
British Standard Code of practice for

Control of condensation in buildings

Contrôle de la condensation dans les bâtiments. Code de bonne pratique

Leitfaden für Schutz vor Schwitzwasserbildung in Gebäuden

Foreword

This British Standard code of practice has been published under the direction of the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee and supersedes BS 5250 : 1975, published as a code of basic data for the design of buildings. BS 5250 : 1975 is now withdrawn.

In buildings, condensation occurs when water vapour, usually produced by the occupants and their activities, condenses on exposed building surfaces (surface condensation) or within building elements (interstitial condensation). Condensation problems are widespread, affecting to some degree 3.5 million homes in the United Kingdom.

Condensation is not always harmful, however. In this code, condensation is divided into three types:

- (a) inconsequential condensation, such as that which can occur in a brickwork cavity wall outer leaf;
- (b) nuisance condensation, such as that on single glazed windows with properly designed drain facilities;
- (c) harmful condensation, which can lead to timber decay, for example.

Nevertheless because damage can occur to building fabric and contents and dampness and associated mould growth can be distressing to occupants, the control of condensation should be an important consideration in building design and construction.

The following features of buildings affect such control: heating, ventilation, building layout and properties of the materials within the various constructional elements. The occurrence of condensation is governed by an often complex interrelationship between these. The designer

should ensure that, under reasonable conditions of use, his choice of heating system, ventilation provision, building plan, and component materials will provide an environment where the risk of harmful or nuisance condensation is kept to a minimum. The builder should ensure that poor workmanship and supervision or misunderstanding of the designer's intentions do not result in constructions with risk of condensation.

It should be recognized that occupants by choice, lack of understanding or force of circumstance often do not use buildings in the manner intended or expected by the designer.

Recent increased awareness of the need for efficient use of energy in the design and management of buildings, as recommended in BS 8207, has led to greater insulation levels and reduced ventilation rates in both new and existing buildings. In turn, this has caused an increase in condensation problems. It is important to remember the complex interrelationship of factors affecting condensation and to take particular care when designing new buildings or considering changes or attempting to remedy problems in existing buildings.

This standard provides guidance for building designers, contractors, owners, managers and occupiers and includes recommendations for heating, ventilation and construction and which should control condensation in all but the most exceptional circumstances. Methods of calculation are also given to help assess and quantify risk.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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Section one. General

1 Scope

This British Standard code of practice describes the causes and effects of condensation in buildings and gives recommendations for their control.

The principles of control and the recommendations given can be applied generally to all buildings, both new and existing, but those with internal environments or ventilation systems differing markedly from typical domestic situations may need special consideration and are outside the scope of this standard.

Methods are given to determine the occurrence and assess the effects of:

- (a) surface condensation, or mould growth, one of its associated effects; and
- (b) interstitial condensation.

Guidance is given on assessing whether any such condensation may be considered harmful.

NOTE 1. A bibliography, containing some of the more important sources of information relevant to this topic is given in appendix F.

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard the definitions given in BS 3533 apply, together with the following:

2.1 condensate. Water formed by the process of condensation (qv).

2.2 condensation. Process whereby water is deposited from air containing water vapour when its temperature drops to or below dewpoint.

(a) **interstitial condensation.** Condensation occurring within or between the layers of the building envelope.

(b) **surface condensation.** Condensation occurring on visible surfaces within the building.

(c) **harmful condensation.** Interstitial or surface condensation which is likely to cause damage to the building fabric, degrade its thermal performance or support mould growth which could be detrimental to the health of the occupants.

(d) **inconsequential condensation.** Interstitial condensation that is not harmful.

(e) **nuisance condensation.** Surface condensation that is not harmful.

(f) **reverse condensation.** Interstitial condensation formed by water vapour travelling from outside to inside, i.e. the reverse to normal condensation.

2.3 dewpoint. Temperature at which air becomes saturated with water vapour.

2.4 draught strip. Strip of material fixed around openable doors, openable windows, etc., so as to reduce the movement of air through the joints between fixed and moveable frames.

2.5 hygroscopic material. Material capable of absorbing water vapour from air.

2.6 moisture content. Proportion of water contained within a material.

NOTE. Expressed as mass/mass, in percentage terms.

2.7 moisture content of air. Ratio of the mass of water vapour present in air to the unit mass of dry air.

NOTE. Expressed as kilograms per kilogram or grams per kilogram of dry air.

2.8 pattern staining. Discoloration on the internal surfaces of buildings caused by the preferential deposition of dust at relatively cool locations.

2.9 relative humidity (r.h.) (percentage of saturation).

Ratio, expressed as a percentage, of the vapour pressure in air at a given temperature to the saturation vapour pressure at the same temperature.

2.10 saturation vapour pressure. Water vapour pressure in air at dewpoint temperature.

2.11 sponge effect. Ability of the fabric of a building (and the building contents) to absorb and desorb water vapour.

2.12 thermal bridge (cold bridge). Part of a structure of lower thermal resistance which bridges adjacent parts of higher thermal resistance and which may result in localized cold surfaces on which condensation and/or pattern staining may occur.

2.13 vapour control layer. Material of construction (usually a membrane) that substantially reduces the water vapour transfer through any building component in which it is incorporated.

NOTE. The term 'vapour control layer' has been adopted throughout this standard in preference to the terms 'vapour check' and 'vapour barrier' which usually refer to materials alone. The performance of a vapour control layer is dependent upon the material, workmanship and buildability, all of which need to be assessed by the designer.

2.14 vapour diffusivity. Rate at which water vapour will diffuse through a unit thickness of material when a difference of unit water vapour pressure exists between the air on opposite sides of the material. Expressed as $\mu\text{g}\cdot\text{m}/\text{N}\cdot\text{s}$.

This is numerically equivalent to $\text{kg}\cdot\text{m}/\text{GN}\cdot\text{s}$ or $\text{g}\cdot\text{m}/\text{MN}\cdot\text{s}$.

2.15 vapour pressure. (Non-preferred: partial water vapour pressure.) That part of atmospheric pressure due to water vapour present in the air.

NOTE. Vapour pressure is expressed in kPa (1 kPa = 10 mbar = 1000 N/m²).

2.16 vapour resistance. Measure of the resistance to water vapour diffusion of a material or combination of materials of specific thickness.

NOTE 1. Vapour resistance is expressed as MN-s/g.

NOTE 2. For thin membranes, performance is stated as vapour resistance. For other materials, vapour resistance can be obtained by multiplying thickness by vapour resistivity.

2.17 vapour resistivity. Measure of resistance of a unit thickness of material to water vapour diffusion when a difference of unit water vapour pressure exists between the air on opposite sides of the material.

NOTE. Vapour resistivity is expressed as MN-s/g-m.

2.18 vented air space. Cavity or void that has openings to the outside air placed so as to allow some limited, but not necessarily through, movement of air.

2.19 ventilated air space. Cavity or void that has openings to the outside air placed so as to promote through movement of air.

2.20 ventilation rate. Rate at which air within a building is replaced by fresh air.

NOTE. The ventilation rate may be expressed as:

(a) number of times the volume of air within a space is changed in one hour (air changes per hour (ac/h));

(b) rate of air change in cubic metres per hour (m^3/h).

2.21 water vapour. Water in its invisible gaseous phase.

