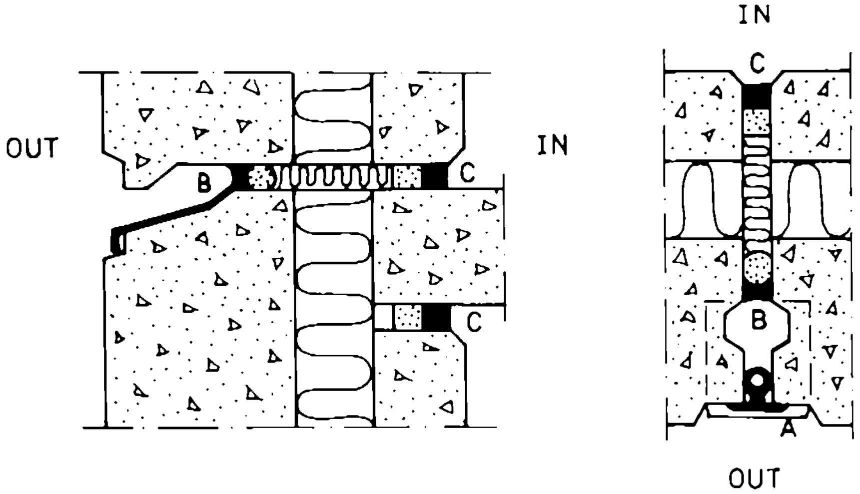
The design of joints between concrete elements is specific with respect to manufacturer and object.

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 or 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 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, 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 can penetrate joints and cause problems despite the internal airtightness.

As an example of solutions the design of an element joint accoring to the 2-stage sealing principle is shown in Figure A9.12. 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.



Side elevation of horizontal joint   *Plan of vertical joint*

Figure A9.12.

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.

A9.5 Sealing around penetrations

ELECTRICAL OUTLETS

A Canadian technique to achieve a good vapour barrier seal around electrical outlets is shown in Figure A9.13. Considerable care must be used with this technique to get a good seal. The work sequence should be as follows:

- install blocking
- staple vapour barrier pan
- drill hole through blocking to pass wire, caulk at pan
- wire electrical box
- fill pan with insulation
- provide bead of acoustical sealant around pan
- press wall vapour barrier into sealant
- cut hole in wall vapour barrier to pass electrical box.

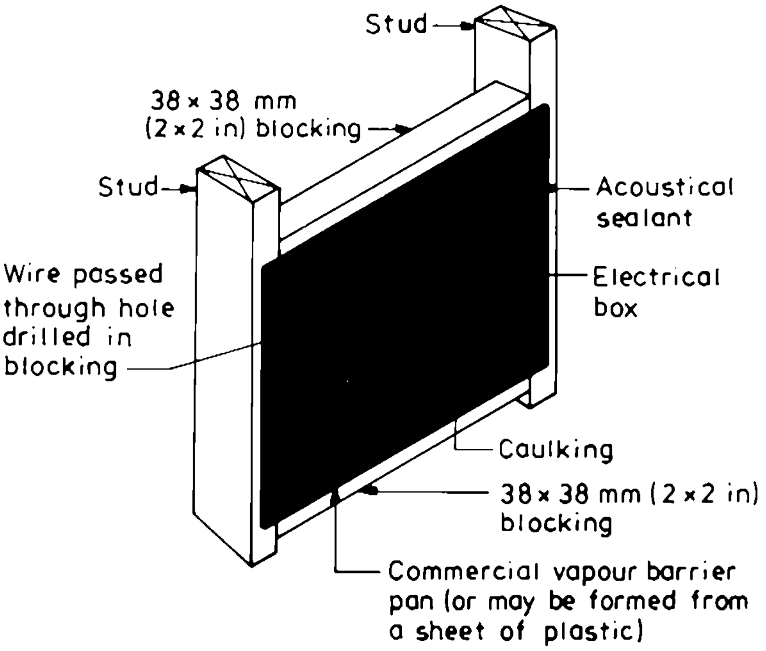


Figure A9.13. Vapour barrier installation around electrical box.

VENT PIPES

Figure A9.14 illustrates a technique for the vapour barrier around a plumbing vent stack. The expansion joint is necessary, as plastic

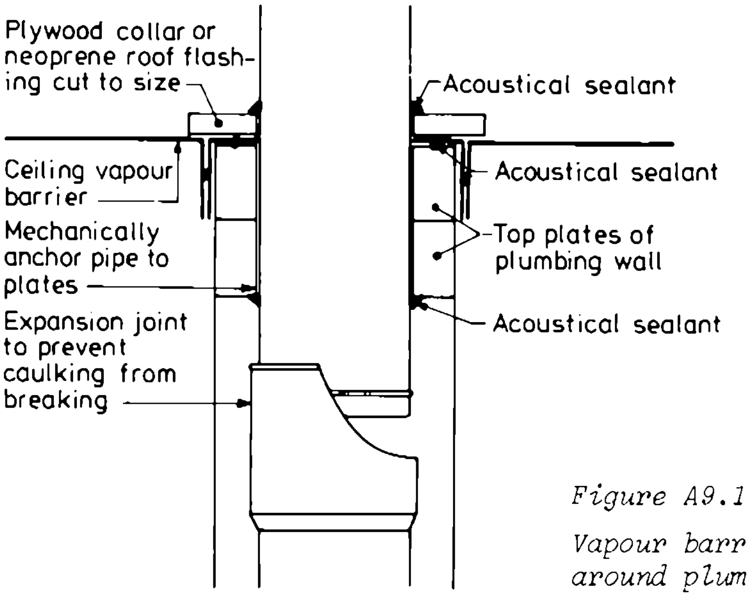


Figure A9.14.

Vapour barrier installation around plumbing vent stack.

piping used in homes can expand and contract as much as 25 mm (1 in.) because of temperature changes.

A9.6 Weatherstrips for windows and doors

TYPES OF WEATHERSTRIPS ON THE BUILDING MARKET

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

Naturally, these types of strips caused an appreciable improvement in airtightness at the time. However, it is a common characteristic of fibre strips and foam strips that they are permeable to air and must therefore be extensively compressed to perform as intended. Foam strips are nowadays mainly sold as dust excluders and are placed between the casement in double glazed windows.

The modern types of strips are made of impermeable materials and have a profile of such design that they can be deformed relatively easily so that the door or window is easy to close while providing a satisfactory seal. The strips must at all times endeavour to regain

STRUCTURAL SOLUTIONS

Gaps between frames can often be detected by inspecting the opening and closing action and weatherstrips. Gaps can also be detected by using a candle or smoke, or by applying thermography. Detection is faciliated if the room is subjected to negative pressure.

Resealing of windows and doors should include the following steps:

a) Inspect the windows and doors. Do they require repainting or the putty replacing?

b) Check that the casement/door can be closed and opened easily and adjust where necessary.

c) Check that the window/door furniture works properly and adjust and lubricate where necessary.

d) Check that the air gap between the casements of all double windows/doors has not been rendered ineffective as a result of repainting etc. A gap of 1-2 mm is required. If the gap between the casements is greater than 2 mm, 2 pervious dust-tight strips can be fitted in order to reduce the air circulation between the panes thereby achieving certain savings in energy.

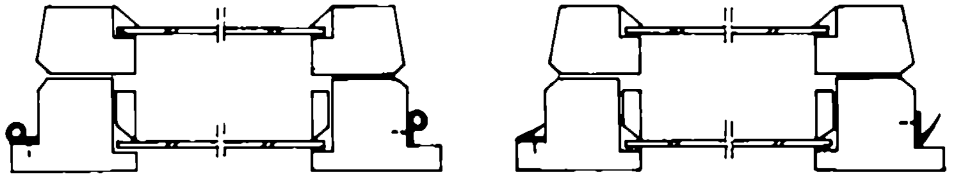
e) Always paint exposed wood surfaces (surfaces which lack finishing coat, glazing paint, etc.) before reapplying putty and fitting weatherstripping.

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

g) Select the weatherstripping. When selecting strip for use between the casement and the door, the gap width measured in f) must be considered. When selecting weatherstrips, strips of silicone rubber and EPDM rubber have exhibited the best sealing and ageing properties. Tubular strips provide the best seal but angular strips are also effective. Angular strips are recommended for doors where a low closing pressure is required.

h) The way in which weatherstrips are fitted is important for their correct function. Special attention must be paid to the corners where gaps often occur. Figure A9.17 illustrates how strips should be positioned.

INWARD OPENING WINDOWS. The strip is to be placed on the casement



OUTWARD OPENING WINDOWS. The strip is to be placed on the frame

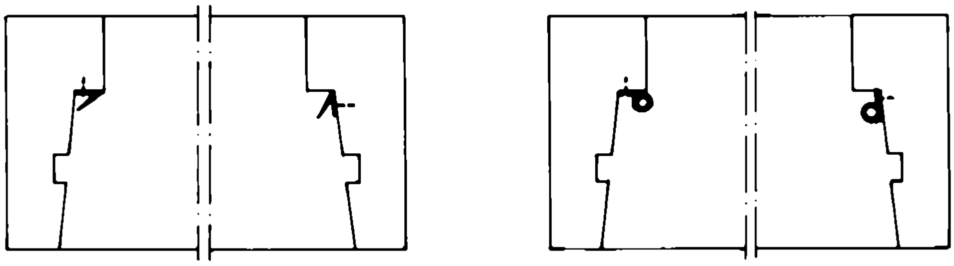


Figure A9.17. Positioning of sealing strips between casements and frames in inward and outward opening windows respectively.

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AIRTIGHTNESS OF WINDOWS

Studies of airtightness of windows have been made by Höglund & Wånggren (8). In determining the leakage of air through windows the guarded pressure box method was used. The measurements were made in wood windows which had a design in conformity with the appropriate Swedish standard. Both double-glazed and triple-glazed windows were used. The weatherstrips were placed where the casement abuts on to the frame. The gap for the weatherstrips varied from about 2 mm to over 4 mm.

The results are summarized in Figure A9.16. The types which best satisfied the airtightness requirements in the Swedish Building Code were strips of tubular or angular profile. A properly chosen expanded strip could also provide satisfactory airtightness. In most cases foam and fibre strips did not satisfy the requirements stated in the regulations.

The results also showed that it was extremely important for mounting to be done with care. A good result was easier to reach with tubular strips than with angular strips.

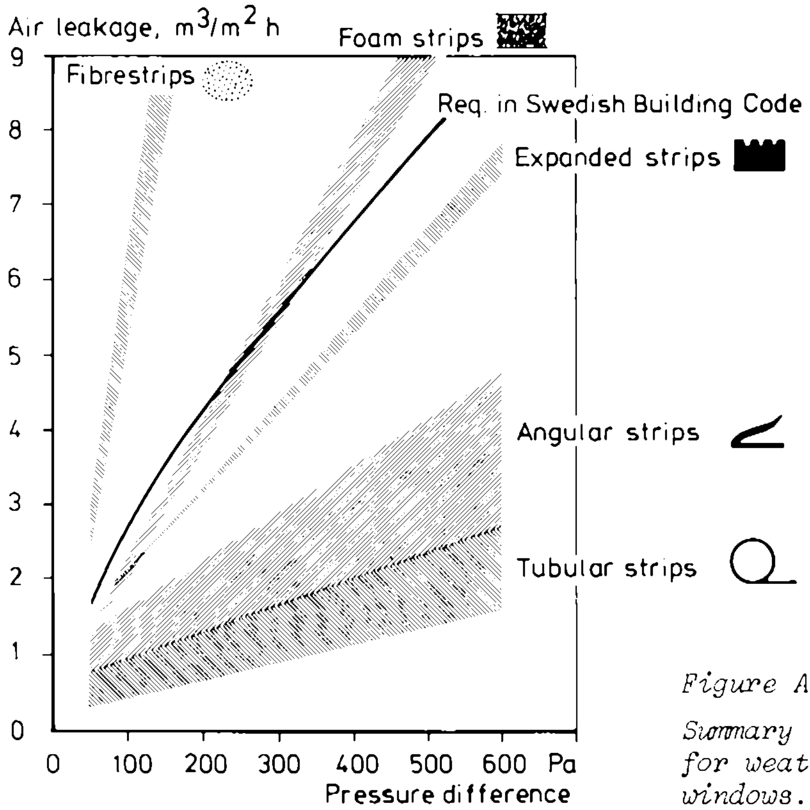
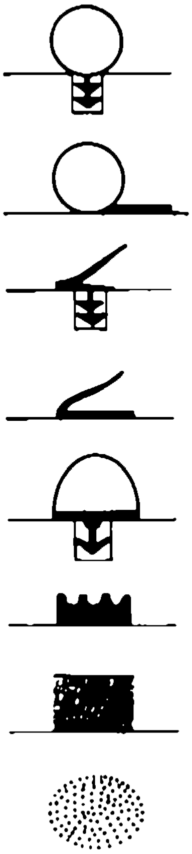


Figure A9.16.

Summary of test results for weatherstrips in windows.

their original shapes (i.e. they must be resilient). Strips of this type often have a tubular or angular profile. Different types of strips are shown in Figure A9.15.

Types



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

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

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

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

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

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

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

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

Figure A9.15. Types of weatherstrips for windows and doors.

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

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

(7) Holmberg, Å., Fönsterhålet. Inbyggnad av träfönster i nya hus. Wooden Windows in New Buildings. (In Swedish.) (Swedish Council for Building Research.) R15:1981. Stockholm 1981.

(8) Höglund, I. & Wånggren, B., Studies of the Performance of Weatherstrips for Windows and Doors. (Swedish Council for Building Research.) D4:1980. Stockholm 1980.

A10 RETROFITS IN EXISTING BUILDINGS

Air leakage in older buildings has often been found to be unnecessarily high, considering the requirements for air quality for both heating and air conditioning (1).

Considerable energy savings are possible in many cases using relatively cheap and simple sealing measures. As example of this is the "House Doctor's Program" carried out in the United States, described later in this chapter. Another example is given in Table A10.1 which shows that energy consumption is lower in houses in which good quality weatherstripping has been fitted to windows (2, 3).

Since there are few data on true energy savings that result from carrying out sealing measures, this chapter only discusses the measures themselves without considering their cost-effectiveness.

Problems that arise from inadequate ventilation must always be considered when sealing measures are used in a building. In houses with natural ventilation, air is supplied partly through leaks in the structure and partly through openable ventilation provisions. This limits how far sealing measures can be taken without having to install special supply air devices.

In houses with mechanical exhaust ventilation, the influence of the fan has a dominating effect on the amount of ventilation. Flow through the fan is not changed significantly as the building envelope is further sealed. However, the negative pressure in the house does increase. This also limits how tight the building shell can be made. Further sealing does not provide any more energy savings. There may be other valid reasons, apart from energy savings, for sealing the building, e.g. draughts in occupied areas, desired ventilation distribution; see Figure A10.1 (4).

Houses with balanced exhaust and supply ventilation should, however, be made as tight as possible to avoid unnecessary ventilation. This is particularly important if energy recovery using a heat exchanger fitted to the exhaust air is to be optimized.

The main principle for sealing existing buildings must be to ensure that sufficient but not excessive ventilation is achieved and that

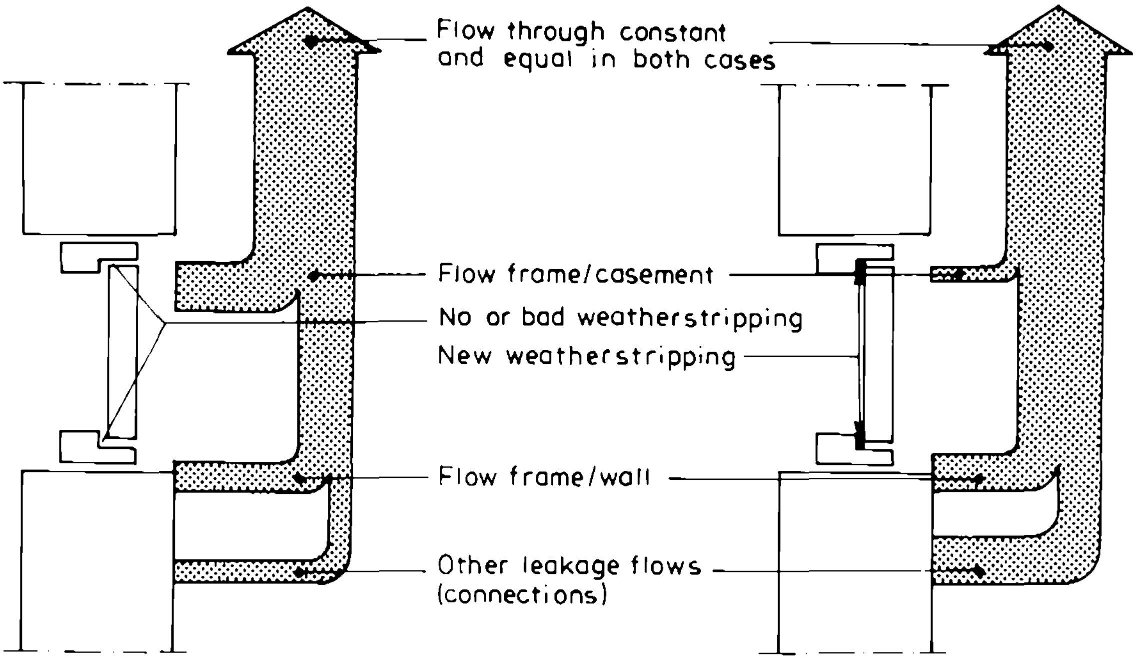
Table A10.1. Average energy consumption and heated volume with standard deviations after retrofit for existing single-family houses in Sweden with different types of weatherstrips in windows. Almost all of the houses have natural ventilation.

Principal type of weatherstrips between window-frames and casement	Number of houses surveyed	Energy consumption after measures being undertaken, litre oil/dwelling		Heated volume per dwelling, m^3	
		Average	Stand. deviation	Average	Stand. deviation
Weatherstrips non-existent	23	4220	2726	426	215
Foamstrips surrounded with fibre	47	4071	1114	473	–
Fibre strips (wool or cotton)	93	3877	1075	454	–
Foamstrips (foamplastics with open pores)	107	3802	1152	466	158
Tubular strips (synthetic rubber)	124	3761	1069	415	144
Angular strips (synthetic rubber)	51	3624	977	464	152
Expanded strips (porous rubber with closed pores)	211	3541	1047	418	–
Fixed windows (not openable)	11	3294	1165	409	142

the supply air enters the building where it causes the least draught, cold downdraught or other discomfort. If these criteria are fulfilled, the airtightness of the house can be improved to the extent that is economically and technically feasible.

It is very important when planning sealing measures to consider the construction of the actual building, e.g. to study drawings or building documents from the time of erection in order to learn how houses were built at that time, and from there to plan the measures.

Either before or when the building is tightened an investigation should be made into locating the most severe air infiltration sites in the building. This can be done through negative pressure testing



a) Before sealing *b) After sealing*

Figure A10.1. Flow change in an exhaust air ventilated house when windows are fitted with new weatherstripping. The relatively constant total flow is redistributed in proportion to the perviousness of the different leakage locations. Wind forces are often of subordinate importance as the driving force of the air leakage.

combined with thermography or leakage location using an airflow meter for example. Suitable measurement methods are discussed in Chapter A11.

Common points where air leakage occurs (apart from the wall, ceiling and floor structures themselves) are joints between building sections and penetrations in structures for installations etc. as illustrated in Chapter A2. Joints between different building sections and between different materials are usually weak points with respect to air leakage. In buildings made of brick or concrete, for example, air leakage is often greatest around windows and doors and at joints between building elements.

Incoming air to floor structures and intermediate walls may be transported long distances inside the building before it enters a room. This might lower surface temperatures on walls and floor structures and cause discomfort.

Moisture should also be carefully considered when selecting tightness measures.

Airsealing measures carried out from the building's warm inside are usually more dependable than those carried out from the cold outside, since vapour transport through the structure is ususally from the inside (having a higher vapour content) to the outside. An airtight layer on the cold side is often so vapour-tight that condensation can arise within the wall and insulation.

However, it is often easier to improve the airtightness on the outside of the building where a continuous sealing layer can be applied. Work on the inside is very often hindered by fixed furnishings, intermediate walls, etc. Sealing inside intermediate walls and joist edges must supplement other internal tightening. There are often points which exhibit the greatest air leakage.

A material which is airtight but permits vapour diffusion is necessary if sealing measures are to be carried out on the cold side of the wall. Moisture storage capacity may also prove to be valuable to avoid moisture condensing and running off. Measures taken with this type of material could be used in dwellings with low internal humidity.

The aim of sealing measures should be to provide the building with permanent airtightness. The extent of the measures taken depends on the condition of the house with respect to airtightness, design and construction.

Simple measures such as the installation of new weatherstripping in windows and doors are considered normal maintenance at varying invervals whereas drastic measures such as sealing the whole house with a layer of polyethylene film are justified only under special circumstances.

A10.1 Windows and doors

Methods for sealing between window and door frames in new houses have been described in Chapter A9. Different types of weatherstripping, and methods of fitting these to doors and windows, are discussed in detail. Such methods are also sometimes applicable when improving existing buildings. Careful consideration of material choice is necessary since many windows and doors in existing buildings have not been designed for the installation of weatherstripping.

Different types of weatherstripping in windows seem to affect energy consumption in different ways.

Investigations in single-family houses have shown that expanded angular and tubular strips of synthetic rubber (EPDM) result in lower energy consumption than when weatherstripping of foam and/or fibre is used (2); see Table A10.1. These results were confirmed by significance tests on the data given in the table.

There was an obvious difference in energy consumption between houses where weatherstrips did not exist and houses where fixed windows (not openable) were installed, though there were few houses with fixed windows.

The result correspond well to the results of an earlier investigation where the efficiency of different types of weatherstrips, in terms of airleakage, has been evaluated in laboratory tests (5).

A10.2 Joints

Gaps and joints can be sealed using mastic or polyurethane foam. Mastic demands a good base, for example mineral wool or a rubber strip. Precautions should be taken when applying polyurethane foam to minimize health risks.

Sealing under existing sills can be difficult with respect to accessibility. Even if the joint is easily accessible, the joint width is often too narrow for the systems described in Chapter A9. It may be possible to use mastic, see Figure A10.2. This method can also be used between concrete elements. An external improvement to the wind barrier as illustrated in Figure A10.3 may be a solution in such cases (6).

A10.3 Joist connections

Airflow within joist structures normally occurs in non-homogeneous structures such as timber joists. The problem often arises when cold air is transported within the joist structure so causing discomfort in the form of cold floors and ceilings. The greatest air leakage often occurs where supporting joists pass through the sealing layer, e.g. where an intermediate joist meets an external wall.

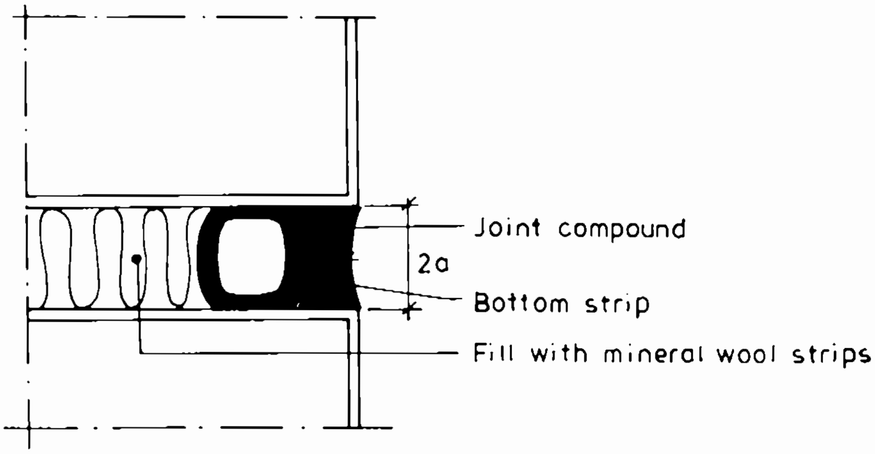
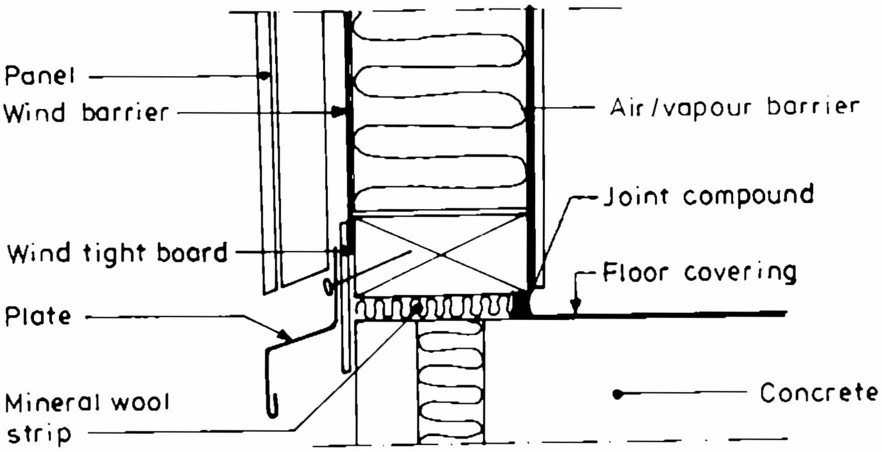


Figure A10.2. *The jointing compound must not fill the whole depth of the gap. The compound loses its elasticity and adhesion to the base can release. The depth should therefore not be greater than half the gap width. Fill with mineral wool, rubber or timber battens before the compound is injected.*

Avoid external sealing with sealing compound! If a compound is used externally, make sure the joint can be aired and drained.



The joint between the external wall and the foundations may be difficult to get at since the facade cladding often extends past the footings. In such cases, the joint can be made accessible by sawing away the bottom piece of the facade cladding. Saw opposite the sill to avoid damaging the wind barrier where fitted

- o *Clean the joint*
- o *Where possible, seal the joint with strips of mineral wool*
- o *Cover the joint with impervious paper or board. Replace the piece of cladding with a metal sheet or a weatherboard*

Sealing compound should not be used on the outside unless there is an efficient vapour barrier on the inside

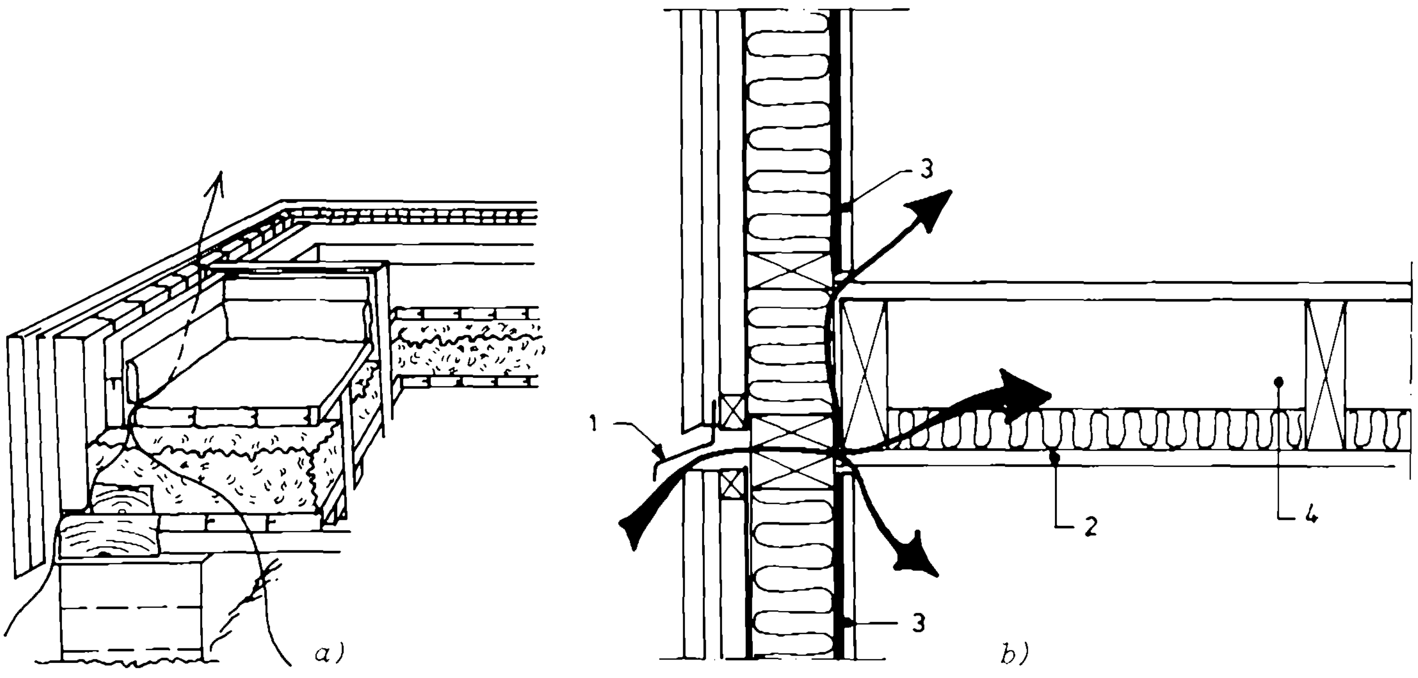
Figure A10.3. *External sealing next to the sill.*

Figure A10.4 shows examples of common leakage routes in floors and intermediate joists. In the case of homogeneous joist structures, airtightness measures can often be limited to joint sealing as shown in Figure A10.2 between joist structure/wall and possibly to element joints in the bottom joists structures adjacent to crawl spaces. An investigation by Axén & Pettersson in 1979 (7) showed that of the 19 multi-family houses with concrete joists structures investigated, 15 had airtightness faults in the joist structure connections at floors and ceilings.

The edges of timber joists can be difficult to seal. If the leakage route is known, it may be possible to seal the leak using mastic or polyurethane foam on the inside. It is often necessary to take the floor up which can be both time-consuming and expensive. Special measures may be necessary in order to apply the mastic.

Another method which has been applied with a certain measure of success is the injection of urea formaldehyde foam (carbamide resin foam) around the outer edge of the joist structure, see Figure A10.5. When carefully carried out, this measure reduces the air leakage and increases the thermal insulation. This plastic does have disadvantages, however. Since water is released from the foam, it is important that foam is not injected in cavities where drying out is prevented by tight material layers. The material quality is dependent on the constituents of the mix and, consequently, only reliable contractors should be engaged for the work. The material shrinks to a certain extent and releases formaldehyde, a matter that must be taken into consideration (see Chapter A8). Other foams, such as polyurethane, can be used in the same way.

Figure A10.6 shows a common fault in the tightness and insulation function at the eaves. One measure to combat this is to set up a wind barrier at the edge of the eaves with a filling of carefully packed wood chips.



a) *Leaks between the sill and the footings could cause undesirable air leakage*

Timber floor joists often provide an inferior air and vapour barrier, wind barrier and insulation. Moisture damage is not uncommon

b) *Common joint between intermediate joist and external wall. Since there is no seal between beams which limit the element, there is often air leakage at the joint*

Designations:

1) *drip plate*

2) *internal roof cladding possibly on secondary spaced boarding*

3) *internal wall cladding on a base of plastic film. Film often discontinued at joist structure*

4) *intermediate joist structure possibly fitted with thin mineral wool filler (acoustic duct insulation)*

Possible measures:

- *internal sealing with mastic between the wall's capping and the sill of the eaves. The floor needs to be taken up for this job. Furthermore, it may be difficult to apply the mastic*
- *injecting urea formaldehyde foam into the joist structure. Observe that water is added to the structure when foaming thus demanding facilities for drying out. The foam contains formaldehyde*

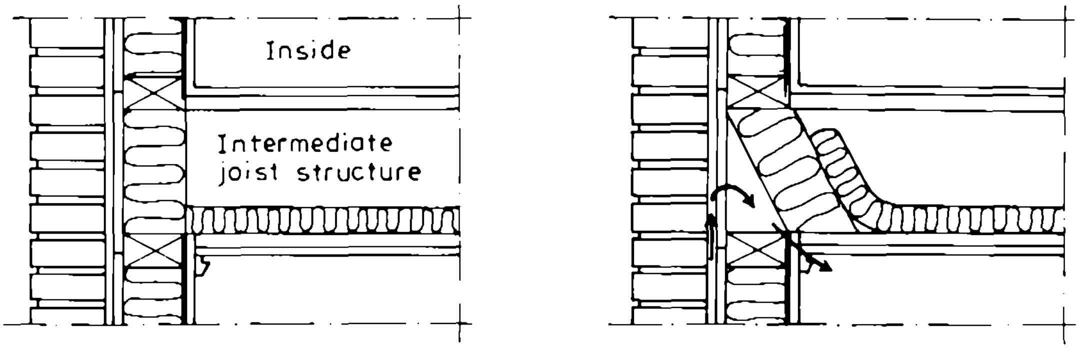
Figure A10.4. Joist structure connections.

External wall, from the outside:

facade brickwork
asphalt impregnated particle board
95 mm mineral wool
polyethylene (PE) film (not continuous)
13 mm plasterboard

Intermediate joist structure, from the top:

floor covering
chipboard
air gap
50 mm mineral wool (B quality)
19 mm secondary spaced boarding
13 mm plasterboard



a) Structure of the intermediate joist where joined to the external wall (from drawing)

b) Faults noted at inspections in the insulation and tightness work. There is no continual internal airtightness layer at the joist connections. There are also faults in the actual insulation procedure

c) Cellular plastic material after injection.

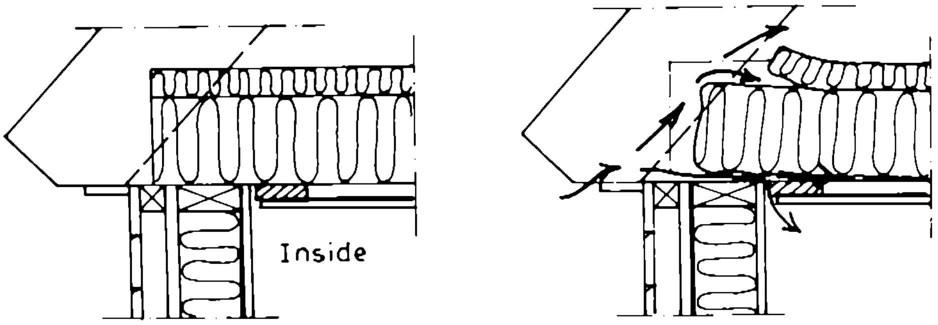
The following was carried out:

Injection of urea formaldehyde foam from the external wall and 80-100 cm into the joist structure

Result:

The thermographic investigation of the building section before and after the work showed a considerable improvement, both in the thermal insulation and the airtightness. The inspection was carried out approximately 2 months after the work was completed. The shrinkage in the foam material was estimated to be approximately 5 per cent when inspected

Figure A10.5. Example of injecting urea formaldehyde foam in joist structures to provide satisfactory insulation and airtightness.

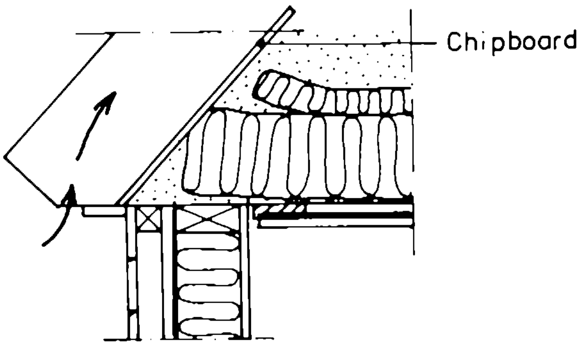


a) Construction of the roof joist structure

From above:

50 mm mineral wool with
wind barrier (paper)
150 mm mineral wool
19 mm secondary spaced boarding
polyethylene (PE) film
13 mm plasterboard

b) Faults observed. Inaccurate cutting and fitting of the material to the joist structure, partly due to electrical equipment installation. The internal airtightening layer, the polyethylene film, was not overlapped at the corners and air leakage was observed



c) The following measures were taken:

An approximately 20 cm thick layer of wood chips was added to the existing mineral wool insulation with the material carefully packed around roof trusses and at the eaves. The chipboard was fitted at the eaves partly to keep the material in place and partly to ensure ventilation of the roof

Result:

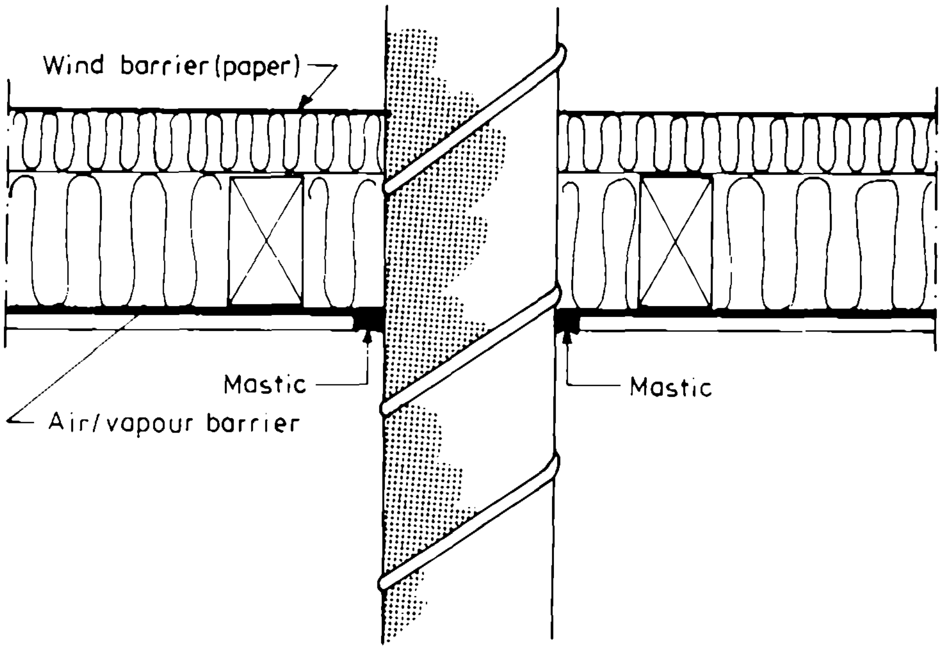
The thermographic investigation of the building section after the work was completed showed that the thermal insulation and airtightness were satisfactory. Air leakage at the eaves had ceased

Figure A10.6. An example of faulty insulation and airtightness at the eaves. Filling was done with wood chips packed tightly around the structural items to prevent air leakage in the structure. A particle board was fitted to provide an air gap between the roof and the mineral wool.

A10.4 Penetrations

Air leakage around installation penetrations is common and is relatively difficult to rectify permanently, partly because pipes and ducts are often enclosed and partly because moisture and temperature movements are different in the structure and the actual installation. Great elasticity is required of the jointing material to achieve a permanent seal.

When sealing with mastic and bottoming with mineral wool as shown in Figure A10.7, the mineral wool must be packed properly to provide sufficient support for the mastic. The wind barrier is improved on the outside.



Ensure that the insulation fills the cavity well

Figure A10.7. There are often leaks where different types of ducts pass through the ceiling. These are normally difficult to seal, partly because fire safety requirements demand that combustible materials are not used around certain smoke and ventilation ducts. It is especially difficult to seal when more than one duct is penetrating the vapour barrier close together or when a duct is surrounded by insulation.

Penetrations in the joist structure for loft hatches often show considerable inadequacies in both airtightness and thermal insulation.

Figure A10.8 shows two examples of how loft hatches can be sealed and thermally insulated (8).

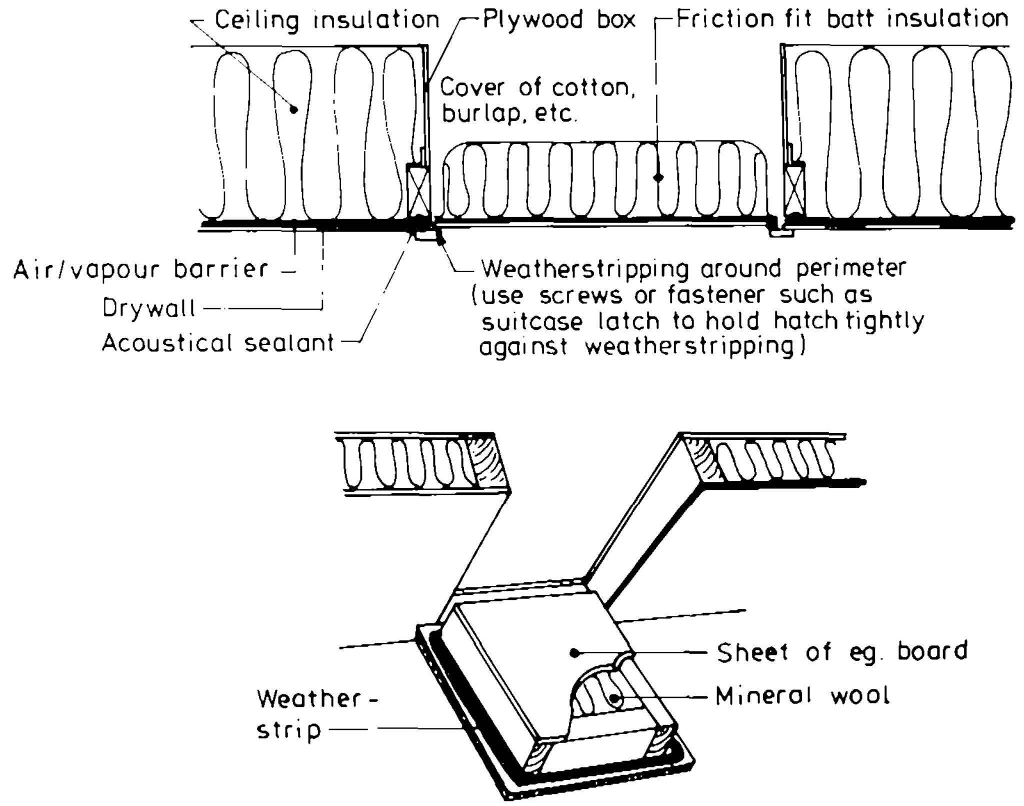


Figure A10.8. Attic hatch detail.

The upper figure shows detail for the attic hatch. Additional weitht may be added to the hatch door to aid in the sealing process. Bricks attached with sealant have worked well.

The lower figure shows detail of an attic hatch opening inwards.

It would be far simpler to eliminate the interior attic hatch and put an opening into the attic from the outside, such as in the gable end or the garage. (A lock may be necessary.)

A10.5 Floor joist structures

Sealing the complete joist structure may be necessary to avoid air leakage through a suspended timber floor. This may be achieved by welding and bonding plastic matting provided that sealing under the inner wall is possible.

Sealing by laying out polyethylene film below or on top of an existing floor is also possible. Great care must be observed in both cases when joining the sealing layer to internal and external walls. Polyethylene film on top of existing floors must be supplemented with a new floor covering. Moisture must be carefully considered since many older joist structures are designed to allow a certain amount of air leakage so that a good moisture balance is maintained in the structure. In such cases, sealing with polyethylene film can drastically change the moisture balance resulting in the risk of damage. Particular care should be exercised when sealing joist structures above crawl spaces.

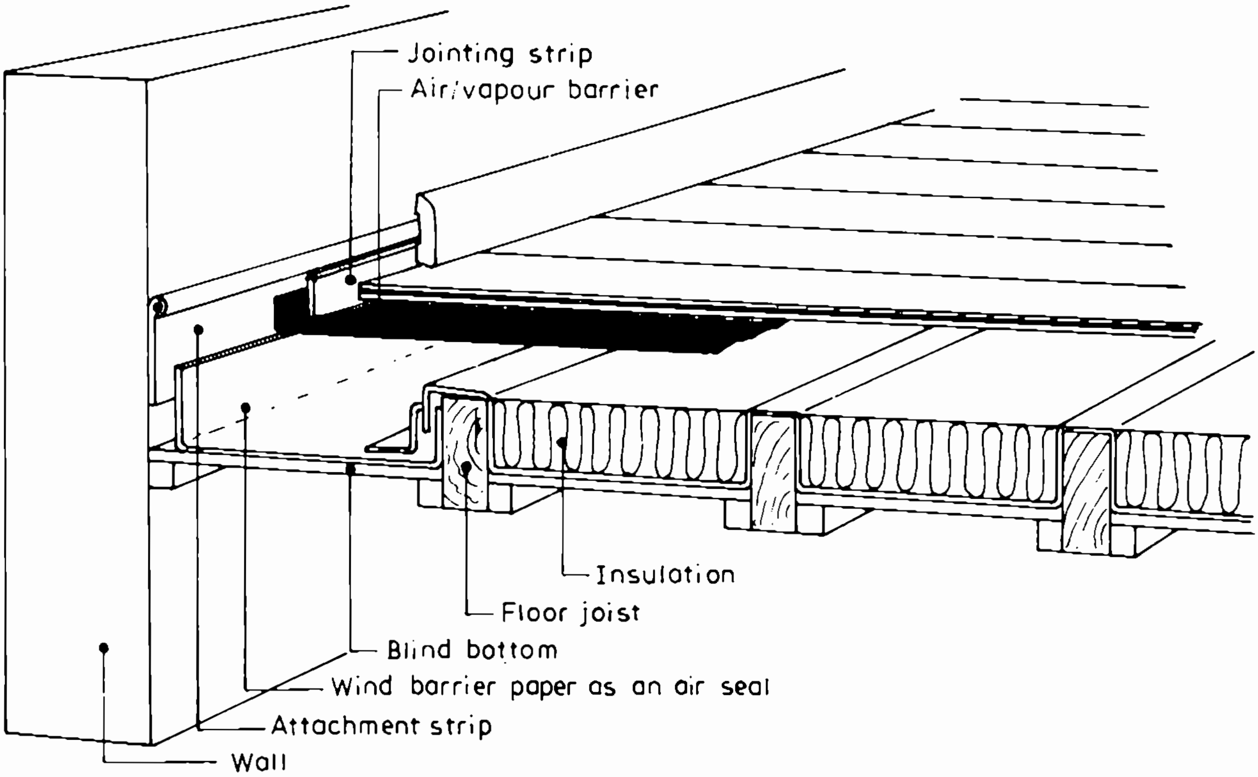
An example of airtightening using paper is illustrated in Figure A10.9. This is a comprehensive measure and is best carried out in conjunction with the installation of supplementary insulation of the joist structure.

The joist structure's wind barrier can often be improved from the underside using vapour-permeable paper or board. Changes to the existing structure can thus be avoided. The procedure can be as outlined in Figure A10.10. The effectiveness of the method is reduced if the joist structure edge leaks.

A10.6 Walls

Older stud wall structures are sometimes not fully insulated and the workmanship is such that possibilities for air leakage exists at several points. There is also a considerable risk that wind will damage the thermal insulation. Before retrofitting it is necessary to examine all the constructional details carefully and determine what can be done (9). In some cases it can be possible to improve the windbarrier and the air/vapour barrier. In some cases additional insulation can be added by injecting some kind of foam taking into account the risks of moisture and other problems, see Figure A10.11. In this case the result of an exterior additional insulation could be absent.

Joints between airtight boards in external walls can often be sealed in conjunction with wall papering using filler or mastic. Note that the board must be sealed all round against the building frame. The jointing material used must be able to absorb movements in the board resulting from seasonal and moisture variations. If the external wall itself is pervious, an airtight layer can be applied from the inside.

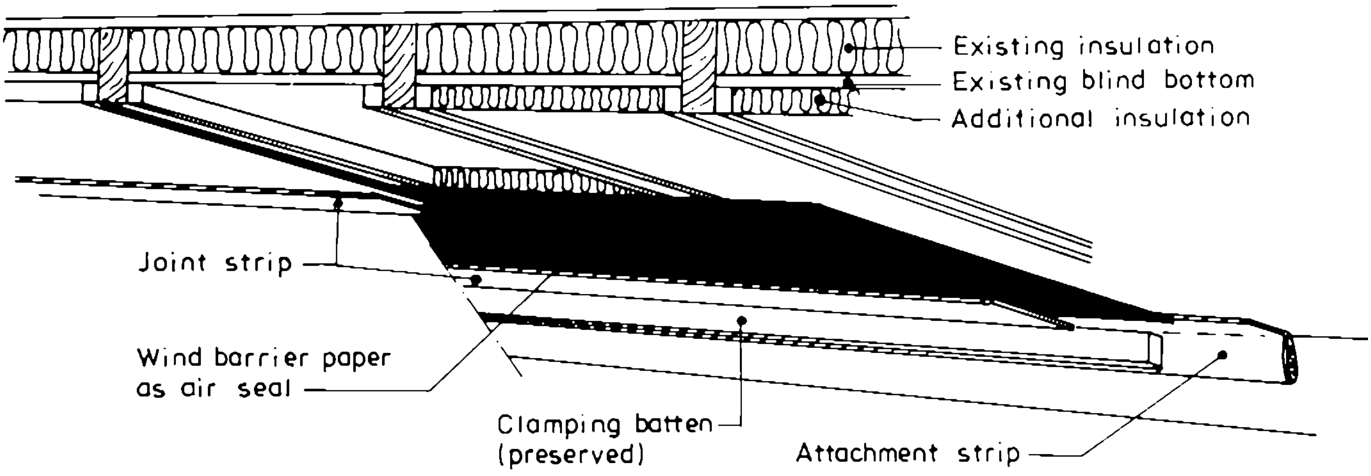


Working steps:

1) *Affix the attachment strip to the wall*
2) *Lay the wind barrier as an air seal on all blind bottoms and over the floor joists*
3) *Seal all joints and attachment strip with jointing strip*
4) *Install the insulation in accordance with the manufacturer's instructions*
5) *Lay out the vapour barrier and seal it at all joints and at the attachment strip at the walls*

Figure A10.9. An example of a floor joist structure above a cold area exposed to outdoors, e.g. above a crawl space. If the method is used above crawl spaces ensure that there is adequate ventilation and that moisture emission from the ground is insignificant by laying a plastic film on the ground in the crawl space. Use preserved wood to the floor joists and blind bottom.

This layer can be polyethylene film, metal foil or paper of a sufficient size to produce a minimum of joints. The layer must be carefully sealed against the floor, ceiling and windows, see Figure A10.12. Internal cladding is used as a base for wallpaper. This type of measure can be suitably combined with the installation of supplementary insulation.



Working steps:

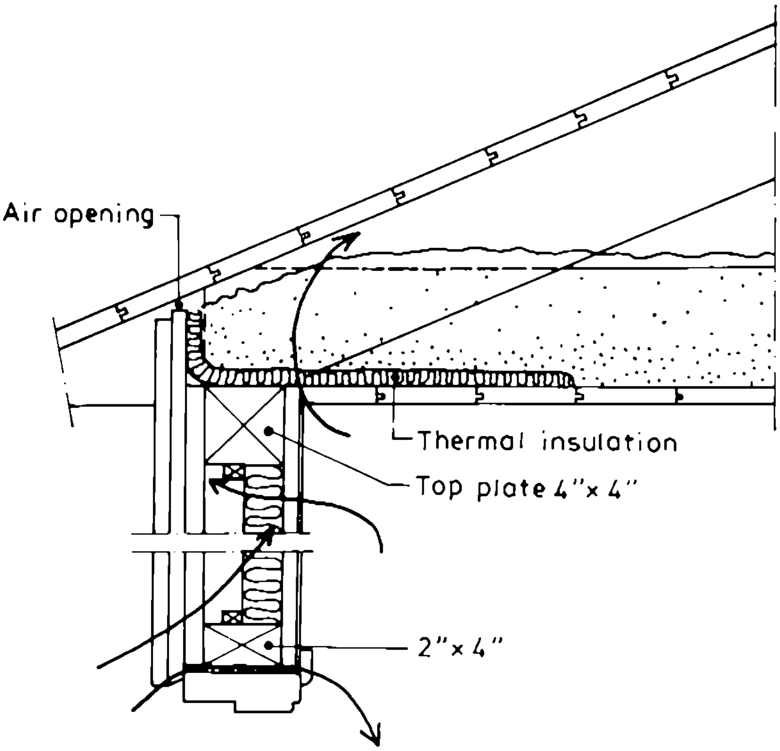
1) *Attach attachment strip with a batten at the sill round the whole of the foundations. Then fit the insulation*
2) *Tack up the wind barrier as an air seal (tack only at the overlap joints)*
3) *Seal all joints and attachment strip with jointing strips*

Figure A10.10. An example of setting up a new wind barrier on the underside of a timber joist structure to improve airtightness.

It may be simpler to improve the wall's wind barrier from the outside if there is a good vapour barrier on the inside. As shown in Figure A10.13, this method can be combined with supplementary insulation. The advantage of working from the outside is that a continual airtightening layer can be applied more easily.

To minimize the condensation risks, a material open to vapour diffusion should be used on the outside. A material that seems to have that property and still acts as a wind and infiltration barrier is spunbonded polyolefin which is a plastic material. Experience of the use of this material is, however, limited and proper working methods for application are as yet unformulated.

Internal walls often leak at the top and bottom in existing buildings. This means that internal walls often act as additional ventilation flues through which considerable air leakage can take place. Thus leakage in internal walls must be stopped in conjunction with other sealing work.



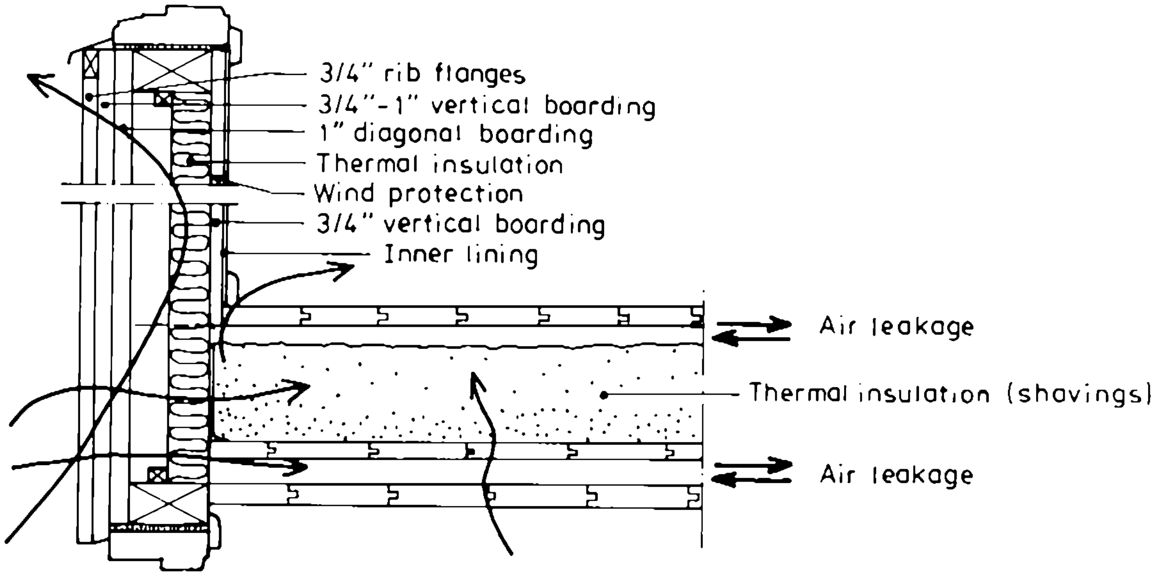


Figure A10.11. *Stud wall – not fully insulated. In this older construction there is many possibilities for air leakages and risks for damaging the thermal insulation.*

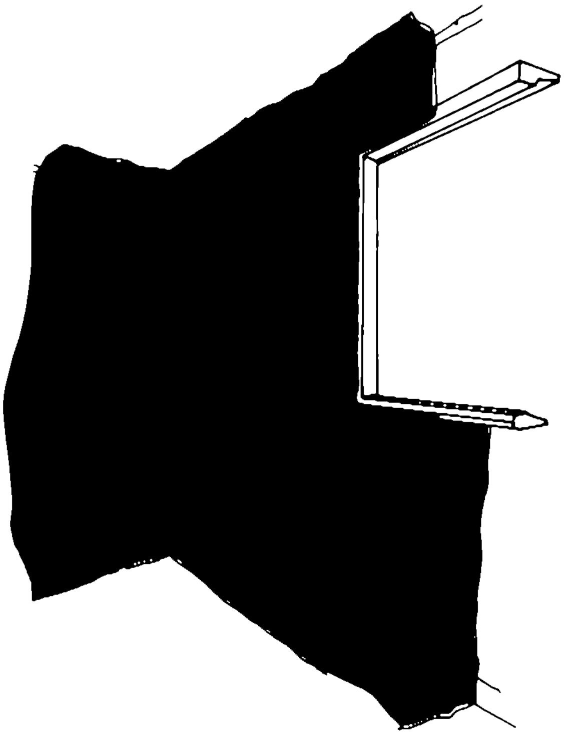


Figure A10.12. New air/vapour barrier on the inside of external walls. The plastic film must be carefully sealed against the floor, ceiling and windows. Use clamped joints and acoustical sealant. Try to get large size film in order to minimize the number of joints.

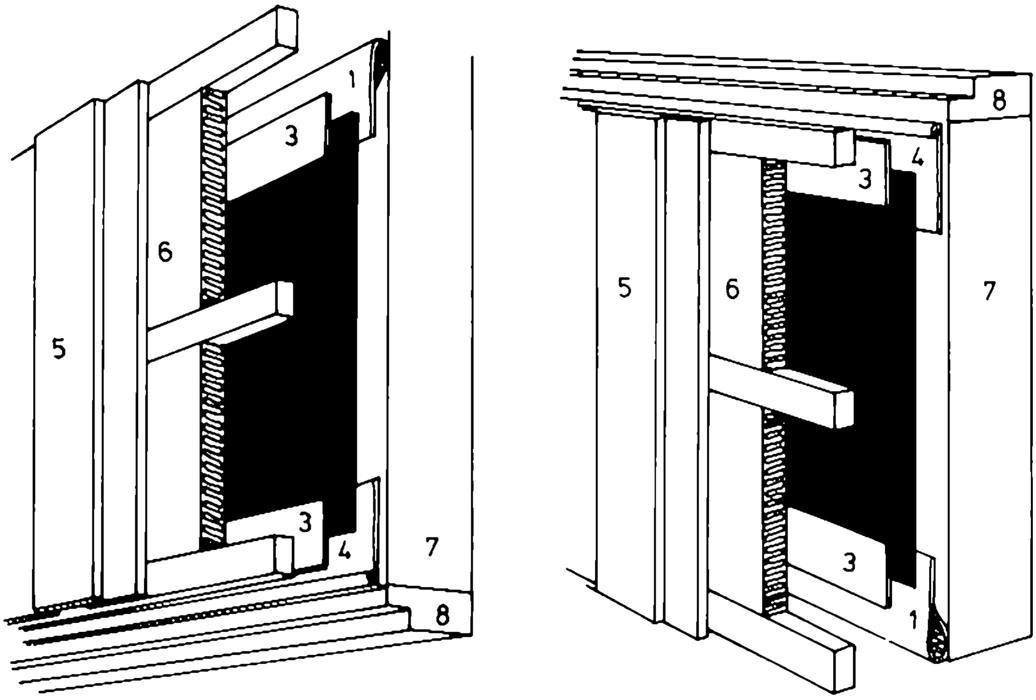
This can be done from the loft by applying a strip of polyethylene film which is joined to the sealing layer of the joist structure; see Figure A10.14.

Mastic or polyurethane foam can be used for narrow gaps.

A10.7 Roof spaces

In buildings with sufficient room height, leakage to the roof space can be prevented by sealing and thermally insulating from the inside as shown by the example in Figure A10.15. Good sealing against the walls is important if the measures are to be efficient. Particular attention should be paid to sealing internal walls in the same plane.

In unfurnished lofts, the joist structure can be treated from above if there is sufficient room, see Figure A10.16. The wind barrier should not be improved just by itself since moisture diffusion and



1) Attachment strip I
2) Wind barrier paper
3) Jointing strip
4) Attachment strip II
5) New facade of timber panel
6) Thin insulation
7) Existing wall
8) Window frame

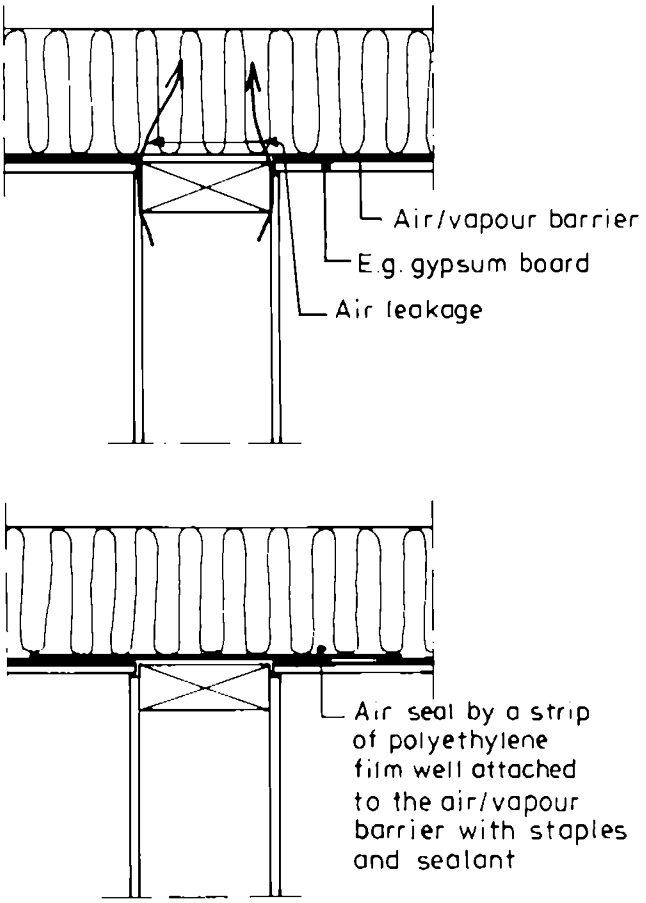
Working steps:

Remove the old facade panel carefully so that you can reuse a large part of it

1) *Seal against the woodwork, the bottom sill and the eaves using suitable attachment strips*
2) *As an air seal, affix the wind barrier nearest the original external wall*
3) *Fit a nailing batten for the facade panel. While nailing the panel boards in position, fit facade cladding quality insulation to the wind barrier (face the paper inwards to the wall)*

Figure A10.13. An example of fitting a new wind barrier in conjunction with supplementary insulation of external walls. The house's airtightness is improved considerably by applying carefully thought out methods when fitting the wind barrier paper.

convection can be transported through the structure and can condense on the wind barrier and cause moisture damage. To avoid moisture problems in joist structures, the airtightness layer should be integrated with the vapour barrier.



a) At structural partition walls the vapour barrier in the roof joist structure very often is discontinuous where a considerable leakage can take place

b) By using a strip of polyethylene film the air leakage can be stopped

Figure A10.14. Sealing internal walls.

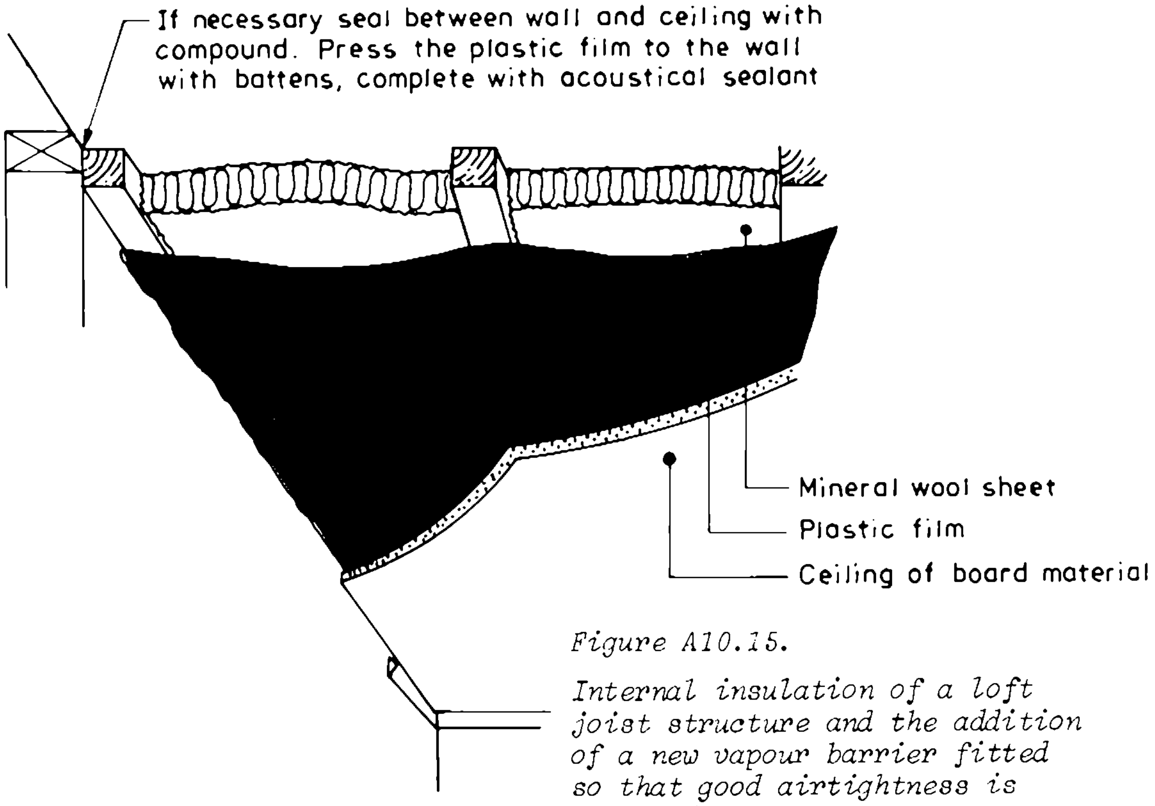
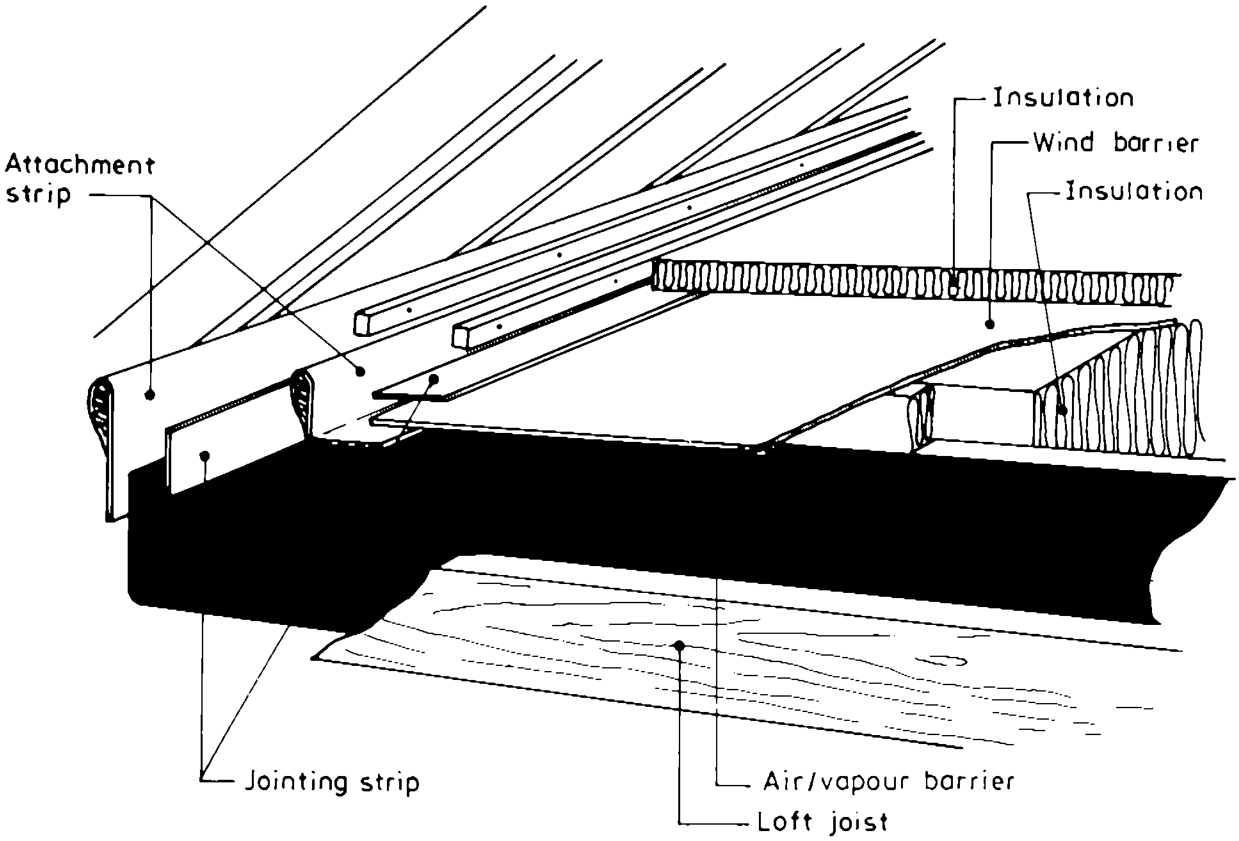


Figure A10.15.

Internal insulation of a loft joist structure and the addition of a new vapour barrier fitted so that good airtightness is achieved.



Working steps:

1) Remove the existing insulation

2) Carefully seal against the roof trusses and panels with jointing strips and attachment strips

3) Lay the vapour barrier as an air seal against the ceiling and seal it with attachment strips and with jointing strips at the joints

4) Lay out the insulation

5) Roll out the wind barrier over the insulation and seal carefully against the vapour barrier at the walls and at all joints with jointing strips

6) Roll out a thin layer of joist insulation on top of the wind barrier

Figure A10.16. An example of improvement to the wind barrier and airtightness in conjunction with supplementary insulation of a roof joist structure.

A10.8 A method to improve airtightness and thermal insulation in timber flat roofs

A considerable number of the roofs in Denmark and Sweden are flat roofs with roofing felt. Mould and rot often occur in such roofs (10). One common reason is that warm moist air penetrates the roof cavity from the dwelling through leaks in the vapour barrier. Large amounts of moisture may condense on the upper part of the roof component during the winter period. This moisture may start fungal attack on wood or wood-based materials in the structure. It can also cause such movements in the roof deck that the roofing membrane may crack, see Figure A10.17. The roofs must be repaired and provided with new roofing membrane. Because of increasing energy costs it is sensible to combine the maintenance with additional insulation.

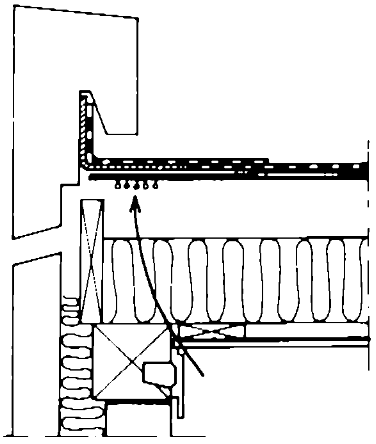


Figure A10.17.

Penetration of moist room air into the roof cavity.

A method which has been used is to add insulation on the top of the existing roofing-felt, build up a new joist and wooden boards with new roofing felt and close the existing ventilation openings (Figure A10.18).

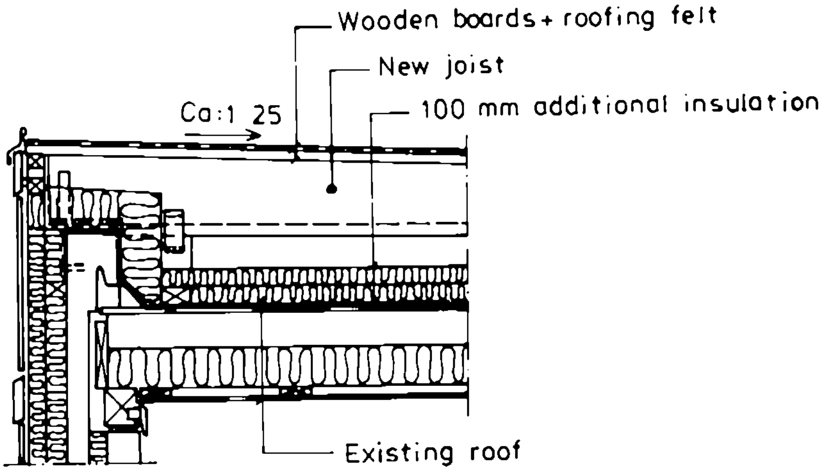


Figure A10.18. The final renovation of the 'garden' house roofs at Albertslund, including also further insulation of the facades. The roof slope is increased from 1:100 to 1:25 and the cavity above the added insulation is ventilated to the outside. Existing roofing felt now acts as a vapour barrier. Internal gutters at fascia boards were replaced by external gutters.

Before the additional insulation is applied, condensation on the plywood deck depends mainly on whether the air from rooms can penetrate to the roof cavity through cracks and holes – air leakage – in the vapour barrier. The added insulation thickness should not be less than 100 mm. The reason is that the thickness of the additional insulation must be sufficient to prevent – under existing temperature, moisture and pressure conditions – detrimental condensation which occurs on the original roof deck which, after the application of the insulation, serves as a new air vapour barrier.

A10.9 Sealing of the entire envelope

A method for sealing the complete climate shell has been tested in Saskatoon, Canada. A detached house was completely covered with polyethylene film from the outside. Thick additional insulation was carefully fitted to the house and a new facade layer was erected. The procedure used is described in detail by Marshall & Argue (11). A number of case studies are presented of houses which achieved savings in space heating requirements of approximately 75 per cent.

It is important in cases such as this for the externally fitted insulation to be carefully fitted and that cold bridges are avoided to prevent condensation on the inside of the polyethylene film.

When correctly treated, the house is as good as a new one. Practical experience of long term energy savings is lacking, however.

A10.10 House Doctor's Program

The program was produced and developed by Princeton University in conjunction with the Twin Rivers project in New Jersey, United States, to analyse energy usage and to carry out simple energy saving measures in a large number of buildings in a rational and similar fashion (12). The method has been subsequently refined and is described here in its entirety despite the fact that it includes more than airtightness measures.

The program is conducted by a well-trained team of two or three persons who handle the energy analysis and retrofitting. The house doctors use a carefully selected kit of instruments to speed their house diagnoses of energy loss (13); see Figure A10.19. The end

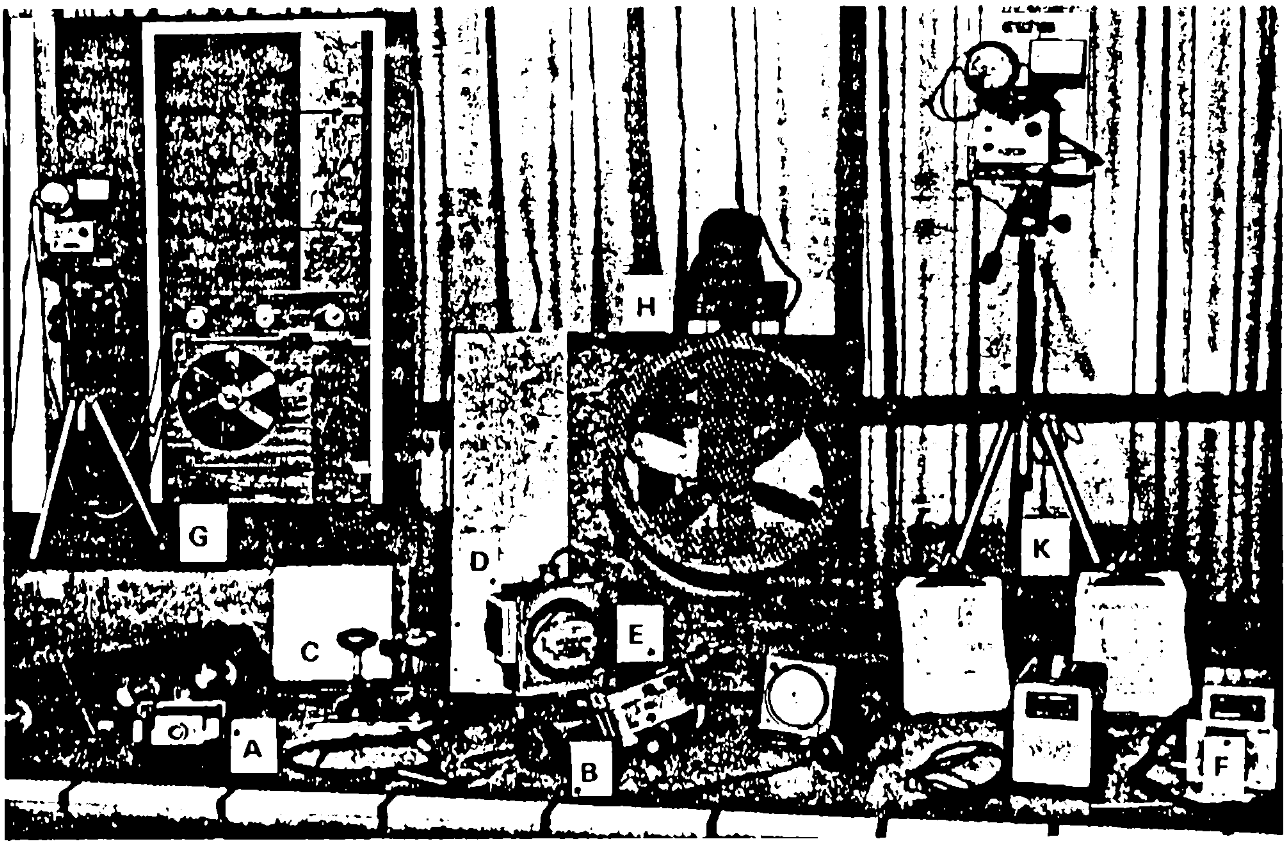


Figure A10.19.

The energy auditing equipment includes: camera A; measuring stick to appear in outer wall photographs B; furnace efficiency measuring devices C; appliance energy consumption meter D; portable infrared scanning equipment E; temperature measurement probes (AC and battery powered) F; (insert) the blower door assembled in a doorway where principle components include G; the lower door (18-in.) blower powered by a variable speed DC motor H; and blower door control panel with differential pressure and rpm readout J. Clipboards, K, are used to record on-site data.

result is a prescription for appropriate retrofit measures that partly takes place during the visit of the team. Although a given house may call for a change in procedures to meet certain particular needs, there is a recommended approach that is described below.

PROCEDURE

The prodecure that has been used in the house doctor approach begins with an external examination of the structure, sizing the house and cataloguing its important features. The objective is to measure the size of dwelling and to record the exterior details of the structure.

During the preliminary portion of the visit, any energy problems encountered by the homeowners are also noted: cold rooms, localized draughts, inadequate insulation, poor windows, etc. The final item is a room-by-room survey to determine how well the temperature is balanced and whether the thermostat (s) is functioning properly. A multiple setback clock thermostat may be installed by the house doctor so that temperatures can be programmed over the full 24-hour day (this includes daytime setback when appropriate). For residents not currently setting their temperature back at night (but who would do so if a clock thermostat were available) these thermostats would be very cost-effective.

The next priority is to determine the leakiness of the building envelope. A Blower Door, a large calibrated multispeed fan system, is installed in an exterior doorway and the house is pressurized (see Chapter A11). The amount of flow required to pressurize (or depressurize) the house over a range of pressure levels is recorded. This test not only indicates the amount of leakage, but rates the house with others as to tightness. Should the house be sufficiently tight further leak sealing is not necessary. Princeton has set 6 ac/h at 50 Pa as a temporary criterion. The 6 ac/h is when pressure testing with vents and stacks unplugged and for a house not making use of mechanical ventilation. Results from pressurization tests and levels of airtightness in buildings in different countries have been discussed earlier in Chapter A3.

Leak site detection begins with the attic. A slightly pressurized house means that a greater than normal amount of air is forced through a variety of attic floor leakage sites. These leaks are detected by scanning the attic floor with portable infrared equipment. Even with insulation in place the leaks are readily visible using the infrared technique. "Bypasses" from interior walls, plumbing stacks, electrical fixtures and wiring holes are just a few of the leaks that are detected. Often there are large energy loss sites due to lowered (soffit) ceilings, whole house fan openings, special piping or ducting chases, etc. These sites frequently have leakage levels that demand immediate attention. Large openings are sealed with a plastic sheet placed over the leak and under the insulation. Smaller openings are sealed with foam, compressed glass fibre, caulking or tape. The access to the attic is often a major leak site and requires weatherstripping or perhaps an insulated sealing cover to cure the problem. Any sealing improvements can be measured while the Blower Door instrumentation is in place. In this way the house doctor knows that progress is being made — the patient is improving.

Next the house is depressurized by reversing the Blower Door fan. Under these conditions ceiling leakage can be double checked from the inside. Now we are dealing with cooler surface areas (under heating season conditions). Inadequate insulation and the presence of leaks are identified by cool patterns across the interior surfaces. The infrared viewer is used to survey all the interior surfaces of the house. Interior walls receive equal attention in this survey. Piping and wiring through the internal walls often are the cause of major leakage paths from the living space or basement to the attic. This condition results in characteristic cool stripes extending from floor to ceiling and indicate high priority sites for retrofitting. Soffit ceilings appear as cool areas in need of an attic seal. The floor is also scanned in the internal surface check. Often leakage along the floor-wall joint is a major source of air infiltration, as are the electrical outlets. The latter leaks may be cured using closed-cell plastic gaskets as a retrofit measure. Transparent caulking on the joints along floor edges and around windows can prove to be very worthwhile. This tightening process typically yields 10-35 per cent improvement in reduced air infiltration in the dwellings investigated.

Having catalogued problems in the building envelope due to air leakage and insulation shortcomings, attention is next turned to the heating system. Both oil and gas fired systems have shown marked improvements through tune-up. Remember a 5 per cent improvement on a heating system with a 70 per cent seasonal performance translates into a more than 7 per cent overall gain. The house doctor should use the best measuring equipment available for these tests. Direct readout of performance is helpful so that the tests and adjustment if necessary may be done in about 15 minutes. This may prove to be the conservation measure with the fastest payback. Since this check takes place after the Blower Door testing the house has cooled down, ensuring reasonably long burner operation times.

Last but not least in the checklist for the house doctor is the inspection of major appliances. Generally, additional insulation on the outside of gas and electric water heaters have a relatively short payback period. The hot water temperature should be set as low as possible to meet household needs. This setback can save as much as upgrading the insulation. Where needed, flow limiting devices should be employed in showers and sinks. The refrigerator may require some additional monitoring if questions arise as to its performance. Princeton University has developed a simple meter that provides such data by monitoring over a 24 hour period. This meter measures the cumulative energy consumption and avoids the problem created by on and off cycles of the compressor, fans and other components.

RETROFITS WHICH MAY BE PERFORMED DURING HOUSE DOCTOR'S VISIT

{where applicable, after Dutt (14)}

- *Insulate water heater with 9 cm (R-11) foil-backed glass fibre insulation.*
- *Insulate first 3 metres of hot water pipe from water heater.*
- *With homeowner's permission turn water heater temperature down to 50°C. Show homeowner hos to turn temperature up if 50°C is unsatisfactory.*
- *With homeowner's permission install low-flow shower head (s) or DOE shower flow controllers. Leave old one behind. Show homeowner how to change it back if unsatisfactory.*
- *With homeowner's permission install sink tap areators.*
- *Install foam gaskets behind a few leaky switchplates and electrical outlets. Leave a set of gaskets for homeowner to install on the rest of the switchplates and outlets.*
- *If attic door or trap door is not insulated then staple or glue 200 mm thick insulation on door. (Use 100 mm if 200 will not fit.) Add additional weight (e.g. a brick) if a trap door is too light to seal properly (see Figure A10.8).*
- *Weatherstrip attic door.*
- *Seal around plumbing pipes and electrical wires where they penetrate the attic floor.*
- *Stuff openings around furnace flue with glass fibre.*
- *Seal openings over dropped ceilings using polyethylene sheeting and best fastening method.*
- *Seal leaky ducts in attics and basements.*
- *Seal (with caulking compound or caulking rope) the gap between foundation wall and sill plate.*

- o *Seal other major leakage sites identified during the audit.*
- o *Replace furnace air filter if necessary.*
- o *Adjust furnace to maximum steady-state efficiency.*
- o *Set back plenum temperature at which furnace fan goes off to 38°C.*
- o *Install clock thermostat.*

A10.11 References

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A11 METHODS OF AIR INFILTRATION MEASUREMENTS

A schematic overview of different methods for infiltration measurements is given in Table A11.1. This table contains the advantages and disadvantages of each method.

Table A11.1. Comparison of methods for air infiltration measurements.

	Method	Advantages	Disadvantages	Result
Determination of air changes (ventilation) in whole buildings or part of the buildings (single rooms)	Tracer gas (instantaneous)	Gives information about ventilation rate under running conditions. Needs relatively cheap equipment	Indirect method. Result depends on actual weather conditions. Mixing is difficult. Needs special training	Simultaneous air changes per hour (ac/h), m^3/s or m^3/h at operating conditions
-"-	Tracer gas (continuous)	Gives information about the ventilation rate over a longer period under different operation conditions	Indirect method. Expensive equipment. Needs specialists. Can only be used in research and development projects	Air changes at operating conditions (ac/h, m^3/h or m^3/s)
-"-	Tracer gas (container sampling)	Simple to handle and cheap method	Indirect method. Low control of taking samples	ac/h
Determination of the airtightness of the building envelope	Whole house pressurization	Gives information about the leakiness of the building envelope. At high difference in pressure between in- and outside, the method is mostly independent of weather conditions. Cheap equipment. Easy to handle	Gives no information about actual ventilation degree. Gives information about airleakage at other pressure differences than operating conditions	Air leakage at high pressure differences (ac/h, m^3/s or m^3/h)
-"-	Components pressurization	A possibility to quantify airleakage through building components. Simple equipment. Relatively easy to handle	Takes time to adjust the equipment to actual component	Air leakage in m^3/h, m^3/s or m^3/m^2h at x Pa
Qualitative detection of air leakage sites	Thermography	Gives information about leakage sites and at the same time defects in the thermal insulation. Can be used as control of workmanship	Expensive equipment. Needs temperature difference of at least 10°C between outside and inside. Needs specialist	Identifying leakage sites
-"-	Smoke pencil	Gives information about leakage sites and air movements. Very simple and cheap method	Difficult to find leaks especially with internal overpressure	Identifying leakage sites

A11.1 Tracer gas

The tracer gas method can be used to measure the amount of ventilation in a variety of spaces, such as houses, apartments in apartment buildings, offices, etc. The ventilation rate is usually dependent upon the ambient weather conditions, and so the results of tracer gas measurements can therefore vary considerably with temperature and wind. For this reason long term averaging of air infiltration is necessary for assessing energy losses due to air infiltration.

The use of tracer gas, as the name implies, provides a method by which the air in the building can be identified so that an assessment can be made as to how much outside air replaces it. A small quantity of tracer gas is added (seeded) and mixed with air in the building under measurement. Over time, the concentration decay is observed in the smallest home or the largest building complex (1-7). A wide choice of tracer gases is available, but based on the criteria of safety, simplicity, quantity, and cost certain gases have proved to be preferable (5). Some common choices are sulphur hexafluoride (SF_6), nitrous oxide (N_2O) and ethane (C_2H_6). Specific limits for concentrations of these gases exist in occupied rooms.

It can be questioned whether tracer gas measurements are properly representative of the airtightness characteristics of a building. If one is interested in heat losses from ventilation or indoor air quality then the degree of mixing between the outside and inside air is very important. The mixing action between outside air leaking into a building and the inside air lies somewhere between the limits of perfect mixing and no mixing at all. This latter extreme can mean that the outside air either passes the inside air in some way without mixing with it, or that it propels the "old" air before it lika a front. The mixing itself, using fans, can also influence the air changes.

As the mixing between the tracer gas and the air in the building can never be absolutely perfect measurements made at a single point in the test space are sometimes not realiable measures of the condition of the space as a whole. This problem can be dealt with in practice by means of the following three alternatives.

1) Air is collected at a number of points and mixed together, after which the concentration of tracer gas in the mixture is used in calculating the ventilation rate.

2) The rate of decrease of concentration is measured at several points and the measurement point which exhibits a rate of decrease which is nearest to the average rate from all points is selected and used thereafter.

3) The decrease in concentration is measured at several points and the average value is used when calculating the ventilation rate.

The detection equipment itself is rather sophisticated (5). For example, to detect SF_6 one version of the equipment includes a portable gas chromatograph, coupled to an electron capture detection system. The gas chromatograph separates the SF_6 from other background gases, including oxygen, and the detector supplies the quantitative information as to the actual gas concentration. The sensitivity of current equipment allows concentrations below one part per billion to be measured, thus the amount of SF_6 necessary to seed a typical house is less than 40 cm^3 (3). Such equipment is rather expensive. Detectors for other tracer gases, however, are of comparable complexity and cost, and use such principles as thermal conductivity, chemiluminescence and nondispersive infrared detection.

The use of tracer gas techniques can involve anything from a short term check of an hour or so, to long term monitoring of a week or even a year or more. For the short term tests, the detector can be brought to the site and (after seeding with the appropriate amount of tracer gas) the concentration decay is monitored over a period of two hours.

Another approach is to seed and then gather samples of the building air in bags or bottles. Sampling before and after retrofits can be done in this manner. These containers are then analyzed back at the laboratory.

Automated monitoring requires more complex equipment. Such equipment, if it uses discrete sampling to observe the tracer gas concentration decay, requires that periodically new tracer gas must be injected and that the readings must be recorded on a regular basis. An example of such an automated system that has been developed for a variety of air infiltration measurement applications is described Refs. (3) and (4).

The most recent development in this type of equipment uses a microcomputer to control sampling from a variety of building locations (6). Using this computer, the output is immediately calculated in air changes per hour and the data are stored on a floppy disc.

Depending upon the actual details of the equipment and methods, measurements can be made in accordance with one of the following variants:

- decreasing gas concentration
- constant gas emission
- constant gas concentration.

The decreasing gas concentration method is most commonly used. The governing relationship for this tracer gas decay technique is Beer's law as stated

$$C(t) = C_o e^{-nt}$$

where C is the concentration as a function of time, t. C_o is the initial concentration and n is the air infiltration rate (hr^{-1}).

Another approach using tracer gas utilizes a constant gas emission technique (4). This means the tracer gas is steadily injected, thereby minimizing mixing problems between tracer gas and the house volume under measurement. Since the concentration is not constant, a volume term will be present and the equation is

$$Q = \frac{F}{C} - \frac{V}{C}\frac{dc}{dt}$$

where Q = the infiltration

F = the flow of tracer gas

V = the effective volume.

The change in tracer gas concentration is recorded using an appropriate detector. That portion of the record where the concentration changes are small represents the condition where the second term in the equation above represents a small correction. The system can run for days and thus gives continuous infiltration measurements. One disadvantage of the system is that large changes of the air infiltration rate will drive the gas analyser off the scale, thus losing the data (7).

As previously discussed, long term averaging of air infiltration is necessary for proper assessments of associated energy loss. A simpler, low-cost version of the constant flow system is being used to meet this need. The system makes use of two sampling pumps. One slowly pumps a bag of tracer gas (SF_6) into the home over a period of days and another pump slowly fills a bag with house air containing a representative concentration within the range of the detector. Measurements of SF_6 to 1 part in 10^9 allow high sensitivity and a large dynamic range (7).

Adding a microprocessor to a constant gas emission system allows adjustment to avoid the off-scale problem previously mentioned. Reference (6) refers to "continuous flow" infiltration monitoring in describing this system. The governing equation, using the previous definitions, is

$$C\ (t) = \frac{F}{Q} + (C_o - \frac{F}{Q})\ e^{-\frac{Q}{V} t}$$

As in the tracer gas decay automated system, the microprocessor plays an active role and calculated values are stored on a floppy disc.

Constant gas concentration is the only method that can give a reliable measure of the outdoor air entering each room of a multi-cell dwelling and is not affected by cross-flows from chamber to chamber. It is a direct measurement method since the gas is injected to maintain constant concentration being directly proportional to the fresh air entry. However, this requires a feedback-type design where the rate of injected tracer gas is directly proportional to the buildings' air exchange rate. This is a difficult problem to solve. Developments on such new measurements systems were reported by English, Danish and Canadian investigators at the First Air Infiltration Centre Conference (Windsor, United Kingdom, October 6-8, 1980). In multi-zone buildings, whether zoned houses or more complex structures, it is necessary to maintain constant gas concentration to analyse multi-cell interactions. Some of the systems measure as many as ten zones simultaneously.

An alternative solution is to use a variety of tracer gases and detectors.

SIMPLE AND LOW-COST TRACER GAS TECHNIQUES

If one is not interested in a detailed history of the air infiltration rate but wants only the total air exchange rate over a period of specified time then it is possible to remove the tracer gas monitoring equipment from the field site and use air sample bags or containers to collect the concentration levels of the tracer at specific instants (8, 9). This method is shown schematically in Figure A11.1. The tracer gas (SF_6) is initially injected into the dwellings using syringes. After a mixing time of about half an hour an initial air sample is taken on each storey of the building. The tracer gas is allowed to decay for a period of 1 to 2 hours and a second set of air samples is taken on each storey. The air samples are shipped to a laboratory and analysed for their concentration. The air infiltration rate can then be determined.

