

Code of practice for control of condensation in buildings

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Committees responsible for this British Standard

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- Association of Building Component Manufacturers
- Association of Manufacturers of Domestic Appliances
- Autoclaved Aerated Concrete Products Association
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- ODPM — Represented by BRE
- Chartered Institution of Building Services
- Concrete Block Association
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- Electricity Association
- EURISOL
- Flat Glass Manufacturers' Association
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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 5250:1989, published as a code of practice for the design of buildings. BS 5250:1989 is now withdrawn.

The start and finish of text introduced or altered by Amendment No. 1 is indicated in the text by tags **[A1]** **[A1]**.

In buildings, condensation can occur when water vapour, usually produced by the occupants and their activities, condenses on exposed building surfaces (surface condensation) where it supports mould growth, or within building elements (interstitial condensation). Condensation and mould problems are widespread, affecting about 15 % of homes in the United Kingdom to some degree.

Condensation is not always a problem; for example, it regularly occurs on the inner surface of the outer leaf of a cavity wall, which receives very much more water from driving rain. Nevertheless, damage can occur to the building fabric and contents, and the dampness and associated mould growth can be distressing to occupants and a major cause of respiratory allergies. The control of condensation is therefore an important consideration in building design and construction.

The occurrence of condensation is governed by complex interrelationships between heating, ventilation, moisture production, building layout and properties of the materials making up the fabric of the building. Under reasonable conditions of use, the designer's choice of heating system, ventilation provision, building plan and component materials will provide an environment where the risk of condensation is kept to a minimum. Good workmanship and supervision and the builder's understanding of the designer's intentions will result in constructions free from the risk of condensation. It should be recognized that occupants by choice, lack of understanding or force of circumstances often do not use buildings in the manner intended or expected by the designer.

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 in both new and existing buildings. In turn, this has caused an increase in condensation problems. The complex interrelationships between the factors which affect condensation means that particular care is needed when designing new buildings or considering changes or attempting to remedy problems in existing buildings.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iii, a blank page, pages 1 to 82, an inside back cover and a back cover.

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1 Scope

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

The principles of control and the recommendations given can be applied generally to both new and existing buildings. Some constructions, e.g. curtain walling or those around cold stores and those buildings with unusually high internal humidities, such as swimming pools or buildings with wet industrial processes, are outside the scope of this standard and need specialized treatment.

This standard provides guidance for building designers, contractors, owners, managers and occupiers and includes recommendations for heating, ventilation and construction which can control condensation. Methods of calculation are also given to help assess and quantify risk.

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.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 3533, *Glossary of thermal insulation terms*.

[A1] BS 5534:2003, *Code of practice for slating and tiling (including shingles)*. **[A1]**

BS 8215, *Code of practice for design and installation of damp-proof courses in masonry construction*.

BS EN ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*.

BS EN ISO 10211-1, *Thermal bridges in building construction — Heat flows and surface temperatures — General calculation methods*.

BS EN ISO 13788, *Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods*.

NFRC Technical Bulletin Number 6: *Pitched roof underlays*. London: NFRC Publications.

3 Terms and definitions

For the purposes of this British Standard the terms and definitions given in BS 3533 and the following apply.

3.1

airtight layer

layer that prevents the convective movement of air under the normal pressure differences found in buildings and which may also act as a vapour control layer

NOTE Such a layer is sometimes referred to as “convection tight”.

3.2

****[A1]** breather membrane**

membrane with a vapour resistance of less than or equal to $0.6 \text{ MN} \cdot \text{s/g}$

3.3

high water vapour resistance (type HR) underlay

underlay which has a vapour resistance greater than $0.25 \text{ MN} \cdot \text{s/g}$ **[A1]**

A1 3.4

low water vapour resistance (type LR) underlay

underlay which has a water vapour resistance less than or equal to $0.25 \text{ MN}\cdot\text{s/g}$

NOTE 1 This definition is consistent with BS 5534:2003.

NOTE 2 Type LR underlays are sometimes referred to as “vapour-permeable”, or “vapour-open” underlays.

NOTE 3 Some LR underlays may also possess a degree of air permeability, see 8.4.2.1.3.