Section two. The nature of condensation

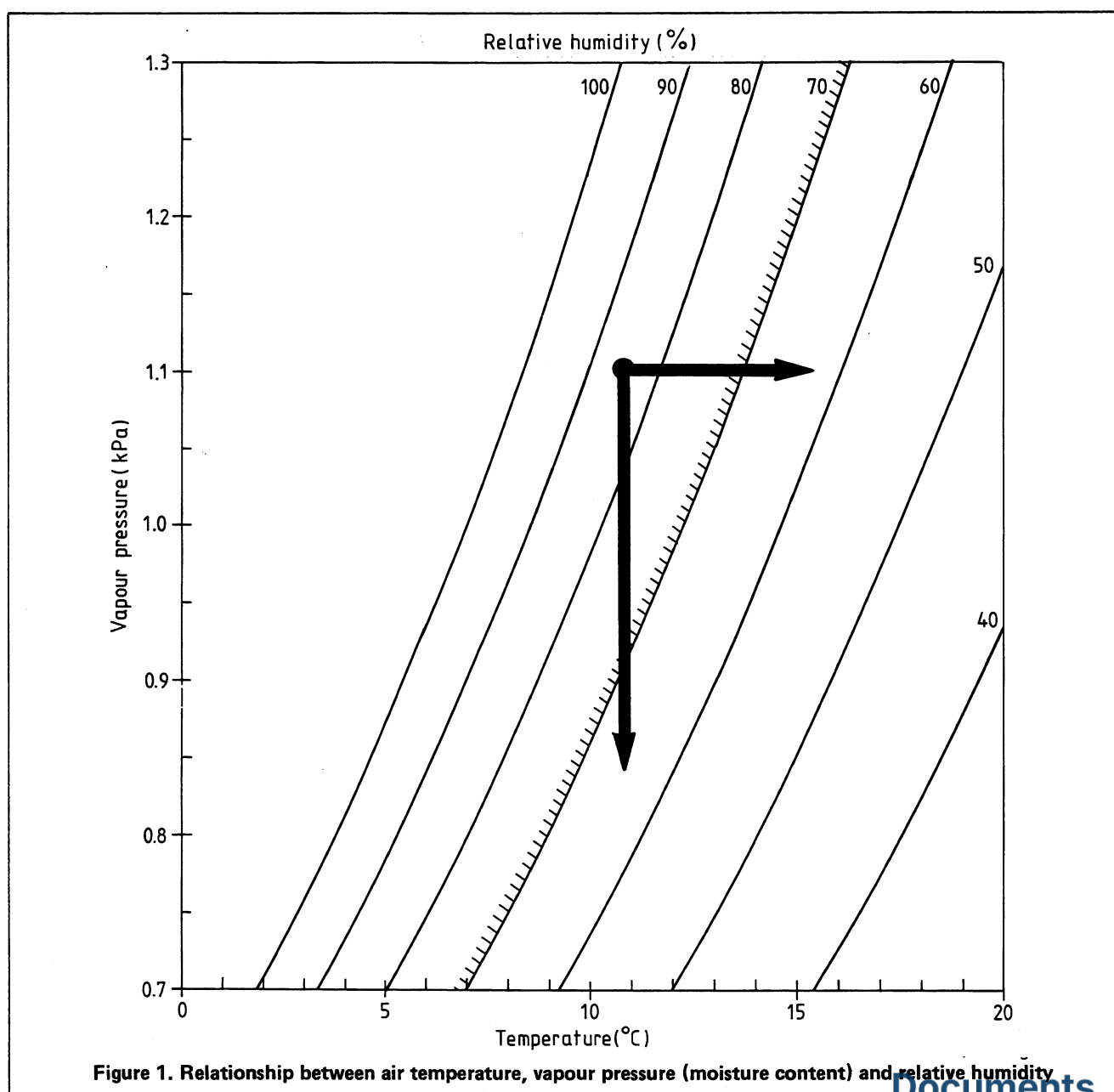
3 Behaviour of water vapour in air

At a given temperature air is capable of containing a limited amount of water as invisible vapour; the warmer the air the more water vapour it can contain. If moisture laden air comes into contact with a cold surface, either inside the building or an interface within the building fabric, condensation will occur at the temperature at which the air becomes saturated (dewpoint).

Water vapour in the air exerts a pressure, the vapour pressure, and so air containing a large mass of water vapour has a higher vapour pressure than drier air. This pressure will cause vapour to diffuse from high to low pressure areas. The term usually used to describe whether air is dry or water laden is relative humidity (r.h.).

Figure 1 shows the inter-relationship of these factors and is called a psychrometric chart. The vapour pressure is plotted on the vertical axis with the temperature on the horizontal axis. The curved lines show the percentage relative humidity resulting from the combination of temperature and vapour pressure. Percentage relative humidity is a good indicator of the risk of condensation, mould growth and degradation of absorbent materials. Where the air remains around or above 70 % r.h. for lengthy periods, there is a high risk of condensation and mould growth on some part of the external fabric. The arrows on the chart indicate that the risk can be reduced by increasing the temperature, by decreasing the vapour pressure or by a combination of these two factors.

NOTE. The inter-relationship of moisture content and temperature is given in greater detail in appendix A.



4 Causes of condensation

4.1 General

Two categories of condensation should be distinguished:

- (a) surface condensation; and
- (b) interstitial condensation.

The former occurs on visible surfaces within the building whilst the latter occurs within or between the layers of the building envelope.

Most materials will absorb water vapour from the environment: some, subjected to high humidity, can absorb moisture sufficiently to cause damage even though no actual condensation has taken place. In considering the risk of condensation, consideration should therefore also be given to the actual levels of humidity to which materials will be exposed.

Sources of water vapour will include atmospheric moisture, construction water, the occupants and their activities (see tables 1, 2 and 3).

4.2 Causes of surface condensation

Surface condensation will occur on surfaces which are at or below the dewpoint of the air immediately adjacent to them e.g. internal surface of external elements of a building and cold pipes and cisterns within a building.

The two parameters which control this effect are the temperature of the surface and the vapour pressure of the air.

The temperature of the surface will depend on the following factors:

- (a) the type(s), amount, time and rate of heating of the building;
- (b) the ventilation rate;
- (c) the thermal properties of the element and its surface finish;
- (d) the external temperature.

The vapour pressure of the air is determined by:

- (1) the water vapour production;
- (2) the ventilation rate;
- (3) the moisture content of the replacement 'fresh' air;
- (4) the ability of the building fabric and contents to absorb or desorb water vapour (sponge effect). This will reduce or increase the vapour pressure depending on whether the building is cooling or heating.

Anything which warms surfaces or reduces the vapour pressure of the air will reduce the effect of problems due to surface condensation.

4.3 Causes of interstitial condensation

4.3.1 General. The interior of buildings in winter will usually be warmer and the air contain more moisture than outside, so heat and water vapour will try to migrate out through the structure, both by air leakage and by diffusion.

For air leakage, rates of flow will depend on wind and stack pressures and on the dimensions of openings, joints and cracks. Unless these gaps are sealed, it has been found that the dominant internal/external transport mechanism of water vapour is by mass movement of air.

For diffusion, rates of flow will vary depending on the interior/exterior conditions and the thermal and vapour resistance properties of each part of the structure. This process alone is able to transport sufficient water vapour through the structure to cause interstitial condensation.

Interstitial condensation occurs within the fabric of a building when the temperature of some part of the structure equals the dewpoint. At this temperature the air is saturated; thus further vapour passing through the structure will condense rather than increase the vapour pressure.

Such condensation is more likely to occur on the surfaces of materials within a structure, particularly on the warm side of relatively vapour resistant layers, but it is possible to have condensation occurring within the material when the dewpoint and the structural temperatures coincide throughout the material.

It is possible to have interstitial condensation on more than one surface in a structure due to moisture evaporating from one surface and recondensing on a colder one.

4.3.2 Reverse condensation. The phenomenon of reverse condensation or summer condensation is most frequently observed when the sun shines on damp walls. It is caused by the moisture in the wall being vaporized by the heating effect of the sun; the resulting pressure difference drives the water vapour towards the inside of the building. If a vapour control layer is included in the construction, interstitial condensation may occur on the outside face where it may run down to affect vulnerable materials.

This is most likely to be observed in the thermal improvement of solid walls by the use of internal insulation systems. Although the severity of the problem is not known it is more common in thin masonry walls, walls of an absorbent nature or on walls which remain saturated because of their exposure. The moisture content of such walls and the consequent risk of reverse condensation may be reduced by a weatherproof treatment or system. Weatherproofing should be applied to the outer surface of the wall and should be of low vapour resistance or be vented.

Reverse condensation should not be confused with the problems of interstitial condensation that can occur in building elements where the environmental conditions on both sides of that element differ from those normally encountered (for example in cold stores where the temperature conditions on both sides of the element are the reverse of those normally encountered in buildings).

5 The effects of condensation and high humidity

5.1 General

Condensation can reveal itself in a number of ways, the most common being the presence of condensate, mould growth, decay of timber, and corrosion of metals.

5.2 Condensate

Condensation may be treated as nuisance condensation, provided that the condensate can be adequately dealt with by drainage or by mopping it up before it collects and runs to vulnerable parts. For example, such nuisance condensation often occurs on single glazed windows in bathrooms and kitchens.

5.3 Mould growth

Mould growth is often associated with surface condensation and damp houses can provide good conditions for its development*.

Mould spores exist in large numbers in the atmosphere and to germinate need a nutrient, oxygen, a suitable temperature and moisture. Sources of nutrition are widespread in buildings and the internal environment provides a suitable temperature for growth. As oxygen is also always present, mould growth is principally dependent upon the moisture conditions at surfaces and the length of time these conditions persist. Studies have shown that moulds do not necessarily require the presence of water. As a guide, if the average relative humidity within a room stays about 70 % for a long period of time the localized relative humidity at

external wall surfaces will be higher and is likely to support the germination and growth of moulds.

5.4 Dampness

Condensation or dampness can occur on or in furniture and furnishings if they are situated in unheated spaces or in parts of rooms sheltered from heating systems. Typical cases are unheated bedrooms, cupboards or wardrobes placed against external walls, and roof spaces.

Interstitial condensation can cause dampness of components in a structure, but this may be inconsequential. An example is condensation on the outer leaf of a masonry cavity wall, where the amount of condensate may be small compared to the effect of wetting by rain.

5.5 Degradation of materials

Sustained condensation may cause decay of timber or corrosion of metal coverings and/or components and so should be termed harmful. Hygroscopic materials should not be used in locations where a high relative humidity is maintained as they may degrade even though no condensate is deposited upon them. Persistent timber moisture contents in excess of 20 % (by mass) may lead to decay. Over a winter season, absorbent and hygroscopic materials are likely to accumulate moisture; during the summer this will tend to evaporate. The rate of this evaporation is difficult to calculate; but it should be borne in mind when assessing whether condensation is harmful.

In addition to mould growth and deterioration of fittings or components, condensation can cause dimensional changes, reduction of thermal resistance, migration of salts, liberation of chemicals or electrical failure.