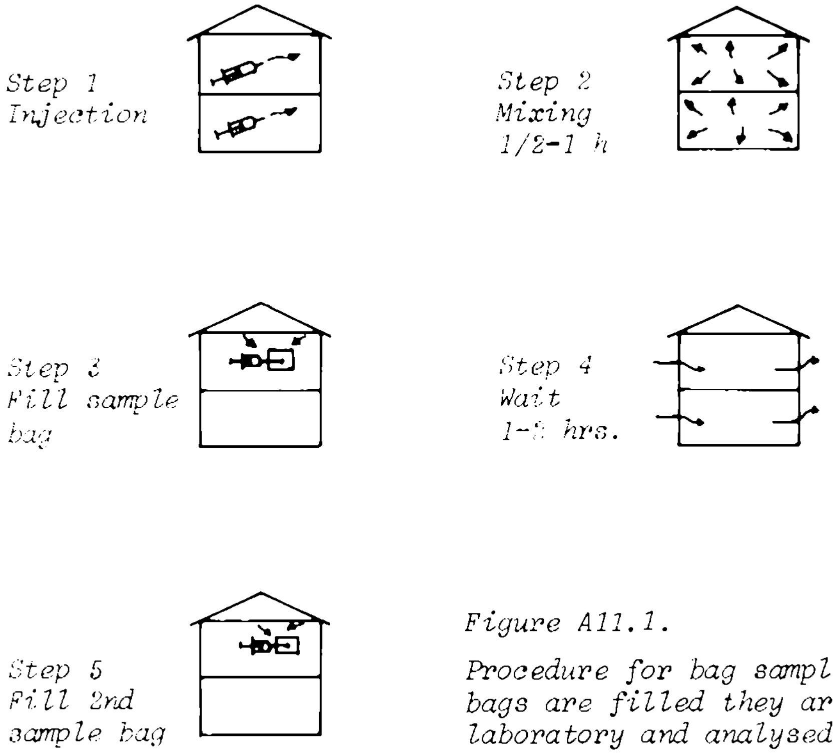

Figure A11.1.

Procedure for bag sampling. When the bags are filled they are shipped to the laboratory and analysed.

MONITORING RADON OR CO_2 TO ESTIMATE AVERAGE AIR EXCHANGE RATES

If the rate of production of an indoor airborne pollutant is known, it may be used as a natural tracer for determining air infiltration. Radon is a possibility for this and CO_2, generated by the occupants, also holds out possibilities (10). Indeed, the proposed new ASHRAE 63/81 ventilation guidelines allows a choice as to when to supply outside air which is based upon staying below prescribed pollutant concentrations. Monitoring is of course necessary for this approach.

Use of methods that would integrate the effect of air exchange rate over time could prove useful in providing an average air exchange rate before and after a retrofit. One simple injection-collection technique has already been described. Remember, however, that for this technique to work the generation rate and extinction of the pollutant must be a constant or, at the very least, follow a well-prescribed pattern. For radon this is not likely as radon emissions from soil vary greatly.

A11.2 Pressurization: Determining the leakiness of the building envelope

Another approach to rating the tightness of a building envelope makes use of pressurizing or depressurizing the building and measuring the air exchange rate under these artificial conditions.

Several countries[x] use this approach (2, 11-17). Efforts to correlate these measurements with tracer gas measurements were discussed in Chapter A7. Used as a *leakage rating method*, the pressurization technique provides a pressure vs flow graph for the building being inspected and achieves this goal in a manner of minutes. This may be done at any time of the year since natural infiltration only plays a minor role under these artificial test conditions. For retrofit performance testing this is an important advantage. The method is not recommended when it is too windy outside and when the outdoor temperature is below $-10^{o}C$. Figure A11.2 illustrates a series of such tests uncovering leakage sites. In addition, the actual sites of infiltration and exfiltration can be quickly determined as well. The use of infrared scanning and/or smoke tracers aids the *leakage site survey*.

A fan or blower is used to pressurize or depressurize the structure. The variations include fans with calibration sections included and

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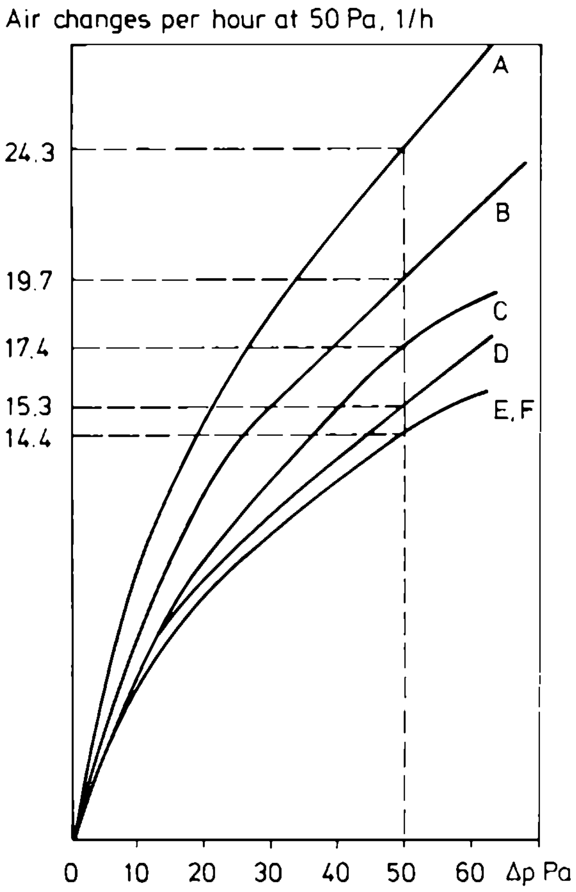
[x] These countries include Canada, Denmark, Netherlands, Norway, Sweden, Switzerland, United Kingdom and the United States.



A = nothing tightened

B = bathroom closet door closed, fireplace covered

C = + taped windows

D = + taped bathroom closet

E = + taped water manifold door

F = + taped ceiling light and exhaust fan in kitchen

Figure A11.2. An example from the United States of air leakage vs pressure difference illustrating steps to reduce infiltration.

others where the calibration is done in the laboratory and fan speeds and pressure differences are translated into air flow rates. One equipment design, the Blower Door, is shown in Figure A11.3. In Figure A11.4 different methods of measuring the air flow is schematically outlined.

Window and attic fans may also be used in leak detection, although they are less effective. Because these fans are not calibrated, one cannot rate the house tightness nor can one be sure the retrofits have not made the house too tight. Many houses, however, are so leaky that this does not represent a problem.

Some of the designs make use of the windows as an access point whereas other designs use the door opening as a means for mounting the "Blower Door". Sweden has made use of pressurization techniques to monitor tightness in new housing. The test procedures in Sweden, Norway and Canada prescribe that all ventilation openings should be

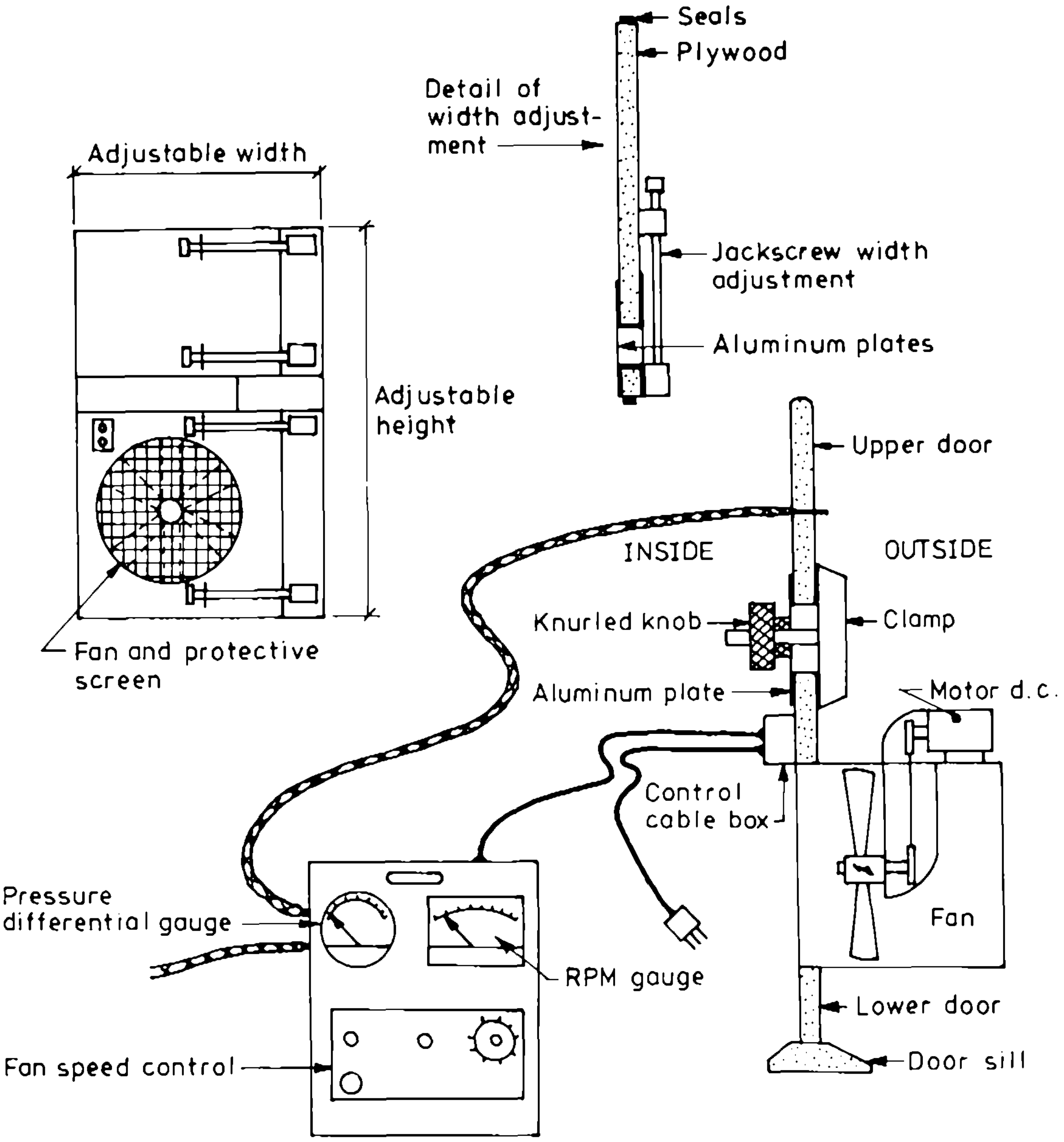
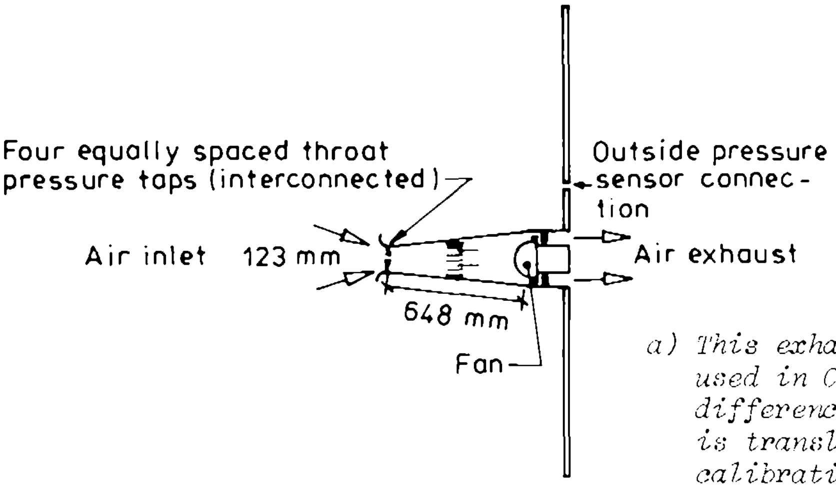


Figure A11.3. Blower Door and control panel.

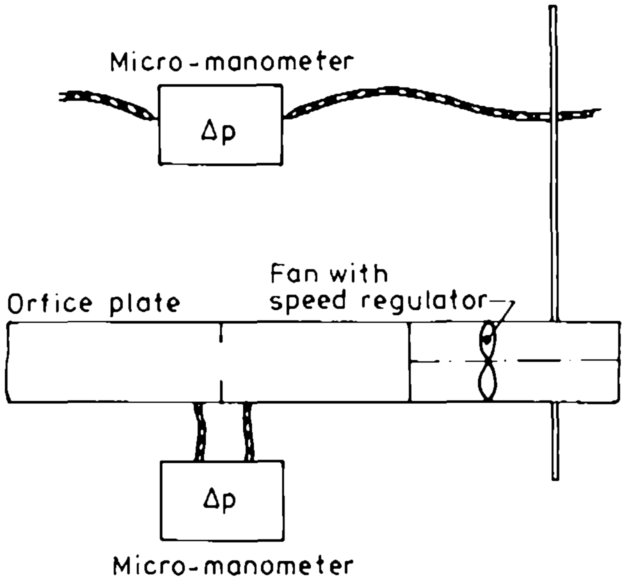
well sealed before the test. This includes sealing the fireplaces over the grate or in the chimney.

In other countries the test is made with such openings not sealed. That means that a comparison between the results from different countries is difficult (see Table A11.2).

An important feature that was previously mentioned, is that this approach can not only point out when a home is too leaky and then monitor the improvements, it can also point out when the house is too tight. Values of tightness approaching the Swedish Standard mean



a) *This exhaust fan apparatus is used in Canada. The pressure difference created in the nozzle is translated to air flow by a calibration curve*



b) *Most equipments used in e.g. Sweden have a long measuring pipe where the pressure difference over an orifice plate or pitot tube is translated to air flow via a calibration curve*

c) *The "Blower Door" uses the speed of the fan to determine air flows. The fan is calibrated in a laboratory*

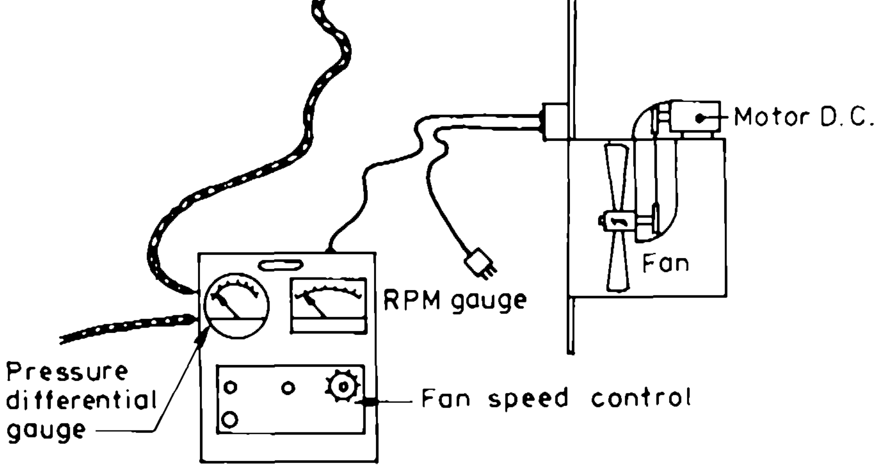


Figure A11.4. Different methods of measuring air flow when pressurizing or depressurizing a building.

Table A11.2. Pressurization tests in different countries.

Country	Standard	Volume	Vents	Reported value
Canada	CGSB 149-GP-10[1]	Incl. basement and inside vapour barrier	Blocked	Equivalent leakage area at 10 Pa or ac/h at 50 Pa depress
Netherlands	In preparation	Heated volume	Both not blocked and blocked	Flow rate at not blocked situation extrapol. to 1 Pa (measurement inverval ~10-100 Pa). Press. and depress
Norway	NS8200	Heated volume (primary part)	Blocked	Average ac/h at 50 Pa press. and depress
Sweden	SS021551	Heated volume	Blocked	Average ac/h at 50 Pa press. and depress
Switzerland		Heated volume	Both not blocked and blocked	ac/h at 50 Pa
United Kingdom		Heated volume	No modification to the dwellings	Average m^3/h or ac/h at 50 Pa press. and depress
United States	ASTM E799-81	Heated volume	Both not blocked and blocked	Effective leakage area at 4 Pa or ac/h at 50 Pa

1 *Draft standard.*

that forced ventilation is necessary to avoid problems of indoor pollution and excessive moisture.

A modified method for pressurization of tall buildings has been developed by Nylund (18). For tall, big buildings it is normally not possible to use a movable fan. Instead the fan equipment for the ventilation system installed in the building is used. Air flow is measured in the duct system close to the fan. During calm wind conditions only the stack effect influences the pressure difference inside — outside. This stack effect is very stable and is easy to determine on different floor levels. The fan creates a change in pressure difference and makes it possible to determine air changes versus pressure differences. For well-designed and airtight buildings it is possible to achieve a pressure difference between 20-40 Pa using this method. In many cases this is enough to calculate the air leakage through the building envelope during operating conditions.

The location of air infiltration sites makes use of the abilities to pressurize and depressurize the house. Using pressurization in the living space and forcing warm air into the attic (heating season example) infrared scanning to detect the leakage sites can be used. Often these locations are associated with plumbing and electrical penetrations of the envelope. However, even interior partitions can leak air to the attic. Depressurizing the house draws cold air through cracks in the envelope, as shown in Figures A11.5a and A11.5b. These heat leakage areas are the result of cold air moving into the walls (Figure A11.5a) or across the ceiling between floors (Figure A11.5b) (10). These are, of course, just two illustrations of heat leaks. Many of the leakage sites listed in Chapter A2 can be easily detected with infrared. A handbook has been produced by Swedish researchers (19) illustrating such leakage problems. Figure A11.6 is taken from that reference.

Where temperature differences are inadequate for proper infrared scanning (less than 5°C), smoke tracers can be substituted to seek out leaks. If the house is pressurized, any leak causes the smoke to stream toward the opening. The smoke tracers work well in evaluating window leak sites, a location where infrared scanning is sometimes difficult because of emissivity variations of the materials involved (aluminium, glass, plastic, etc.).

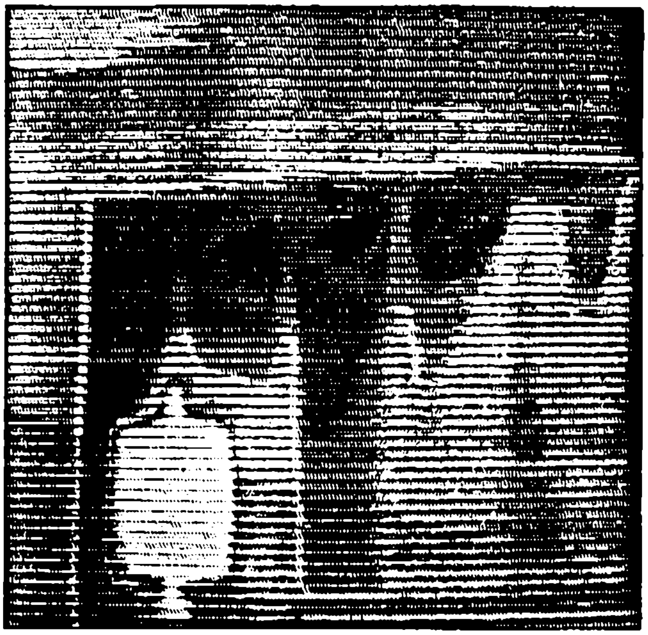


Figure A11.5a. Heat leakage path from attic shown behind interior wall identified by using infrared scanning.

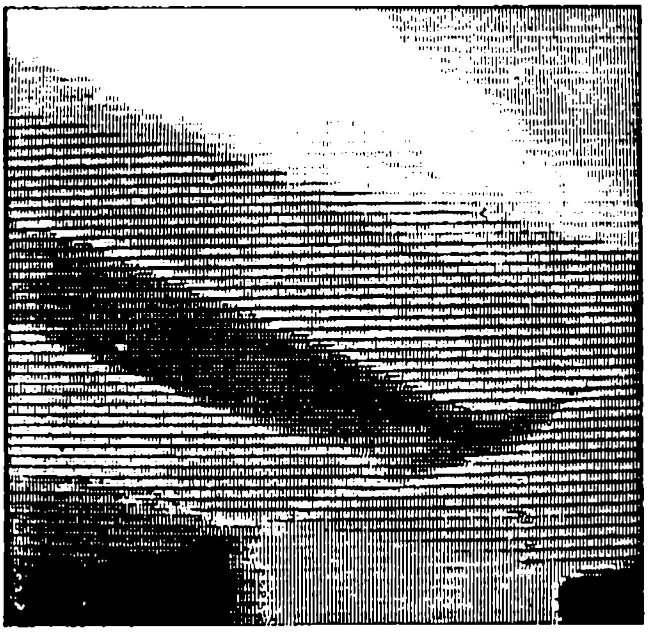
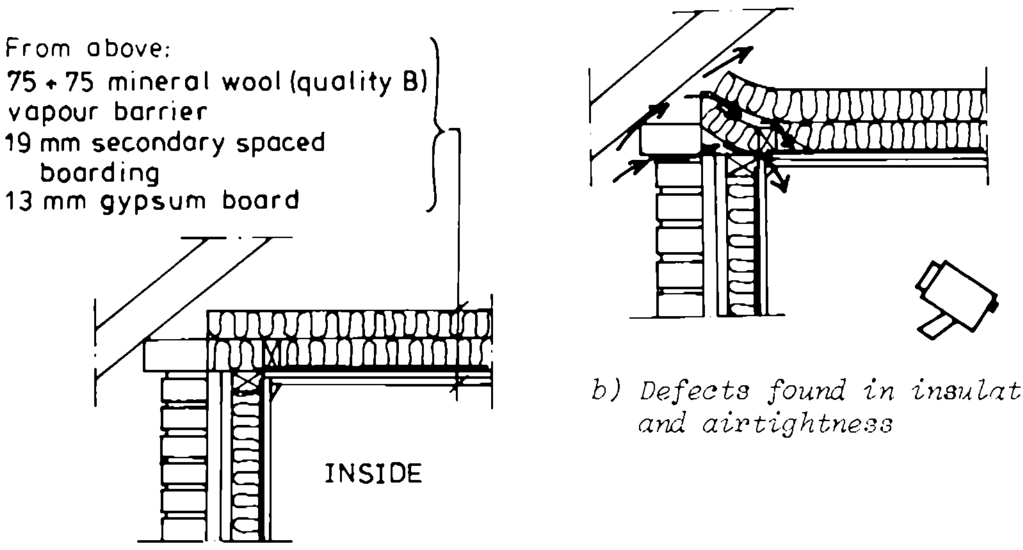


Figure A11.5b. Heat leakage from across ceiling (between 1st and 2nd floor) – also shown is heater duct path.

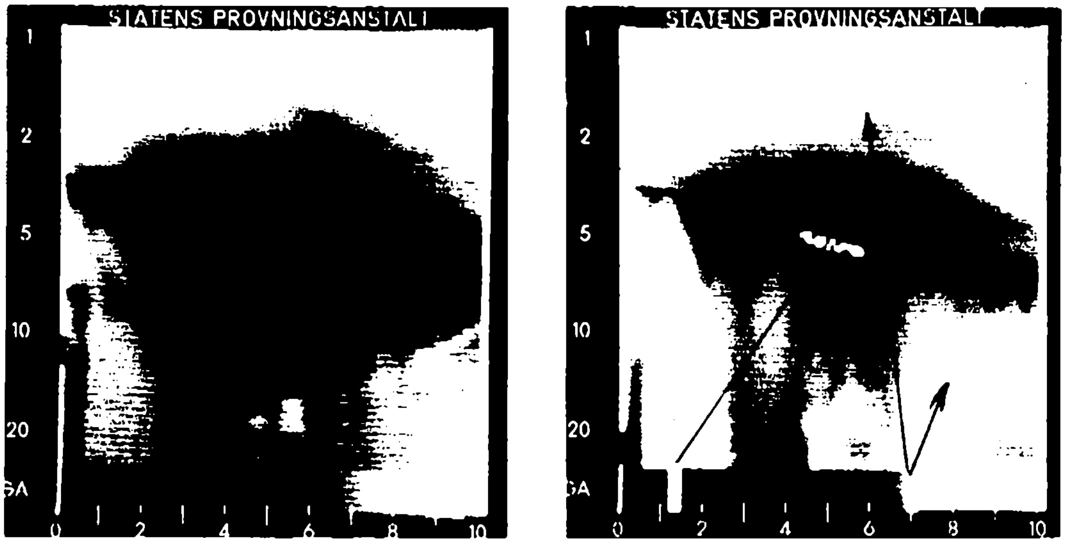


b) Defects found in insulation and airtightness

a) Construction at the eaves from drawing

Conditions during measurement:

cloudiness	*cloudy*
outdoor air temp.	$-7^{o}C$
indoor air temp.	$+21^{o}C$
wind conditions	*about 2 m/s (perpendicularly to facade)*
pressure difference $p_i - p_o$	*-20 Pa*



c) Thermogram of section at wall-ceiling junction. The colder area here has a typical "serrated" contour, which indicates leakage of air

d) air speed, v = 1.0-1.5 m/s (at wall-ceiling junction)

temperature difference at inner surface, Δt = $17^{o}C$

Figure A11.6. Thermogram of a typical construction leak site from Reference (19).

Comparative thermograms – gable roof (floor junction) Insulation and airtightness defect at the eaves due to incorrect fitting of the insulation material and to bad placing of windprotection.

A11.3 Pressurization: Determining the leakiness of building components

Tightness testing of walls, doors, wall elements, etc., can be carried out either in the laboratory or in the field using a guarded pressure box; see Figure A11.7. In this method, an outer and an inner box are placed against the test object. The boxes can be simply constructed using wooden battens and plastic film so that they can easily be adapted to different sized test objects. Supplementary sealing is done with tape, mastic and weatherstripping. The same pressure is produced in the inner and the outer boxes. In this way, leakage is prevented through the inner box's connection to the test object. The outer box could be an entire room when field testing.

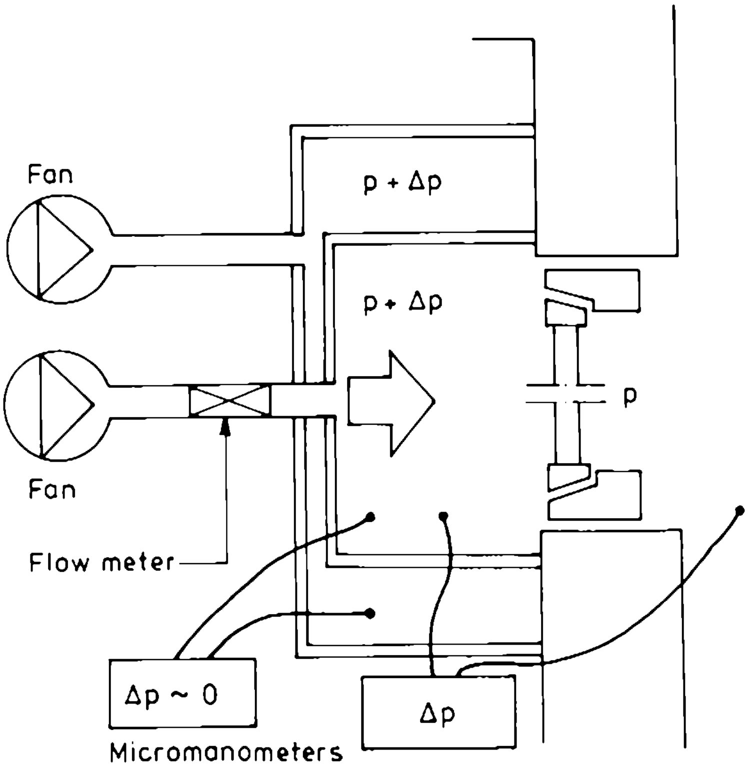


Figure A11.7. *GUARDED PRESSURE BOX design principle. It must be possible to regulate the fans, e.g. by using a thyristor, so that a variable pressure difference can be maintained.*

All air supplied to or extracted from the inner box (gauge and negative pressure respectively) must pass through the test element, i.e. a window, a door, wall element. Leakage curves can be calculated in this way. By successively using tape to seal possible leakage routes, through a window for example, the way in which the leakage occurs can be determined relatively easily. Examples of such curves are shown in Figures A11.8a and A11.8b (20).

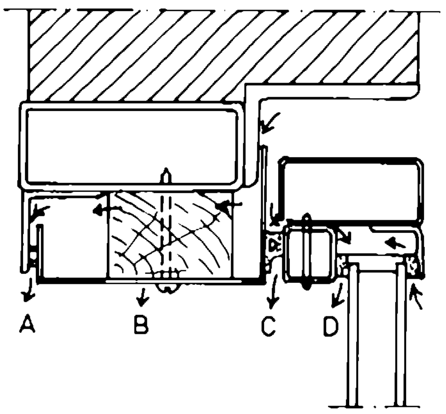


Figure A11.8a.

Detail of test casement/frame. Possible leakage routes are marked.

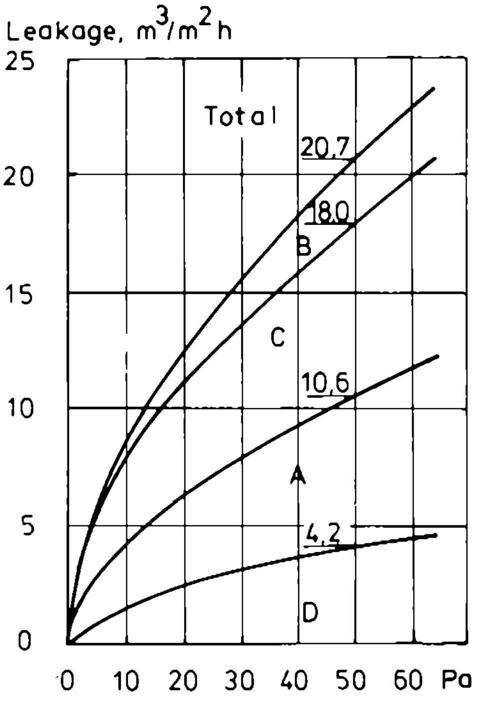


Figure A11.8b.

Examples of leakage curves for a tested window which was successively sealed with tape at various gaps as shown in Figure A11.8a adjacent. Leakage between casement and frame, leakage route C, is 18-10.6 = 7.4 m^3/m^2h.

When testing multi-layer wall elements, leakage routes through the plane of the wall must be carefully considered. This can usually be done through the suitable choice of box sizes.

A technique for measuring approximately the distribution of leakage to the exterior of a building has been developed in the United Kingdom (21). Such measurements use two fans and can provide useful data on the distribution of openings on the structure.

A11.4 References

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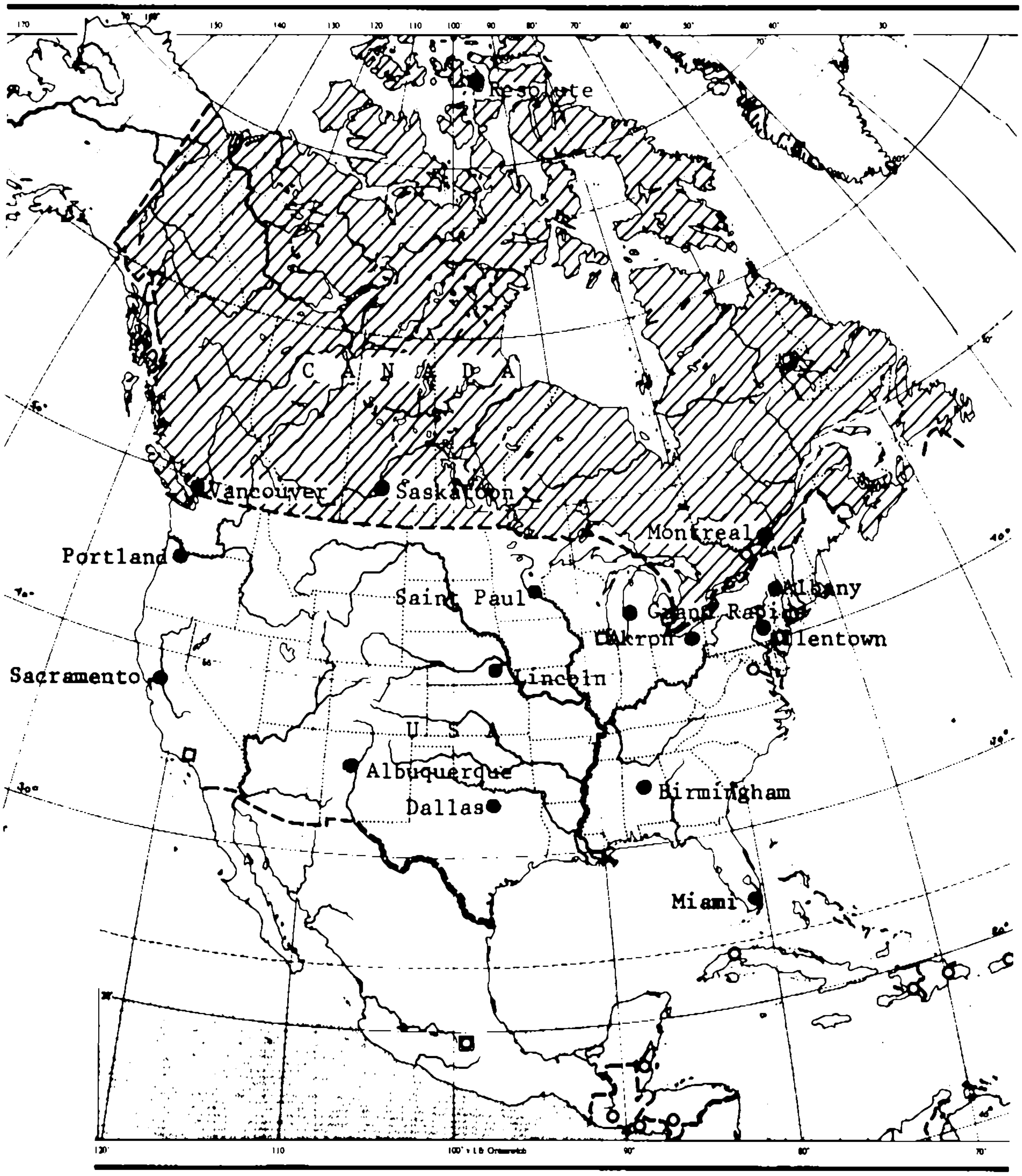
PART B

CANADA

PART BI



BI.1 REGULATIONS AND PRACTICE

The primary document that sets the standard for residential buildings in Canada is "Residential Standards" (1). In this the measures required are given in the section "Measures to Prevent Condensation". Another document, "Measures for Energy Conservation in New Buildings" (2) contains the recommended minimum standards for energy conservation levels in Canada. (Publication of an updated version of the latter document is expected in 1983.) Each province of Canada is responsible for setting its own requirements. These two documents are regarded only as model codes, and are not mandatory requirements unless adopted locally.

BI.1.1 Airtightness of buildings and building components

The standards for allowable infiltration for building components are documented in subsection 3.5 of the "Measures for Energy Conservation in New Buildings". Subsection 3.5 is reproduced in Appendix A.

At present, there is a draft standard for conducting pressure tests of residences prepared by the Canadian General Standards Board: "Determination of Airtightness of Buildings by the Fan Depressurization Method" (3).

In the standard, the equivalent leakage area for the building is calculated using the following formula

$$\text{ELA} = 1.157 \sqrt{\rho}\, C\, 10^{n-0.5}$$

where ELA = equivalent leakage area (m^2)

ρ = density of air (kg/m^3)

$C = \dfrac{Q}{(\Delta P)^n}$ as measured in pressure test $\{m^3/(s\ Pa^n)\}$

n = exponent from pressure test.

Note that there is not a strict proportionality between the ELA values and the ac/h at 50 Pa values. The ELA is calculated for a 10 pascal pressure difference, and the ac/h value is calculated at 50 pascals; in addition the ELA is a measurement of hole size irrespective of the size of the house, while the ac/h value is equal to the air flow divided by the volume of the house.

However, no airtightness standard such as exists in Sweden had been introduced as of 1982. Standards for the airtightness of manufactured components such as windows and doors (ASTM-E283-73) are suggested in Reference (2).

BI.1.2 Minimum ventilation requirements

Residential Standards 1980 has the following model code for the ventilation of residences. The requirements are given in Appendix B.

The majority of Canadian detached residences are ventilated by natural means. Normally the houses are sufficiently leaky for stack effect and wind pressures to provide sufficient air exchange. Typically in new construction an exhaust fan is located in the bathrooms, and usually an exhaust fan is installed in the kitchen. However, these fans are used only intermittently.

In the more airtight houses, natural ventilation often does not provide sufficient air exchange to limit moisture buildup and condensation on windows during the colder month. Consequently a fairly common practice in newer homes is to install a 100 or 125 mm diameter duct to the outside and to connect this outside air duct to the return air duct on the warm air furnace. When the furnace fan is running, the negative pressure caused by the fan draws in fresh air. The air is exhausted by the chimney if the house has a combustion heating system. In a number of very airtight residences, an air-to-air heat exchanger is used to preheat outside air at a low energy cost. Typically, flow rates of the order of 40 l/s have been used for houses with an average occupancy load.

BI.1.3 Heat transfer coefficients

The present minimum amount of insulation recommended by the Federal Government is documented in "Measures for Energy Conservation in New Buildings". As earlier mentioned the standards are not binding unless adopted locally. For houses, low rise apartment buildings, nursing homes, motels and heated warehouses, the required thermal resistance values are those listed in Appendix A. A number of qualifying statements accompany the table; these are also included. The thermal resistance (m^2 $^oC/W$) is the reciprocal of the heat transfer coefficient (W/m^2 ^oC).

As Canada has such vastly different climatic areas (ranging from 3000 to 13000 ^oC-days per year), insulation levels also vary and are necessarily greater in the colder regions. For ceiling insulation, the recommended maximum heat transfer coefficients (W/m^2 ^oC) vary in the range of 0.21 to 0.14 for combustible construction. In certain parts of the country, however, a number of low energy houses have ceiling insulation levels with heat transfer coefficients as low as 0.07 W/m^2 ^oC, and wall insulation levels with heat transfer coefficients as low as 0.09 W/m^2 ^oC. These levels of insulation are, of course, much greater than present Code requirements.

BI.2 CLIMATIC DATA

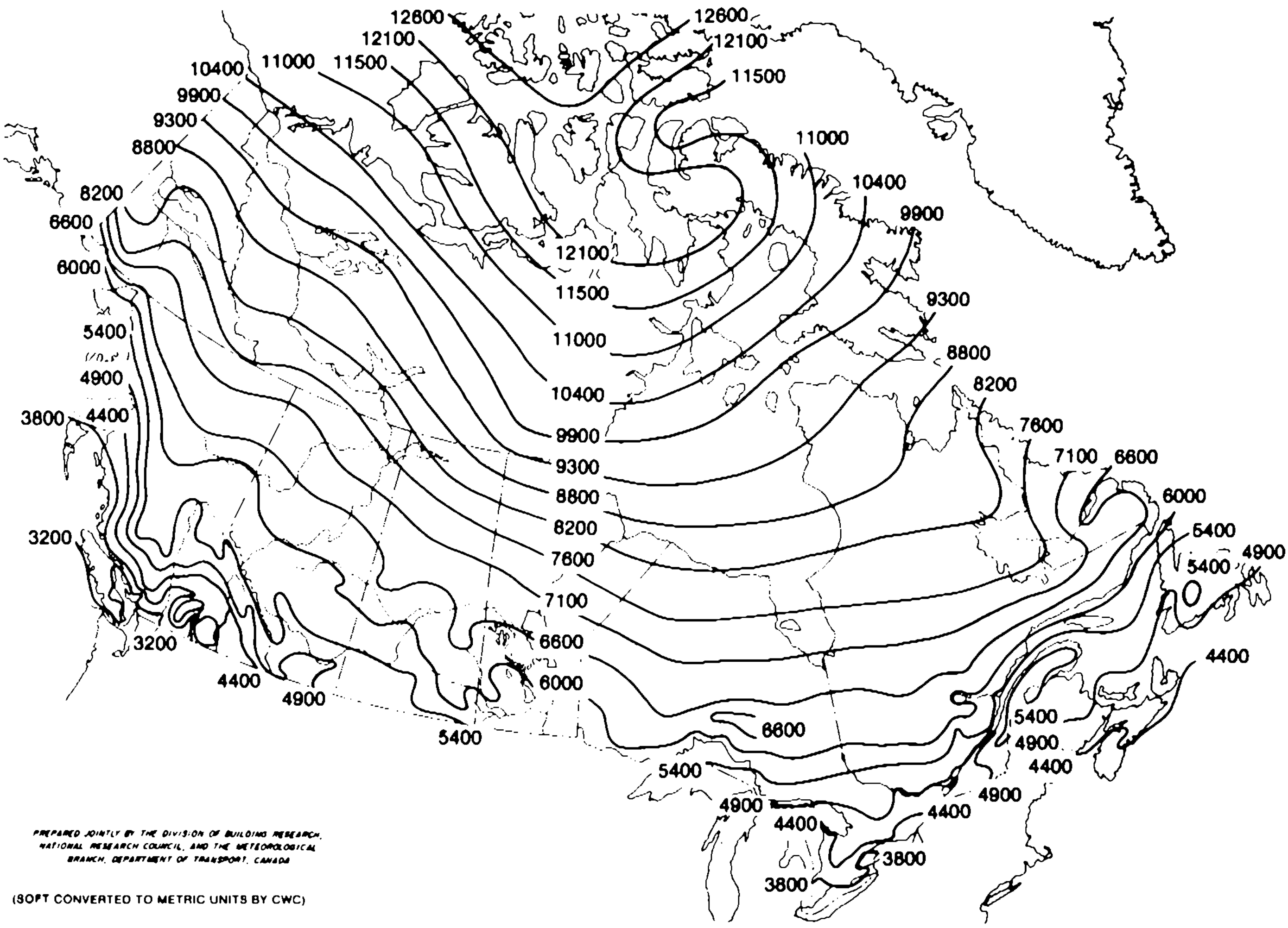
BI.2.1 Degree days

The calculation method for degree days was presented in Section A6. The temperature of 18^oC is used as the reference temperature.

The annual total degree days for all locations in Canada are shown in Figure BI.1.

Within Canada, the degree days per year vary from a low of about 3000 in the Victoria, B.C. area to a high of about 13000 in the Northern Arctic Islands. Over 95 per cent of the population resides in areas with fewer than 6000 degree days per year.

In much of Canada's housing stock, the space heating energy consumption of a given house is generally proportional to the number of degree days accumulated. Hence the popularity of the degree-day concept. In low energy housing, however, the linear relation has been found not to hold over the full range of degree days, as internal heat gain and passive solar gain have dramatically reduced the temperature at which the space heating system must be used.



PREPARED JOINTLY BY THE DIVISION OF BUILDING RESEARCH, NATIONAL RESEARCH COUNCIL, AND THE METEOROLOGICAL BRANCH, DEPARTMENT OF TRANSPORT, CANADA

(SOFT CONVERTED TO METRIC UNITS BY CWC)

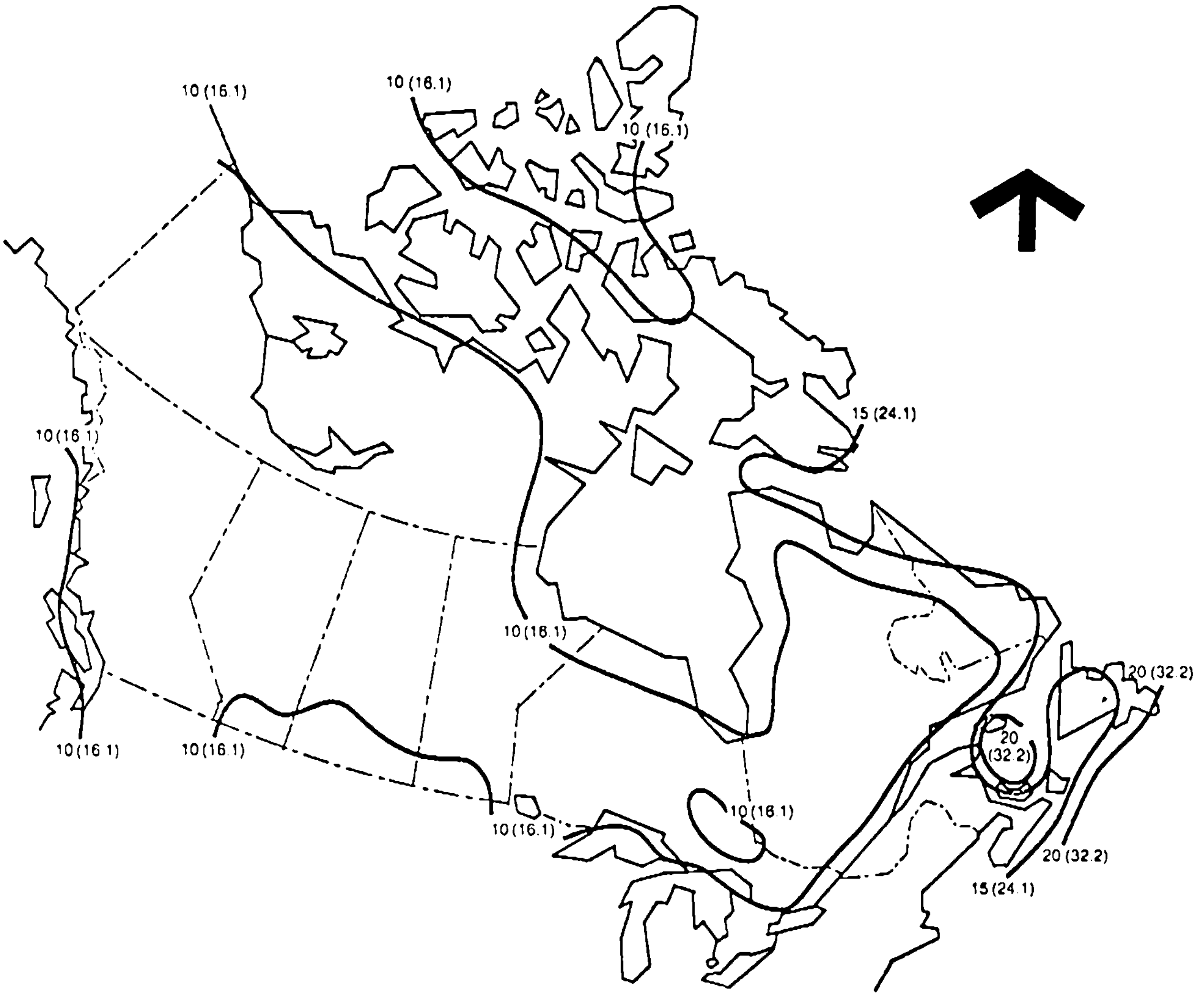
Figure BI.1. Annual total degree days (below $18^{o}C$).

BI.2.2 Temperature and windspeed zones

For the purposes of the document "Measures for Energy Conservation in New Buildings 1978", the country is divided into five temperature zones:

1) up to 3500 Celsius degree days
2) 3501 to 5000 Celsius degree days
3) 5001 to 6500 Celsius degree days
4) 6501 to 8000 Celsius degree days
5) more than 8000 Celsius degree days.

A map of the mean winter wind speeds in Canada is provided in Figure BI.2.



Source: *Climatological Atlas of Canada* (Ottawa: National Research Council of Canada and Department of Transport, 1953).

Figure BI.2. Mean winter wind speeds in Canada — in miles/hour (with km/h in parentheses).

Daily mean and extreme temperatures, wet bulb temperatures and windspeeds for four different locations in Canada are shown in Figure BI.3.

SASKATOON, Saskatchewan
lat. 52°10'N long. 106°41'W
elevation 501 m

MONTREAL, Quebec
lat. 45°28'N long 73°45'W
elevation 30 m

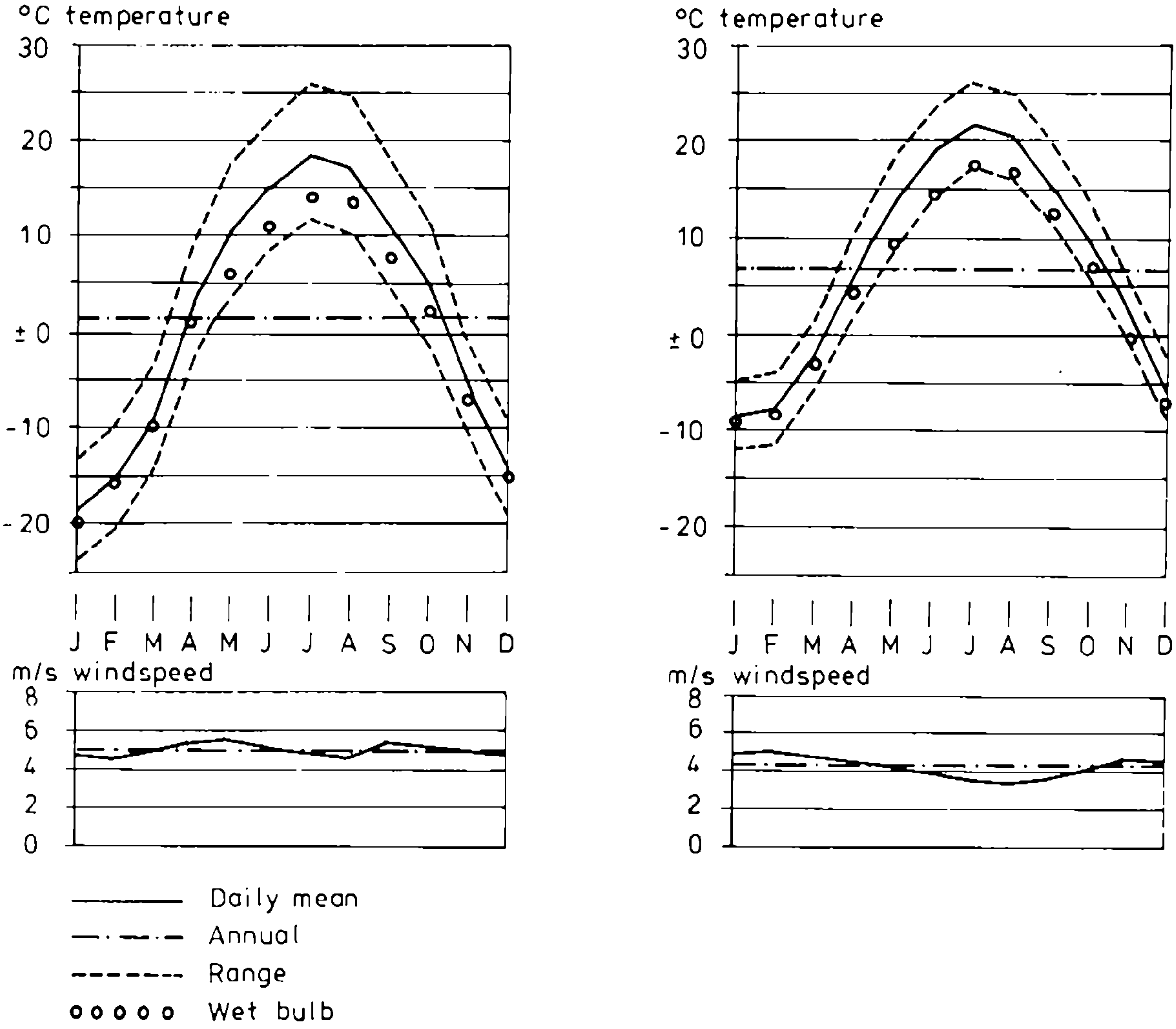
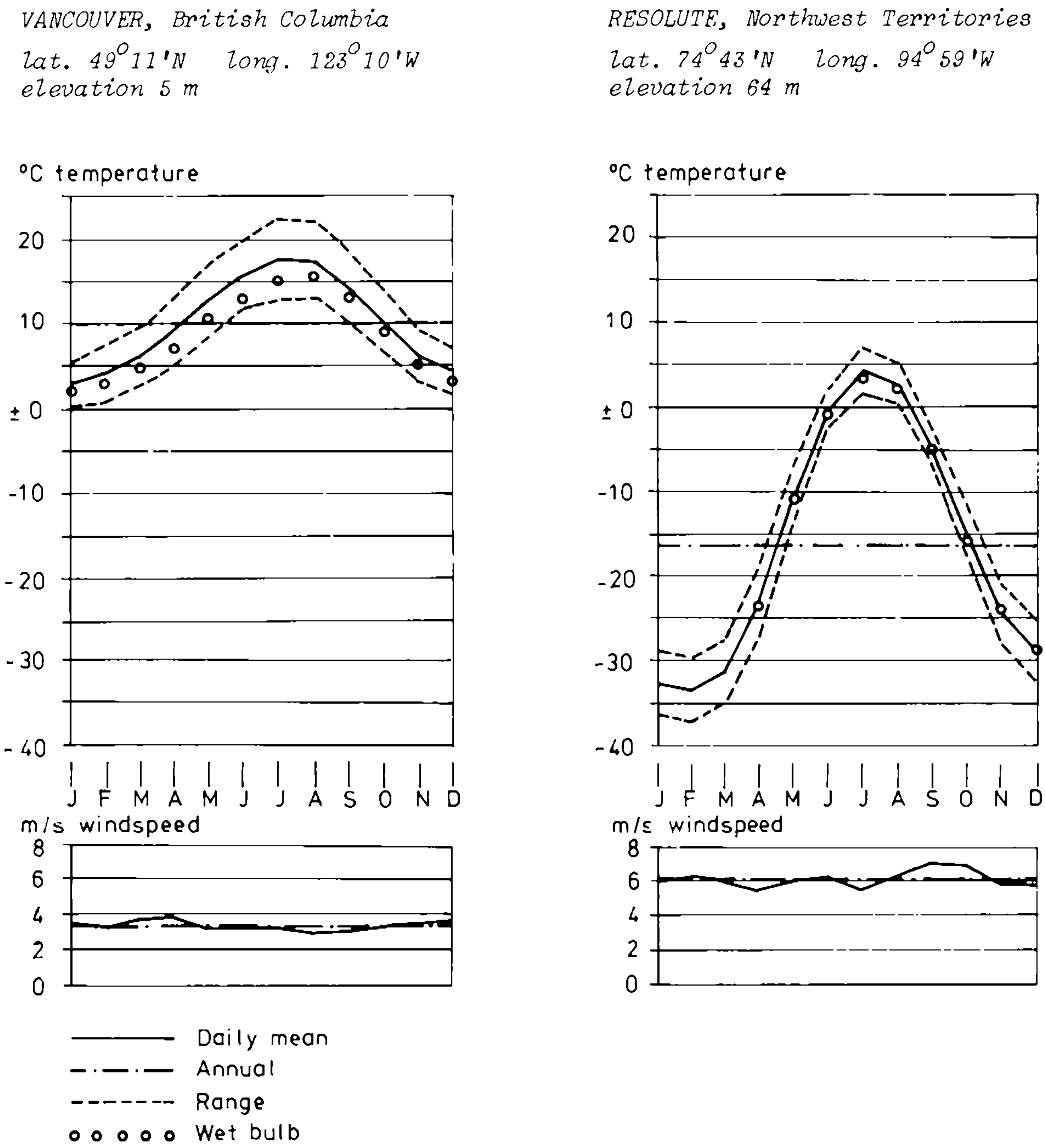


Figure BI.3a.



VANCOUVER, British Columbia
lat. 49°11'N long. 123°10'W
elevation 5 m

RESOLUTE, Northwest Territories
lat. 74°43'N long. 94°59'W
elevation 64 m

Figure BI.3b.

Figure BI.3. Climatic data on four different locations in Canada. For background information to the plots see Chapter A6.

BI.3 DWELLING CONSTRUCTION

BI.3.1 Conventional construction

Most residential construction in Canada is wood-frame construction, with the vapour barrier provided by the installation of a polyethylene sheet on the warm side of the insulation. If properly installed, this sheet also serves as an air leakage barrier. Hence the polyethylene is sometimes called an air-vapour barrier.

In conventional Canadian wood-frame construction as of 1980, the standard vapour barrier used was 50 µm (2 milli-inch) polyethylene. In a conventional installation, an attempt is made to provide continuity of the vapour barrier, but there are numerous locations in the house where it is difficult to achieve this.

In Figures BI.4-BI.8 some details of a standard vapour barrier installation are shown.

As shown in Figure BI.4, there are a number of weak spots for airtightness using the approach illustrated. Continuity of the air-vapour barrier is not maintained. Later in this section, alternative approaches will be demonstrated which allow greater airtightness to be achieved.

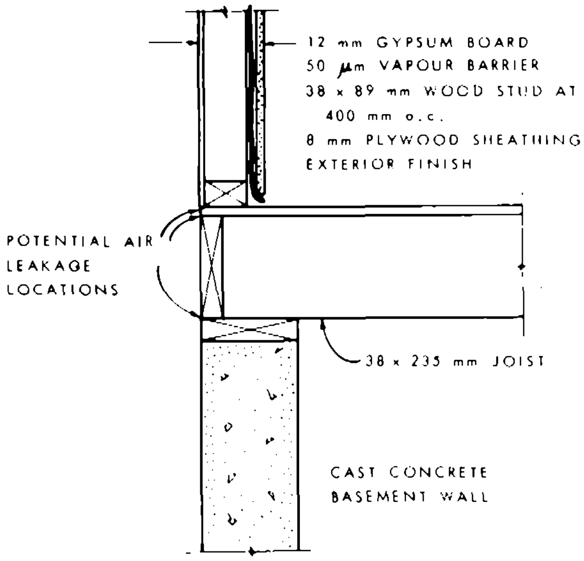


Figure BI.4.

Conventional vapour barrier installation – floor level.

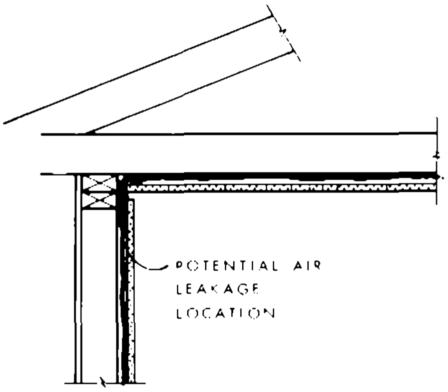


Figure BI.5

Conventional vapour barrier installation. Ceiling level – exterior wall.

In Figure BI.5, the technique used at a joint between the wall and ceiling vapour barrier is shown. Generally, in conventional construction, no caulking or taping is used to join the polyethylene sheets together, The sheets are lapped only.

Figure BI.6 shows the technique used at the location where an interior partition meets the ceiling vapour barrier. Although a strip of vapour barrier is placed between the two top plates, no attempt is made to caulk or tape this to the ceiling vapour barrier sheet.

Figure BI.7 shows the technique used at a location where the floor joists are cantilevered. Again, there is a gap in the continuity of the vapour barrier.

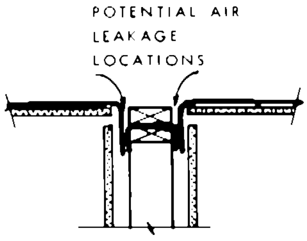


Figure BI.6.

Conventional vapour barrier installation ceiling level – interior partition.

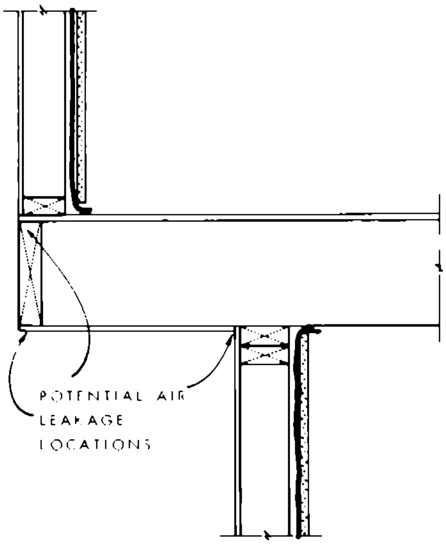


Figure BI.7.

Conventional vapour barrier installation – cantilevered floor section.

Figure BI.8 presents the technique commonly used for the vapour barrier at the windows and doors.

Other penetrations of the vapour barrier, such as plumbing pipes, electrical conduits, telephone wires, ducts, and chimneys are generally not caulked or sealed in conventional construction, and thus are potential sites for air leakage.

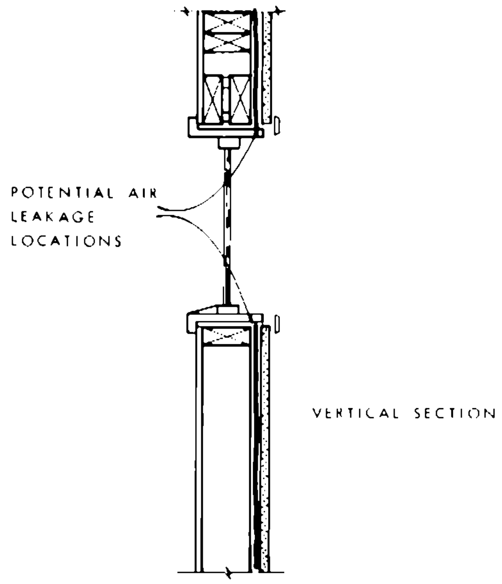


Figure BI.8.

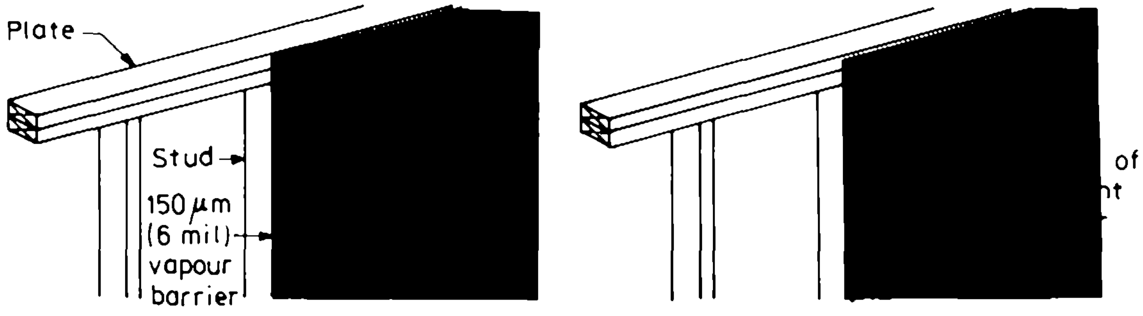
Conventional vapour barrier installation — window location.

BI.3.2 Airtight construction

A number of publications have been written in Canada which discuss techniques for reducing air leakage in residences. The most comprehensive publication written to date on the subject of improved techniques is "Air-Vapour Barriers" (4). In addition, the booklets "Low Energy Passive Solar Housing" (5) and "Energy Efficient Housing — A Prairie Approach" (6) also contain substantial amounts of information on achieving airtight residential construction.

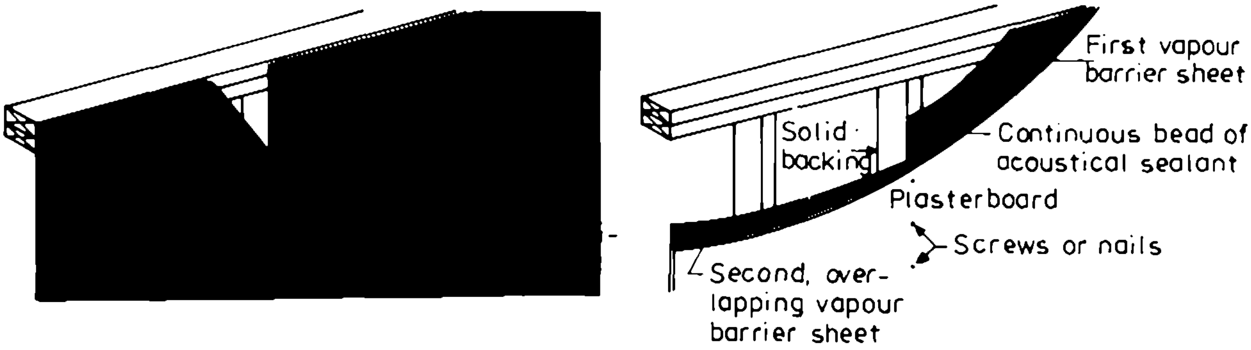
The recommended vapour barrier is a 150 μm (6 milli-inch) thick polyethylene sheet. Figure BI.9 {from Ref. (6)} shows a technique for joining the sheets. The material used to join the sheets is a moderately priced non-hardening caulking compound, "acoustical sealant". In the approach outlined in Figure BI.10-BI.20, an attempt is made to make a continuous seal of the house {Figures BI.10, BI.12 and BI.14-BI.20 are from Ref. (6)}.

Figure BI.10 presents the technique used at the joint between floors. Note the offset of the floor joist system and the continuous vapour barrier around the header joist. To prevent condensation on the vapour barrier, exterior insulation is used at this location. Also shown in Figure BI.10 is the sealing technique at the joint between the wall and ceiling vapour barrier sheets. As already mentioned, an acoustical sealant compound is used.



a) *Staple 150 micrometre (6 mil) vapour barrier to studs and plates*

b) *Place a bead of acoustical sealant over top of vapour barrier, ensuring that the sealant is continuous and in line with the stud*



c) *Overlap second vapour barrier sheet (always join the vapour barrier over a solid backing such as a stud)*

d) *Cover vapour barrier with rigid material (plasterboard, wallboard, etc.)*

Figure BI.9. Improved technique for joining vapour barrier sheets on wall studs (insulation not shown).

In Figure BI.11, the sealing technique recommended at the joint between an interior partition and the ceiling is shown. Note that the ceiling vapour barrier has been installed in a continuous sheet and that the interior partition does not interrupt the sheet. This method requires that the conventional construction sequence be altered. A less desirable technique for achieving air tightness is shown in Figure BI.12. This method requires a large amount of caulking at the ceiling level.

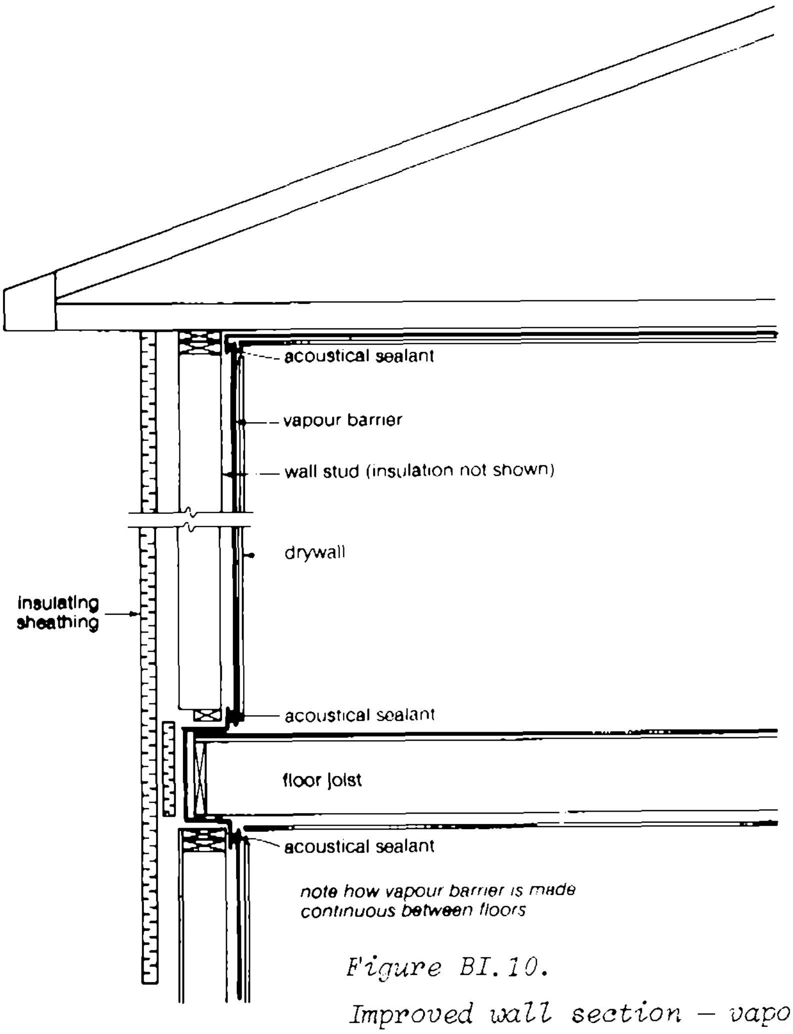
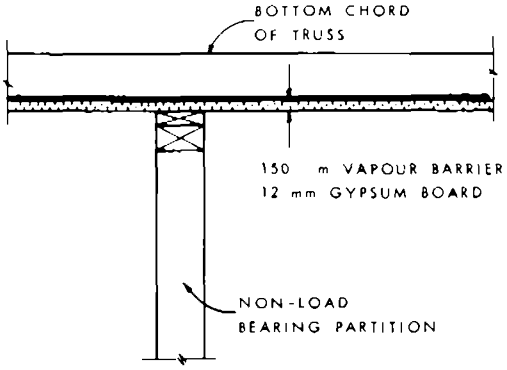


Figure BI.10.

Improved wall section – vapour barrier detail.



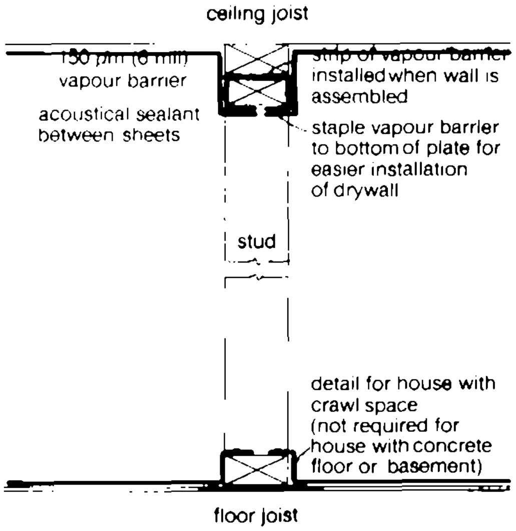


Figure BI.11.

Improved technique for vapour barrier installation at a non-load-bearing partition.

Figure BI.12.

Improved vapour barrier installation for partition wall.

Figure BI.13 shows a recommended technique for cantilevered floor systems.

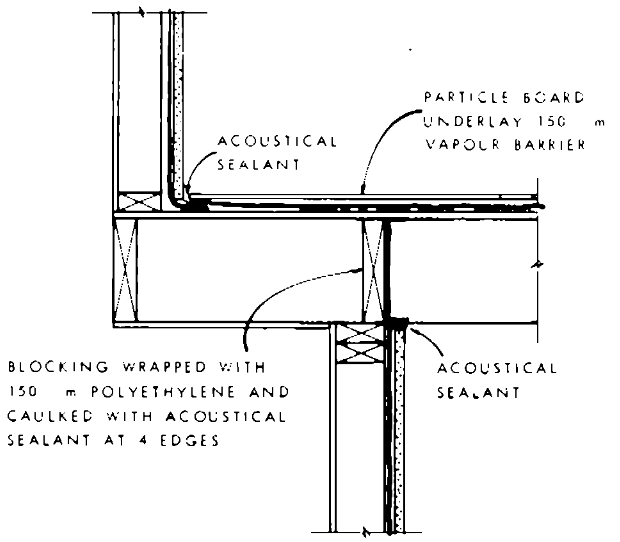


Figure BI.13.

Improved technique for vapour barrier installation for a cantilevered floor.

In Figure BI.14, a technique for achieving airtightness at the windows and doors is shown. Figure BI.15 shows a technique for electrical boxes.

Figure BI.16 shows a technique for achieving airtightness around a plumbing vent stack.

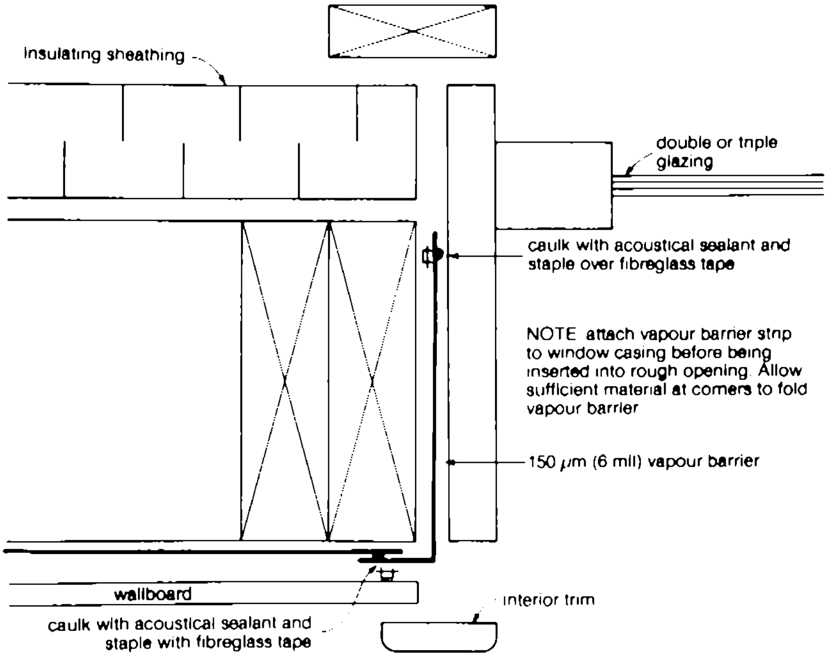


Figure BI.14. Improved vapour barrier installation at window.

A unique double stud wall system has been developed which eases the installation of a vapour barrier. Figure BI.17 shows the wall assembly. Note that the vapour barrier is positioned in the outside of the inner stud wall. With this design the electrical wiring can be run on the inside of the vapour barrier.

Figures BI.18 and BI.19 present two wall sections illustrating the use of the double stud design.

In Figure BI.20, a wall section incorporating a single stud design is shown.

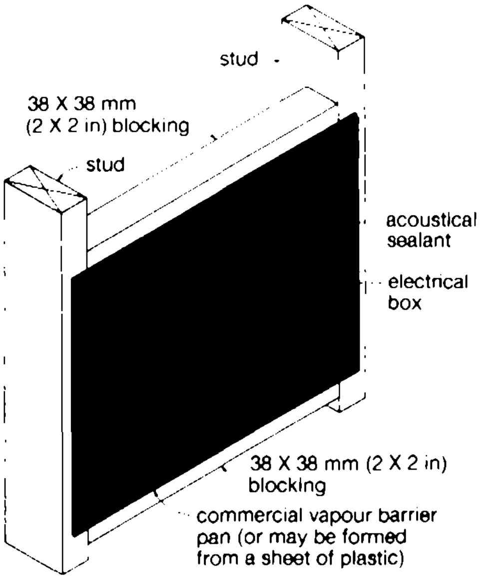


Figure BI.15.

Improved vapour barrier installation around electrical box.

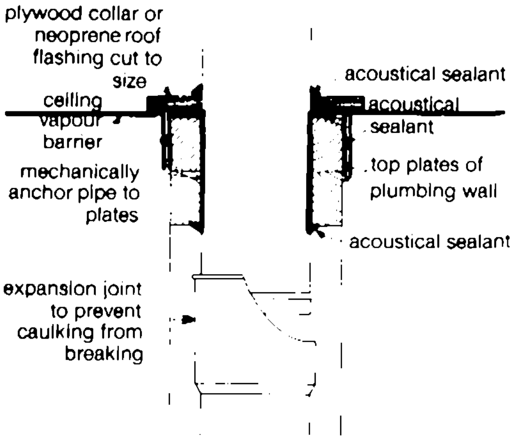


Figure BI.16.

Improved vapour barrier installation around plumbing vent stack.

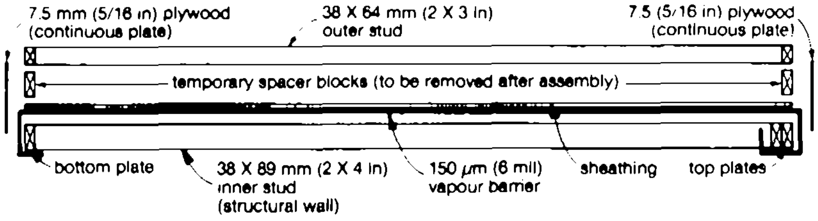
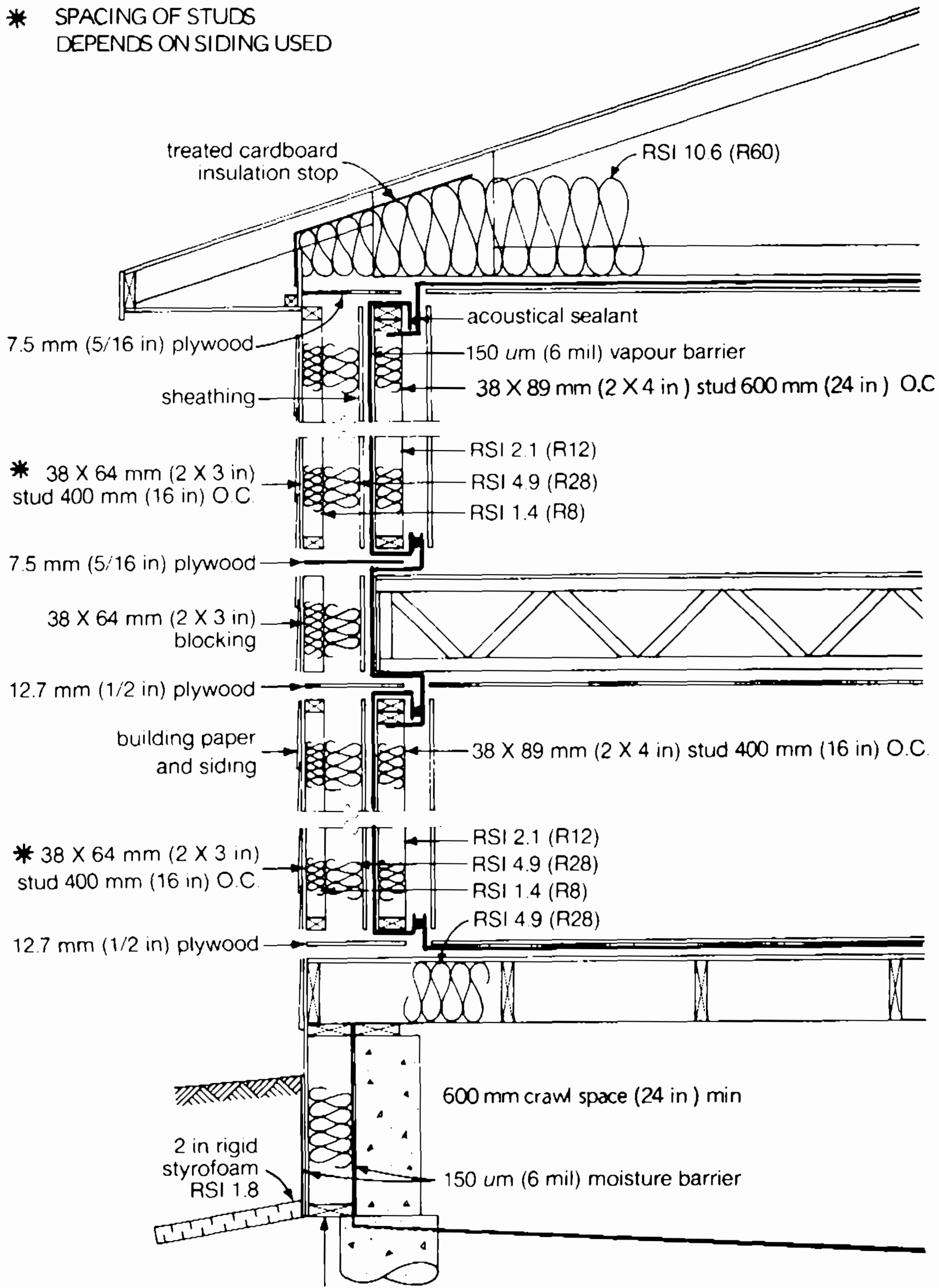


Figure BI.17. Double stud wall assembly.



NOTE: All wood within 225 mm of the earth should be pressure treated

Figure BI.18. Wall section of double stud design – grade beam and piling foundation.

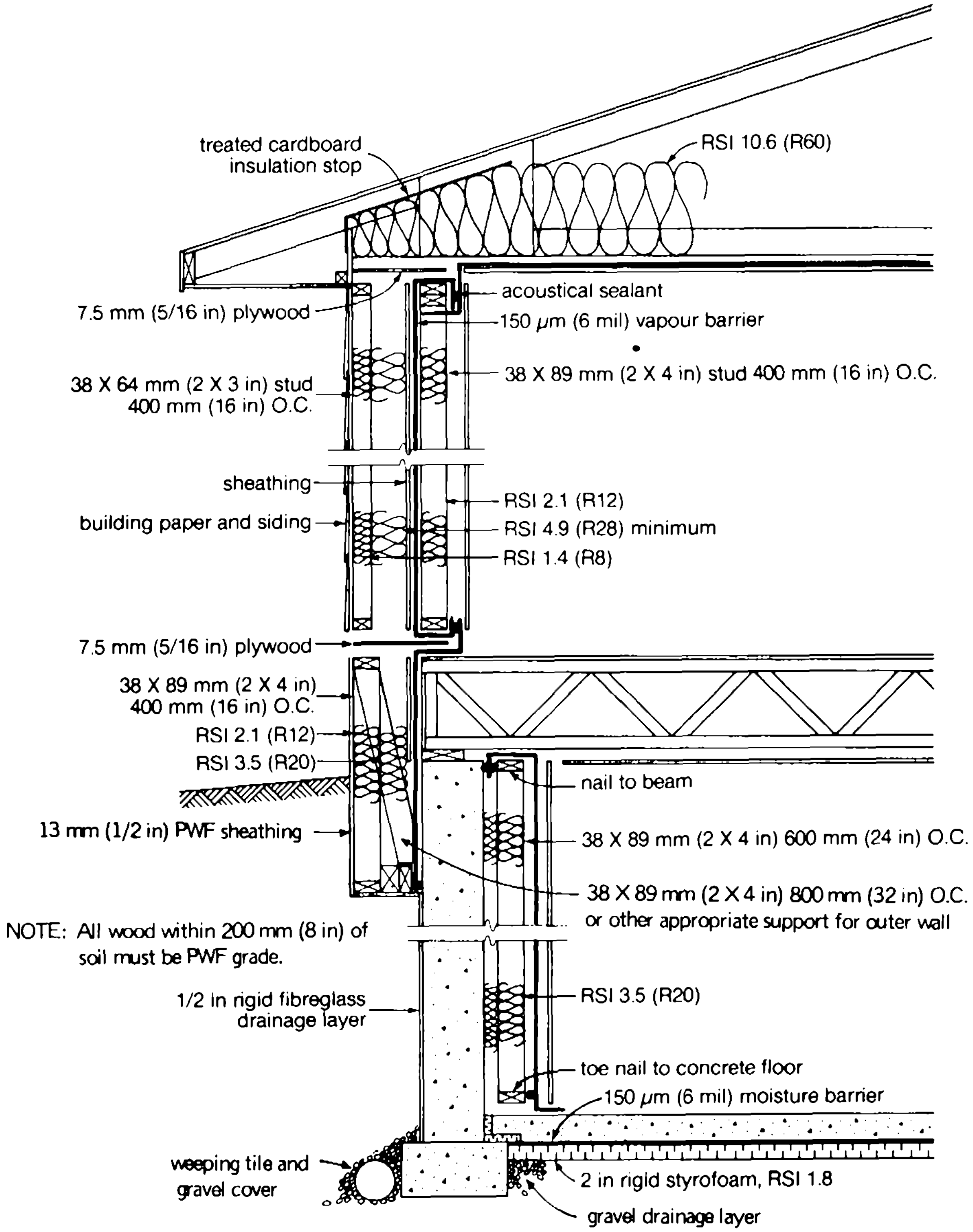


Figure BI.19. Wall section of double stud design – concrete basement wall and footing foundation.

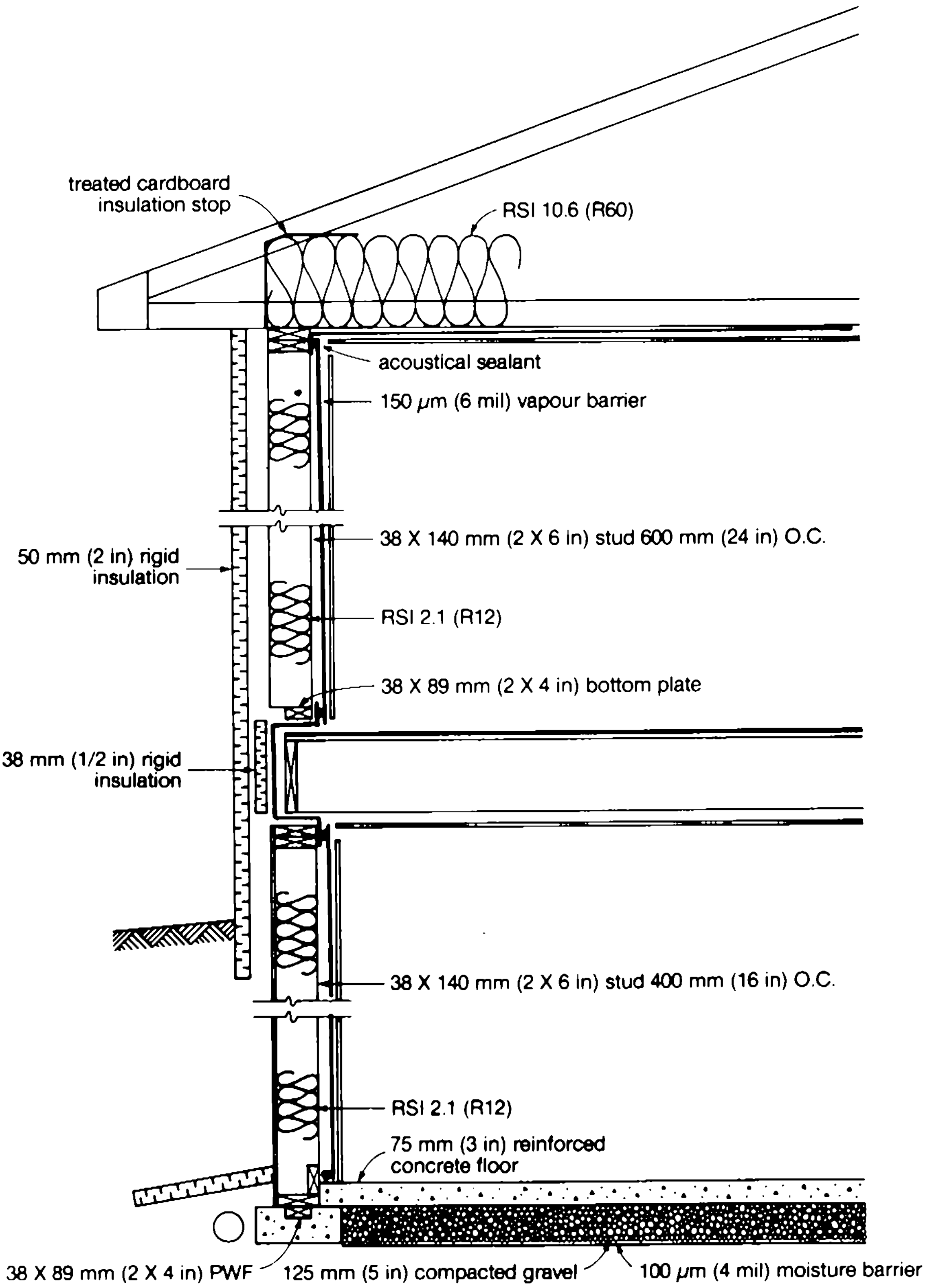


Figure BI.20. Wall section – single stud wall.

BI.4 REFERENCES

(1) Residential Standards, Canada. (Associate Committee on the National Building Code, National Research Council of Canada.) Ottawa 1980.

(2) Measures for Energy Conservation in New Buildings — 1978. (Associate Committee on the National Building Code, National Research Council of Canada.) NRCC No. 16574. Ottawa 1978.

(3) Determination of Airtightness of Buildings by the Fan Depressurization Method. (Canadian General Standards Board Draft Standard.) 149-GP-10, CGSB. Ottawa 1981.

(4) Eyre, D. & Jennings, D., Air-Vapour Barriers. (Saskatchewan Research Council.) Publication E-825-2-E.-81. Saskatoon, Saskatchewan, Canada 1981.

(5) Low Energy Passive Solar Housing. (Department of Mechanical Engineering, University of Saskatchewan.) Saskatoon, Saskatchewan, Canada 1979.

(6) Energy Efficient Housing — A Prairie Approach. (Office of Energy Conservation, Saskatchewan. Mineral Resources and Energy Conservation Branch, Alberta Energy and Natural Resources.) Canada Oct. 1980.

EXTRACT DEALING WITH THERMAL RESISTANCE FROM "MEASURES FOR ENERGY CONSERVATION IN NEW BUILDINGS 1978"

SECTION 3 ENCLOSURES FOR BUILDINGS WITH LOW ENERGY REQUIREMENTS FOR LIGHTING, FANS AND PUMPS

SUBSECTION 3.1 SCOPE

3.1.1. Except as provided in Article 3.1.2., this Section shall apply to *buildings* of all *occupancy* classifications.

(Normally, houses, low rise apartment *buildings*, nursing homes, motels and heated warehouses fall within the requirements of this Section.)

3.1.2. Where the *owner* can demonstrate that the total load of all wired-in interior lighting, plus the total rated power of all fans and water pumps, excluding standby equipment, exceeds an average of 25 W/m^2 of *floor surface area* in those parts of the *building* that are heated or cooled, the requirements in Section 4 may be used in lieu of the requirements in this Section.

SUBSECTION 3.2 THERMAL RESISTANCE OF ASSEMBLIES

3.2.1. Except as provided in Articles 3.2.2. to 3.2.7., and except for doors, windows, skylights and other *closures* the thermal resistance of each *building* assembly through any portion that does not include framing or furring shall conform to Table 3.2.A.

3.2.2. Except as provided in Article 3.2.3., the thermal resistance of the insulated portion of a *building* assembly incorporating metal framing elements, such as steel studs and steel joists, that act as thermal bridges to facilitate heat flow through the assembly, shall be 20 per cent greater than the values shown in Table 3.2.A. unless it can be shown that the heat flow is not greater than the heat flow through a wood frame assembly of the same thickness.

3.2.3. Article 3.2.2. for *building* assemblies incorporating thermal bridges does not apply where the thermal bridges are insulated to restrict heat flow through the thermal bridges by a material providing

Table 3.2.A. Forming part of Article 3.2.1.

MINIMUM THERMAL RESISTANCE (R VALUE), $m^2 \cdot {}^oC/W$

Building Assembly	Maximum Number of Celsius Degree Days(1) up to 3 500	5 000	6 500	8 000 and over
Wall assemblies above ground level (other than foundation walls) separating heated space from unheated space or the outside air	2.5	3.0	3.4	3.7
Foundation wall assemblies separating heated space from unheated space, outside air or adjacent earth (2)	1.6	1.6	1.6	1.6
Roof or ceiling assemblies separating heated space from unheated space or the exterior				
(a) if *combustible construction* is permitted	4.7	5.6	6.4	7.1
(b) if *noncombustible construction* is required	2.5	3.0	3.4	3.7
Floor assemblies separating heated space from unheated space or the exterior				
(a) if *combustible construction* is permitted	4.7	4.7	4.7	4.7
(b) if *noncombustible construction* is required	2.5	3.0	3.4	3.7
Perimeters of slab-on-ground floors that are less than 600 mm below adjacent ground level (insulation only)				
(a) slabs where heating ducts, pipes or resistance wiring are embedded in or beneath the slabs	1.3	1.7	2.1	2.5
(b) slabs other than those described in (a)	0.8	1.3	1.7	2.1

Notes to Table 3.2.A.:

(1) Where the number of degree days for a particular area is different from those listed, interpolation between values shown in the table may be made to obtain the minimum required thermal resistance values for that area. (Methods of calculation degree days are shown in Chapter A6.)

(2) Every foundation wall face having more than 50 per cent of its area exposed to outside air and those parts of foundation walls of wood-frame construction above exterior ground level shall have a thermal resistance conforming to the requirements for wall assemblies above ground level.

a thermal resistance at least equal to 25 per cent of the thermal resistance required for the insulated portion of the assembly in Article 3.2.1.

3.2.4. The thermal resistance of a *building* assembly may be reduced by not more than 20 per cent from that required in Articles 3.2.1. and 3.2.2., and the amount of glazing may be increased to more than that permitted in Article 3.3.4., where it can be shown that the total calculated heat loss from the *building* enclosure does not exceed the heat loss that would result if the enclosure were constructed in conformance with the minimum thermal resistance requirements in Articles 3.2.1. and 3.2.2. and with the maximum amount of glazing permitted in Article 3.3.4., provided no allowance is made for solar heat gains or for the orientation of the glazing as described in Article 3.3.6.