3.5

condensate

water formed by the process of condensation (3.6)

3.6

condensation

process whereby water is deposited from air containing water vapour when its temperature drops to or below dewpoint (3.14), or the vapour pressure rises above the saturated vapour pressure at a given temperature

3.7

interstitial condensation

condensation (3.6) occurring within or between the layers of the building envelope

3.8

surface condensation

condensation (3.6) occurring on visible surfaces within the building

3.9

harmful condensation

interstitial condensation (3.7) or surface condensation (3.8) that is likely to cause damage to the building fabric, degrade its thermal performance or support mould growth

3.10

inconsequential condensation

condensation (3.6) that is not harmful

3.11

nuisance condensation

surface condensation (3.8) that is not harmful

3.12

reverse condensation

interstitial condensation (3.7) formed by water vapour travelling from outside to inside, i.e. the reverse to normal condensation

3.13

cooler side

side of a structure with a lower temperature compared to the warmer side (3.37)

NOTE The cooler side usually has a lower vapour pressure compared to the warmer side.

3.14

dewpoint

temperature at which air becomes saturated with water vapour

3.15

evaporation

process whereby liquid water becomes a vapour when in contact with unsaturated air

3.16

hygroscopic material

material capable of absorbing water vapour from air **A1**

[A₁] 3.17**moisture content by weight**

mass of water contained within a kilogram of dry material

3.18**moisture content of air**

mass of water vapour present in unit mass of dry air

NOTE This is expressed as kilograms per kilogram or as grams per kilogram of dry air.

3.19**night sky radiation**

loss of heat from the outside surface of a building to a clear night sky, which lowers the outside surface temperature below the external air temperature

3.20**passive stack ventilation****PSV**

ventilation system using ducts from the ceiling or walls of rooms to terminals on the roof which operate by a combination of the natural stack effect, i.e. the movement of air due to the difference in temperature between inside and outside and the effect of wind passing over the terminal

3.21**pattern staining**

discolouration on the internal surfaces of buildings caused by preferential deposition of dust at relatively warm locations

3.22**relative humidity**

ratio of the vapour pressure in air at a given temperature to the saturation vapour pressure at the same temperature; commonly expressed as a percentage

3.23**sarking boards**

sawn softwood boards, typically 150 mm wide, laid across the rafters, with a 2 mm gap between

3.24**saturation vapour pressure**

water vapour pressure in air at dewpoint temperature

3.25**sheet sarking**

continuous sheets of OSB, plywood, chipboard or similar material laid over the rafters below tiles or slates

3.26**sponge effect**

ability of the fabric of a building and the building contents to absorb and desorb water vapour

3.27**thermal bridge****cold bridge**

part of a structure of lower thermal resistance which bridges adjacent parts of higher thermal resistance and which can result in localized cold surfaces on which condensation, mould growth and/or pattern staining can occur **[A₁]**

3.28

vapour control layer

material of construction that substantially reduces the water vapour transfer through any building component in which it is incorporated by limiting both vapour diffusion and air movement

NOTE 1 It is usually a membrane.

NOTE 2 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.

3.29

vapour diffusivity

rate at which water vapour will diffuse through a unit of thickness of material when a difference of unit water vapour pressure exists on opposite sides of the material

NOTE Vapour diffusivity is expressed as $\mu\text{g}\cdot\text{m}/\text{N}\cdot\text{s}$, which is numerically equivalent to $\text{g}\cdot\text{m}/\text{MN}\cdot\text{s}$.

3.30

vapour pressure

part of atmospheric pressure due to water vapour present in the air

NOTE Vapour pressure is expressed in kPa ($1\text{ kPa} = 10\text{ mbar} = 1\,000\text{ N}/\text{m}^2$).

3.31

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 in $\text{MN}\cdot\text{s}/\text{g}$.

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

3.32

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 the opposite sides of the material

NOTE Vapour resistivity is expressed as $\text{MN}\cdot\text{s}/\text{g}\cdot\text{m}$.

3.33

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

3.34

ventilated air space

cavity or void that has openings to the outside air placed so as to promote through movement of air

3.35

ventilation rate

rate at which air within a building is replaced by outside 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 (h^{-1})); b) rate of air change in litres per second (l/s).