*See MANT Report (in the list of publications referred to).

Section three. Design to control condensation

6 Design objectives

This section is primarily intended to give guidance on the design of new buildings but in many respects is equally applicable to complete refurbishment of older buildings, although some options are not then available. More information on upgrading or remedial work in existing buildings is given in section four.

Design for the control of condensation depends upon obtaining a satisfactory relationship between air conditions (internal and external air temperature and humidity) and the properties of external elements of construction (thermal and vapour resistance).

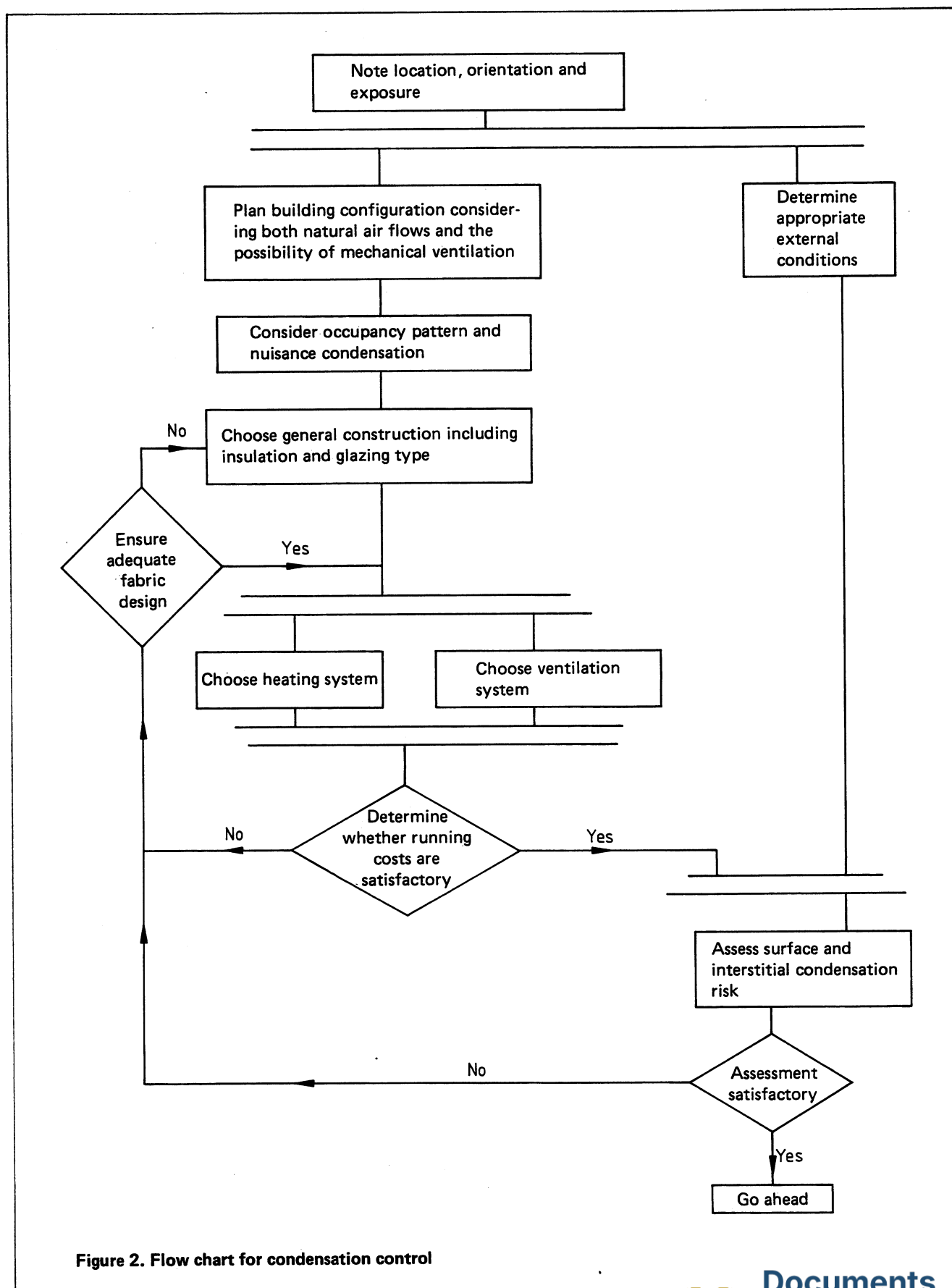
The objectives should be as follows:

- (a) prevention of harmful surface or interstitial condensation;
- (b) prevention of mould growth;
- (c) economical reduction of nuisance condensation.

7 Design procedure

Condensation control should be considered as part of the design process. Successful control will depend on factors such as prevailing winds, room layout, number of storeys and type of heating system as well as the more usually accepted aspects such as construction, heating, ventilation and moisture production. All these aspects therefore should be considered carefully and, as they are interdependent to a greater or lesser degree, they should also be considered together.

Various factors which should be taken into account are given in figure 2 with the consequent actions required for condensation control.



8 Design principles

8.1 General

8.1.1 General. The fundamental principle of designing to minimize condensation is to maintain a balance of the three factors shown in figure 3 in order to achieve either low vapour pressure and/or high structural temperature.

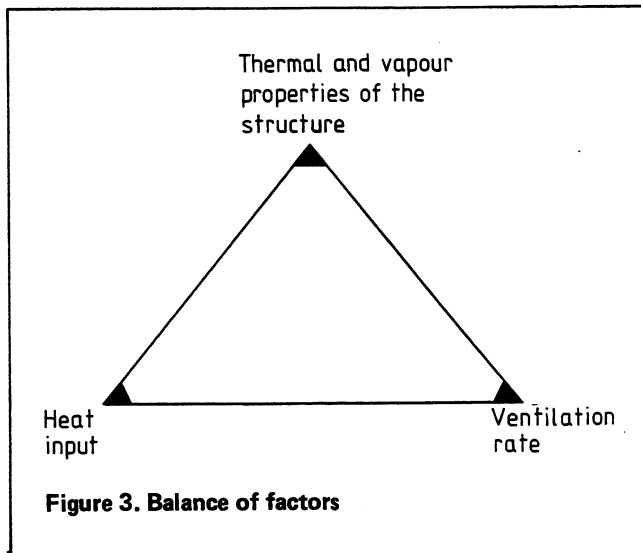


Figure 3. Balance of factors

8.1.2 Controlling surface condensation. To minimize surface condensation it is necessary to do one or more of the following:

- (a) obtain low vapour pressures by ventilating, or reducing moisture input in the building;
- (b) obtain high surface temperatures by providing more insulation and/or increasing the heat input.

8.1.3 Controlling interstitial condensation. To minimize interstitial condensation it is necessary to do one or more of the following:

- (a) obtain low vapour pressures by ventilating, or reducing moisture input in the building;
- (b) use materials of high vapour resistance near to the inner, warm side of the construction;
- (c) use materials of low vapour resistance, or provide ventilated cavities, near to the outer, colder side of the construction;
- (d) obtain higher internal temperatures by increasing the heat input and/or providing more insulation;
- (e) use materials of low thermal resistance near to the inner side of the construction;
- (f) use materials of high thermal resistance near to the outer side of the construction.

Note that any one particular procedure taken in isolation may not necessarily minimize the risk of condensation.

8.2 Occupant activity and heating and ventilating regime

In considering the effect of occupant requirements and activity on building plan and structure and on heating and ventilation requirements, designers should be aware that:

- (a) occupants and some domestic appliances generate moisture;
- (b) rising fuel costs can introduce a reluctance to provide adequate heating for buildings or alter the type and pattern of heating;
- (c) patterns of use of buildings have changed and can change e.g. there has been an increase in intermittent heating of dwellings due to alterations in working patterns.

8.3 Building configuration

In a heated building, air will rise and leak from the building via the roof space and through gaps and ventilators, carrying moisture with it; this is the so-called 'stack effect'. Replacement colder drier air will be pulled in at low level through gaps or ventilators.

Wind will tend to push fresh air in from one side of a building and stale air out of the other side. The balance of these two effects will be the natural infiltration movement: generally it is in at low level on the windward side and out at high level on the leeward side. At high level, windward and low level, leeward, the direction will be found to alter depending on the relative strengths of the two effects.

Such air movements are the main cause of moisture movement within buildings.

In addition, water vapour will tend to spread from areas of high vapour pressure to those of low vapour pressure (irrespective of the relative humidity and temperature), i.e. from areas of high moisture content to areas of low moisture content.

Thus in the absence of other constraints, moisture producing areas should be located with regard to these flows so that air and moisture tend to flow directly out of the building rather than spreading within it, especially to unheated areas.

If it is intended to use mechanical air movers in some form, the above is of less importance. Fans will almost certainly alter the direction of natural flows (but only of course whilst they are running).

8.4 Construction

There are many forms of construction available for walls, floors, glazing and roofs and often the choice will be made on grounds other than for condensation control, e.g. structural requirements or client preferences. However, the following principles should be considered.