3.2.5. Where the indoor winter design temperature is less than 18°C, the minimum thermal resistance R_1 shall be determined in conformance with the formula

$$R_1 = \frac{t_i - t_o}{18 - t_o} \cdot R$$

where t_i is the indoor winter design temperature (°C),

t_o is the outdoor design temperature based on the $2\frac{1}{2}$ per cent value for January (°C), and

R is the thermal resistance required in Article 3.2.1. or 3.2.2. ($m^2 \cdot {}^\circ C/W$).

3.2.6. The thermal resistance values in Article 3.2.1. and 3.2.2. for roof or ceiling assemblies separating heated space from unheated space or the exterior may be reduced near the eaves to the extent made necessary by the roof slope and required ventilation clearances, except that the thermal resistance at the location directly above the inner surface of the exterior wall shall be at least 2.1 $m^2 \cdot {}^\circ C/W$.

3.2.7. The thermal resistance values required in Article 3.2.1. may be reduced to take into account the effect of thermal inertia resulting from the mass of the *building* in conformance with Building Research Note No. 126, published by the Division of Building Research, National Research Council of Canada, January 1978.

3.2.8. Insulation applied to the exterior of a foundation wall or slab-on-ground floor shall extend down at least 600 mm below the adjacent exterior ground level or shall extend down and outward from the floor or wall for a total distance of at least 600 mm measured from the adjacent finished ground level.

3.2.9. Insulation applied to the interior of a foundation wall shall extend from the underside of the flooring above such walls, down to at least 600 mm below the exterior adjacent ground level, except as required in Article 9.26.5.6. of the NBC 1977.

SUBSECTION 3.3 GLAZING

3.3.1. Except as provided in Articles 3.3.2., 3.3.3. and 3.3.5., all glazing that separates heated space from unheated space or the exterior shall have a thermal resistance of at least 0.30 $m^2 \cdot {}^oC/W$. (Double glazing with at least a 6 mm air space, or single glazing wigh a storm sash is considered to provide the required thermal resistance.)

3.3.2. Except as provided in Articles 3.3.3. and 3.3.5., where a *building* is located in a climate area where the number of Celsius degree days exceeds 6 500, all windows and skylights shall have a thermal resistance of at least 0.45 $m^2 \cdot {}^oC/W$. (Triple glazing with at least 6 mm air spaces, or double glazing with at least 6 mm air space and with a storm sash is considered to provide the required thermal resistance.)

3.3.3. Where an enclosed unheated space, such as a sun porch, enclosed verandah or vestibule, is separated from a heated space by glazing, the unheated enclosure may be considered to provide a thermal resistance of 0.16 $m^2 \cdot {}^oC/W$, or the equivalent of one layer of glazing.

3.3.4. Except as provided in Articles 3.3.5. and 3.3.6., the total area of glazing, including glazing for doors and skylights, that separates heated space from unheated space or the exterior shall not exceed 15 per cent of the *floor surface area* of the *storey* served by the glazed areas and shall not exceed 40 per cent of the total area of the walls of that *storey* separating heated space from unheated space or the exterior. (In the case of a sloping wall, the area of the opaque portion of the wall is calculated as its projected area on a vertical plane.)

3.3.5. Where the thermal resistance of glazing is different from that required in Articles 3.3.1. and 3.3.2., the area of such glazing for the purpose of applying Article 3.3.4. may be assumed as being equal to the actual area multiplied by the ratio of the required thermal resistance divided by the actual thermal resistance of the glazing.

3.3.6. Except as provided in Article 3.3.7., the area of glazing that contains clear glass or that has a shading coefficient of more than 0.70 that is unshaded in the winter and faces a direction within 45^{o} of due South may be assumed to be 50 per cent of its unshaded area in calculating the maximum area of glazing in Articles 3.3.4. and 3.3.5. provided the *building* is designed with a system that is capable of distributing the solar heat gain from such glazed areas throughout the *building*. (For the purpose of determining whether or not the glazing is shaded in the winter, the shading shall be calculated using the noon sun angles of December 21.)

3.3.7. Article 3.3.6. shall not apply where the *building* is designed to be cooled unless the glazing described in 3.3.6. is shaded in the summer with exterior devices. (For the purpose of determining whether or not the glazing is shaded in the summer, the shading shall be calculated using the noon sun angles of June 21.)

EXTRACT DEALING WITH INFILTRATION FROM "MEASURES FOR ENERGY CONSERVATION IN NEW BUILDINGS 1978"

SUBSECTION 3.5 INFILTRATION

3.5.1. Windows separating heated space from unheated space or the exterior shall be designed to limit the rate of air infiltration to not more than 0.775 dm^3/s for each metre of sash crack when tested at a pressure differential of 75 Pa in conformance with ASTM E283-73, "Standard Method of Test for Rate of Air Leakage through Exterior Windows, Curtain Walls and Doors".

3.5.2. Manually operated exterior sliding glass door assemblies that separate heated space from unheated space or the exterior shall be designed to limit air infiltration to not more than 2.5 dm^3/s for each square metre of door area when tested in conformance with Article 3.5.1.

3.5.3. Except where the door is weather-stripped on all edges and protected with a storm door or by an enclosed unheated space, exterior swing type door assemblies for *dwelling units*, individually rented hotel and motel rooms and suites shall be designed to limit the rate of air infiltration to not more than 6.35 dm^3/s for each square metre of door area when tested in conformance with Article 3.5.1.

3.5.4. Door assemblies other than those described in Articles 3.5.2. and 3.5.3. that separate heated space from unheated space or the exterior shall be designed to limit the rate of air infiltration to not more than 17.0 dm^3/s for each metre of door crack when tested in conformance with Article 3.5.1.

3.5.5. Caulking material to reduce air infiltration shall conform to the requirements in Article 9.28.4.3. of the NBC 1977.

3.5.6. The junction between the sill plate and the foundation, joints between exterior wall panels and any other location where there is a possibility or air leakage into heated spaces in a *building* through the exterior walls, such as at utility service entrances, shall be caulked, gasketed or sealed to restrict such air leakage.

3.5.7. Air leakage between heated space and adjacent roof or attic space caused by the penetration of services shall be restricted in conformance with the requirements of Articles 9.26.6.6. to 9.26.6.14. of the NBC 1977.

EXTRACT DEALING WITH VENTILATION FROM "RESIDENTIAL STANDARDS, 1980"

SECTION 33 VENTILATION

A. SCOPE

(1) The requirements for natural ventilation in this Section apply to all buildings regardless of size. The requirements for mechanical ventilation apply only to buildings that are not more than 3 storeys in building height and with a building area of not more than 600 m^2. For buildings exceeding these limits the requirements in Part 6 of the National Building Code of Canada 1980 shall apply.

(2) This Section applies to the ventilation of rooms and spaces by natural ventilation and mechanical ventilation where the rated fan capacity does not exceed 2 m^3/s.

(3) Where the rated fan capacity exceeds 2 m^3/s, mechanical ventilation shall conform to Part 6 of the National Building Code of Canada 1980.

(4) A garage for parking more than 5 cars shall be ventilated in accordance with Part 3 of the National Building Code of Canada 1980.

B. GENERAL

(1) Rooms and spaces in buildings shall be ventilated by natural means in accordance with Subsection C or by mechanical means in conformance with Subsection D, except that where a dwelling unit is heated with other than fuel-fired equipment within the dwelling unit, a mechanical exhaust system of 1 or more fans or blowers having a total capacity of at least 0.05 m^3/s at a pressure differential of 2.5 mm of water shall be provided for each dwelling unit.

(2) A space that contains a fuel-fired heating appliance shall have natural or mechanical means of supplying the required combustion air.

(3) Where the ventilation system forms part of the heating system, Section 34 shall also apply.

(4) Air contaminants released within buildings shall be removed insofar as possible at their points of origin and shall not be permitted to accumulate in unsafe concentrations.

(5) Every building in which dust, fumes, gases, vapour or other contaminants tend to create a fire or explosion hazard shall be provided with an exhaust ventilation system designed to conform with Part 6 of the National Building Code of Canada 1980 and shall be provided with explosion relief devices and vents or other protective measures to conform with Part 3 of the National Building Code of Canada 1980.

C. NATURAL VENTILATION

(1) The unobstructed ventilation area to the outdoors for rooms and spaces in residential buildings ventilated by natural means shall conform to Table 33A. Where a vestibule opens directly off a living or dining room within a dwelling unit ventilation to the outdoors for such rooms may be through the vestibule.

(2) Openings for natural ventilation other than windows shall be constructed to provide protection from the weather and insects. Screening shall be of rust-proof material.

Table 33A — Natural ventilation

	Location	Minimum Unobstructed Area
Within dwelling units	Bathrooms or water-closet rooms	0.09 m^2
	Unfinished basement space	0.2 per cent of the floor area
	Dining rooms, living rooms, bedrooms, kitchens, combined rooms, dens, recreation rooms and all other finished rooms	0.28 m^2 per room or combination of rooms
Other than within dwelling units	Bathrooms or water-closet rooms	0.09 m^2 per water closet
	Sleeping areas	0.14 m^2 per occupant
	Laundry rooms, kitchens, recreation rooms	4 per cent of the floor area
	Corridors, storage rooms and other similar public rooms or spaces	2 per cent of the floor area
	Unfinished basement space not used on a shared basis	0.2 per cent of the floor area

D. MECHANICAL VENTILATION

(1) Where rooms or spaces are mechanically ventilated, the system shall be capable of providing at least 1 air change per hour. Where a kitchen space is combined with a living area, natural or mechanical ventilation shall be provided in the kitchen area.

(2) No air from any dwelling unit shall be circulated directly or indirectly to any other dwelling unit, public corridor or public stairway.

(3) Except for self-contained systems that serve individual dwelling units, exhaust ducts from rooms containing water closet, urinals, lavatories, showers or slop sinks, and exhaust ducts serving rooms containing cooking equipment, shall not be interconnected, and shall not be connected to duct systems serving other areas of the building, except at the inlet of the exhaust fan. Where such a connection is made,devices shall be installed to prevent the circulation of exhaust air through the building when the fan is not operating.

(4) Where a vertical service space contains an exhaust duct that serves more than 1 fire compartment, the duct shall have a fan located at or near the exhaust outlet to ensure that the duct is under negative pressure, and such individual fire compartments shall not have fans that exhaust directly into the duct in the vertical service space.

(5) Air intakes shall be located so as to avoid contamination from exhaust outlets or other sources in concentrations greater than normal in the locality in which the building is located.

(6) Exhaust ducts shall discharge directly to the outdoors. Where the exhaust duct passes through or is adjacent to unheated space, the duct shall be insulated to prevent moisture condensation in the duct.

(7) Ventilation equipment shall be accessible for inspection, maintenance, repair and cleaning. Kitchen exhaust ducts shall be designed and installed so that the entire duct can be cleaned where the duct is not equipped with a filter at the intake end.

(8) Outdoor air intake and exhaust outlets shall be shielded from weather and insects. Screening shall be of rust-proof material.

(9) Outdoor air intake openings into the cold air return system shall be provided with a manually operated or automatic damper. Air intake openings larger than 127 mm diameter shall be equipped with a manually operated closure if the system is gravity type, or an automatic closure if the system is mechanically operated.

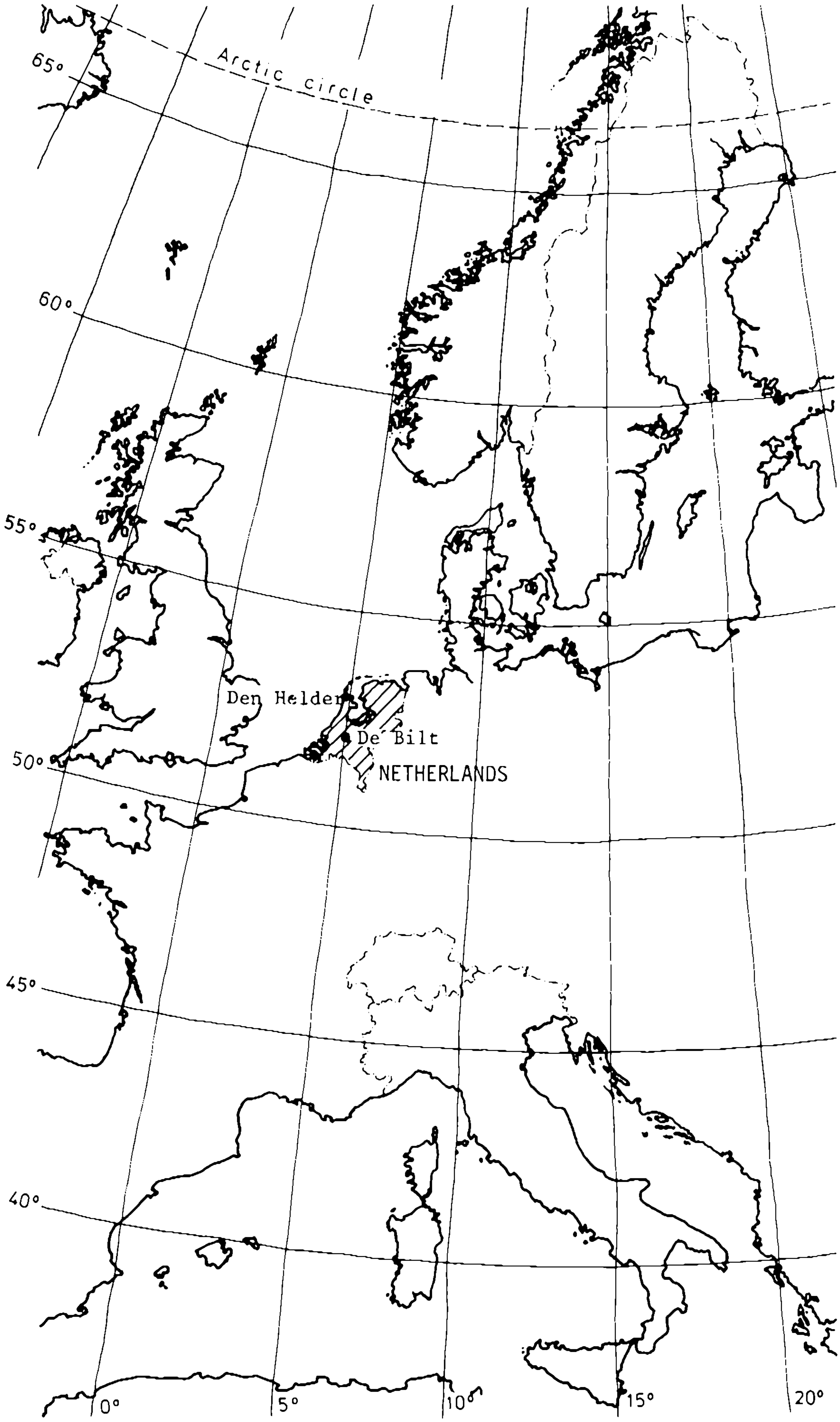
(10) Except as provided in (11), every ventilating duct shall conform to the requirements of Section 34 for supply ducts.

(11) An exhaust duct that serves only a bathroom or water-closet room and that is contained entirely within a dwelling unit or space that is common to no other dwelling unit may be of combustible material provided the duct is reasonably air tight and constructed of a material impervious to water.

(12) Underground ventilating ducts shall be adequately drained. Such ducts shall have no sewer connections and shall be provided with access for inspection and cleaning.

NETHERLANDS

PART BII



BII.1 REGULATIONS

BII.1.1 Introduction

In The Netherlands there are about 4.8 million houses. Approximately one-third are apartments or flats and two-thirds single-family houses (1). A typical example of both is given in Figures BII.1 and BII.2.

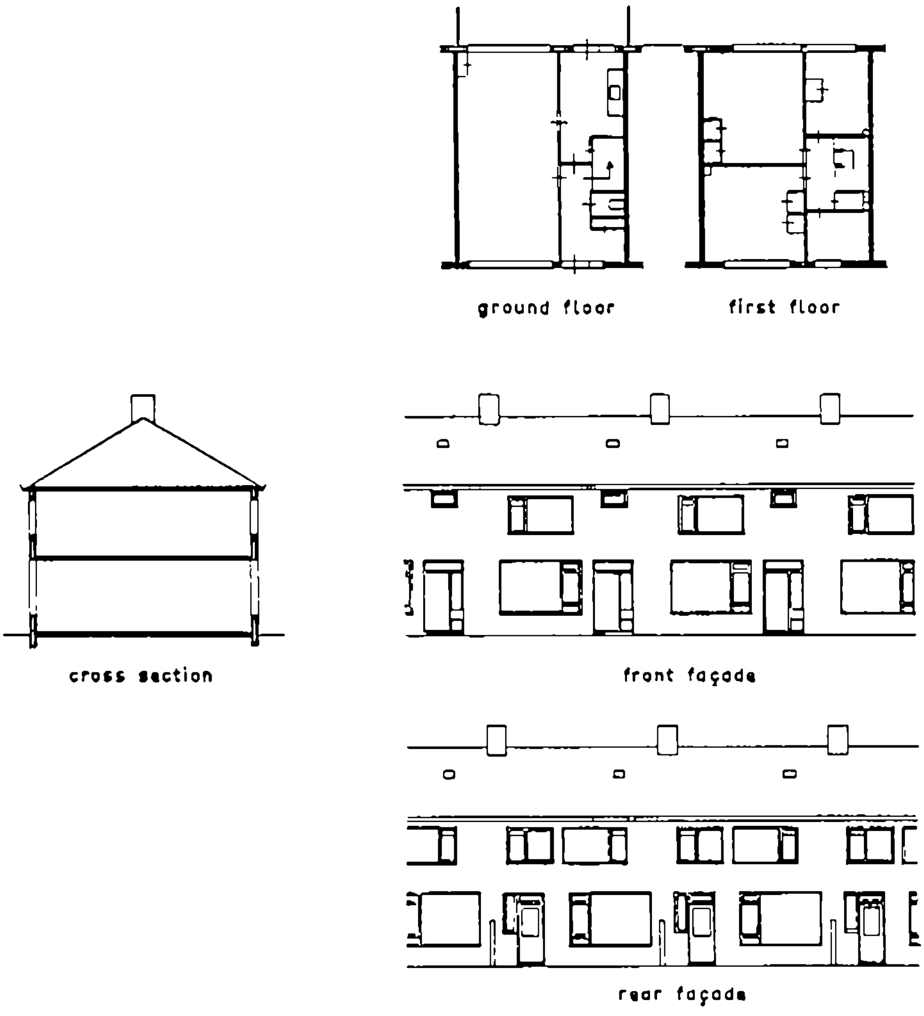


Figure BII.1. Floorplan and facades single-family house.

The heating system normally consists of a gas-fired boiler with hot water radiator panels. In apartment buildings there is commonly one central boiler plant. Most single-family houses have their own heating system.

Apartment buildings above 13 m high have mechanical extract ventilation systems. Most other houses are naturally ventilated.

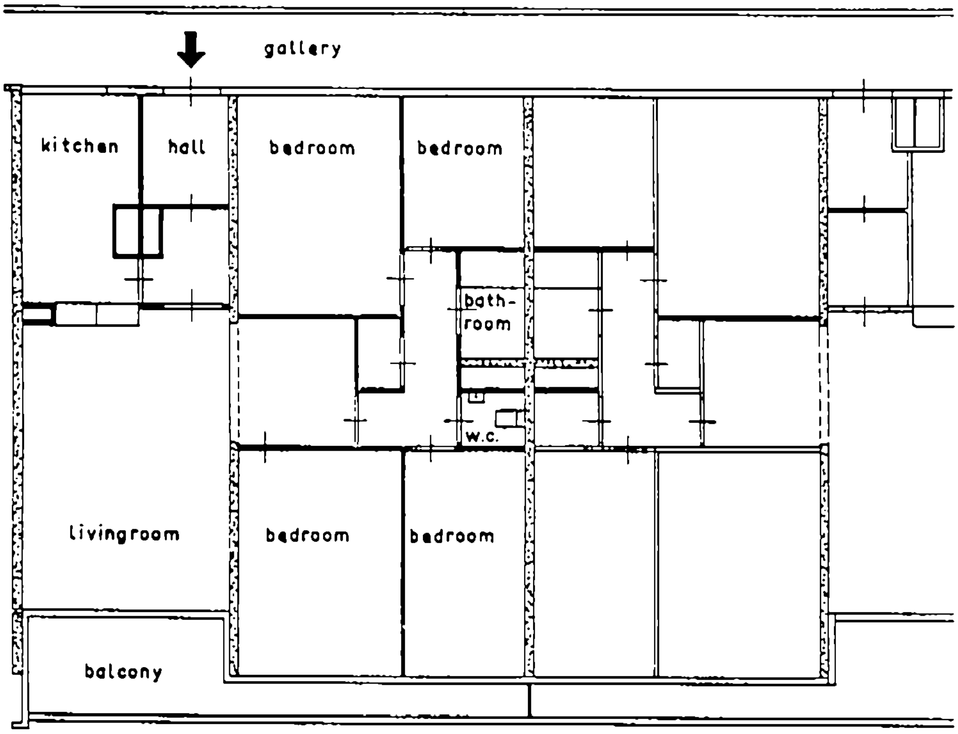


Figure BII.2. Floorplan of a flat.

Ventilation in The Netherlands is always dependent on both wind and buoyancy forces. See Figure BII.3.

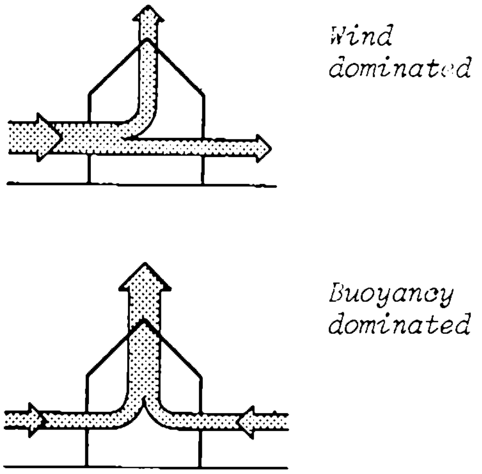


Figure BII.3.
Air flow through dwellings.

The important parts of the energy consumption of a dwelling are due to heat transmission and ventilation.

Considering that normal ventilation rates are between 0.5 (h^{-1}) and 1 (h^{-1}) the ventilation heat loss varies from 10 to 30 per cent of the total energy consumption for single-family houses and from 20 to

50 per cent for apartments (2). These losses depend on the amount of thermal insulation present.

An energy balance for an apartment near the North Sea coast has been measured by the Research Institute of Environmental Hygiene — TNO, and is given in the Appendix.

BII.1.2 Airtightness

There are no standards on airtightness apart from the one on air leakage through cracks of windows.

The air leakage through the cracks of windows is given in Table BII.1. The best estimate of the air leakage of houses can be seen in Figure BII.4. The air leakage is expressed as a flowrate at a pressure difference of 1 Pa. For purposes of comparison 0.1 m^3/s at 1 Pa is equal to an air change rate at 50 Pa of about 12 ac/h, or equal to an open area of about 0.08 m^2.

Table BII.1. Air leakage of windows according to NEN 3661 (3).

Height of the building in which the window is situated m	Exposure	Pressure difference Pa
15	Normal	150
40	"	200
100	"	250
15	Coast	300
40	"	350
100	"	400

At these pressure differences an air flow rate of 5 dm^3/s per m crack length may not be exceeded.

The distribution of the air leakage over the building envelope for single-family houses is given in Figure BII.5 (4). An example of what this air leakage means in relation to air change rates at heat loss can be seen in Figure BII.6 (5).

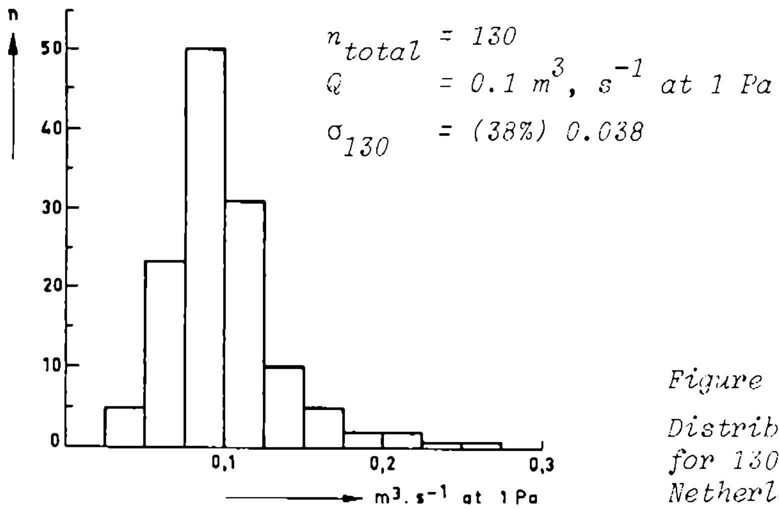


Figure BII.4.

Distribution of air leakage for 130 dwellings in The Netherlands.

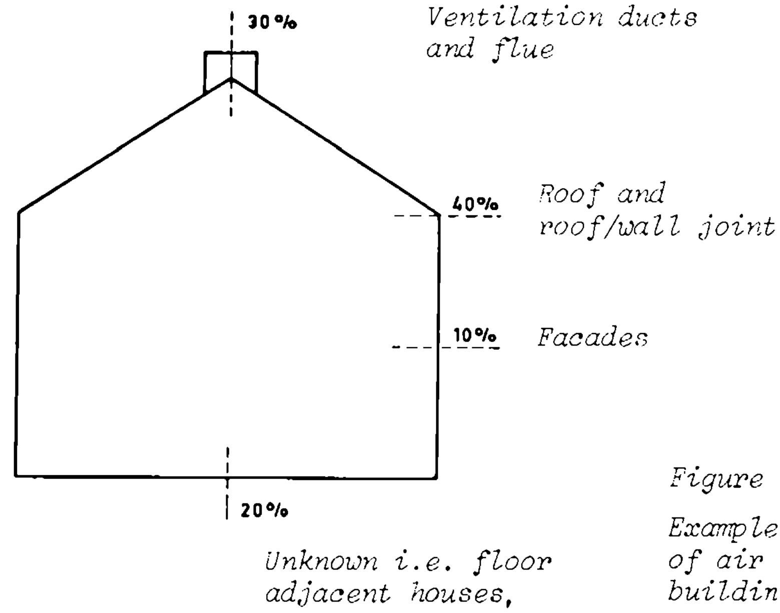


Figure BII.5.

Example of the distribution of air leakages over the building envelope.

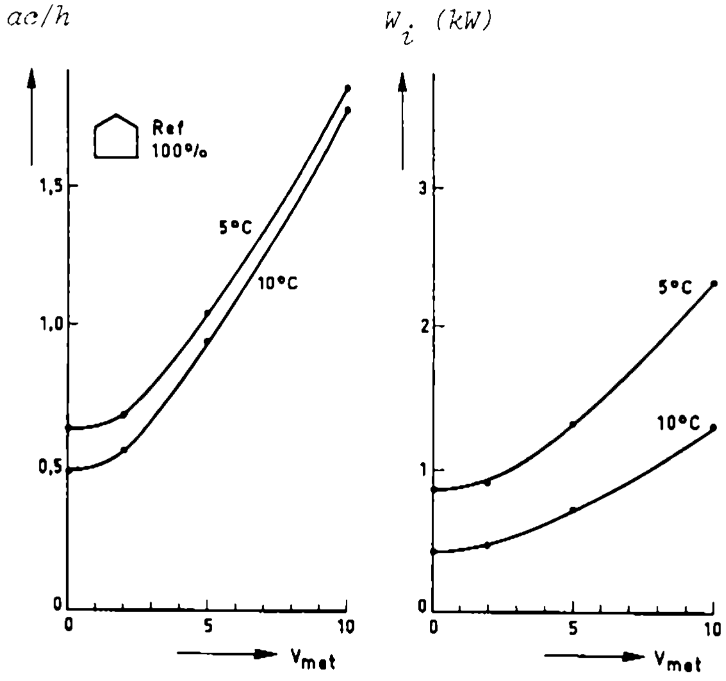


Figure BII.6.

Infiltration rates, ac/h, and infiltration heat losses, W_i, versus wind velocity.

BII.1.3 Minimum ventilation requirement

The minimum ventilation requirements are regulated in the Dutch standard for ventilation of dwellings (6). A basis for minimum ventilation is choosen to an airflow rate of 7 dm^3/s per person.

The requirements for the different rooms are tabulated in Chapter A5. The philosophy of the standard committee was to require airflows based on health and indoor climate. There is a code of practice in which these flow requirements are translated to openable window areas and sizes of ventilation ducts (7).

For buildings with a height above 13 m mechanical extract ventilation is required. This is also the case when the kitchen is in open connection (no door) with the living-room.

BII.1.4 Heat transmission

For design purposes there are no standards on heat transmission calculations. Nevertheless there are rules in normal practice as described in a technical note (8). These rules, which are almost always used, are based on DIN 4701.

The design indoor temperatures can be seen in Table BII.2. The design outside temperatures and wind velocities are given in Figure BII.7. An outside temperature of -10°C and wind velocities of 5 to 8 m/s are normal in The Netherlands.

The building code (9) requires minimal thermal resistance (m^2K/W) for floors, roofs, walls, glazing, etc. The corresponding thermal transmittance values are given in Table A5.6 in this handbook.

Table BII.2. Design temperature in dwellings according to ISSO publ. 4.

	Temperature °C
Living-room	20
Bedroom	18
Kitchen	18
Bathroom	22
Corridor/Hall	15
WC	10

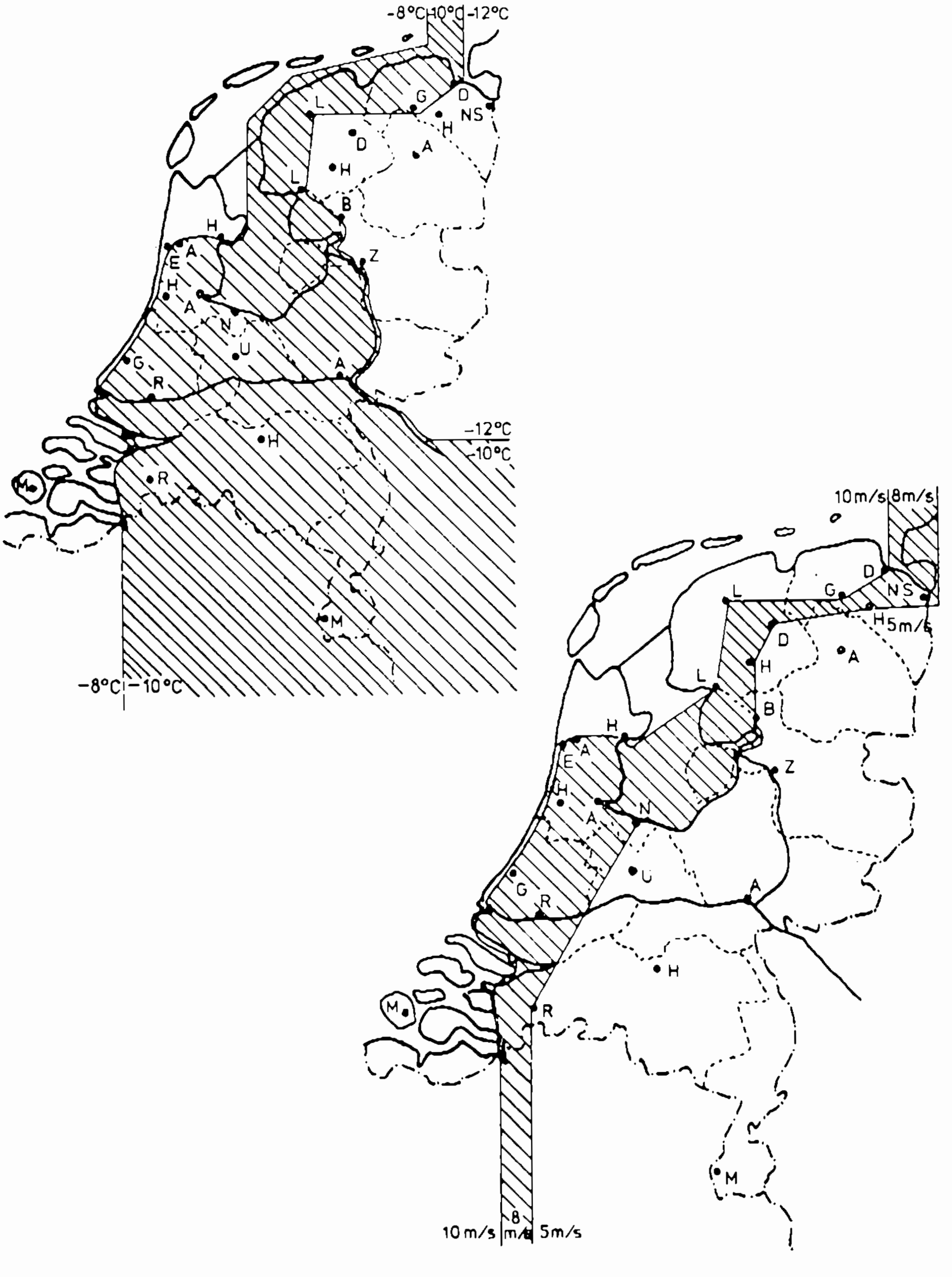


Figure BII.7. Design outside temperatures and wind velocities.

There is a standard on thermal insulation of buildings (10). This standard gives calculation methods for thermal insulation.

The committee on standards of thermal insulation of buildings introduced in the new standard the term insulation index I_t. This quantity is defined as

$$I_t = \frac{80 \cdot A_o/V \cdot (1-\overline{k}) + 30}{4 \cdot A_o/V + 1}$$

where I_t = thermal insulation index

A_o = total external surface area (m^2)

V = gross volume of the building (m^3)

$\overline{k}$ = overall thermal transmittance (W/m^2 K)

BII.2 CLIMATIC DATA

The climatic data used in this handbook for The Netherlands are based on publications from the Royal Dutch Meteorological Institute (11). These are frequency tables of the main climatic elements calculated from the results of measurements.

The climatic tables given in Figure BII.8 have been derived from measurements for the standard period 1931-1960.

De Bilt is a principal station in the middle of The Netherlands. Den Helder is a principal station at the north-west corner of the country. This station is more representative of the coastal area.

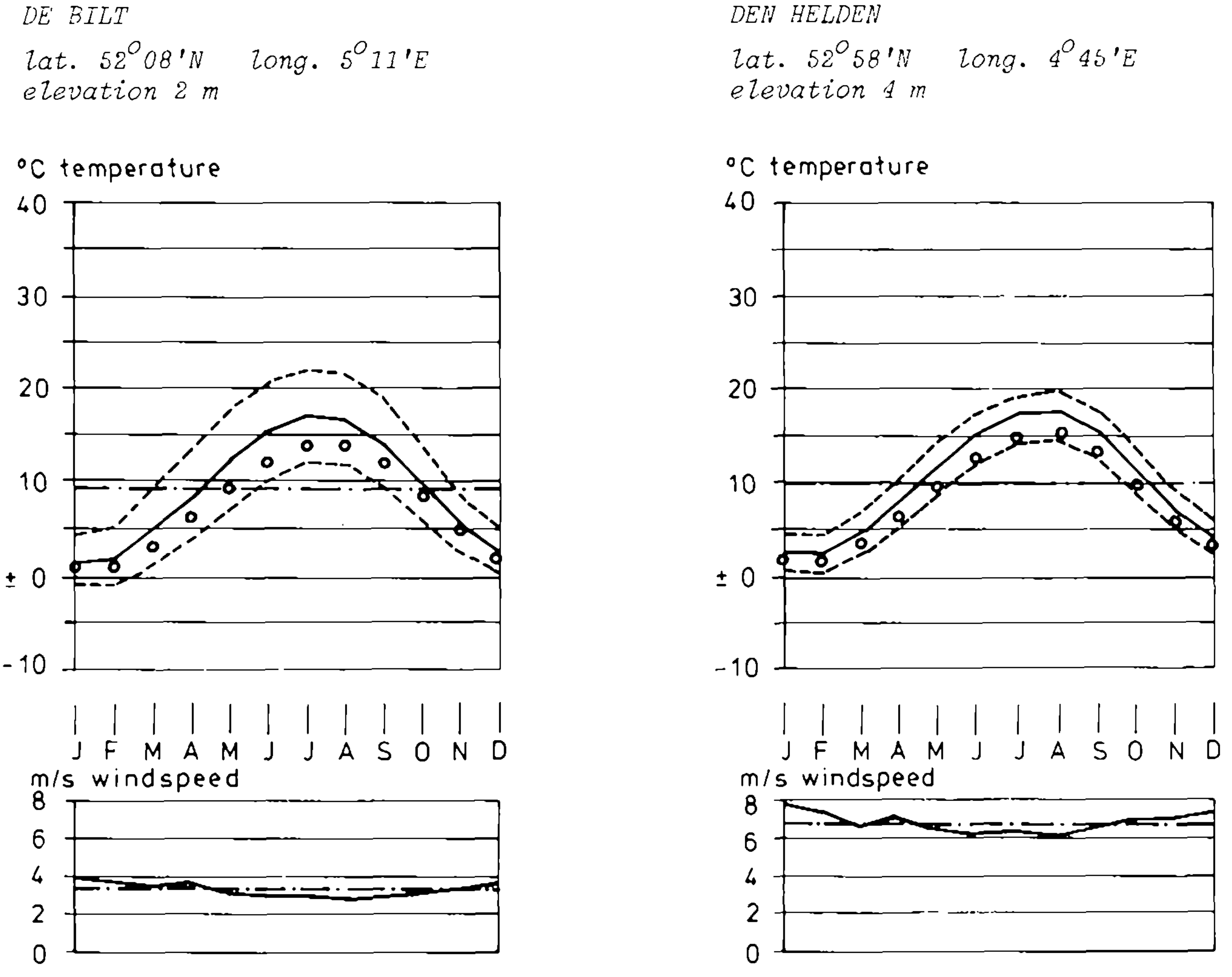


Figure BII.8.

Climatic data for two typical meteorological stations in The Netherlands.

BII.3 BUILDING CONSTRUCTIONS

BII.3.1 Introduction

The housing stock of The Netherlands can be catalogued by different constructional designs. See Table BII.3. Some typical examples of these wall, floor and roof constructions with and without thermal insulation are given in the Figures BII.9 and BII.10 (12). House constructions in The Netherlands are normally without any special provision for airtightness. Condensation of water vapour in the construction can require some additional provisions, such as vapour barriers.

Table BII.3. Typical post-war house constructions.

Period	Single-family houses	Apartments
1945-1955	brickwork cavity walls wooden floors wooden roof with tiles	concrete walls, floors and roofs
1955-1965	brickwork cavity walls concrete element floors wooden roof with tiles	concrete element walls, floors and roofs
1965-1980	on site concrete walls, with outside brickwork prefabricated facade panels wooden roof with tiles	on site concrete floors and roofs prefabricated facade panels

The most important air leakage paths are the joints between roof and wall and the leakages between crawlspace and ground floor. The masonry walls are almost always finished with plaster and wall paper and the leakages through these facades are normally in the order of 10 per cent of the total leakage. Improvements in floor and roof/wall joints are necessary to minimize uncontrolled infiltration.

Most details given are quite normal for building practice in The Netherlands. Small additional measures are added to improvement on airtightness such as:

- tape
- sealing compounds
- foam
- lead sheet or strips
- plastic film
- bitumen

Good workmanship is necessary to achieve good airtightness.

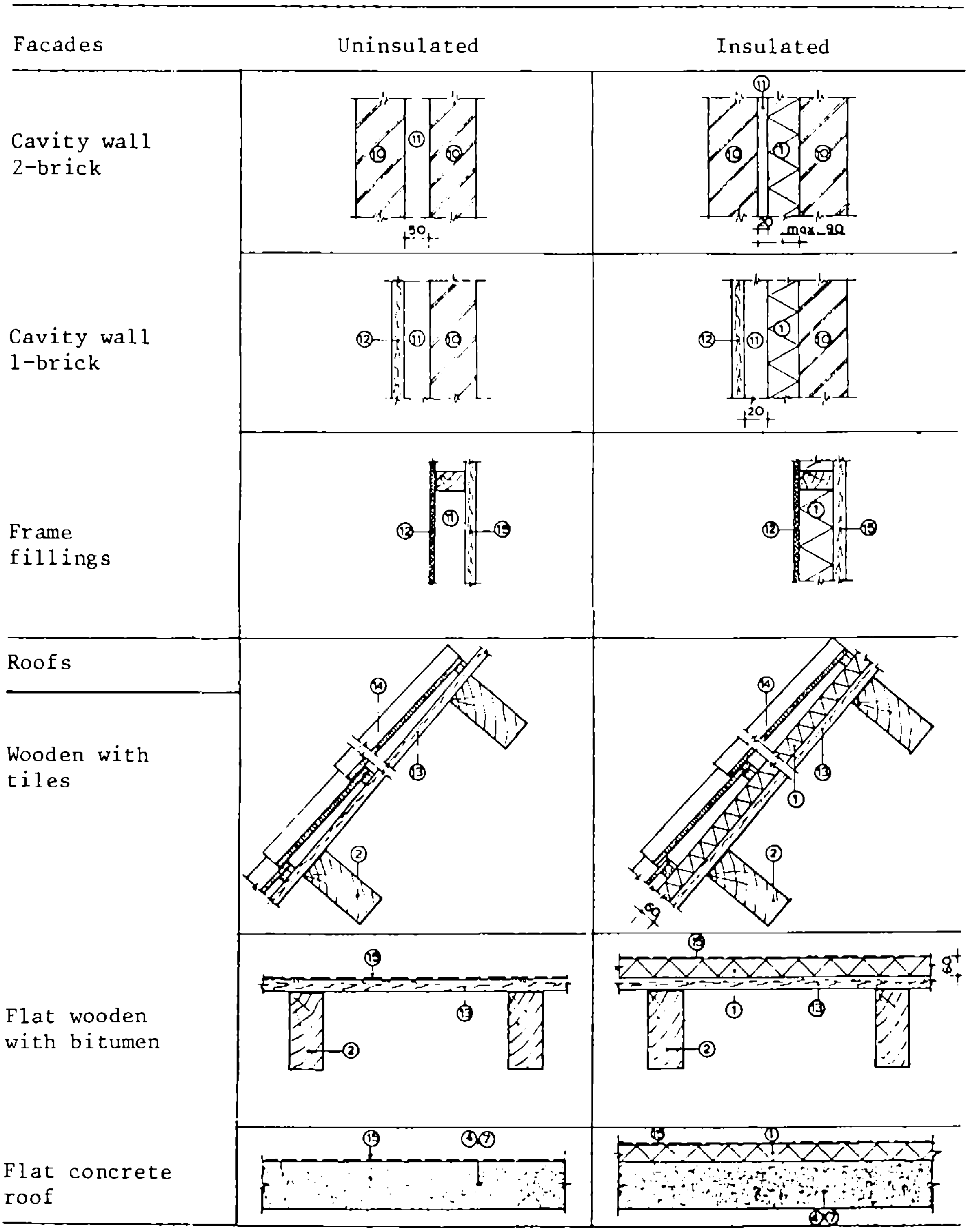


Figure BII.9. Wall and roof constructions.

Explanations to the figures – see below Figure BII.10.

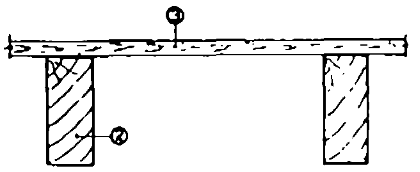
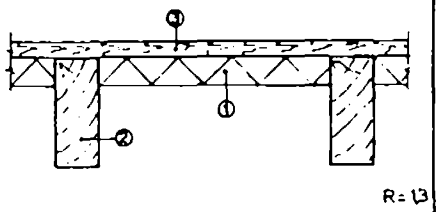
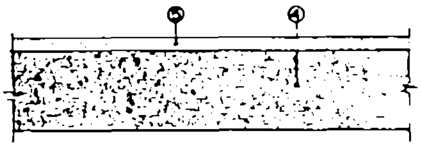
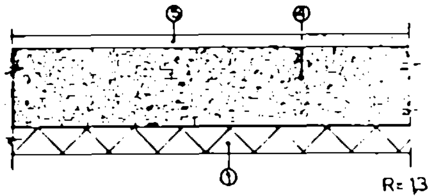
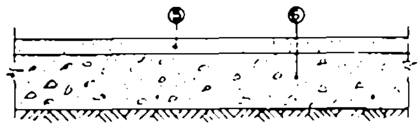
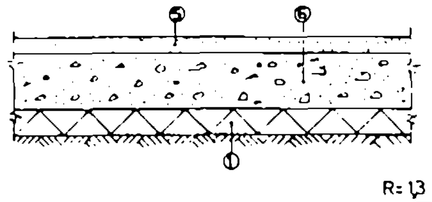
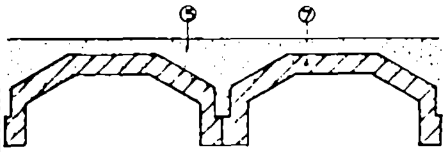
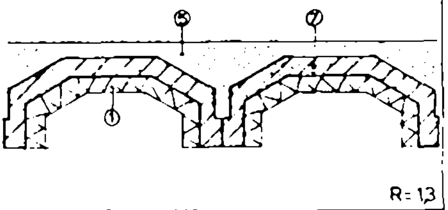
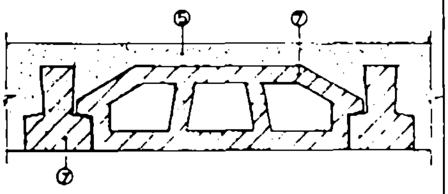
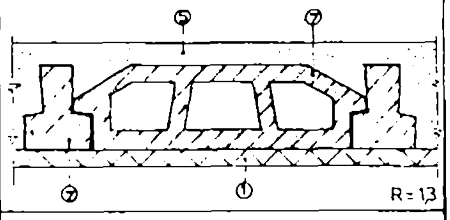
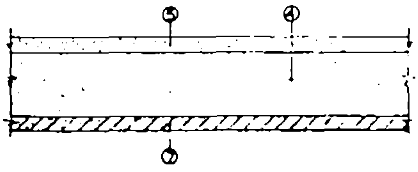
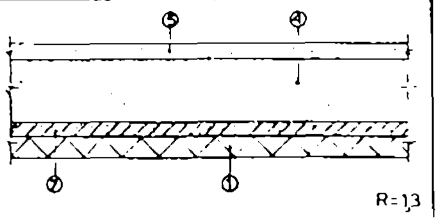
Floors	Uninsulated	Insulated
Wooden		
Reinforced concrete		
Rammed concrete		
Concrete elements		
Hollow bricks		
Boarding slabfloor		

Figure BII.10. Floor constructions.

Explanations to the Figures BII.9 and BII.10:

1	*Insulation*	9	*Slab floor*
2	*Durling*	10	*Masonry*
3	*Wooden floor boards*	11	*Cavity*
4	*Reinforced concrete*	12	*Plate material*
5	*Upper layer*	13	*Roof boarding*
6	*Rammed concrete*	14	*Roof tiles*
7	*Concrete elements*	15	*Bitumen*
8	*Hollow brick element*		

R = heat resistance (m^2K/W).

WALL CONSTRUCTIONS

The cavity wall construction is normal building practice in The Netherlands. Both inner and outer layer can be of masonry. The inner layer is sometimes brick but for new houses mostly concrete. Some new house constructions have one layer of sheeting material instead of brick or concrete. Wood frame constructions are rarely used (see Figure BII.9).

ROOF CONSTRUCTIONS

Almost all roof constructions of single-family houses with sloping roofs have wooden purlins, wood roof-sheeting and ceramic tiles. Most flat roofs are of concrete with bitumen on the outside (see Figure BII.9).

FLOOR CONSTRUCTIONS

Old houses have wooden floors. Most single-family houses have concrete elements or hollow bricks with an upper layer of mortar as the ground floor above the crawlspace. Apartment floors are made of concrete in most cases (see Figure BII.10).

BII.3.2 Construction details

The most important air leakage in Dutch houses can be seen in Figure BII.11. Examples of constructional details with a first attempt on airtightness, are given in Figures BII.12-BII.18 (4, 13).

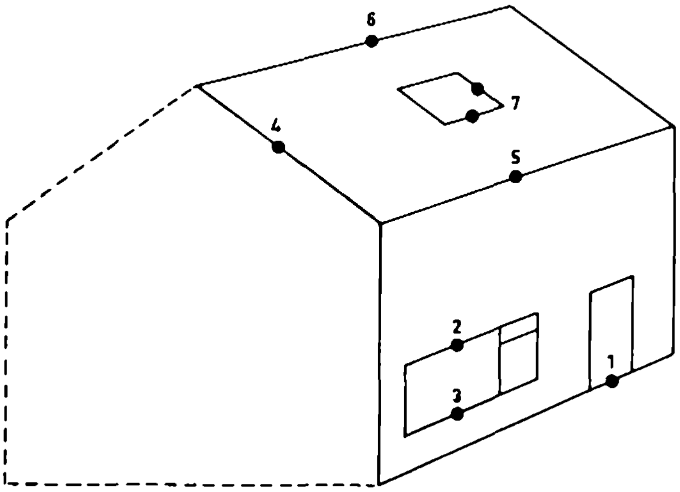


Figure BII.11.

Most important air leakages in Dutch houses.

DOOR SILL

The airtightness depends mainly on the sealing strip between door frame and concrete tile. The lead stripping avoids water transport. This detail is normal in building practice, Figure BII.12.

HEAD PIECE WALL JOINT

The sealing strip (16 · 20 mm) is in a lath in the inner side and these is lead sheathing between inner lintel and window frame outside. The sealing strip can be seen as an improvement on normal building practice, Figure BII.13.

WINDOW SILL CAVITY WALL

A polyethylene film is jammed between inner wall and insulation and between a special wooden lath and window frame. The sheet to the outer layer is glued on the lath, Figure BII.14.

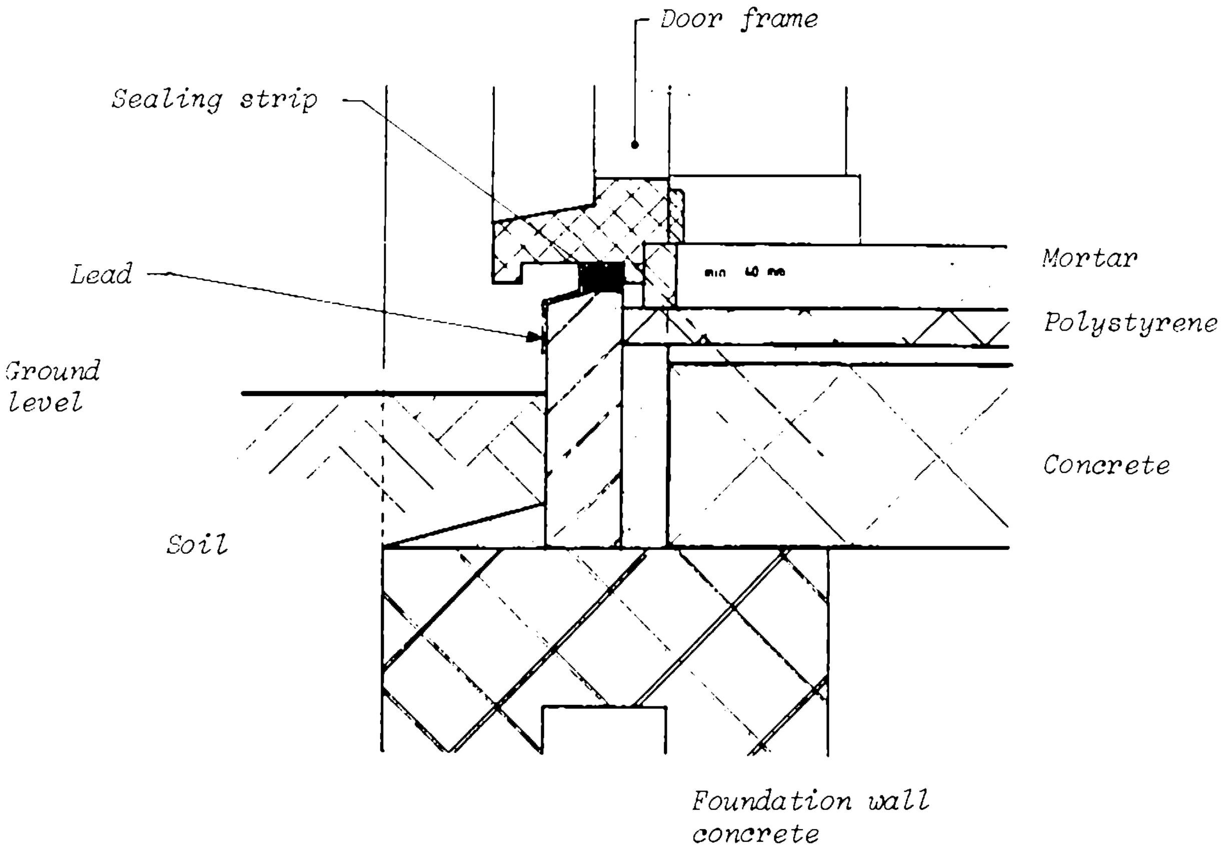


Figure BII.12. Door sill.

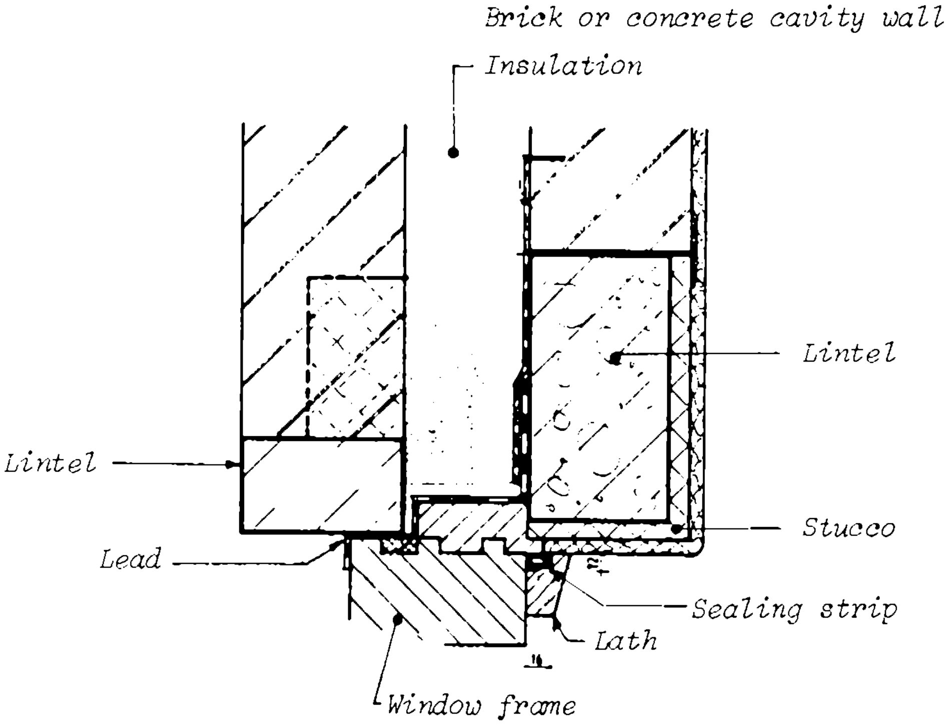


Figure BII.13. Head piece wall joint.

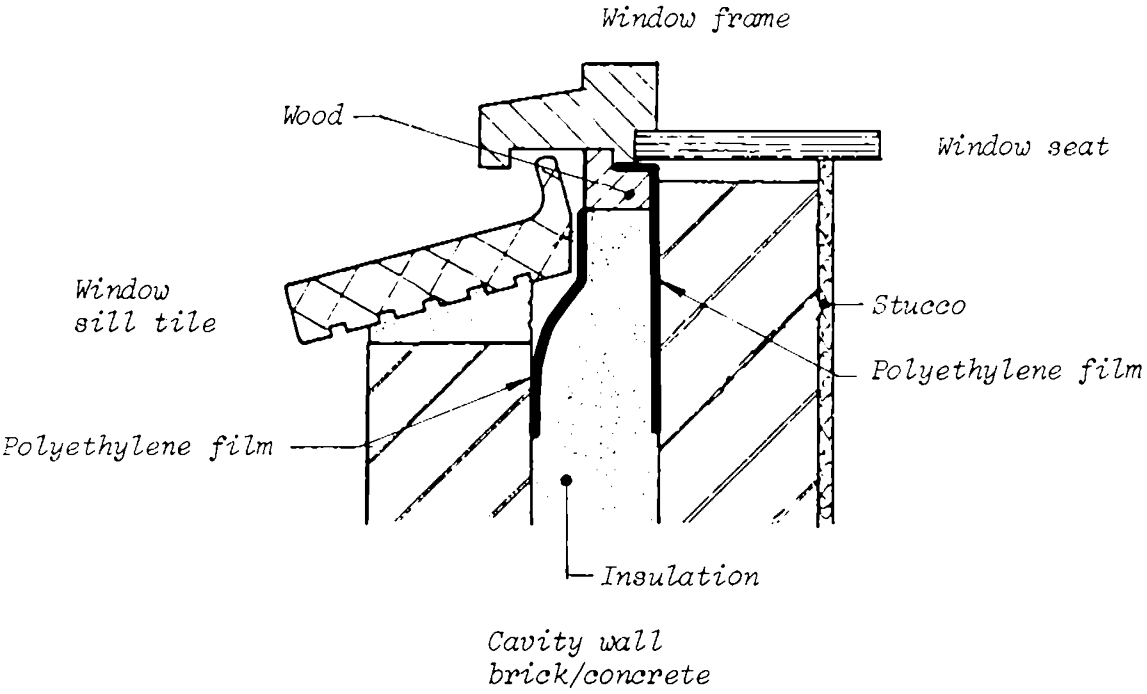


Figure BII.14. Window sill cavity wall.

ROOF/PARTY WALL

The connection joint between roof-element and wall must be carefully filled with foam. This is a special measure for air tightness. The mineral wool between the roof-sheeting gives some sound insulation.

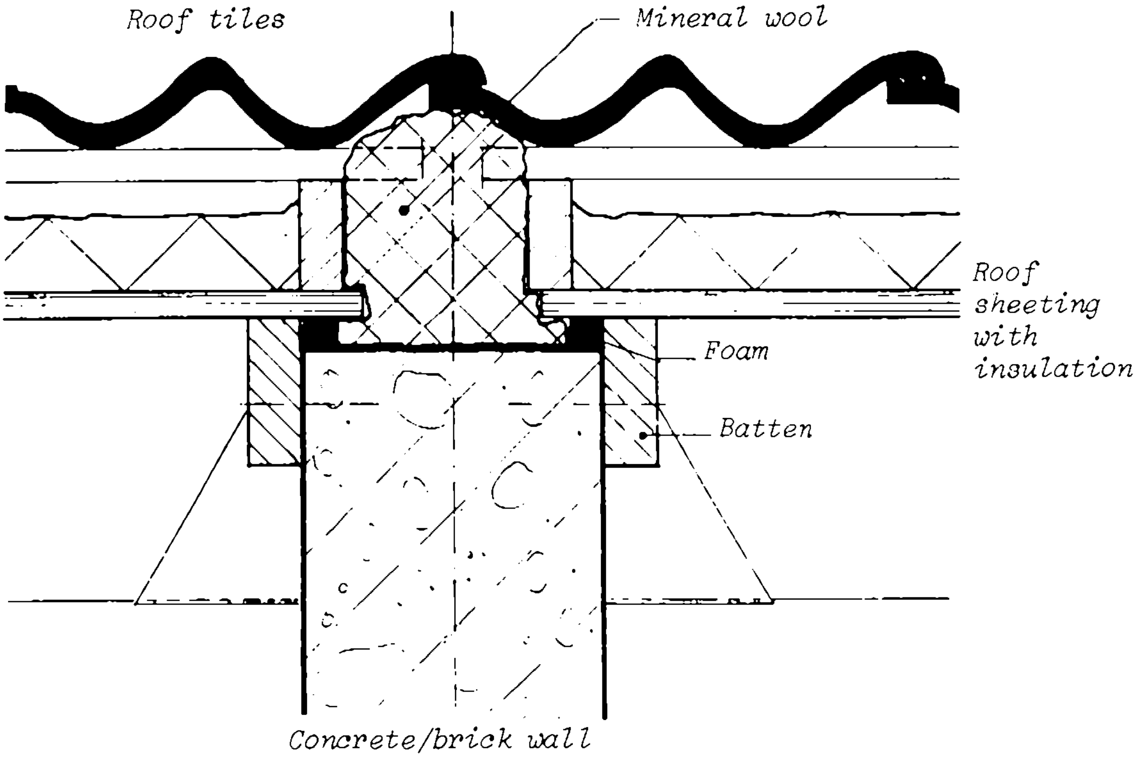


Figure BII.15. Roof/party wall.

JOINT ROOF/WALL

Bitumen glued strip between roof-sheeting and top rail, with additional foaming on the inside are special measures for improving air tightness. On the mortar layer of the concrete floor a sealing compound strip (16 · 20 mm) jammed in a lath is also necessary to avoid unintentional leakage. The seam between two roof-sheeting elements must be taped off.

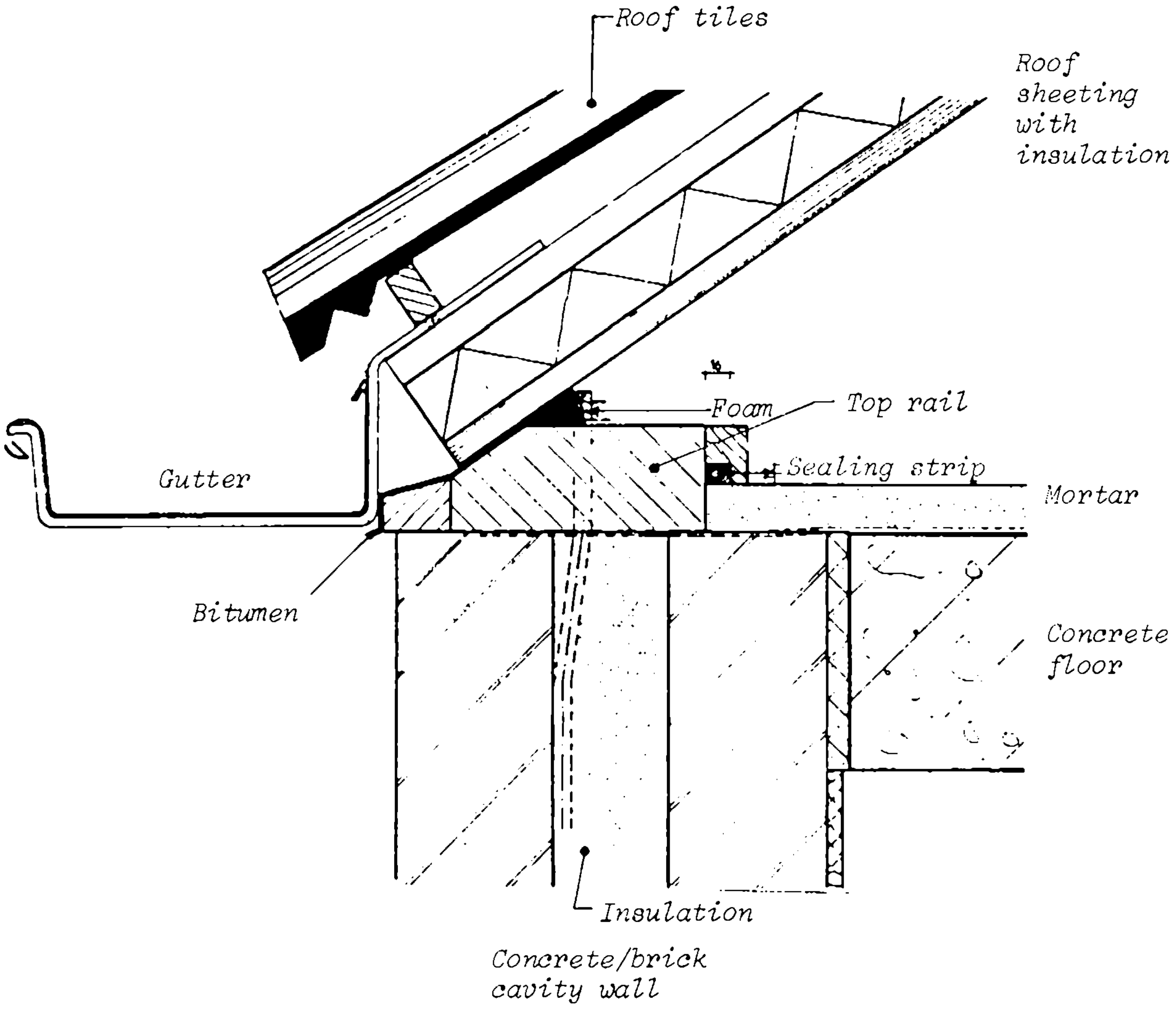


Figure BII.16. Joint roof/wall.

RIDGE

Foaming is necessary in every niche and corner between ridge turret, ridge purlin and roof-sheeting to avoid air leakage, Figure BII.17.

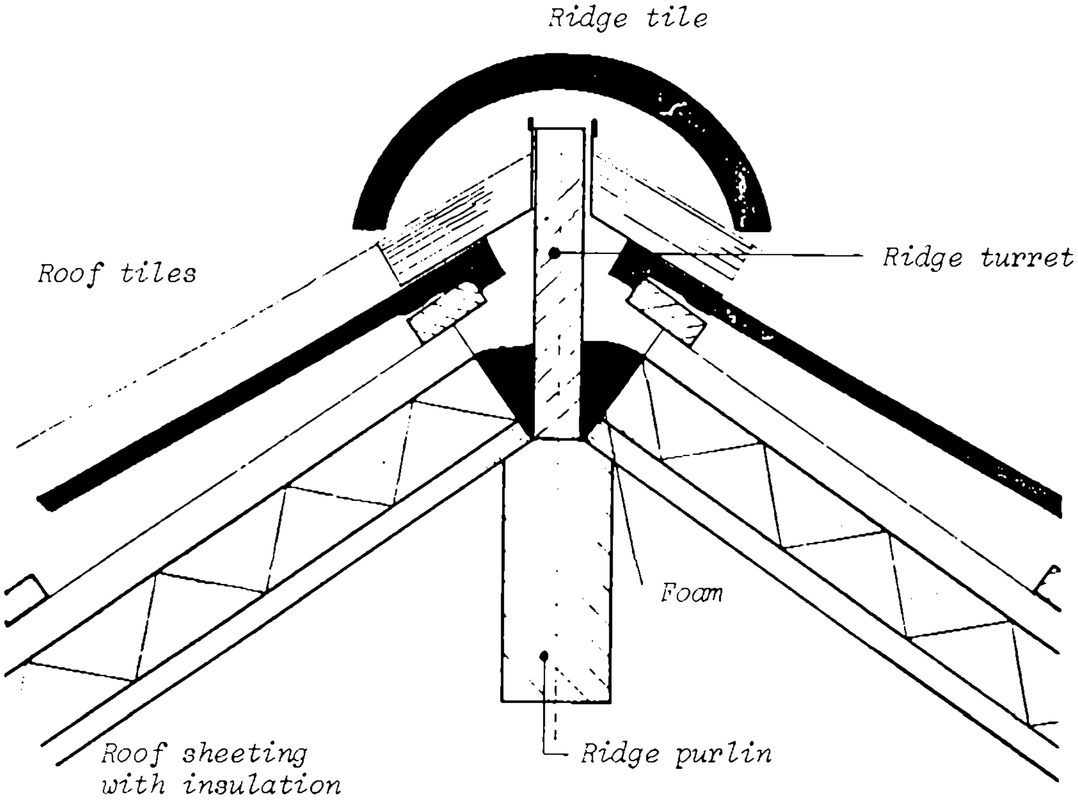


Figure BII.17. Ridge.

ROOF – WINDOW

The detail given is the lower connection between dormer window and roof-sheeting. The seam between dormer window and roof-sheeting must be as small as possible. Foaming in the cavity between roof-sheeting and innersheating is necessary to reach a reasonable airtight construction.

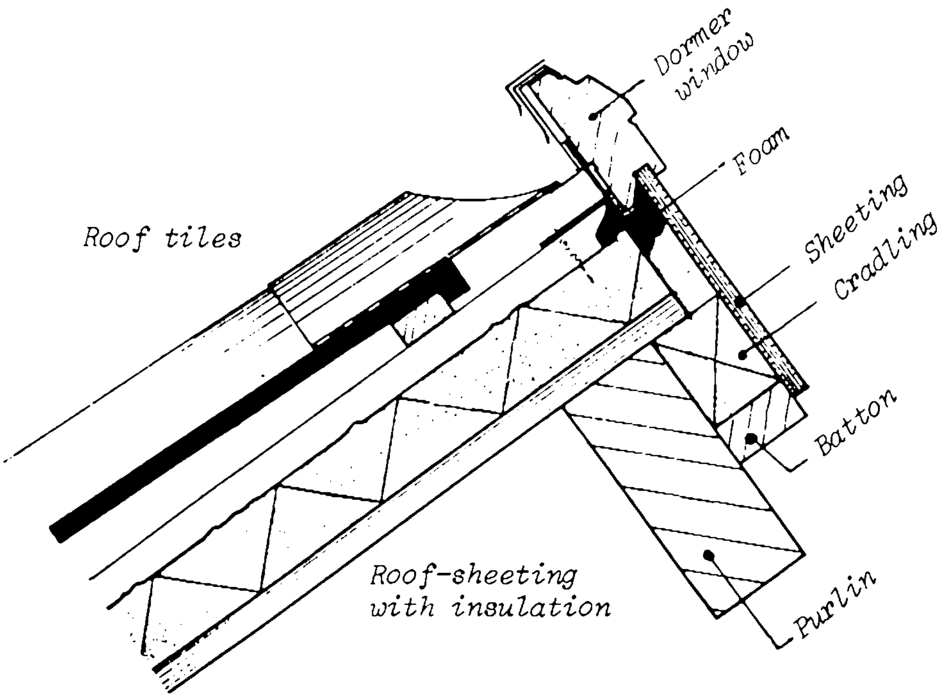


Figure BII.18. Roof window.

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ADDITIONAL ENERGY BALANCES FOR A FLAT IN THE NETHERLANDS

In addition to the energy balances of the single-family houses described in Chapter A3, the following energy balance for a flat near the North Sea coast has been measured by TNO:

IN

Solar heat gain	5.6 MWh
Heating (gas 3200 m^3)	32.2
Hot water	
Electricity	4.2
People	2.0
Total	44.0 MWh = 159 GJ

OUT

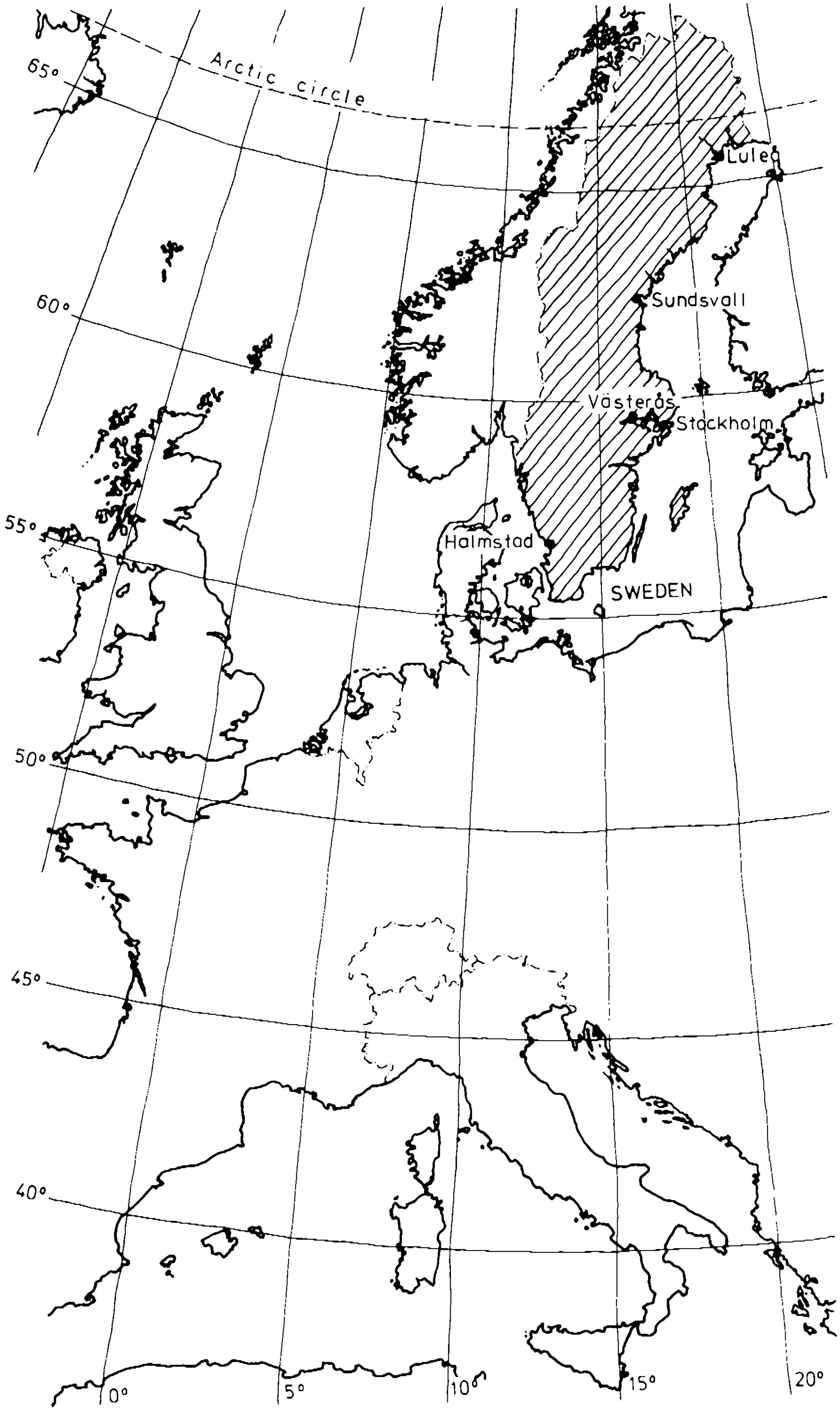
Transmission losses	24.5 MWh
Ventilation losses	3.4
Chimney losses	9.7
Waste-water losses	1.9
Vapour	1.5
Unknown	3.0
Total	44.0 MWh = 159 GJ

Specification

Flat, topfloor, at a corner in use since 1971

Floor area	100 m^2	
Volume	255 m^3	
Single pane window	12.54 m^2	$k = 6\ W/m^2\ K$
Double pane window	23.9 m^2	$k = 3\ W/m^2\ K$
Walls	128 m^2	$k = 1.04\ W/m^2\ K$
Roof	100 m^2	$k = 1.16\ W/m^2\ K$
Ventilation	?	

SWEDEN
PART BIII



BIII.1 REGULATIONS

Building in Sweden is controlled primarily by *Svensk Byggnorm med kommentarer (SBN)* {Swedish Building Regulations with comments (SBN)} issued by the National Swedish Board of Physical Planning and Building. The latest edition is SBN 1980 with its comments compendium and was published in 1981. The regulations state mainly the minimum requirements for safety and comfort in buildings. Energy management requirements are also stated.

To be eligible for government home loans, there are special regulations issued by the Ministry of Housing and Local Government to be complied with. These regulations affect both new buildings and rehabilitation and can almost be considered an appendix to the minimum requirements referred to in Swedish Building Regulations. Nearly all new housing is financed through government loans and thus the loan regulations influence design to a significant degree. Loan regulations also influence the extent of building services. For example, favourable loans for heat exchangers in single-family dwellings has meant that almost 50 per cent of all new single-family dwellings are fitted with such equipment.

BIII.1.1 Airtightness

A considerable degree of airtightness is required by SBN 1980. The requirements are illustrated in Chapter A5 and mean that, when pressure tested, there is a maximum permissible total leakage for the building as a whole. The values referred to are considered to fulfill the requirements demanded for comfort and energy management.

In the comments compendium of 1981, there are stated requirements for airtightness for parts of buildings which are normally applied to type testing of building elements. Refer to Table BIII.1. There are also requirements that joints between various building sections shall be designed so that inconvenient air leakage is prevented.

It is envisaged that sample testing can be demanded by local authorities to ascertain airtightness of buildings in accordance with the pressure test method. A guarded pressure box is used for testing building elements. The methods are described in Chapter A11.

Table BIII.1. Values of highest air leakage for building sections and joints between parts with the same function, intended normally for application during type approval of the building element.

Building element	Pressure difference	Building with height in floors		
	Pa	1-2	3-8	>8
Wall exposed to outdoors	50	0.4	0.2	0.2
Windows and doors exposed to outdoors (refers to tightness of corner joints, fenestration and gaps between frame and window or door[1]	50 300 500	1.7 5.6 -	1.7 5.6 -	1.7 5.6 7.9
Roof exposed to outdoors and joist structures exposed to outdoors next to ventilated space	50	0.2	0.1	0.1

1 Letter boxes and door bells constitute further sources of air leakage and higher values can be accepted as a result.

During rehabilitation of buildings, SBN assumes that leakage which gives rise to hygienic problems is rectified.

Windows are classified in a Swedish Standard (SIS 81 81 03) with respect to function and application. There are three classes, A, B and C wherein A relates to the simplest design. Airtightness is tested according to prescribed methods using a guarded pressure box. Windows are tested at both negative and positive pressure. Only the actual window's leakage is tested with this method and the test does not include the joint next to the outer wall.

The permissible air leakage (q) for windows in each class is stated in $m^3/h\ m^2$ and is determined by the formula

$$q = k \cdot p^{2/3}$$

where q = air leakage in m^3 per h and m^2 window area

k = a coefficient (0.2 for class A and 0.125 for classes B and C)

p = pressure difference in Pa between inner and outer surfaces of the window.

A diagram of the highest permissible air leakage and classification is illustrated in Figure BIII.1. Requirements for rain tightness and security against wind loading are included in addition to airtightness requirements.

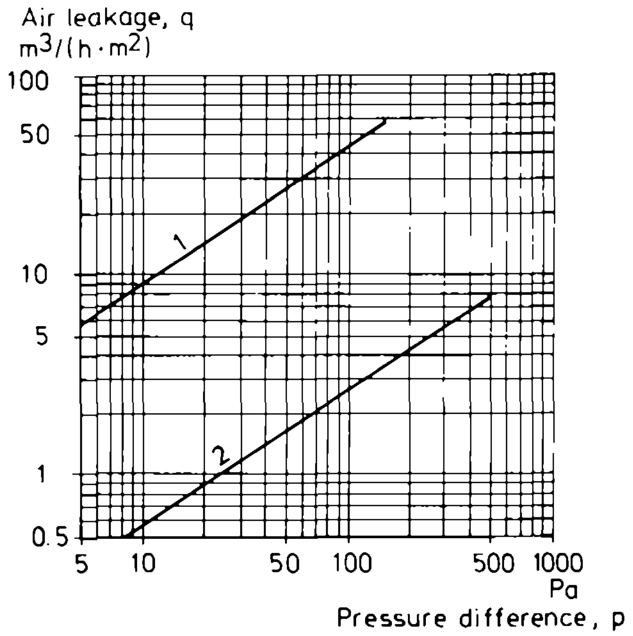


Figure BIII.1. *Classification of windows by highest permissible air leakage according to Swedish Standard (SIS 81 81 03).*

Class A: air leakage shall be below curve 1 up to 150 Pa

Class B: air leakage shall be below curve 2 up to 300 Pa

Class C: air leakage shall be below curve 2 up to 500 Pa.

BIII.1.2 Minimum ventilation

According to SBN, dwellings are to be equipped with ventilation installations which permit continual air change (in addition to forced flow) of at least 0.35 l/s m^2 of dwelling area in the entire apartment. In terms of normal ceiling height, 240-250 cm in Sweden, this is approximately 0.5 air changes per hour. The lowest design airflows from different types of rooms (e.g. kitchen, bathroom, w.c.) are tabulated in Chapter A5.

In addition, ventilation shall ensure that sanitary problems do not arise as a result of excessive concentrations of injurious or obnoxious gases.

The annual mean concentration of radon decay products must not exceed 70 Bq/m^3 in areas continually occupied by people.

Demands for airtightness have meant that all new multi-family housing and nearly all new single-family dwellings have mechanical ventilation to fulfill the requirements for minimum ventilation and air quality.

BIII.1.3 Heat transfer

The highest permissible k-values (U-values) for different building sections are illustrated in Table BIII.2. The requirements are also differentiated with respect to temperature zones, see Figure BIII.2. Deviation from the regulations are permitted if the total heat radiation from the building does not increase. The values in columns 3 and 4 in the table must not be exceeded however. This means that if

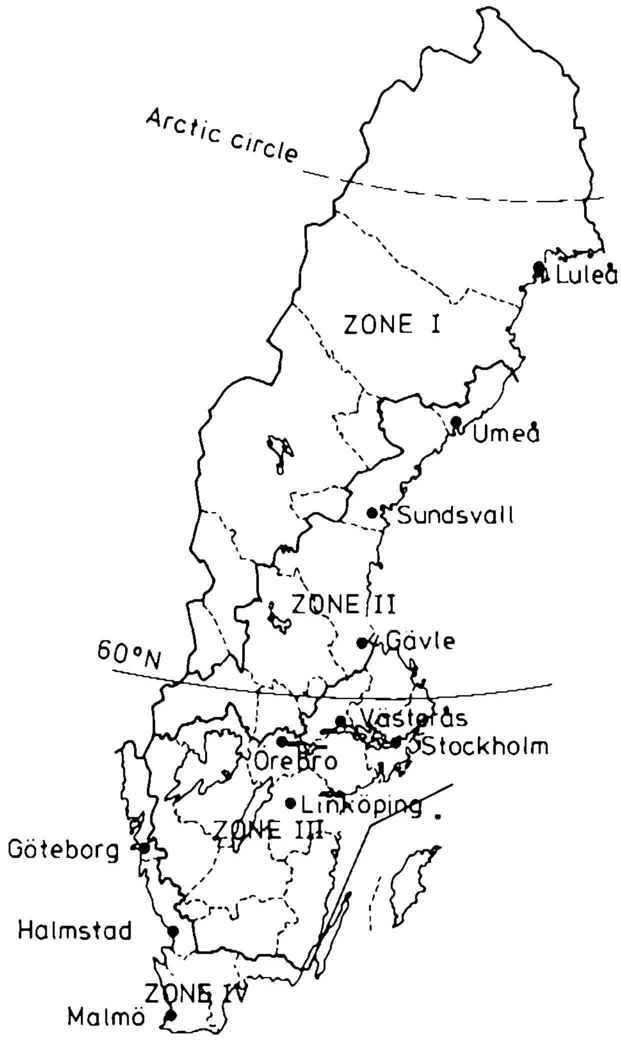


Figure BIII.2.
Temperature zones.

Table BIII.2. Prescribed maximum values for coefficient of heat transfer (k-value, W/m^2 °C) for building parts for rooms to be heated to more than +18°C.

Building section	Normal value		Limiting value	
	Temperature zones as per Figure BIII.2		Temperature zones as per Figure BIII.2	
	I+II	III+IV	I+II	III+IV
	1	2	3	4
Wall exposed to outdoors or through earth to outdoors	0.25	0.30	0.50	0.60
Roof without roof joist structure or roof joist structure with roof	0.17	0.20	0.50	0.60
Floor joist structure exposed to outdoors	0.17	0.20	0.35	0.40
Floor joist structure above outdoor air ventilated crawl space[1]	0.30	0.30	0.40	0.45
Floor on ground	0.30	0.30	0.40	0.40
Windows and doors exposed to outdoors: unglazed section of door (incl. frame)[2]	1.00	1.00	1.50	1.50
Windows plus door glazing (incl. frame and casement)[3]	2.00	2.00	3.00[4]	3.00[4]
Walls and joist structures adjacent to stores in cellars and other areas to be heated to between +10°C and 0°C	0.50	0.50	0.50	0.50
Walls and joist structures adjacent to stair wells, rooms in cellars and other areas to be heated to between +18°C and +10°C	1.00	1.00	1.00	1.00

1 *For fan ventilation the air change rate must not exceed 2 m^3/h and m^2 joist structure area. In the case of natural ventilation, the total opening area must not exceed 0.2 m^2 per 100 m^2 joist structure area.*

2 *Higher values may be applied for doors in openings intended for the passage of vehicles.*

3 *Frames and casements shall be constructed so that uncomfortable cold bridges do not occur.*

4 *Refers to k-value of glazed portion. The value of 2.50 applies in rooms where the area of windows and glazed doors within the external dimensions of the frame (Af) amount to 60 per cent or more of the internal wall area. Af does not include the area of unglazed ventilation device or unglazed portions of a glazed door.*

Note: As of 1986, special regulations apply to single-family dwellings in which direct electrical heating is installed. These houses must be designed for lower energy consumption to include lower maximum k-values for outer walls and roofs (0.17 and 0.12 W/m^2 °C resp.). Heat recovery from ventilation air will also be a requirement.

any building part has inferior insulation, this can be compensated by another part having better insulation.

The total window area of a building must not exceed 15 per cent of the different floors' area plus an additional maximum of 3 per cent of their inner area, see Figure BIII.3.

Calculating the effect of cold bridges on the heat transfer coefficient for different building sections (for example, timber

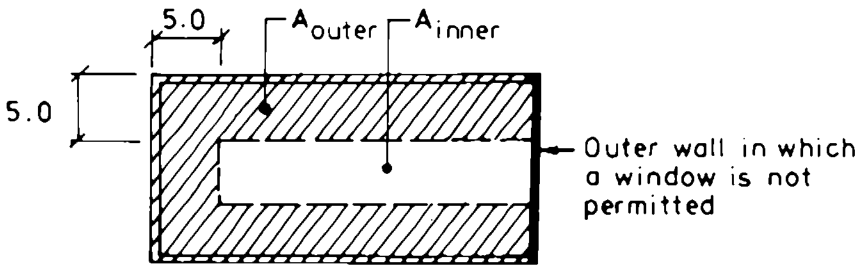


Figure BIII.3. *Example of calculation of permissible window area. If the length of the house is 40 m, and its width 15 m, the window area is:*

$$0.15(40 \cdot 10 + 5 \cdot 5) + 0.03 \cdot 5 \cdot 35 = 69 \ m^2 \text{ per floor.}$$

frames in mineral wool layers) has been dealt with in Chapter A7. In the comments on SBN, there are special regulations on how cold bridges are to be treated at different joints, e.g. joist edges, balconies, external corners.

BIII.2 CLIMATIC CHARACTERISTICS OF SWEDEN

Extending, appr. between latitudes 55°N and 68°N Sweden exhibits an unusually wide range of climatic conditions as compared with most European countries. With respect to the range of conditions found within the country, Sweden may largely be compared with Canada, with the exception of arctic areas and the western Pacific coast.

A rough comparison of conditions in corresponding parts of the northern hemispehere of mean temperatures in January along 60°N is given by Table BIII.3.

Table BIII.3. *Northern hemisphere mean temperatures in January along latitude 60°N.*

	°C
Northern Canada	-20 — -30
Greenland	- 5
Northern Europe	+ 1 — -12
Oslo	- 5
Bergen	+ 1
Stockholm	- 3
Helsinki	- 7
Leningrad	- 8
Siberia	-30 — -40

Annual mean temperatures in Sweden range from -2°C to +8°C with strong regional differences during winter, weak during summer.

Figure BIII.4 shows the regional variation in Sweden of LUT 50, i.e. 50 hours/year falling below given temperatures. Temperature zones for maximum k-values according to the Building Regulations were earlier given in Figure BIII.2.

Annual percipitation ranges from <400 mm to >1000 mm.

Average relative humidities are lowest in May (60-70 per cent) and highest in December (86-90 per cent).

The number of clear days/month is 4-8 in spring and 1-6 in winter, the lowest numbers found along the coasts of southern Sweden. Corresponding data for cloudy days are 6-15 during summer months with highest numbers in northern parts, 12-23 during winter with highest numbers in southern parts.

Temperatures, air humidity and windspeeds at five different places in Sweden are shown in Figure BIII.5. The background to the plots is described in Chapter A6.

In a very broad sense the country may be divided, with respect to preconditions for heating requirements, as follows:

a) Coastal areas south of lat. 59°N (e.g. Halmstad).

Predominantly maritime climate. Along the west coast moderately severe exposure to S-W winds and rainfall during the winter half year.

b) Inland areas south of lat. 59°N (e.g. Västerås).

Moderately continental climate, winter temperatures significantly lower than in a). Wind exposure generally weak, moderate precipitation.

c) Coastal areas north of lat. 59°N (e.g. Stockholm, Sundsvall, Luleå).

Moderate maritime influence with less extreme winter temperatures than in d). Exposure to cold N-E winds. Moderate exposure to rain with E-S winds.

d) Inland areas north of lat. 50°N.

Continental climate with cold or very cold winters. Relatively low monthly precipitation except in mountains. Topographical effects on temperature strongly pronounced (cold valleys) during winter. Winds generally weak, very high frequencies (30-50 per cent) of calm in valleys during winter.