3.36

warmer side

side of structure with a higher temperature than the cooler side (3.13)

NOTE The warmer side usually has a higher vapour pressure compared with the cooler side.

3.37

water vapour

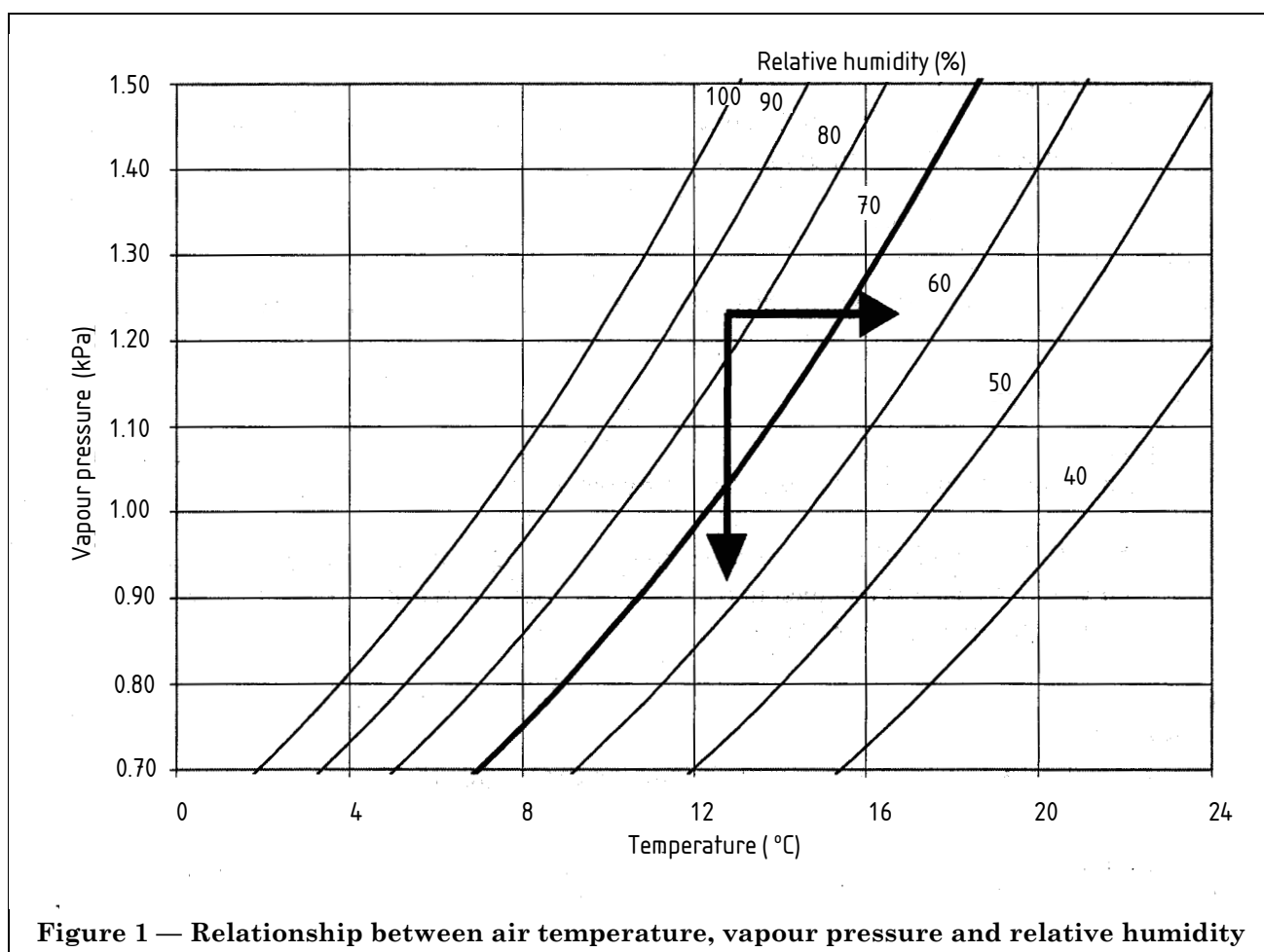
water in its invisible gaseous phase **A1**

4 Behaviour of water vapour in the air

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

Water vapour in the air exerts a pressure, the vapour pressure, so air containing a large mass of water vapour has a higher vapour pressure than drier air, which causes 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 is a psychrometric chart showing the inter-relationship of these factors. 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 mould growth on some parts 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. The inter-relationship of moisture content and temperature is given in greater detail in Annex A.