It is important to match the thermal response of the internal layers with the proposed heating and activity regime. High mass elements will warm and cool slowly

(slow thermal response) and they are therefore more suitable for buildings which are heated for long periods. Low mass elements will warm and cool quickly (fast thermal response) and are particularly suitable for infrequent heating.

The more a part of the structure is insulated, the warmer will be the internal surface for the same room heat input and hence there will be less of a surface condensation risk. Conversely, layers to the outside of any extra insulation will be colder, and therefore more prone to interstitial condensation. If that condensation is judged to be harmful, then steps need to be taken to limit the amount of moisture reaching the colder elements by using vapour control layers or inner layers of relatively high vapour resistance or by having some ventilated airspace between the insulation and the outer elements.

Thermal bridging should be minimized and decisions made on how much nuisance condensation is to be tolerated, balanced by the cost of reducing it. For example, consideration should be given to nuisance condensation on cold water pipes, cisterns and to areas around window and door openings.

8.5 Heating and ventilation

8.5.1 Heating systems. Heating will normally be tailored to personal comfort in the building, taking the cost into consideration. However, in addition, for condensation control, it should match the combined effects of occupancy pattern, building mass and insulation, the period it is intended to heat the building, and any ventilation system, natural or induced. The principles are explained by reference to extreme conditions.

If the heating maintains comfort levels in the whole building at all times, condensation problems will be minimized, but costs will be high. If the heating is infrequent and only in one room, that room may suffer condensation because the structure will remain cold, and moisture resulting from the sponge effect will add to moisture being produced by the occupants; other rooms will also remain cold and moisture will migrate to them causing severe condensation problems. These infrequent heating effects will be exacerbated if the structure has a high thermal mass and if the heating is purely convective. A whole range of conditions exist between these extremes.

8.5.2 Ventilation. If stale air is extracted from each room and replaced by external air (and loss in temperature compensated for by heating), condensation risk is again minimized, but costs are high. At the other extreme, if minimal ventilation exists and the air movement is from the moisture-producing areas into the rest of the building, problems are likely.

The ideal ventilation system would extract air from the moisture producing areas to outside and replace it with fresh air flowing in via the other rooms. This would reduce the amount of moisture at source, prevent its spread and ventilate the whole building with fresh air.

Adequate ventilation for condensation control exceeds the minimum rate of fresh air change necessary for health and comfort and should normally be between 0.5 and 1.5 air changes per hour for the whole building (see table 4 in appendix B and BS 5925).

8.6 Heating and ventilating costs

Control of condensation is always carried out at some cost and having designed the building with its heating and ventilating system the construction and running costs can be determined. If these are not acceptable some alteration to the heating and ventilating system will be required, possibly in conjunction with improvements to the building fabric. Where achieving these acceptable running costs involves compromise, this may result in increased condensation risks.

NOTE 1. An assessment of heating costs can be obtained by reference to a suitable computer program such as BREDEM, or by reference to BS 8211 : Part 1 or the Department of Energy Notes 'Cutting Home Energy Costs' (see publications referred to).

NOTE 2. The designer should agree with the client the heating programme required to produce the minimum amount of heating necessary to minimize condensation. The building owners should then decide whether or not to retain sufficient control of the heating system to ensure that this heating is provided. Where this obligation is transferred to users, they should be provided with simple operating instructions. To avoid misunderstandings in landlord/tenant situations the obligations of each party should be defined in the leasing agreement.

8.7 Risk assessment

At this stage it is advisable to make full checks on the likelihood of surface and interstitial condensation and determine if these would be harmful. The calculation procedures are given in appendix C and appendix D. Saturation vapour pressures are given in table 5 and thermal and vapour properties are given in tables 6, 7 and 8 in appendix B. If the checks are considered satisfactory, then construction can proceed as far as condensation control is concerned; if not, it means that the design will have to be altered by following through the above procedure again. Vapour resistances and permeances of materials can be expressed in many varied and unusual units; conversion factors to change some of the more commonly occurring ones into the units used in this standard are given in appendix E and table 12.

9 Application of design principles

9.1 General

Basic principles for condensation control have been outlined in clause 8. The following clauses provide more detailed guidance on building according to those principles and are set out for ease of reference. It is essential that designers read the general information on the particular element before referring to the specific examples (e.g. read 9.3.1 before 9.3.2).

Different types of construction are described according to their structure and position of insulation, with sketches, notes and comments. Thermal bridging is similarly described. The figures shown in 9.3 to 9.6 are not working drawings but illustrate principles previously outlined, and are commented on in further detail. It is important to note that in illustrating these principles, thicknesses of materials may be exaggerated for emphasis, and other components such as damp proof courses and fixings are omitted for clarity. Although a range of popular forms of construction is shown these will vary and all eventualities have not been described.

Due to the diversity of materials and construction methods, slight variations may well be encountered. It is recommended therefore that the risk of interstitial condensation be assessed by using the calculation procedures in appendix D for a range of values in order to determine where it is likely to take place and whether it is harmful. It should then be possible to decide whether a vapour control layer is needed and/or if it is necessary to vent or ventilate any air space.

The ventilation openings referred to in the following clauses are effective free areas; particular attention should be paid to potential restrictions to air flows, including the effects of mesh.

Care should be taken to ensure that external air outlets from moisture producing appliances (e.g. balanced flue heaters) are placed away from ventilation air inlets.

Due to the complexities of air movement it is necessary to have a larger space between the layers of the building element even though at or near the entry or exit points the gap may be considerably less.

Where the desired thermal performance can only be achieved by the properties of 2 or more separate layers of a construction, careful attention should be paid to the balance of these insulants. For example, in an existing masonry cavity wall with a partial cavity fill, interstitial condensation is likely to occur at the outer leaf where it is inconsequential. If this wall were upgraded with an insulated dry lining, the interstitial condensation may move to the inner leaf where it could be harmful. This is the reason for sometimes providing a vapour control layer with insulated dry lining. Similarly, where an existing roof construction is satisfactory, the provision of an insulated suspended ceiling may cause a condensation problem unless the thermal balance and its effect on thermal response are considered.

Construction, use, heating and ventilation all interrelate and it is essential that they be considered as a whole.

9.2 Vapour control layers

The concept of a vapour barrier is misleading as in practice it is extremely difficult to construct an impervious layer. While a vapour control layer laid above a roof deck may be constructed to have a high resistance to water vapour flow, this is certainly not the case when the same material is fixed to the soffit. Therefore the performance of a vapour control layer depends upon the material selected, workmanship and buildability. Any holes for fixings,

pipes, electrical fittings, etc., will downgrade the performance of a vapour control layer and should be considered in the design.

Where a vapour control layer is specified it should be of appropriate vapour resistance and should be situated on the 'warm' side of the insulation. Alternatively the vapour control layer can be placed within the insulation where it should be maintained above the dewpoint but this is less reliable.

Joints in a flexible sheet vapour control layer should be kept to a minimum. Where joints occur, they should be either overlapped by a minimum of 100 mm or sealed with an appropriate sealant and should be made over a solid backing member or substrate. Similarly, tears and splits should be repaired using an overlay of the same material, jointed as above. If polyethylene sheet is used, it should be of virgin, not recycled, material, to reduce the risk of degradation occurring.

Where a vapour control layer is incorporated in or on a rigid board, joints between adjacent boards should be sealed with an appropriate sealant or covered or otherwise closed to avoid mass transfer of water vapour due to air leakage.

Holes and penetration for services through a vapour control layer should be kept to a minimum, but where they occur they should be cut neatly and sealed using an appropriate sealant. At abutments to or projections through roofs, the vapour control layer should be bonded or sealed to the structure to avoid water vapour penetrating to form condensation on the underside of flashings.

9.3 Walls

9.3.1 General. The designer should take account of five sources of dampness: the weather, ground moisture, surface condensation, interstitial condensation and construction water. Whilst the problems of dampness from the ground can be dealt with by the use of suitably placed damp proof courses, the selection and arrangement of materials to keep out the weather will have implications in dealing with the other three sources.

Design guidance on differing types of wall construction is given in 9.3.2 to 9.3.5. However the following factors should also be considered.

- (a) To minimize surface condensation it is essential to provide a construction such that the inner surface is maintained above the dewpoint temperature for the design conditions. Decisions need to be made therefore on the type, thickness and position of insulation required to achieve this, taking into account the relationship between mass and thermal response described in 8.4.

The relationship of the insulation to the main structure and detailed structure at openings or junctions of elements where structural components, often dense and with high thermal transmittance, meet, should be considered so that thermal bridging is minimized. Where thermal bridges cannot be avoided, it is recommended that a maximum U -value of $1.2 \text{ W/m}^2 \cdot \text{K}$ should be specified at such bridges.

(b) To minimize harmful interstitial condensation within a wall, designers should aim to specify materials of decreasing vapour resistance from inside to outside. As an approximation, materials on the warm side of any insulation should have a total vapour resistance of at least five times the sum of the vapour resistances on the cold side of the insulation.

This may not always be practicable; some external claddings, such as profiled metal sheeting, are not only weather resistant but are also highly resistant to the passage of water vapour. Other constructions such as plywood sheathed timber framed panels have intermediate layers with relatively high vapour resistance.