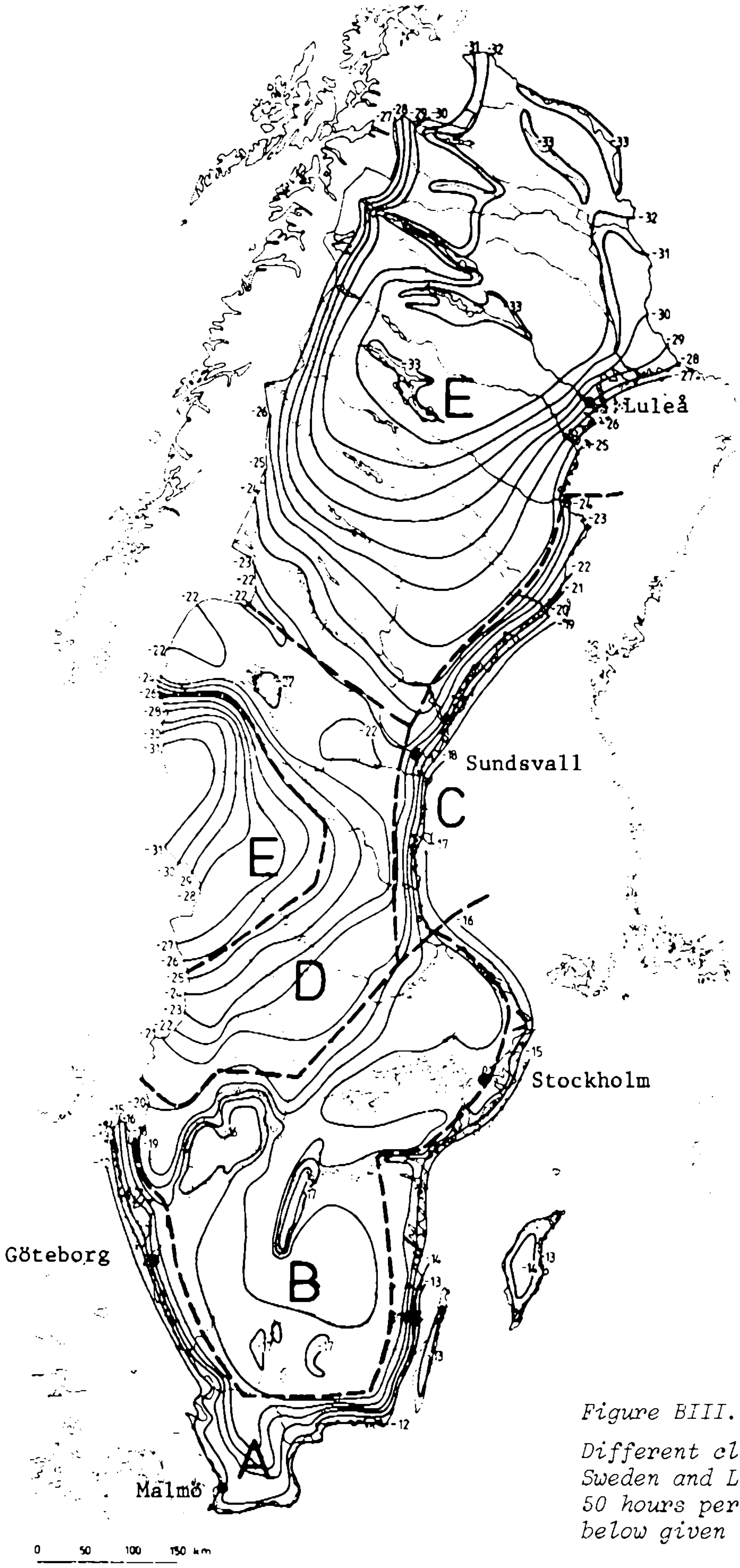
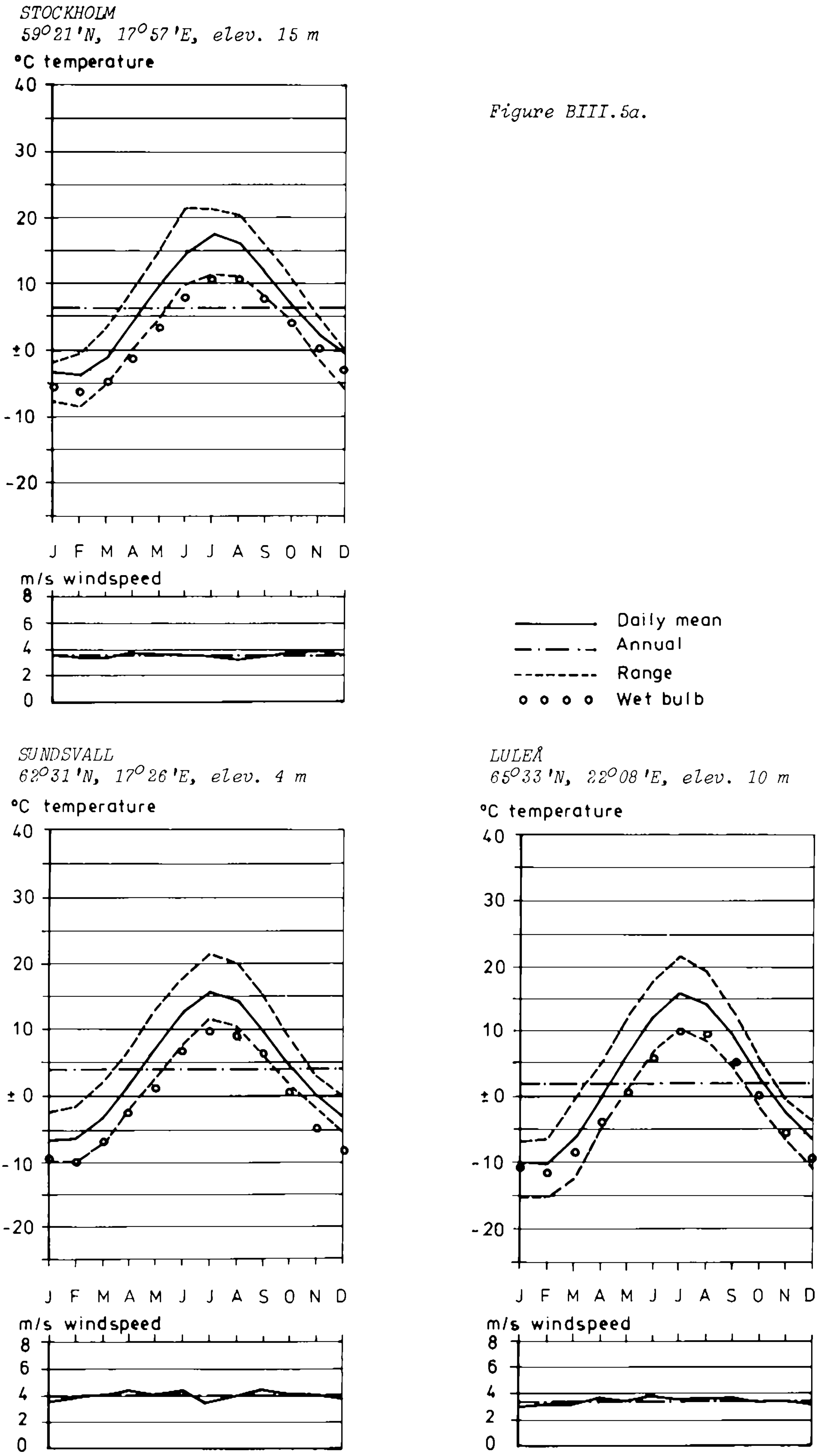
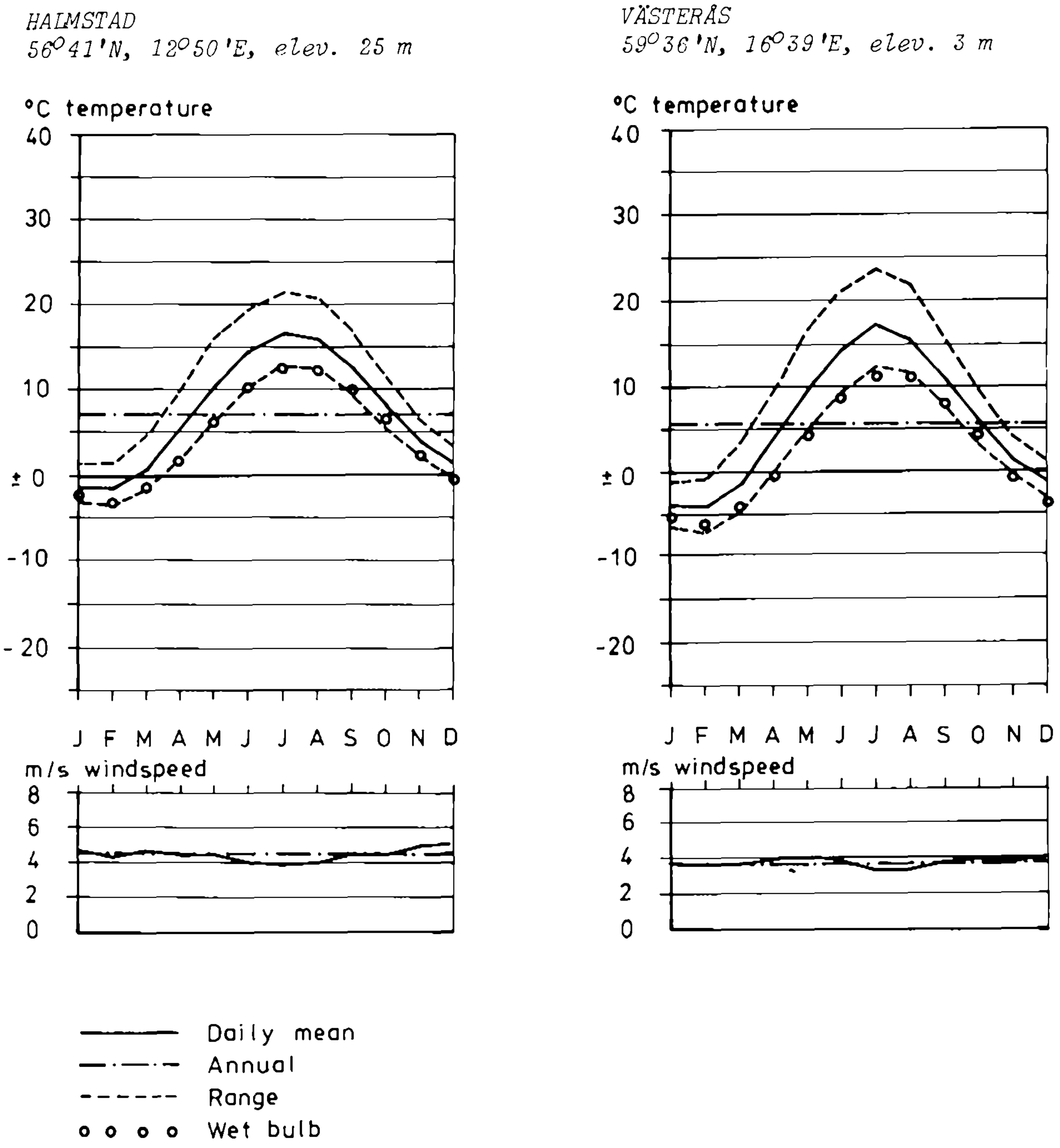


Figure BIII.4.

Different climatic zones in Sweden and LUT 50 e.g. the 50 hours per year falling below given temperatures.

Figure BIII.5a.





HALMSTAD
56°41'N, 12°50'E, elev. 25 m

VÄSTERÅS
59°36'N, 16°39'E, elev. 3 m

Figure BIII.5b.

Figure BIII.5. Temperature, wet bulb temperature and wind speed at five different places in Sweden. (Normal monthly values.)

BIII.3 BUILDING DESIGN SOLUTIONS

BIII.3.1 External walls

TIMBER WALLS

By tradition, external walls with a timber frame construction are quite common in Sweden both in single-family dwellings and in dividing walls in multi-family housing. The basic design is illustrated in Figure BIII.6. The choice of facade cladding is optional to a certain extent. Brick or timber are common in single-family dwellings whereas timber or metal cladding is used on multi-family housing. Sheets of timber material or plasterboard are often used as a wind barrier. Paper is sometimes used. Mineral wool is the dominating insulating material. Polyethylene film is often used as an air/vapour barrier in conjunction with an inner cladding of particle board or plasterboard. For the design to be as simple as possible and correct, it is important for the frame timbers to be positioned correctly so that standard format sheets of insulation and cladding can be accomodated as far as possible.

This type of wall is suitable for both on-site and factory production.

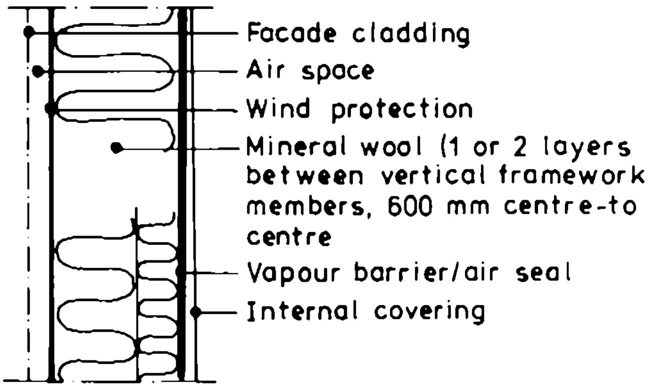
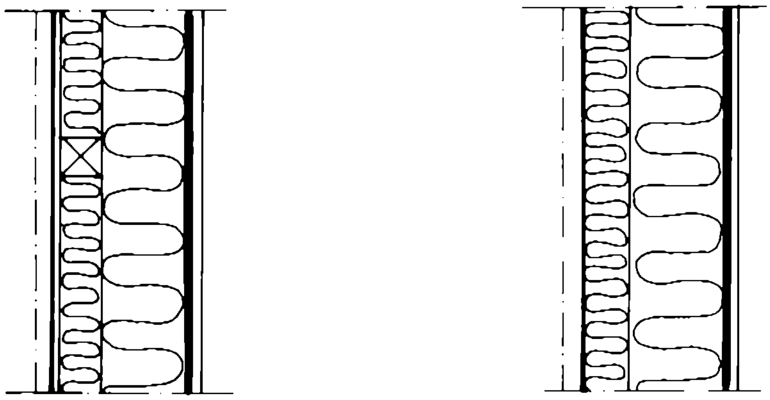


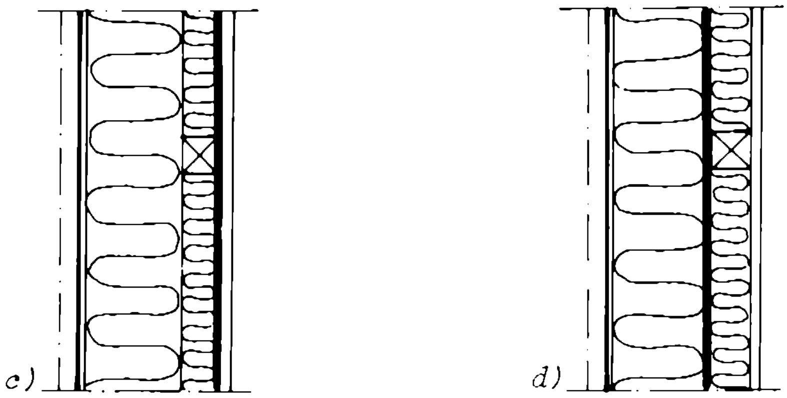
Figure BIII.6.
The basic design for a wooden-framed wall.

Current demands for thermal insulation often mean that insulation thicknesses often exceed 150 mm. Up to this thickness, a single frame timber can be used and the insulation installed as a single layer. But certain difficulties may arise in getting a satisfactory result using a single layer of this thickness — air gaps occur easily adjacent to frame timbers. Thus the use of several layers of insulation is becoming more common. Several variations of wall structures are illustrated in Figure BIII.7.



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

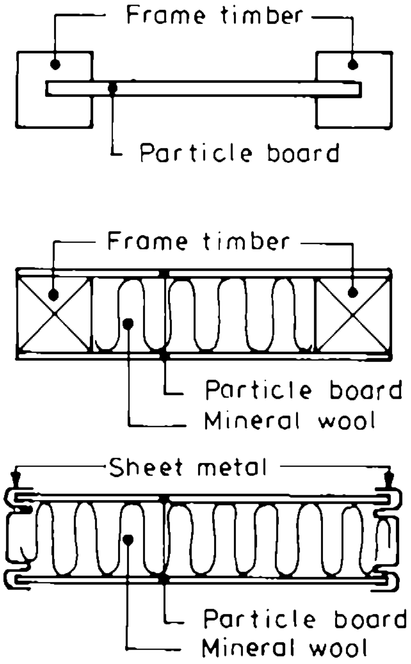


External vertical load-bearing framework and internal horizontal framework (the positioning of the air/vapour barrier differentiates the two methods)

Figure BIII.7. External walls with two insulation layers. Normally the total insulation thickness for these types of walls in Sweden is 145 or 165 mm.

When walls are constructed with a horizontal frame it could permit the installation of electrical parts entirely inside the air/vapour barrier if this is positioned in the wall as shown in Figure BIII.7d. Holes can almost completely be avoided and thus the potential for building an airtight house is greatly increased. Moisture considerations mean however that there must be sufficient insulation outside the vapour barrier. At least 2/3 of the total insulation thickness should be outside the vapour barrier.

For even greater insulation, walls sometimes employ a triple frame construction with a triple layer of insulation. As an alternative, several new timber frame designs have been developed which allow the insulation thickness to be significantly increased without the quantity of timber needing to be increased. These designs also reduce the thermal bridging effect of timber studs. Examples of the principles of such light frame designs are illustrated in Figure BIII.8.



a) "The Masonite beam" is constructed of two frame timbers, approx. 45 x 45 mm, which are joined together with particle board. Jointing is achieved by glueing and pressing according to a specially developed method.

b) In this construction, two thin frame timbers are joined with two thin particle boards with mineral wool between.

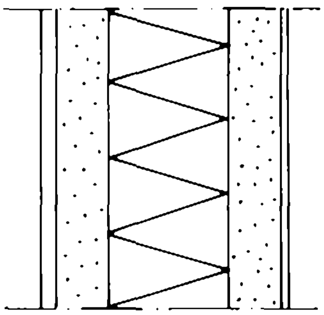
c) This construction employs galvanised steel sheeting instead of frame timbers.

Figure BIII.8. Examples of light frame constructions used in walls with thick insulation.

The light frame structures are interesting from an economical aspect at insulations thicknesses of 200 mm and upwards. Compared with homogeneous timber frames they have the advantage that they are straighter and less sensitive to moisture movement.

CELLULAR CONCRETE WALLS

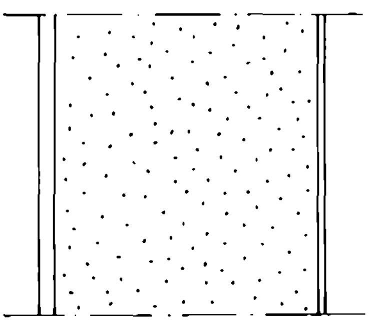
Cellular concrete walls are used primarily as dividing walls in multi-family housing. The reason for this is the requirement for a plastered facade and an uncomplicated wall. Two types of cellular concrete wall are used, sandwich structures known as lightweight elements and homogeneous cellular concrete in elements or blocks. See Figure BIII.9. Aerated concrete elements are manufactured to suit the



a) Cellular concrete "Lightweight element"

3-layer surface plastering or prefabricated facade
70 cellular concrete, quality group 500
160 polystyrene plastic, $\gamma = 15$ kg/m^3
70 cellular concrete, quality group 500
internal plastering

$k \sim 0.2$ W/m^2 ^{o}C



b) Homogeneous cellular concrete blocks

3-layer surface plastering outside
350 homogeneous cellular concrete
plaster + surface treatment

$k \sim 0.3$ W/m^2 ^{o}C

Figure BIII.9. Examples of types of cellular concrete walls.

height of apartments and 300 mm or 600 mm wide elements. Assembly is facilitated by the use of a building crane. Sealing between elements is done by jointing with easy-flowing cement in special joint channels. Cellular concrete is, in itself, sufficiently airtight and thus buildings made of the material are often very airtight. Among the advantages of cellular concrete walls is that electrical installations can be incorporated in the walls without risking the loss of airtightness.

CONCRETE WALLS

Sandwich walls of concrete are similar in construction to lightweight element walls. They are used to a relatively small extent in housebuilding. However, concrete is often used in gable end walls in multi-family housing. The gable wall is often made up of a sandwich structure as shown in Figure BIII.10. Concrete walls are airtight and provide a sufficiently good vapour barrier providing holes for cast mould bars are sealed.

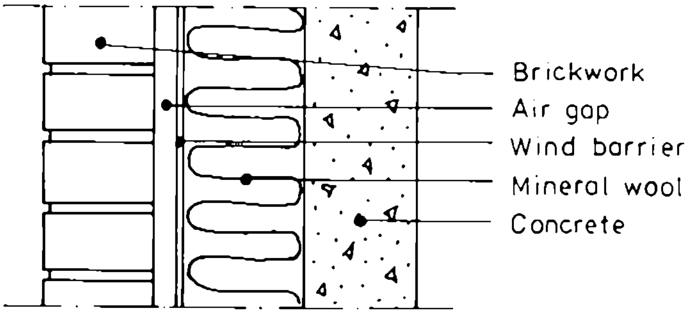


Figure BIII.10. Example of a gable external wall of load-bearing concrete in multi-family housing with brickwork facade.

BIII.3.2 Details for multi-family housing

A common method of building multi-family housing in Sweden is to use concrete for load-bearing walls and joists as illustrated in Figure BIII. 11. Gable walls of concrete with external insulation are fitted with a facade layer — often brickwork.

Longitudinal facades are made of light curtain walls whose prime function is a climate barrier. These are normally prefabricated. The problem of achieving an airtight structure on site is primarily concentrated at the joints around the edges of curtain walls and at windows and doors built into the walls.

Figure BIII.12 shows joints in lightweight elements for intermediate and roof joist structures and next to windows. Figure BIII.13 shows an intermediate joist structure joint at an infill wall of timber.

Inadequate airtightness in the intermediate joist structure joint together with the cold bridge effect can give rise to discomfort for those occupying the dwelling. Airtightening must therefore be carried out carefully and must be well prepared on drawings. The intermediate joist structure's connection to the gable wall with a brickwork facade is illustrated in Figure BIII.14.

The jointing of internal load-bearing walls to external walls is illustrated in Figure BIII.15. The figure shows a plan of joints for two different types of external walls.

A further sensitive item at intermediate joist structures is where concrete slabs extend outwards, for example at balconies. A conflict

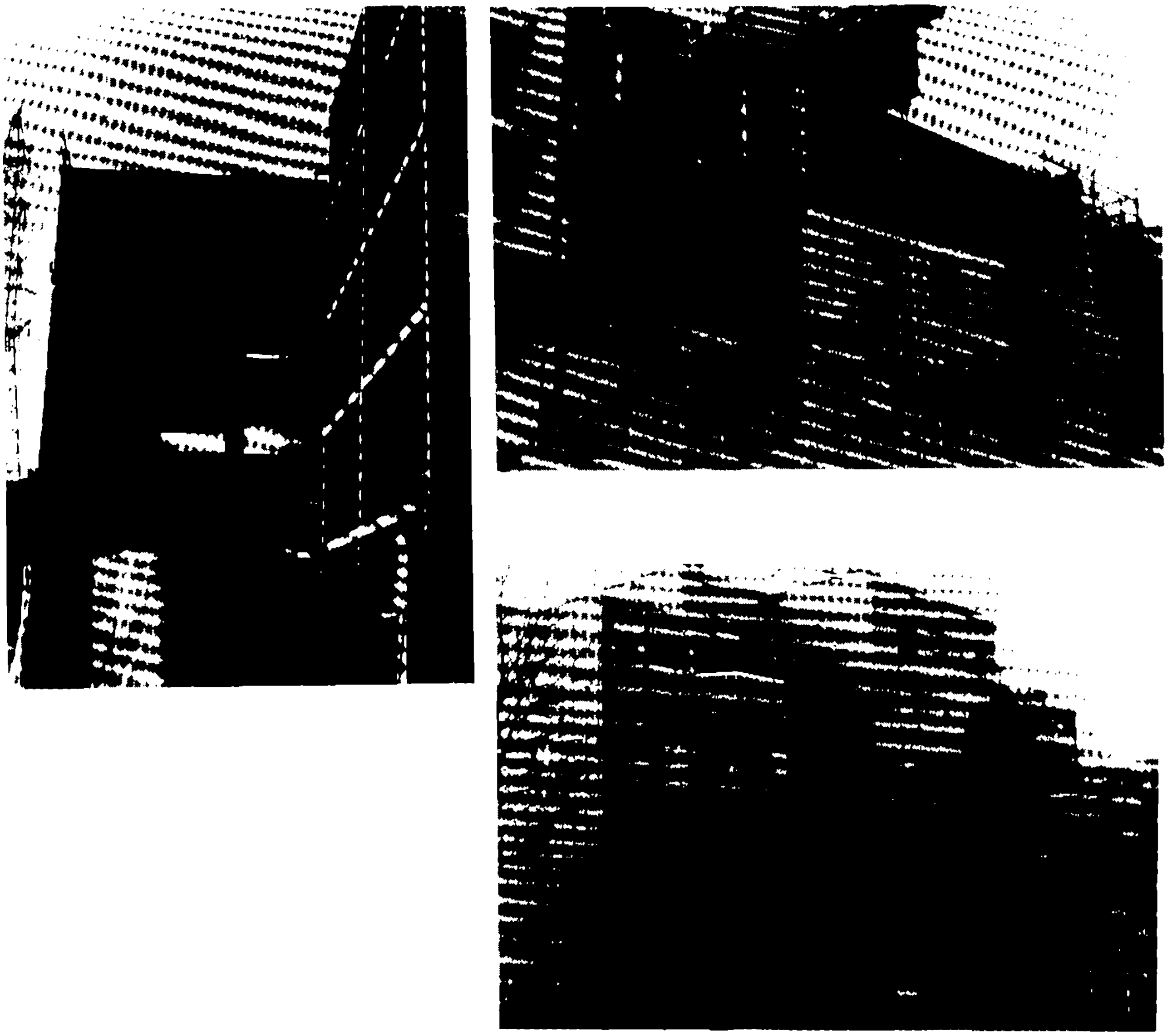


Figure BIII.11. The framework principle in a multi-family dwelling. Vertical and horizontal load-bearing frames are made of a concrete structure. Gable walls are insulated externally and have facade covering. Other external walls are often made of lightweight curtain walls.

The polyethylene sheets of the outside of the curtain walls in the figure are joined at the edge of the floor structure. This part is insulated and wind protected from the outside prior to erecting the facade.

arises between load-bearing and thermal insulation function at this location. Figure BIII.16 shows examples of solutions for two different types of external walls.

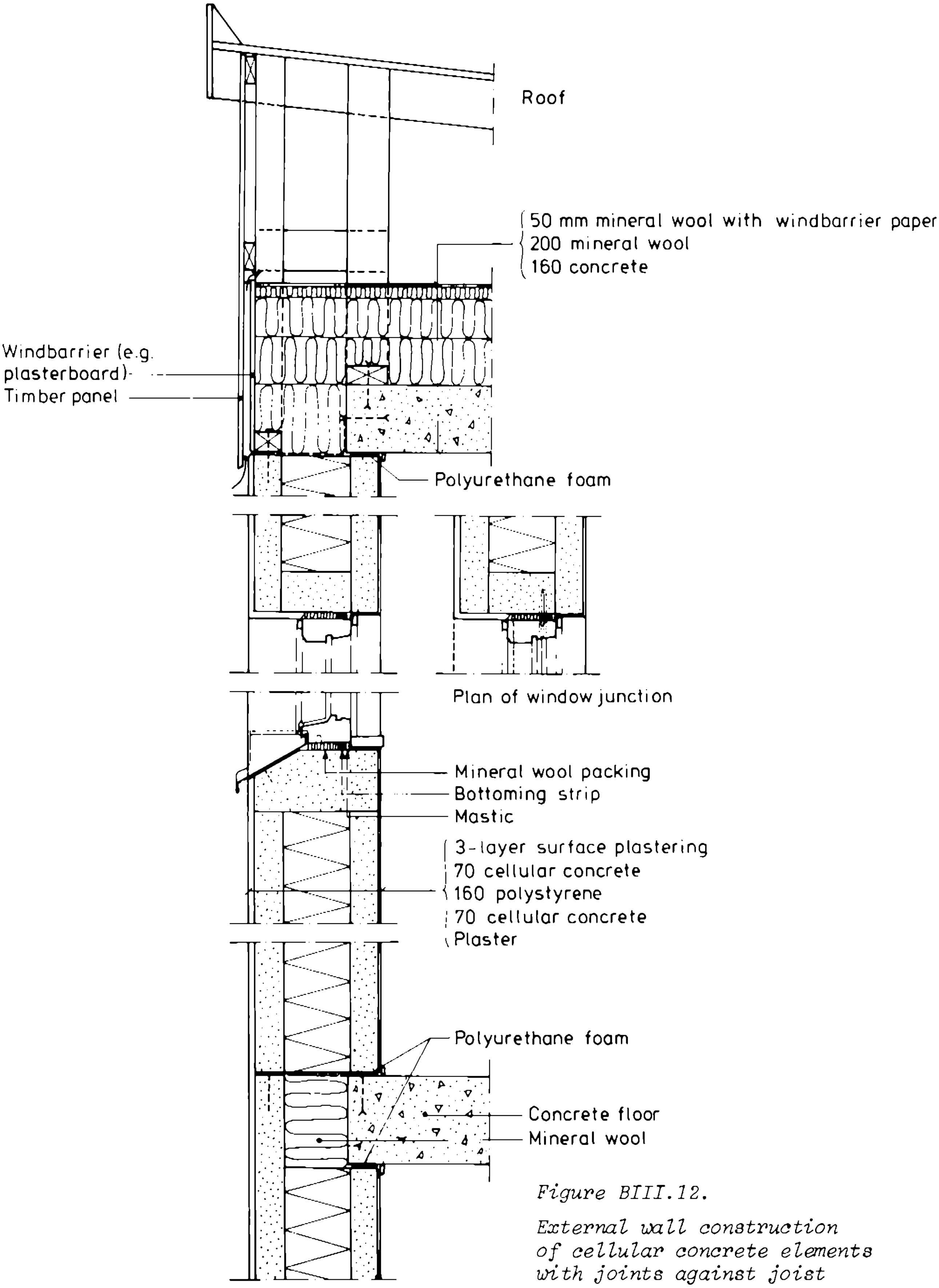


Figure BIII.12.

External wall construction of cellular concrete elements with joints against joist structures, windows and intermediate joist structures. Concrete and cellular concrete is in itself sufficiently airtight.

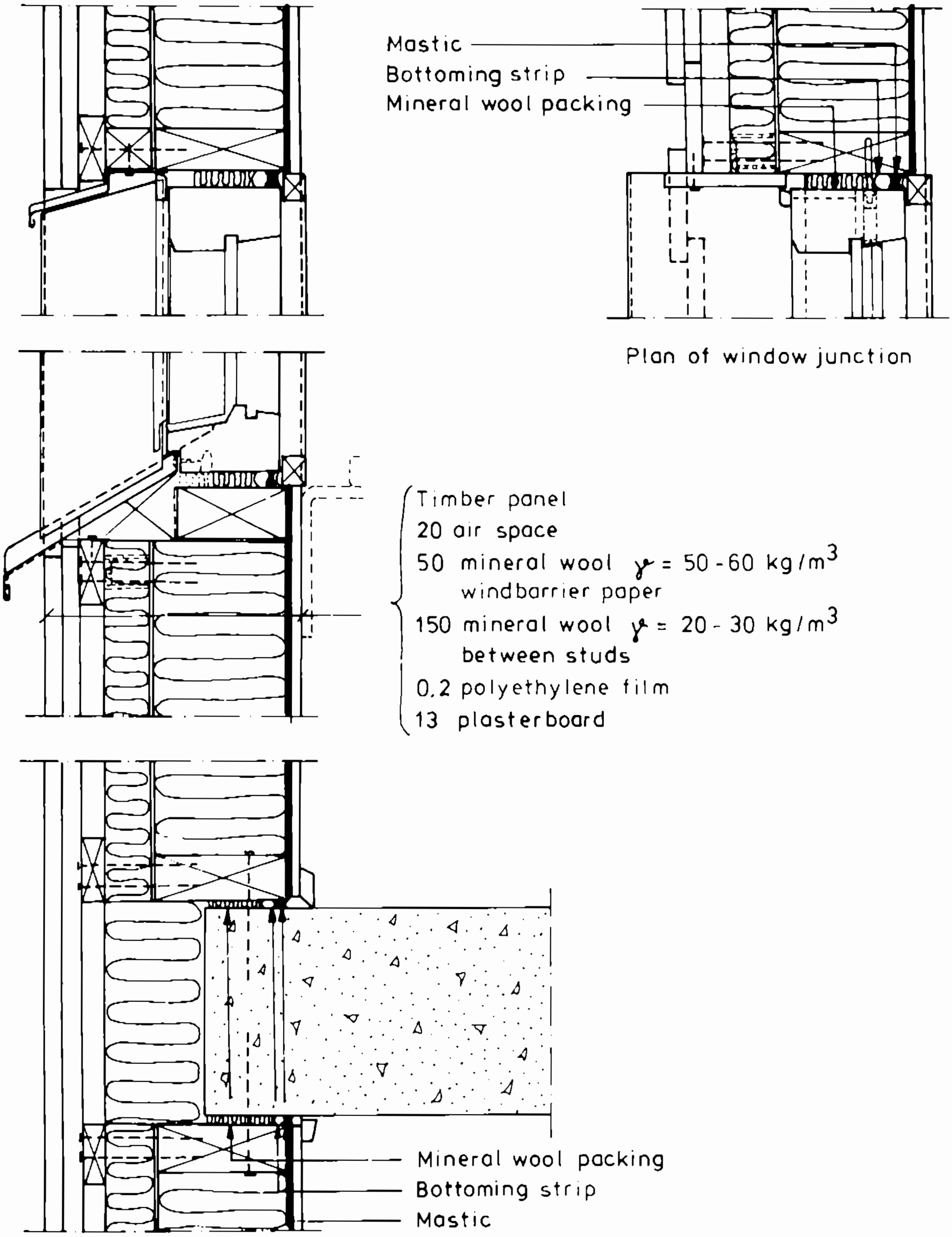


Figure BIII.13. External wall made up of timber curtain elements with joints against joist structures and windows. It is particularly important that the air seal around windows is positioned so that tightness against the polyethylene film is achieved.

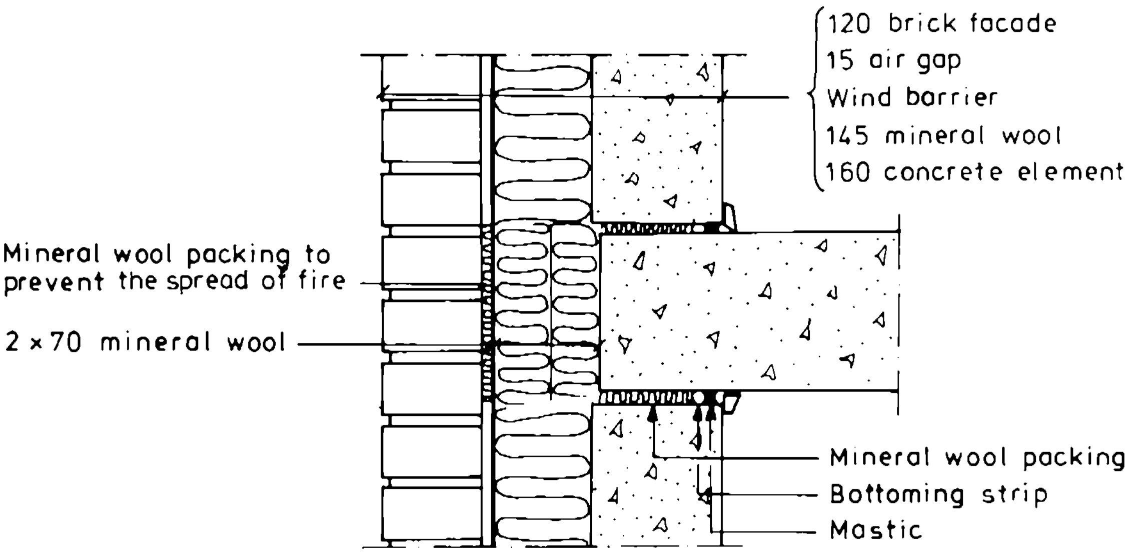
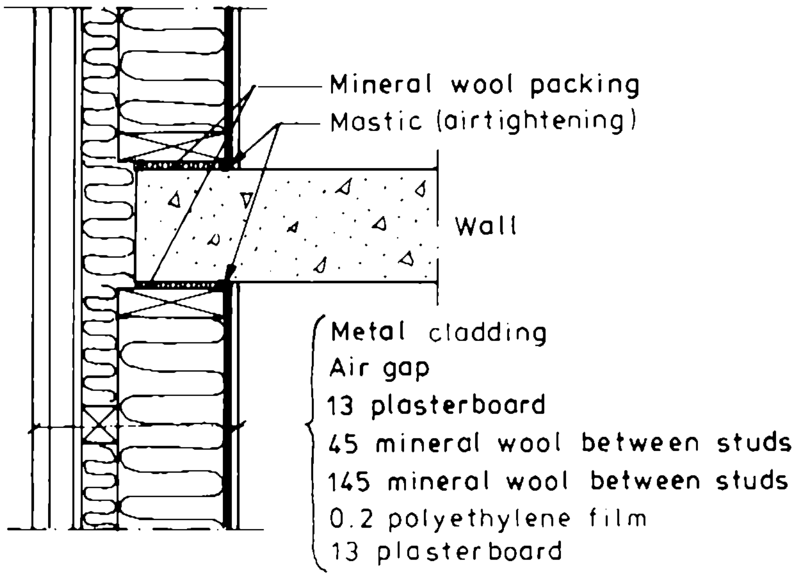


Figure BIII.14. The joint between a gable external wall of load-bearing concrete and an intermediate joist structure. Airtightness is achieved with mineral wool strips and internal mastic. From an insulation aspect, the full thickness of mineral wool should be opposite the joist structure.



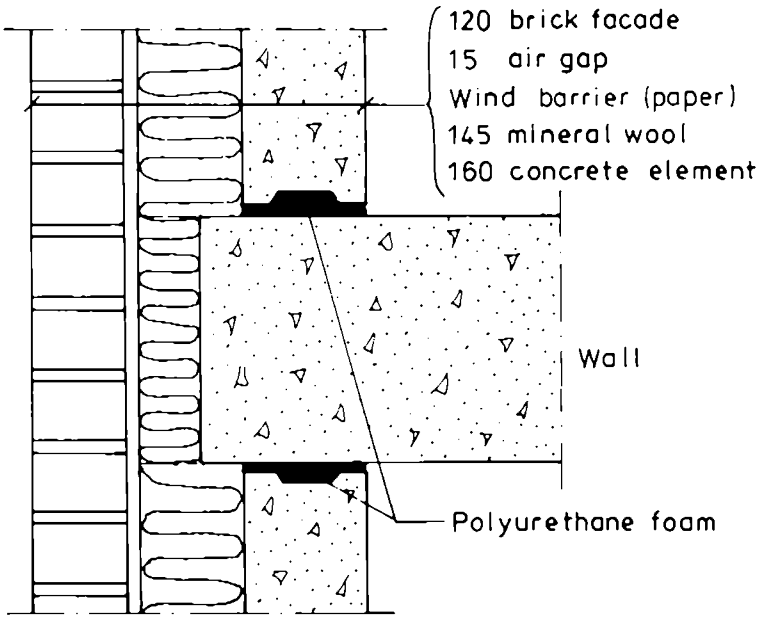


Figure BIII.15. Plan of joint between load-bearing internal wall and two different types of curtain wall. Joint sealing employs internal mastic with mineral wool. The latter comprises the actual airtightness and should be positioned so that airtightness is achieved against the polyethylene film in the actual wall element. Polyurethane foam is used to seal against concrete elements.

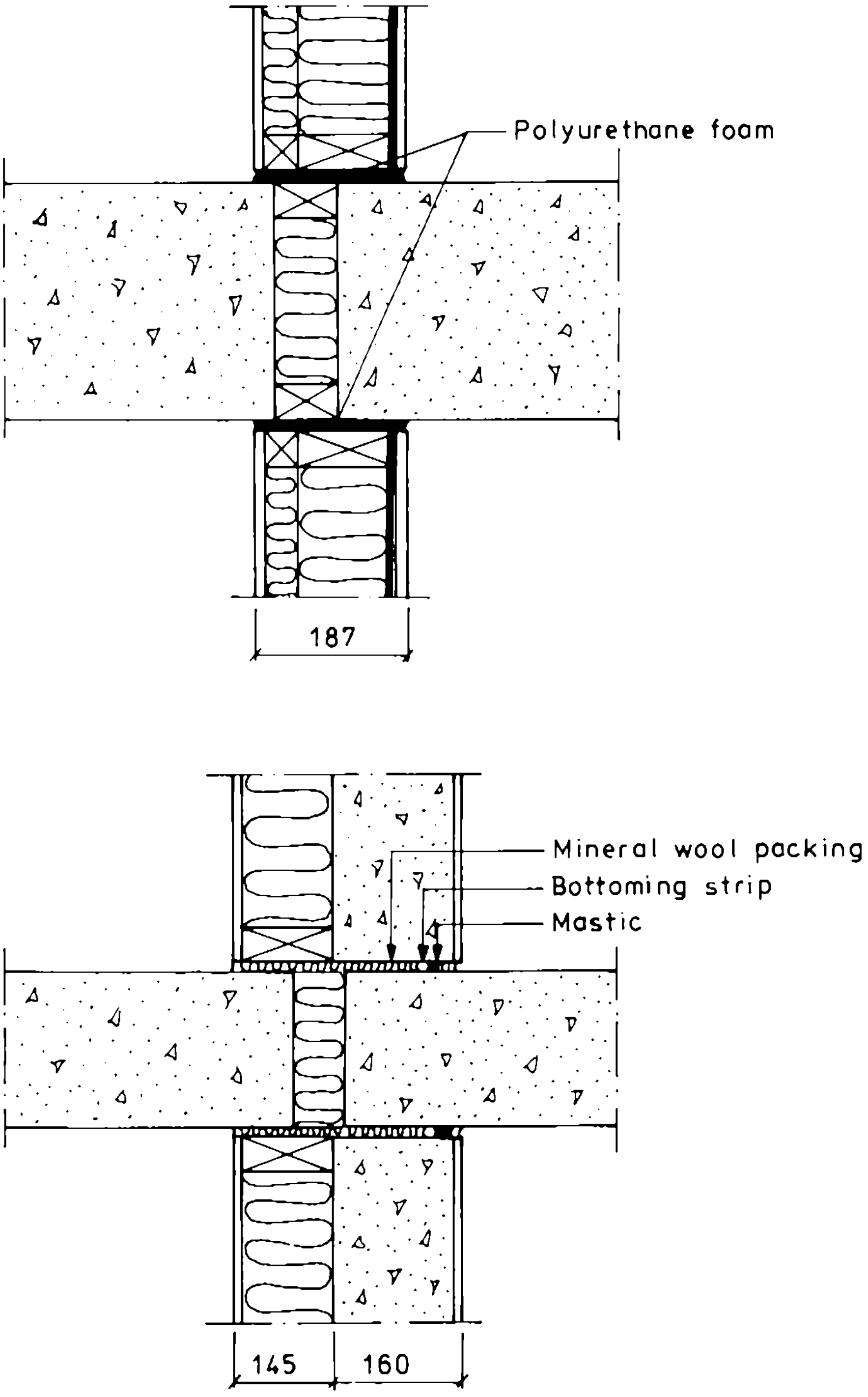


Figure BIII.16. *Joints in two different external wall constructions against joist structures at balconies. Bearing in mind that, for structural reasons, it may be necessary to reduce the insulation thickness between the edge of the joist structure and the balcony, it is particularly important that the cold bridge effect is not amplified by air leakage. Airtightening must therefore be carried out carefully. The example shows two different ways of achieving airtightness — polyurethane foam and mastic respectively.*

BIII.3.3 Single-family dwellings

The majority of single-family dwellings currently constructed in Sweden use timber in the supporting structure. A small number of houses are built of other materials – primarily lightweight cellular concrete. Single-family dwellings are built in several different ways: detached houses, terraced houses, linked houses or patio houses. Detached houses are often built as units using a large proportion of prefabricated elements. Brickwork is often used as facade material. Other house types are usually built in groups using timber as the primary facade material.

The following shows examples of both detached and non-detached housing constructed of both timber and lightweight concrete. There are also examples of design solutions which are assumed to comply with the particular requirements demanded as of 1 January 1983 for houses heated directly by electricity.

The examples shown are common single-family dwellings in Sweden in 1982. A large proportion of the houses are thermographed and pressure tested to check airtightness and the state of thermal insulation.

DESIGN FOR SITE-BUILT DETACHED HOUSES

This construction is an example of a standard design produced and applied by Svenska Riksbyggen – one of Sweden's largest housing customers. This house type is very common – it is known as a 1 1/2-floor house.

When developing solutions, experience gained from building has been noted continually so that the solutions become as simple as possible without jeopardizing function. A principle drawing shows a summary of the construction's makeup (Figure BIII.17). An assembly diagram shows where the airtightening polyethylene film may be jointed. Joints are not permitted elsewhere. The way in which joints and junctions are to be made is shown on a large number of detail drawings (Figures BIII.18-BIII.25).

All design details should be shown on drawings — the majority in a format suitable for use on site

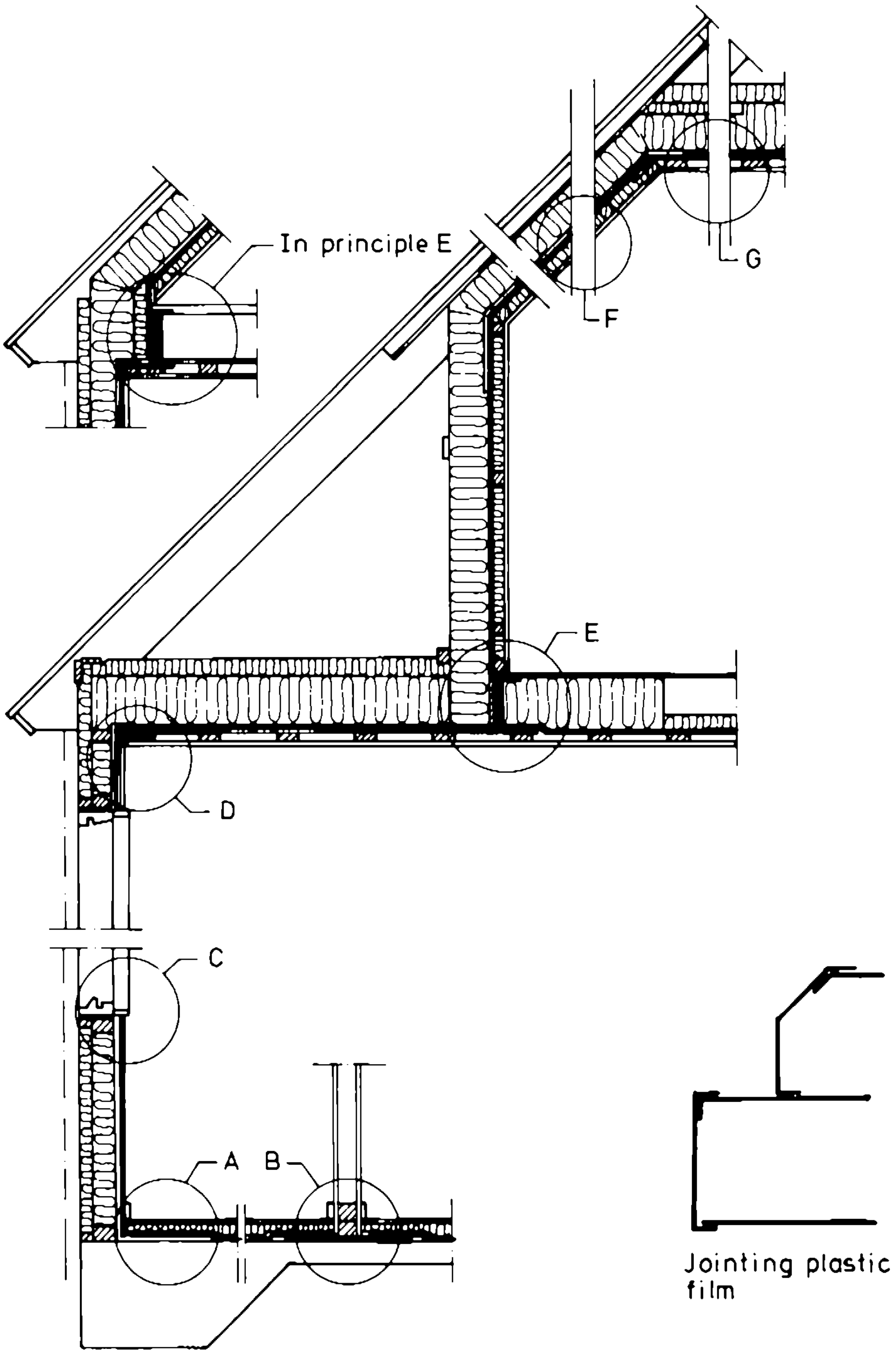


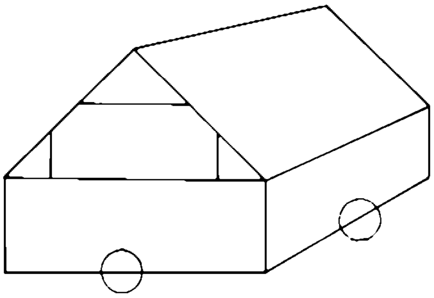
Figure BIII.17.

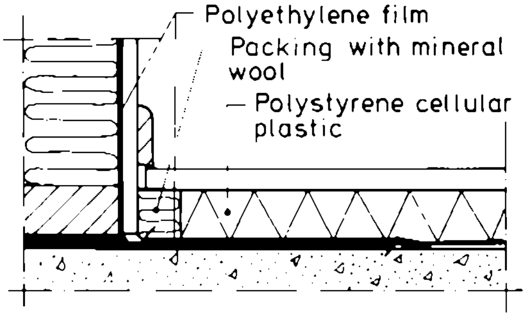
Standard for fitting polyethylene film according to Svenska Riksbyggen. The film used shall comply with the requirements of the Swedish Plastics Federation, Verksnorm 2000. Polyethylene fabric in joist structures must withstand accidental foot pressure in accordance with Memorandum 1976:15 issued by the National Swedish Board of Occupational Safety and Health.

If the film is damaged, small holes may be repaired with tape whereas the film must be replaced if there are large holes. The latter must be of a format which permits clamping all round against the rest of the film.

Unless otherwise stated in the building description, the building contractor is responsible for satisfactory sealing of services openings and holes.

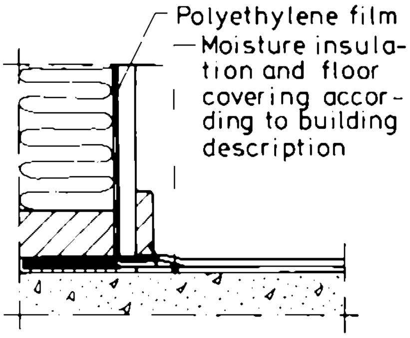
Details A — G are shown in Figures BIII.18-24.





Floor's polyethylene film is to overlap the wall's by at least 200 mm

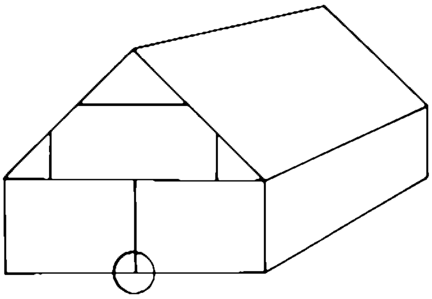
a) Thermal insulation above concrete slab

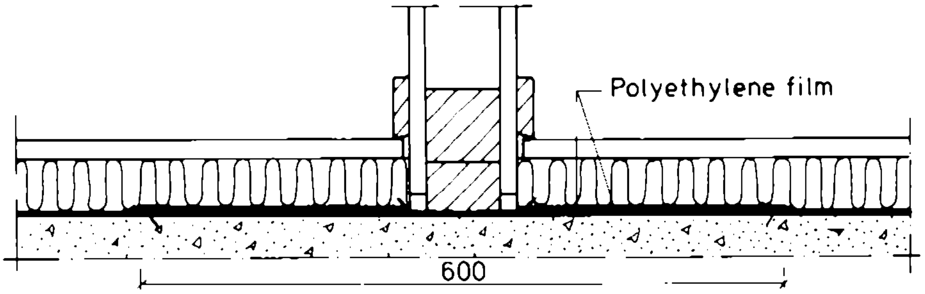


The wall's film is tacked to the wall while the floor's moisture insulation is being applied. The film is then cut off and folded down so that it overlaps the floor's moisture insulation by 15-20 mm

b) Thermal insulation below the concrete slab

Figure BIII.18. Detail A — Joint between external wall/ground construction (floor at ground level).

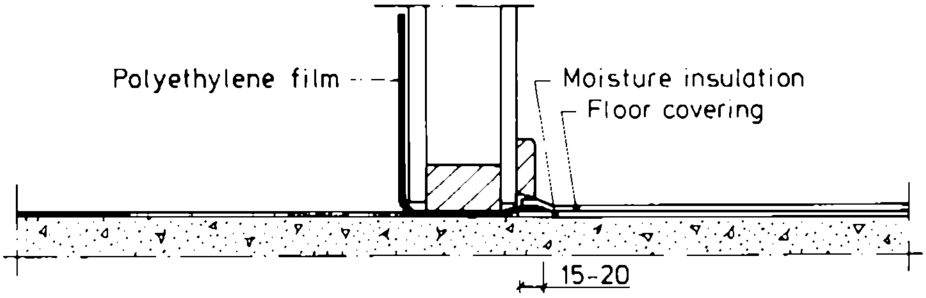




A polyethylene film, at least 600 mm wide is laid under the wall. the rest of the floor film must overlap this as shown in detail

It is very important for timber battens not to be in direct contact with the foundation plate bearing in mind the risk of moisture damage

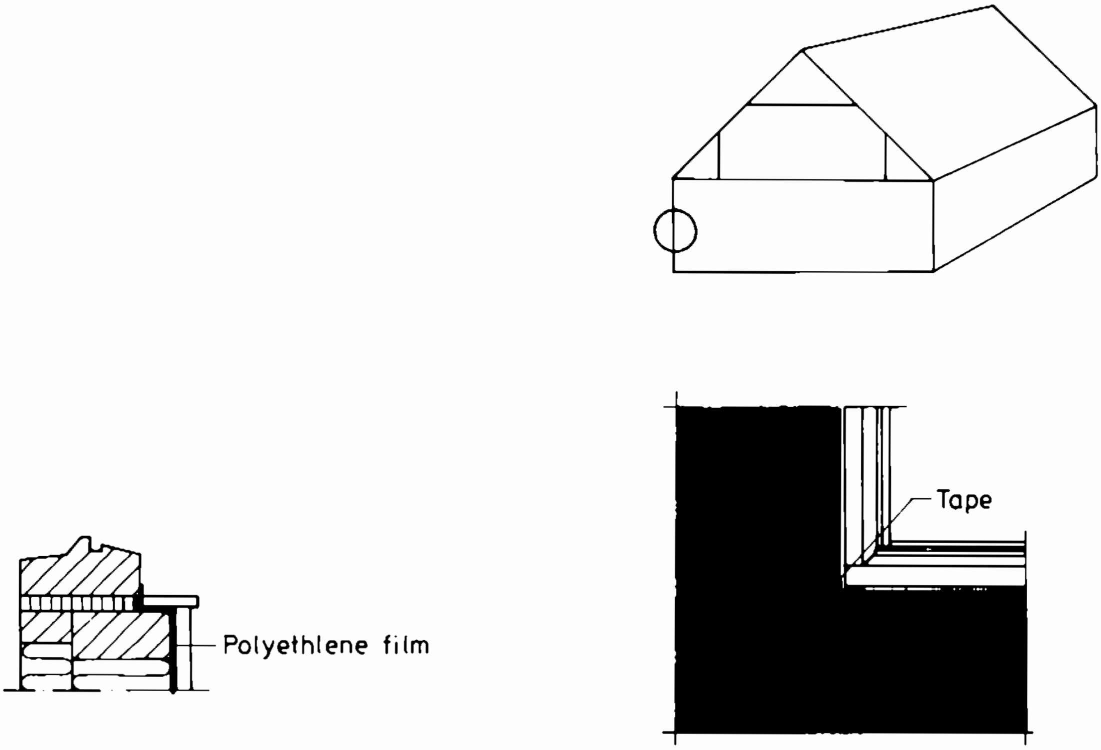
a) Thermal insulation below concrete slab



A polyethylene film is placed under the wall. This film is tacked onto the wall while the floor's moisture insulation is applied (e.g. painting with primer). The moisture insulation is to be applied up to the wall. The folded-up film is trimmed off so that, after folding down, it overlaps the floor's moisture insulation by 15-20 mm

b) Thermal insulation below the concrete slab and floor covering (plastic matting for example) directly above the concrete

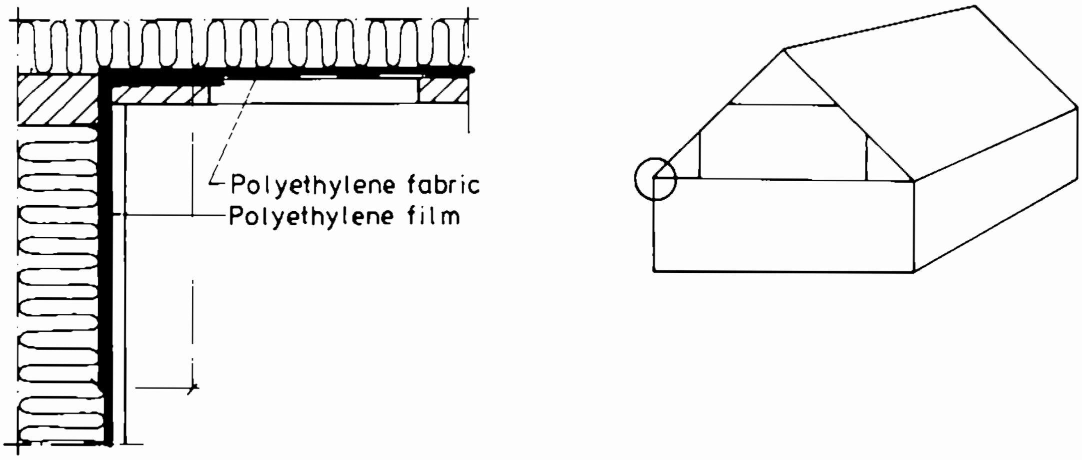
Figure BIII.19. Detail B — Joint between load-bearing inner wall — floor construction.



The polyethylene film is carefully fitted against the seal around the window frame. The joints at the window splay are taped as shown in the figure to the right

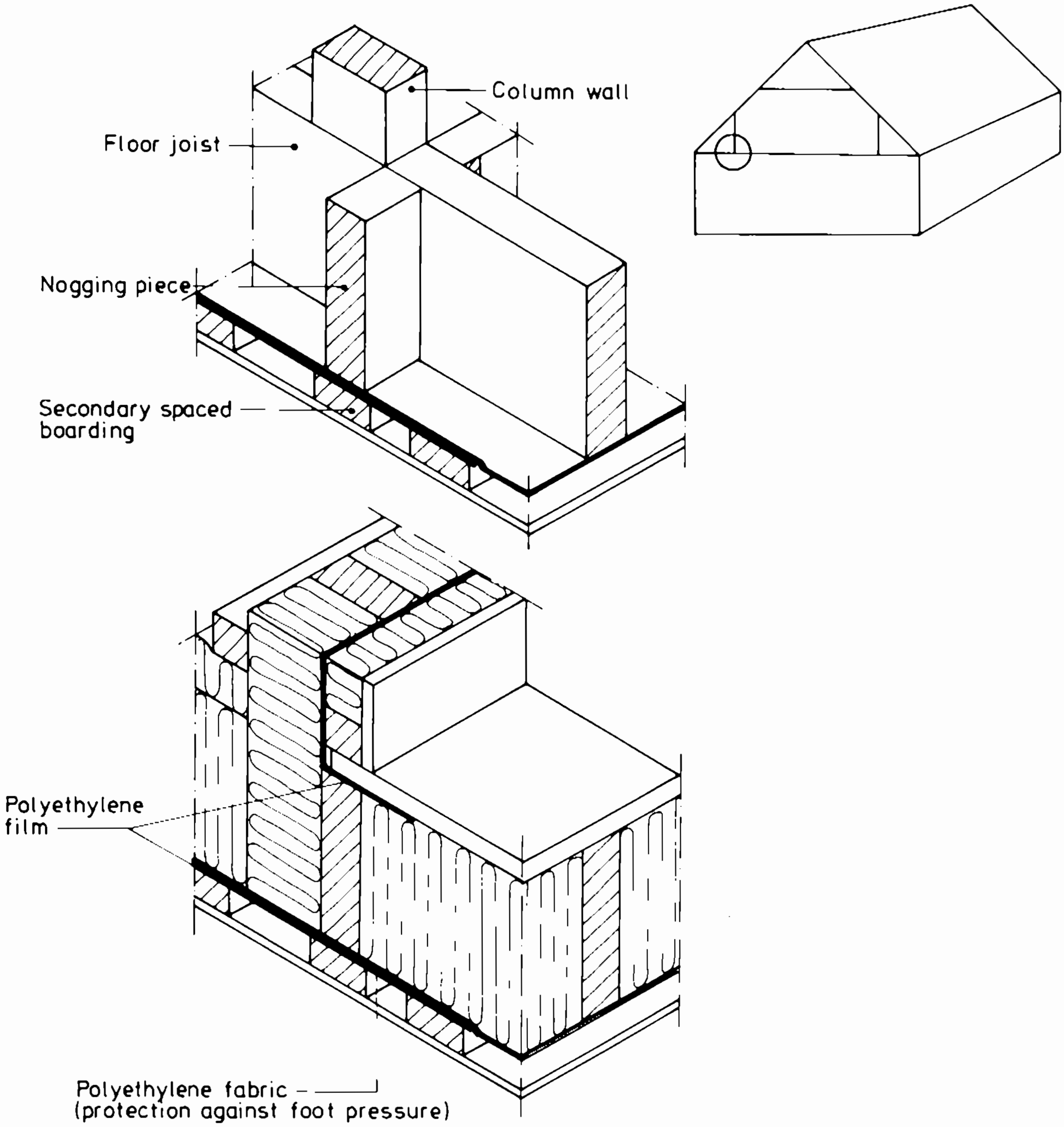
The window should be positioned as near to the inside as possible so that airtightness between the frame and wall is in the same plane as the airtightness – film – in the wall. In this way, the risk of leakage at the corners is reduced

Figure BIII.20. Detail C – Joint between outer wall – window.



The jointing of the polyethylene film in the wall against the film and fabric in the roof is made by overlapping which is clamped in position when the internal board is fitted

Figure BIII.21. Detail D – Joint between outer wall – roof.

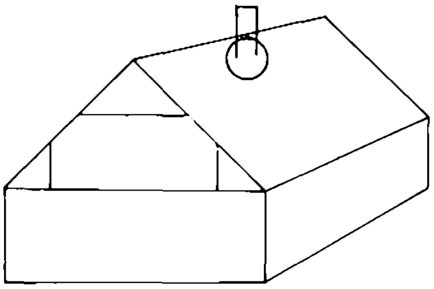


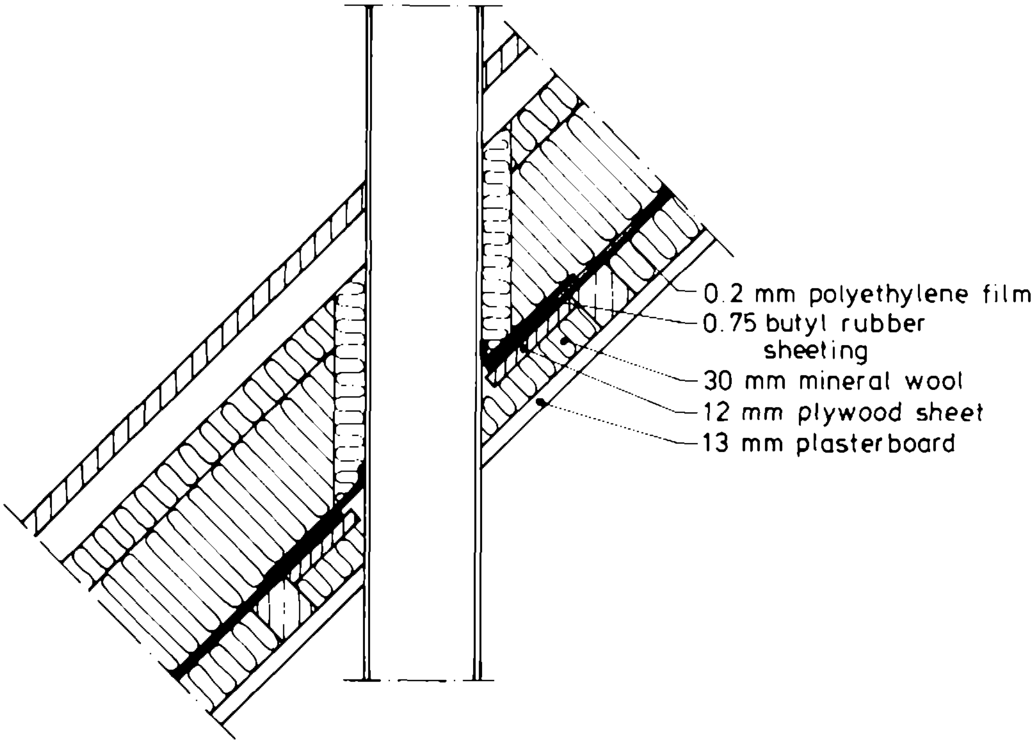
This is the most difficult detail to make airtight in this type of house. In the example, the load-bearing floor joists are alternated at the column wall. In this way, the number of joists passing the airtightness layer is reduced while at the same time the film joints can be pressed together

The column wall's film is folded out over the nogging piece and clamped between it and the floor material

The ceiling's film is fitted and clamped between the nogging piece and the secondary spaced boarding. If the boarding's position is unsuitable for this, an additional batten is fitted for clamping the film against the nogging piece

Figure BIII.22. Detail E – Joint between column wall – intermediate joist structure.

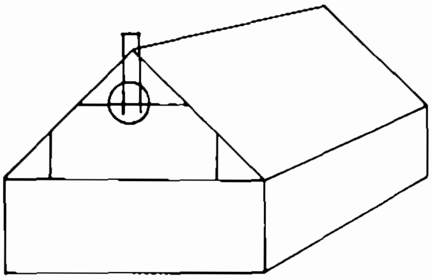


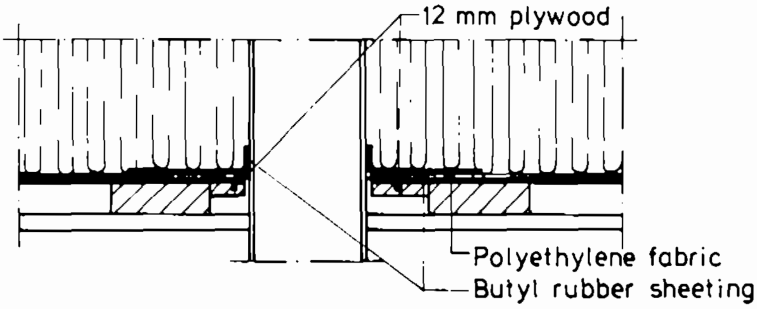


A plywood sheet is attached under the roof trusses and between battens in the section where the duct is to pass through. An oval hole is made in the plywood sheet somewhat larger than that required for the passage of the duct. A sheet of butyl rubber in which a hole has been made is placed on the plywood sheet. The hole diameter should be approximately 50 mm less than the outer diameter of the duct. The rubber sheeting should overlap the polyethylene film by at least 100 mm

Considerable work is required for a passage of this type to have good airtightness. It is therefore important that the number of passages is as small as possible. Note that if two ducts are positioned adjacent to eachother that it is almost impossible to achieve good airtightness

Figure BIII.23. Detail F — Duct passage through sloping roof.

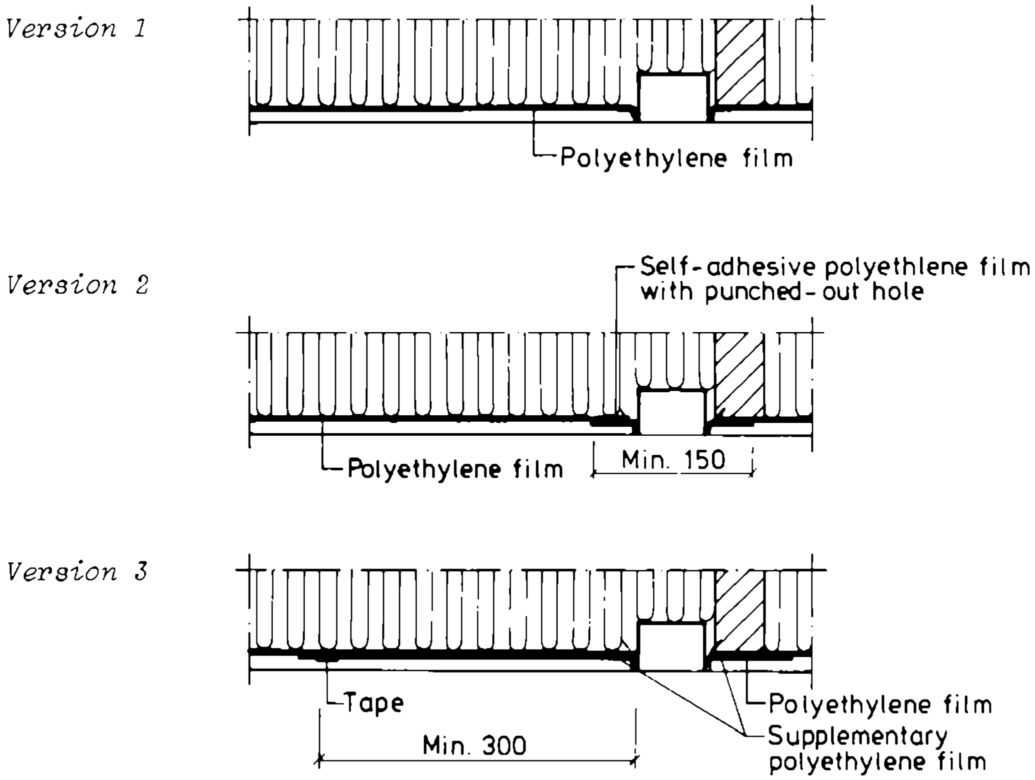




A plywood sheet is affixed under the roof trusses and between secondary spaced boarding in the sections where the pipe passages are to be situated. A hole somewhat larger than the pipe's outer diameter is made. A sheet of butyl rubber in which a hole has been made is placed on the plywood sheet. The hole diameter should be approximately 50 mm less that the pipe's outer diameter. The rubber sheeting should overlap the polyethylene fabric by at least 100 mm

Refer also the the comments under Figure BIII.23

Figure BIII.24. Detail G – Pipe passage in flat roof structure.



Fitting polyethylene film around an electrical socket can be carried out in one of the three following ways:

Version 1

Make a round hole in the polyethylene film opposite the electrical socket somewhat smaller than the socket and then stretch the film over the socket

Version 2

Make a hole in the polyethylene film opposite the electrical socket and roughly the same diameter as the socket's outer diameter. The film is then supplemented with a self-adhesive polyethylene film with minimum dimensions 150 x 150 and with a punched hole smaller than the socket. The film is then stretched onto the electrical socket

Version 3

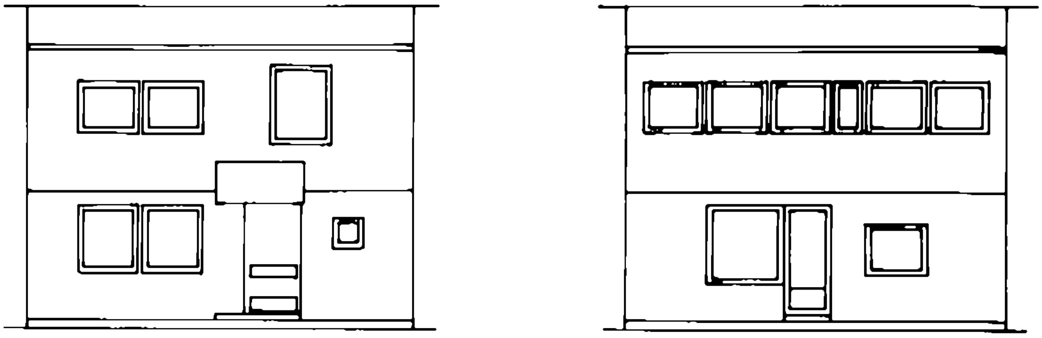
Make a hole in the polyethylene film opposite the electrical socket and roughly the same diameter as the socket's outer diameter. The film is then supplemented with a self-adhesive polyethylene film in which a ϕ 50 mm hole had been made. The supplementary film must overlap the wall's film by at least 300 mm at the edges which are not clamped against a batten. Tape edges which are not clamped

Irrespective which version is applied, the airtightness depends to a considerable degree on the quality of the work at the site. Avoid locating electrical sockets in external structures

Figure BIII.25. Sealing around electrical sockets in external or party walls.

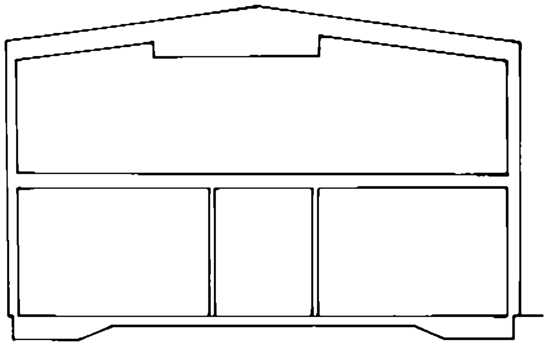
CONSTRUCTION FOR SITE-BUILT TERRACED HOUSING

The following example is based on design drawings from a building contractor (AB Folkhem). The constructions are taken from current production and refer to a 2 floor terrace house. The contractor has made use of experience from the Åkersberga project (see Section A3.2) to achieve optimum airtightness and energy consumption. The total purchased energy for heating, hot water and domestic electricity is in the range 12-14 MWh/year in the Stockholm climate. The comparatively low consumption has been achieved primarily through the favourable building design, good thermal insulation, considerable airtightness and controlled ventilation. The design of the house is shown in Figure BIII.26. Figures BIII.27-BIII.34 show a number of detail solutions for different critical points which are applied in these houses.

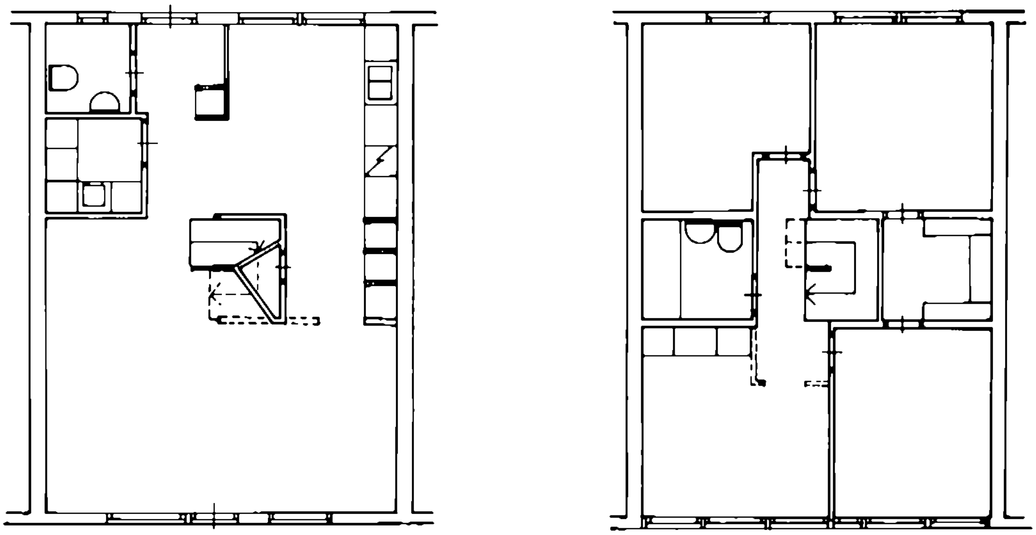


Entrance facade

Garden facade



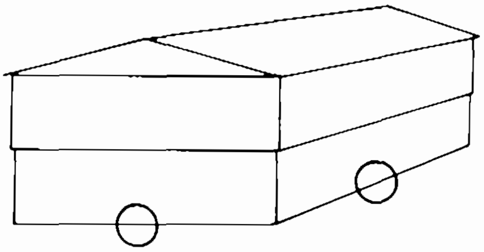
Section

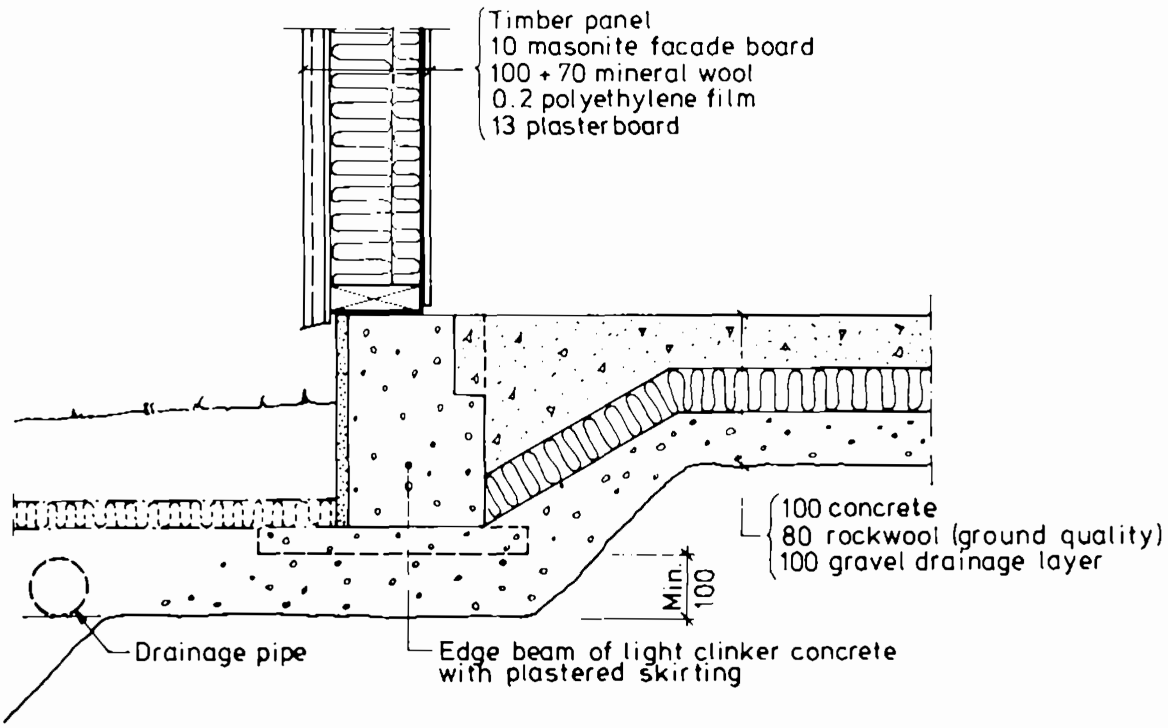


Entrance floor

1:st floor

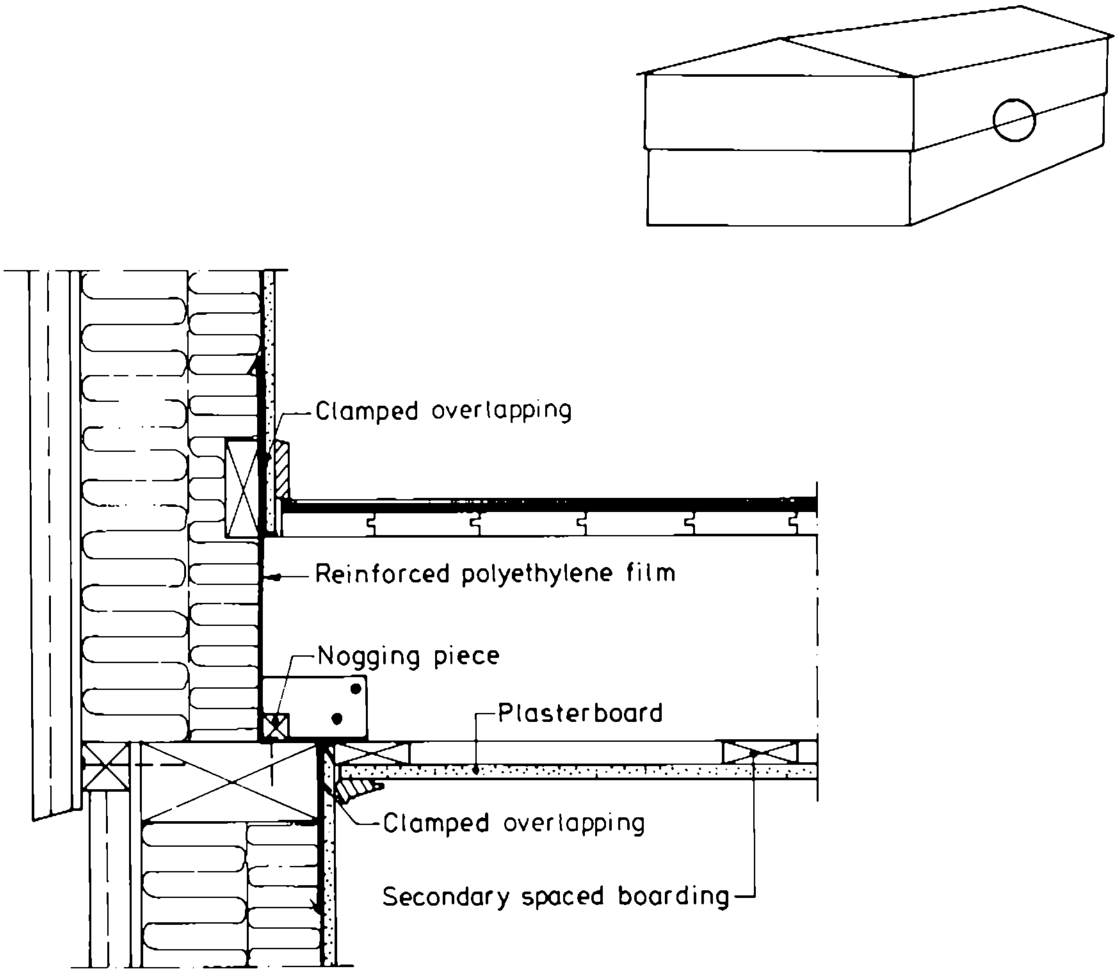
Figure BIII.26. Elevations and plans for the terrace house. The living area is approx. 120 m^2.





The airtightness layer under the sill comprises EPDM rubber strip. This has been found to be satisfactory providing the concrete is even (see Chapter A9). The wall's polyethylene film must be carefully applied to the sill, a string of mastic can be applied to the inside of the sill before applying the film

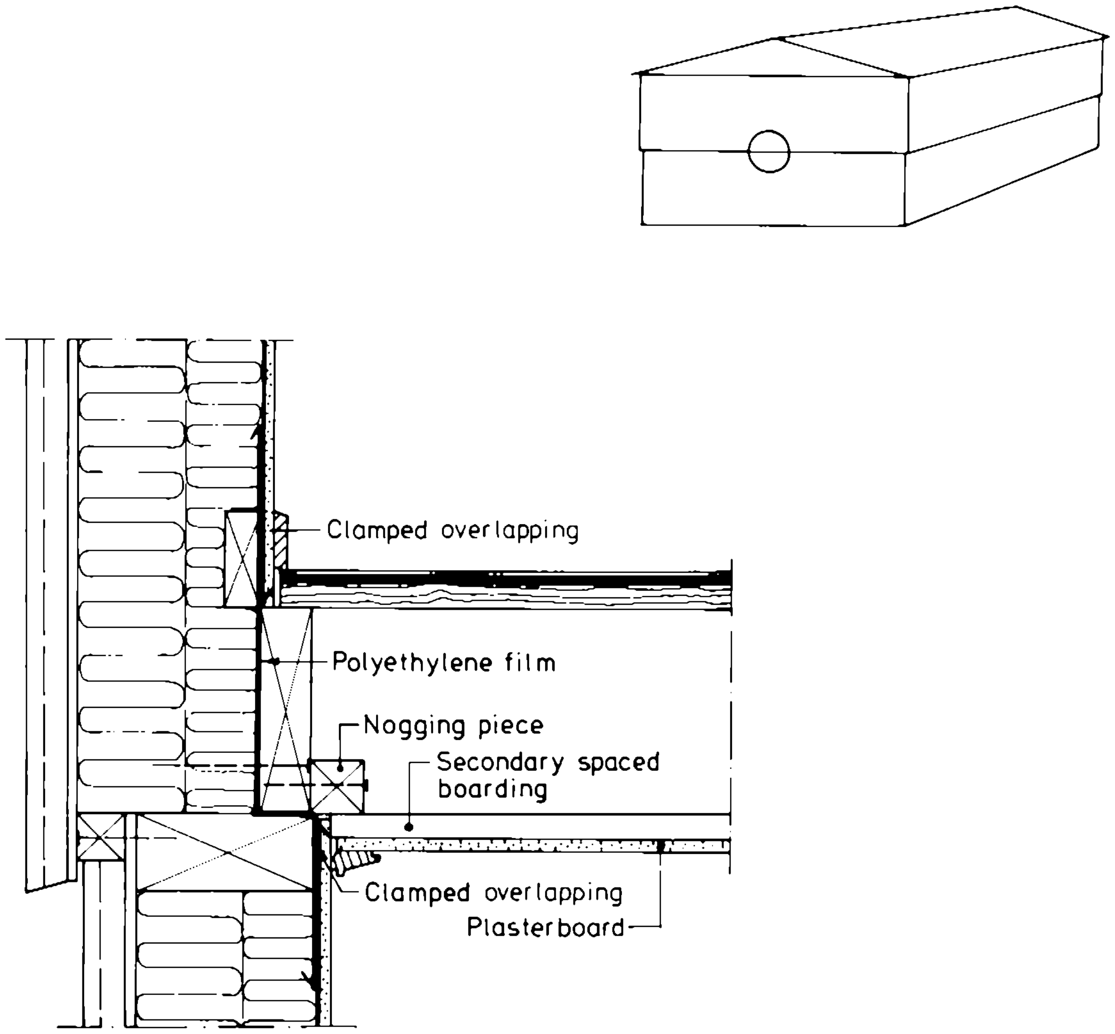
Figure BIII.27. Joint outer wall – foundation plate.



Continuity in the air/vapour barrier is achieved in this example with a strip of reinforced polyethylene film which can pass unbroken between the intermediate joist structure since the external wall in the upper floor is displaced outwards in relation to the external wall on the bottom floor. This strip, fitted when the framework was raised, is held in position between the joists with the aid of a nogging piece

The wall construction is the same as in Figure BIII.27

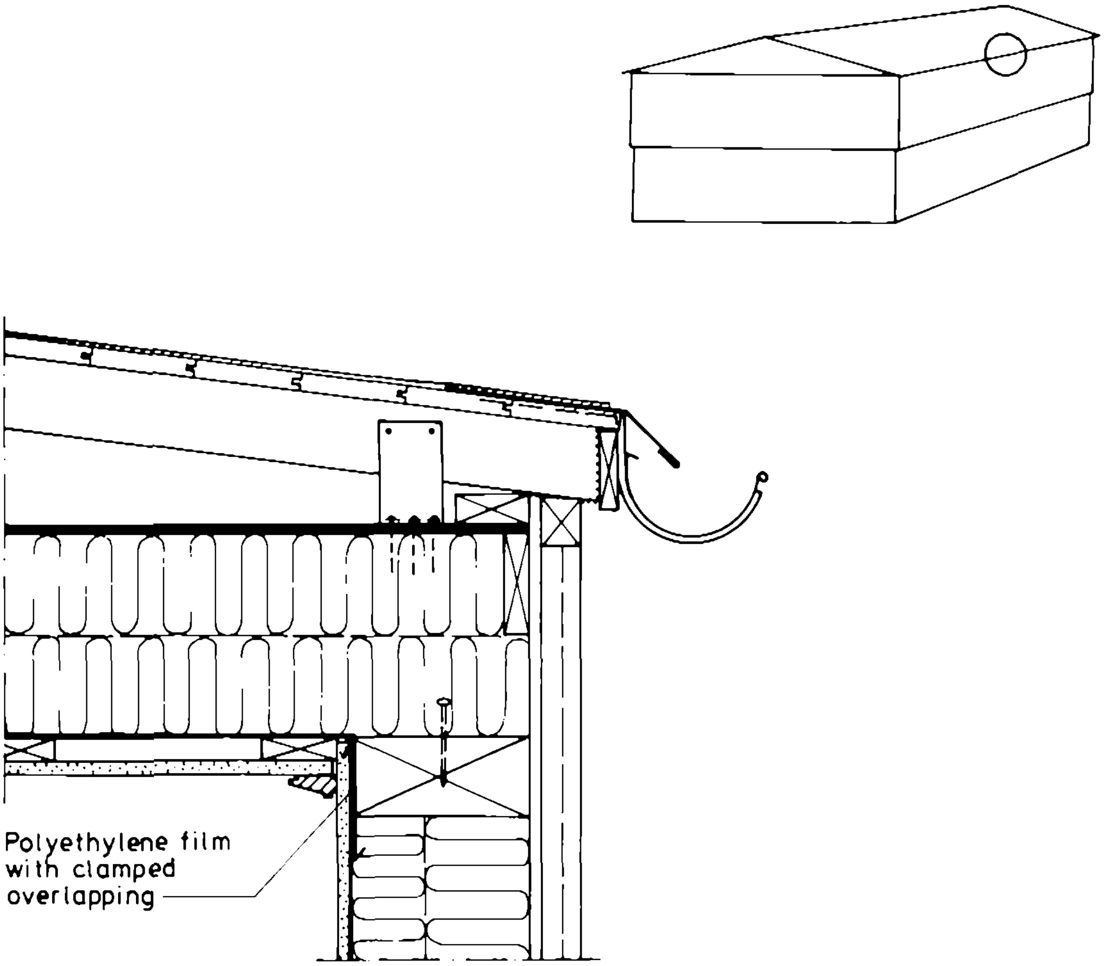
Figure BIII.28. Joint between outer wall (facade wall) – intermediate joist structure.



In this case, the polyethylene film is given support by the floor joists and need not be reinforced

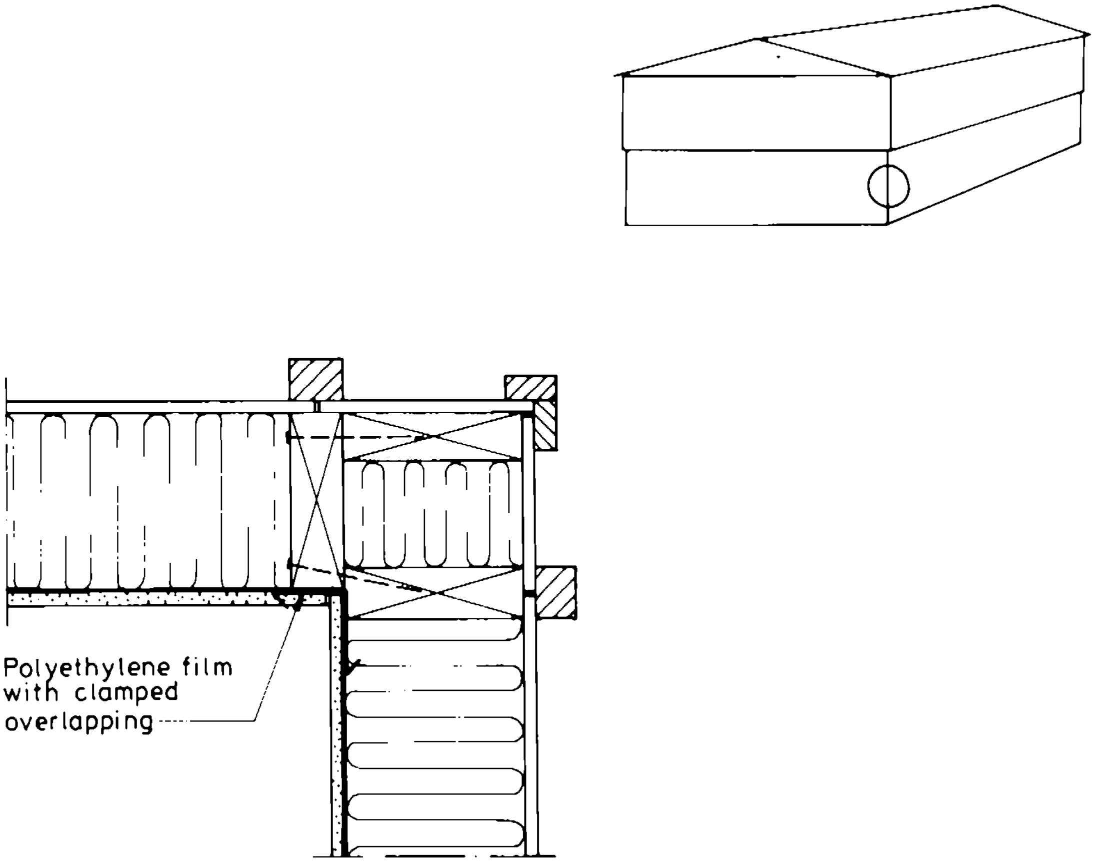
(Nogging pieces are needed for nailing to secondary spaced boarding)

Figure BIII.29. Joint between outer wall (gable wall) – intermediate joist structure.



Airtightness at the eaves is achieved by overlapping the polyethylene film which is clamped by the internal boarding on timber battens (capping plate). It is advisable to fold the film down onto the wall. It is particularly important for this joint to be airtight since incoming air leakage will give rise to cold downdraught along external walls. This can often cause hygienic discomfort – an amplified sense of draught

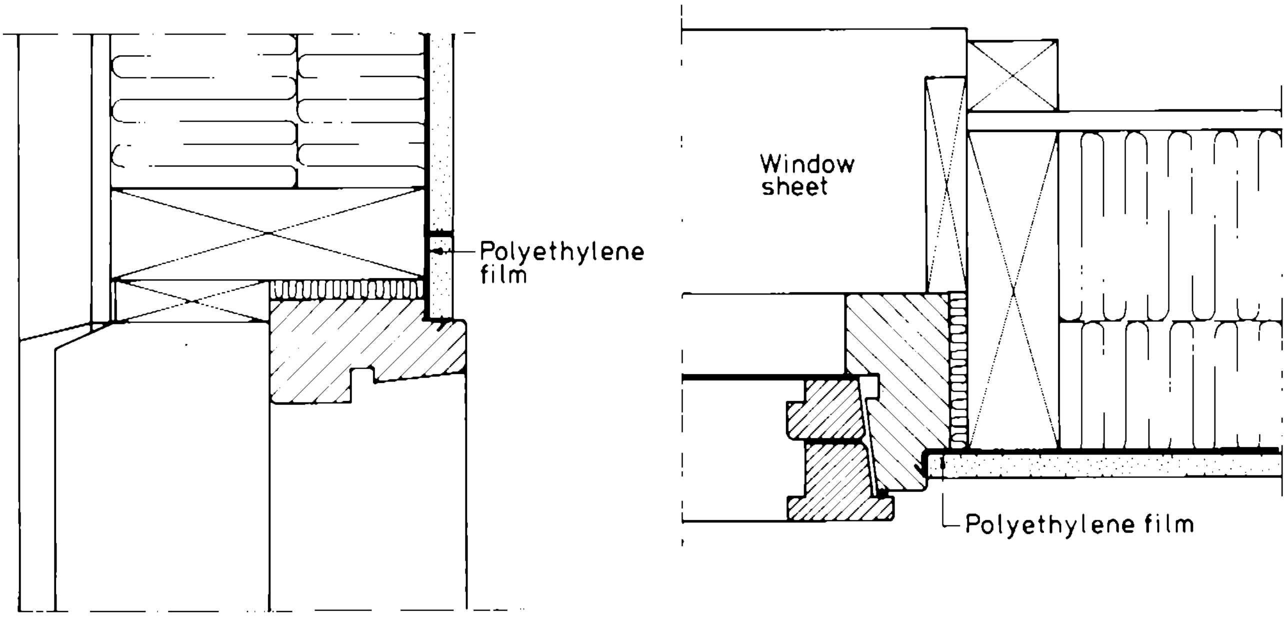
Figure BIII.30. Joint at the eaves.