5 Causes of condensation

5.1 General

Two categories of condensation should be distinguished:

- a) condensation on surfaces within the building; and
- b) interstitial condensation 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 include atmospheric moisture, construction water, the occupants and their activities and any wet processes within the building (see Table B.1, Table B.2, Table B.3, Table B.4 and Table B.5 in Annex B).

5.2 Causes of surface condensation

Surface condensation occurs on surfaces, such as the internal surface of external fabric elements or cold pipes and cisterns, that are at or below the dewpoint of the air in contact with them, and is controlled by the temperature of the surface and the vapour pressure of the air.

The temperature of the surface depends 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 and surface finish of the building fabric;
- d) the external temperature.

The vapour pressure of the air is determined by:

- a) the water vapour production within the building;
- b) the ventilation rate;
- c) the moisture content of the “replacement” outdoor air;
- d) 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.

NOTE Anything that warms surfaces or reduces vapour pressure of the air will reduce the incidence of surface condensation.

5.3 Causes of interstitial condensation

5.3.1 General

In the winter, the interior of buildings will usually be warmer and the air will contain more moisture (i.e. have a higher vapour pressure) than outside. Heat and water vapour will diffuse out through the materials of the structure and be carried by bulk air movement through gaps and cracks into and through the structure.

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

Interstitial condensation occurs within the fabric of a building when the temperature of some part of the structure equals the dewpoint at that point, which is determined by the balance of flows of moisture to and from the point. 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 also 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.

Although interstitial condensation usually occurs when water vapour is diffusing out from the interior of a building, there are circumstances, e.g. an air-conditioned building in warm, humid weather, in which the interior is cooler and drier than outside; water vapour will then enter the structure from outside. In this document, reference will be made to the warmer sides and cooler sides of the structure; in all but the most exceptional circumstances, these will correspond to the higher and lower vapour pressure sides respectively. In spring and autumn as well as summer, even though the external air temperature may be lower than inside, the external surface of south facing walls, which might have been wetted by driving rain, can be sufficiently heated by the sun to cause water vapour to diffuse into cooler areas where it can condense (reverse condensation).

5.3.2 *Hygroscopic materials*

Most building materials are hygroscopic, i.e. they have a porous structure that absorbs water vapour from the air, even before interstitial condensation has taken place. Water can therefore be built into a construction by:

- the water of hydration in cement, concrete or mortars;
- the inclusion of hygroscopic materials which have been stored outside undercover in humid conditions. For example, 25 mm plywood stored at 90 % r.h. will hold almost 3 kilograms of water in every square metre;
- rain impact during construction before the weatherproof layer is in place. For example, 10 mm of rain falling on an absorbent insulation layer of a roof will deposit 10 kg/m^2 .

This water can then move through a structure under temperature and humidity gradients by a mixture of vapour diffusion and liquid flow through the pores and accumulate at impermeable layers.

The absorption of water by hygroscopic materials can have a buffering effect, reducing the chance of interstitial condensation during short periods of cold weather, or on clear frosty nights, when the external surface can cool by night sky radiation.

Many structural elements are subjected to significant diurnal temperature changes; the external surface temperature of a flat roof in spring or autumn can rise to 50°C during a sunny day and fall to -10°C on a clear night. This causes movement of water into the structure during the day and outwards overnight. The water that is initially spread uniformly through the structure at low concentrations can then become concentrated at interfaces raising the moisture content of vulnerable materials such as timber high enough to cause local problems of decay. High external surface temperatures due to solar gain can force water in through gaps in a vapour control layer during the day, giving rise to roofs that apparently leak only in hot dry weather.