If condensation at these layers is considered harmful then:

- (1) a vapour control layer of adequate resistance should be located on the warm side of the insulation; possibly in conjunction with;
- (2) a vented or ventilated airspace provided to the immediate inside of any highly resistant cladding.

Service openings through a vapour control layer should be reduced to a minimum. Where these occur they should be taped and/or sealed.

Vented airspaces should have openings to the outside air of at least 500 mm² per metre length of wall, with a

minimum width of 10 mm (e.g. an open perpendicular every 1.5 m). Where cavities are not continuous but occur between studs, frames or cavity barriers, each individual cavity should have at least one vent. Care should be taken to prevent the ingress of large insects, small mammals or birds and avoid rainwater penetration.

Where external claddings require the use of a membrane to avoid rain penetration, or where the insulation is protected by such a membrane, this should be a breather type to BS 4016.

(c) During the drying out of the building, there will be a higher risk of surface condensation and interstitial condensation (including reverse condensation) than when the construction has dried out.

(d) Consideration should be given to the vulnerability of certain internal and external insulants or insulation systems to mechanical damage and fire performance.

(e) If the above recommendations are followed, the risk of decay to timber components should be minimized. Nevertheless, for practical reasons it may be advisable to increase the durability of critical timber components by preservative treatment. Timbers rated moderately durable or better* and which contain no sapwood do not normally require preservative treatment.

(See BS 5268 : Part 5.)

*See BRE, Digest 296 (see publications referred to).

9.3.2 Masonry cavity walls (see figure 4).

To minimize surface condensation the heating system should be matched to the construction.

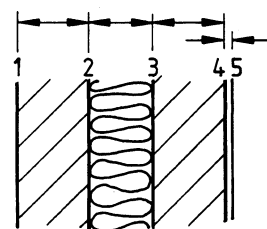
The thermal response is slow to medium and therefore regular heating is recommended.

Thermal bridges should be minimized, particularly around openings and junctions.

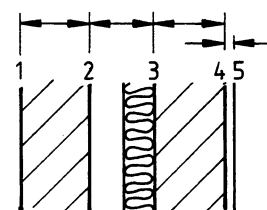
NOTE 1. Interstitial condensation is likely to occur on the inner surface of the outer leaf, but in general this will be inconsequential.

NOTE 2. Any cavity insulant increases the risk of rain penetration* which may be mistaken for condensation.

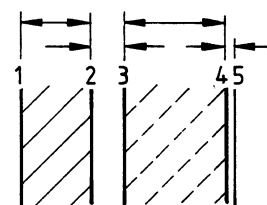
Damp proof courses should be carefully designed, and cavity trays should have stop ends. Detailed design should follow the recommendations of BS 5628 : Part 3.



(a) Full cavity fill



(b) Partial cavity fill



(c) Insulating masonry inner leaf

- 1 to 2 Masonry
- 2 to 3 Full cavity fill or airspace plus partial cavity fill or airspace
- 3 to 4 Masonry
- 4 to 5 Internal finish

Figure 4. Masonry cavity wall

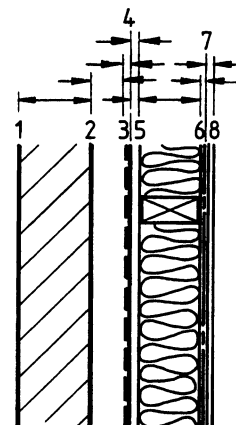
*See 'Cavity insulation of masonry walls — dampness risks and how to minimize them' (BBA, BRE, BEC and NHBC (England and Wales)) (see publications referred to).

9.3.3 Framed walls (see figures 5 and 6)

NOTE. Surface condensation is unlikely to occur because of the fast thermal response.

Regular heating is preferable but infrequent heating may be used with this construction.

Thermal bridges should be minimized, particularly at external wall/floor and external wall/roof junctions. Care should be taken to minimize thermal bridges associated with concrete or metal frames (see 9.6).



- 1 to 2 Masonry
- 2 to 3 Vented cavity
- 3 to 4 Breather membrane
- 4 to 5 Sheathing
- 5 to 6 Frame/insulation
- 6 to 7 Vapour control layer
- 7 to 8 Internal lining

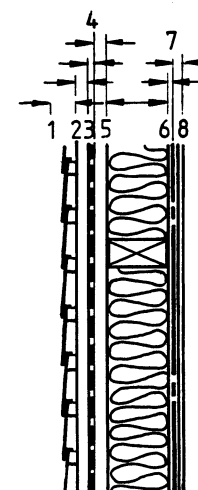
Figure 5. Framed wall

There is a risk of interstitial condensation occurring on the inner surface of the sheathing and in most cases this would be considered as harmful; therefore a vapour control layer is essential on the warm side of the insulation.

There is also a risk of interstitial condensation occurring on the inner surface of the cladding; because of this it is essential that the construction be vented, preferably by a cavity.

If the cladding is of high vapour resistance material, e.g. metal or plastic, a cavity is essential and it should be drained.

When the cladding also functions as the sheathing, it may be impractical to provide an airspace. In this situation, the cladding should have as low a vapour resistance as possible or have open joints at horizontal laps.



- 1 to 2 Vertical tiling on battens
- 2 to 3 Counter battens
- 3 to 4 Breather membrane
- 4 to 5 Sheathing
- 5 to 6 Frame/insulation
- 6 to 7 Vapour control layer
- 7 to 8 Internal lining

Figure 6. Framed wall with tile cladding

9.3.4 Solid walls: internal insulation

(see figure 7)

NOTE. Surface condensation is unlikely to occur because of the fast thermal response.

Regular heating is preferable but infrequent heating may be used with this construction.

Consideration should be given to minimizing thermal bridges at external wall/floor junctions and insulation and vapour control layer where provided should be returned into the reveals of any opening.

There is a risk of interstitial condensation occurring on the inner surface of the masonry which in some instances would be considered harmful. In these cases, a vapour control layer should be provided on the warm side of the insulation. However, the use of a vapour control layer may create a risk of reverse condensation on its outer surface. If this is considered harmful a vented airspace should be provided on the cold side of the insulation and/or a weatherproof surface finish to the wall (see also 4.3.2).

External weather protection of low vapour resistance should be applied to reduce rain-water penetration: this in turn reduces the risk of damage to parts of the construction and the risk of reverse condensation.

Any fixings or spacers should be durable: where timber battens are used, they should be preservative treated.

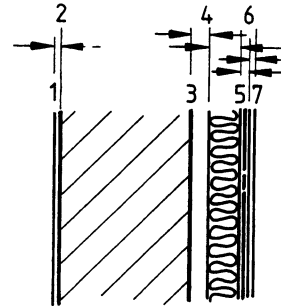
9.3.5 Solid walls: external insulation (see figure 8). To minimize surface condensation the heating system should be matched to the construction.

The thermal response is slow and therefore constant low-output heating is recommended.

To avoid thermal bridging the insulation should be returned into the reveals of any openings and particular attention paid to wall/roof and wall/floor junctions.

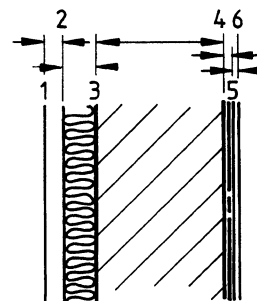
NOTE. Interstitial condensation is unlikely if the external insulation system (insulant and finish) is of low vapour resistance.

If the external insulation system contains materials of high vapour resistance interstitial condensation is likely to occur. If this is considered harmful a vapour control layer should be provided on the inside of the wall construction and/or a vented airspace on the immediate inside of the layer of high vapour resistance.



- 1 to 2 Weather protection (if required)
- 2 to 3 Masonry
- 3 to 4 Airspace (if required)
- 4 to 5 Insulation
- 5 to 6 Vapour control layer (if required)
- 6 to 7 Internal lining

Figure 7. Solid wall: internal insulation



- 1 to 2 External finish
- 2 to 3 Insulation
- 3 to 4 Masonry
- 4 to 5 Vapour control layer (if required)
- 5 to 6 Internal finish

Figure 8. Solid wall: external insulation

9.4 Roofs

9.4.1 General. Roofs are usually divided into two broad categories: pitched and flat.

However for the purposes of condensation control, roofs can be categorized as follows.

- (a) Roofs where there is a large readily ventilated space within the roof construction above the insulation and therefore a vapour control layer is not normally required; for example a typical domestic pitched roof (see 9.4.7.1).
- (b) Roofs where there is limited space above the insulation which may be difficult to ventilate adequately and therefore a vapour control layer would be necessary; for example a cold deck flat roof (see 9.4.8.1).
- (c) Roofs where there is no airspace above the insulation and therefore no possibility of ventilation. A material of high vapour resistance (typically 1000 MN-s/g) is essential to minimize moisture transfer to the cold side of the insulation. For example a warm deck flat roof (see 9.4.8.2).

The designer should take account of four sources of dampness: the weather, interstitial condensation, surface condensation and construction water in wet constructions. The selection and arrangement of materials to eliminate weather penetration will have implications in dealing with the other sources of dampness.

Design guidance on differing types of roof construction is given in 9.4.7 to 9.4.9, however the following should also be considered.