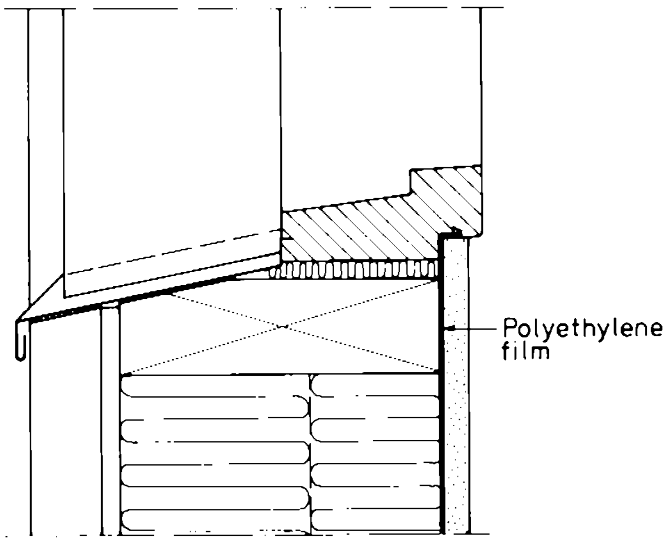
The horizontal view of the joint between external walls illustrated in Figure BIII.27. An extra batten is required in the corner to be able to affix boarding

The polyethylene film need not normally be jointed at the corner

Figure BIII.31. Joint between external walls (horizontal view).



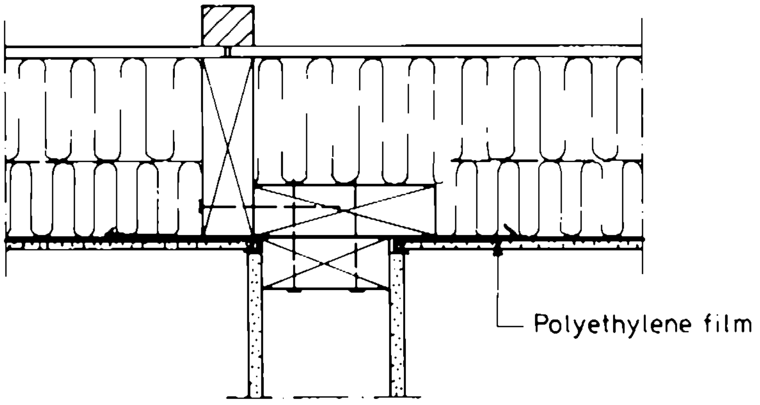
Plan



Section

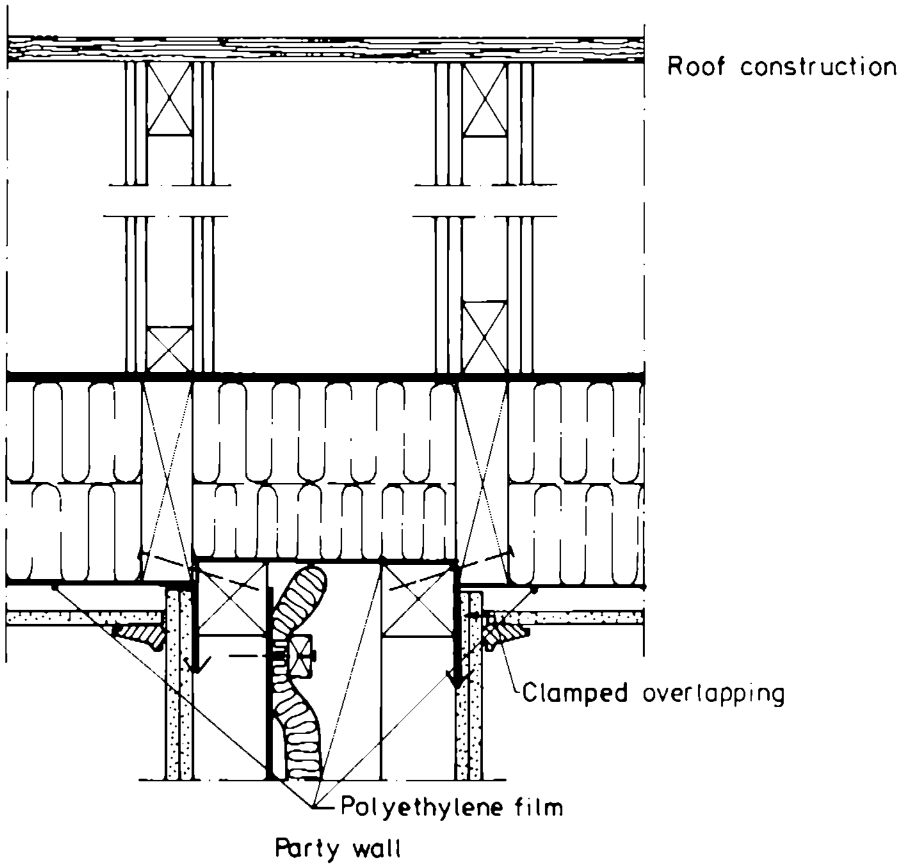
Airtightness in the joint is achieved by allowing the polyethylene film to pass the gap between the window and the wall and then clamping it with internal boarding against the window. This solution functions admirably but requires great accuracy during installation

Figure BIII.32. Joint at window.



A polyethylene film strip is installed in conjunction with frame erection against which the respective wall film is jointed. The position of battens ensures clamped joints and that the airtightness layer is continuous

Figure BIII.33. Joint between external wall – load-bearing internal wall (horizontal view).



Continuity in the airtightness layer is achieved in this case as well with a polyethylene film strip which is jointed to the polyethylene film in the respective house roof. By drawing this strip down a bit on the wall, clamped joints are possible. This film strip also prevents airflow within the party wall. This assumes of course that air leakage is prevented both at facades and at ground level

Figure BIII.34. Joint between party wall – roof (vertical view).

THE CONSTRUCTION OF SINGLE-FAMILY DWELLINGS WITH PARTICULARLY LOW ENERGY CONSUMPTION

As of 1983, houses which are directly heated by electricity must be particularly low energy users. Demands for thermal insulation will become more stringent and the demand for some form of heat recovery from ventilation air will be introduced. The following design example shows how a solution with greater insulation thickness can be applied. What are known as Masonite beams are used for wall, roof and joist structures. This means that the structures contain a minimum of cold bridges. The same spacing between battens in walls and roof trusses is used, i.e. c-c 1200 mm. This means that a relatively thick – 16 mm – chipboard with low formaldehyde content is used as internal boarding. The airtightness layer is made up of 0.2 mm polyethylene film except in floors where adequate airtightness is achieved through floor chipboard being nailed and glued to floor joists.

The design examples in Figures BIII.35-BIII.41 are based on solutions applied by Masonite AB to detached houses. The houses can be either site-built or prefabricated.

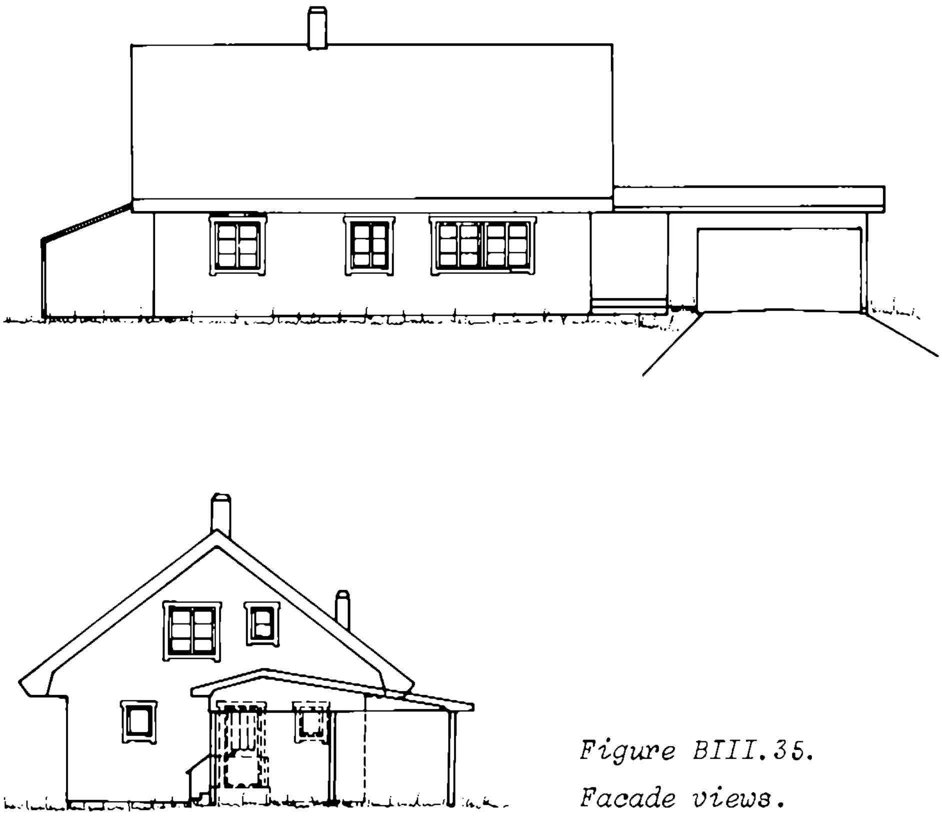
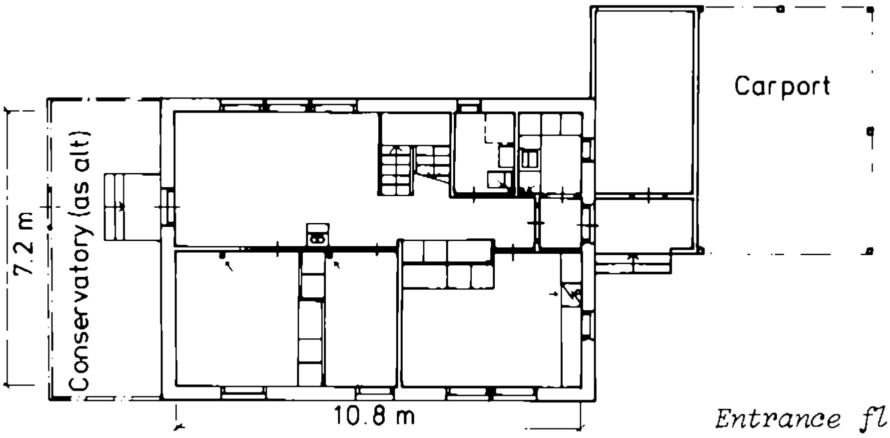
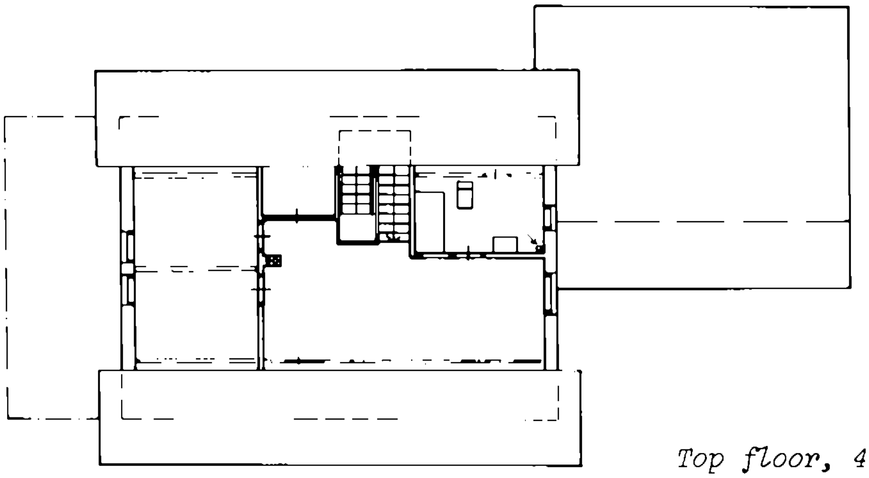


Figure BIII.35. Facade views.



Entrance floor, 78 m^2



Top floor, 47 m^2

Figure BIII.36. Plan views.

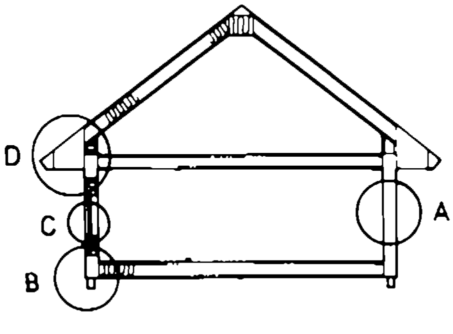
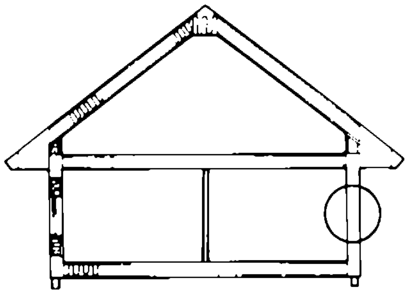
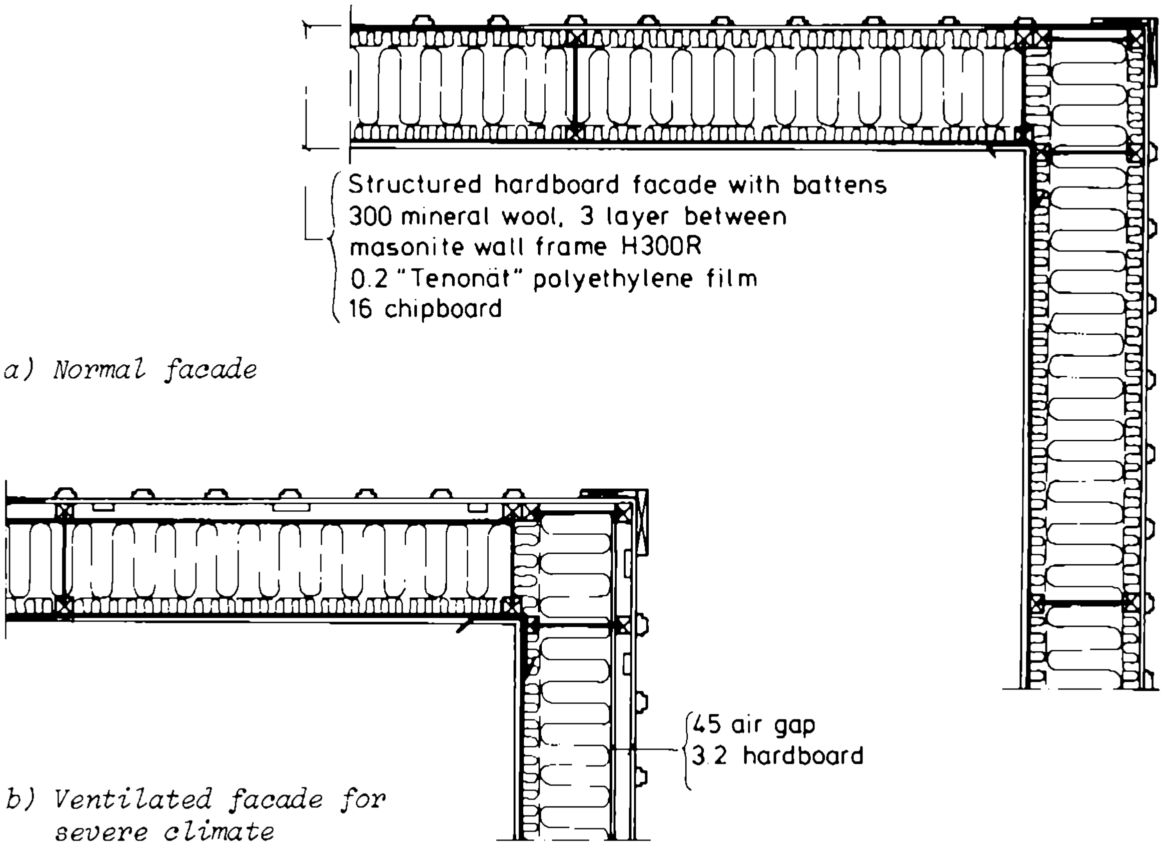


Figure BIII.37. Shell-frame system (C 1200).

The section shows the house's shell made up of Masonite beams C 1200 for both walls, joists and roof structures. The solutions at A-D are illustrated in the following.



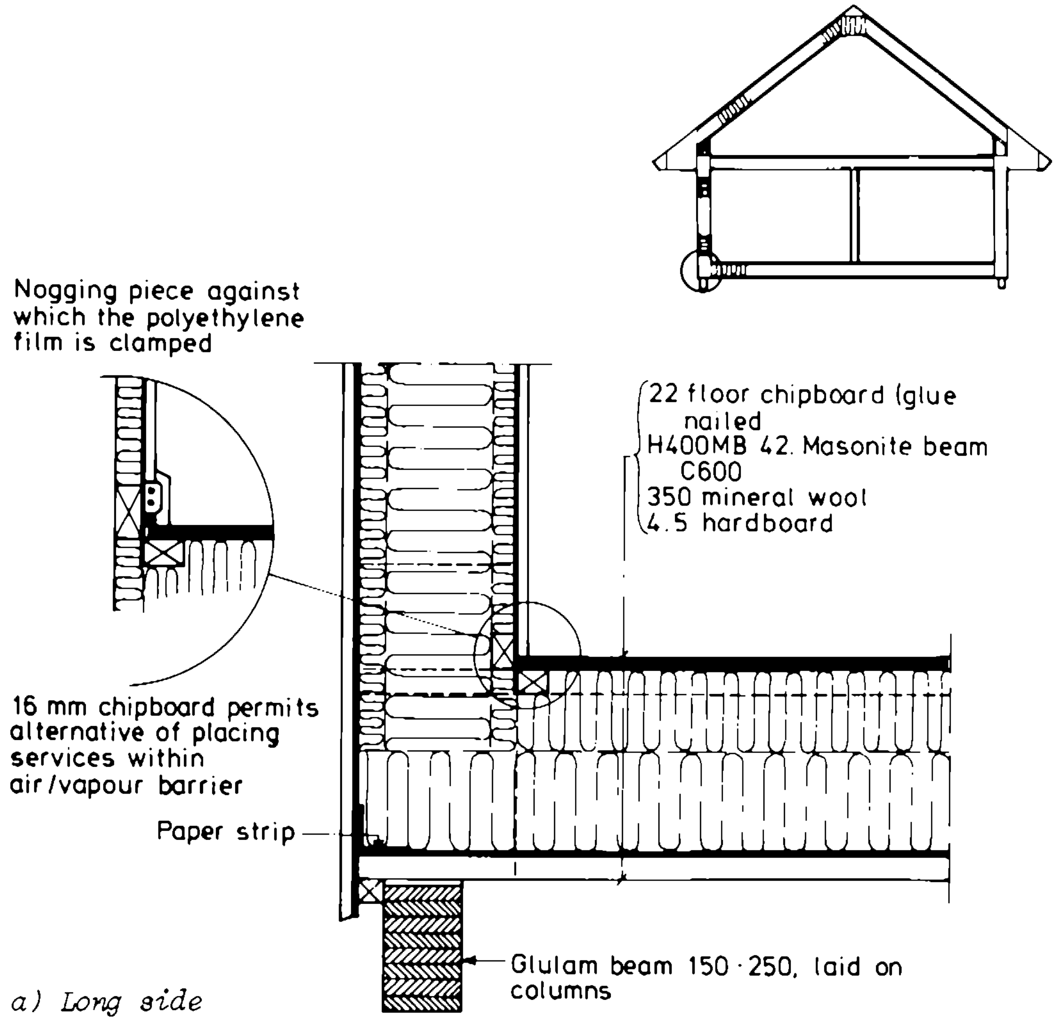


a) Normal facade

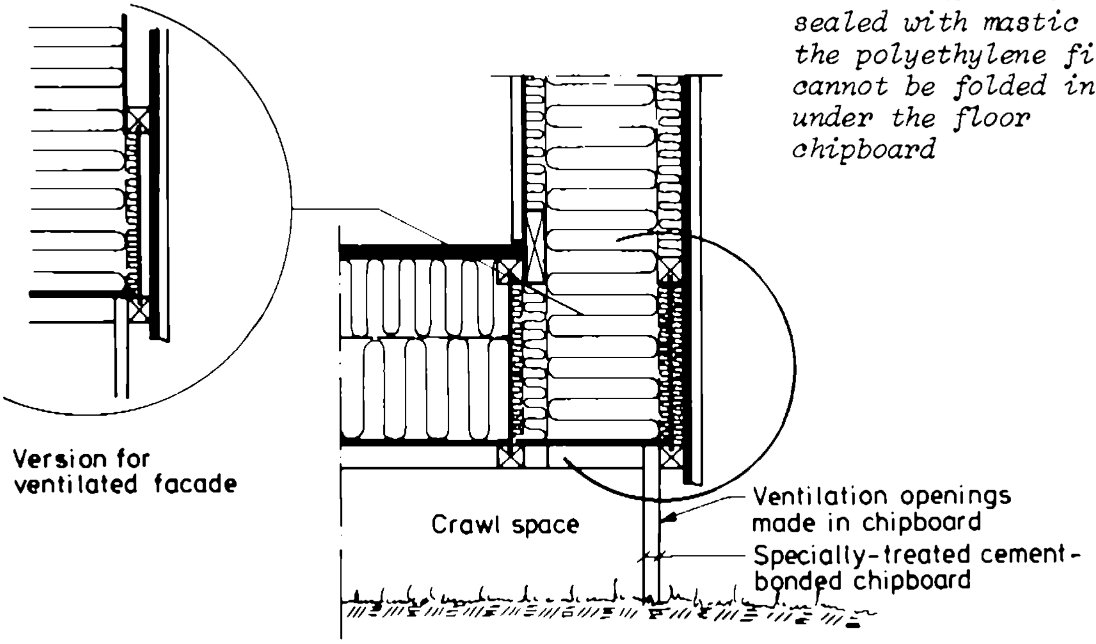
b) Ventilated facade for severe climate

In the case of site-built construction, the polyethylene film can be drawn "round" the corner so that continual sealing is achieved. The corners are sealed with mastic in prefabricated elements

Figure BIII.38. Joint between external walls (outer corner) detail A (horizontal view)



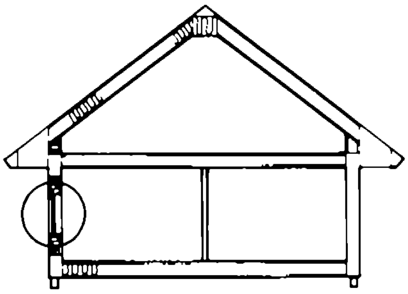
a) Long side

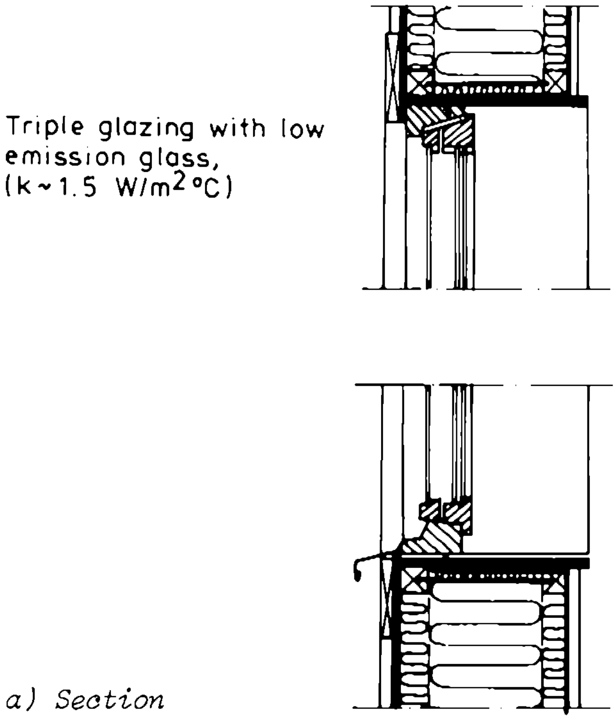


Floor corners are sealed with mastic if the polyethylene film cannot be folded in under the floor chipboard

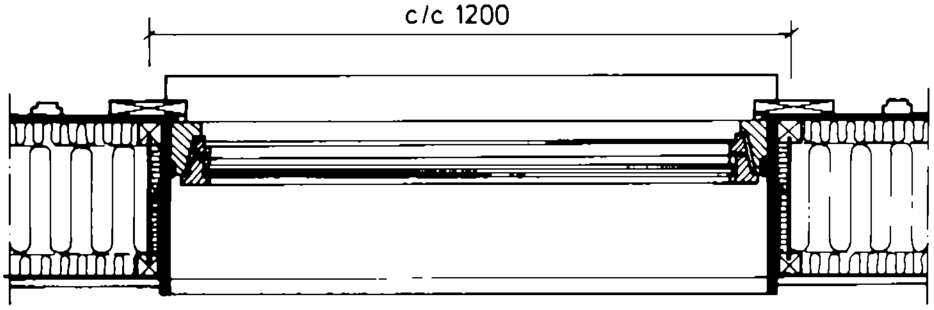
b) Gable

Figure BIII.39. Joint between crawl space joist – external wall (detail B).





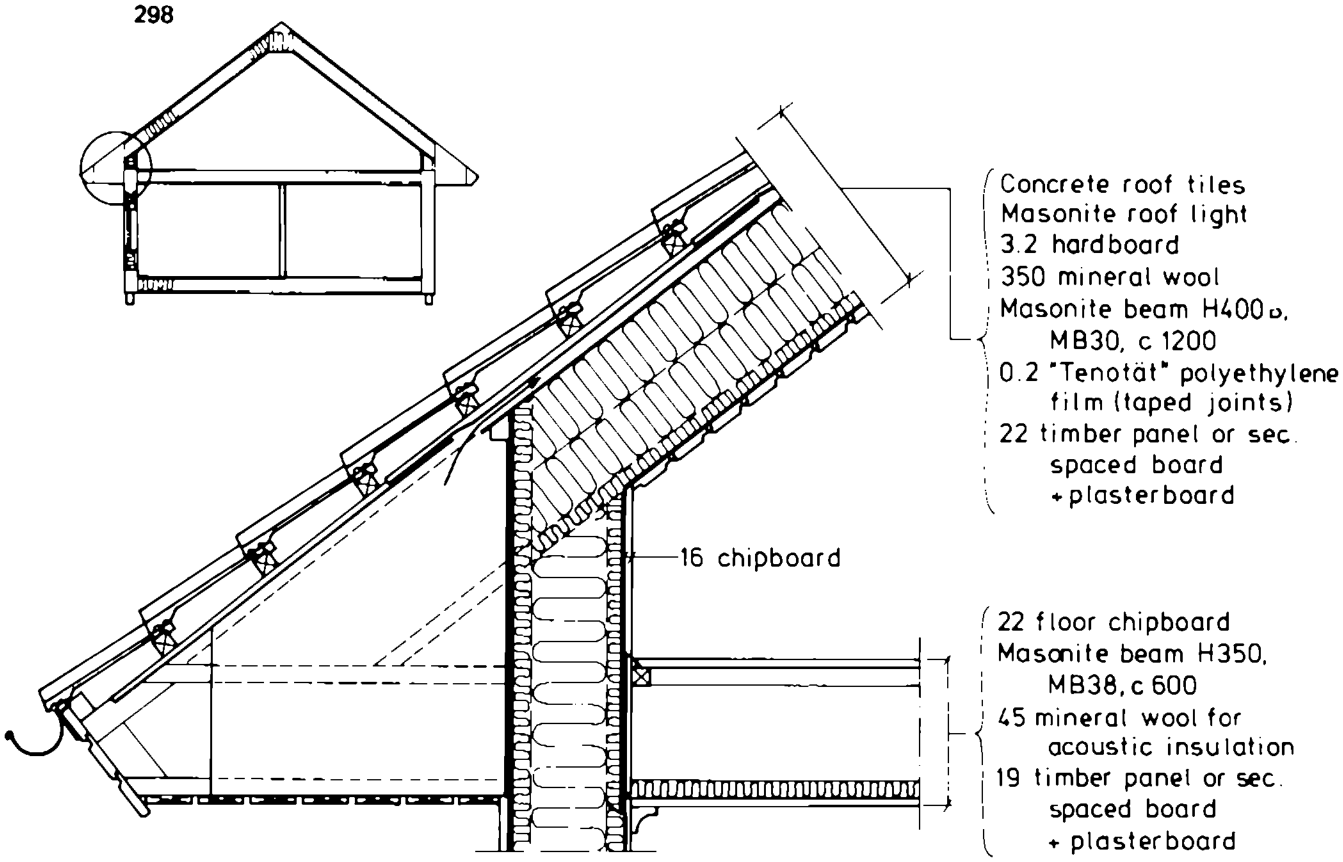
a) Section



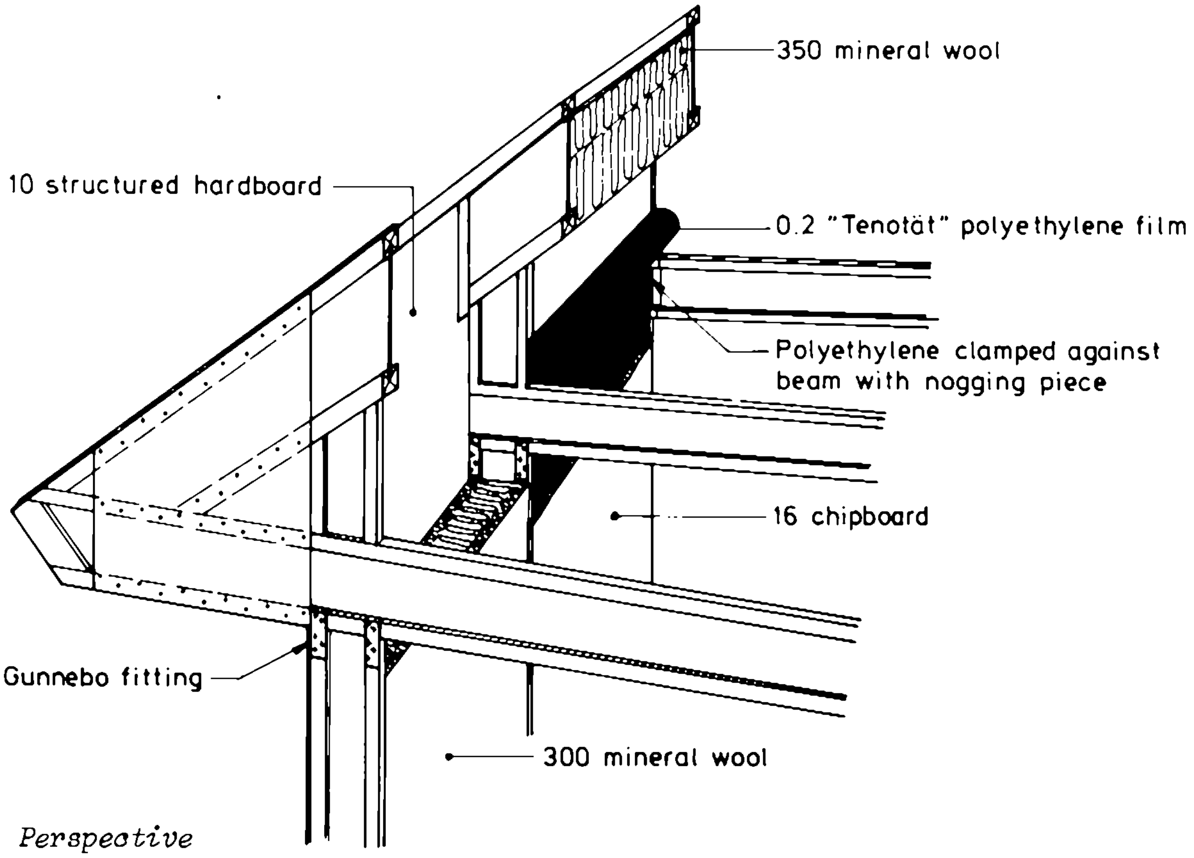
b) Plan

A sheet of chipboard is positioned in the window opening against which the window is mounted with the jointing against the inside. The chipboard is nailed and glued against the wall battens

Figure BIII.40. Joint external wall – window (detail C).



a) Section

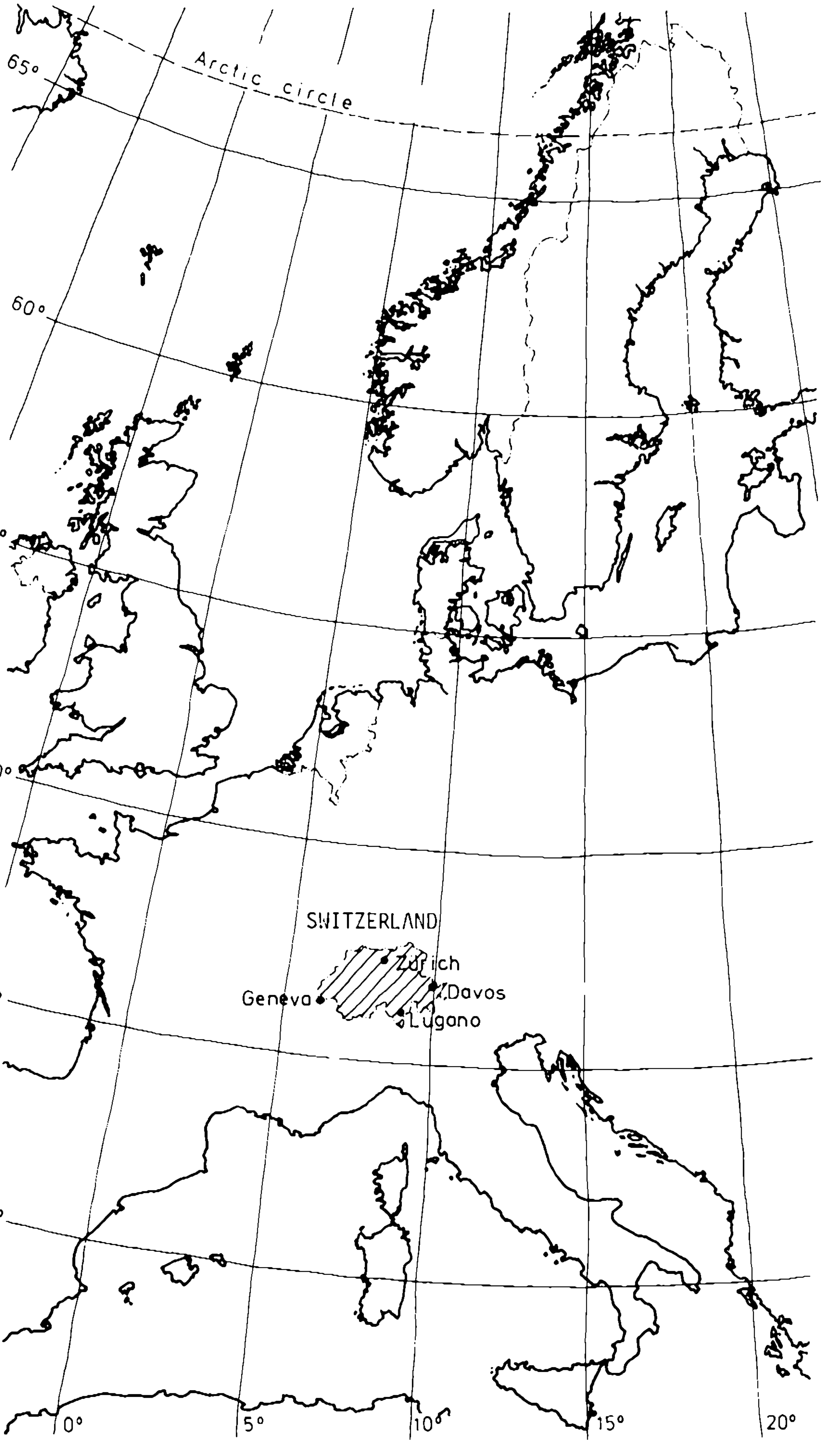


b) Perspective

The solution is difficult and requires considerable accuracy when installing to achieve good airtightness. It is important that both the thermal insulation and the polyethylene film be drawn unbroken past the joint

Figure BIII.41. Joint external wall – sloping roof (detail D).

SWITZERLAND
PART BIV



BIV.1 REGULATIONS

In Switzerland, each canton and several towns have their own building codes with generally very different arrangement and contents. Therefore, it is nearly impossible to make any statements with general validity. The building codes are most comparable with regard to coefficients of thermal transmittance and air permeability of joints.

At present, there is a tendency to standardize the building codes. For that purpose, the Federal Office of Energy – in cooperation with the cantons and the Swiss Association of Engineers and Architects – is about to work out model codes, e.g. with regard to

- transmission heat loss
- heat loss due to infiltration and ventilation
- installations for heating and ventilation.

All "Codes of Practice" in this field are established by the following associations and are mandatory.

- Swiss Association of Engineers and Architects (SIA) (most Swiss standards on thermal protection and HVAC-problems).
- Association of Swiss Heating and Cooling Firms (VSHL).
- Swiss Association of Heating and Cooling Engineers (SWKI affiliated with ASHRAE). (Recommendations for heating installations, ventilation, air conditioning plants, refrigerating plants).

BIV.1.1 Airtightness

With regard to airtightness none of the existing recommendations include more than some indications of air leakage values for windows and doors.

Usually the values should be in the ranges shown in Figure BIV.1.

	A	*B*	*C*	*D*
Test pressure (Pa)	*150*	*300*	*600*	*>600*
Altitude of buildings (m)	*<8*	*8-20*	*20-100*	*-*
Allowable coefficient for air permeability of joints ($m^3/m\ h\ Pa^{2/3}$)	*0.44*	*0.22*	*0.22*	*0.22*

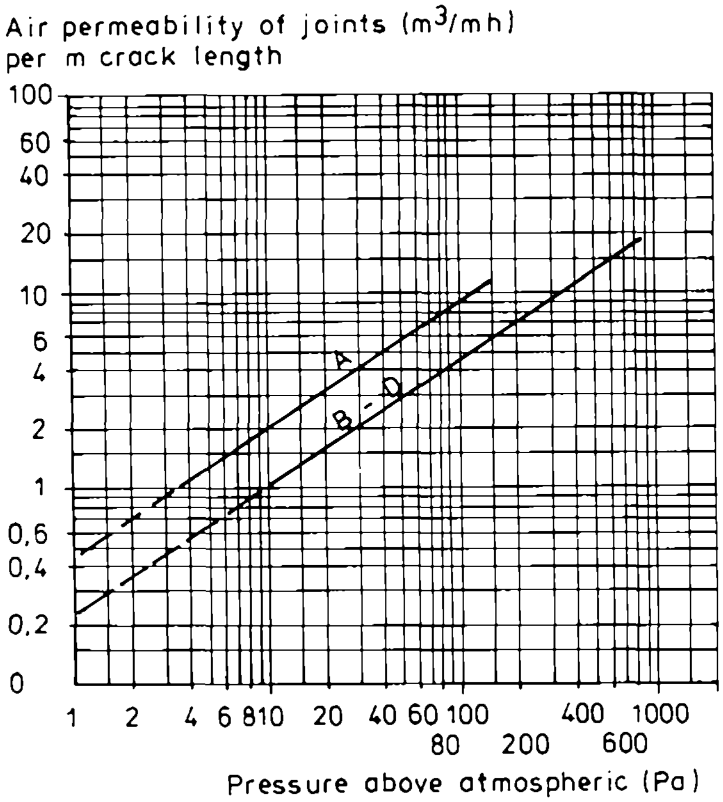


Figure BIV.1. Air permeability of joints of windows and doors (table and diagram).

BIV.1.2 Minimum ventilation rates

Standards exist only for specific types of buildings and spaces where ventilation systems are prescribed (restaurants, theatres, etc.).

- Residental buildings

o Recommendations exist only for interior bathrooms, toilets and kitchens (SIA 384/2, building codes of cantons and local government).

Examples:	kitchen	80-120 m^3/h
	bathroom with toilet	min. 60 m^3/h
	toilet	min. 30 m^3/h

o In some cantons there exist special regulations in the building codes on the requirements for fresh air at construction processes (gas heating, etc.).

BIV.1.3 Thermal insulation

The recommendation SIA 180/1 "Thermal Protection of Buildings in Winter" has been developed by the Swiss Association of Engineers and Architects. This redommendation covers the transmission heat loss of the building shell limiting the allowable heat transfer coefficient of the building shell, k_m

$$k_m \leq k_{m_{allowable}}$$

Besides this limitation the requirements on the k-values of each building element (windows, walls, etc.) must be fulfilled.

$$k \leq k_{allowable}$$

Below, the expressions $k_{m_{allowable}}$ and $k_{allowable}$ are clarified

- $k_{m_{allowable}}$

$$k_{m_{all.}} = C_0 \cdot C_1 \cdot C_2 \cdot C_3 \; (W/m^2 \, K)$$

where $C_0 = 0.75 \; W/m^2 \, K$

C_1 = geometry factor (0.8-1.4)

C_2 = climate factor (0.8-1.1; 1.0 for most Swiss houses)

C_3 = room temperature factor (0.8-1.2; 1.0 for 20°C).

The solar gain through east-, west- and especially southfacing windows is introduced by a reduction of their k-values in the calculation of k_m.

·· $k_{allowable}$

Besides the limitation of k_m of the building shell the following requirements have to be fulfilled:

o	roofs	$k \leq 0.5\ W/m^2\ K$
o	walls facing outside air	$k \leq 0.6\ W/m^2\ K$
o	windows	$k \leq 3.3\ W/m^2\ K$
o	floors facing outside air	$k \leq 0.6\ W/m^2\ K$
o	floors facing unheated rooms or earth	$k \leq 0.8\ W/m^2\ K$.

Sometimes triple glazed windows are required when the wall is facing north in order to fulfil the allowable k_m.

Calculations of k-values are made regardless of thermal bridges.

The gross areas are used in the calculations.

BIV.2 CLIMATE IN SWITZERLAND

Switzerland is a country with large differences in altitude. The climate is much more dependent on the height above sea level than on the geographic location. The temperature gradient on the south side of the Alpes is larger than on the north side.

The mountains also affect wind velocity and wind direction. There are two main wind directions: south and west. Figure BIV.3 shows temperature and wind plots for four Swiss cities which locations are given in Figure BIV.2 (for further information see Chapter A6).

The annual heating degree day value HGT 20/12 may be calculated from the annual mean temperature with Figure BIV.4 (see SIA 381/3 and also Section A6.1).

Switzerland is nominally divided in 12 climate zones. The 12 zones are reduced in Figure BIV.2 to 3 zones, which are used to calculate the minimal building construction temperature (SIA 271).

Switzerland could be divided in three different climate zones:

Zone I:

a)	*Swiss "Middle-Land" and Jura (except Chasseral)* *Valley grounds in mountains*	$\theta_{min.} = -15^{o}C$
b)	*Protected coastal regions of lakes*	$\theta_{min.} = -13^{o}C$
c)	*Region of La Brēvine*	$\theta_{min.} = -23^{o}C.$

Zone II:

Swiss parts south of the Alps, Bergell, Puschlav, Wallis $\theta_{min.} = -(2.0+0.85\cdot\frac{H}{H_o})^{o}C$

Zone III:

Alpine region, highest Jura-region (Chasseral) $\theta_{min.} = -(13.5+0.45\cdot\frac{H}{H_o})^{o}C$

where θ_{min} = *min.temp. for building-construction. Column 5, Tab. 0. SIA 180 (and 271)*

H = *elevation, m*

H_o = *100 m*

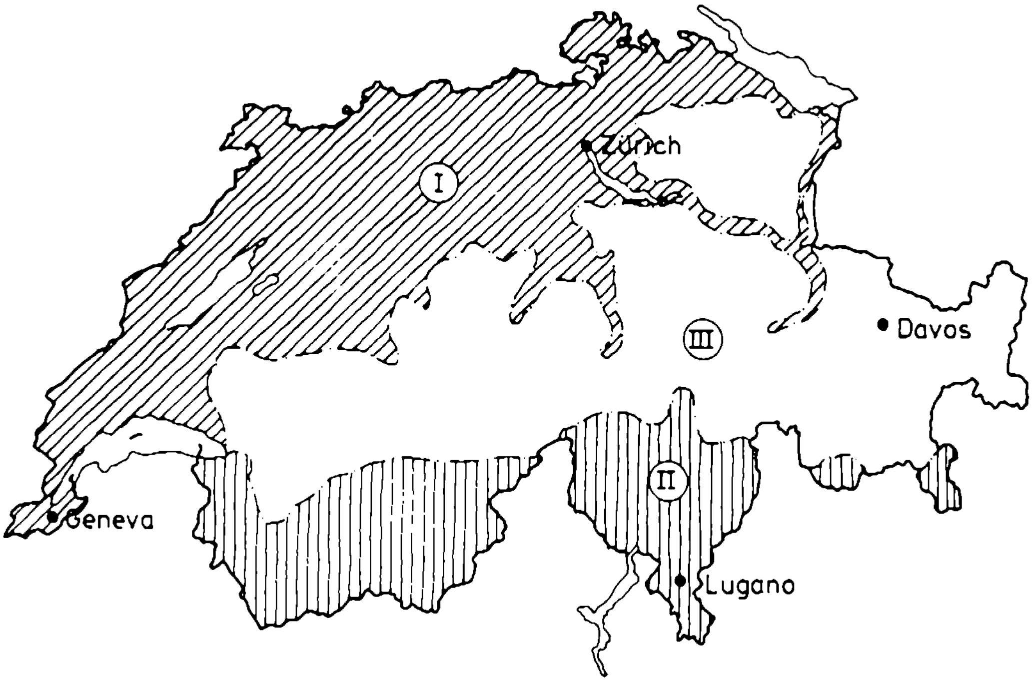


Figure BIV.2. The climate zones of Switzerland.

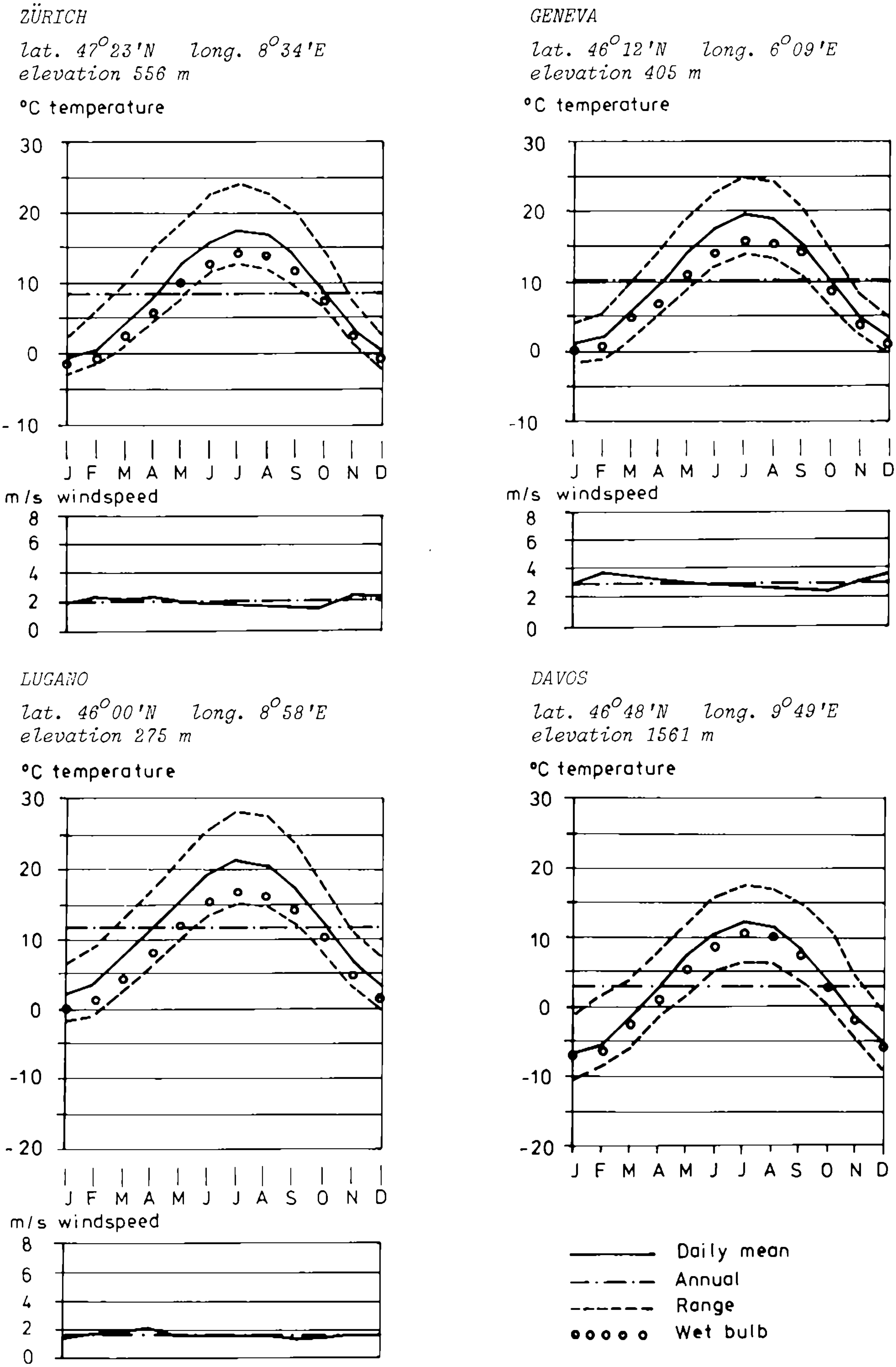


Figure BIV.3. Daily mean, extreme and wet bulb temperatures and windspeeds for four cities in Switzerland. The plots are based on monthly mean values according to Chapter A6.

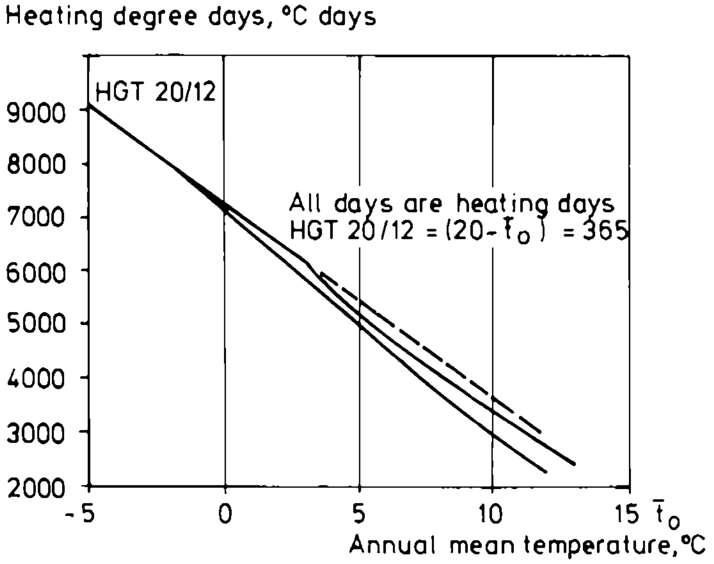


Figure BIV.4. Heating degree days HGT 20/12 as function of annual mean temperature (Switzerland).

BIV.3 COMMONLY USED CONSTRUCTIONS IN SWISS DOMESTIC BUILDINGS

In Swiss domestic buildings today the methods of construction in common use are based on the traditional building types, namely massive construction, framework construction and timber construction. From many building materials available a great variety of largely standardized detail constructions have been developed. Table BIV.1 shows the most commonly used building materials and their application.

In order to illustrate the problems of achieving airtightness in Swiss buildings, four typical dwelling houses were selected. In choosing these particular buildings, the primary considerations were that the type of construction was commonly used and that a large number of critical details of the constructions with regard to airtightness were covered.

The construction details shown in Section BIV.3.2 apply to the typical buildings shown in Section BIV.3.1. In some cases, related designs have been integrated in order to cover the widest possible spectrum of detail solutions in common use.

The standard constructions used in Switzerland are primarily conceived to seal against driving rain and diffusion of vapour but not to achieve satisfactory airtightness. For this reason a practical construction of improving airtightness was worked out for most of the illustrated details.

Table BIV.1. The most commonly used building materials and their application.

	Massive construction				Skeleton construction					Cellular construction				
	EW/SW	F/C	WD	IW	EW	F/C	ST	WD	IW	EW	F/C	SW	WD	IW
Wood			x		x	x	x	x		x			x	
Brick	x			x					x	x	x	x		x
Concrete	x	x				x	x		x	x	x	x		
Lightweight concrete	x													
Steel						x	x							
Gypsum wallboard, plaster-board				x	x				x	x				x
Asbestos cement					x					x				
Glass			x		x			x					x	
Sheet metals, metals			x		x			x		x			x	
Synthetics			x		x			x		x			x	
Particle board			x		x			x		x			x	x
Cement wood products				x	x				x	x				x
Insulating materials	x	x			x	x	x			x	x	x		

EW = external walls; F/C = floors/ceilings; IW = non-supporting internal walls; SW = supporting internal walls; WD = windows, doors; ST = supports

BIV.3.1 Typical buildings

As typical buildings four dwelling houses were selected. These represent the most common construction methods currently in use:

- o conventional massive type of construction
- o cellular construction, pre-cast concrete construction
- o wooden framework construction.

The selected buildings illustrate the majority of critical points in construction with regard to airtightness:

Important structural elements with regard to airtightness	Doors	Windows	Sash windows	Roof windows	Roller blind housings	Frame-work details	Wood-joist ceiling	Attic	Roof-details	Curtain walling
See Section BIV.3.2	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
Critical construction details/structural elements										

In the following section the important structural elements relating to airtightness in the selected buildings will be noted in tabular form as above.

CELLULAR CONSTRUCTION

Distribution

Terrace houses, representing a growing proportion of single-family houses in urban areas.

Selected example

Terrace house, year of construction 1960.

- *Construction*

Supporting party walls, fireproof consisting of two leaves of 15 cm brick. Floors of reinforced concrete spanning whole house width, ventilated crawl space above ground, flat roof covered with topsoil and grown over, internal walls of plastered brick, whole south facade of wooden windows with sealed double panes, north facade wood concrete bricks[x] 20 cm thick.

- *Technical equipment*

Heating by means of hot-water radiators, central heating plant for whole group of houses. Central hot-water preparation in combination

---

[x] Wood concrete bricks are a special kind of hollow blocks with an average λ = 0.15 W/m K.

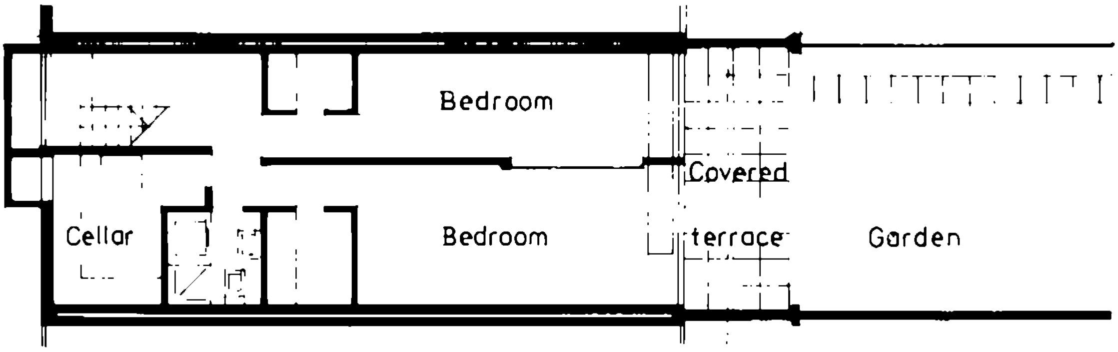
with heating. Distribution of piping in accessible ducts. Internal bathrooms and kitchens mechanically ventilated. Ventilator manually operated with capacity of 200 m^3 per hour.

- *Construction details*

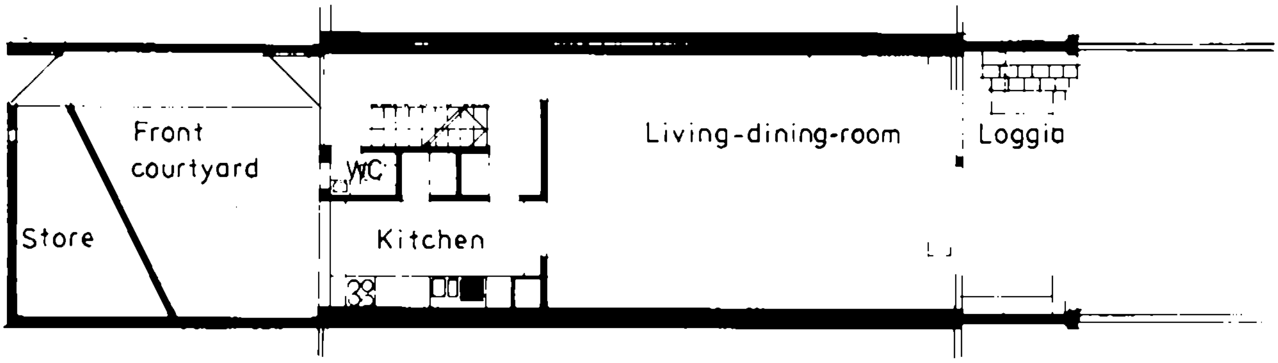
For important structural elements and corresponding construction details relating specifically to airtightness, see following table:

Important structural elements with regard to airtightness	Doors	Windows	Sash windows	Roof windows	Roller blind housings	Frame-work details	Wood-joist ceiling	Attic	Roof-details	Curtain walling
See Section BIV.3.2	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
Critical construction details/structural elements	X	X	X							

BASEMENT PLAN



GROUND FLOOR PLAN



FIRST FLOOR PLAN

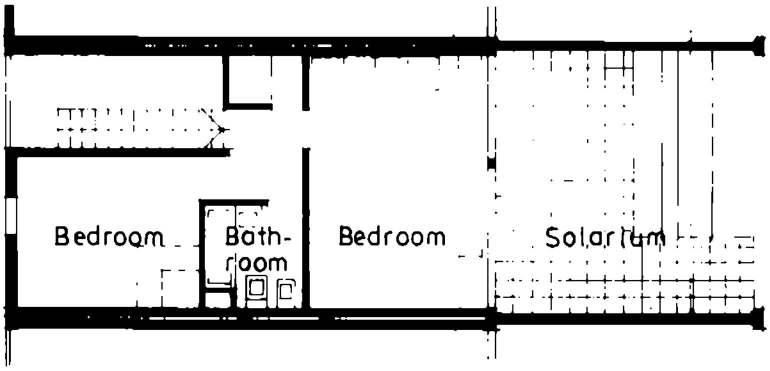


Figure BIV.5a. Cellular construction.

SECTION

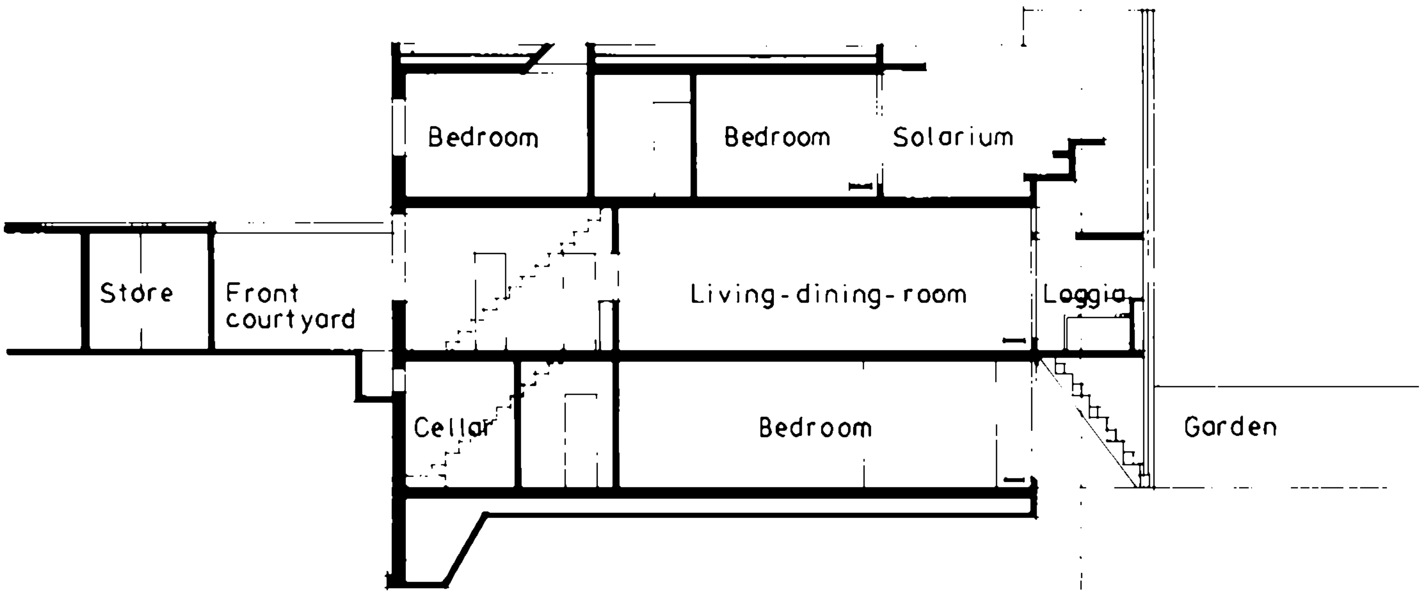


Figure BIV.5b. Cellular construction.

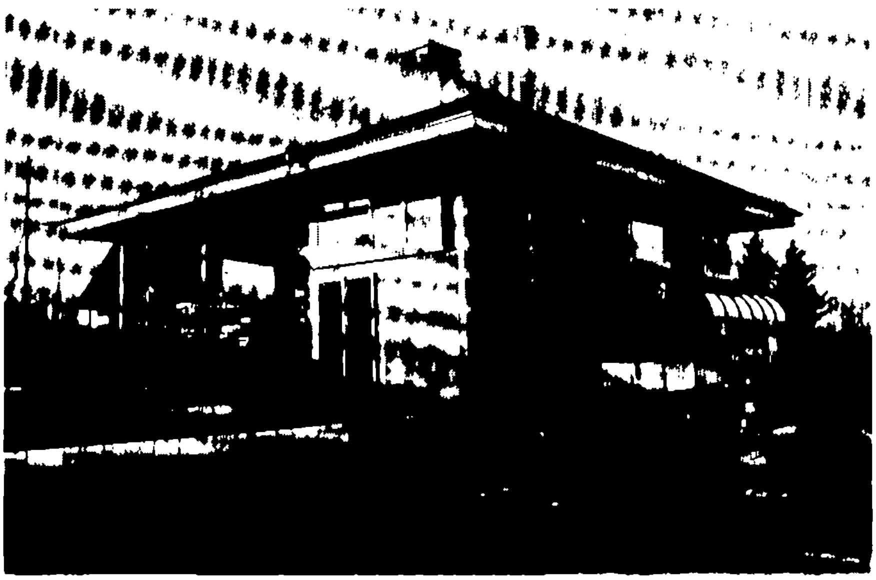
WOODEN FRAMEWORK CONSTRUCTION

Distribution

Single-family houses in rural areas (including weekend and holiday homes), agricultural buildings, small multi-family houses in rural areas.

Selected example

Detached single-family house, year of construction 1978.



- *Construction*

Reinforced concrete in basement walls and floor. Ground- and first-floor of wooden framework construction, internal and external panels filled with 10 cm insulating material, mostly mineral wool. Wooden roof structure with boarded rafter system, insulation and asbestos cement roofing (Everlite), wooden windows with insulating glass (2 panes) and lip sealing.

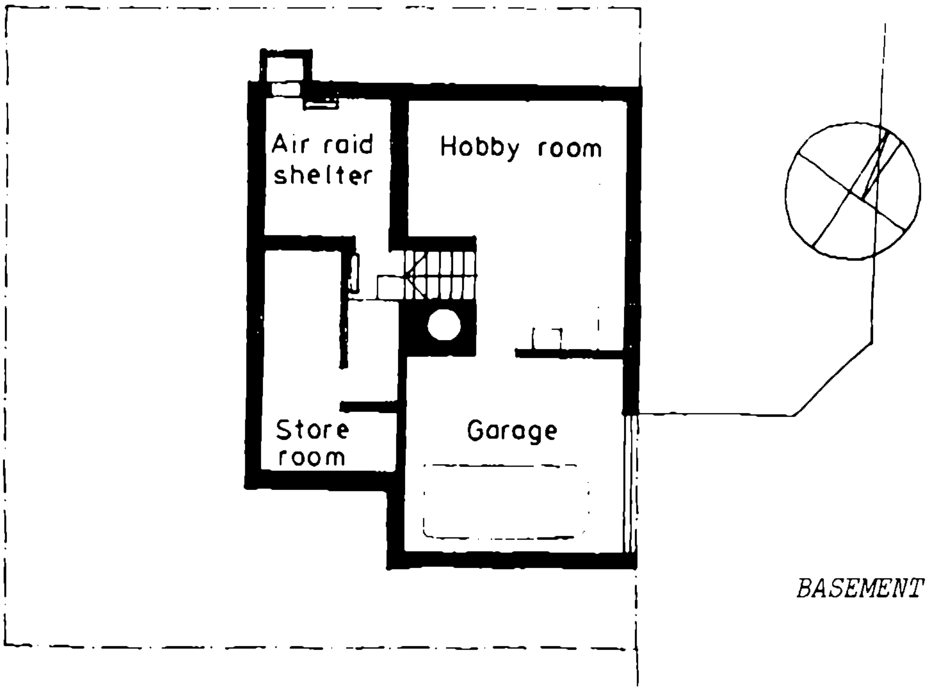
- *Technical equipment*

Low temperature floor-heating, water storage container heated by wood-fired boiler. Internal bathrooms and kitchens mechanically ventilated with fans operated by light switch, fans continue to work for a limited period after light is extinguished.

- *Construction details*

For important structural elements and corresponding construction details relating specifically to airtightness, see following table.

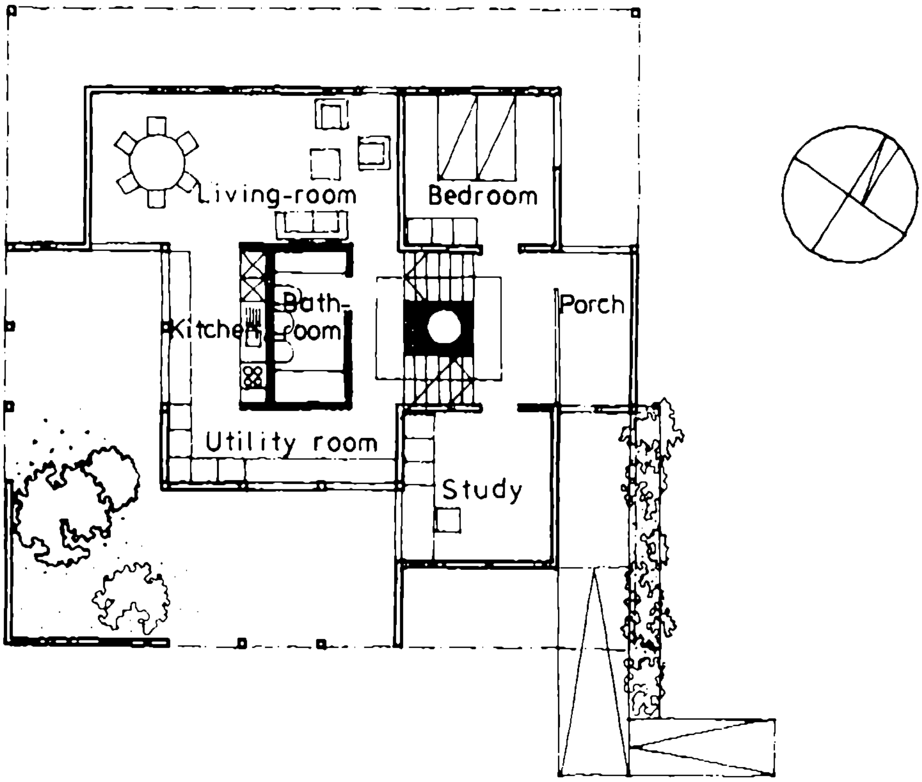
Important structural elements with regard to airtightness	Doors	Windows	Sash windows	Roof windows	Roller blind housings	Frame-work details	Wood-joist ceiling	Attic	Roof-details	Curtain walling
See Section BIV.3.2	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
Critical construction details/structural elements	X	X	X	X		X			X	



BASEMENT PLAN

Figure BIV.6a. Wooden framework construction.

GROUND FLOOR PLAN



FIRST FLOOR PLAN

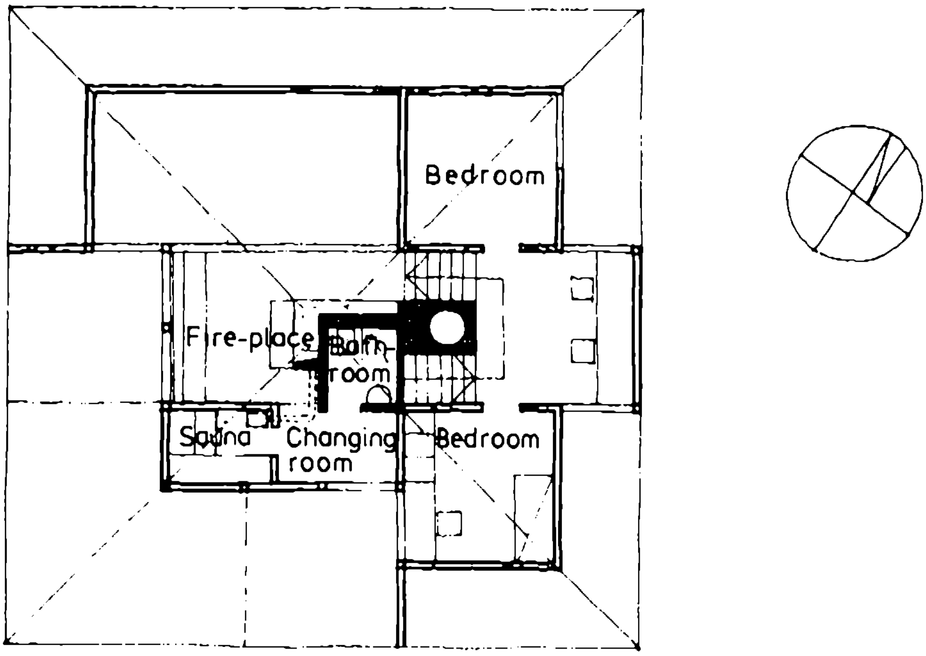


Figure BIV.6b. Wooden framework construction.

SECTION

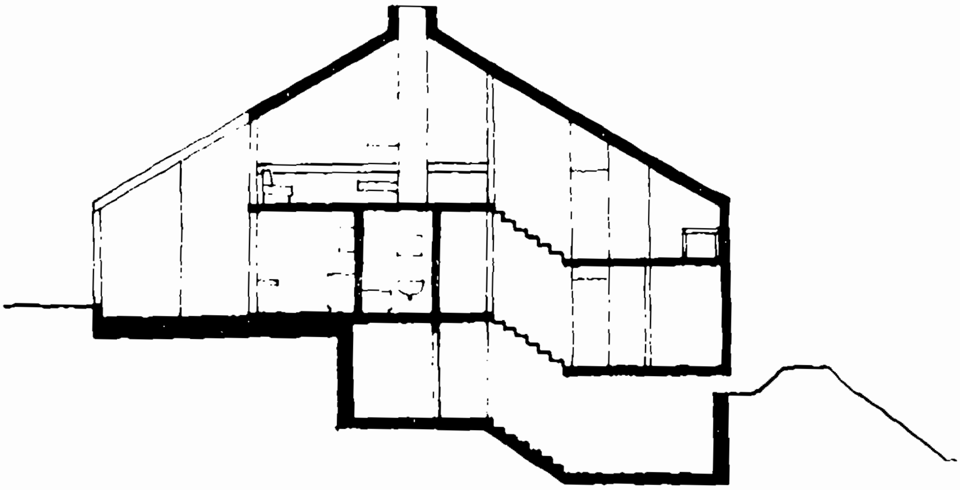


Figure BIV.6c. Wooden framework construction.

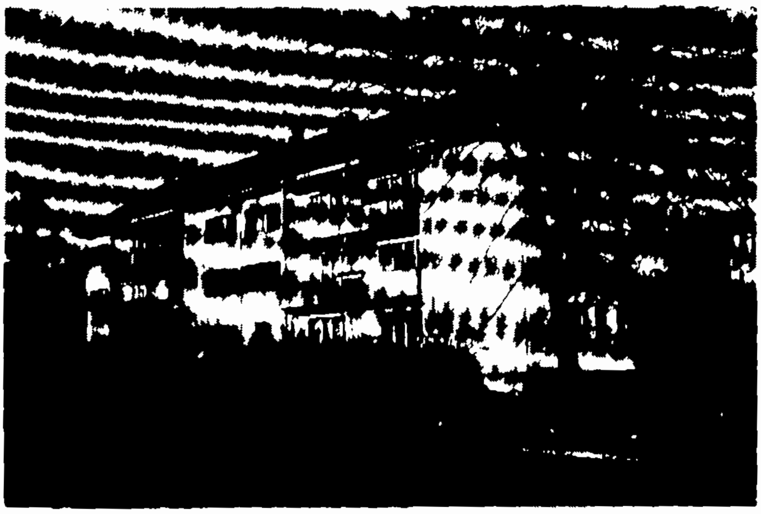
MASSIVE TYPE OF CONSTRUCTION

Distribution

Small multi-family houses. Single-family houses in urban and rural areas.

Selected example

Six-family house, year of construction 1958.



- Construction

Reinforced concrete walls in basement, 30 cm brick facade walls, partition walls between apartments and other internal walls of brick.

Reinforced concrete floors. Roof construction rafters covered with double Roman clay tile, attic partially insulated and habitable, double glazed wooden windows.

- *Technical equipment*

Hot-water heating by means of radiators, oil-fired central-heating boiler, hot-water preparation with individual electric boilers in apartments. Internal bathrooms with ventilation stack, gravity ventilation by means of adjustable flaps.

- *Construction details*

For important structural elements and corresponding construction details relating specifically to airtightness, see following table:

Important structural elements with regard to airtightness	Doors	Windows	Sash windows	Roof windows	Roller blind housings	Frame-work details	Wood-joist ceiling	Attic	Roof-details	Curtain walling
See Section BIV.3.2	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
Critical construction details/structural elements	X	X		X	X		X	X	X	

BASEMENT PLAN

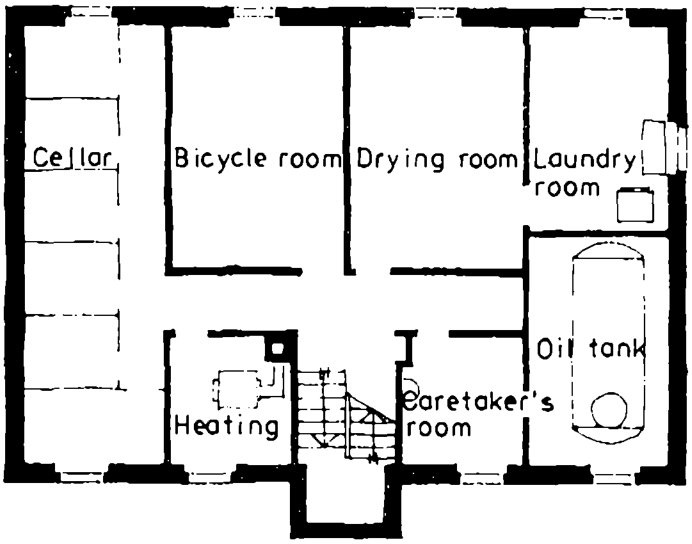
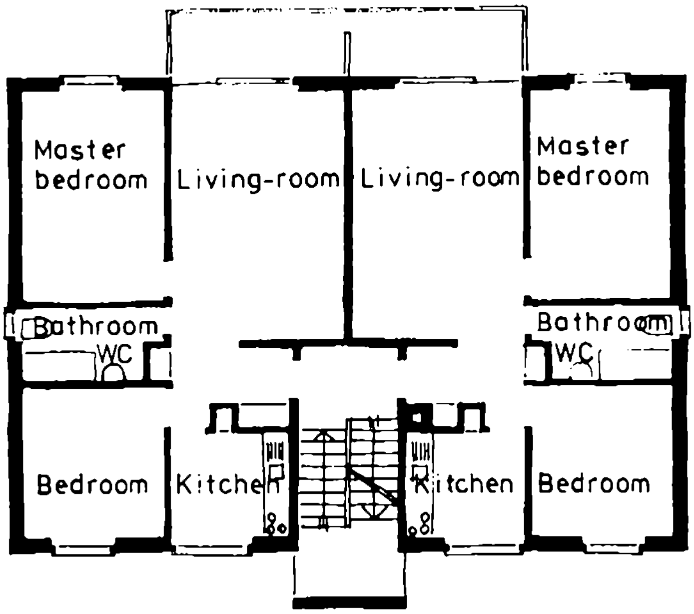


Figure BIV.7a. Massive type of construction.

GROUNDFLOOR/FIRST FLOOR PLAN



SECOND FLOOR PLAN

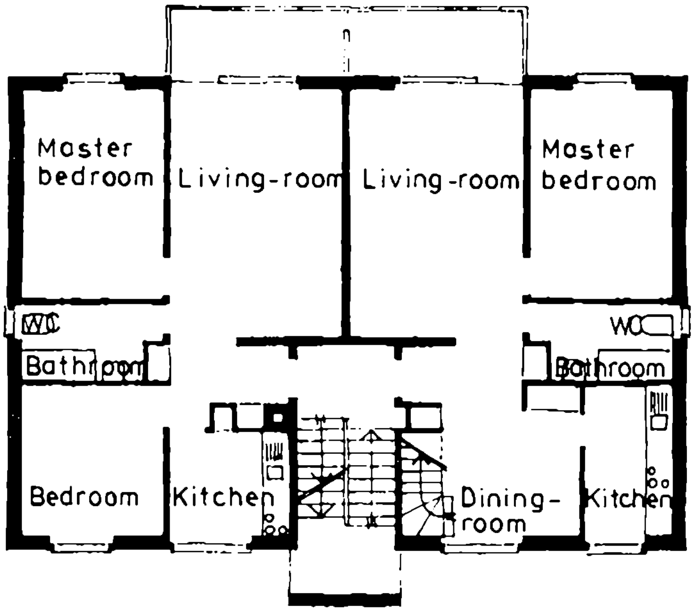
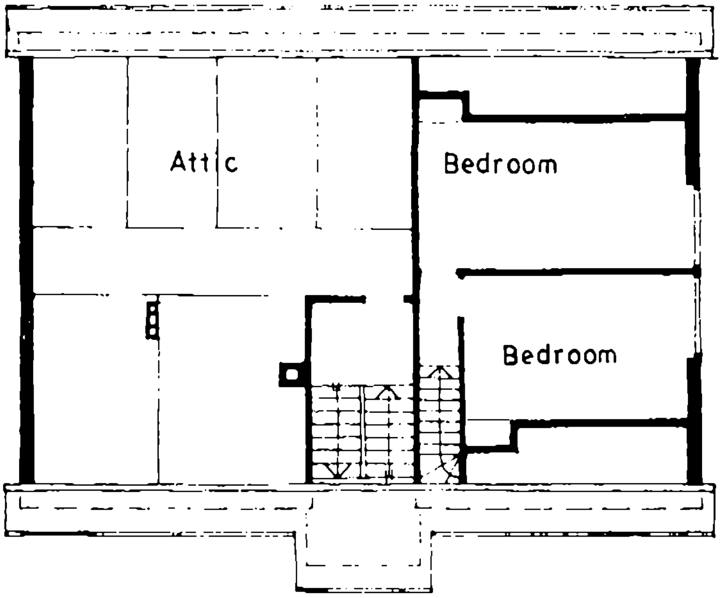


Figure BIV.7b. Massive type of construction.

ATTIC PLAN



SECTION

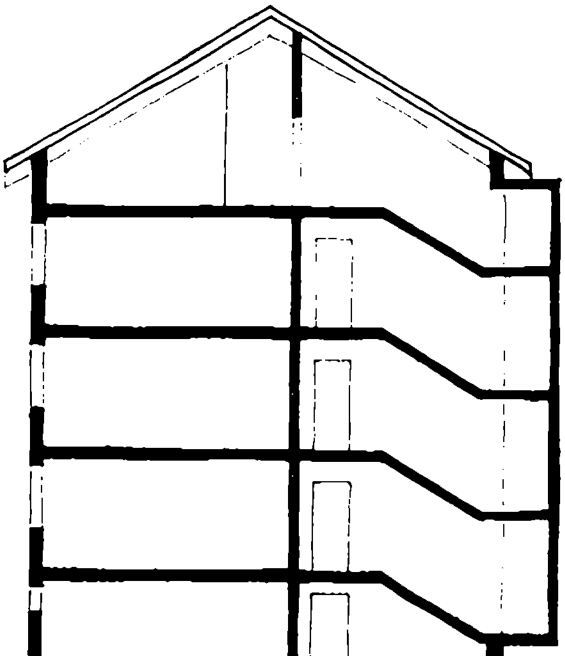


Figure BIV.7c. Massive type of construction.

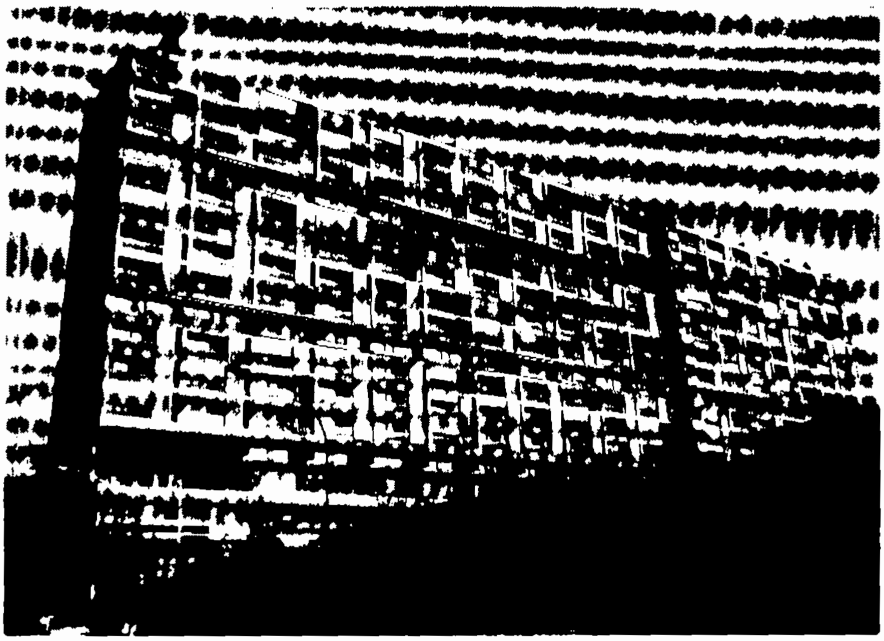
PRE-CAST CONCRETE PANEL CONSTRUCTION

Distribution

Large urban developments.

Selected example

18-storey block with over 300 apartments, year of construction 1964.



- *Construction*

Pre-cast concrete panel supporting structure for partition walls, side facades and floors. Non-supporting partition walls and main facades of light-weight building components, accessible flat roof with roof apartments, double glazed wooden windows throughout.

- *Technical equipment*

Central heating system and central hot-water preparation for whole development. One-pipe radiator room heating system. Bathrooms and kitchens mechanically ventilated (air change prescribed only for the kitchens and bathrooms to 5 ac/h).

- *Construction details*

For important structural elements and corresponding construction details relating specifically to airtightness, see following table:

Important structural elements with regard to airtightness	Doors	Windows	Sash windows	Roof windows	Roller blind housings	Frame-work details	Wood-joist ceiling	Attic	Roof-details	Curtain walling
See Section BIV.3.2	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
Critical construction details/structural elements	X	X			X					X

STANDARD FLOOR PLAN

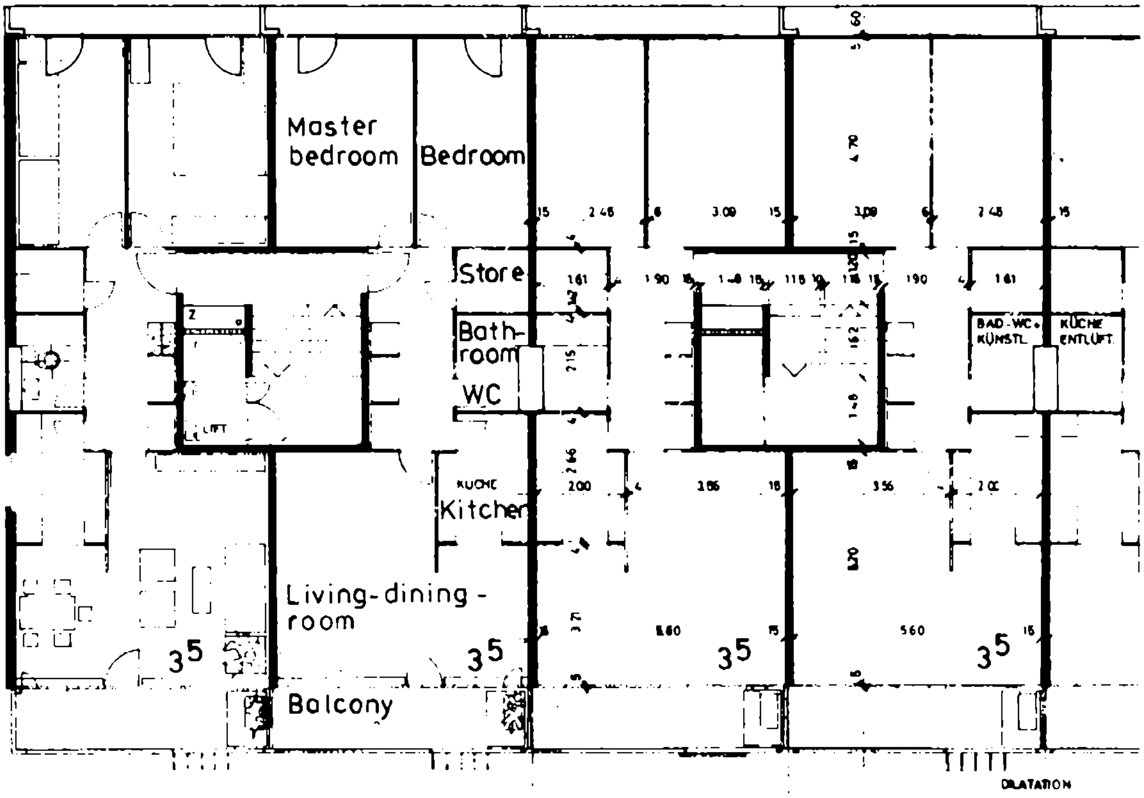


Figure BIV.8a. Pre-cast concrete panel construction.

SECTION

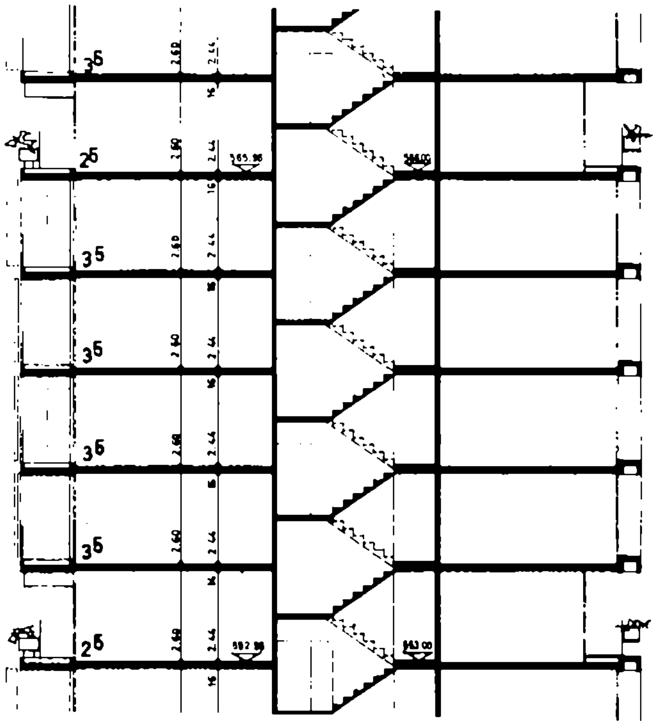


Figure BIV.8b. Pre-cast concrete panel construction.

BIV.3.2 Construction details

In principle, light-weight types of construction present far more problems with regard to airtightness than massive types. Whatever the type of construction, all connections, openings, joints and seams in the building shell are critical points when considering airtightness.

The following construction details apply to the typical buildings described in Section BIV.3.1. These are mostly standardized methods, which are widely used in Switzerland and have proved their expediency. It should be noted that these standardized methods are primarily conceived to seal against driving rain and diffusion of vapour. In relation to the present level of building practice, however, several of these standard methods are not entirely satisfactory. For this reason a practical method of improving airtightness was worked out for most of the illustrated details. A number of these improvements are also attainable by use of construction systems other than those illustrated here.

a) DOORS

In order to reduce to a minimum the loss of warm air through door joints, the following points should be observed:

- use of suitable fittings
- lip-sealing between door-frame and door-leaf
- sealing strip (if possible double) between door-frame and adjoining structural elements.

Apartment doors opening onto staircase

Note

The loss of warm air through door joints between unheated rooms and fully heated or partially heated rooms is often overlooked.

Standard construction

Non-warping door construction without seal, with two rabbets.

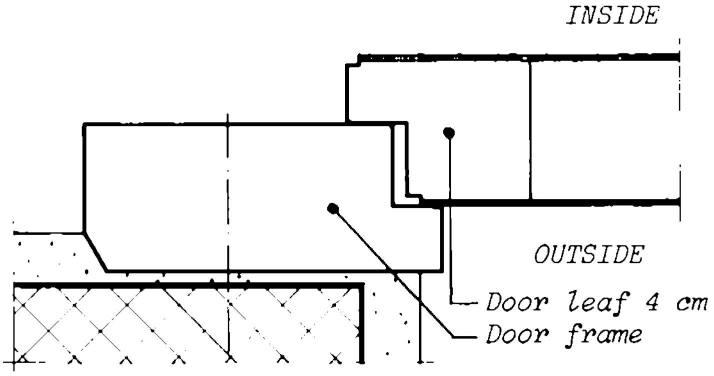


Figure BIV.9a. Doors.

Improved construction

Non-warping door construction with additional lip-sealing and sealing-strip between door frame and wall, single rabbet only.

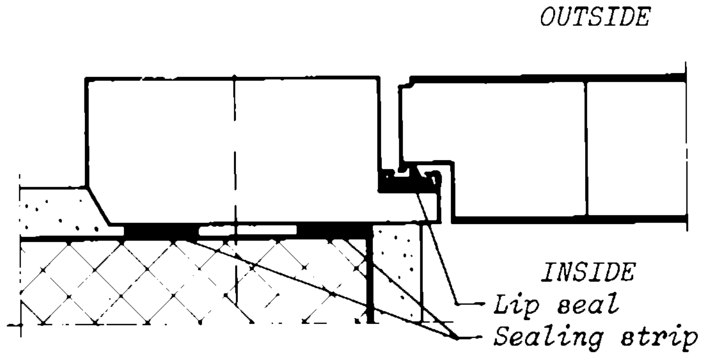
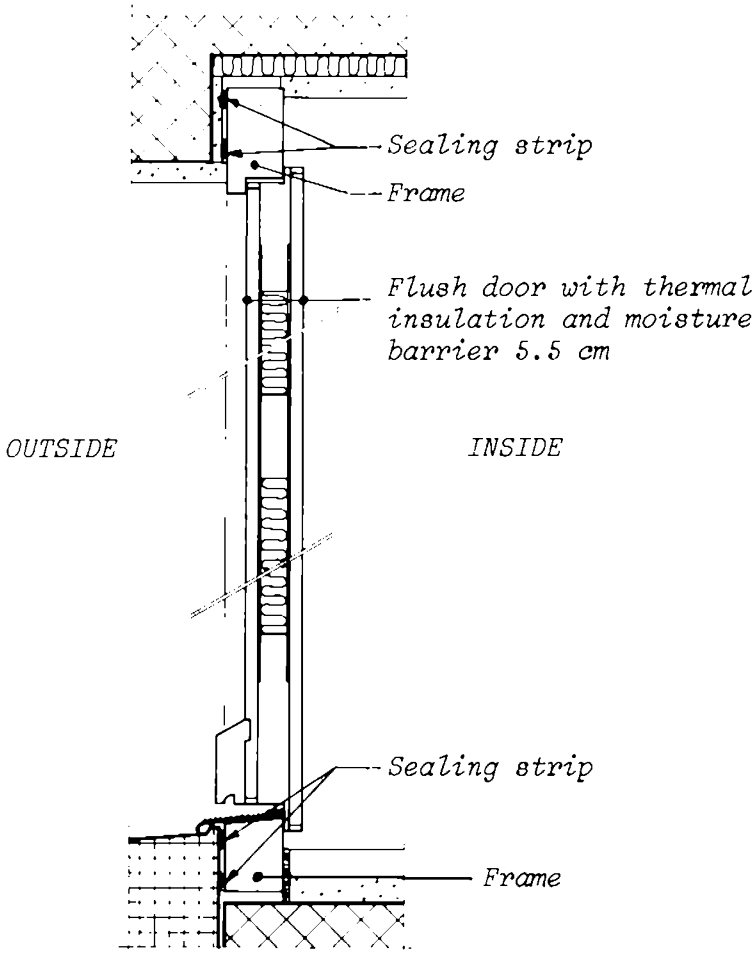


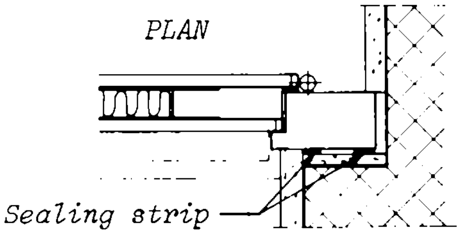
Figure BIV.9b. Doors.