5.3.3 *Reverse condensation*

An excellent example of moisture movement in hygroscopic materials under temperature gradients is given by reverse condensation. This phenomenon is most frequently observed when the sun shines on damp walls. It is caused by the moisture in the wall being vaporized by the heat 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 can occur on the outside face where it can 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 that remain saturated because of their exposure. A weatherproof treatment or system can reduce the moisture content of such walls and the consequent risk of reverse condensation. Weatherproofing should be applied to the outer surface of the wall and should be of low vapour resistance or be vented.

NOTE This type of reverse condensation should not be confused with the problems of interstitial condensation that can occur in building elements, e.g. in cold stores or air conditioned buildings, where the internal conditions are colder and drier than outside.

These complex phenomena, such as liquid water movement under temperature gradients, are becoming better understood and a number of computer models that can give reliable performance predictions are currently under development and in use by consultants. Work is under way to standardize these and develop a formal protocol for the assessment of structures.

6 The effects of condensation and high humidity

6.1 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.

6.2 Condensate on surfaces

Condensate frequently occurs on:

- single glazing in bedrooms overnight or in kitchens and bathrooms at any time;
- double glazing, especially near to the frames, in rooms with relatively high humidities;
- on WC cisterns or cold pipes in bathrooms or kitchens;
- on the walls of hall ways and stairs in buildings of heavy masonry construction after a change from cold dry weather to mild wet weather;
- on the underside of lightweight single skin roofs of industrial buildings due to night sky radiation;
- on massive floors in offices or industrial buildings, which remain cold after a change to warmer more humid weather, or when heating is turned on in the morning;
- on the walls or surrounds of swimming pools.

Condensate is often only a nuisance. However, more serious consequences can result from, for example:

- condensate from glazing promoting decay in the wooden window frames or condensate running from sills onto the wall below, damaging the décor;
- condensate dripping from roofs onto food preparation processes or sensitive electronic equipment;
- condensate on certain floor types, leading to a slip hazard.

It is sometimes possible to deal with the condensate by drainage or by mopping up before it collects and runs to vulnerable areas. However, persistent severe condensation on glazing, especially double glazing, in many rooms, suggests that there can be excessive moisture production or inadequate ventilation within the dwelling, which can lead to the more serious problems described in 6.3 and 6.4.

6.3 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 particularly dependent on moisture conditions at surfaces and the length of time these conditions exist. Studies have shown that moulds do not require the presence of water, but can germinate and grow if the relative humidity at a surface rises above 80 %. This is a considerably less severe criterion than the 100 % r.h. required for surface condensation to occur. As the internal surfaces of external walls will be colder than the air temperature within the building in winter, the relative humidity at the wall will be about 10 % higher than in the centre of a room. This temperature and relative humidity difference will be reduced if the walls are well insulated. As a guide, however, it may be assumed that, if the average relative humidity within a room stays at 70 % for a long period of time, the relative humidity at the external wall surfaces will be high enough to support the growth of moulds.

Moulds and mildews can occur on furniture, curtains, carpets and clothing, especially leather jackets, shoes or suitcases, if they are situated in unheated spaces or in parts of rooms sheltered from heating systems. Unheated bedrooms, cupboards or wardrobes placed against external walls and items stored in roof spaces are especially vulnerable.

6.4 Interstitial condensation

Interstitial condensation can increase the moisture content of components in a structure, but this can be inconsequential, e.g. condensate occurring on the outer leaf of a masonry cavity wall, where the amount of condensate can be small compared to the effect of wetting by rain.

Sustained condensation can 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 can cause degradation even though no condensate is deposited upon them. Persistent timber moisture contents in excess of 20 % (by mass) can lead to decay. Over a winter season, absorbent and hygroscopic materials are likely to accumulate moisture; during the summer, this moisture 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.

Accumulation of condensate within thermal insulation will significantly increase the thermal conductivity of the insulation. Dimensional changes, migration of salts, liberation of chemicals and electrical failure can also result.

7 Design principles

7.1 General

7.1.1 Introduction

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 recommendations on upgrading or remedial work in existing buildings is given in Clause 10.

Design for the control of condensation depends upon obtaining a satisfactory relationship between air conditions (internal and external air temperatures and humidity) and the properties of the 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.