- (1) Moisture should be extracted at source to reduce the risk of water vapour transfer from occupied areas to the roof.
- (2) Water vapour penetration to the cold side of a roof construction should be minimized. The infiltration of moist air through a gap in a vapour control layer will often carry much more moisture into a region beyond than will diffusion through the material alone.
To reduce the amount of water vapour which can penetrate to 'cold' voids, constructional gaps and holes in ceilings should be kept to a minimum. Holes for service openings such as water pipes and light drops should be sealed carefully after the service has been installed.
- (3) Where vapour control layers are provided, it is essential that they are adequately lapped and sealed, and their integrity maintained.
- (4) To achieve adequate cross ventilation, ventilation openings should where possible be placed on the longer sides of a typical rectangular roof.
- (5) If ventilation openings are sited at intervals, they should be of equivalent area to the continuous openings recommended, and avoid stagnant air pockets due to inadequate through-flows. Opening sizes are minimum provisions; with certain constructions there are advantages in increasing these in order to ensure air movement through the roof void.

(6) Designers should ensure that ventilation openings cannot be blocked by dust, airborne debris, paint or frost, and that the ingress of rain, snow, birds and large insects is prevented. A nominal mesh size of 4 mm is recommended, which would achieve this and avoid excessive airflow resistance. Consideration should be given to the use of proprietary ventilators where these will avoid problems, or be more practicable in use. The ventilation openings should provide a continuous weatherproof path from the roof void to the outside without impairing the weatherproof function of the structure, e.g. the roof underlay, vapour control layers or the roof covering.

(7) The minimum free airspaces defined should be maintained throughout and particular attention should be paid to potential restrictions at changes in roof slope, changes in constructional details and at junctions with walls.

(8) Where the roof construction includes wet processes, or where wetting occurs from rain during construction, it should be ensured that moisture is not trapped between the waterproof roof covering and a vapour control layer positioned at a lower level. If necessary, provision should be made for venting any trapped water vapour.

9.4.2 Pitched roofs. Pitched roofs are those where the weatherproof finish is sloped at a pitch greater than 10°.

Design guidance appropriate to particular roof constructions is given in 9.4.7. However the following factors should also be considered.

- (a) To reduce the amount of water vapour which can penetrate into cold voids, loft access points should not be located in, or adjacent to, moisture generating areas. Access doors should either be heavy or clamped, with a compressible seal between them and the frame.
- (b) Where ventilation at high level (e.g. at or near the ridge) is recommended, this is in addition to any low level requirement. High level ventilation should never be used on its own as the suction effect created will increase water vapour transfer into the roof void.
- (c) The use of smooth impermeable materials as under-tiling membranes can cause problems due to run-off of condensate. Ventilation of the roof void alone may not prevent this problem and materials which are permeable to water vapour are preferred. There is benefit in using materials which are absorbent since they can absorb any condensate which may be deposited and re-evaporate it when conditions are more favourable.

9.4.3 Flat roofs

NOTE. Flat roofs are those where the weatherproof finish is sloped at a pitch at 10° or less. They can be subdivided into two types (see 9.4.3.1 and 9.4.3.2).

9.4.3.1 Cold deck. Cold deck roofs have the insulation located below the roof deck, usually at ceiling level. It is essential that both a vapour control layer such as polyethylene and adequate ventilation of roof voids to disperse water vapour are provided. Specific recommendations on the overall size and location of ventilation openings is given in 9.4.8.1 and 9.4.9.1.

9.4.3.2 Warm deck. Warm deck roofs have insulation located above the roof decking. This type of roof relies on a high resistance vapour control layer.

The inverted roof, also known as the protected membrane or upside down roof, is a type of warm roof construction in which the insulation is above the weatherproof finish.

The weatherproof finish also functions as a vapour control layer. Design guidance appropriate to particular roof constructions is given in 9.4.8.2, 9.4.8.3, 9.4.9.2 and 9.4.9.3.

9.4.4 Lightweight sheeted roofs. Lightweight sheeted roofs can be subjected to particularly low temperatures in winter. The lowest temperatures to which sheeted roofs can fall occur on clear nights when radiation heat loss takes place to the cold night sky. This can result in the temperature of the sheeting (and the inner surface temperature) falling considerably below air temperature. In these circumstances it is possible that if the underside of the sheeting is ventilated with outside air, condensation will occur without there being a source of moisture within the roof void. This phenomenon is most frequently seen on lightweight roofs of garages or factories.

If this condensation is regarded as being harmful, or an unacceptable nuisance, then the construction should be changed.

9.4.5 Copper, lead and similar roofs. Copper, lead and other metal roof finishes require provision for expansion and contraction of the sheet material; this is usually provided by some form of rolled and lapped joints. In existing warm deck flat roof designs this has given rise to problems; the temperature within the roof void can be lowered during a rain shower resulting in a drop in pressure which can cause rainwater to enter the roof at the joints. This in turn can result in corrosion of the finishing.

In this type of roof, it is suggested that a ventilated air space be provided on the cold side of the insulation, primarily to reduce this effect, in addition to a high performance vapour control layer near the inner surface.

9.4.6 Suspended ceilings under roofs. The provision of a suspended ceiling will tend to lower the plane of condensation and if the ceiling is insulated or has insulating properties, it is helpful to check condensation risk by the calculation procedure described in appendix D. It is essential that the insulation above the vapour control layer is balanced with the insulation below to ensure that the plane of condensation does not occur at or under the vapour control layer.

Where a suspended ceiling is provided under a deck which needs to dry out (such as in situ concrete) the ceiling should be of low vapour resistance and capable of withstanding large moisture fluctuations without damage.

Alternatively, the void space above the suspended ceiling should be ventilated to the outside to remove moisture vapour. A vapour control layer at ceiling level should never be used with a 'wet' construction where ceilings may have to withstand large moisture fluctuations for several years.

Where the suspended ceiling is below a roof deck of lightweight construction, it is essential to minimize the amount of water vapour penetrating to the underside of the decking. The decking may be susceptible to localized surface temperature variations at weaknesses in the insulation layer, such as at eaves, gutters and rainwater outlets. These surface temperature changes may be sudden, for example as a result of a shower of rain, or more prolonged due to radiation to the clear night sky. If water vapour is present, these conditions can lead to heavy deposits of condensate which may 'rain' on to the suspended ceiling.

9.4.7 Pitched roofs (see figures 9, 10 and 11)

9.4.7.1 Tiled or slated: ceiling horizontal, insulation horizontal. Surface condensation is unlikely to occur due to the fast thermal response, provided that there is adequate insulation which should be continuous over the whole ceiling including the access trap.

Thermal bridging should be minimized particularly at the external wall/ceiling junction.

NOTE. Interstitial condensation is unlikely to occur where moisture entering the roof space is minimized and there is adequate ventilation.

Gaps in the ceiling should be minimized and service openings should be sealed.

Ventilation openings should normally be provided at low level on two opposite sides of the building, usually at the eaves.

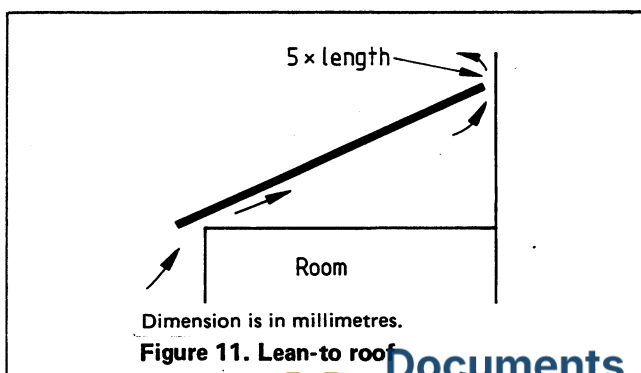
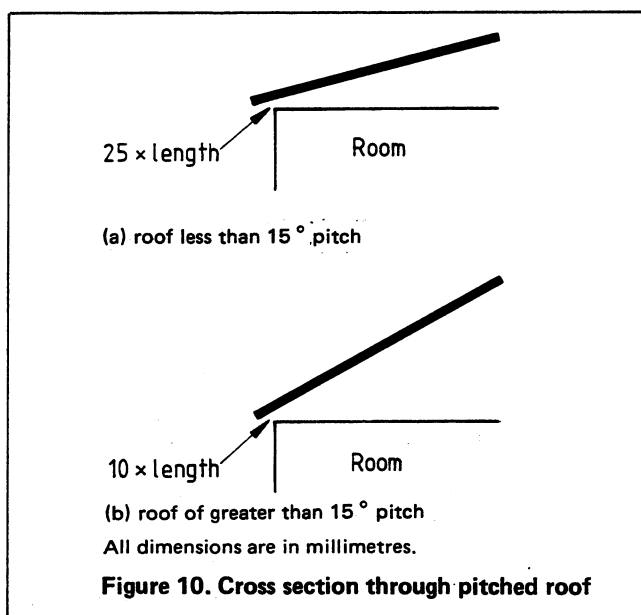
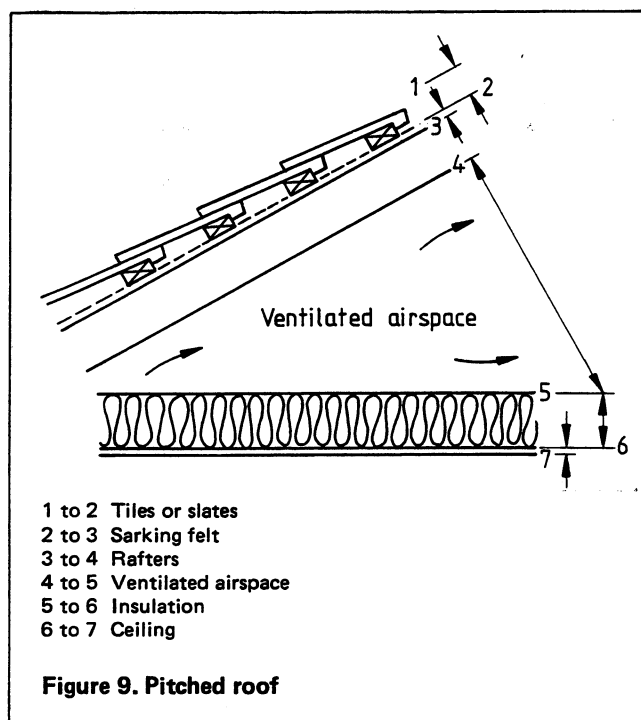
Ventilation openings should be equivalent in area to a continuous opening of not less than:

- (a) for pitches of 15° or less, 25 mm x length at eaves;
- (b) for pitches of greater than 15° , 10 mm x length at eaves.

Increased ventilation may be provided by high level openings equivalent in area to a continuous opening of 5 mm. At pitches of 35° and over or spans in excess of 10 m this is particularly recommended.

Lean-to and mono-pitch roofs, not having two opposite eaves, should be provided with ventilation openings at high level equivalent in area to a continuous opening of 5 mm. This is in addition to the low level provision.

Where the eaves ventilation airway is provided between the insulation and the sarking, they should be separated from one another by at least 25 mm, irrespective of eaves opening size.



9.4.7.2 Tiled or slated: ceiling inclined, insulation inclined (see figures 12, 13 and 14). Surface condensation is unlikely to occur due to the fast thermal response, provided that there is adequate insulation and it is continuous over the whole ceiling.

Thermal bridging should be minimized particularly at the external wall/ceiling junction and around roof windows.

Interstitial condensation is likely to be a problem unless moisture entering the roof is minimized and there is adequate ventilation. If it does occur it will normally be on the underside of the sarking felt.

The vapour control layer should be a minimum of 500 gauge polyethylene with sealed gaps (or equivalent).

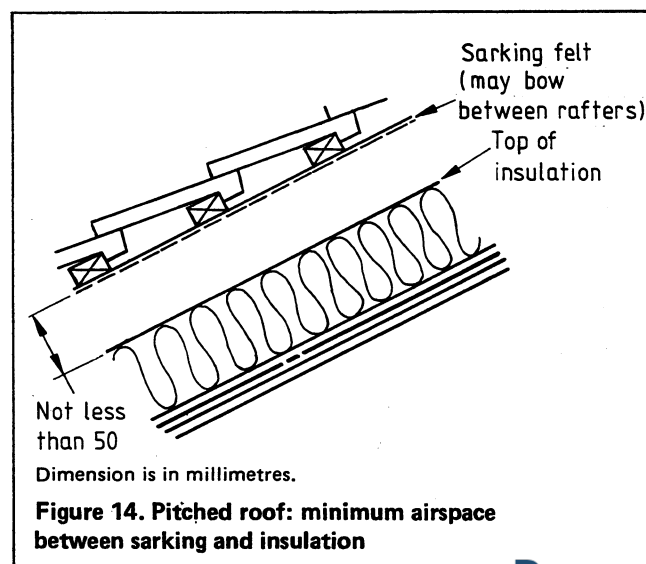
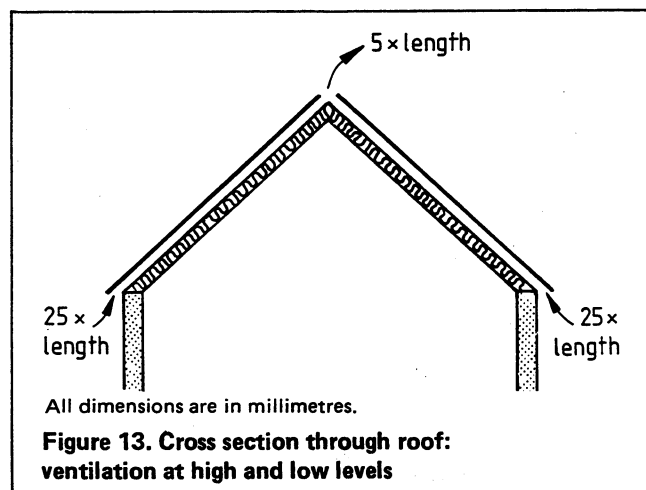
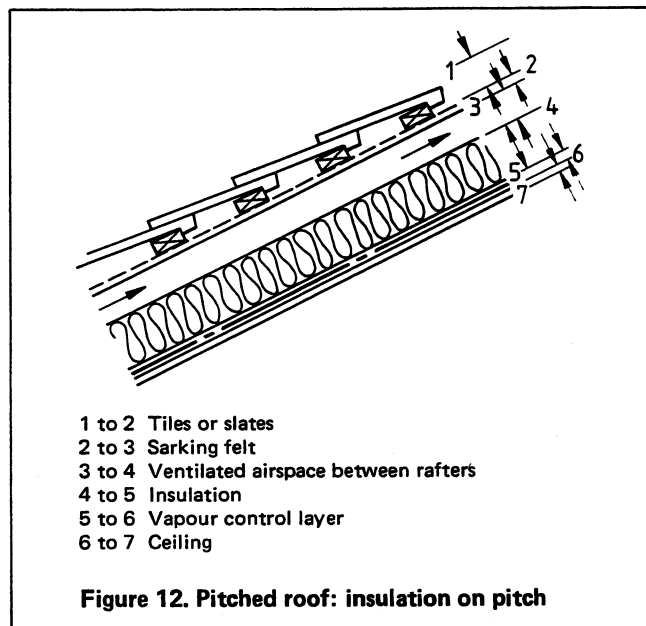
Gaps in the ceiling should be minimized and service openings should be sealed.

Ventilation openings should be provided at each and every roof void at both low and high level. At low level, these openings either side of the roof should be equivalent in area to a continuous opening of not less than 25 mm x length at eaves. At the ridge, the openings should be equivalent in area to a continuous opening of 5 mm. At high level close to the ridge 5 mm openings should be provided on each side.

A 50 mm airspace should be maintained between the underside of the sarking and the top of the insulation. Close to the eaves this may be difficult to achieve.

Sufficient thermal insulation should be provided to maintain the vapour control layer above dewpoint. Provision should be made to ensure that the insulation does not 'slump' after positioning.

Timbers not rated moderately durable or better should be preservative treated.



9.4.7.3 Tiled or slated: ceiling inclined, insulation inclined and of high vapour resistance (see figure 15). This construction relies on insulation of high vapour resistance with sealed joints possibly in conjunction with a vapour control layer.

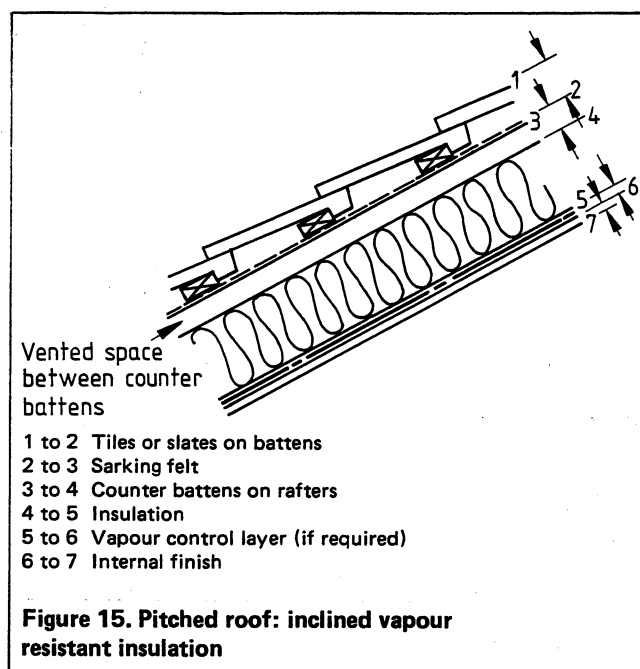
Surface condensation is unlikely to occur due to the fast thermal response provided that there is adequate insulation which should be continuous over the whole ceiling.

Thermal bridging should be minimized particularly at the external wall/ceiling junction and around roof windows.

Interstitial condensation may occur on the underside of the sarking felt. If this is considered harmful it is recommended that a vented airspace be provided under the sarking.

It is likely that the insulation may be subjected to periods of moist conditions; materials should be chosen accordingly.