House front door

Standard construction SECTION



PLAN



Improved construction with additional lip-seal

PLAN

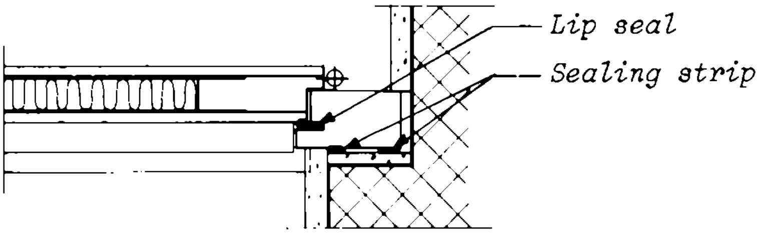


Figure BIV.9c. Doors.

b) WINDOWS

In order to keep the loss of warm air through window joints to a minimum, the following points should be observed:

- use of suitable fittings
- sealing-strip at joints between window-frame and rabbet
- lip-sealing between window-frame and casement.

Double-glazing windows in double-leaf masonry wall

Standard construction

Frames sealed with sealing strip, no casement sealing.

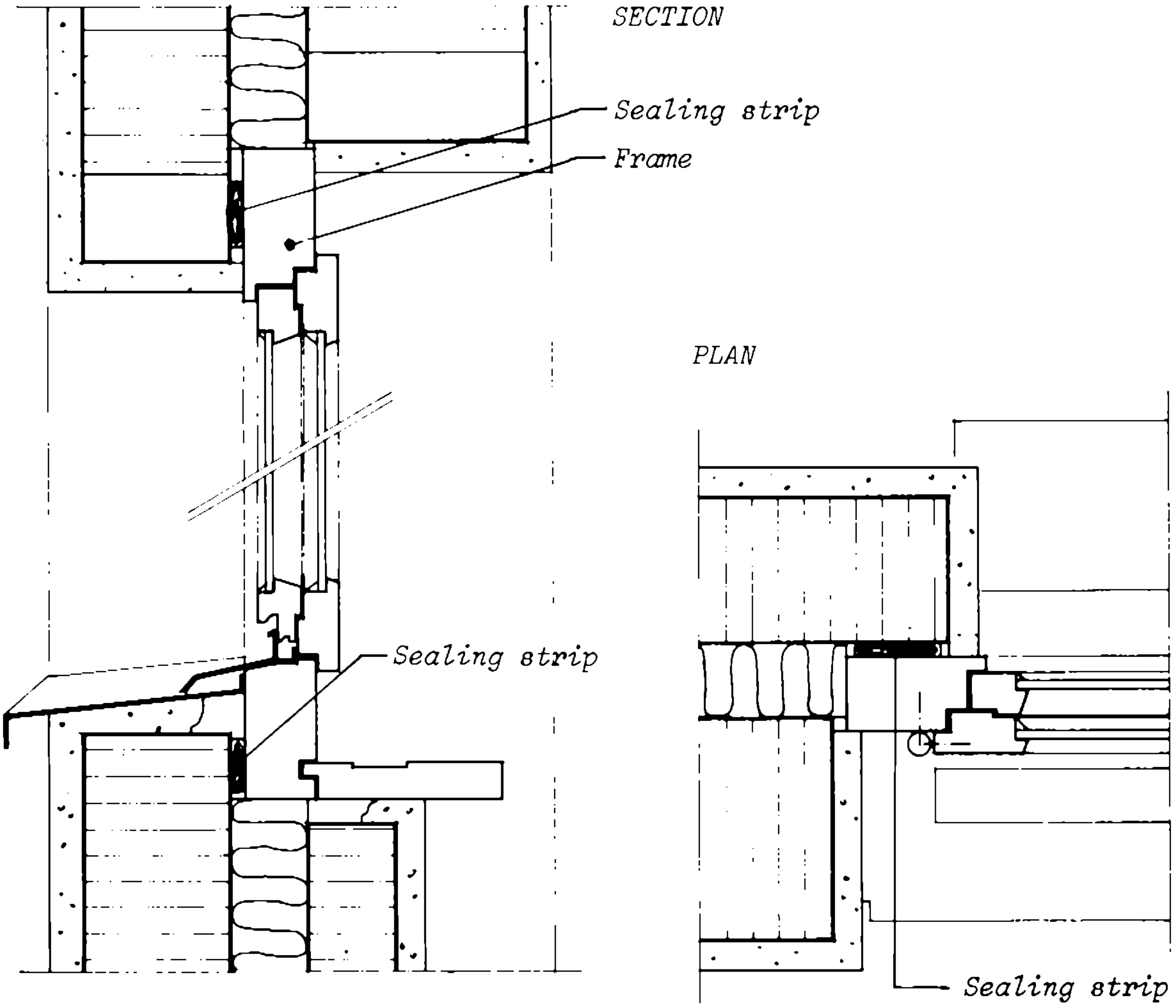


Figure BIV.10a. Windows.

Improved construction

Additional casement seal and external frame seal.

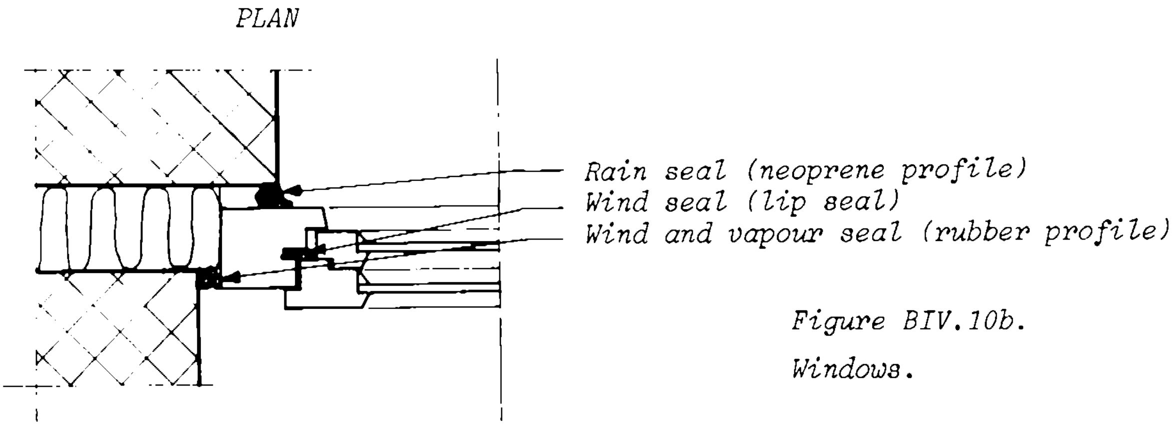


Figure BIV.10b.
Windows.

Alternatives with double-glazed windows, standard constructions

With external insulation, window rabbet in embrasure

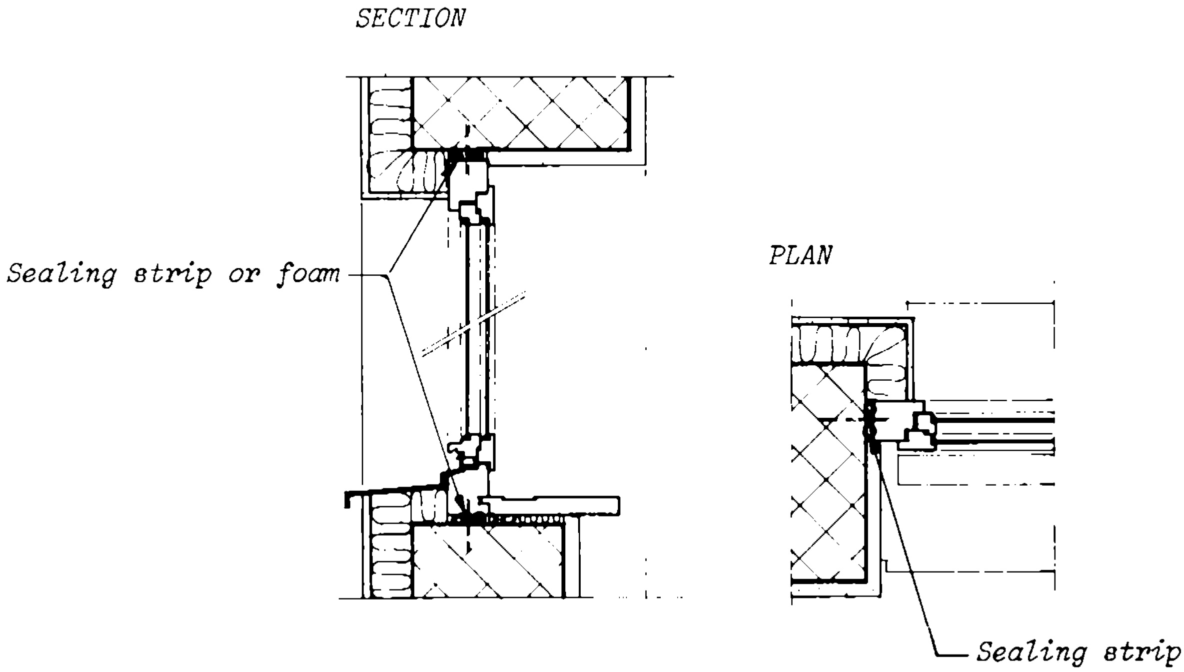


Figure BIV.10c. Windows.

Window rabbet flush with facade

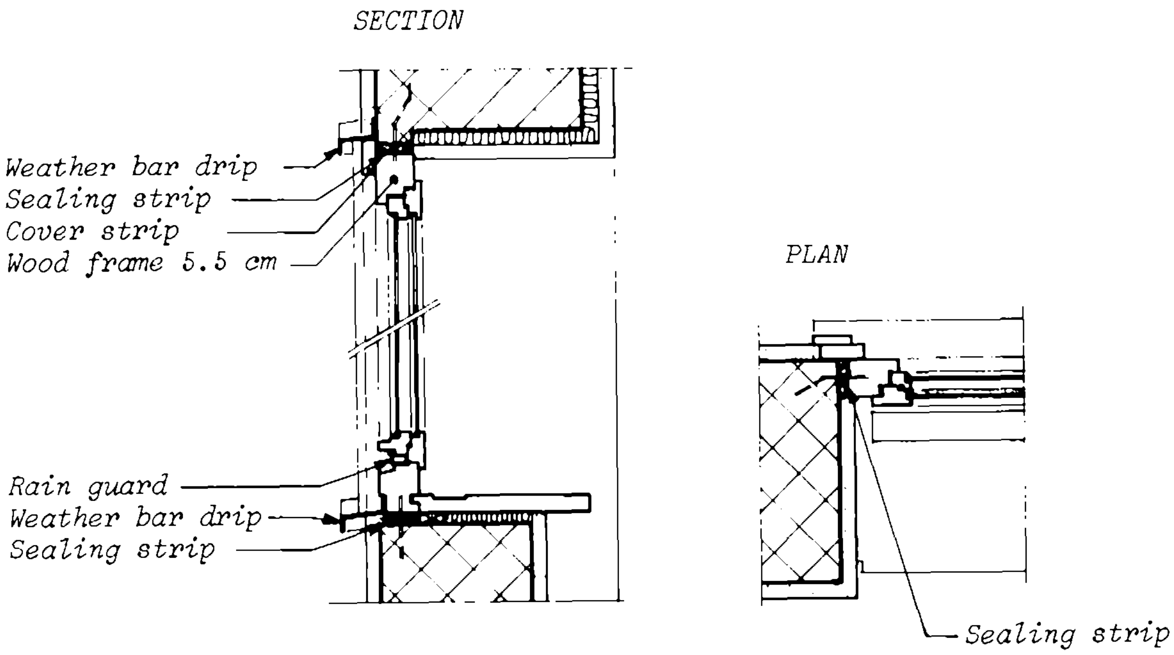


Figure BIV.10d. Windows.

<u>Note</u>: *Whether insulating glass or double glazing is used, the problems with regard to airtightness remain basically the same.*

c) SASH WINDOWS

In order to minimize the loss of warm air through joints in sash windows, complicated and costly structural measures must be taken. The following points should be observed:

- o joints between frame and rabbet
- o joints between fixed window casement and frame
- o special attention must be paid to joints between opening window casement and frame.

Sliding sash window

Optimal solution for achieving airtightness by a mechanism, which presses the seals in the closing position.

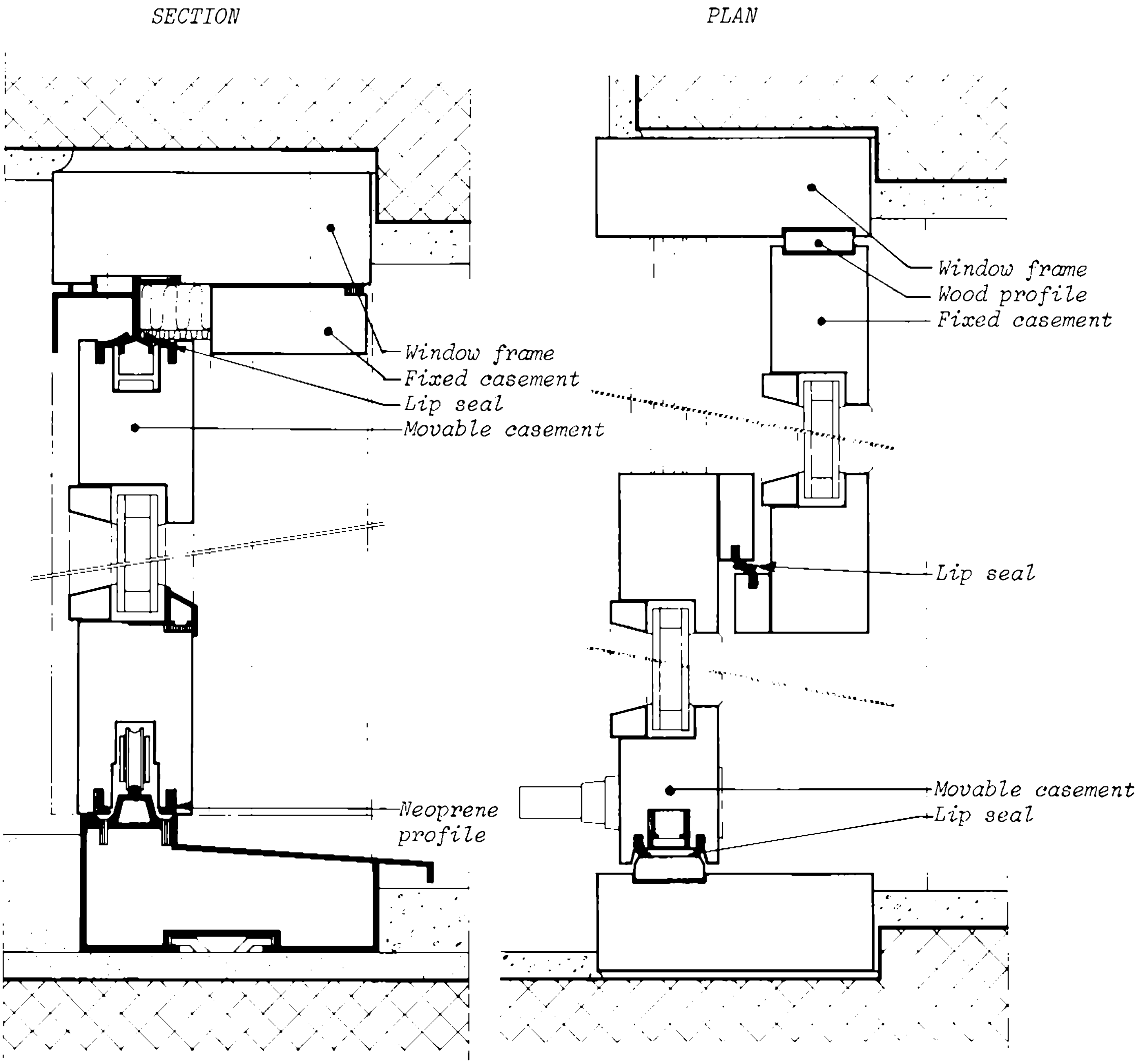


Figure BIV.11. Sash windows.

d) ROOF WINDOWS

With regard to airtightness roof windows create very much the same problems as standard window types (see b) Section BIV.3.2).

Centre-hung roof window

Standard construction with built-in lip seal. Optimal solution for achieving airtightness.

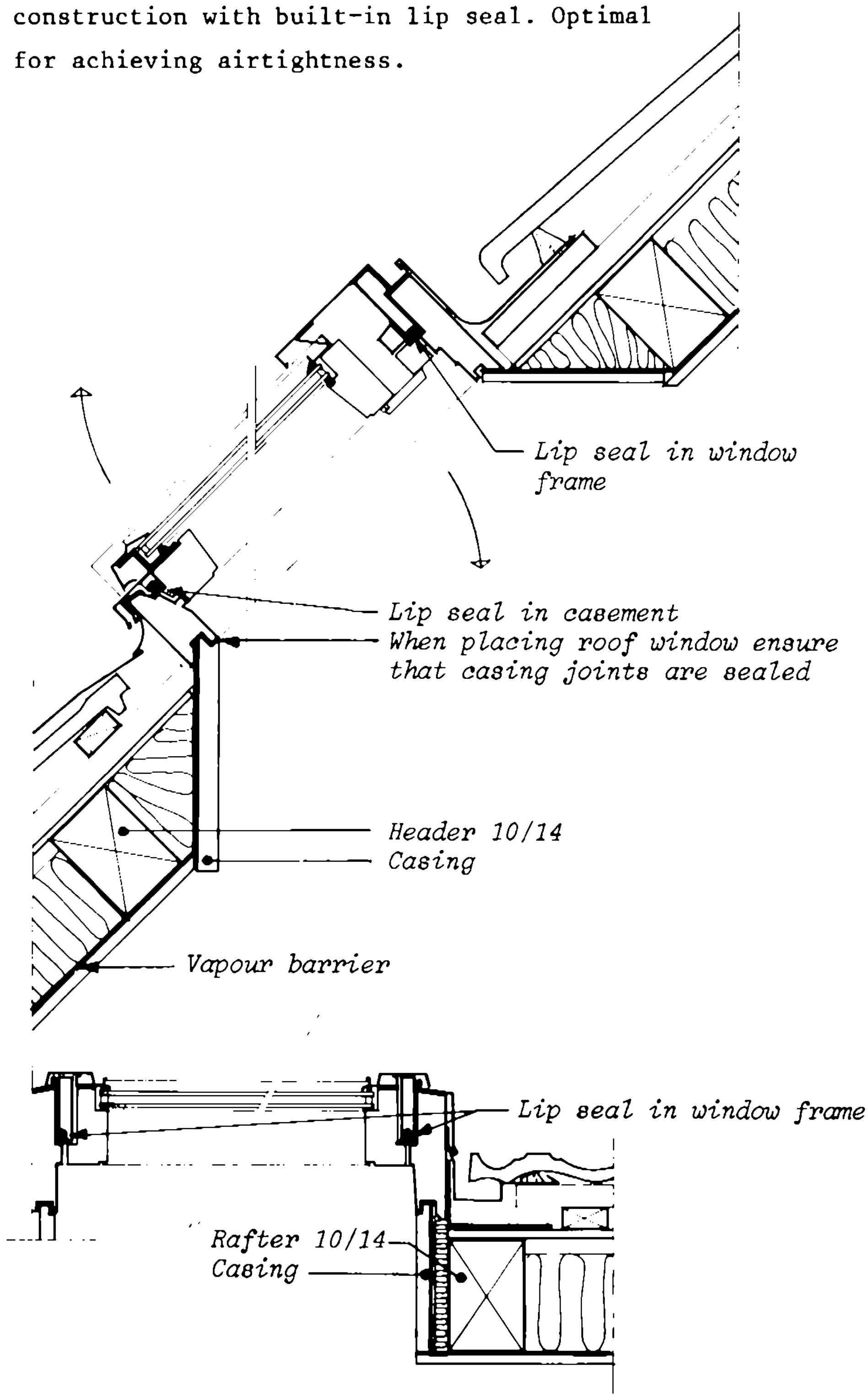
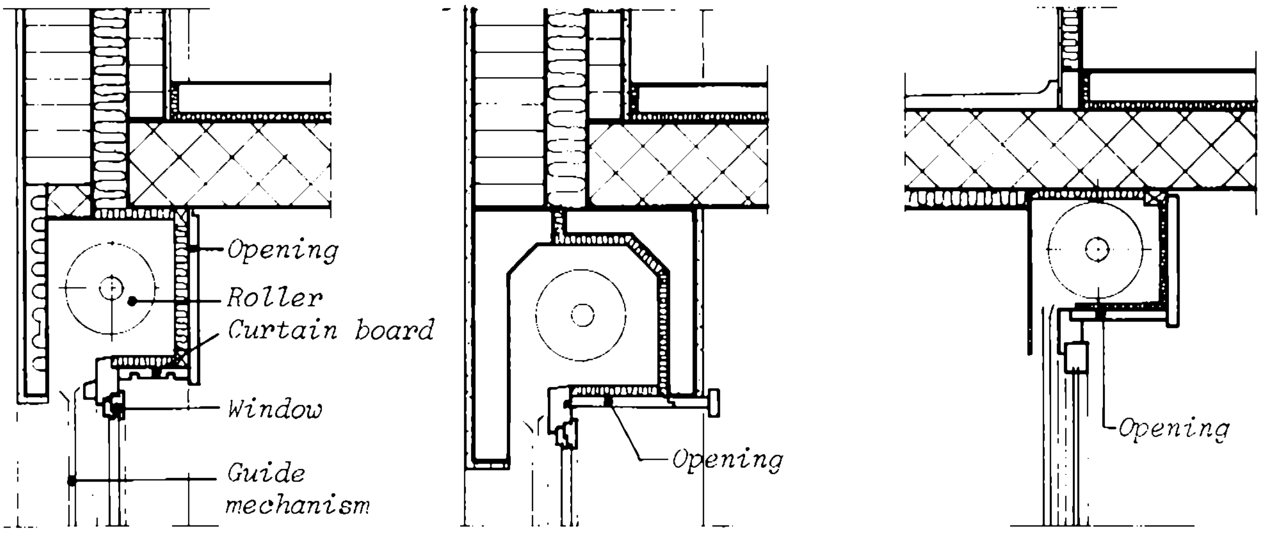


Figure BIV.12. Roof windows.

e) ROLLER BLIND HOUSING

The airtightness of roller blind housings is often insufficient. In particular the standard construction with internal opening for maintenance purposes has many joints which can often only be satisfactorily sealed with great difficulty.

Standard construction
Housing with internal opening for maintenance.



Detail two-leaf masonry wall

Detail curtain walling

Figure BIV.13a. Roller blind housing.

Improved construction
External housing across facade; only one internal opening for roller blind crank.

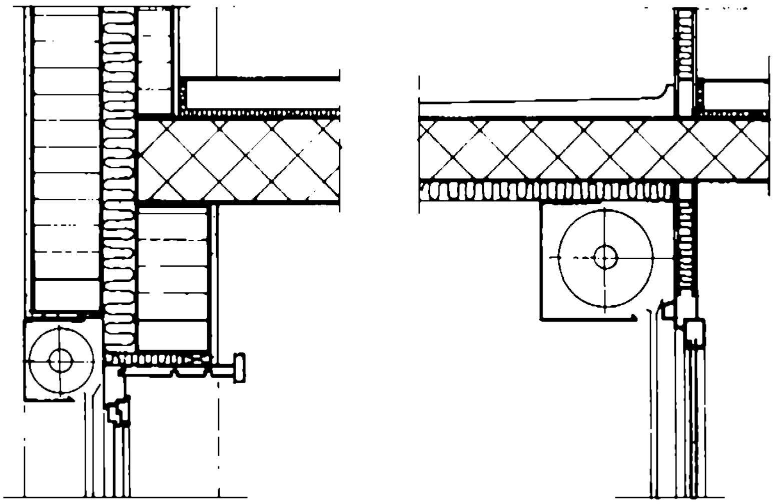


Figure BIV.13b.
Roller blind housing.

f) FRAMEWORK DETAIL

In order to keep the loss of warm air in wooden types of construction to a minimum, all joints must be sealed with elastic material with good age resistance. The construction must allow for shrinkage, swelling and creeping without loss of airtightness.

Join between framework and basement ceiling

Standard construction

Joint between sill and infilling sealed, joint between sill and base as normal.

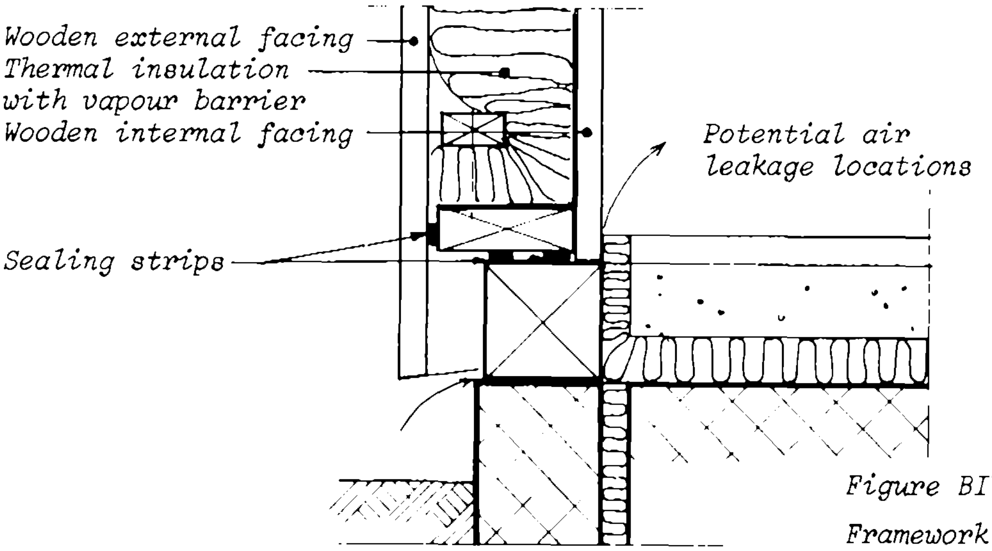


Figure BIV.14a. Framework, detail.

Improved construction

Additional putty-joint or sealing strip between base and sill.

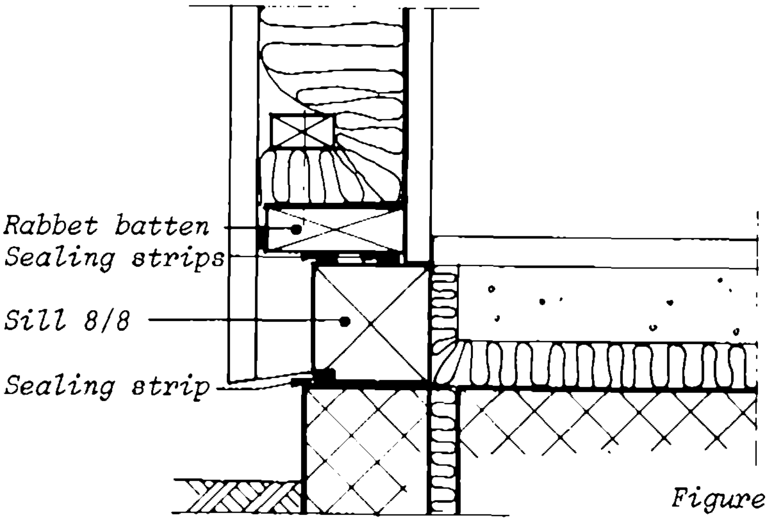


Figure BIV.14b. Framework, detail.

Facade construction for framework-construction

Standard construction

Infilling with sealing strips and battens between vertical studs and beams.

SECTION, general view *SECTION, general view* *SECTION, detail*

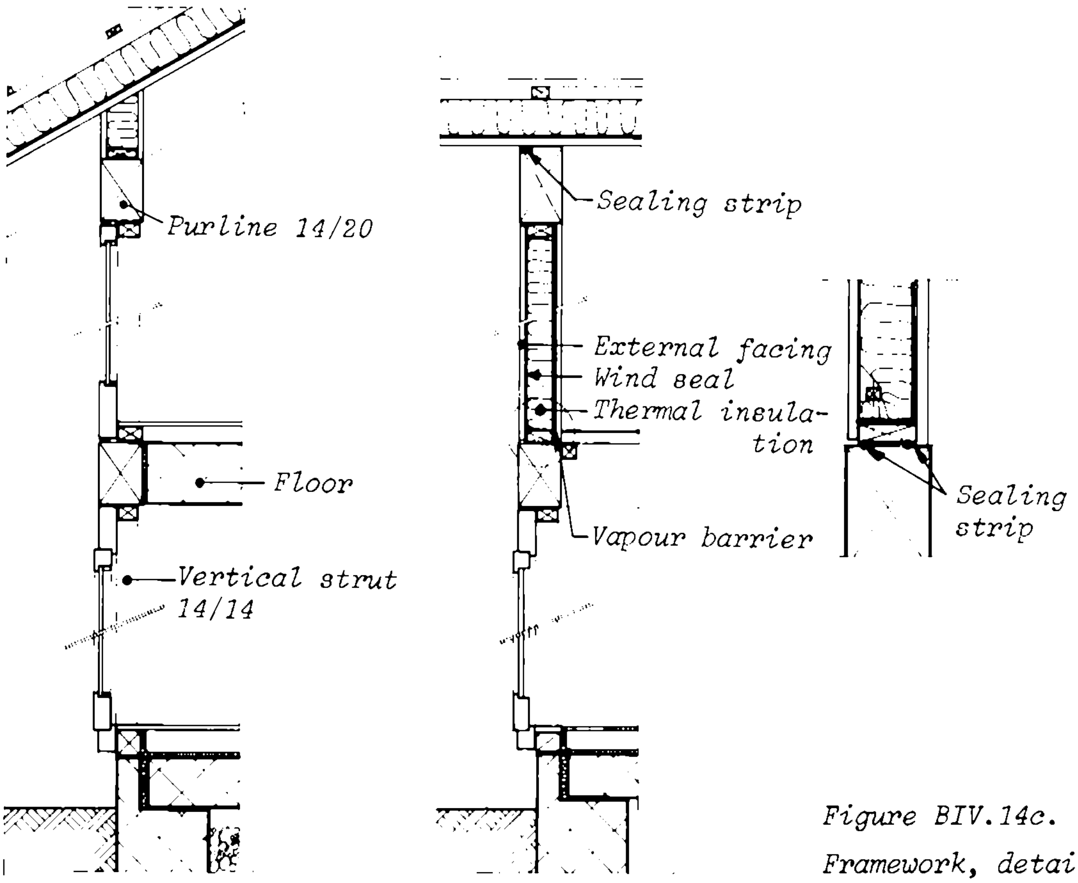


Figure BIV.14c.
Framework, detail.

Improved construction

Construction not exposed, air seal throughout beneath continuous external facing.

SECTION, general view *SECTION, detail*

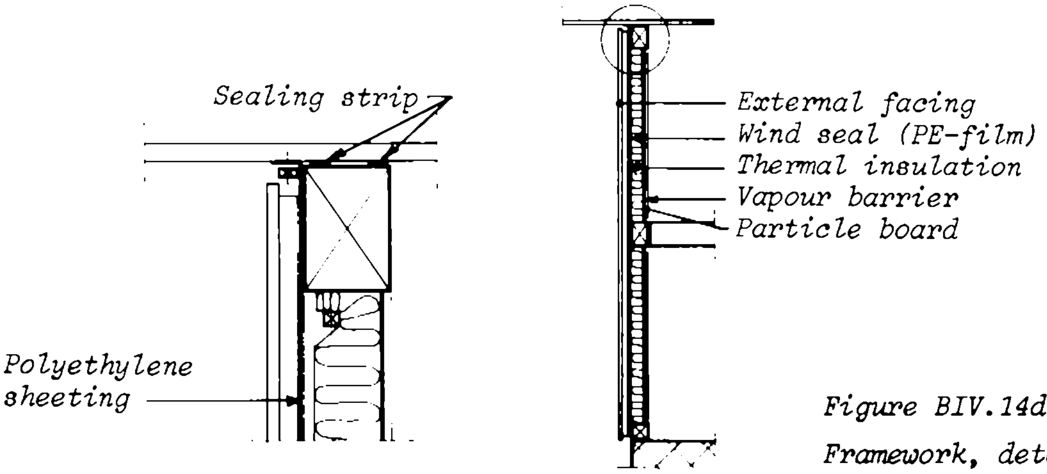


Figure BIV.14d.
Framework, detail.

g) WOOD JOIST CEILING

The loss of warm air through the ceiling into the unheated attic is often overlooked.

Standard construction

Insulation of attic floor between wood joists (variant 1) or over boarding (variant 2). Thermal insulation with vapour barrier.

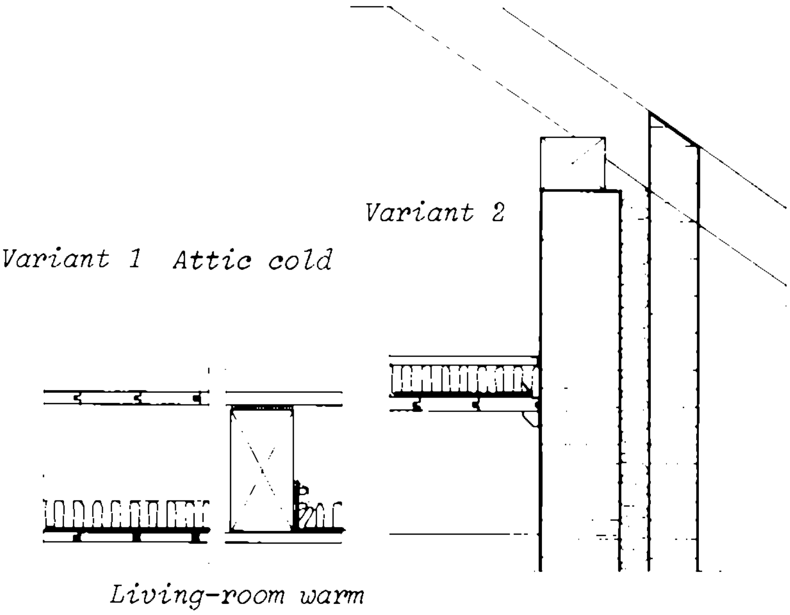


Figure BIV.15a. Wood joist ceiling.

Improved construction

As standard construction but with a separate polyethylene film built in throughout as air seal and vapour barrier.

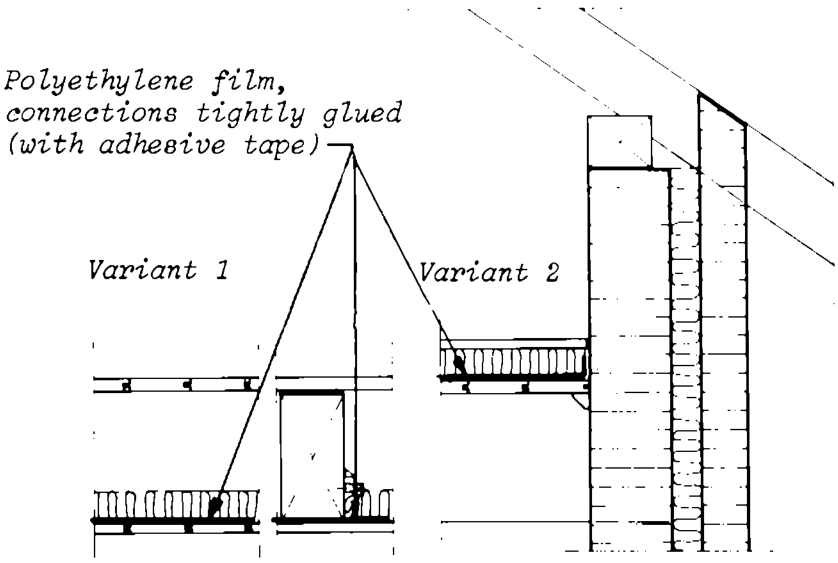
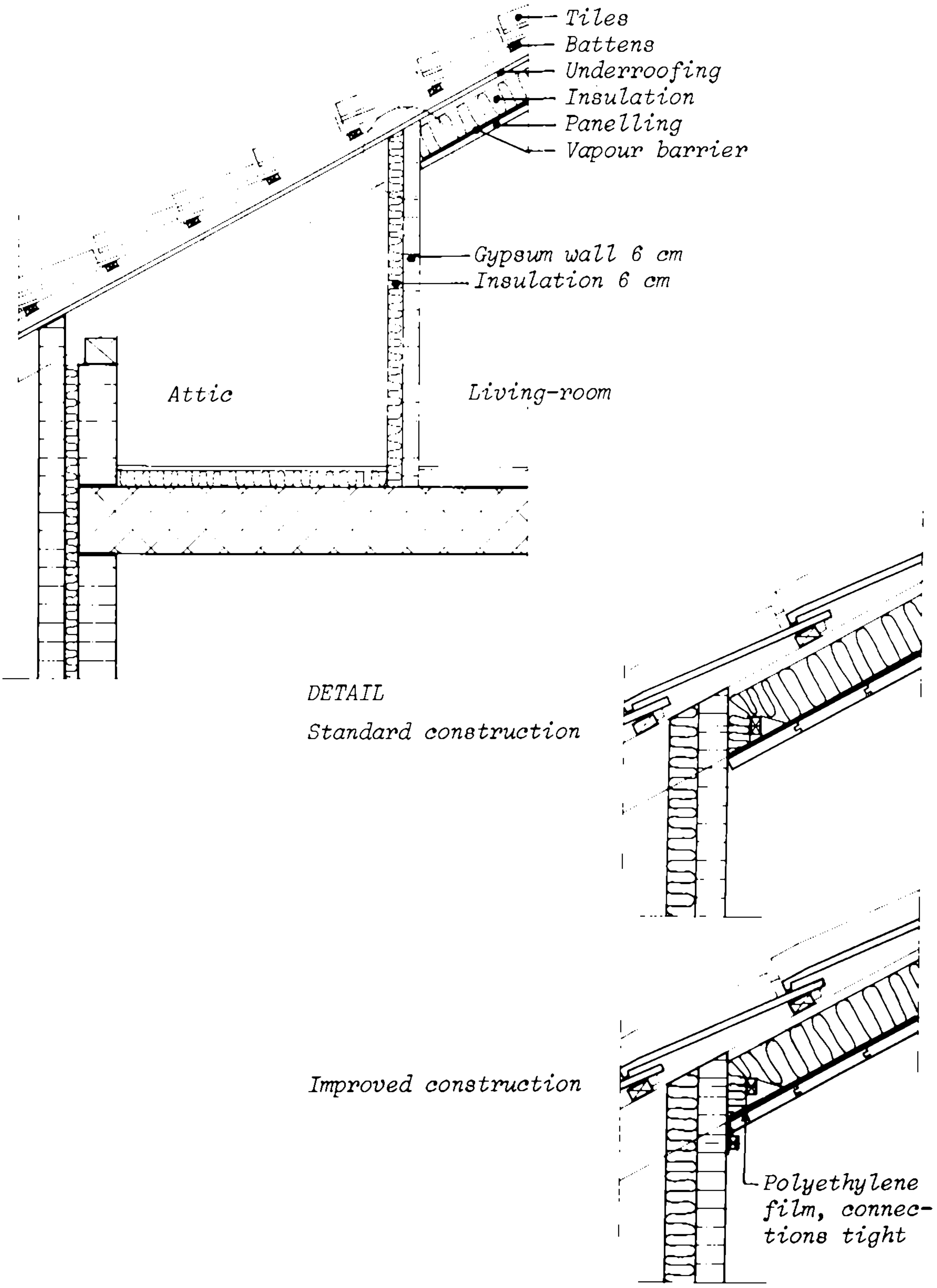


Figure BIV.15b. Wood joist ceiling.

h) ROOMS IN ATTIC

The loss of warm air at the joints between wall and roof construction is often overlooked.

GENERAL VIEW



DETAIL

Standard construction

Improved construction

Figure BIV.16. Rooms in attic.

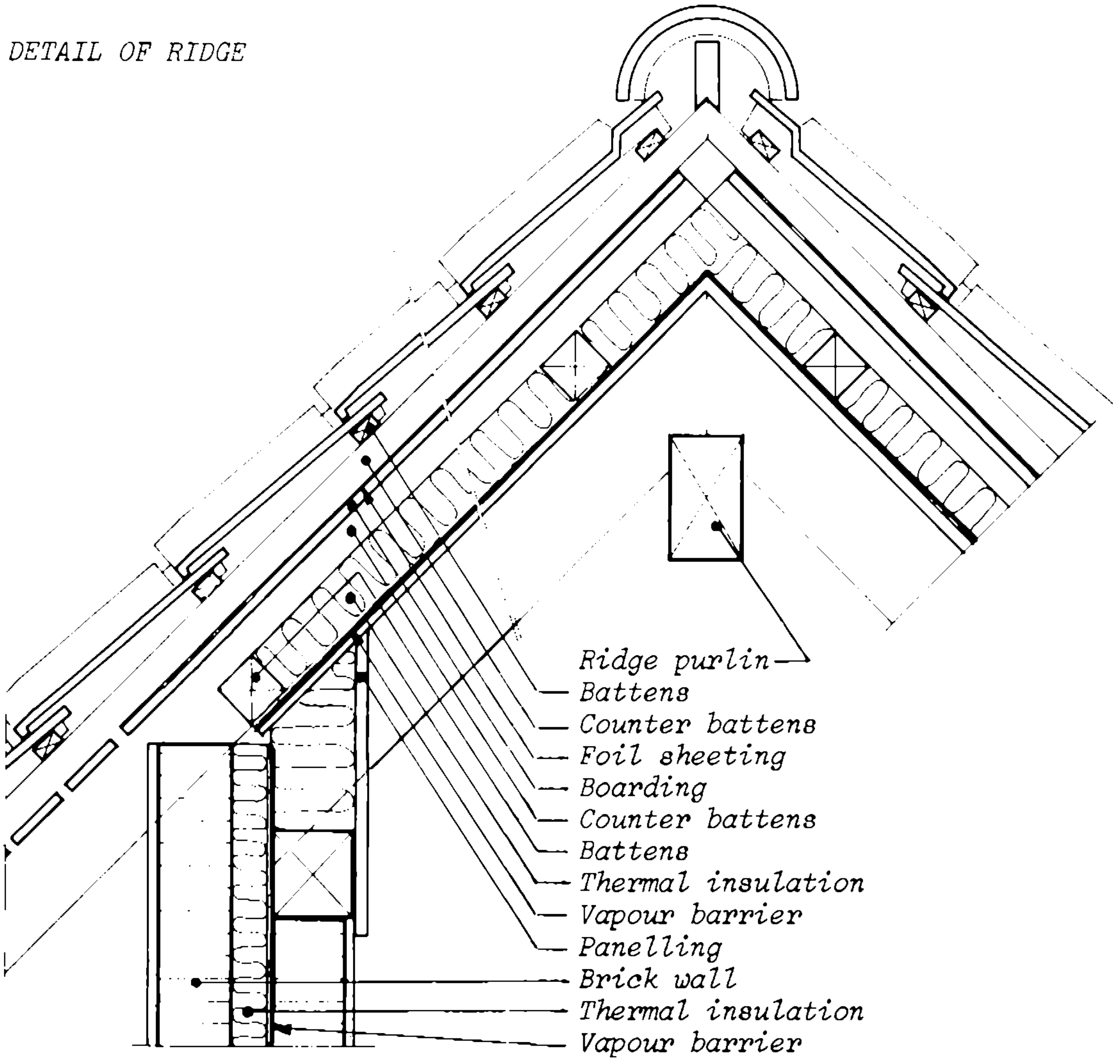
i) ROOF DETAIL

The same problems arise as with framework construction details (see f) Section BIV.3.2).

Roof construction with exposed rafters

Standard construction

DETAIL OF RIDGE



DETAIL OF VERGE

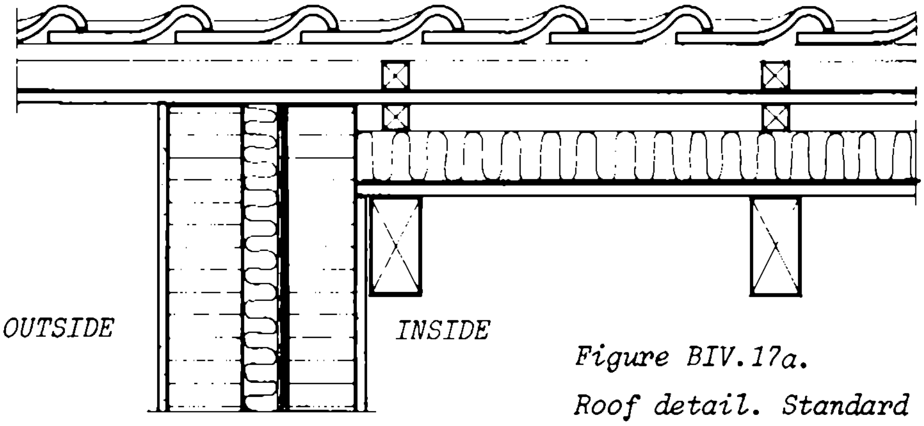


Figure BIV.17a.

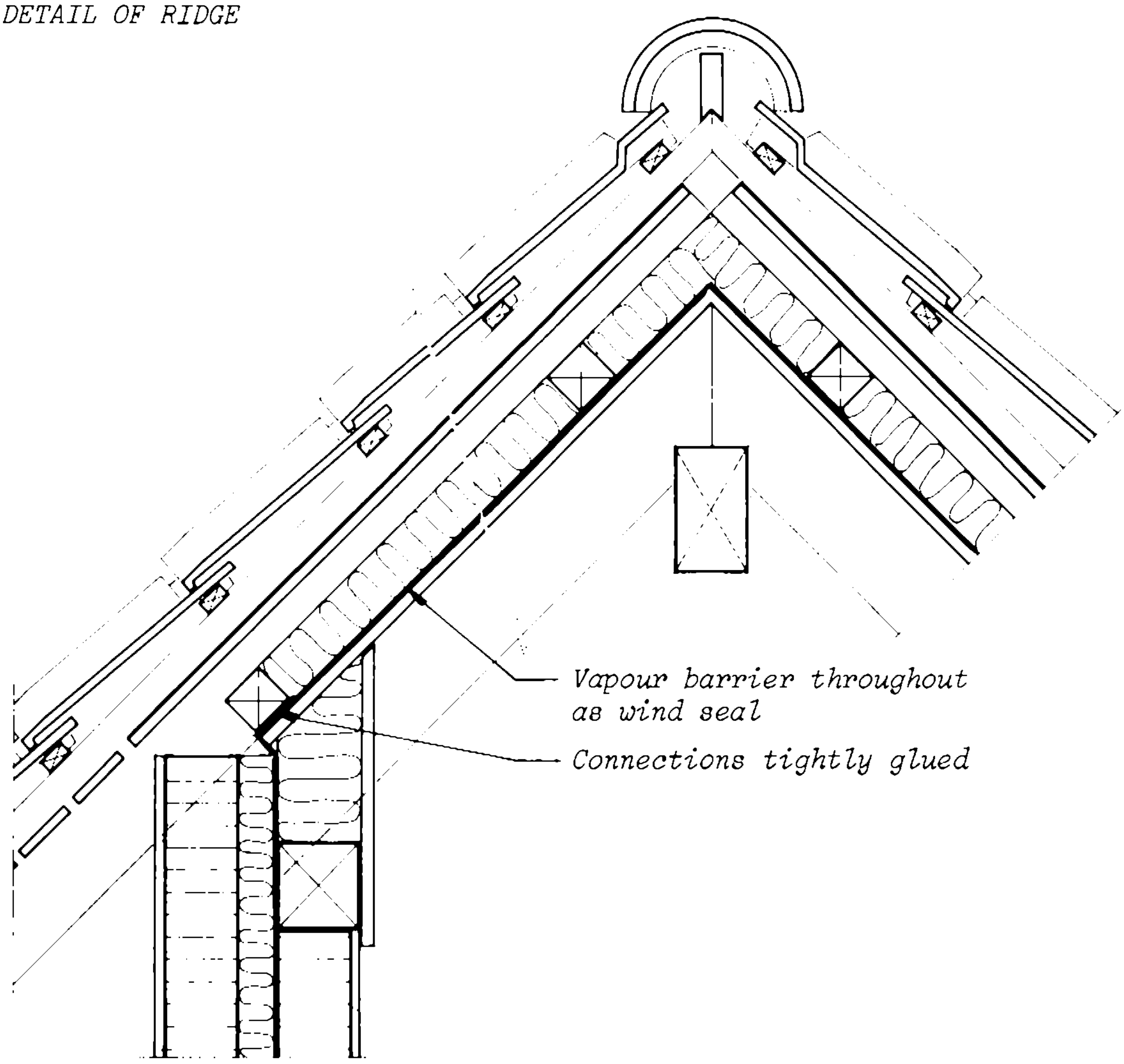
Roof detail. Standard construction.

Roof construction with exposed rafters

Improved construction

Vapour barrier as wind seal.

DETAIL OF RIDGE



DETAIL OF VERGE

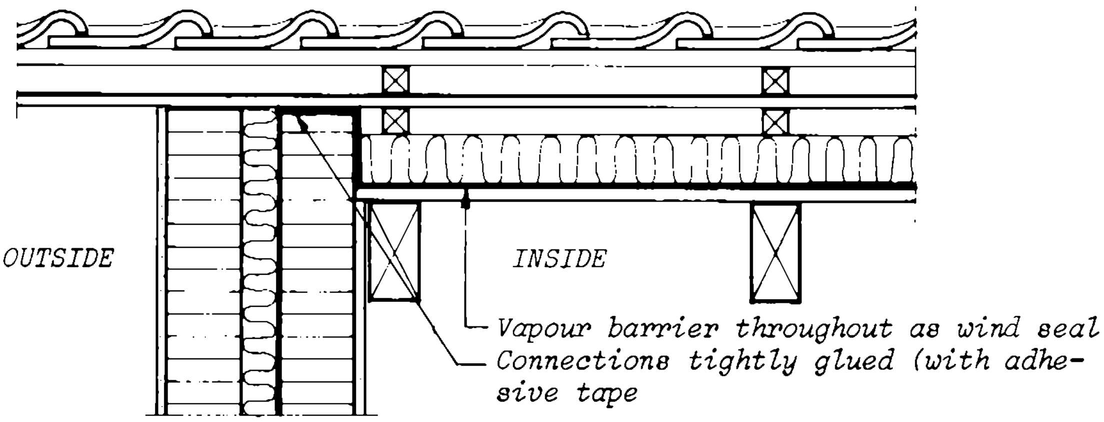


Figure BIV.17b. Roof detail. Improved construction.

Steep pitched roof with boarded rafter system in massive type of construction

Standard construction

Thermal insulation between rafters, internal boarding on rafters.

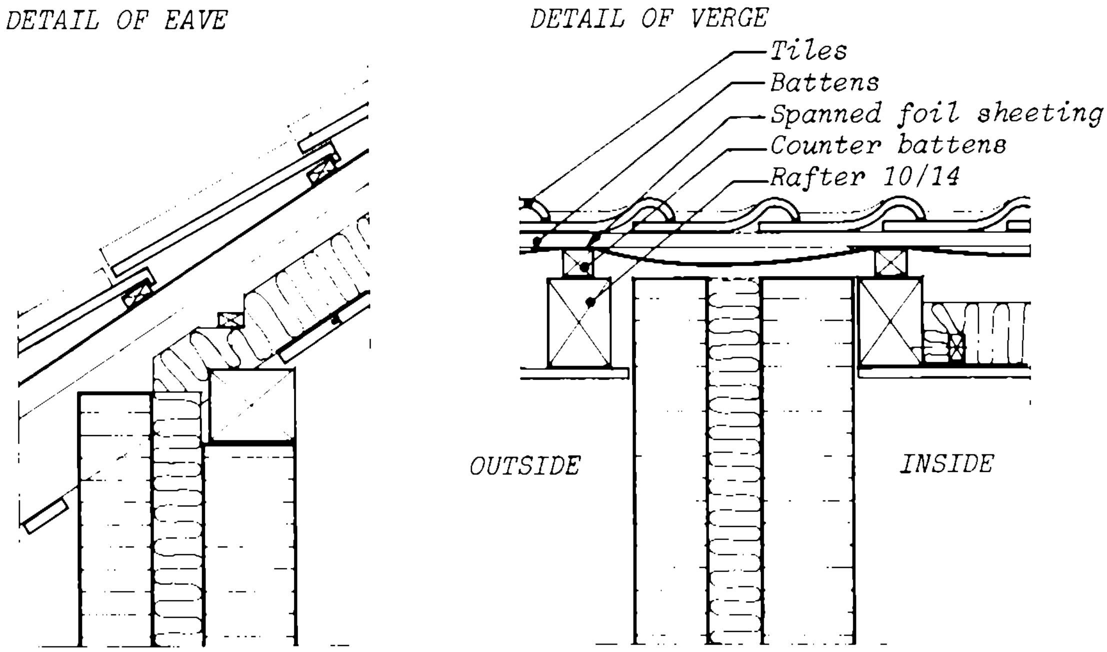


Figure BIV.17c. Roof detail.

Improved construction

Continuous wind protection membrane between rafters and boarding.

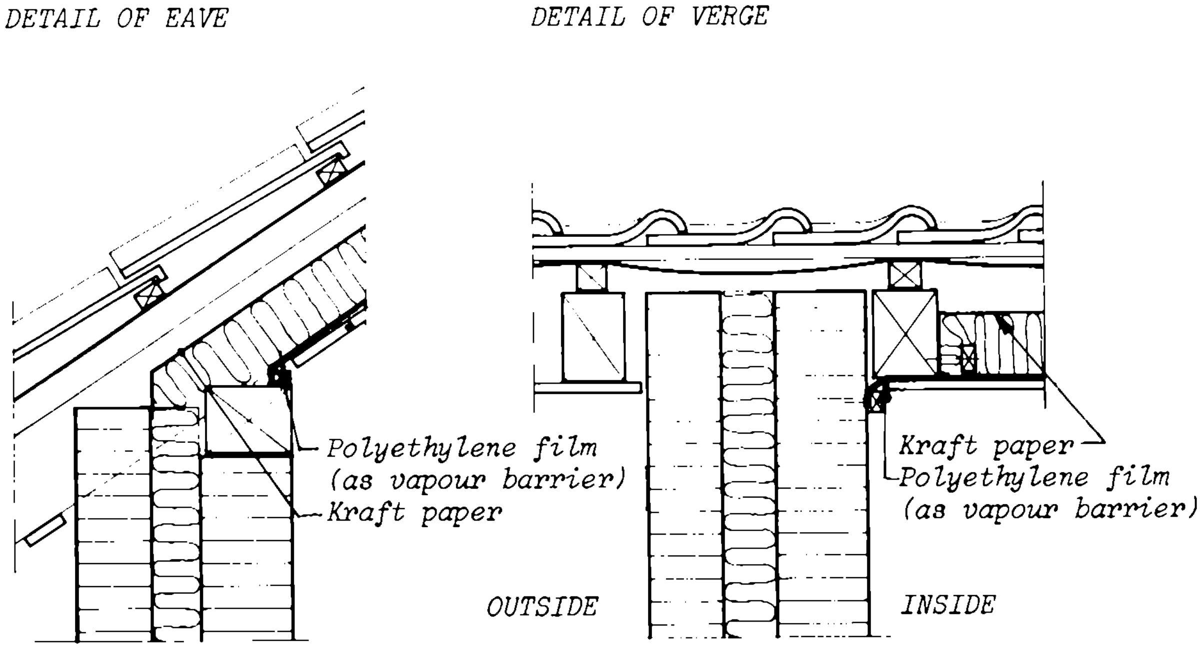


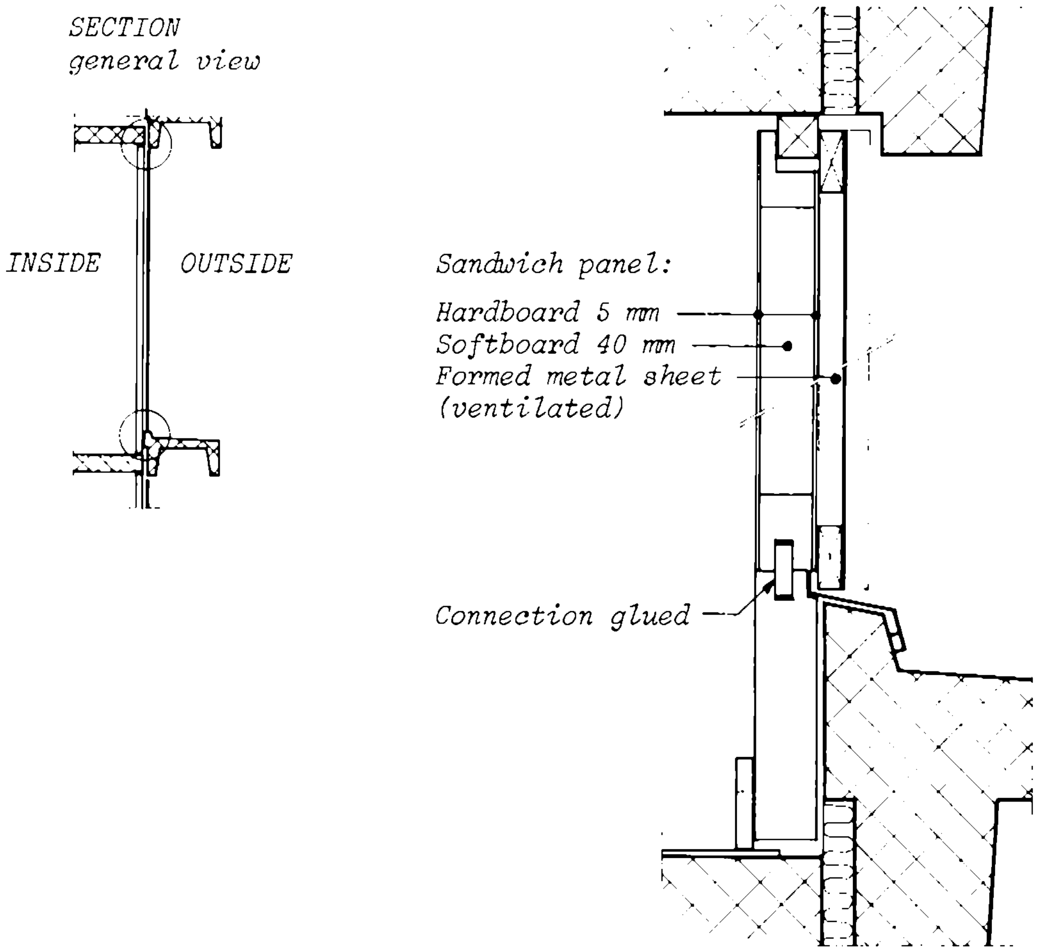
Figure BIV.17d. Roof detail.

j) CURTAIN WALLING

In order to reduce to a minimum the loss of warm air through joints in curtain walling, the following points should be observed:

- joints between curtain walling and adjoining structural elements
- impermeable surface.

Standard construction



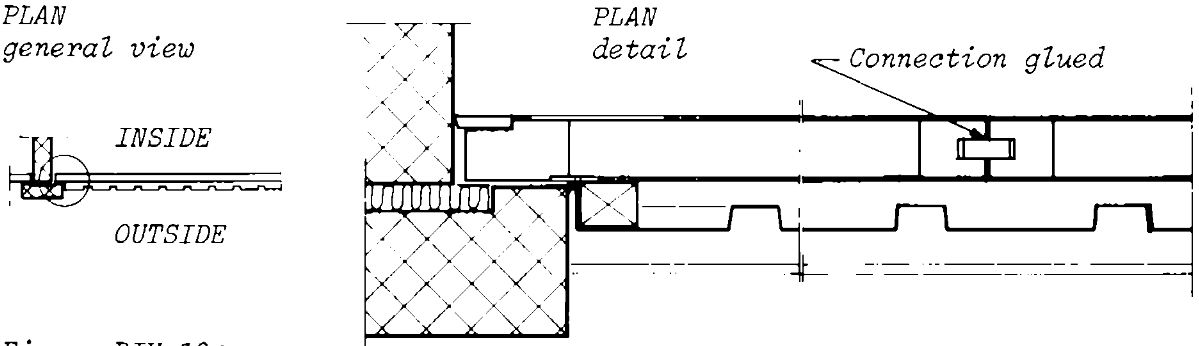
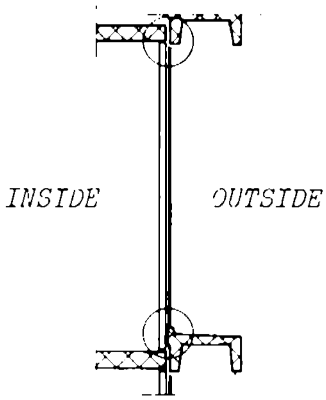


Figure BIV.18a.

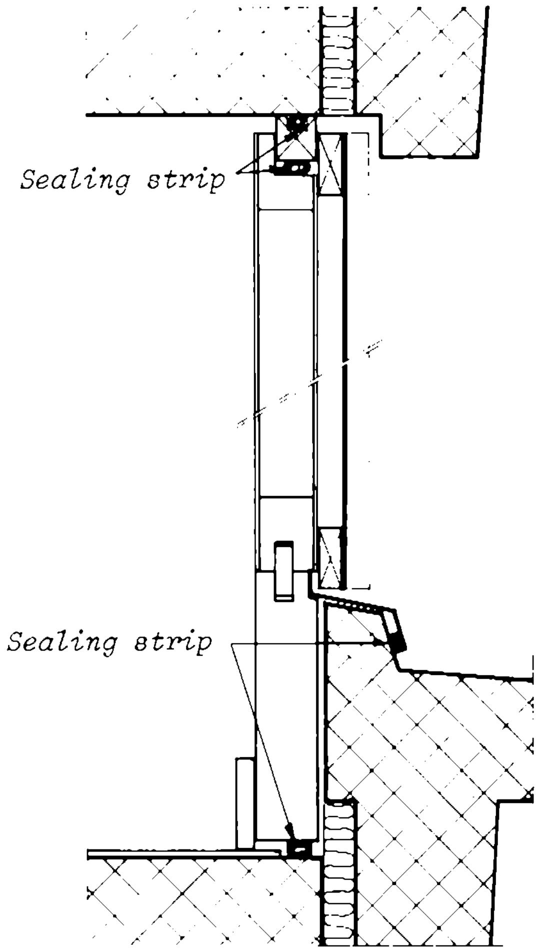
Curtain walling.
Standard construction.

Improved construction

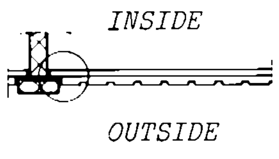
SECTION
general view



SECTION
detail



PLAN
general view



PLAN
detail

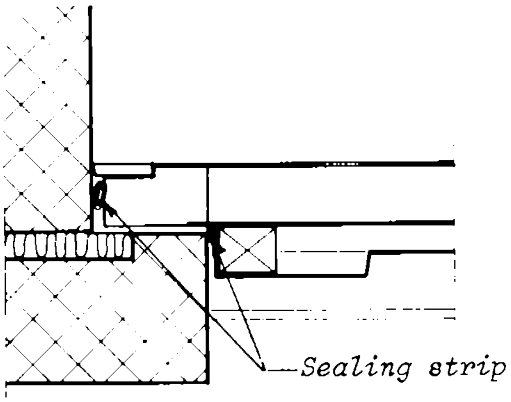


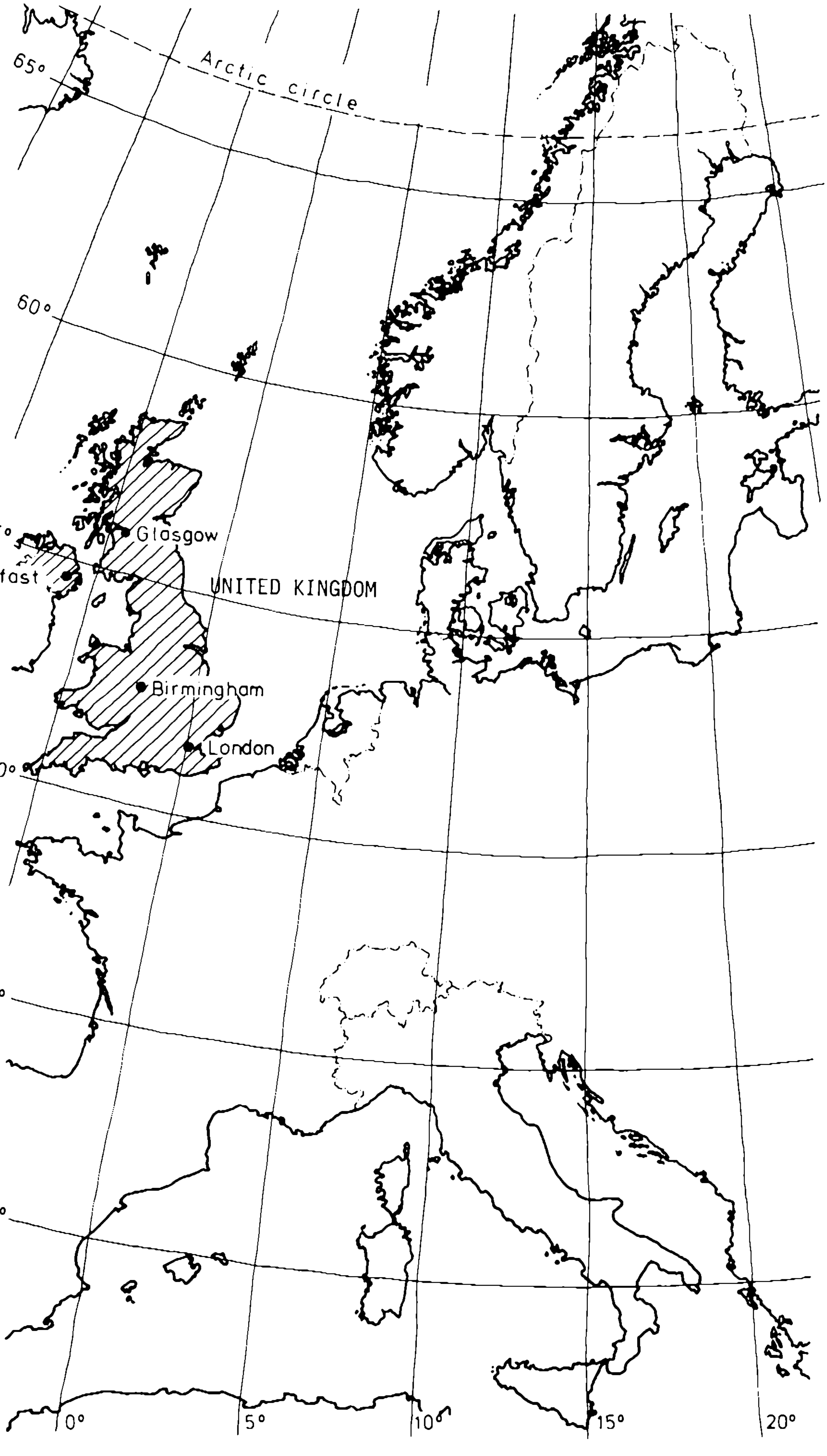
Figure BIV.18b. Curtain walling. Improved construction.

BIV.4 REFERENCES

SIA - Codes and Recommendations

SIA CODE NR.	TITLE
180	Thermal Protection of Buildings (principles).
180/1	Thermal Protection of Buildings for Winter Conditions.
180/3	Annual Heat Consumption of Buildings (simple calculation method).
271	Flat Roofs (principles).
279	Thermal Insulation Materials (requirements, testing).
381/1	Building Construction Materials (characteristics).
381/2	Climatic Data for Solar Energy Applications.
381/3	Heating Degree Days for Switzerland.
382/1	Ventilation Installations (special conditions for installation).
384/1	Central Water Heating Systems (techn. requirements for installation).
384/2	Heating System Design Rules.
384/7	Central Heating Systems
385/3	Domestic Hot Water Preparation Systems.

UNITED KINGDOM
PART BV



BV.1 NATIONAL REGULATIONS FOR HOUSING IN THE UNITED KINGDOM

BV.1.1 Requirements for airtightness

The UK has neither mandatory nor recommended standards for the airtightness characteristics of complete dwellings.

However, a draft standard (DD4:1971) has been issued by the British Standard Institution as an interim standard for development. This document gives preliminary recommendations on the grading of windows in respect of resistance to wind loads, air infiltration and water penetration and is expected to be revised and reissued as a full British Standard in the near future. The air leakage limits from DD4 are as follows:

Exposure rating	Pressure difference under test (Pa)	Maximum air infiltration rate
Sheltered	100	12 m^3/h per metre length of crack
Moderate	150	
Severe	200	

The three exposure ratings are defined in terms of the wind's maximum gust speed, averaged over a 3 second period, which is expected on a once in 50 year probability, as follows:

Exposure	Maximum 3 s gust speed (m/s)
Sheltered	40
Moderate	45
Severe	50

There are no similar national standards for doors, although the criteria which have recently been proposed for the selection of doors and door sets include requirements for air infiltration rates, but these are less stringent than for windows. A guidance document is to be published by the Building Research Establishment.

BV.1.2 Minimum ventilation rates

The Building Regulations for England and Wales contain a requirement for mechanical ventilation rates, in respect of sanitary accommodation only. This applies to all building types including housing, but only as an alternative to natural ventilation. All other ventilation provision in the Regulations is expressed in terms of area of ventilation opening (see Table A5.5 in Part A).

Table 12 of the Scottish Building Standards gives more specific requirements for ventilation rates in a great variety of types of room and building occupancy. For kitchens, bathrooms and WCs, these requirements are expressed in terms of air change rates and for living-rooms and bedrooms, as a volume of fresh air per person, the number of persons being the number for which the room is designed.

In Inner London, the GLC Building (Constructional) Bylaws require natural ventilation by means of openable windows to all habitable rooms and kitchens. In addition, there is a basic requirement for these rooms to have permanently open ventilation of 2000 mm^2 (see Table A5.5 in Part A). However, District Surveyors (London Building Control Officers) have the discretion to approve mechanical ventilation to such rooms where natural ventilation is not possible. The mechanical ventilation rate must be at least 22 m^3/h per occupant or 5 m^3/h per m^2 floor area, whichever is the greater. There are no specific rates given for bathrooms but the District Surveyors' Association have agreed to follow the requirements of BRE Digest 78 (3 air changes per hour). The ventilation of WC compartments is controlled by Environmental Health Inspectors under the GLC's Drainage Bylaws, under which there are no specified ventilation rates laid down.

Recommendations are also made in British Standards and also CIBS publications. The recently published British Standard for ventilation principles and design (BS 5925) draws on the CIBS Guide Section A1 to give minimum and recommended ventilation rates, but only for air-conditioned residences (i.e. not applicable generally to UK housing).

BV.1.3 Requirements for thermal insulation

The thermal insulation requirements for housing in the UK, to which reference is made in Part A, were amended in 1982. They apply to buildings for which approval is sought after the 1st April 1982 (England & Wales) or 17th March 1982 (Scotland). In Inner London, the GLC Building (Constructional) Bylaws include no requirement for thermal insulation.

The main features of the amended national regulations are:

- lowered maximum permitted k-values (U-values) for elements of the building (walls, roofs, etc.)
- new requirements to limit the risk of condensation in lofts and roof spaces
- the omission of the calculated average k-value for perimeter walling
- its replacement with requirements to limit the area of glazing relative to that of the perimeter walling.

MAXIMUM k-VALUES (U-VALUES)

The maximum permitted k-values are as shown in Figure BV.1.

LIMITING CONDENSATION RISK

The following alternative methods of limiting the risk of roof space condensation are accepted:

- construction in accordance with clauses 22.8 to 22.16 of BS 5250 (these clauses give general guidance on how to avoid condensation problems in flat and pitched roofs of dwellings, including the use of vapour barriers and vapour checks

OR

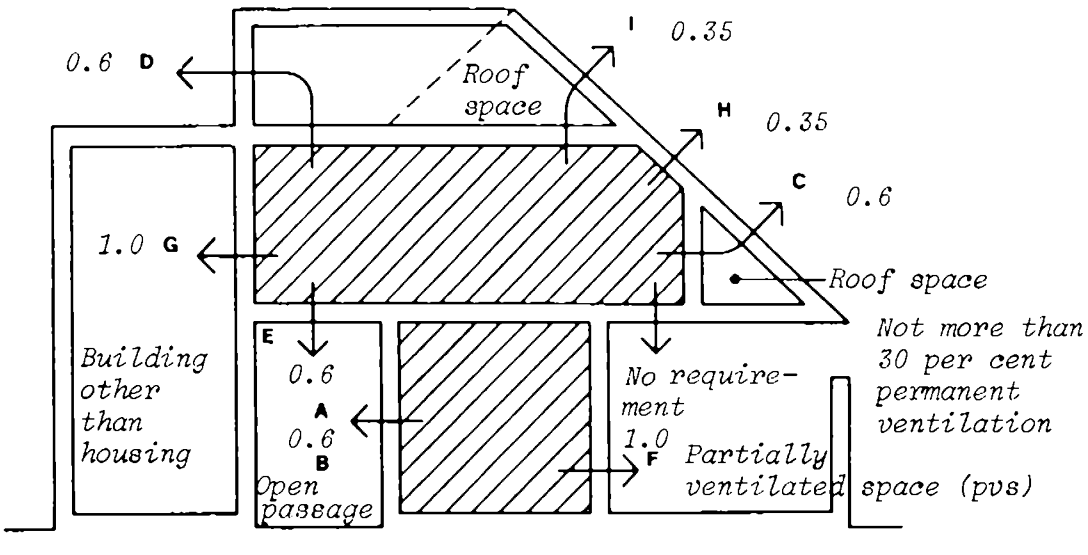
- cross ventilation by means of permanent ventilation to the roof space (cold roof design) with a total free area not less than 0.3 per cent of the roof plan area, but evenly distributed around the perimeter of the roof

OR

- cross ventilation to pitched roofs of rectangular plan shape by means of permanent ventilation providing a free area equivalent to a continuous gap width of:

  10 mm (if roof pitch $>15^{o}$)

  25 mm (if roof pitch $\leq 15^{o}$).



Maximum k-value (W/m^2 °C)		Element of construction
0.6	A	External wall construction
	B	Wall construction between a dwelling and a space which has more than 30 per cent of its boundary wall used for permanent ventilation
	C	Combined construction of internal wall, roof space and roof. (Room-in-the-roof conditions)
	D	Combined construction of ceiling, roof space and external wall. (Gable wall condition)
	E	Exposed floor construction between a dwelling and the open air, or a space which has more than 30 per cent of its boundary wall used for permanent ventilation
1.0	F	Wall construction between a dwelling and a space which has not more than 30 per cent of its boundary wall used for permanent ventilation, i.e. partially ventilated space (PVS)
	G	Wall construction between a dwelling and any part of an adjoining building which is not housing
0.35	H	The roof of a dwelling
	I	The combined construction of ceiling, roof space and roof finish

Figure BV.1. Diagram showing maximum permitted k-values (U-values) for various building elements.

PERMITTED AREAS OF GLAZING

The area of single glazing should be no greater than 12 per cent of the *perimeter wall* area when the external wall k-value is 0.6 W/m^2 K. The "perimeter wall" includes party walls and walls between the dwelling and unheated ventilation spaces.

Adjustments may be made for double and triple glazing as follows:

> double glazed area ÷ perimeter wall area must not be greater than 24 per cent
>
> triple glazed area ÷ perimeter wall area must not be greater than 36 per cent.

Alternatively, if the designer wishes to use an external wall construction with a k-value less than 0.6, there is the opportunity to increase the area of glazing, provided that the combined rate of heat loss through the windows and wall of the proposed design is no worse than if the above rules for percentage glazing areas had been applied, i.e.

$$\underbrace{(WA_{0.6} \cdot 0.6) + (GA_R \cdot GU)}_{\substack{\text{Thermal transmittance} \\ \text{using percentage glazing}}} \geq \underbrace{(WA_{<0.6} \cdot WU_{<0.6}) + (GA_p \cdot GU)}_{\substack{\text{Thermal transmittance of} \\ \text{proposed design}}}$$

where $WA_{0.6}$ = wall area with k = 0.6 W/m^2 K

GA_R = area of glazing designated in the Regulations

GU = k-values of the glazed areas:

$$\left.\begin{array}{l}\text{- single glazing} = 5.7 \\ \text{- double glazing} = 2.8 \\ \text{- triple glazing} = 2.0\end{array}\right\} \text{values assumed for the purposes of this calculation}$$

$WA_{<0.6}$ = wall area with k < 0.6 W/m^2 K

$WU_{<0.6}$ = actual k-value of wall with k < 0.6 W/m^2 K

GA_p = proposed area of glazing in the wall with k < 0.6 W/m^2 K.

For this calculation, it is permitted to determine the area of glazing either as the structural opening into which the window is placed (provided the wall k-value is maintained up to the window frame) or alternatively the area of the structural opening plus the area of the wall (i.e. at window sills, lintels and reveals) which does not meet the k-value requirement.

There is therefore no specific requirement to avoid cold bridge detailing. However, the fact that the permitted area of glazing can be increased if cold bridges are avoided, provides some incentive for designers to choose this option.

BV.2 THE CLIMATE OF THE UNITED KINGDOM

BV.2.1 General description

Owing to its elongated shape between latitudes 50 and 60 degrees north, the United Kingdom has a considerable variation in climate within a relatively small area. There is a clear climatic distinction between 'highland' areas (Scotland, Wales and parts of the South West) with land higher than 400 metres above sea level and lowland areas of the South and East of England and also Northern Ireland.

Figure BV.2 shows the location of high ground and Figure BV.3 the temperature and windspeed plots for four cities in the United Kingdom. Further details of climate are given in Section A6.

Figure BV.2. Map showing the parts of the UK where land is higher than 400 metres above sea level.

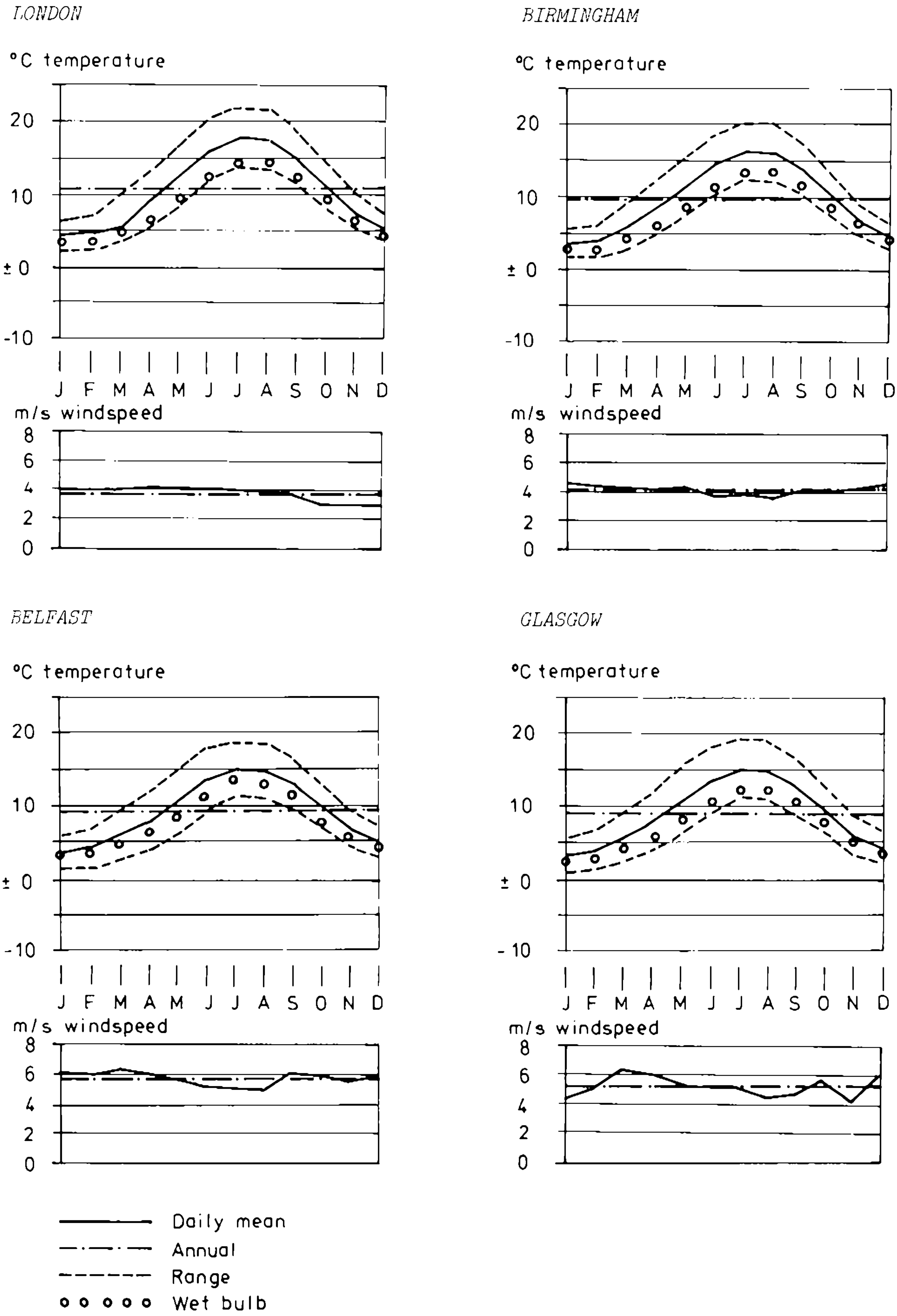


Figure BV.3. Climatic data for four cities in the UK.

BV.2.2 Degree days and design temperatures

The difference between average temperatures in the South of England and those in Northern Britain are as follows:

minimum winter temperature difference = 5°K

mean temperature difference in coldest month = 2°K.

This is reflected in the range of degree day values found across the UK. Figure BV.4 shows degree day contours based on a 30 year period between 1921 and 1950 and with a 15.6°C base temperature. In the UK, however, degree days are used only for estimating seasonal fuel consumption, rather than for heating system design, see Section A6.2.

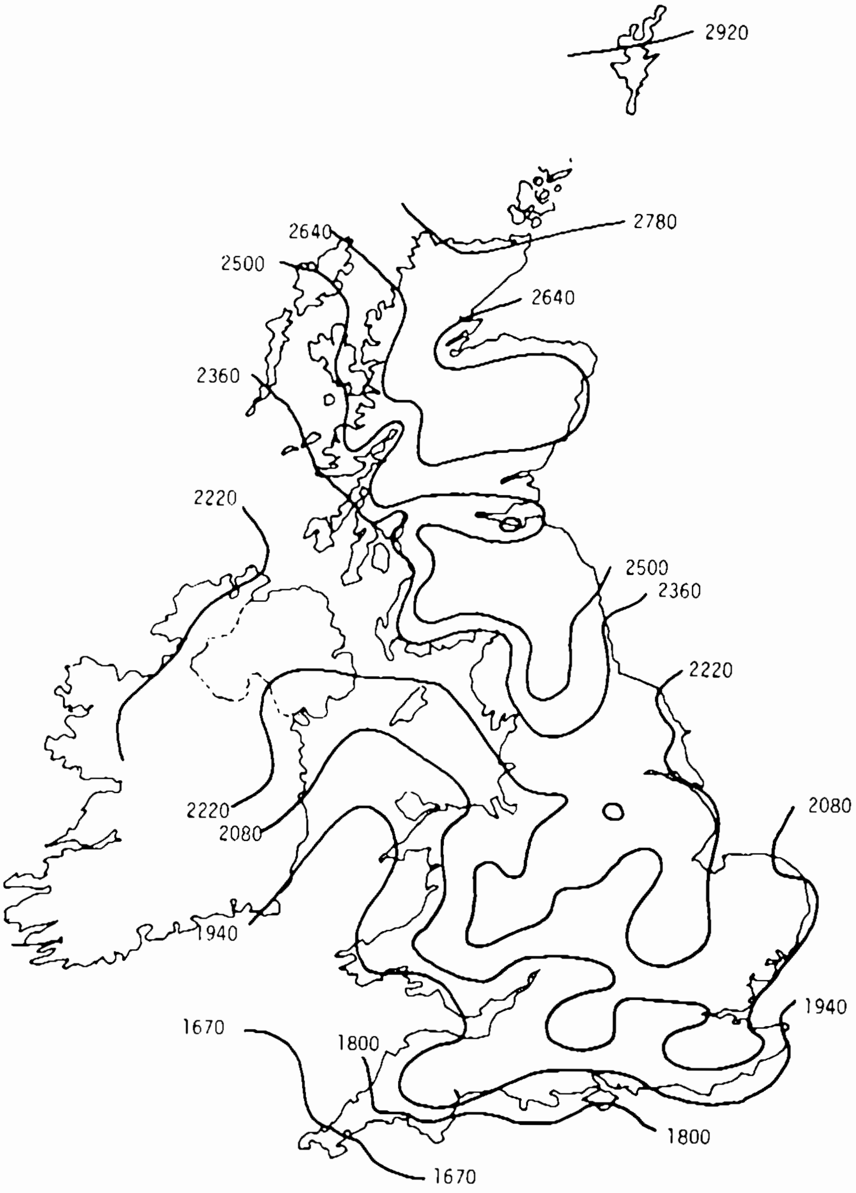


Figure BV.4. Degree day contours for the UK with 15.6°C base temperature (after Shellard 1956).

The use of climatic zones with different external design temperatures has not been adopted as standard practice in the UK. As a result, the majority of design specifications for the whole of the country require the heating installation to maintain the chosen internal temperature when the external temperature is -1°C.

Under these circumstances, the designer is expected to choose whether or not, in order to achieve adequate internal temperatures on very cold days, to increase the power output of the heating system above that derived from the steady state design specification, and run the risk of reduced system efficiency during the many mild days throughout the winter. In the UK, therefore, the part load efficiency of the heating boiler is of particular significance.

BV.3 TYPICAL DOMESTIC BUILDINGS IN THE UNITED KINGDOM

BV.3.1 The housebuilding market generally

Domestic construction activity in the UK is divided between the public sector (Local Authorities and Housing Associations receiving Government support) and the private sector (financed by contractors/ developers and private individuals).

In 1975, a roughly equal share of the housebuilding market was taken by each sector. Since then, the general decline in the UK construction industry has had a greater effect on the public sector and substantially reduced its share of the market.

BV.3.2 Typical dwelling types

There has been a steady decline since the 1960s in the use of multi-storey housebuilding. Indeed, industrialized building systems using large finished components made off-site are now virtually non-existent.

The current emphasis being put on building dwellings for smaller families and for special groups, such as the elderly and handicapped,

Figure BV.5.

Housing for the elderly by a Housing Association.

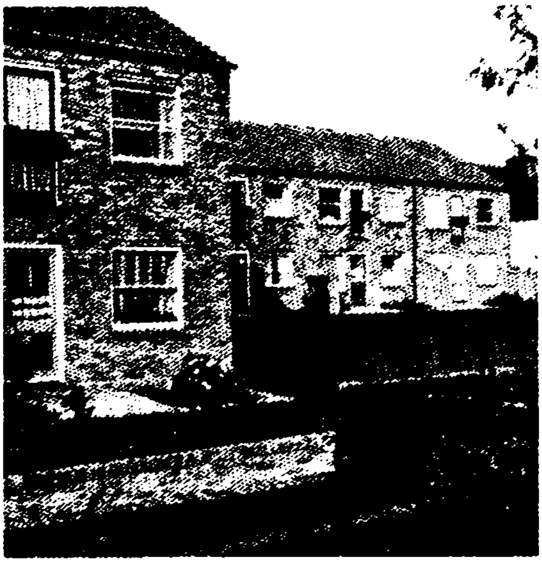


Figure BV.6.

Local authority housing for the handicapped.

has resulted in a predominance of two storey family houses and small scale flat developments. On occasions, flats are built in blocks of three or four storeys.

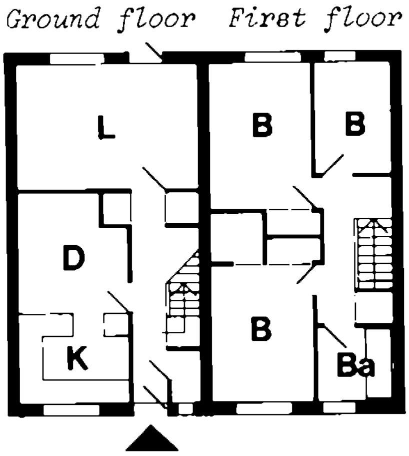
Figure BV.7. Mixed family housing.

Figure BV.8. Two and three person flats.

5 PERSON HOUSES

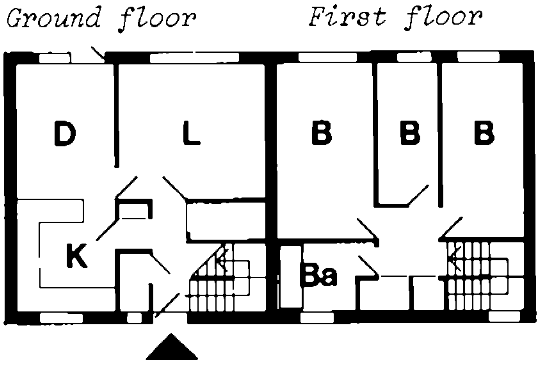
NARROW FRONTAGE

Shell size 4.8 x 9.0 m
Net floor area 83.90 m^2



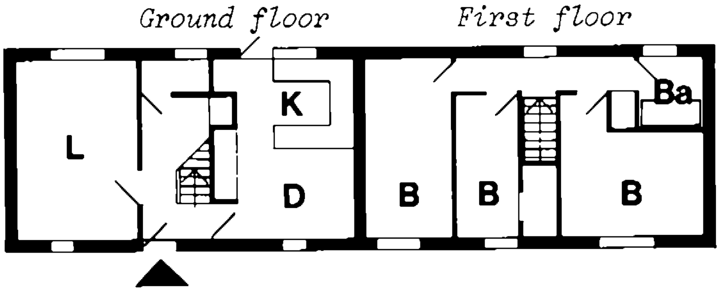
MEDIUM FRONTAGE

Shell size 6.6 x 6.6 m
Net floor area 84.40 m^2



WIDE FRONTAGE

Shell size 9.0 x 4.8 m
Net floor area 83.87 m^2



2 PERSON FLATS

Shell size 6.0 x 8.4 m
Net floor area 48.10 m^2

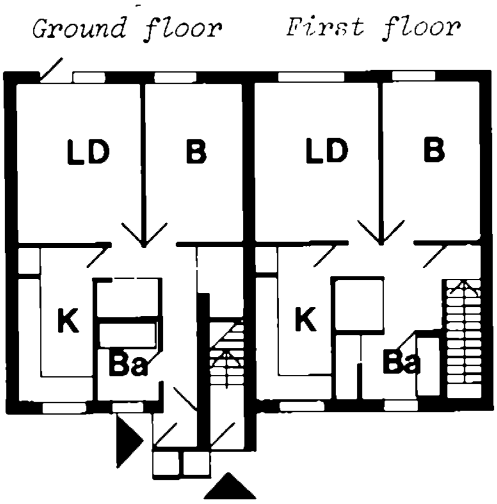


Figure BV.9. Typical popular plan forms used for recent housing projects in the public sector.

BV.3.3 Forms of construction

In the UK, the basic structure of two storey dwellings is either load-bearing masonry (brickwork and blockwork) or timber frame. In both cases, there is a preference for the use of natural materials for the external facing, e.g. brick, clay tiles or timber (see Figures BV.10 and BV.11).

Three and four storey flats are often constructed with concrete floor slabs, supported by load-bearing masonry cavity walls. Roofs are flat and either of concrete or timber construction. The critical details from the point of view of airtightness are associated with the formation of openings in masonry walls and are therefore dealt with in the general discussion of masonry construction.