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 be considered together.

The fundamental principle in designing to minimize condensation is to maintain a balance of the three factors shown in Figure 2 in order to achieve either low vapour pressure and/or high structural temperature.

7.1.2 Controlling surface condensation

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

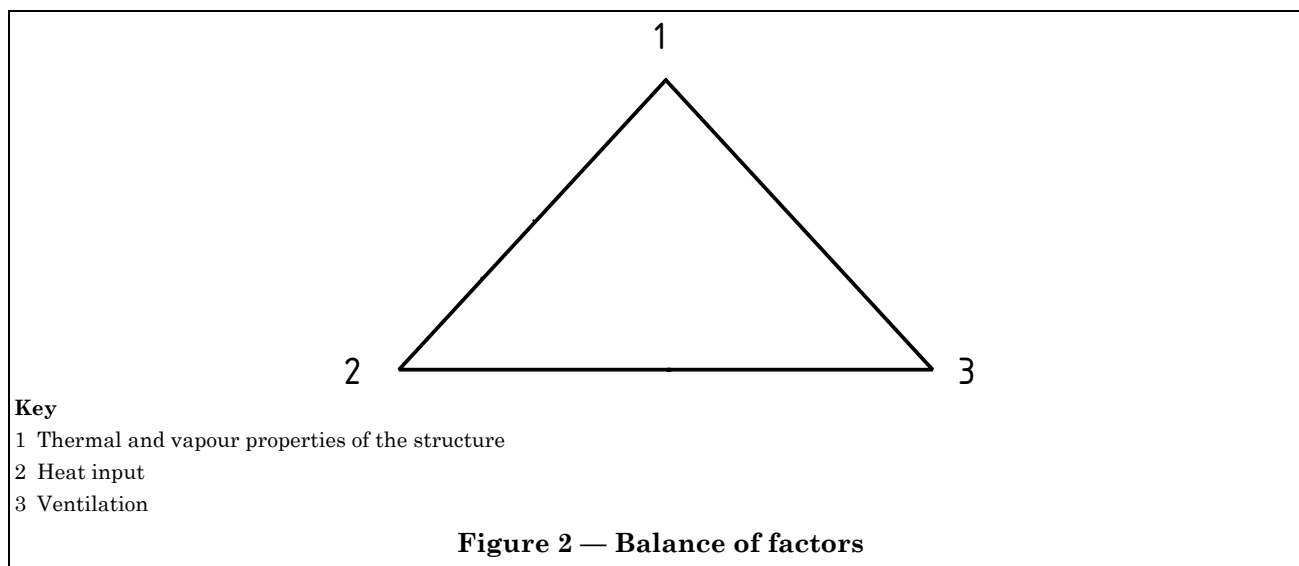
- a) obtain low vapour pressures by ventilation and/or reduced moisture input to the building;
- b) obtain high surface temperatures by providing more insulation and/or increasing the heat input.

7.1.3 Controlling interstitial condensation

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

- a) obtain low vapour pressures by ventilation, and/or reduced moisture input to the building;
- b) use materials of high vapour resistance near to the warmer side of the construction;
- c) use material of low vapour resistance, or provide ventilated cavities, near the colder side of the construction;
- d) use materials of low thermal resistance near to the warmer side of the construction;
- e) use materials of high thermal resistance near to the colder side of the construction.

NOTE Any one particular procedure taken in isolation might not necessarily minimize the risk of condensation.



7.2 Occupant activity and heating and ventilation regime

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

- a) occupants and the activities and processes within buildings, including some domestic appliances, generate moisture; some industrial processes, canteens, kitchens, laundries, shower rooms or swimming pools generate very large amounts of moisture;
- b) fuel costs can make occupants reluctant 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;
- d) the function of a building could change completely, e.g. a building built as a warehouse could be changed to a wet process factory.

7.3 Building configuration

Water vapour is often generated locally within buildings in wet process areas such as kitchens, shower rooms, laundries or a swimming pool in a larger sports centre. The dominant mechanism for transporting this water vapour to other drier and often colder areas is the airflows through the building which depend on the environmental conditions and the internal configuration of the building.