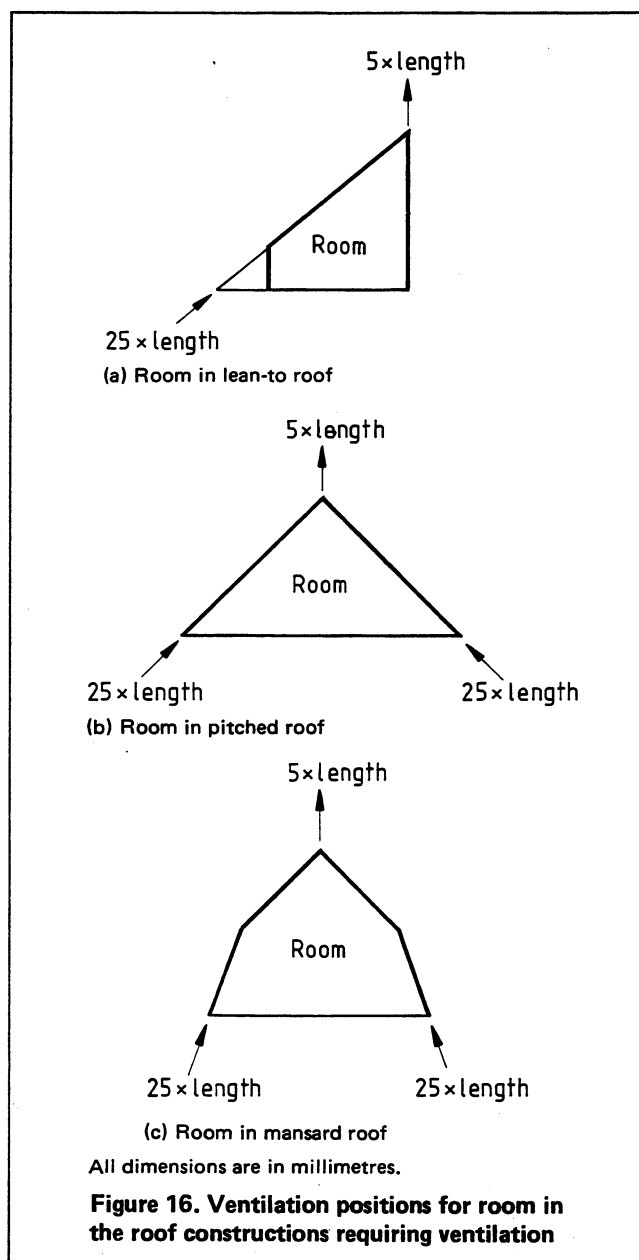
Timbers not rated moderately durable or better should be preservative treated.



9.4.7.4 Pitched roofs containing rooms: fully inclined ceilings (see figure 16). Roof constructions should comply with the recommendations given either in 9.4.7.2 or 9.4.7.3, whichever is applicable.

Where the roof construction is of the type described in 9.4.7.2, ventilation should be provided at the positions shown in figures 16(a), (b) and (c). If an obstruction in the ventilation paths occurs, such as at roof lights or at changes in pitch, the roof void should have additional ventilation openings:

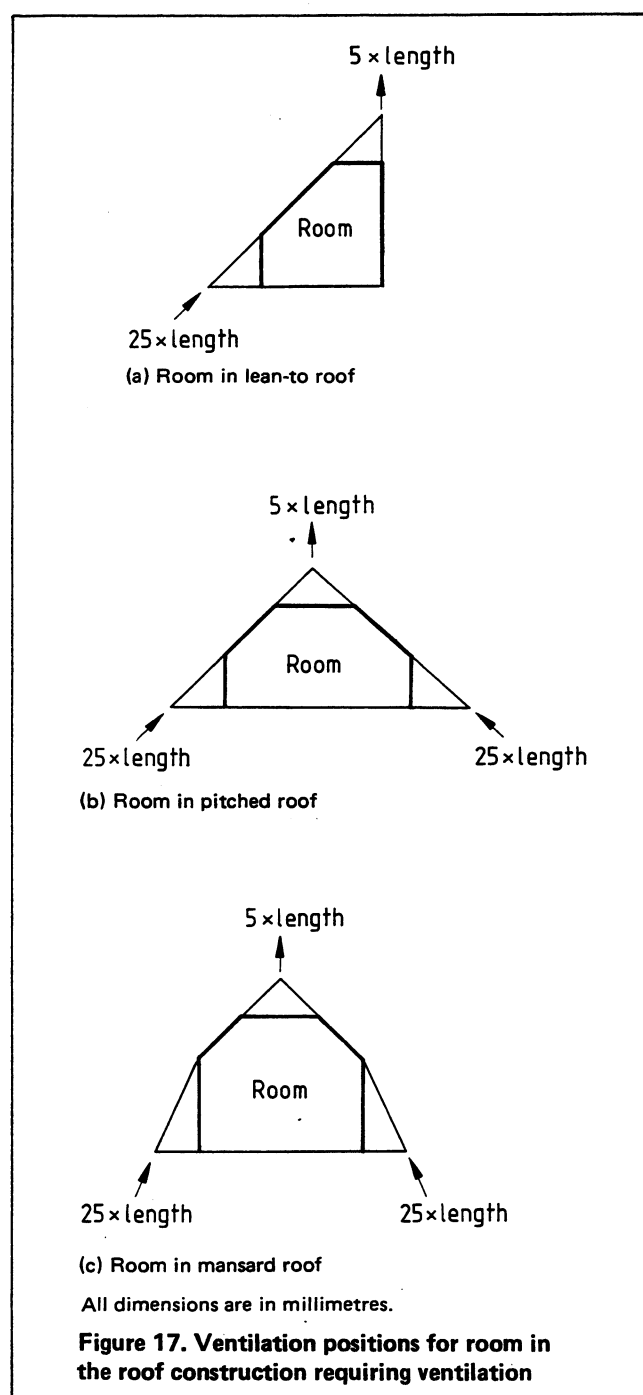
- (a) immediately *below* the obstruction equivalent to $5 \text{ mm} \times \text{length of obstruction}$; and
- (b) immediately *above* the obstruction equivalent to $25 \text{ mm} \times \text{length of obstruction}$.



9.4.7.5 Pitched roofs containing room: partially inclined ceilings (see figure 17). Roof constructions should comply with the recommendations given either in 9.4.7.2 or 9.4.7.3, whichever is applicable.

Where the roof construction is of the type described in 9.4.7.2 ventilation should be provided at the positions shown in figures 17(a), (b) and (c). If an obstruction in the ventilation paths occurs such as at roof lights or at changes in pitch, the roof void should have additional ventilation openings:

- (a) immediately *below* the obstruction equivalent to $5 \text{ mm} \times \text{length of obstruction}$; and
- (b) immediately *above* the obstruction equivalent to $10 \text{ mm} \times \text{length of obstruction}$.



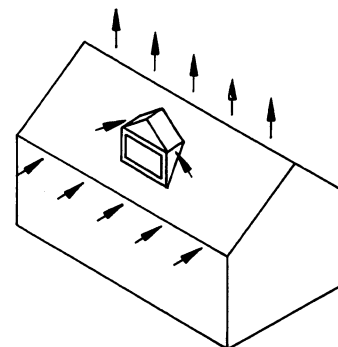
9.4.7.6 Pitched roofs containing rooms: dormers (see figure 18). Roof constructions should comply with the recommendations given either in 9.4.7.2 or 9.4.7.3, whichever is applicable.

Where the roof construction is of the type described in 9.4.7.2, ventilation should be provided at the positions shown in figure 18(a), (b) and (c). The following additional provisions are also recommended.

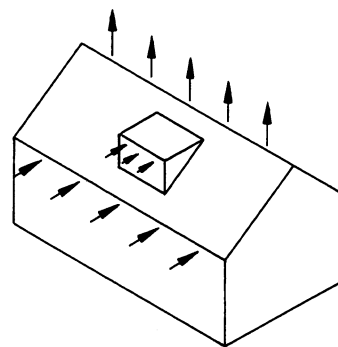
(a) The dormer roof should be ventilated from eaves to eaves if it is a pitched type or from eaves to ridge of main roof if it is a flat type. Ventilation openings should be as recommended in 9.4.7.2.

(b) Where dormers are long and/or abut gable or separating walls, the eaves 'triangle' below the dormer should have ventilation outlets immediately below dormer sill level, equivalent in area to $5 \text{ mm} \times \text{length of dormer}$. Ventilation openings should be located so as to avoid static air.

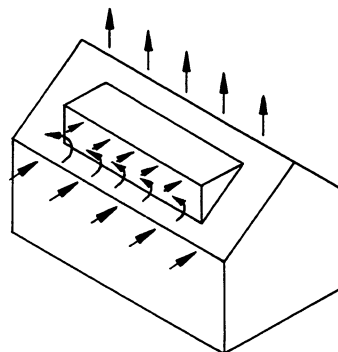
In conversions where the main roof is as shown in 9.4.7.1 and the dormer roof is of a flat warm roof type, the dormer eaves will not be suitable as a ventilation inlet. In this situation the ridge 'triangle' should be ventilated through openings in the roof slope located just above the dormer.



(a) Pitched roof dormer



(b) Flat roofed dormer



(c) Long or abutting dormer

Figure 18. Ventilation positions for roofs with dormers