Whilst masonry construction is often specified for public sector developments, the advantage of timber frame construction in respect of rapid site erection has caused builders and private developers increasingly to choose this form of construction for their speculative developments. Indeed, the general availability of design guidance has changed 'timber frame' from a building 'system' to a form of construction which can be used even by the small scale building contractor.

However, masonry construction will continue to be chosen where concrete floors are preferred as a means of achieving adequate sound insulation between flats and where the designer considers it an advantage from the point of view of the control of the environment within the dwelling.

MASONRY CONSTRUCTION

In load-bearing masonry construction, the cavity walls are conventionally built with a single leaf of brickwork externally and an inner leaf of brickwork or blockwork. Before 1982, it was possible to comply with Building Regulation thermal insulation requirements simply by using a light-weight concrete block for the inner leaf of the wall.

However, since the amendments came into effect in March/April 1982, it has no longer been possible to comply with the maximum k-value requirements without the use of insulating materials with high

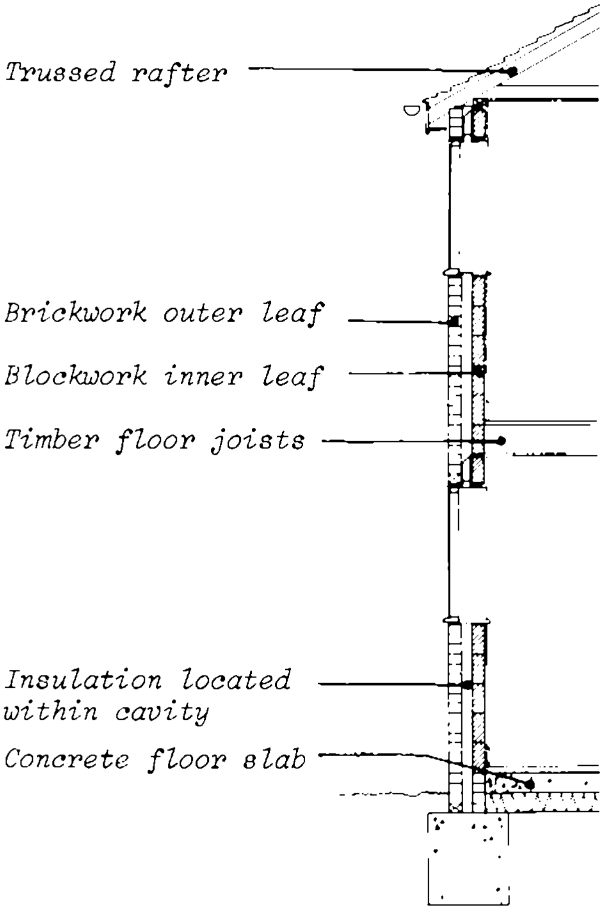


Figure BV.10. Typical masonry house construction.

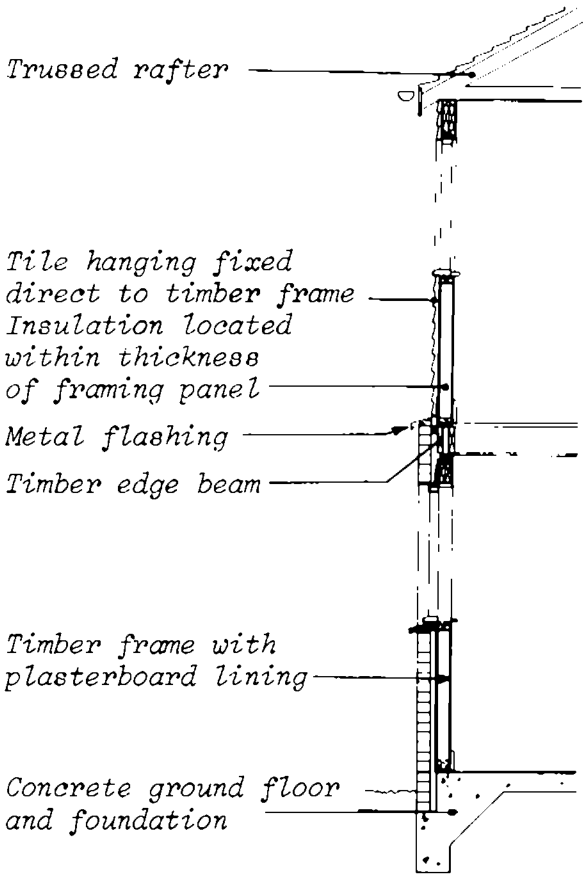


Figure BV.11. Typical timber frame house construction.

thermal resistance within the external wall construction. This is done most conveniently by filling or partially filling the wall cavity as the wall is built with insulating material, usually in quilt or board form.

The load of the first floor and roof is supported on the inner leaf of the cavity wall. Roofs are constructed of trussed rafters with a pitch between $22\frac{1}{2}^{\circ}$ and 30°. The roof trusses sit on a timber wall plate, above the inner leaf and are held down to the masonry wall with metal straps. The use of attic accommodation is not commonplace in public sector housing, but occurs occasionally in the private sector.

The first floor timber joists may be supported on joist hangers built into the inner leaf or alternatively the joist may penetrate the inner leaf so as to have the maximum direct bearing on the wall.

From the point of view of fire resistance, the Building Regulations limit the continuity of air spaces within the elements of construction and between one element and another.

The finish to masonry walls was traditionally wet plaster, but in recent years, plasterboard dry lining has become more popular. When first introduced, it was fixed to timber battens, but this is an expensive solution and methods have been developed which rely on adhesive fixing direct to the masonry wall.

Ground floor construction is either the traditional suspended timber floor with underfloor ventilation or alternatively a solid concrete slab, cast in contact with the ground. Very recently, the use of suspended concrete plank floor has been introduced as an alternative to the traditional timber suspended floor. These concrete floors have also been used in flats as some consider them able to meet the sound insulation requirements (both airborne and impact) more conveniently than does timber construction. It is not common in the UK for the ground floors of dwellings to be insulated as there is no requirement to do so in the Building Regulations. If insulation is included, the aim is to reduce heat loss at the perimeter of the building.

TIMBER FRAME CONSTRUCTION

In timber frame construction, the loads of floor and roof are supported by frame constructed of 75 x 50 or 100 x 50 mm timber studs (posts) stiffened by a sheathing material of plywood or hardboard. The external and party walls of the dwelling are formed from 2 or 3 panels, joined together at an intersection with an internal wall panel. The space between the studs of the external wall panels are insulated with mineral fibre and the framework is lined on the inside with plasterboard. A vapour barrier of polyethylene[x] is introduced as a separate membrane, as a backing to the plasterboard sheet or as a facing to the mineral fibre insulating quilt.

The first floor is supported by the ground floor panels either from joist hangers attached to an edge beam or by bearing directly on the lower panels. The roof structure is formed of trussed rafters (as for masonry construction) which span between the external walls.

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[x] More commonly known as polythene in the UK.

Externally, the frame may be faced with an independent veneer of brickwork separated from the frame by an air space, or with timber or tile cladding fixed directly to the frame. It is common to use a brick veneer up to first floor level with timber or tiles above.

It is normal practice for an impregnated "breather paper" to be applied to the sheathing to protect it from moisture during the construction process and to protect it from wetting by rain driven by wind through open jointed cladding.

The ground floor is usually of concrete with an integral foundation 'toe' to support the brick veneer. Alternatively, a conventional masonry type foundation may be used to support the timber frame and to make it possible to provide ventilation for a suspended timber floor.

As in the case with masonry construction, ground floors are not normally insulated. Insulation above the concrete slab or within a suspended floor ensures that a cold bridge is avoided but the lack of thermal capacity within the building may make it difficult to control internal temperatures. Insulation placed beneath the slab is more satisfactory in this respect but it is not able to prevent heat loss from the perimeter of the floor.

BV.3.4 Construction details

In UK house construction, special care is not normally taken to seal all potential air leakage paths. Emphasis is more often placed on reducing the passage of water vapour through the construction and relying on natural ventilation to avoid interstitial condensation.

As the need to do this is considered to be greater in timber frame than in masonry construction, the potential for improving the air infiltration characteristics of timber frame construction already exists. Great improvements can be made by firstly ensuring that the vapour barrier is correctly fixed and secondly by ensuring that it is continued at junctions of walls, floors and roofs.

Masonry walls which are built with joints well filled with mortar and with plaster finish exhibit very little air leakage. However, the trend to use plasterboard wall lining and the lack of importance often placed on filling mortar joints has increased the potential for air leakage through walls and at their junctions with floor and ceiling.

Also, the ventilation of wall cavities encourages air to penetrate through the inner leaf of the wall, particularly at first floor level where the floor joists are often built into the wall and sealed only with cement mortar. Whilst this sealing method is acceptable as a means of stopping the spread of fire, it is unlikely to be adequate to prevent air infiltration into the building.

Research by the Building Research Establishment and the UK fuel industries (both gas and electricity) is currently in progress to determine the air leakage paths through typical houses and the proportion of the total leakage attributable to each. Published papers do not yet indicate firm relationships between specific construction details and air leakage characteristics. Under these circumstances, it is possible only to identify the potential air leakage paths and suggest ways in which these might be eliminated or substantially restricted.

The principal air leakage paths are associated with the following:

- windows and doors
- floor/wall and wall/ceiling junctions
- openings for access to the roof space
- holes for services.

These are illustrated in Figure BV.12 for a two storey house.

Each of the critical points shown on the diagram are discussed in the following pages, where necessary with separate consideration of masonry and timber frame construction. In each case, the construction detail thought most typical of existing practice is shown, followed by suggested methods for reducing air leakage. Many of these methods still require site evaluation.

Some of the air sealing methods shown are recommended in manufacturers' product literature but not generally applied in practice; others have been chosen for specific low energy housing projects.

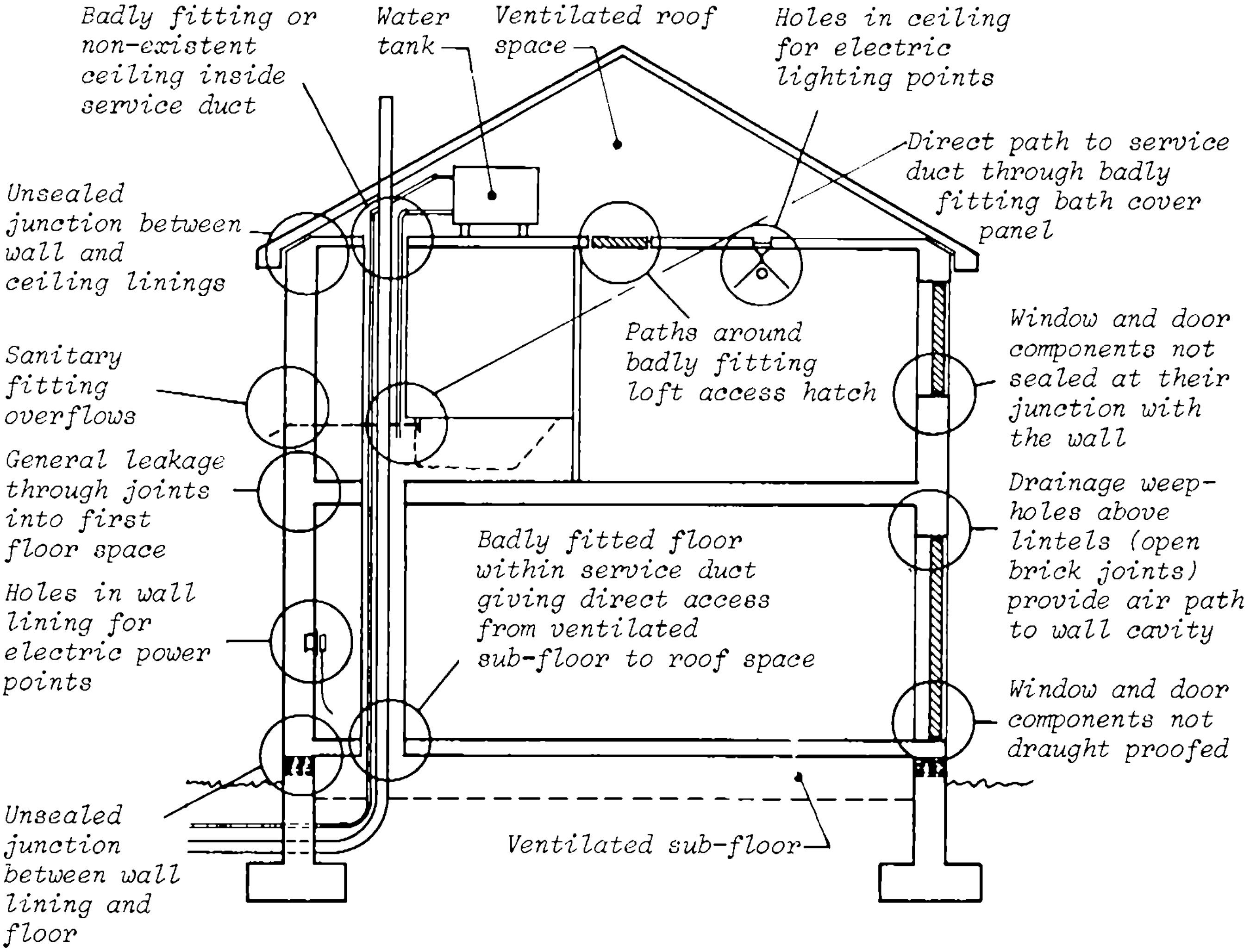
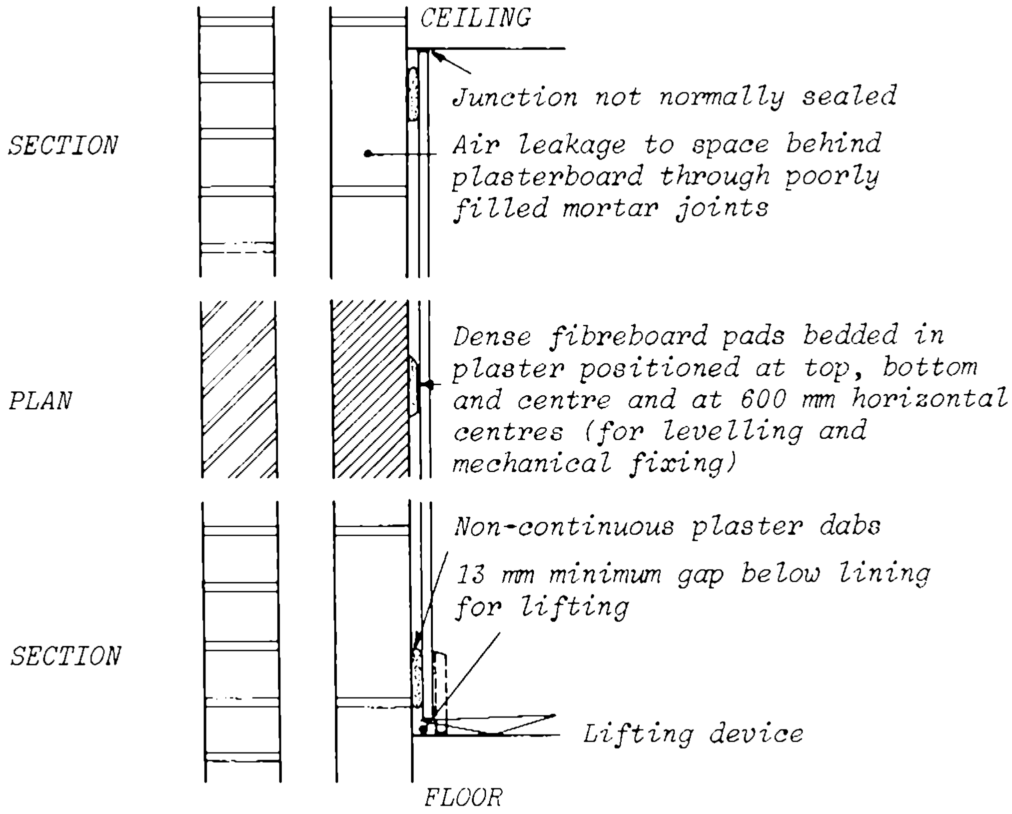
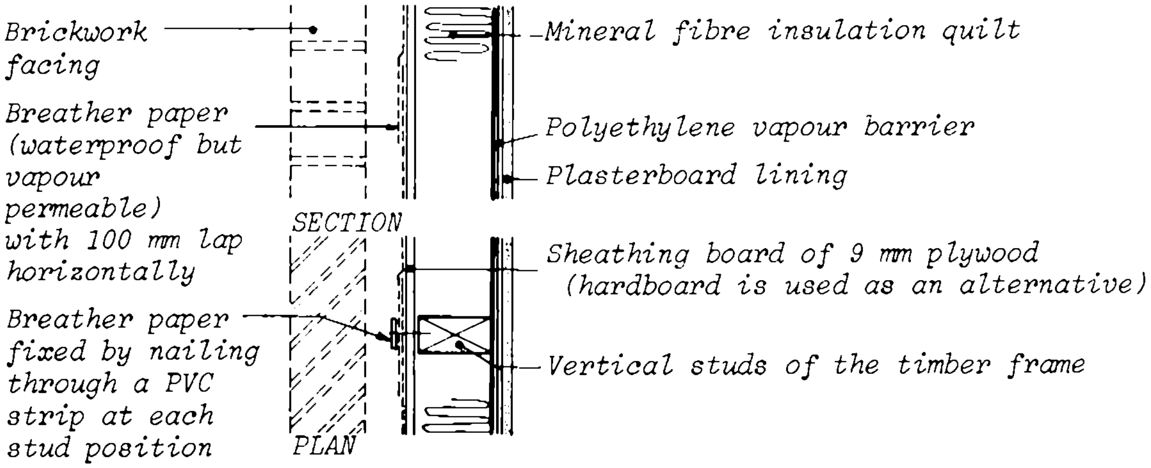


Figure BV.12. Air leakage paths in 2-storey family houses.



Cavity wall with internal blockwork, most frequently lined with plasterboard fixed with plaster dabs. If care is not taken to seal the space behind the lining, there can be a direct path between ground floor and roof space

Figure BV.13. Standard masonry construction.

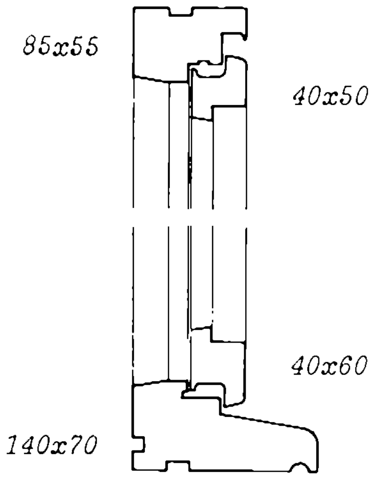


Other than at the panel junctions or where services penetrate, the timber frame panel has reasonably good air infiltration characteristics. However, there is a body of opinion which recommends ventilating within the panel by means of holes drilled in the sheathing at top and bottom. In these circumstances, it is essential to maintain the continuity of the vapour barrier

Figure BV.14. Standard timber frame construction.

WINDOW AND DOOR COMPONENTS

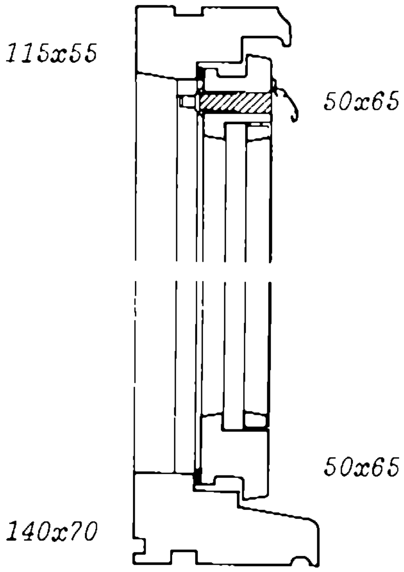
There are now many windows (timber, metal and plastic) which are weatherstripped to meet 'severe' rating of DD4 (see Section BV.1.1). It is not common, however, for external doors to be weatherstripped, although at least one manufacturer is offering an insulated, weatherstripped, metal reinforced door and frame assembly as an "energy efficient" unit.



Outward opening softwood casement window for single glazing, without draught-sealing or slot ventilator; an economy window unit

Figure BV.15.

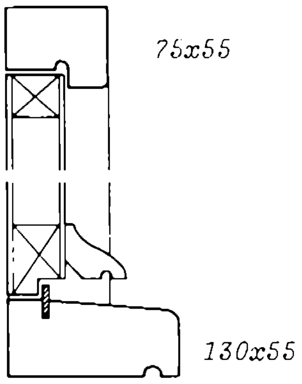
Timber window – standard construction.



Outward opening softwood casement window, suitable for double glazing units, draught-stripped and including a controllable slot ventilator in the window frame

Figure BV.16.

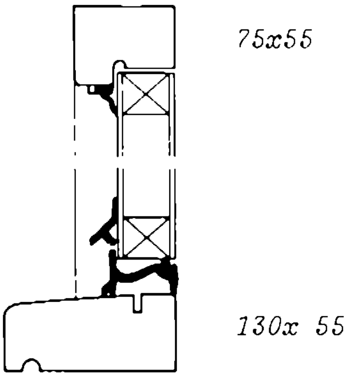
Timber window – improved construction.



Inward opening, plywood faced hollow core door in softwood frame with hardwood sill and weatherbar

Figure BV.17.

External door – standard construction.

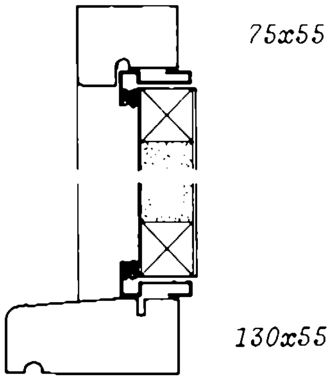


Standard door and frame with weatherstripped head and jambs with a fully weatherstripped sill to replace the weather bar

Many alternative profiles are available if the weather seal is able to be fitted during manufacture

Figure BV.18.

External door – modified standard door.



Steel faced door filled with polyurethane foam, with timber edging, ready hung in aluminum frame, complete with vinyl weatherstripping, designed for site fixing into timber subframe

Figure BV.19.

External door – "Energy saving" unit.

JUNCTION BETWEEN WINDOW OR DOOR COMPONENTS AND EXTERNAL WALLS

In the UK the main emphasis at door and window junctions is to prevent dampness reaching the interior of the building, rather than to reduce air leakage. In Scotland, however, there is a tradition of setting the window frame back from the building face, behind the outerleaf of brickwork.

This practice is recommended for both masonry and timber frame construction, although the designer should be careful to choose window and door components with dimensions that are compatible with the satisfactory setting out of the brickwork. A rebated detail at the window head is unlikely to be possible if standard steel lintel components are used.

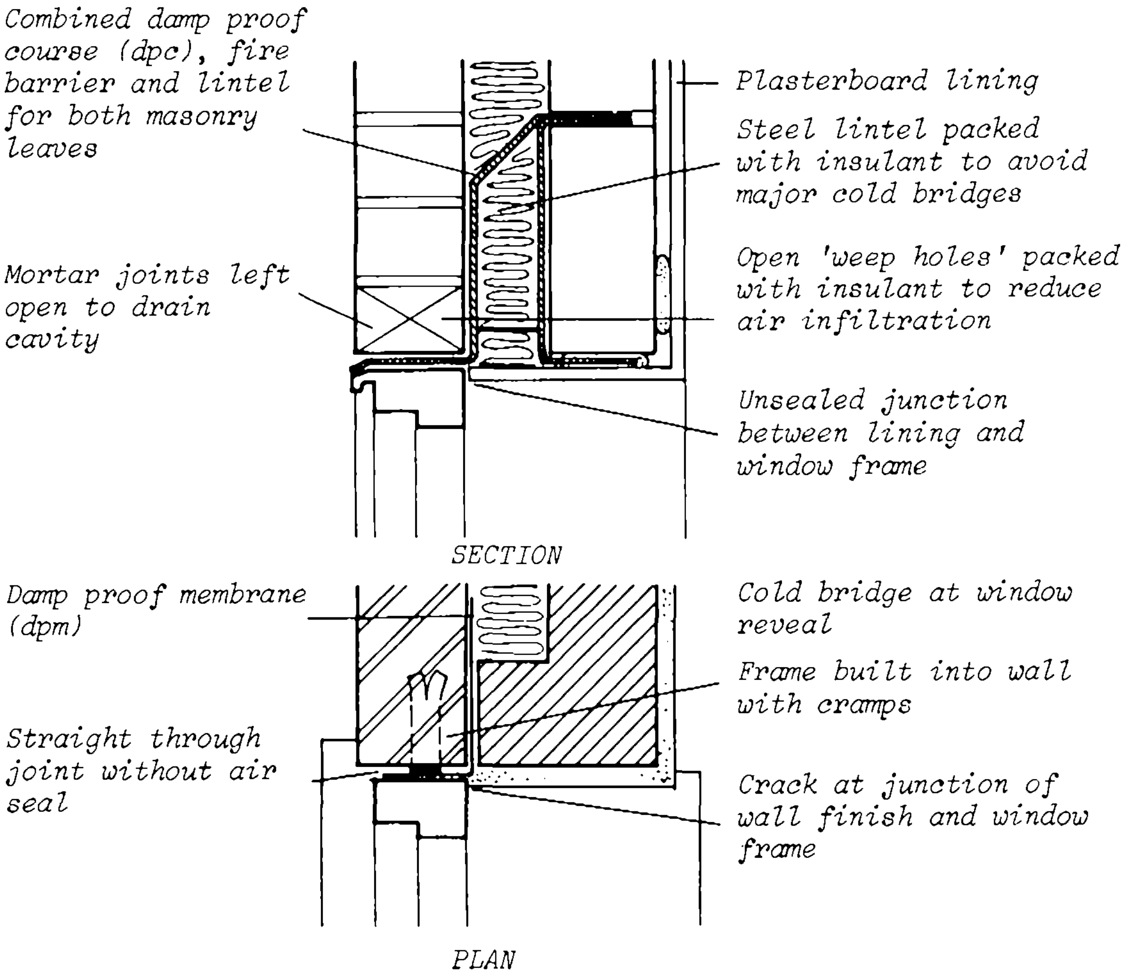
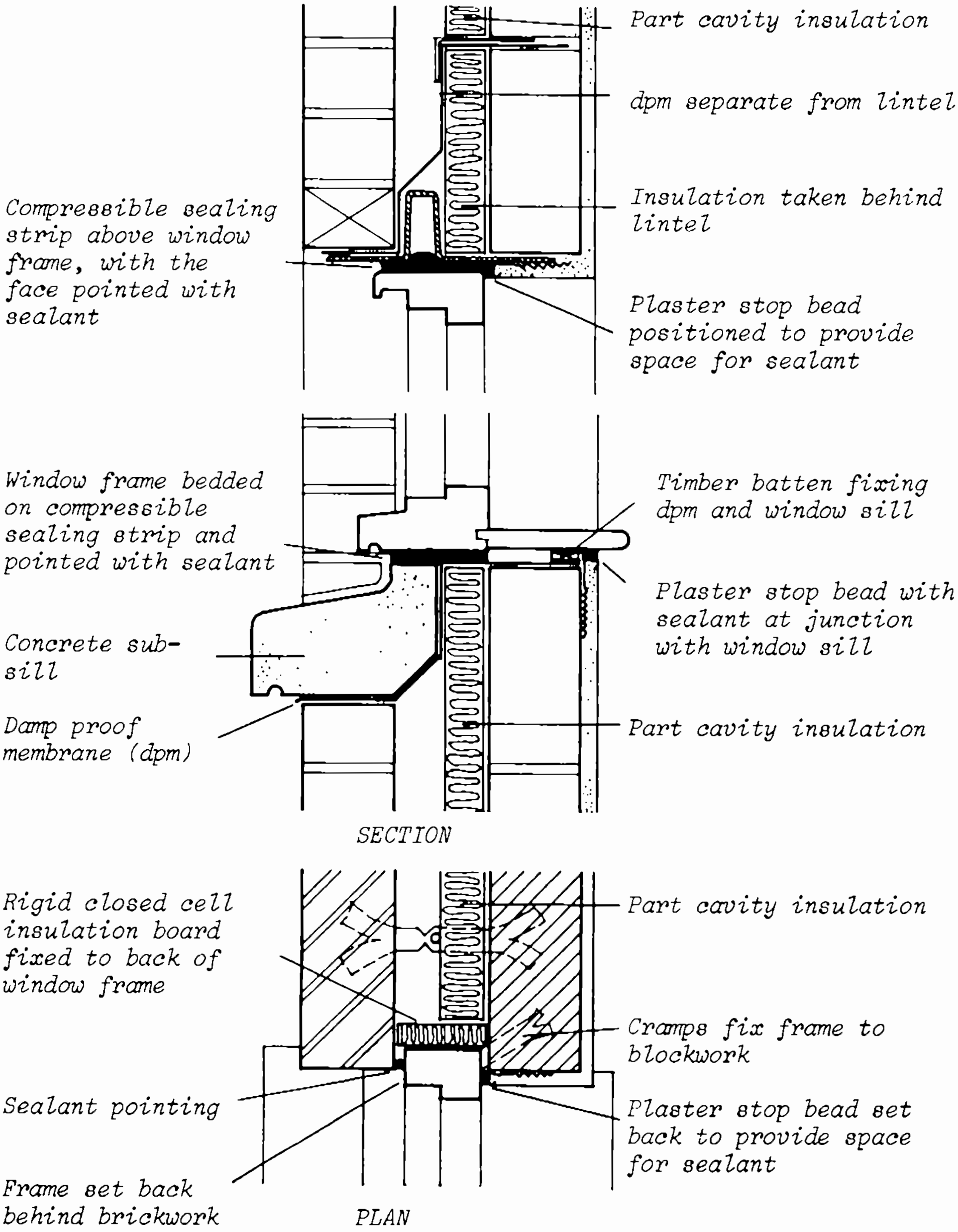
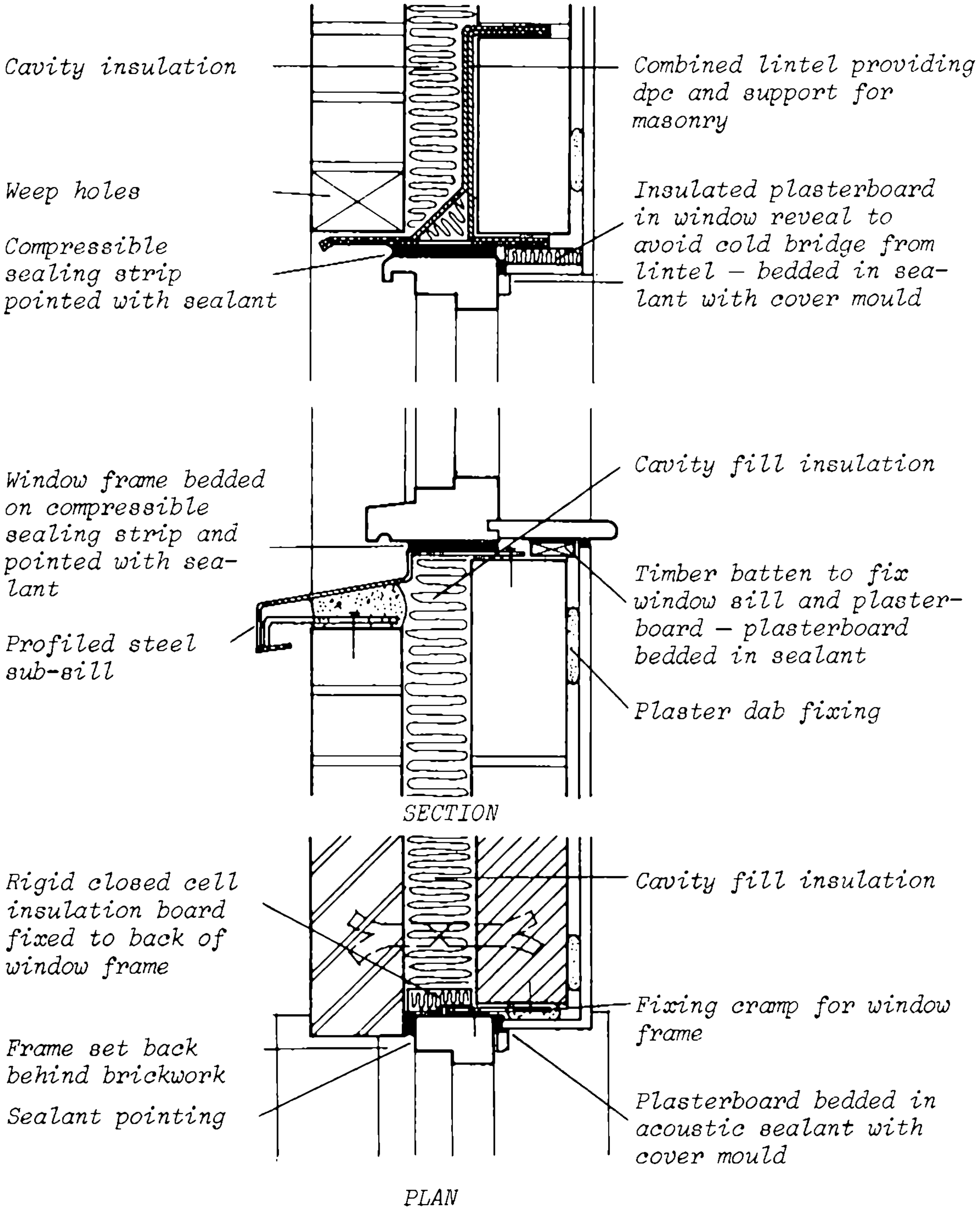


Figure BV.20. Masonry – standard construction.



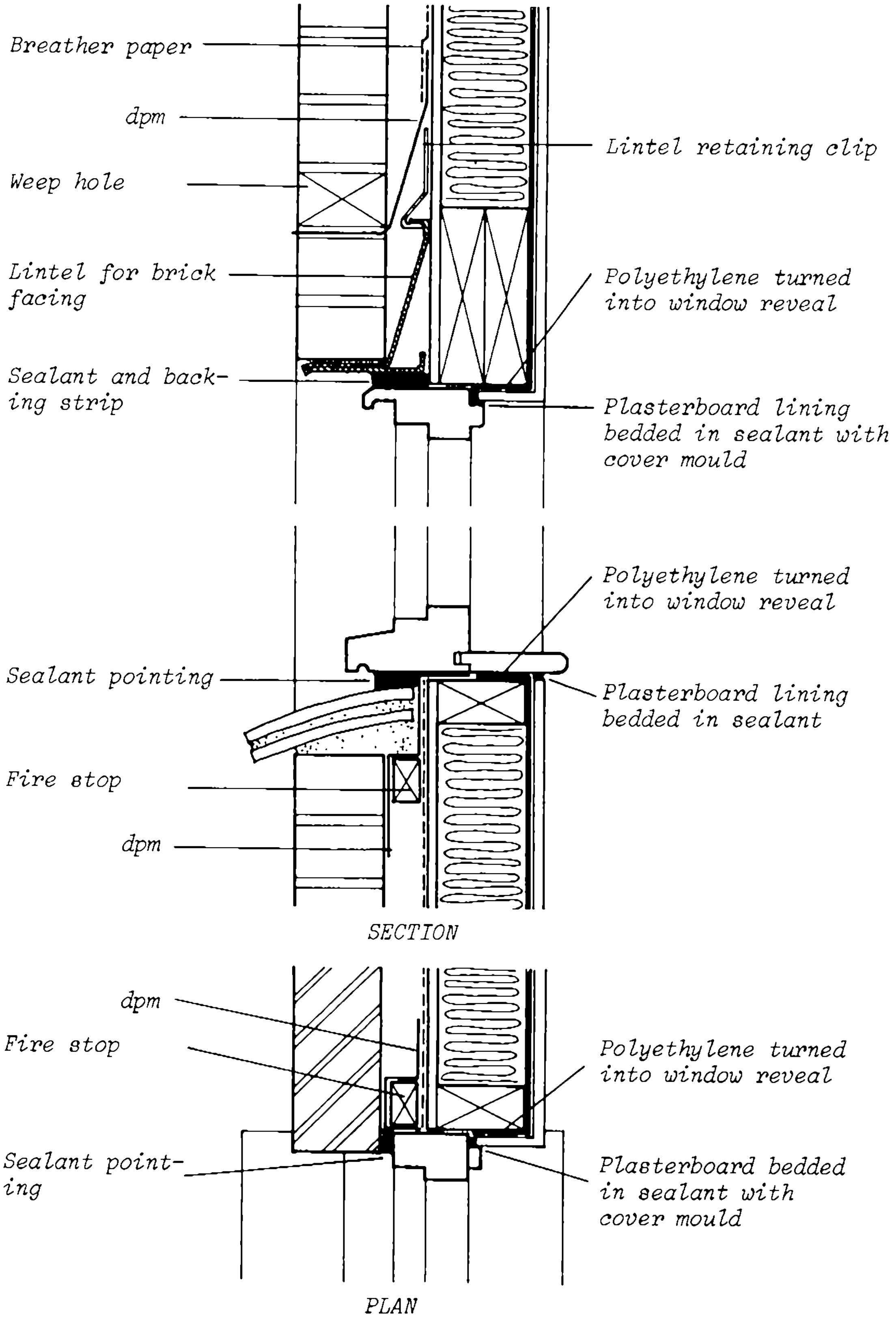
Improvement made by setting frame behind brickwork, pointing carefully with sealant externally and internally between frame and plaster stop bead

Figure BV.21. Masonry – plaster finish – improved construction.



Window frame bedded on a compressible seal and pointed with sealant. Internally, the plasterboard should be bedded in sealant and firmly fixed to a timber batten

Figur BV.22. Masonry – dry lined – improved construction.

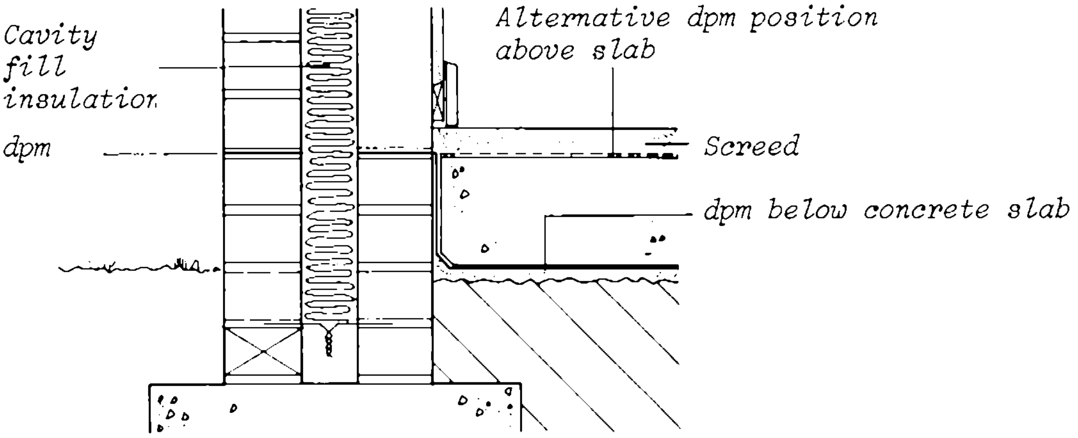


Window frame set behind brick veneer and surrounded by compressible seal to accommodate differential movement between frame and brickwork. Polyethylene turned into reveal, plasterboard sealed at edges

Figure BV.23. Timber frame – improved construction.

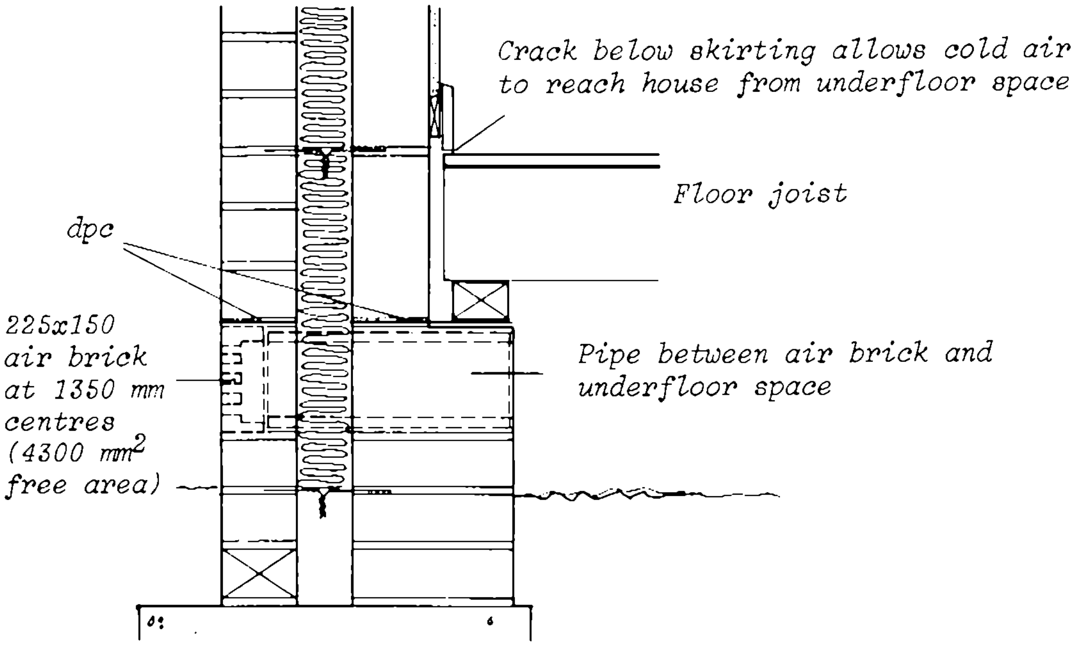
GROUND FLOOR JUNCTION WITH EXTERNAL WALL

Air leakage occurs from the ventilated underfloor space of a suspended floor or through gaps between timber frame panels.



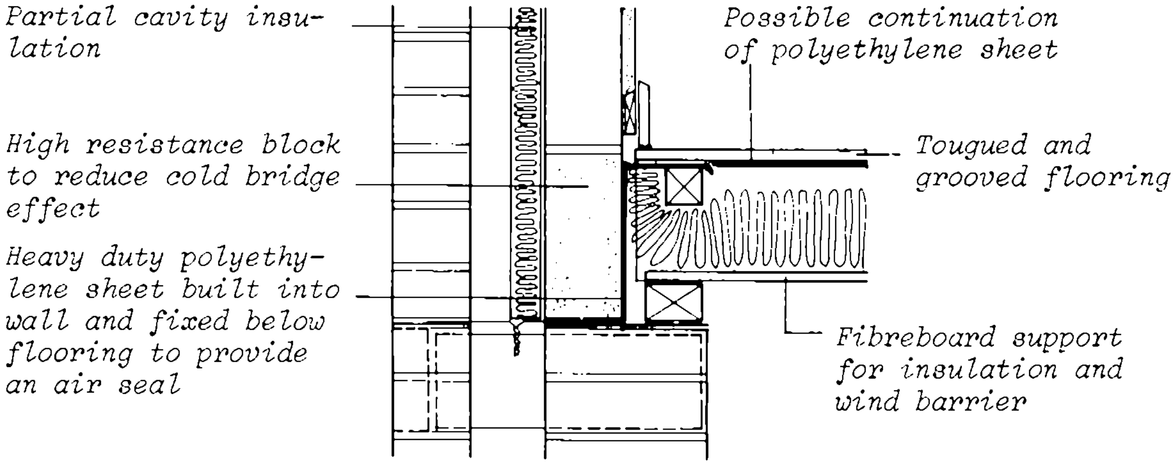
No serious air leakage paths

Figure BV.24. Masonry construction – standard concrete floor.



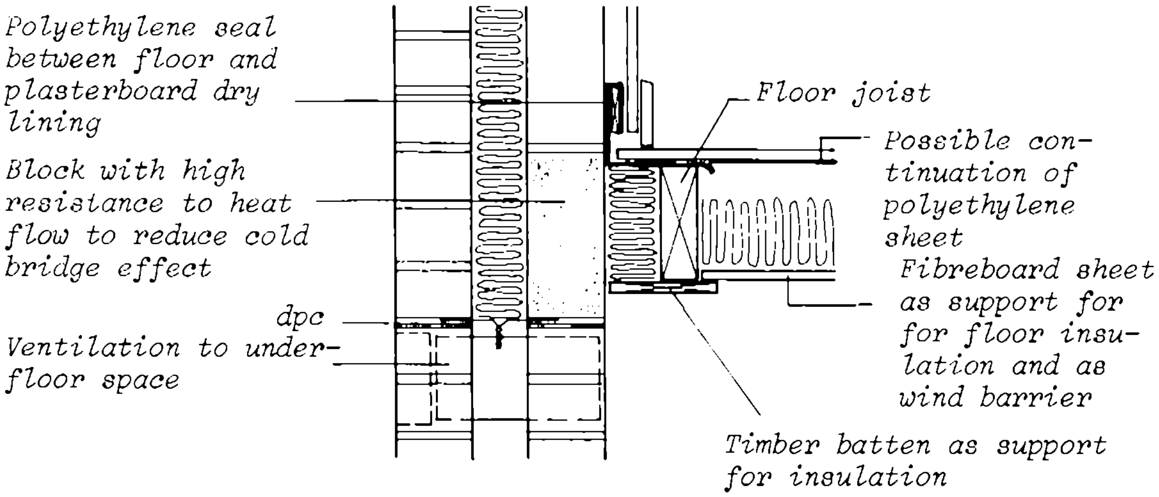
Floor not insulated in the majority of UK houses. Considerable potential air infiltration through crack below skirting from ventilated underfloor space. The continuation of polyethylene across the complete floor is not favoured in the UK because water spillage cannot drain away

Figure BV.25. Masonry construction – standard suspended floor.



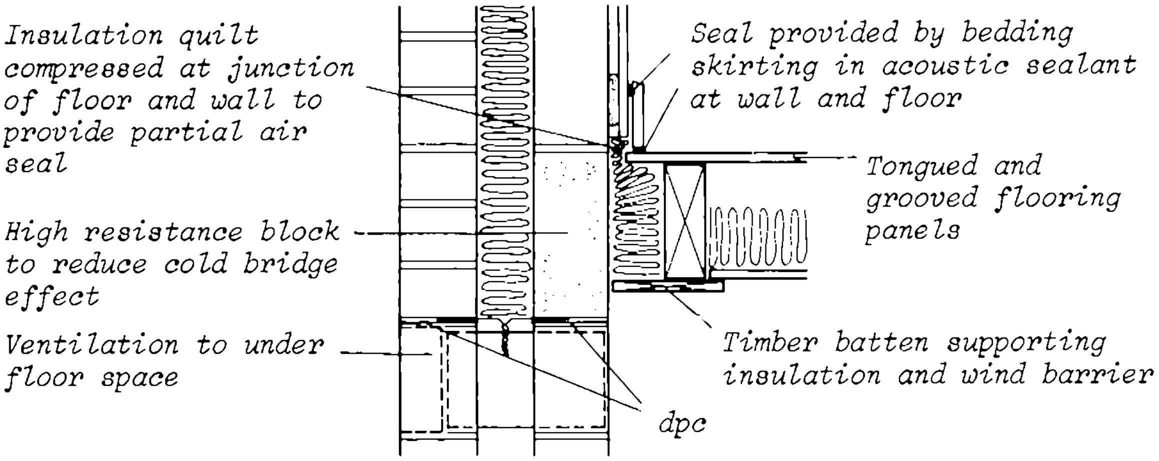
Heavy duty polyethylene links wall and floor to provide an air seal

Figure BV.26. Improved construction – plastered wall finish.



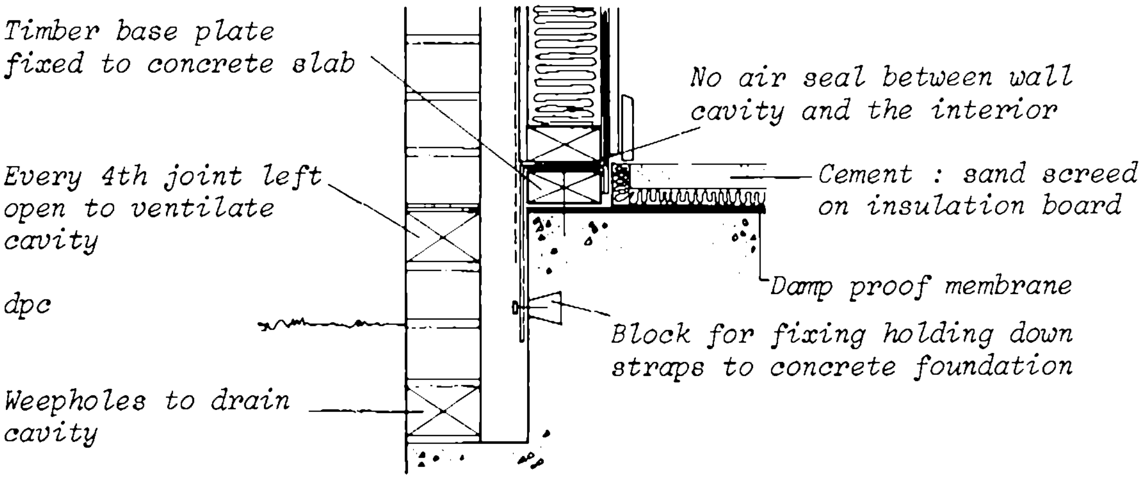
Polyethylene sheet bridges gap between plasterboard fixing batten and floor joist

Figure BV.27. Improved construction – dry lining mechanically fixed.



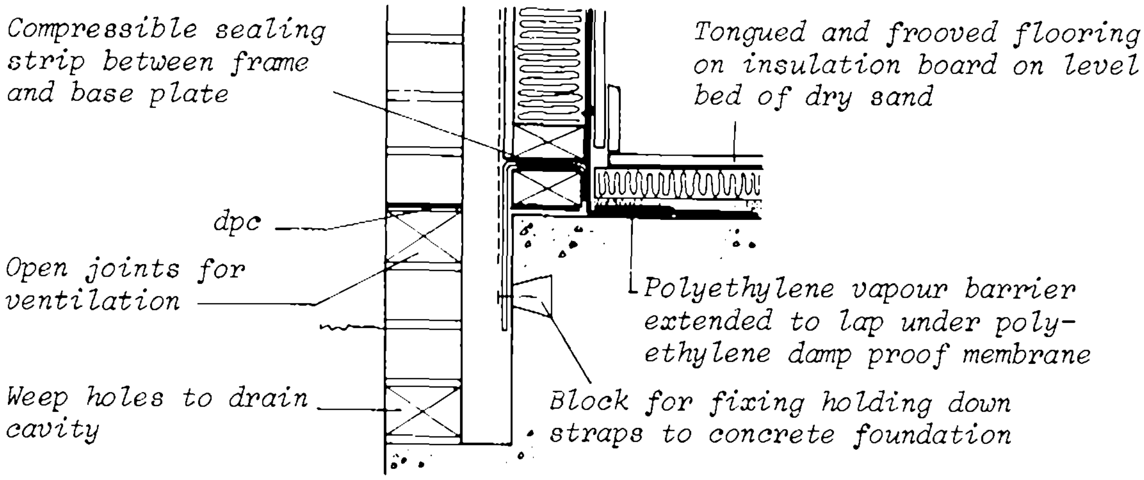
Floor/wall junction sealed at skirting

Figure BV.28. Improved construction – dry lining adhesive fixed.



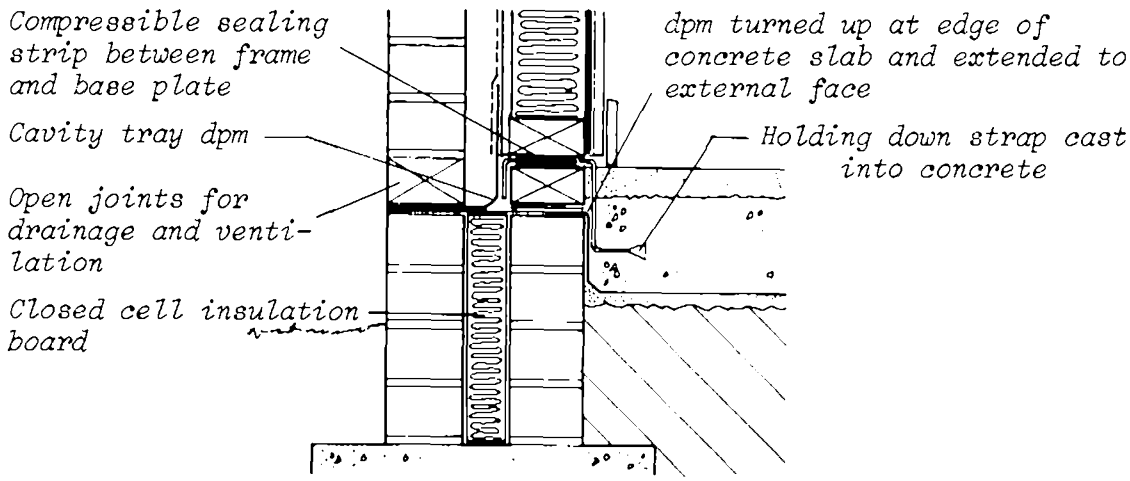
Potential air leakage at frame junctions

Figure BV.29. Timber frame – standard floor construction.



Air seal at panel junction and polyethylene overlap

Figure BV.30. Improved construction – concrete foundation and slab.



Air seal provided at panel junction. In addition polyethylene dpm is built into masonry wall

Figure BV.31. Improved construction – masonry foundation.

FIRST FLOOR JUNCTION WITH EXTERNAL WALL

As the cavity between the inner structure and the brick facing or cladding is ventilated, it is important that air leakage paths are eliminated where the floor meets the external wall.

The use of joist hangers to support the floor joists eliminates the problems resulting from inadequate sealing around built-in floor joists.

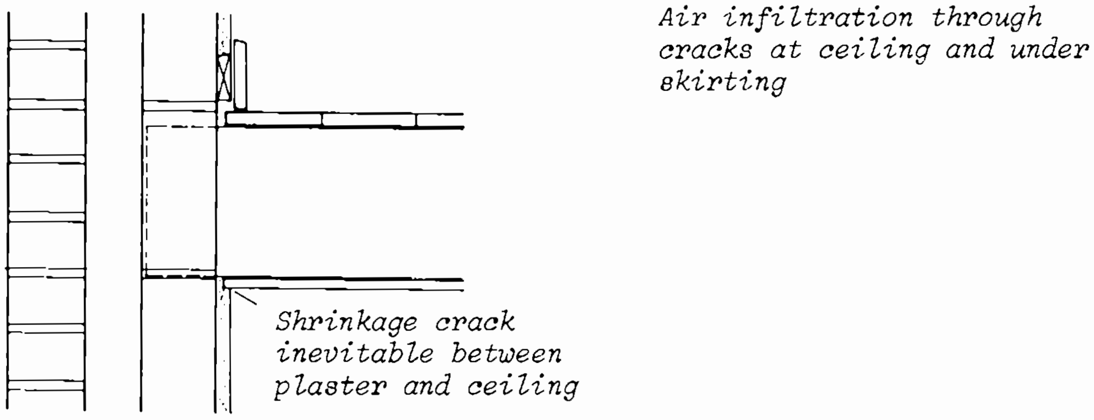
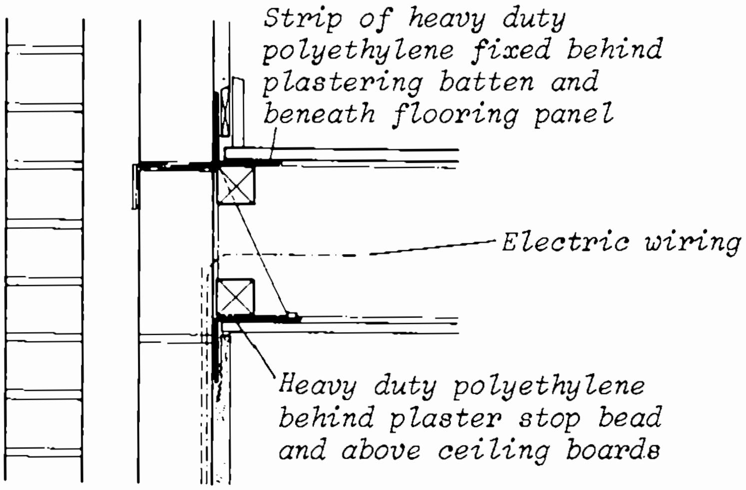
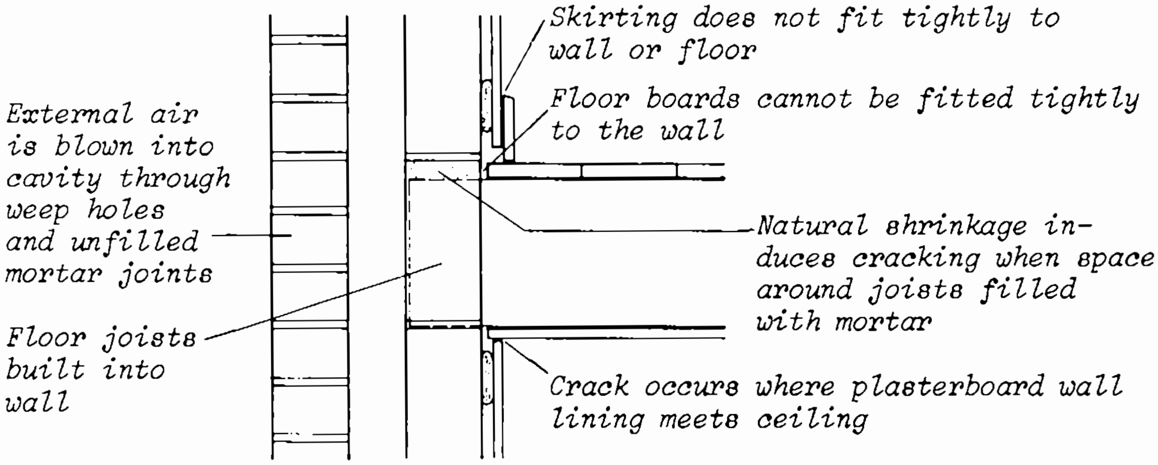


Figure BV.32. Standard construction – masonry with plaster wall finish.



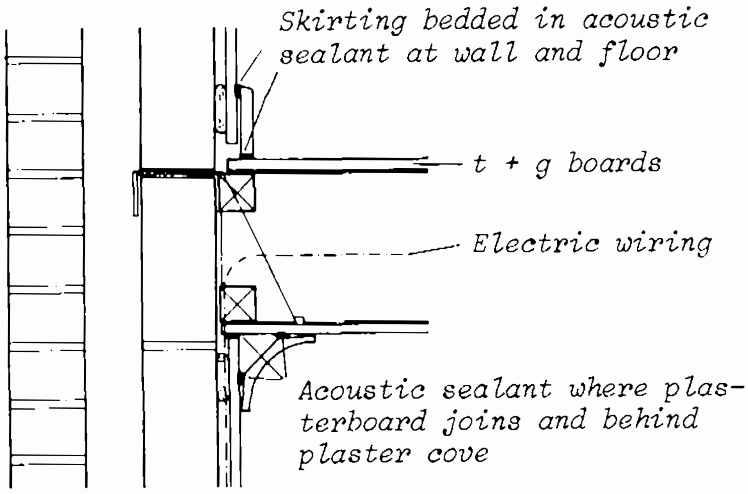
Heavy duty polyethylene seals gap at floor and ceiling

Figure BV.33. Improved construction – masonry with plaster wall finish.



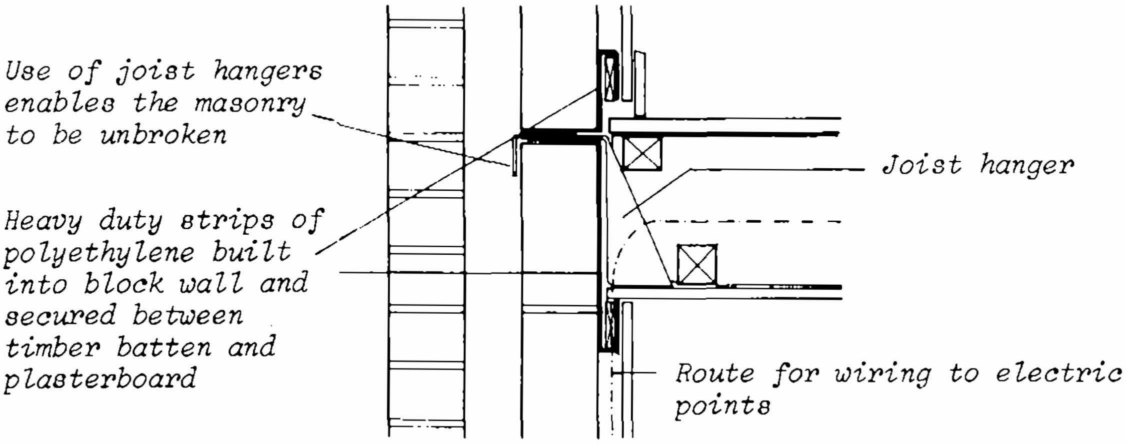
Air infiltration where plasterboard meets ceiling and floor

Figure BV.34. Standard construction – adhesive fixed dry lining.



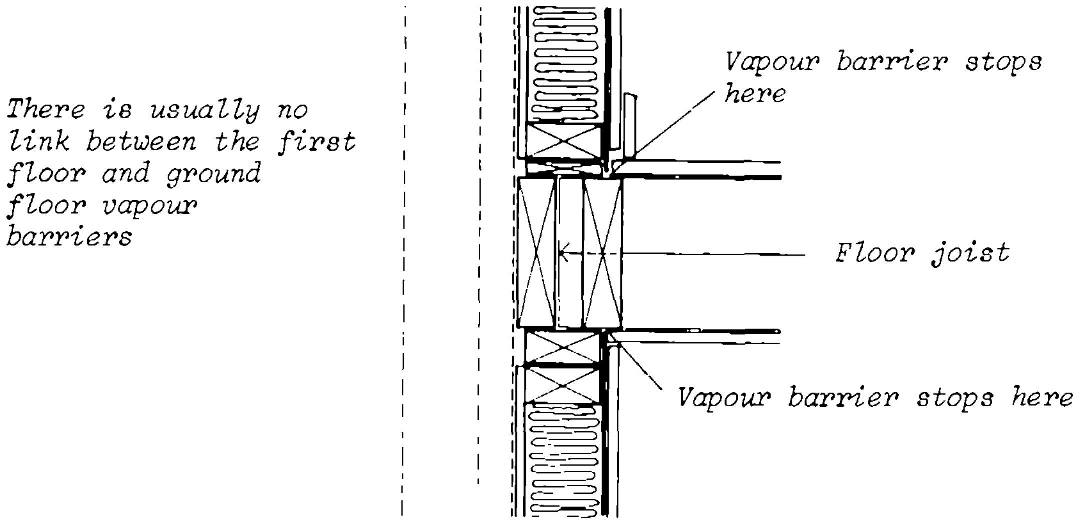
Sealant used to fill gaps at ceiling and where skirting meets the wall and floor

Figure BV.35. Improved construction – adhesive fixed dry lining.



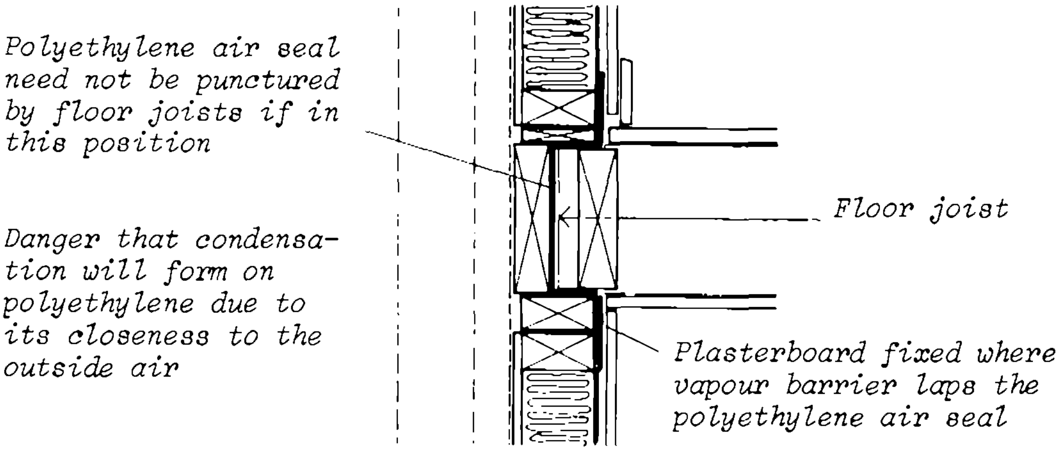
Heavy duty polyethylene built into wall at level of joist hanger and fixed behind plasterboard batten

Figure BV.36. Improved construction – mechanically fixed dry lining.



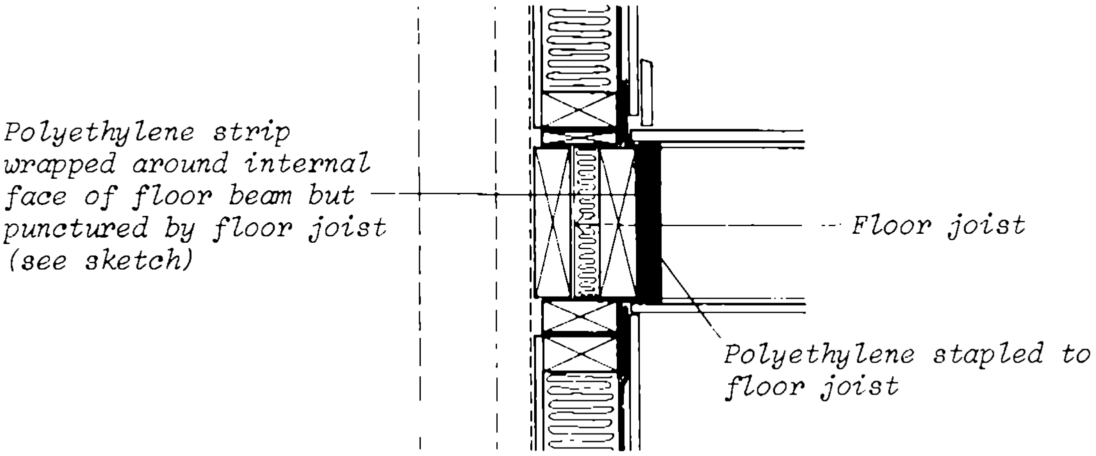
Integrity of vapour barrier broken at first floor level

Figure BV.37. Standard construction – timber frame.



Polyethylene membrane unpunctured by floor joists. There may be insufficient insulation outside the air seal for condensation to be avoided

Figure BV.38. Improved construction – air seal within edge beam.



Polyethylene broken but stapled to sides of floor joists

Figure BV.39. Improved construction – air seal on face of edge beam.

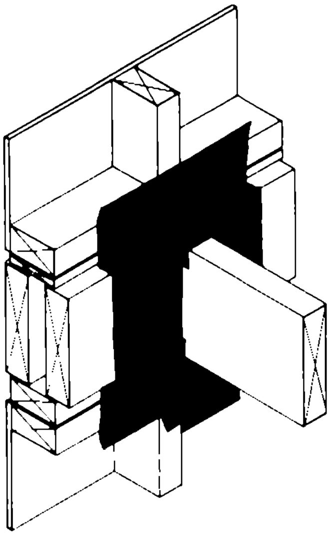
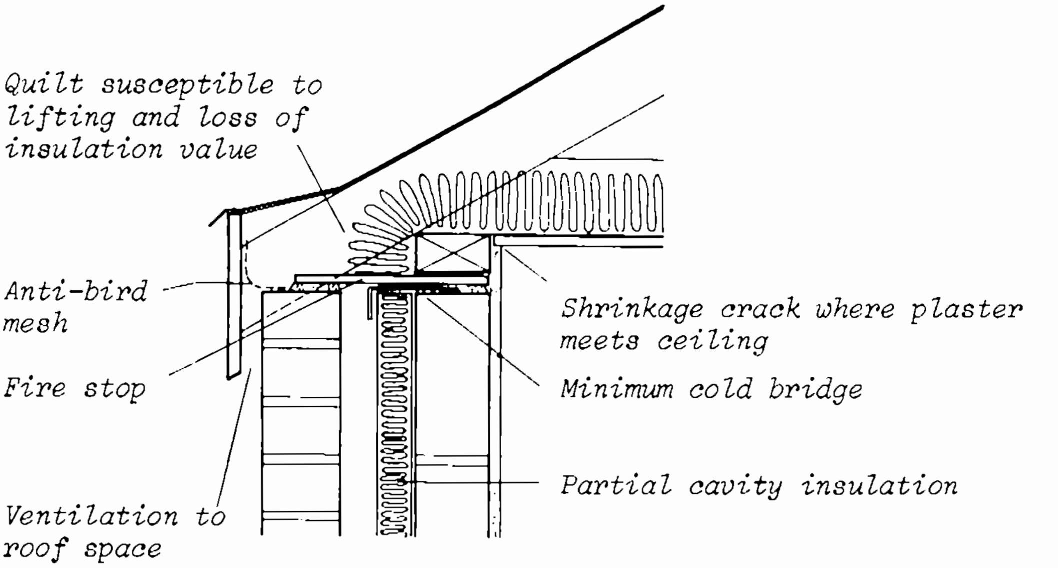


Figure BV.40.

Isometric sketch showing the sealing of the heavy duty polyethylene sheet linking the ground floor and first floor vapour barriers. Polyethylene sheet joined by adhesive tape where punctured by floor joists.

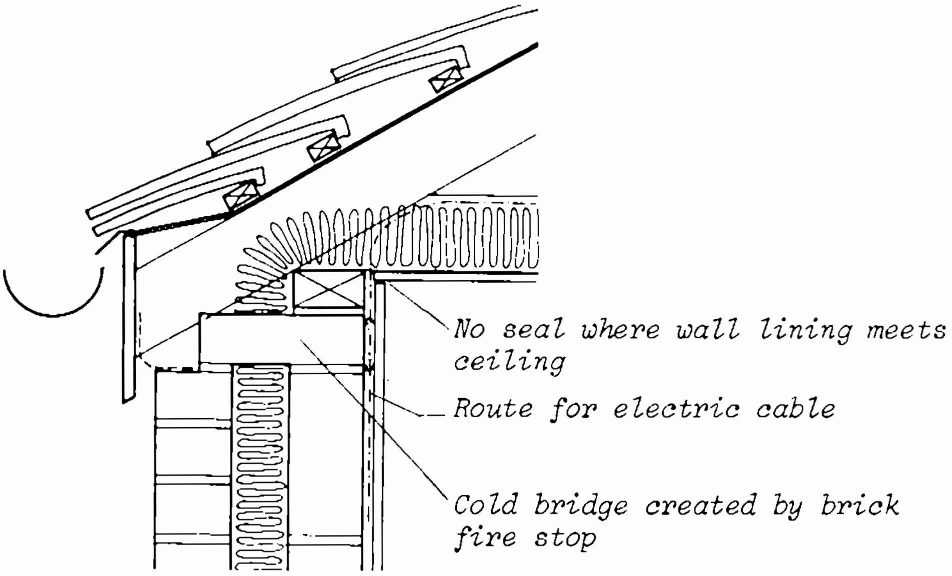
ROOF JUNCTION WITH EXTERNAL WALL

It is essential to improve air leakage at the ceiling/wall junction due to the requirements under Building Regulations to ventilate roofs at the eaves. The insulation should also be contained and protected from ventilation air so as to maintain its insulation value.



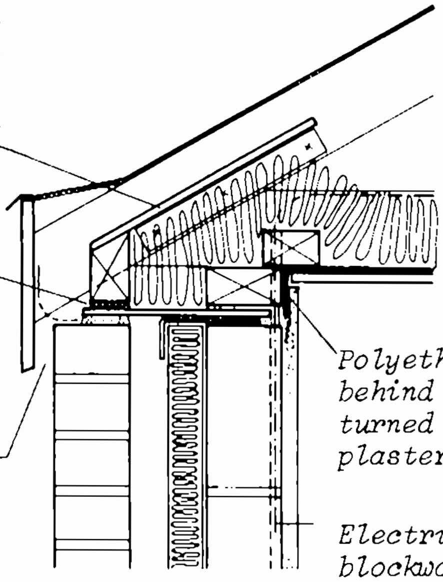
Shrinkage crack forms at ceiling corner. There is no vapour barrier at ceiling level

Figure BV.41. Standard construction – plastered masonry wall.



Air leakage where plasterboard meets ceiling. There is no vapour barrier at ceiling level

Figure BV.42. Standard construction – masonry wall dry lined.



Board between rafters contains and protects insulation — also maintains ventilation to roof space

Batten seated on compressible seal

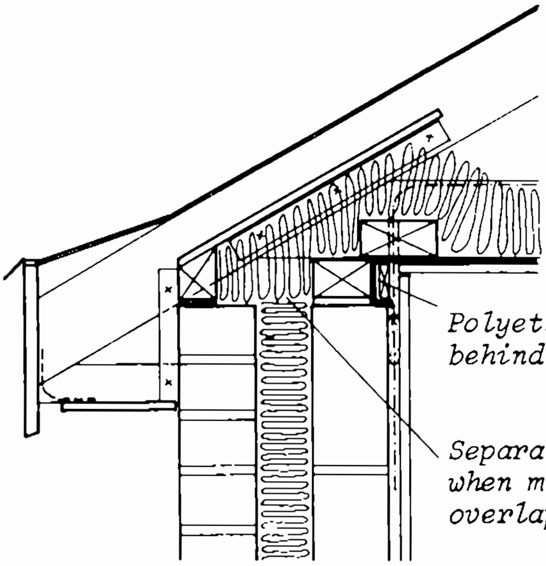
Ventilation gap

Polyethylene vapour barrier behind ceiling plasterboard turned down and fixed behind plaster stop bead

Electrics chased into blockwork

Polyethylene vapour barrier above ceiling turned down wall and fixed behind plaster stop bead. Insulation retained by a board which maintains ventilation gap to roof space

Figure BV.43. Improved construction — plastered masonry wall.

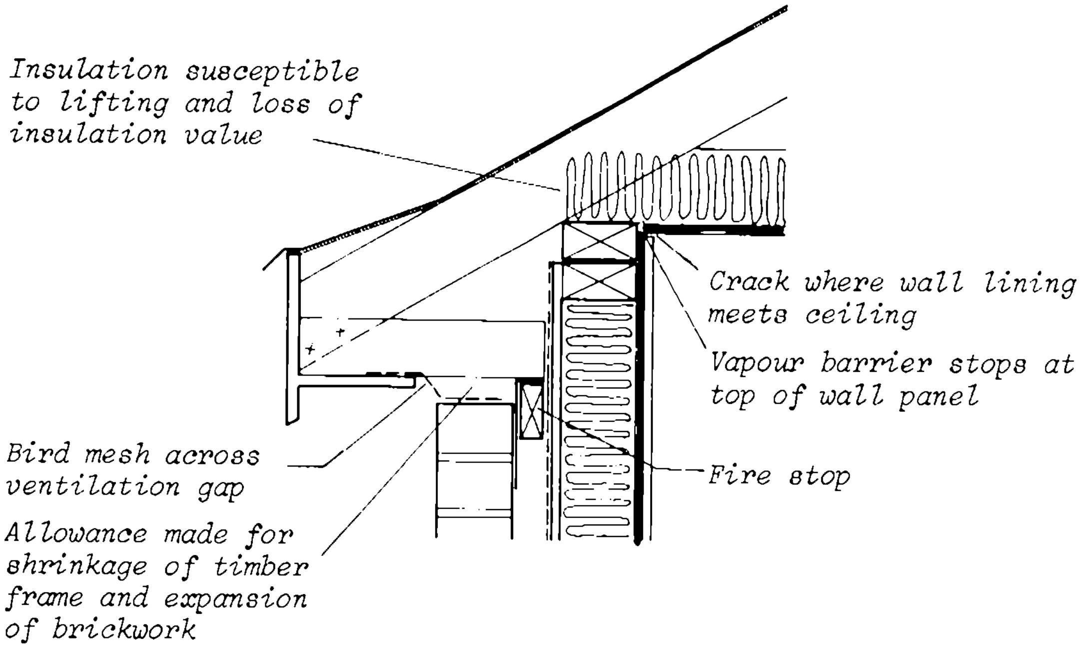


Polyethylene turned down behind timber batten

Separate fire stop unnecessary when mineral fibre insulation overlaps

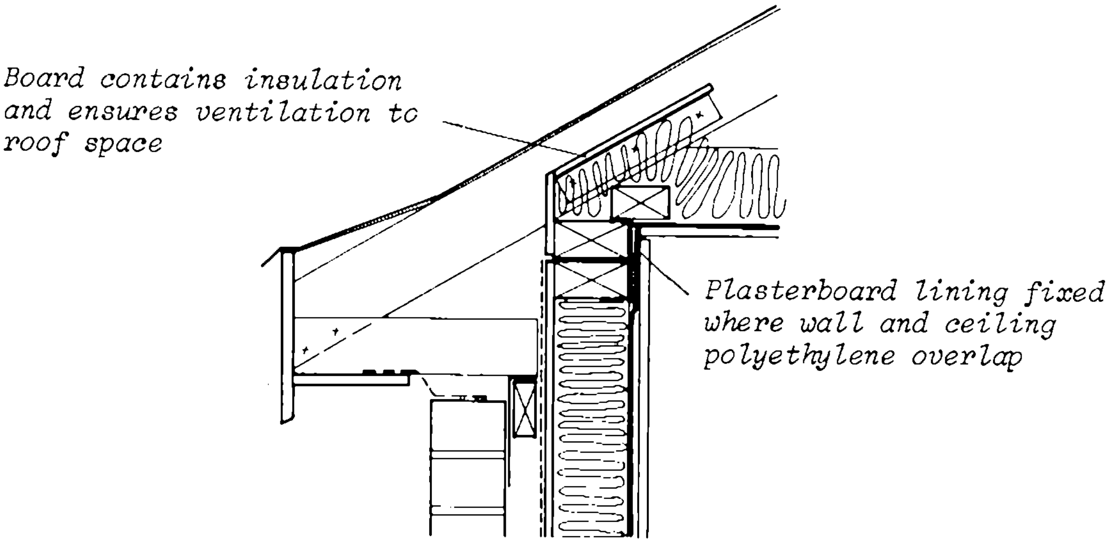
Ceiling vapour barrier fixed behind batten nailed to wall plate supporting trussed rafters

Figure BV.44. Improved construction — masonry wall dry lined.



No continuity between wall vapour barrier and ceiling. Roof insulation unprotected from uplift

Figure BV.45. Standard construction – timber frame.



Vapour barrier introduced across ceiling and turned down at edges to overlap that of the wall panels. Both are secured by the plasterboard which is nailed to the timber frame

Figure BV.46. Improved construction – timber frame – detail 1.

Detail shows close fitting eaves and electric wiring

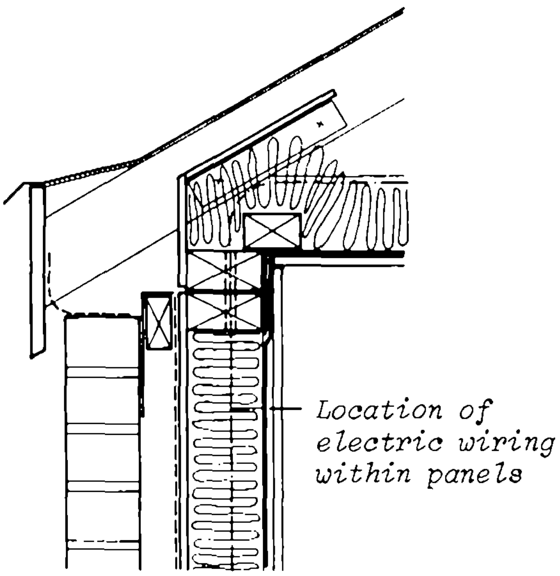
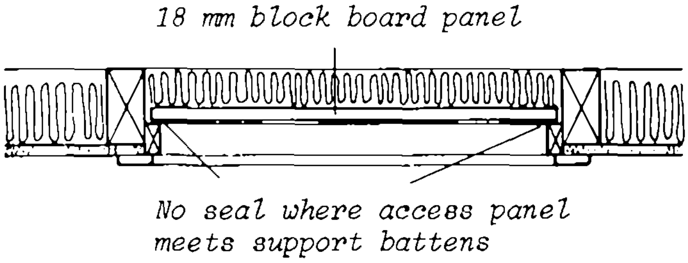


Figure BV.47.

Improved construction – timber frame – detail 2.

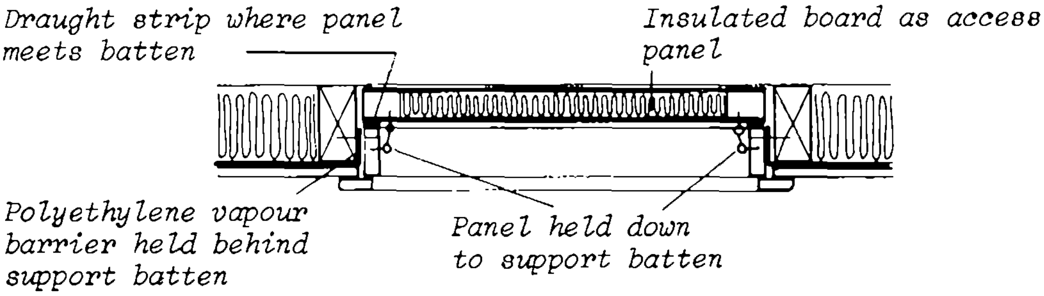
LOFT ACCESS HATCH

Air leakage through the loft access hatch (or panel) is a major contributor to ventilation heat loss and the incidence of roof space condensation.



Access panel unsealed – can be lifted by suction forces in the roof space

Figure BV.48. Standard construction.

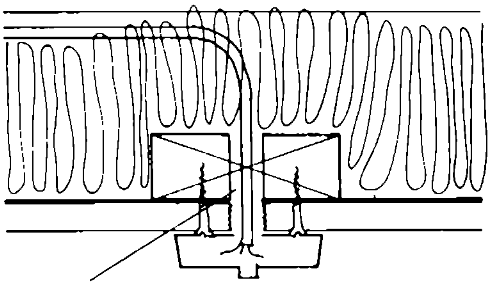


Ceiling polyethylene securely fixed around hatch – hatch draught stripped and held down to frame

Figure BV.49. Improved construction.

ELECTRIC FITTINGS IN WALL AND CEILING FINISHES

The effect of sealing at the perimeter junctions of building elements may be lost unless holes formed to accommodate electric wiring and accessory boxes are also sealed.

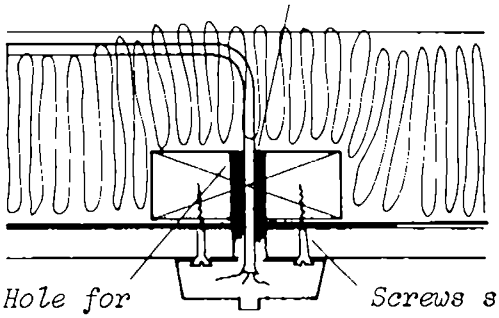


Unsealed hole between room and roof space

Figure BV.50.

Standard construction – ceiling light fitting.

Hole filled with sealant from above



Hole for cable drilled from above

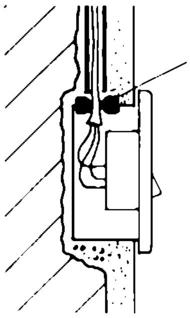
Screws sufficient to compress polyethylene between plasterboard and support batten

Figure BV.51.

Improved construction – ceiling light fitting.

Standard construction – power outlet in masonry wall

No special provisions made.



Grommet or waterproof seal

Box sealed as cable passes through

Figure BV.52.

Improved construction – outlet in plastered wall.

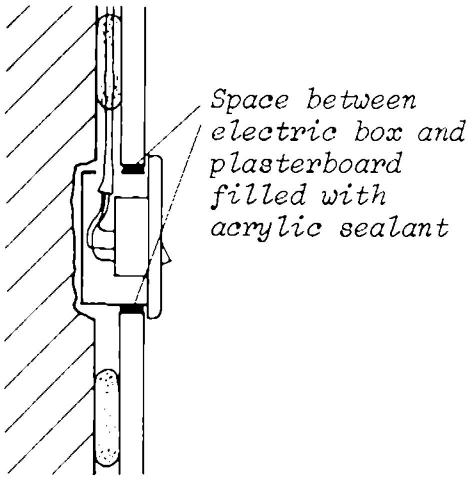
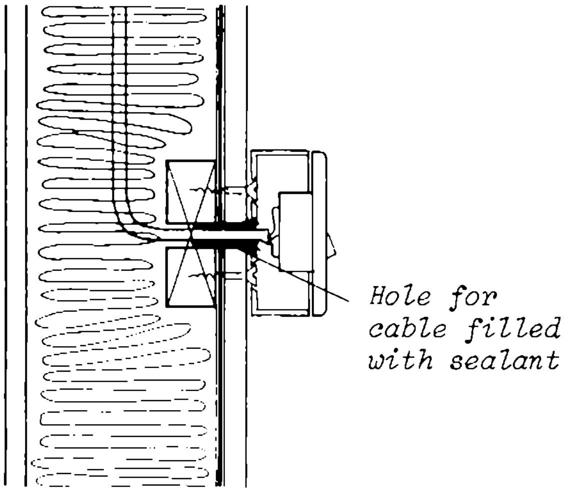


Figure BV.53.

Improved construction – outlet in dry lined wall.

Standard construction – outlet in timber frame wall

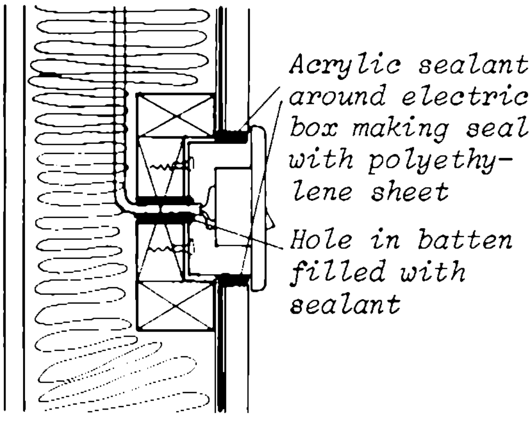
No special provision made to seal the polyethylene, plasterboard or cable entry to power outlets.



The air seal made by applying sufficient sealant to the cable entry hole to reach the break in the polyethylene. Screws fixing the outlet box should be of a length that, when tightened, the polyethylene will be compressed between the plasterboard and the fixing batten

Figure BV.54.

Improved construction – surface mounted outlet.



A sealant is used to eliminate air leakage at the junction between the electric box and the surrounding plasterboard/polyethylene. The hole in the batten for the cable entry is also sealed

Figure BV.55.

Improved construction – recessed outlet.

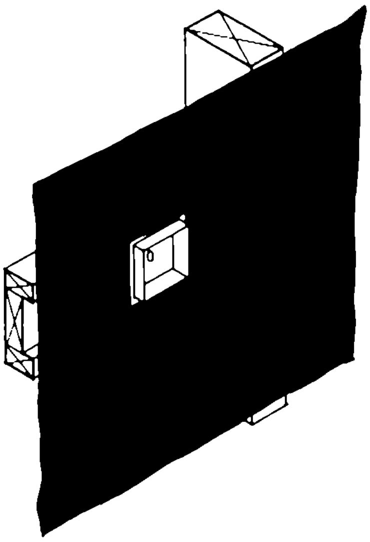


Figure BV.56.

Isometric sketch showing box recessed in framing.

HOLES FOR DRAINAGE AND PLUMBING SERVICES

The distribution of plumbing and drainage services throughout the building requires holes to be made through the major elements (floors, roofs, etc.). When these services are enclosed in ducts or behind kitchen fittings, it is common for less care to be taken to fit floors and ceilings around the pipes because they cannot be seen. This is particularly serious when pipes pass through a suspended ground floor or the roof.

Standard construction

Normal practice is for the drainage stack and the mains water service to enter underground and rise within the building to the roof space. The drainage stack then penetrates the roof to ventilate the drain and the water pipe supplies the storage tank above the first floor ceiling. The tank is situated here to provide sufficient head of water for showers to operate under gravity in first floor bathrooms. Bath overflows are sometimes taken through the external wall direct to the open air.

Improved construction

It is advantageous to reduce the penetration of the first floor ceiling. Consider keeping water storage and distribution pipework below the ceiling, provided suitable sanitary fittings can be selected. An effective seal must be made between the polyethylene vapour barrier and the drainage stack.

A close fitting seal is less easy to achieve at first floor level where there are often a variety of drain entries into the stack. Care should therefore be taken to seal bath access panels and duct covers.

At ground floor level, holes for pipes should be sealed and floors close fitting, particularly beneath kitchen storage fittings.

Bath overflows should be linked directly with the drain fitting, and WC cistern overflows discharged either into the pan or to an alternative visible position.

BV.4 REFERENCES

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(2) Greater London Council, The London Building (Constructional) Bylaws. London, GLC, 1972.

(3) British Standards Institution, Code of Basic Data for the Design of Buildings: the Control of Condensation in Dwellings, BS 5250. London, BSI, 1975.

(4) British Standards Institution, Recommendations for the Grading of Windows. Draft for Development, DD4. London, BSI, 1971.

(5) Building Research Establishment, The Weatherstripping of Windows and Doors. Information Paper IP 16/81. Garston, BRE, October 1981.

(6) British Standards Institution, Code of Practice for the Design of Buildings: Ventilation Principles and Designing for Natural Ventilation. BS 5925. London, BSI, 1980.

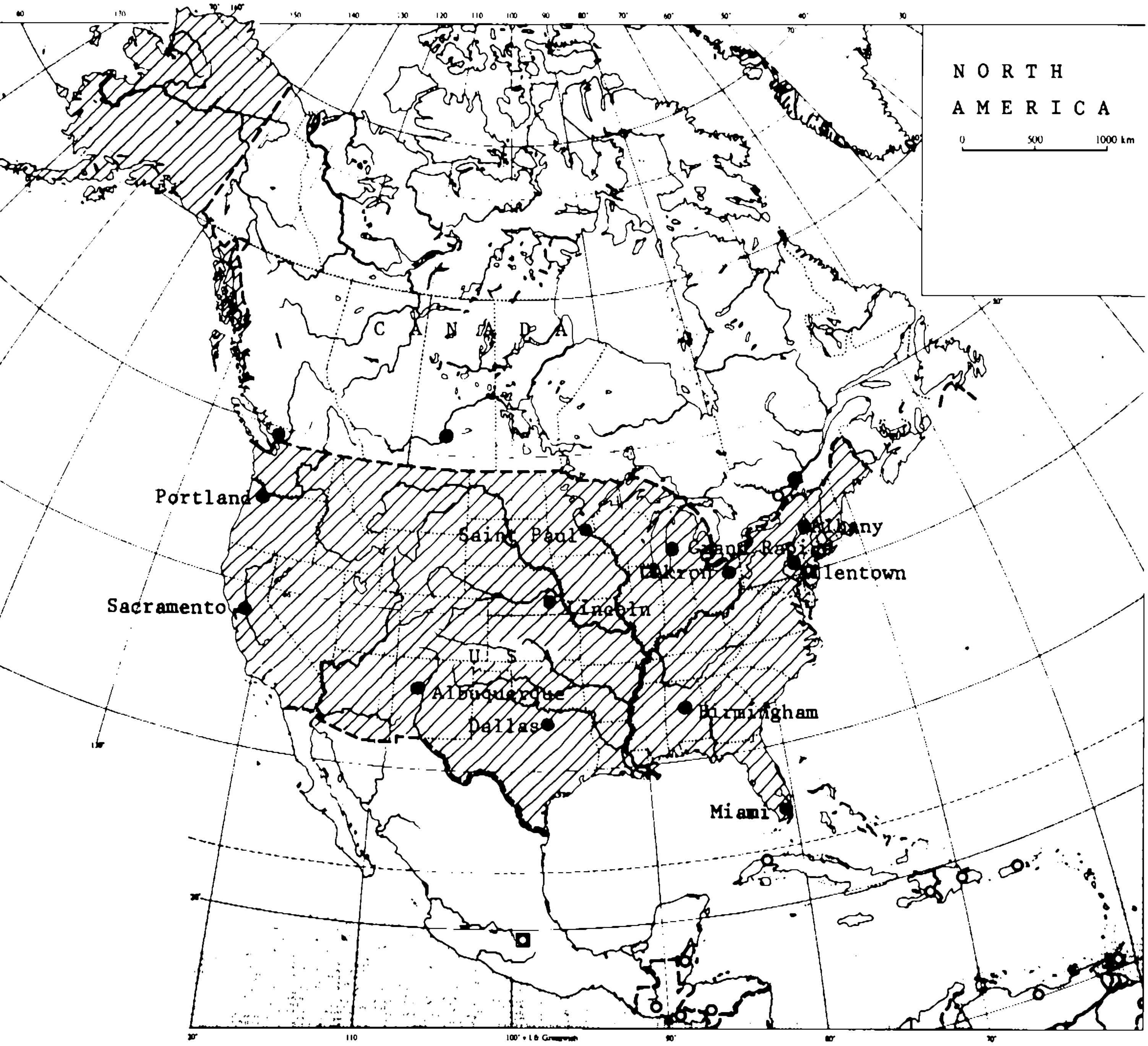
(7) Chartered Institution of Building Services, Environmental Criteria for Design. CIBS Guide, Part A1. London, CIBS, 1978.