In a heated building in winter, warm, moist air will rise and leak from the building at high level often via the roof and be replaced by colder, drier entering at low level; this is known as the stack effect. At the same time, the wind will tend to push outdoor air in from one side of a building and stale air out of the other side. Stack effect will dominate in cold calm weather, wind becomes important in mild windy conditions. Usually, these effects will combine to dominate the airflows through most buildings, resulting in air entering at low level on the windward side and leaving at high level on the leeward side. This pattern can, however, be distorted by mechanical ventilation, ranging from a domestic extract fan or PSV stack in a kitchen or bathroom up to a fully mechanically ventilated office block.

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 production areas should be located with regard to these flows so that air and moisture tend to flow directly out of the building rather than spread within it, especially to unheated areas such as bedrooms. Great care should be taken in the design of buildings to ensure that warm moist air cannot move from local major sources of water vapour, such as a swimming pool, which could have been designed to cope with the high humidity environment, into other areas which have not been designed to as high a standard. Attention should be given to possible movement through concealed spaces such as wall cavities, ventilation ducts or spaces above suspended ceilings. Any mechanical ventilation systems should be designed to draw air from the rest of the building through the moisture generating areas to the outside.

7.4 Construction

There are many forms of construction available for walls, floors, glazing and roofs. Often the choice will be made on grounds other than 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 or intermittent heating.

Some constructions, such as massive concrete floor slabs, contain a large amount of built-in water, often known as “construction water”; this will take many months to dissipate and should be considered as a significant source of water vapour within the building during this period.

Some floor finishes can become very slippery when wet; care should be taken in using these in situations where they can become wet from direct condensation or from dripping of condensate from above.

The more a part of the structure is insulated, the warmer the internal surface will be for the same room heat input and, consequently, the risk of surface condensation or mould growth will be lower. However, 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 should 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 the inclusion of a ventilated air space between the insulation and the outer elements.

Thermal bridging should be minimized by careful design of vulnerable areas such as wall floor junctions, roof eaves and areas around window and door openings (see 8.6).

7.5 Heating and ventilation

7.5.1 Heating systems

Heating will normally be tailored to personal comfort in the building, taking 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 only one room is heated infrequently, that room could suffer condensation because the structure will remain cold; other rooms will remain cold and moisture migrating to them will cause severe condensation problems. These intermittent 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 exists between these two extremes.

7.5.2 Ventilation

The building regulations for England and Wales (Approved Document F), Scotland (Technical **A1**) Handbooks Section 3 **A1**), and Northern Ireland (Technical Booklet K), contain requirements for ventilation of specific rooms in domestic and non domestic buildings, expressed in terms of openable areas, background or trickle vents and the provision of extract fans or passive stack ventilators. There are also specific requirements for ventilation of:

- areas in which specialist activities are taking place;
- enclosed car parks and garages; and
- rooms with mechanical ventilation or air conditioning plant.

If stale air is extracted from a room and replaced by external air (and the loss in temperature made up 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, condensation problems are likely.

The ideal ventilation system would extract air from the moisture producing areas to outside and replace it with outdoor 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 outdoor air.

Adequate ventilation for condensation control exceeds the minimum rate of outdoor 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 B.4 in Annex B and BS 5925).

There are a number of ventilation mechanisms that can be employed, including:

- passive devices such as trickle ventilators;
- passive stack ventilators which extract moist air from kitchens and bathrooms via a duct to the roof ridge;
- supply ventilation systems, installed in a loft which supply air to the dwelling space.

Mechanical ventilation systems have also been effectively installed, providing a quiet, reliable energy efficient solution at reasonable operating costs.

The ideal ventilation system is controllable, responds to occupancy and extracts air from the moisture producing areas to outside during periods of high moisture generation and replaces it with a controllable amount of outdoor air flowing in via the other rooms. This would regulate the amount of air required to remove moisture at source, prevent its spread and ventilate the whole building with outdoor air in a controlled manner.

7.6 Heating and ventilation costs

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

NOTE 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 clear operating instructions. To avoid misunderstandings in landlord/tenant situations, the obligations of each party should be defined in the leasing agreement.