(8) Lacey, R.E., Climate and Building in Britain. (Building Research Establishment.) Report. London, HMSO, 1977.

(9) NBA and TRADA, Manual of Timber Frame Housing: A Simplified Method. (The Construction Press.) London 1980.

UNITED STATES

PART BVI



BVI.1 BUILDING CODE STANDARDS IN THE UNITED STATES

There are a number of building codes in use in the United States and these are based on four model codes. The Southern Building Code is used predominantly in the Southeast; the Uniform Building Code in the West and Midwest; the National Building Code in the Eastern United States and the BOCA Code in the Midwest and Northeast. These are general regions of application since ultimately the responsibility for code choice lies with the states and localities. These governing bodies can and do develop their own codes based upon the model codes and their state or local special building regulations. This has resulted in more than 2000 individualized codes; however, the main building requirements tend to be rather close. To aid in the standardization process there is a National Conference of States on Building Codes and Standards and the Council of American Building Officials.

Building codes in the past have primarily been concerned with public health and safety, types and quality of construction, material selection, administration and enforcement of the code. More recently, through energy-related recommendations as found in ASHRAE Standard 90-75, efforts have been made to emphasize items such as insulation and building tightness. Some 46 states have adapted requirements based on Standard 90 into their building codes. Federal incentives have promted this action. Thus although the standard recommends national insulation levels, it is up to the locality and states to incorporate and enforce the standard into their codes. Ultimately the benefits depend on the understanding and enforcement of the energy-related recommendations by the local inspectors.

The recommendations found in ASHRAE 90-75 are now being incorporated into the model codes. The general reference for building code activities in the United States is the National Conference on Building Codes and Standards, Energy Programs Division, 481 Carlisle Drive, Herndon, Va. 22070, telephone (703) 437-0100.

BVI.2 CLIMATE

The weather in the United States encompasses that found in the northern extremes of Europe to that found in tropical areas of the world. Six air masses influence the weather at various times of the year and at various locations within the United States. Maritime polar flow from the Atlantic and the Pacific oceans as well as a continental polar flow are the sources of the colder weather patterns. Maritime tropical flows from Atlantic Gulf of Mexico and Pacific ocean sources and continental tropical winds control the warmer weather patterns. The flow of the North American jet stream is one influence as to the local dominance of the six air masses. Not only do the air masses influence temperature and humidity, but many areas of the United States experience abrupt changes in weather as they become controlled by one pattern or the other. The most severe air mass interactions result in such events as tornadoes where a severe cold front collides with a mass of hot humid air normally over the central United States, where the land is relatively flat.

This highly variable weather means that there are some areas in the United States with no heating degree days (but with a high cooling loads) and other areas with heating degree days greater than 6000[x] The average value is closer to 3000 but even two cities with identical values may present a contrast in the pattern of the heating season. For example winter in the Pacific Northwest tends to be prolonged but temperatures rarely drop below freezing. Similar degree days are encountered on the East coast but winters are shorter but more severe with temperatures dropping to about $-18^{\circ}C$ for short periods.

This variety of climate is illustrated in Figure BVI.1a-BVI.1c which characterize 12 American cities. The background data to the plots are described in Chapter A6. The extremes between Miami, Florida and Minneapolis – St. Paul, Minnesota are very evident. The differing winter patterns for similar heating degree days are illustrated by Portland, Oregon and Allentown, Pennsylvania weather plots. Portland weather is controlled by Pacific Maritime air flows whereas the extremes in Minneapolis are traced to continental polar flow in winter and maritime tropical for brief periods in the summer. The winter in Allentown changes rapidly depending upon whether continental polar or maritime tropical from the Gulf of Mexico is controlling.

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[x] For method of calculating degree days, see Section A6.2 and Table A6.1.

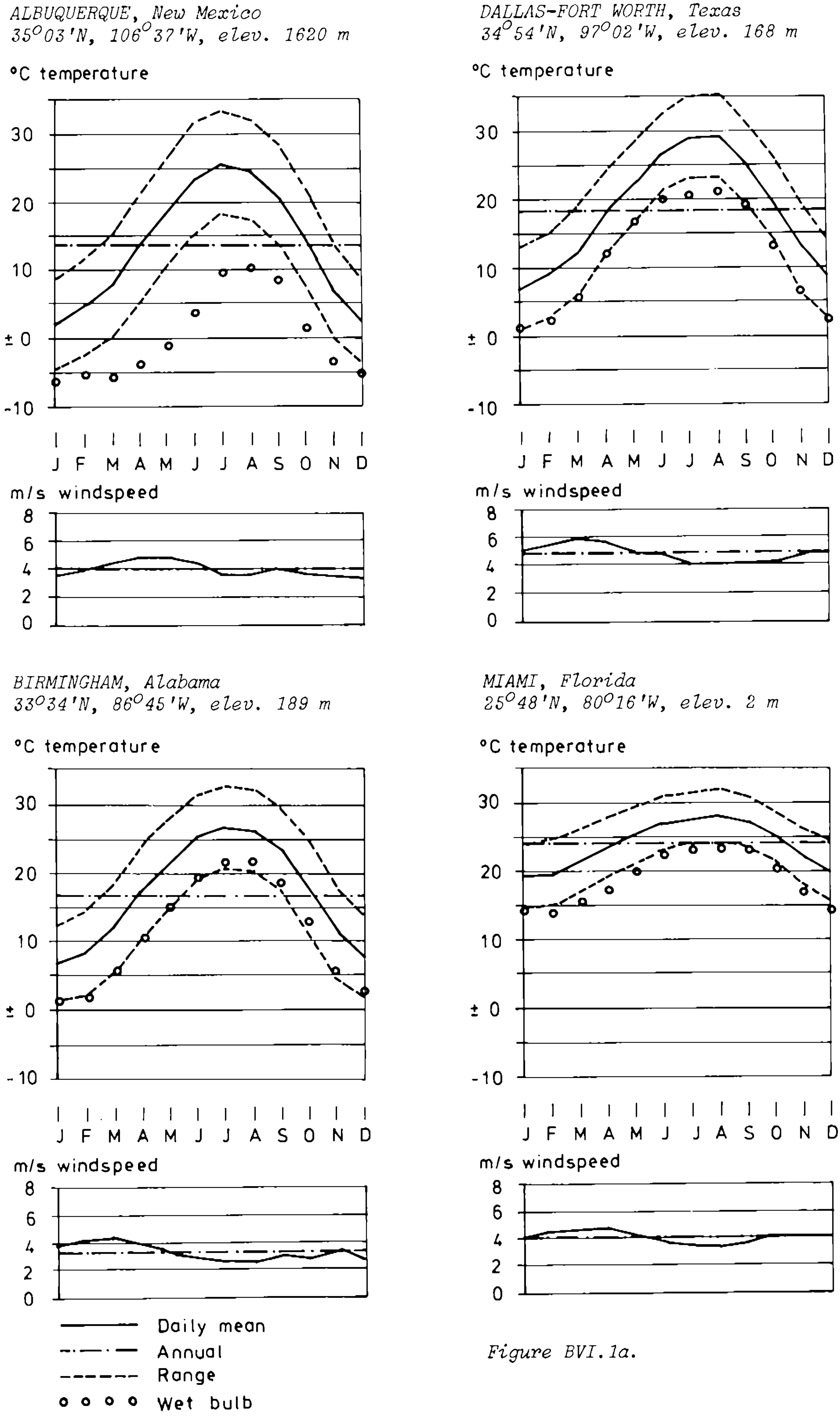
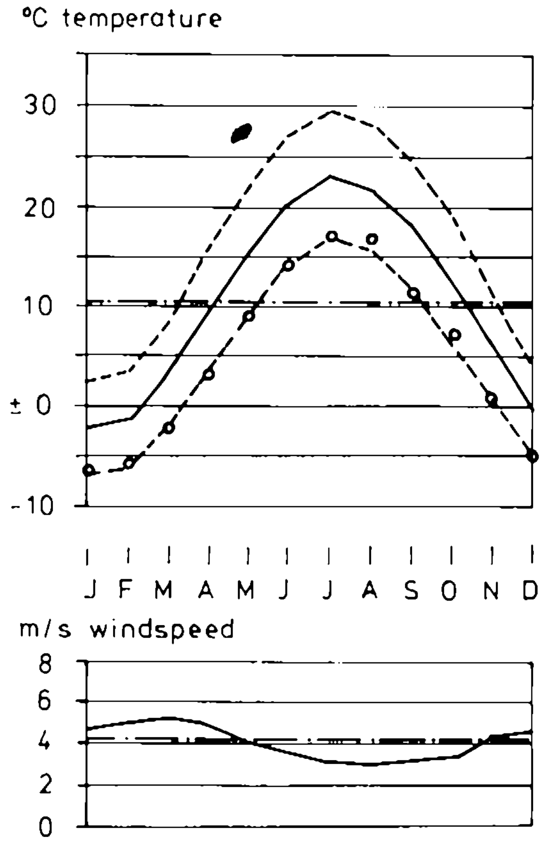
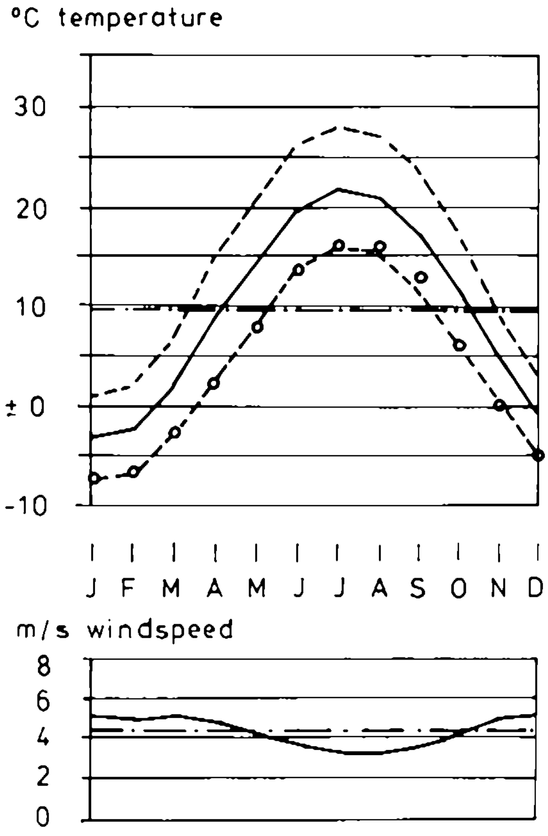


Figure BVI.1a.

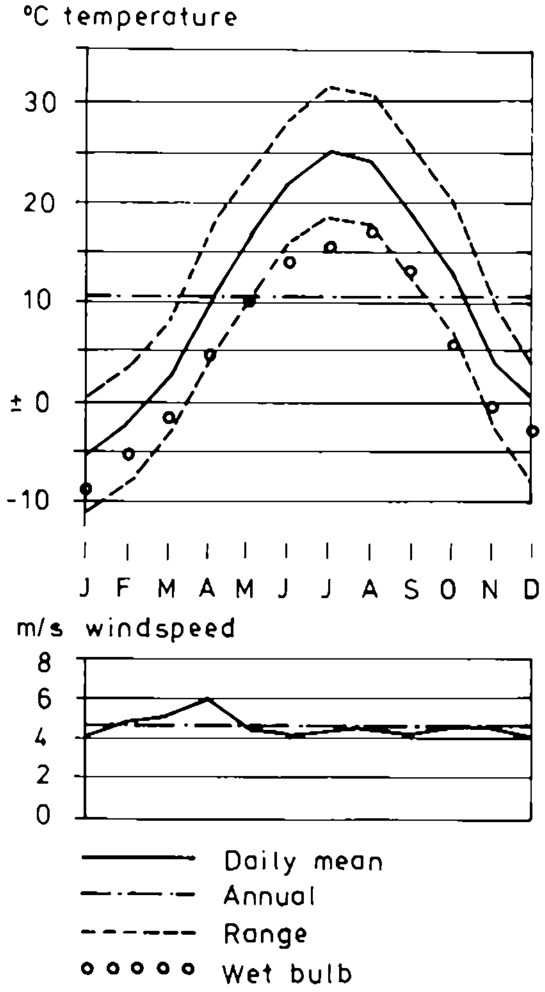
ALLENTOWN, Pennsylvania
40°39'N, 75°26'W, elev. 118 m



AKRON, Ohio
40°55'N, 81°26'W, elev. 368 m



LINCOLN, Nebraska
40°51'N, 96°45'W, elev. 359 m



SACRAMENTO, California
38°31'N, 121°30'W, elev. 5 m

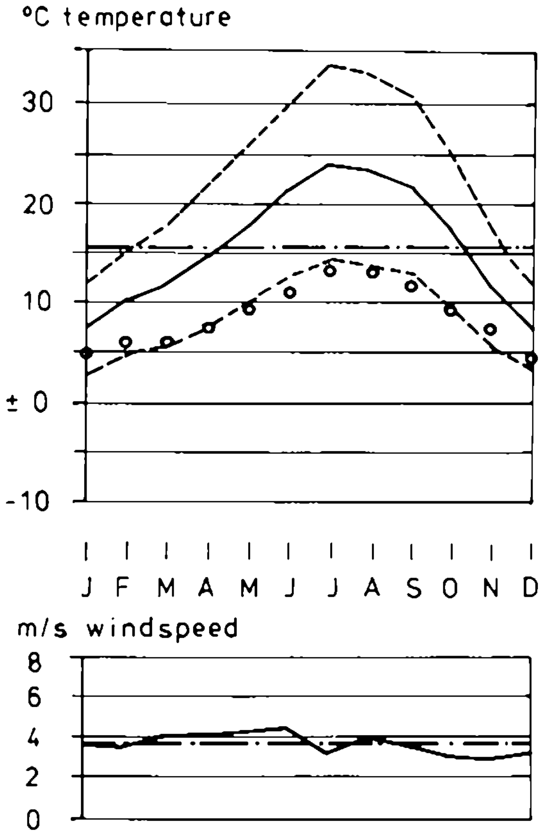
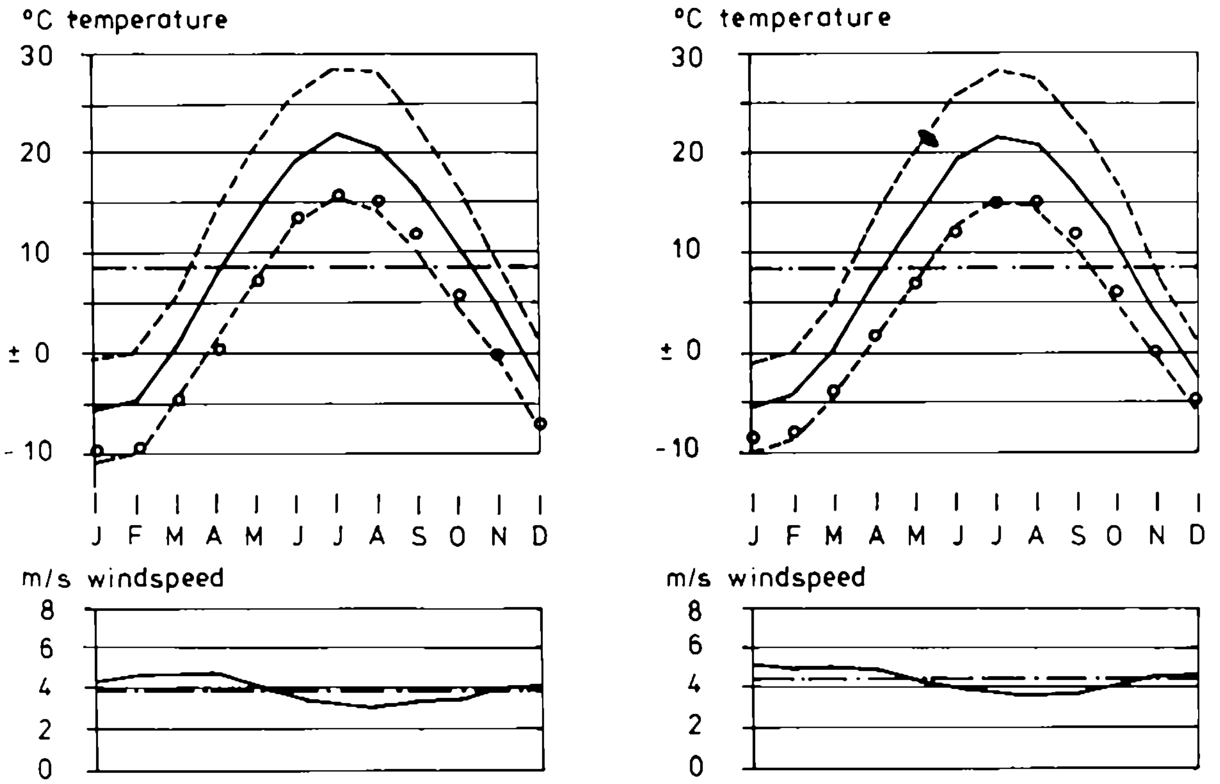


Figure BVI.1b.

ALBANY, New Jersey
42°45'N, 73°48'W, elev. 84 m

GRAND RAPIDS, Michigan
42°53'N, 85°31'W, elev. 239 m



PORTLAND, Oregon
45°36'N, 122°36'W, elev. 6 m

MINNEAPOLIS-ST.PAUL, Minnesota
44°53'N, 93°13'W, elev. 254 m

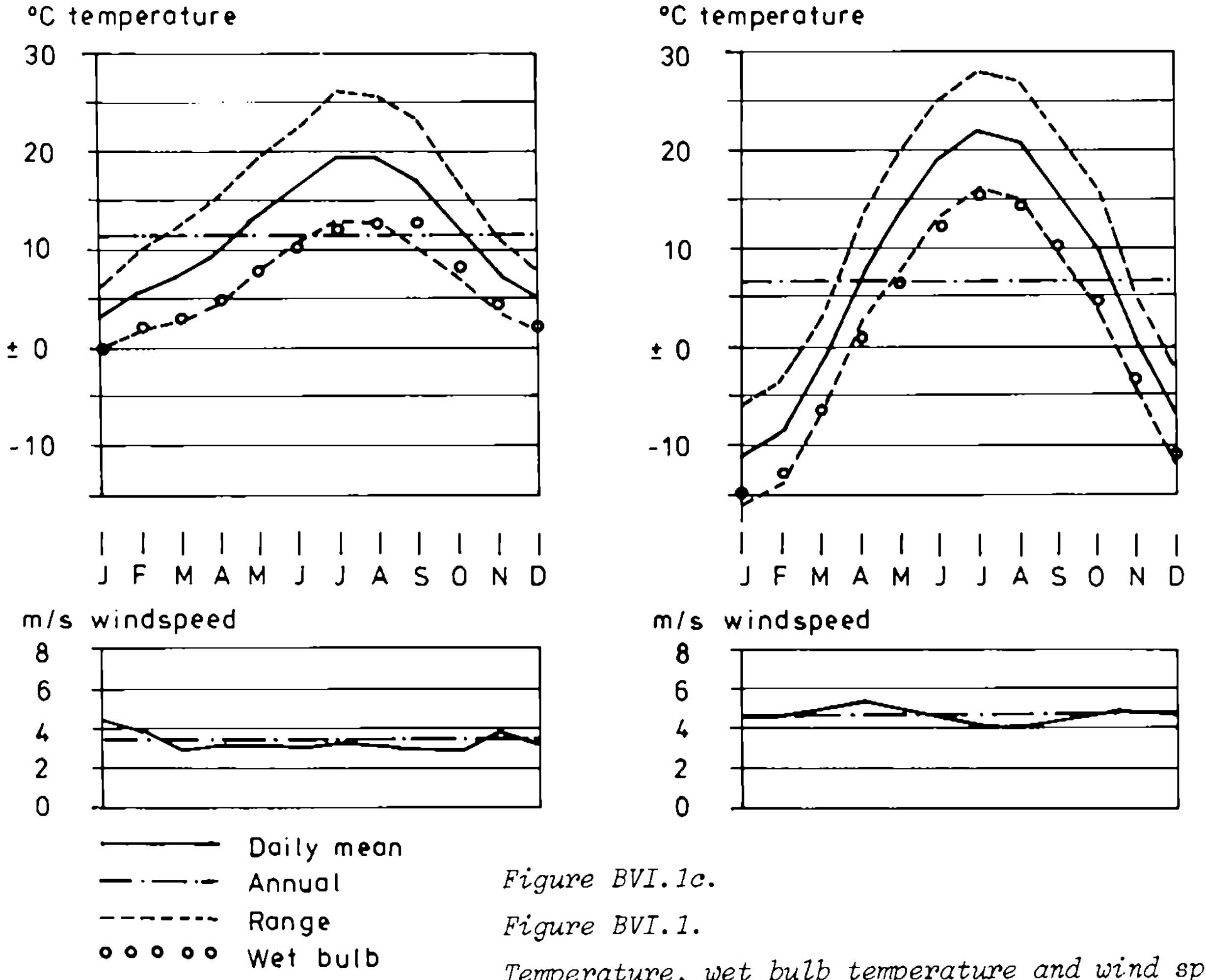


Figure BVI.1c.

Figure BVI.1.

Temperature, wet bulb temperature and wind speed at twelve different places in the United States.

This flow of Gulf air tends to dominate the summer for the Eastern United States making the summers hot and humid. Two examples are Miami and Birmingham, Alabama. To a lesser extent these influences are felt in Akron, Ohio and Allentown, Pennsylvania. Western cities experience a higher temperature but drier summer, e.g. Sacramento, California; Dallas, Texas; Albuquerque, New Mexico and even Lincoln, Nebraska.

BVI.3 DWELLING CONSTRUCTION IN THE UNITED STATES

BVI.3.1 The building envelope and the housing stock

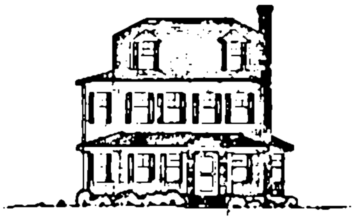
Throughout the United States the residential building envelope takes many forms. Although wood-frame construction is by far the predominant national building choice, certain areas of the country, particularly the southeast, are dominated by masonry construction. Still other areas, the southwest, for example, have other building techniques in evidence such as adobe block construction. Climate and moisture considerations are largely responsible for these local envelope preferences including the choice of window system. The discussion in this section will be mainly concerned with the predominant wood-frame construction. Details of other construction methods will be added where pertinent. Component contributions to air leakage such as window construction details will be added to the more general envelope construction details as a separate section.

UNITED STATES HOUSING STOCK

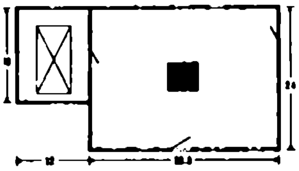
The United States 1975 annual housing survey placed the total number of occupied houses at about 73 million with conventional single-family homes at about 47 million, multi-family housing at 20 million, three million townhouses and three million mobile homes. Because of their number, the emphasis here will be on single-family homes.

The single-family housing may be catalogued by architectural styles. Some of the past architectural influences in the US such as English, Georgian, Norman, Dutch, etc., do not prove very helpful. However, the catagories of Ranch, Colonial, Cape Cod, Victorian and Split-Level do provide more useful information and are illustrated in Figure BVI.2.

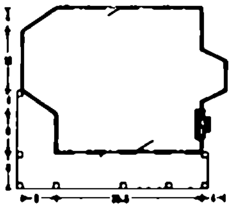
Colonial style



Victorian style

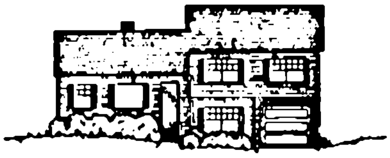


Colonial – floor plan

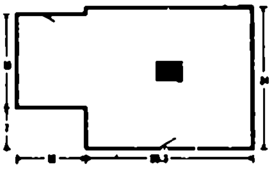


Victorian – floor plan

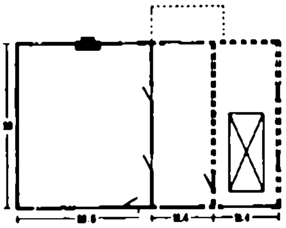
Cape Cod style



Split-Level style

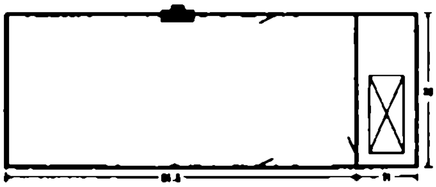


Cape Cod – floor plan



Split-Level – floor plan

Ranch style



Ranch – floor plan

Figure BVI.2. The variety of housing styles most common in the United States.

More than 70 per cent of the single-family homes are one storey. The ranch style is the most common in the US. These homes have often been closely associated with large glass wall areas. The higher ratio of surface area to volume makes the envelope design even more important (about 35 per cent more) than the two-storey houses. Colonial and Cape Cod house designs represent 22 per cent of single-family two-storey homes. Whereas the ranch style homes are popular throughout the US, the two-storey homes are more commonly found in cooler climates such as the northeast. These designs usually have basement to accommodate the heating system and higher pitched roofs to aid snow removal. Often the Cape Cod design is considered as one and one-half storeys because of the dormers. The dormers are a possible source of additional air infiltration because of complex surfaces and corners in the construction.

Of the 7 per cent of the housing not covered by one and two-storey house styles most would be either split-level or the Victorian type. The Victorian design, three or four storeys in height, represents another building era of higher ceilings (3 metres or so), bay windows, dormers and generally larger houses. Even though these features lead to higher heating loads, history has located these houses primarily in the colder areas of the US. In contrast, split-level houses have generally been built in the last 20 years and tend to be of tighter construction. They have a partial basement because of the basic split-level design. Heat loss paths through walls or floor to a garage are also common. Two attics are typical with one adjacent to the exterior wall of the storey that is one half level above.

TYPICAL BUILDING ENVELOPE CONSTRUCTION PRACTICES

Using the frame construction as the principal example, this section describes current insulation and vapour retarder (barrier) installation practice. Because of a variety of building codes and local interpretations, considerable variations can be expected from one area to another in the US.

Figure BVI.3 illustrates a typical cross-section of a two-storey US house with platform construction. This form of construction has been predominant for the past 40 years. Additional air leakage problems are encountered by the construction features between floors. In the

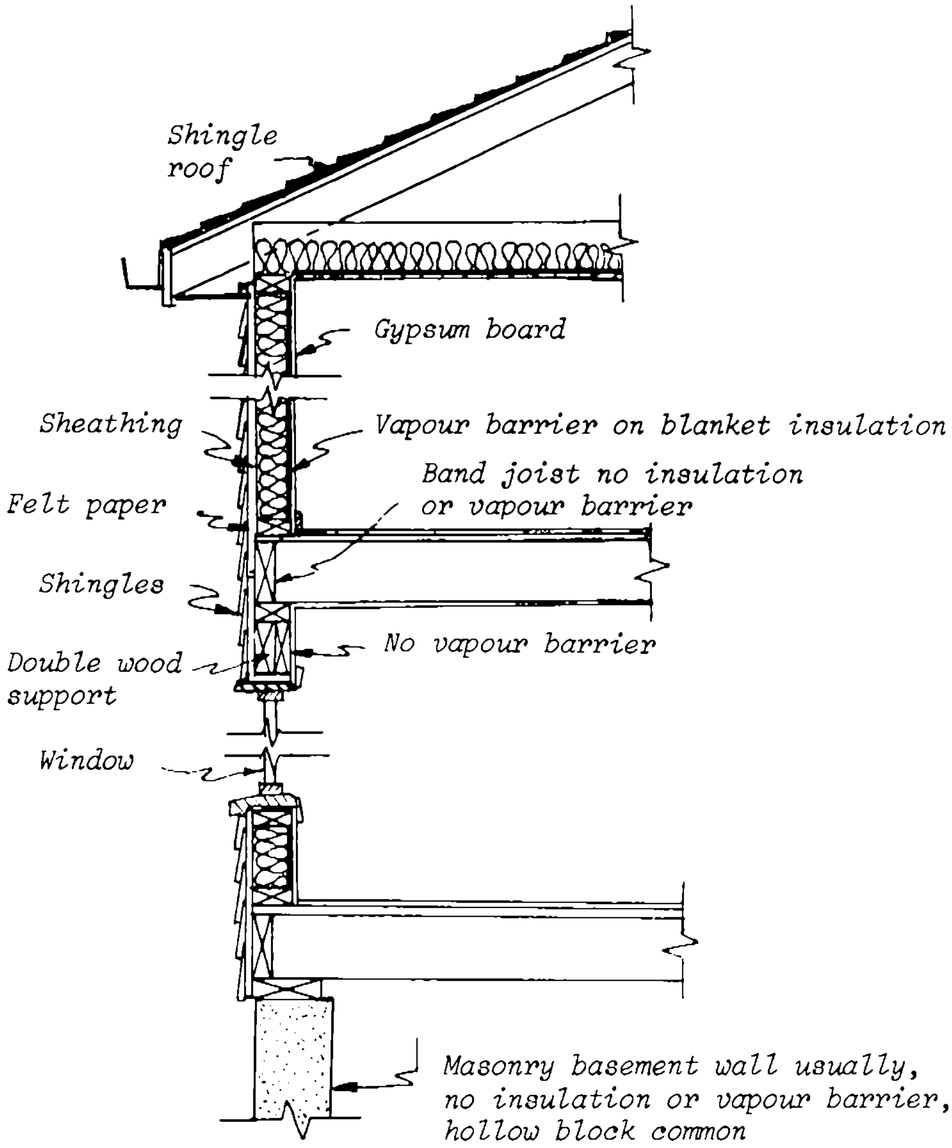


Figure BVI.3. A two storey house cross section using the predominant platform construction.

figure, the single-storey house can be represented by the upper storey construction alone. Normally the walls consist of 2" by 4" studs (the actual stud size is approximately 4 cm x 9 cm) placed ~40 cm on centre[x]. Normally, glass fibre insulation with attached vapour retarder (barrier) is stapled between these studs. The detail of this is shown in Figure BVI.4a. Attachment of the vapour retarder to the studs is accomplished with staple gun or hammer. The staples are

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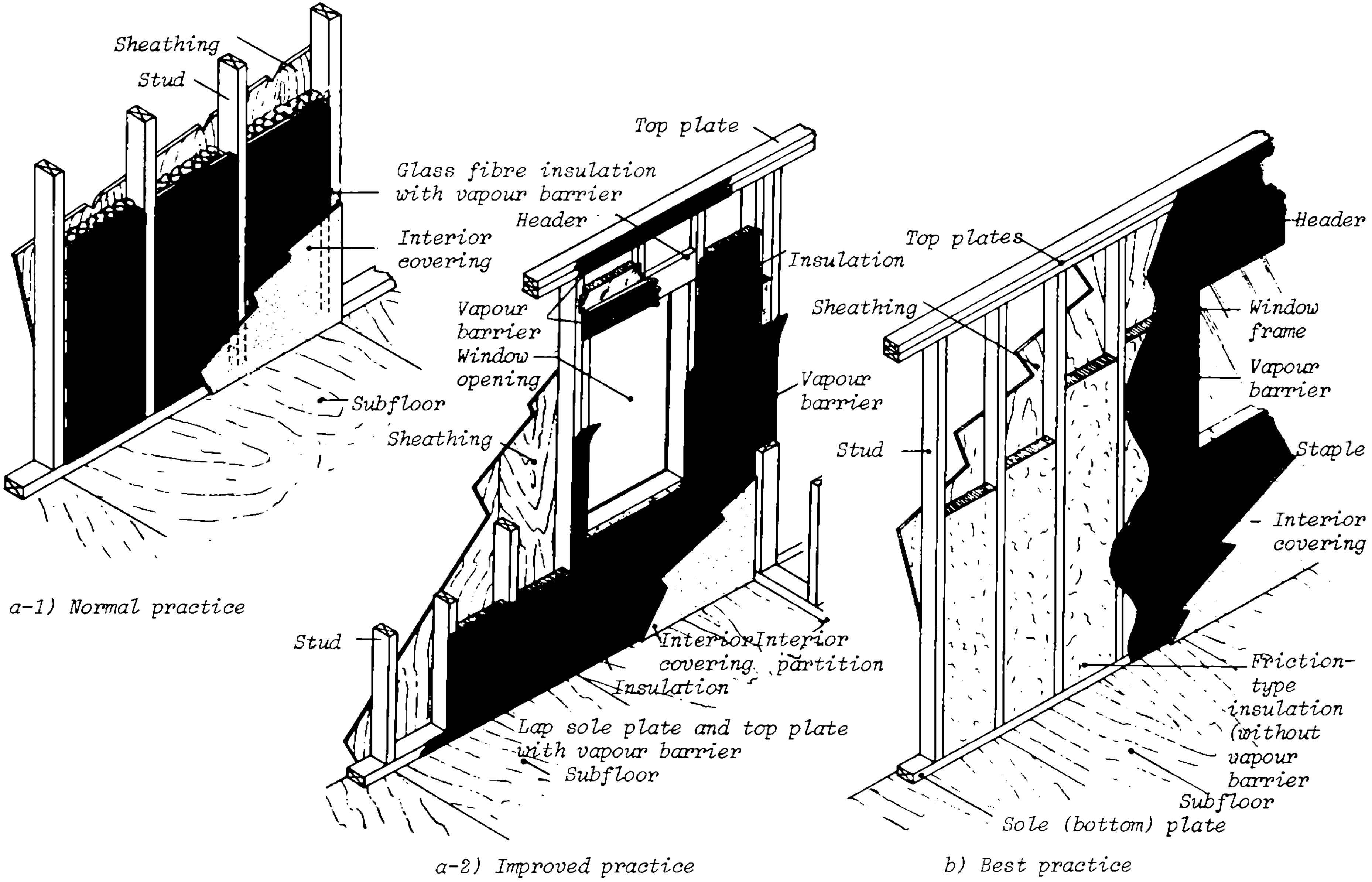
[x] 2" x 6" studs (4 cm x 14 cm) placed ~60 cm on centre has received recent attention in the Arkansas Home. This design allows the standard ceiling insulation (15 cm thick) to be used in the wall cavity.



a-1) Normal practice

a-2) Improved practice

b) Best practice

Figure BVI.4. Methods of attaching insulation: a) shows stapling of the blanket vapour barrier to studs, b) shows the use of a separate vapour barrier with friction fit glass fibre insulation.

fired into the *sides* of the stud so that the stud is not obscured when the sheet rock crew adds the inside wall material.

Problems result from stapling to the sides of the studs. Between each staple gaps occur (called "fishmouths") making the vapour retension feature extremely questionable. The sum of these gaps over the wall surface means that many square centimetres of leakage area are present. If the length of insulation is not accurately measured additional gaps may be present at the top or bottom of each stud cavity. In the piecework nature of the insulation business gaps readily occur, especially around electrical boxes and wiring usually found every 2 metres in the outside wall. The air tightness performance of the wall under this construction procedure is very much a question of how well the gypsum board itself (including the painted surface) seals the air leakage paths. Critical leak locations are along the wall-floor joint, openings associated with electrical boxes and lighting fixtures and the permeance of the wall surface itself.

An alternative wall construction technique that is more common in the colder regions of the US makes use of friction fit glass fibre insulation (slightly oversized so that it holds in the place between the studs) in the stud cavities and then adds a 4 to 6 mil (0.1 to 0.15 mm) polyethylene vapour barrier stapled over an entire wall surface. Details are shown in Figure BVI.4b.

Reviewing the entire wall as shown in Figure BVI.3, it is very evident that between the vapour barrier locations for each floor there exists critical zones, the band joints, where no vapour barriers are present. In the majority of existing housing, this horizontal zone, which surrounds the house, has little or no insulation. Thus, condensation problems may be expected as well as leakage problems. This is particularly true for houses where humidity is added during the heating season, often to levels of 50 per cent RH or even higher in the living space.

The construction features of many existing and even new building in the US has caused a variety of air leakage problems to exist at the ceiling level. As shown in Figure BVI.5, leakage at the top of the interior walls is often traceable to the same construction defect as in the stud wall, i.e. the vapour barrier ends at either side of the

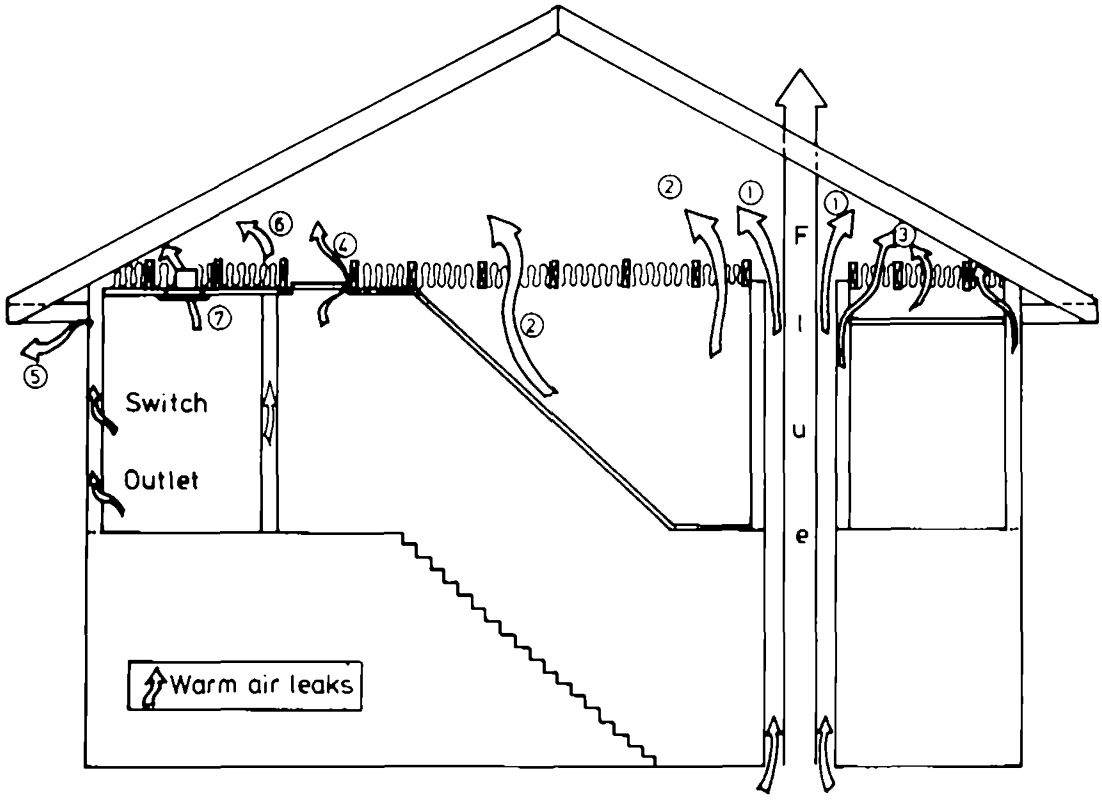


Figure BVI.5. *Common air exfiltration paths from the living space at the upper portions of the house: (1) around flue and plumbing stack, (2) through the insulation, (3) above soffit ceilings, (4) around entries, (5) penetrations in outer walls and eaves, (6) leakage up through interior walls and electrical systems and (7) recessed lights.*

wall or is only loosely in place above the interior wall. As shown in the figure, a number of other leakage sites are quite common. These include recessed lighting, openings around vent pipes and flues, access doors to the attic, and above soffit ceilings and staircase ceilings where the ceiling surface has been separated from the vapour barrier and air movement is through the "fishmouths". The item listed as (2) indicates a connective loop where the air may never enter the living space but can still result in significant heat loss.

The details of the construction for the ceiling and the installation of the insulation/vapour barrier is shown in Figure BVI.6. Three methods of installing blanket insulation in ceilings are shown:
1) laying the vapour barrier faced insulation in from above, when the ceiling material is in place; 2) stapling from below; or 3) installing unfaced friction-fit blankets between the ceiling joists with a

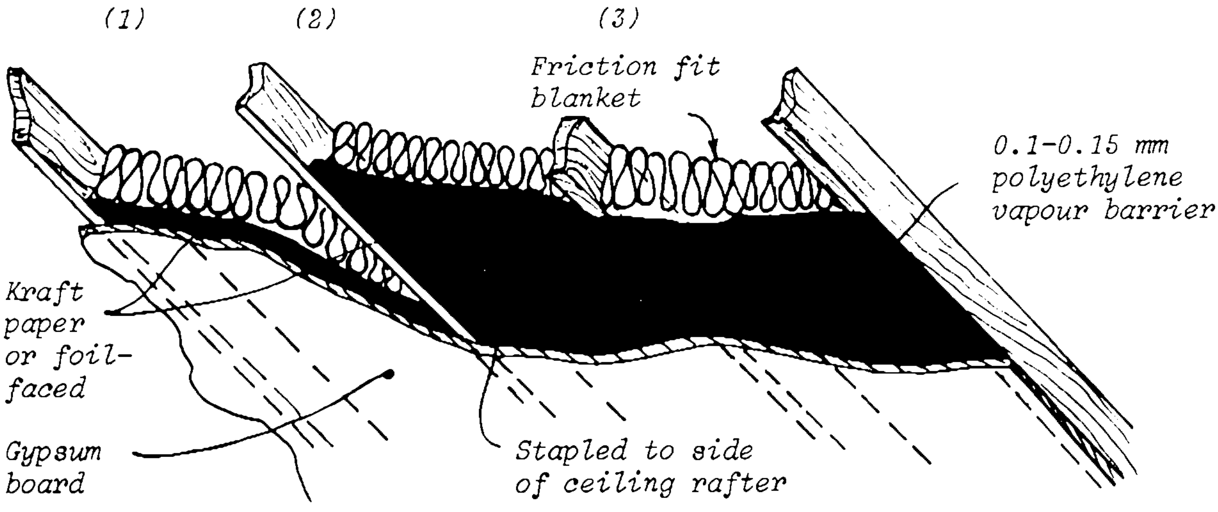


Figure BVI.6. Three methods of installing ceiling insulation: (1) vapour barrier faced insulation installed from above, (2) stapled from below, and (3) unfaced friction fit blankets with separate vapour barrier.

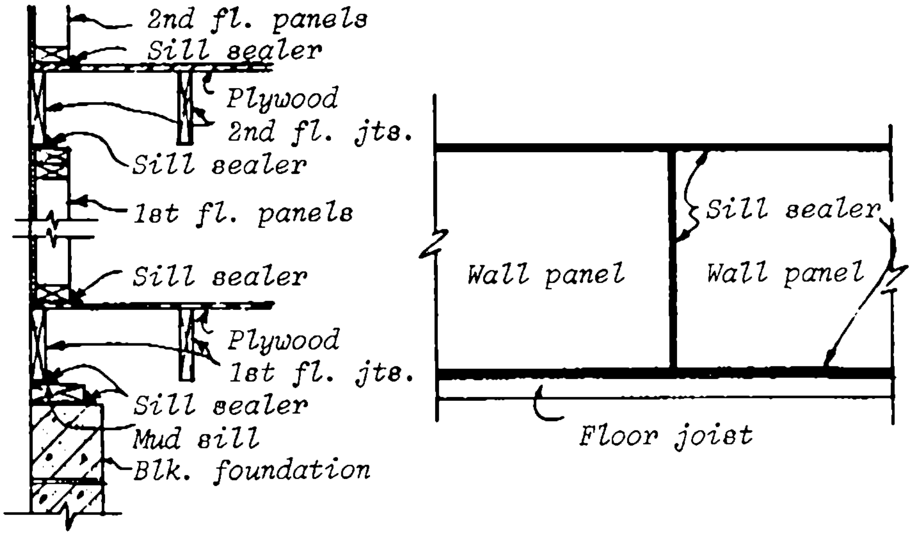
separate vapour barrier. The ceiling joists are traditionally sized as 2" x 8" (4 x 19 cm) and 2" x 6" (4 x 14 cm), or even 2" x 4" (4 x 9 cm) where truss construction supplies the support.

BVI.3.2 Improved construction methods to achieve envelope tightness

In the years following the first oil crisis there has been an increasing emphasis on controlling air infiltration in a variety of US buildings. Cost-benefit analysis places this item high on the energy saving list. A number of common features are present in the better construction practices. One is a conscious effort to control air infiltration by carefully planned approaches in the construction. The use of a polyethylene air/vapour barrier has become much more common. These and other details will be discussed in the sections that follow.

THE IMPORTANCE OF THE WALL

One construction item that had not been given adequate attention was the wall leakage sites and particularly how the wall joined other construction elements. Sensitivity to these problems has resulted in use of caulking and sill sealer where floor and wall meet. One building group makes extensive use of sill sealer (a glass fibre or open cell foam strip approximately 8 cm wide and 1 cm thick). Not only is it used between the masonry and the wood sill plate around the perimeter of the house, it is also used on top of the platform construction, between other wood members and between sections of the wall as they are erected into place. These applications of the sill sealer are illustrated in Figure BVI.7 together with the builder's instruction for use. The method attempts to eliminate gaps of a few millimetres.



INFILTRATION BARRIER

Infiltration barrier or gasket material will be used on all through joints as follows:

a. between foundation wall and framing

b. between mud sill and ring joist

c. between top of deck and bottom plate of exterior walls

d. between top plates and ring joists

e. between top plate and double plate of knee walls

f. between all vertical panel joints of exterior walls including corners

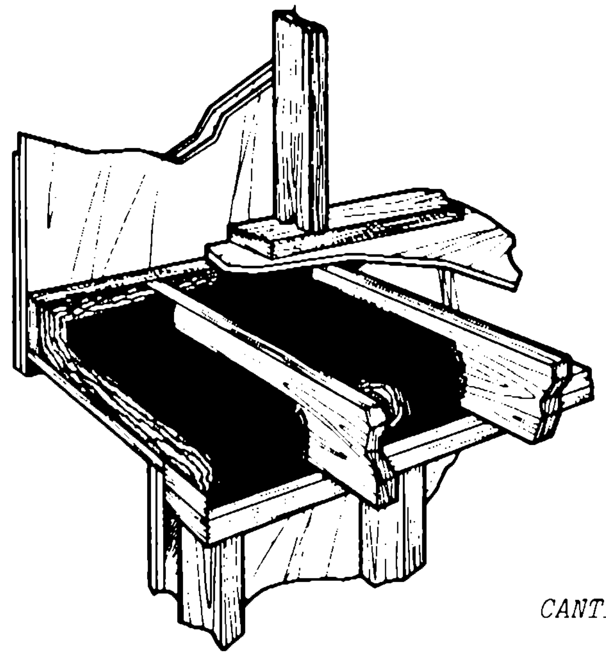
g. between concrete floor and bottom plate of fire walls

h. between end studs of fire wall and foundation

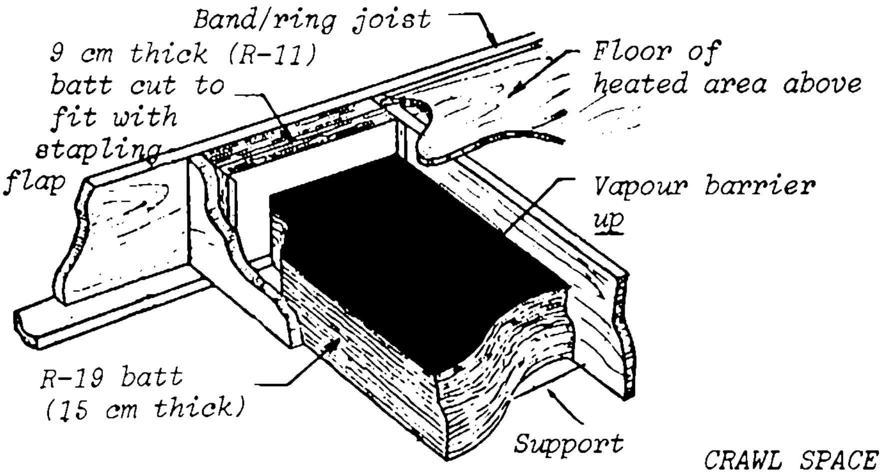
i. at any other through joint between conditioned and unconditioned spaces

Figure BVI.7. Builders instructions on the application of sill sealer in wall application with sketch.

The next procedure to reduce wall leakage concerns the band or ring joist. This critical area is present in the single-storey house just beneath the platform. Figure BVI.8 illustrates the placements of specially cut batts in the band joist area and, in this case of an unheated crawl space or garage, the placement of the vapour barrier on the floor insulation to minimize air and heat leakage. The important point to remember is that in multi-storey construction the air leakage problems at the band joist are repeated at each floor level. Hence careful fitting of the vapour barrier is necessary. Some of the most knowledgeable builders are using air infiltration paper



CANTILEVERED FLOORS



CRAWL SPACE OR GARAGE

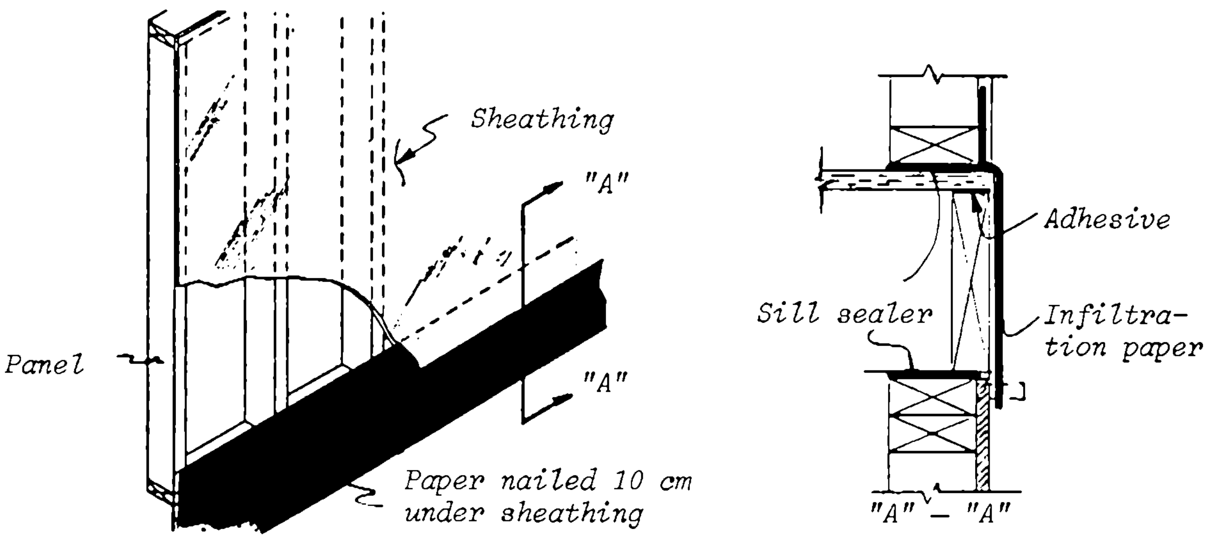
Figure BVI.8. Treatment of the band joist with a specially cut batt and vapour barrier backing including floor insulation above an unheated area with vapour barrier to reduce air infiltration.

on the outside of this critical area. Figure BVI.9 illustrates the use of this paper to reduce wind penetration at the band/ring joint. Some firms are providing a special service to treat these areas just prior to siding installation.

AIR INFILTRATION PAPER

Traditional houses – air infiltration paper shall be installed by the lumber yard at the base of all full height panels. This material shall be used to cover ring joist areas as in sketches

SKETCH A *SKETCH B*



SKETCH C

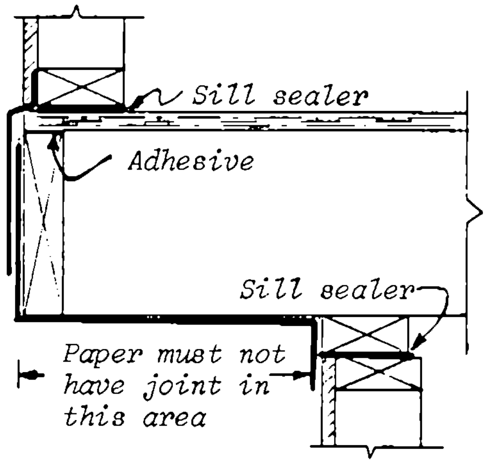
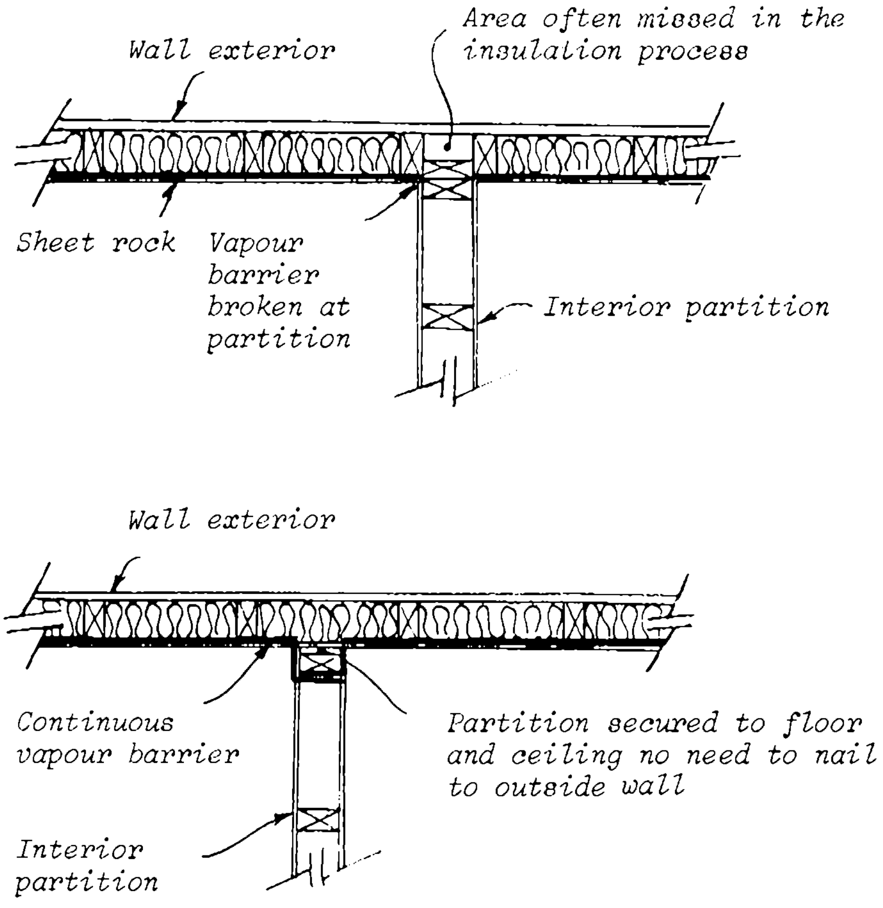


Figure BVI.9. Air infiltration paper added to reduce leakage at the band joist where sketch A shows the sheathing, sketch B conventional band joist and sketch C the band joist and cantilever construction.

Where interior walls (or wing walls) join the exterior walls, additional air infiltration possibilities are presented. The walls are covered with 0.1 mm or 0.15 mm polyethylene. The partition walls are treated as shown in Figure BVI.10.

The use of a low permeability vapour barrier is critical in the achievement of low air infiltration rates in the home. Figure BVI.10 illustrates some of the details of fitting the 0.1 mm - 0.15 mm polyethylene vapour barrier. Detailed instructions vary from builder to



In order to achieve the coutinuous vapour barrier free from the problems of interior partition walls on US custom builder (G. Ledger, New Hampshire, Massachusetts) is completing the interior surfaces prior to adding the interior walls. Not only does this eliminate the gap in the vapour barrier, it also eliminates two studs at each intersection and the insulation gap that is often present where the interior partition joins the exterior wall. The same basic approach is used to make certain the ceiling does not have gaps in the vapour barrier

Figure BVI.10. Eliminating leaks where a partition or wing wall meets the exterior wall.

builder. Typically the film is installed to overlap the floor and the ceiling rafters above by at least 5 cm. Where the polyethylene vapour barrier is used over the crawl space floor the overlap is 60 cm with a gravel cover used to hold it firmly in place. The barrier extends 15 cm up the exterior walls. Figure BVI.11 shows the relative placement of the vapour barriers (red lines) and includes the additional treatment of the crawl space walls with glass fibre insulation.

Figure BVI.12 further illustrates the path of the vapour barrier in crawl space and slab on grade construction. In the arrangement shown 15 cm wall insulation and wiring raceways have been used in the walls.

Moving to the upper portion of the house there is disagreement in the building community as to whether a vapour barrier should be used on the ceiling. Figure BVI.13 indicates use of a polyethylene vapour barrier overlapped at the corner of wall and ceiling. Other building groups have used a well-vented attic (using the ridge vent system) and eliminated the ceiling vapour barrier. The reasoning was that measured air infiltration rates were between 0.2 and 0.5 air changes per hour (down a factor of 3 from an untreated house) and that further reduction would require use of mechanical ventilation. Furthermore, elimination of the ceiling vapour barrier avoids excessive humidity since 25-50 per cent RH levels can be maintained throughout the winter without the ceiling barrier. Use of mechanical ventilation in bathroom or kitchen meant 18 hour's a day operation in one series of houses that had tight wall and ceiling construction.

The complete vapour barrier treatment as shown in Figure BVI.13 further limits weather effects on the house and moves the infiltration rate into the 0.1 ac/h level. The use of air-to-air heat exchangers to recover heat while providing the necessary ventilation air then becomes feasible from an economic standpoint.

Wall systems in some of the low energy, tightly-constructed homes use a double wall. One builder who has constructed a number of such homes is placing the continuous polyethylene vapour barrier as shown in Figure BVI.14. Carefully planning each step of the operation ensures that the vapour barrier is installed to completely cover the wall.

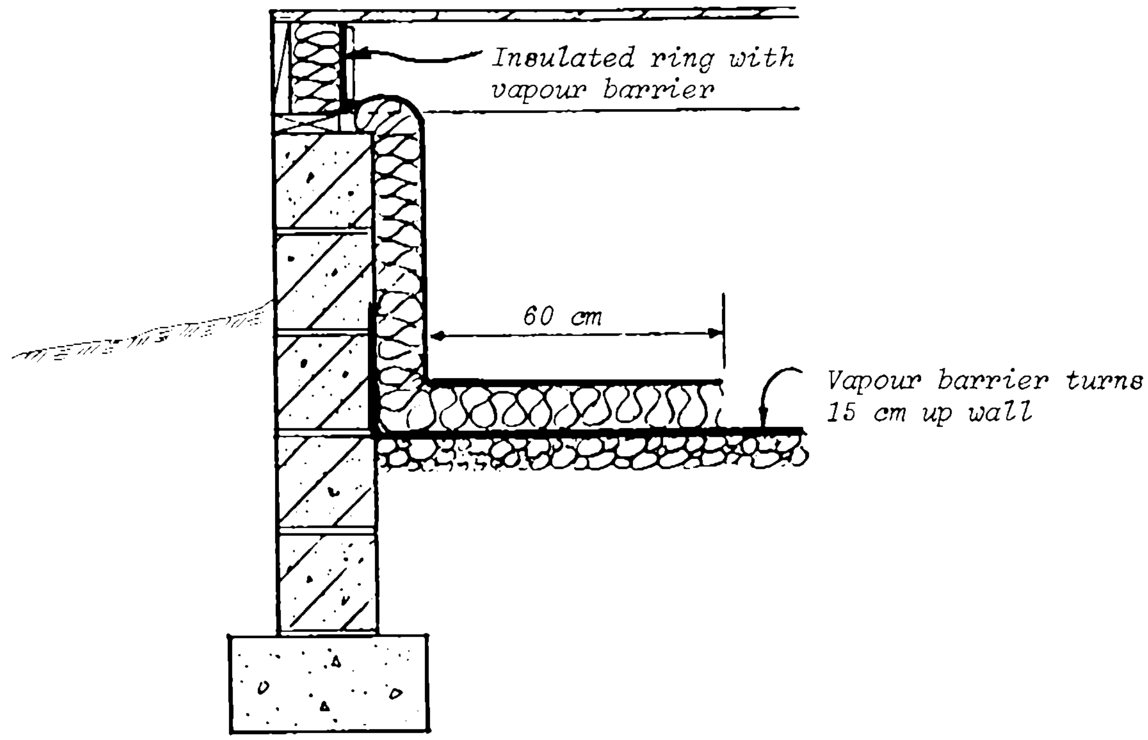
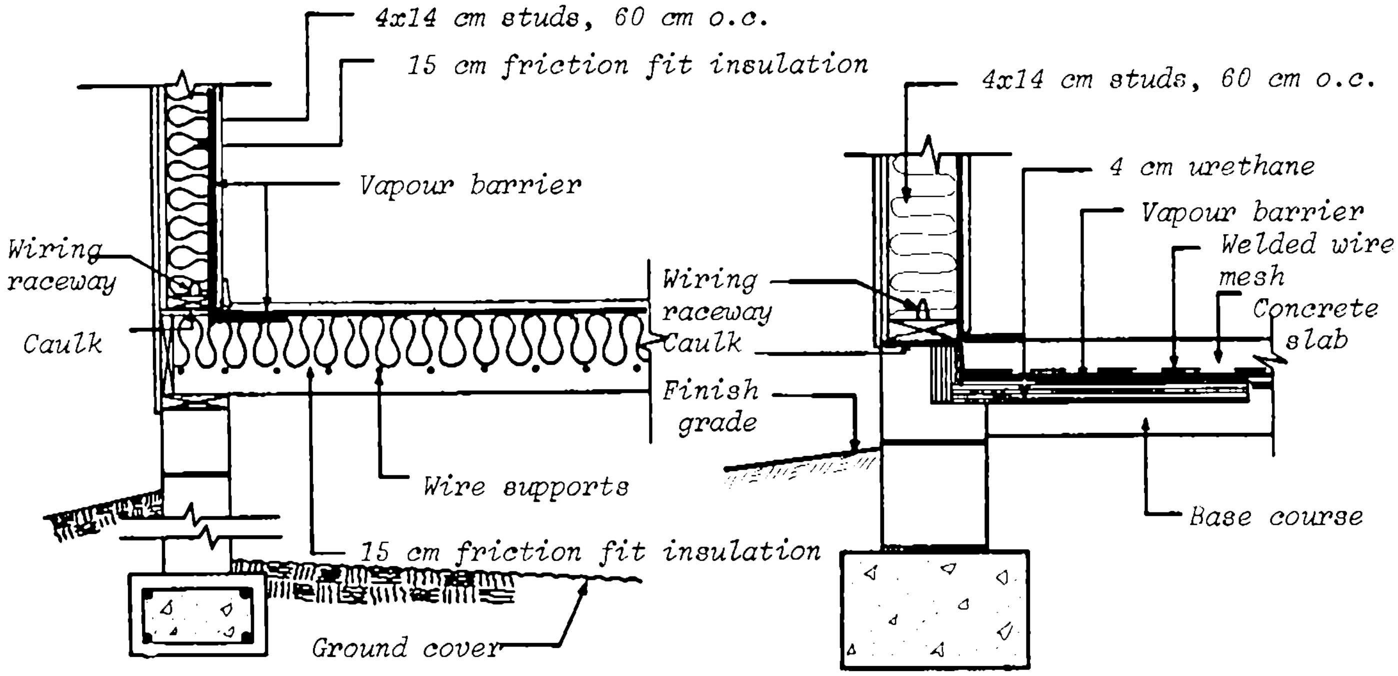


Figure BVI.11. Use of vapour barriers in the crawl space and basement areas to eliminate air and moisture penetration.



CRAWL SPACE CONSTRUCTION (INSULATION) SECTION THROUGH SLAB

Figure BVI.12. Vapour barrier use in the lower portions of the house.

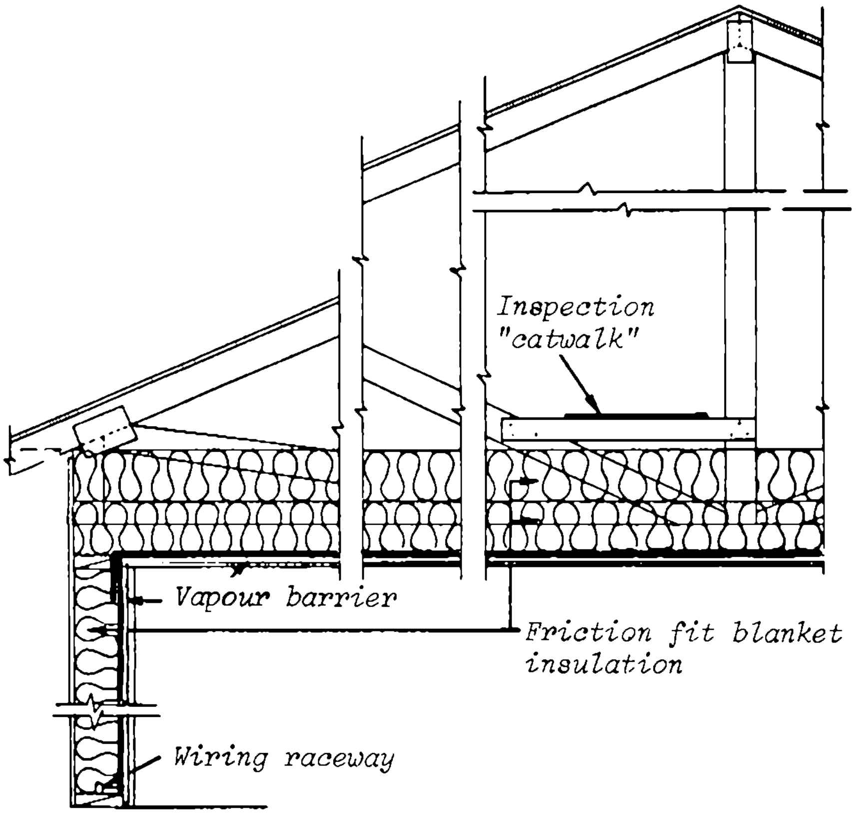
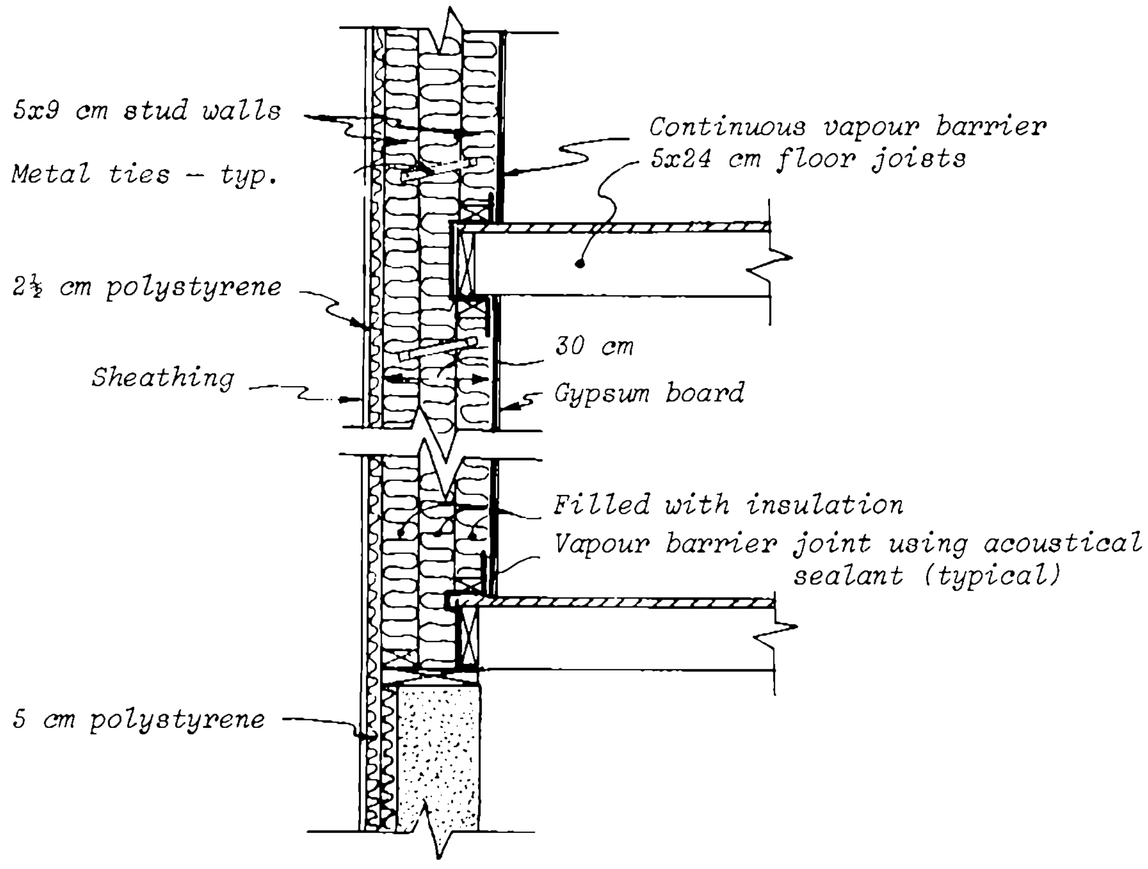


Figure BVI.13. Vapour barrier used to prevent air exfiltration through the ceiling area.

It should be stated that none of the approaches shown in the construction methods reviewed here will succeed unless constant inspection takes place throughout construction. Of particular importance is the attention to detail. The extensive use of adhesives, caulking, foams, glass fibre, and special construction techniques where electrical, plumbing, windows, and vents pass through the building envelope is critical to the success of the overall concept. Such local air leakage sites, when untreated, have resulted in local moisture problems and thereby provided ammunition to the critics of tight construction house designs.



The double wall section shown in the figure is made up of two separate walls. Where windows and doors are present in the wall the inner and outer walls are connected together. Metal strapping is used to tie the walls together where necessary at other locations. The placement of the vapour barrier is critical and considerable care is taken to make it truly continuous. Special notes are added at each of the critical locations on the diagram

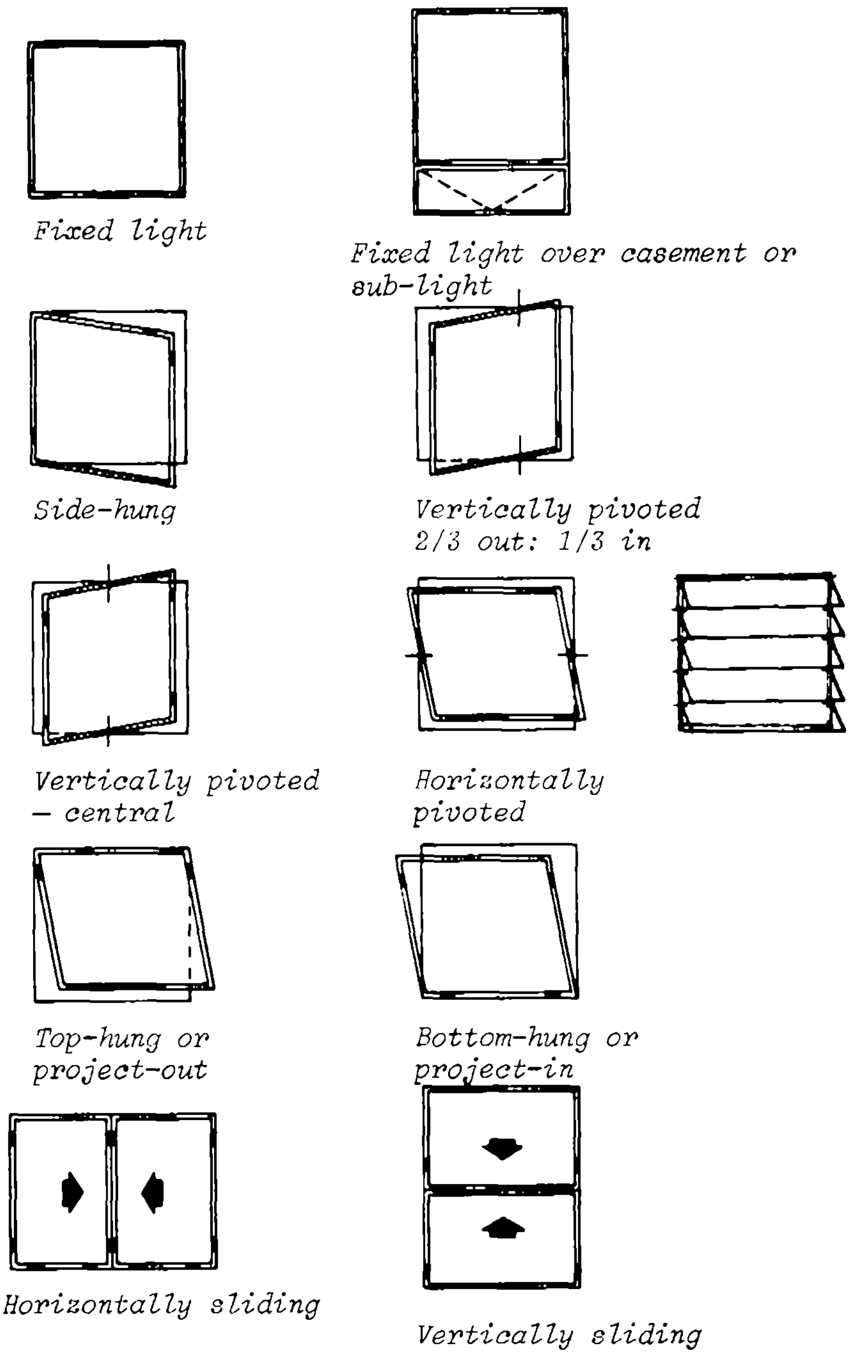
Figure BVI.14. The use of a continuous vapour barrier in one version of double wall house design.

BVI.3.3 Chosing other envelope components

Components that can influence air leakage include windows, doors, vents, fans, lighting and folding stairs. Care must be taken in the component selection to avoid negating the tightness improvements in the envelope construction previously discussed.

WINDOW DESIGNS

Window designs vary widely over the US. Examples of the variety are shown in Figure BVI.15. Unfortunately, the choice of windows has often had little to do with low leakage design. Older homes have tended to use the double-hung window type which tends to be one of



Fixed light

Fixed light over casement or sub-light

Side-hung

Vertically pivoted 2/3 out: 1/3 in

Vertically pivoted — central

Horizontally pivoted

Top-hung or project-out

Bottom-hung or project-in

Horizontally sliding

Vertically sliding

Figure BVI.15. The variety of window designs use in US housing tests.

the leakiest. Modern Colonial home designs continue to use this window design (as do many other new houses) and it remains a common window choice in the US. Sliding seals are part of the leakage problem, together with the leakage perimeter which is large compared to the window area.

At the other extreme of air tightness, casement and awning-type windows, where the seals are compressed thus limiting leakage, are finding wider use in contemporary home designs and are today the leading window choice based upon the latest US windows industry data. Between these two extremes, sliding windows and other window combinations, as shown in Figure BVI.15 are possible choices. To illustrate the extremes in choices, one window system common in the warmest US location is the jalousie window. This window design far exceeds the leakage rates of double-hung windows since glass-to-glass sealing is used and the sealing perimeter is extremely large because of the many louver window pieces.

As pointed out in a study of test laboratory vs actual on-site measurements of window system leakage rates, noticeable differences occur, see Figure BVI.16. These differences can be traced to possible dimensional variations that may have been a result of the actual installation procedure. However, even more important, the nominal leakage rate standard of 0.5 cm^3/lineal foot (1.7 cm^3/m) is only met by 60 per cent of the windows (and only 40 per cent meet the more rigid industry standard) leading one to suspect quality control as the real problem. The leakage measurements applied to fixed glazing indicated that these units are some of the worst.

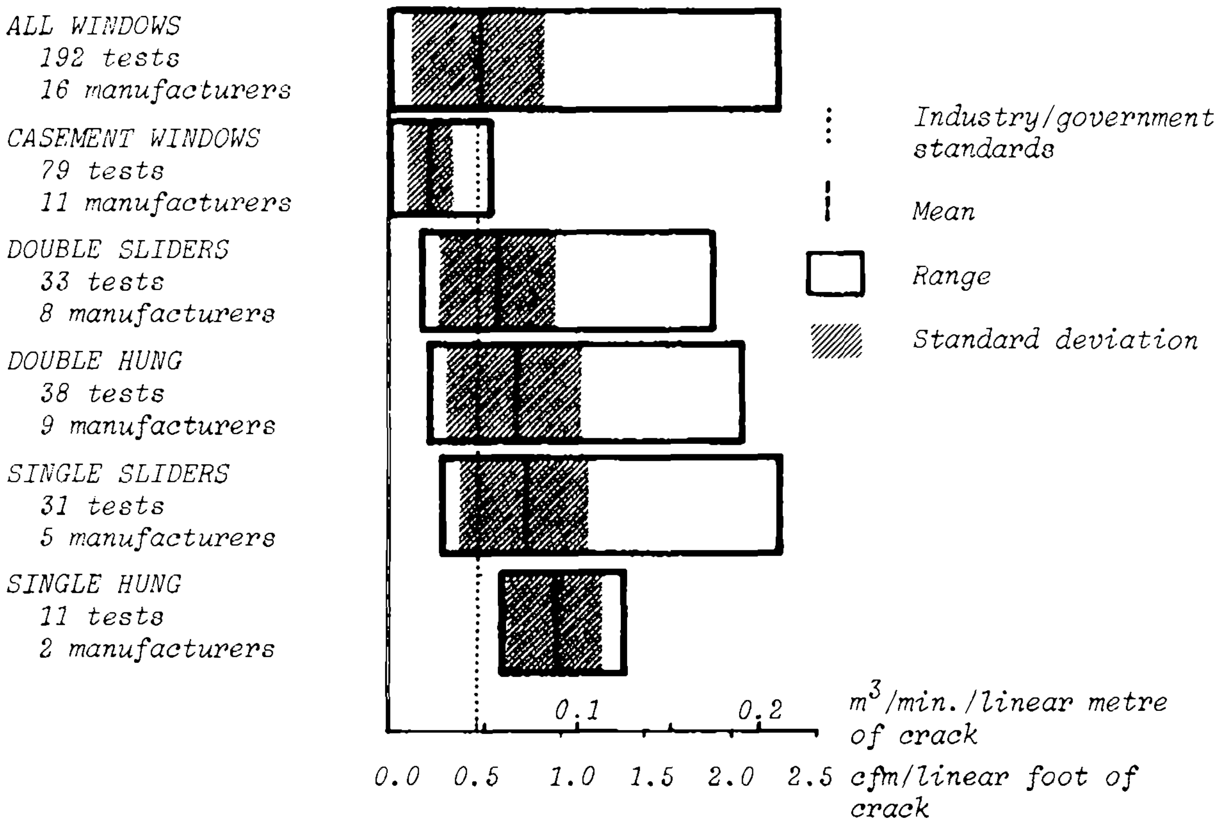


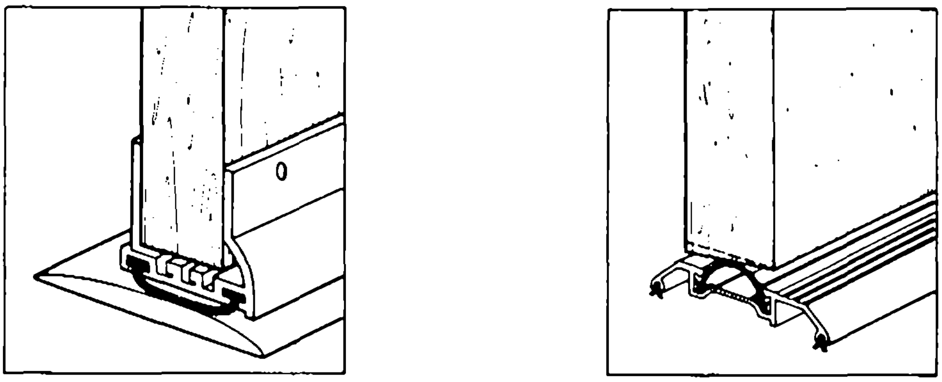
Figure BVI.16. Leakage rates in US windows.

Together with the window selection (as well as the case with the other envelope components) is the important question of how the component fits into the envelope. Leaks between the window and wall are not part of the window leakage standard, hence it is not "checked at the factory". In past procedures, such as those illustrated in Figure BVI.4a, the vapour barrier often never reached the actual window assembly. The void between the window and wall opening was often neglected and only covered with the inside moulding and outside sheathing/siding. More recently the void has been stuffed with glass fibre insulation. In the past few years foam insulation/sealant has been forced into the void providing both insulation and sealing attributes. Proper use of the continuous plastic vapour barrier, as shown in Figure BVI.4b, allows the void to be covered, thereby achieving superior sealing of this critical location (leakage rates around the window can be significant compared to actual window leakage itself).

DOORS

Doors have moved toward improved energy-saving design over the past decade in the US. Insulated doors with metal cladding have provided higher insulation levels (moving from $k = 3.0$ to $0.5\ W/m^2\ {}^oC$), have eliminated the seasonal warping so common with wooden doors and have supplied a surface to which magnetic seals can adhere, thereby allowing for an excellent leak seal. A variety of other sealing methods are available for alternative door designs. One feature that has become almost universal in the US is the threshold seal. This normally consists of an aluminum extrusion holding a vinyl boot which can be adjusted so as to be slightly compressed by the lower edge of the door as shown in Figure BVI.17.

Double front door designs in recent years have made door sealing a greater problem. However, the use of large glass sliding patio doors has been the real challenge in door sealing. These designs prove to be a major source of envelope leakage. Quality of construction and design is highly variable. To provide the needed seal, often a fixed storm door is the only solution during the winter.



DOOR SHOES

VINYL BULB THRESHOLDS

Figure BVI.17. The lower door seal as a control of air leakage.

VENTS

Vents come in a variety of shapes and sizes. In US homes, one common design is used on exterior walls to vent clothes dryers, bathrooms, and kitchens. These vents, as shown in Figure BVI.18, typically rely on gravity to seal the "soup can lid" type flapper in place. Several problems are evident in these designs: 1) lint and other matter tends to build up causing the flapper to remain partly open, 2) corrosion on the hinge takes place over the years, causing the flapper to stick in a partly open position, and 3) local wind conditions cause the flapper to open and close intermittantly. A more recent design has added a magnetic closure system.

Bathroom and kitchen flapper powered vents often have a similar flapper arrangement built in the housing. Unfortunately, many of these arrangements also seal poorly, and tend to depend on metal-to-metal seals. A small number of the kitchen fans have gasketed covers that are hand opened with a pull chain and tend to seal very tightly.

FANS

Fans, where they penetrate the building envelope, present a leakage problem that may require special solutions. Whole house fans, which are mounted in the ceiling and exhaust into the attic (or have louvers in the ceiling where the fan is mounted in the gable end of the attic), represent a major leakage site. Because the ceiling louvers do not provide an airtight seal (nor provide any insulating feature) other

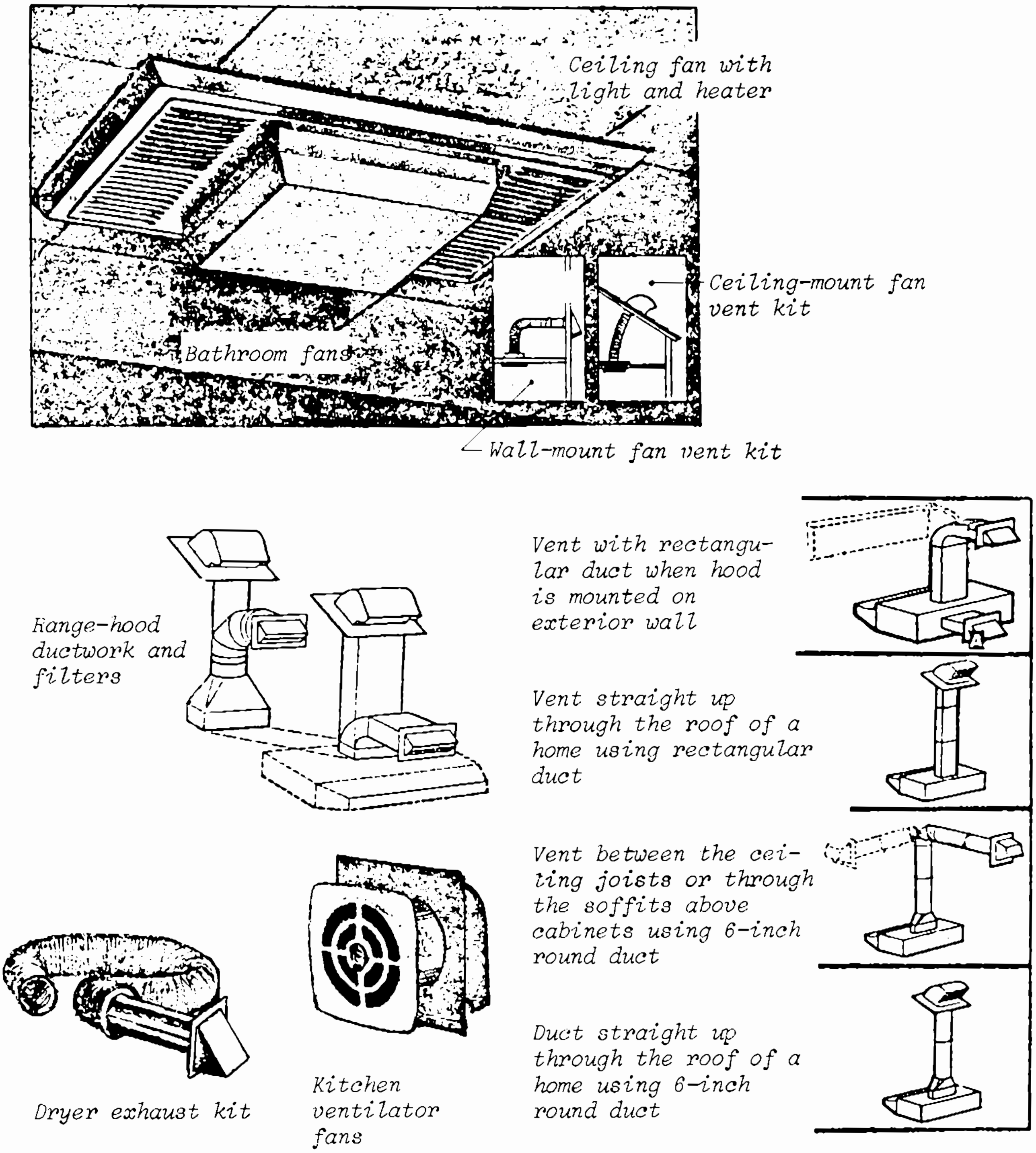
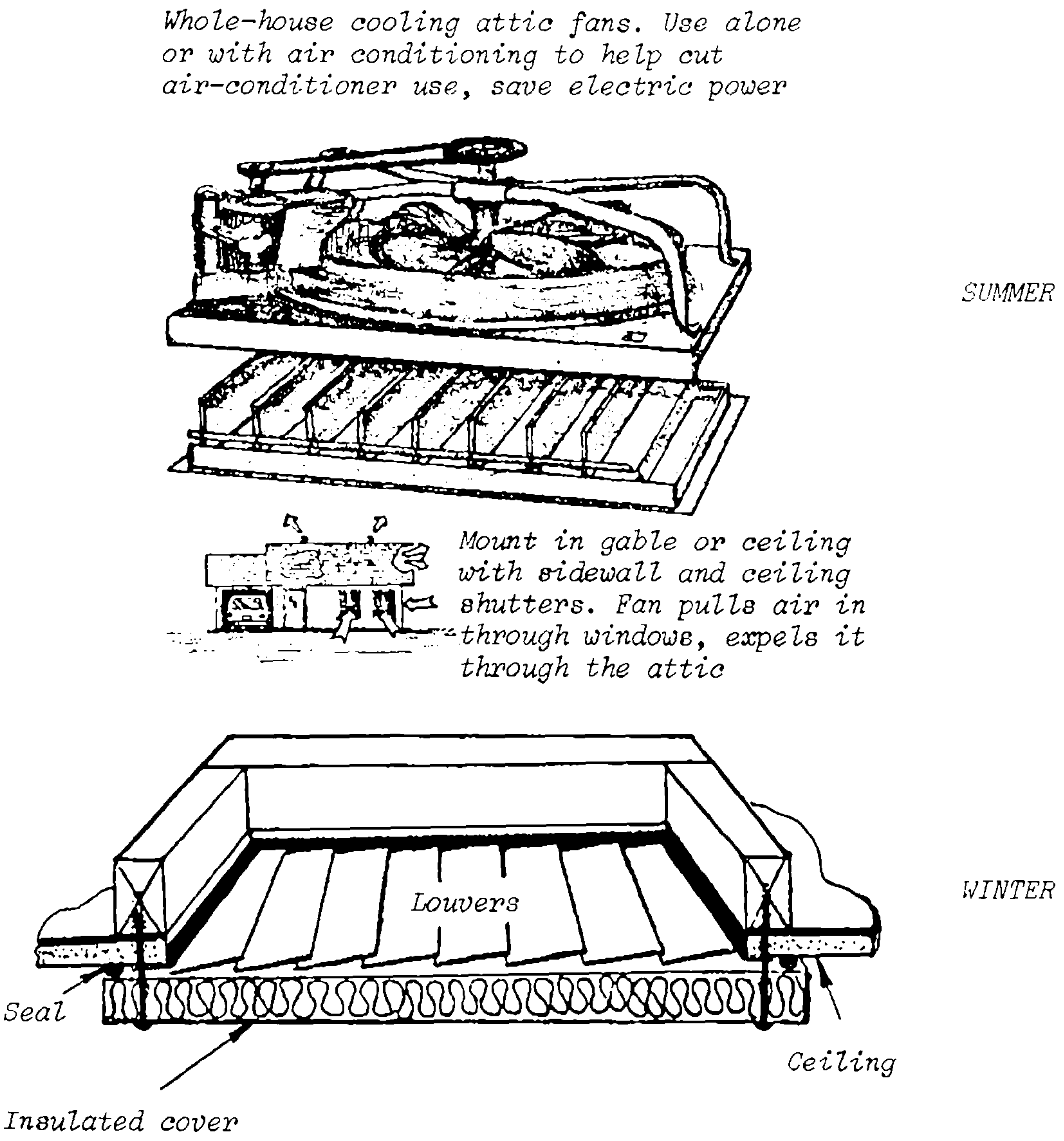


Figure BVI.18. Vents as a source of building envelope leakage.

sealing and insulation methods must be used. A minimum of 5 cm of high insulation value foam, encased so as to eliminate fire danger, can be screwed on as a cover for the louvers, while at the same time it provides the necessary seal as shown in Figure BVI.19.



Whole-house cooling attic fans. Use alone or with air conditioning to help cut air-conditioner use, save electric power

Mount in gable or ceiling with sidewall and ceiling shutters. Fan pulls air in through windows, expels it through the attic

Figure BVI.19. Use of a seasonal fixed seal system for ventilation fans.

LIGHTING

Lighting in the form of recessed fixtures has proven to be a very popular choice in recent years in th US. Unfortunately, unless the seal can be established at the interior surface using a glass cover with gasket, this design results in an uncontrolled leakage site. US electrical and fire codes prohibit any seal on the lamp housing because of heat buildup that can result in structural fires or electrical insulation degradation (and resulting electrical fires). An 8 cm zone around the housing must be kept free from insulation as well. This lighting choice must be avoided wherever possible if air leakage is to be controlled.

FOLDING STAIRS

Folding stairs are a very popular access route to the attic in the US. Attic access doors and covers represent a general problem site for air leakage (see Figure BVI.5). The folding stairs present even a greater energy problem in that the complexity of the stair system makes it difficult to seal and also makes it impossible to insulate beyond the barest minimum (3 cm). The best solution is to use an insulated cover with seals around the edges to limit the leakage and conduction losses as shown in Figure BVI.20

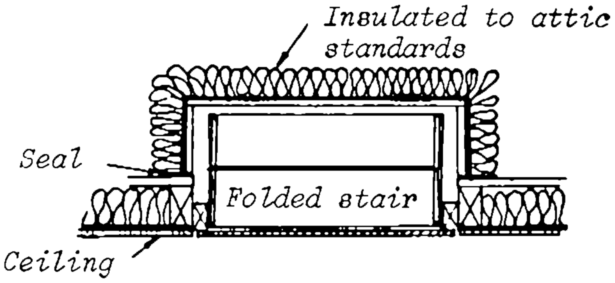


Figure BVI.20. An insulated cover with seals to minimize leakage over a folding stair system or over an attic stair well.

BVI.3.4 Conclusions

It is clear from the previous discussions that the achievement of a tight, low air infiltration rate house does not come about without a well integrated plan. Walls and ceilings constituting the building envelope must be designed to minimize air leakage, or at the very least, control it in a way to avoid problems. These problems include inadequate ventilation for the living space and moisture problems in the envelope itself. The components that penetrate the building envelope must be carefully analysed so that there is no danger of bypassing the construction design with local leakage sites. Properly conceived, executed, and inspected the tightly constructed home can offer not only low energy bills but high marks in living comfort.

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The Air Infiltration Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

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