7.7 Risk assessment

At this stage, it is recommended that full checks are made on the likelihood of surface and interstitial condensation and determine if these would be harmful. BS EN ISO 13788 contains recommended procedures for the assessment of the risk of:

- surface condensation and mould growth; and
- interstitial condensation.

These calculation procedures are discussed in Annex D. Saturation vapour pressures are given in Table A.1 and thermal and vapour properties are given in Table C.1, Table C.2 and Table C.3 in Annex C.

BS EN ISO 13788 contains three criteria for assessing structures.

- a) To avoid mould growth, the thermal design of the structure should be sufficient to keep relative humidity at internal surfaces below 80 % in the most severe month of the year, given internal conditions appropriate to the use of the building.
- b) Any interstitial condensation that occurs within the structure in the winter should all evaporate during the next summer to prevent an accumulation from year to year.
- c) If interstitial condensation occurs over the winter and evaporates in the summer, the risk of degradation to the materials present should be considered in terms of the maximum accumulated condensation.

At present it is not possible to provide hard information as to the amount of condensate that would cause a problem in most situations. However, the following guidelines can be followed.

- Extensive work on flat roofs with continuously supported membranes has shown that they will perform satisfactorily if the winter peak in condensate retained within the roof does not exceed 350 g/m^2 provided that there is no accumulation from one year to the next.
- The prediction of any amount of condensate on wood or wood based materials, especially structural components, should be treated with great caution and steps should be taken to eliminate it.
- An exterior leaf of masonry, which will be wetted by the rain can withstand substantial amounts of interstitial condensate without adverse consequences.
- Condensate on impermeable surfaces such as a metal roof or plastic will not always cause any damage where it occurs but can run or drip onto more vulnerable areas. The effect of various amounts of condensate is summarized in Table 1.

If the checks are considered satisfactory, then construction can proceed as far as condensation control is concerned; if not, it means the design will have to be reassessed by following the above procedure again.

Table 1 — Effect of condensate on an impermeable surface

Amount of condensate g/m^2	Effect
0 – 30	A fine mist that does not run even on vertical surfaces
30 – 50	Droplets forming that will start to run on vertical surfaces
50 – 250	Large drops forming that will run on sloping surfaces 70 g/m^2 will run at a 45° slope 150 g/m^2 will run at a 23° slope
>250	Drops forming that are large enough to drip from horizontal surfaces

8 Application of design principles: building fabric

8.1 General

Basic principles for condensation control have been outlined in Clause 7. The following clauses provide more detailed guidance and recommendations on building according to these principles. It is essential that designers read the general information on the particular element before referring to specific examples (e.g. read 8.3.1 before 8.3.2).

Different types of construction are described according to their structure and position of insulation, with sketches, notes and comments. Figure 3 to Figure 36 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, the thickness of some materials might 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 can be encountered. It is recommended therefore that the risk of interstitial condensation is assessed with the calculation procedures discussed in Annex 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 geometric free areas; particular attention should be paid to potential restrictions to air flows, including the effects of mesh. To overcome this difficulty ventilator performance may be expressed as a particular flow rate in litres per second against a fixed pressure difference of typically 10 Pascals which can be converted into an equivalent geometric free area. Due to the air resistance of long path lengths, 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 can be considerably less. Care should be taken to ensure that external outlets from moisture producing appliances (e.g. balanced flue heaters) are placed away from ventilation air inlets.

Where the desired thermal performance can be achieved only by the combination of two or more separate material layers, careful attention should be paid to the relative properties of these layers. For example, in an existing masonry cavity wall with 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 can move to the inner leaf where it could be harmful, necessitating the inclusion of a vapour control layer. Similarly, where an existing roof construction is satisfactory, the provision of an insulated suspended ceiling can cause a condensation problem unless the thermal balance and its effect on the thermal response are considered.

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

8.2 Vapour control layers

A) The measures required to achieve a functional vapour control layer must be carefully considered at the design stage. A vapour control layer should extend over the whole of the element into which it is incorporated and must be integrated with and sealed to adjoining elements, such as masonry, upstands and glazing systems, and to any VCL in those elements.

Vapour control layers may be formed with a membrane within the structure, a lining board with an integral membrane, or with a suitable coating applied to the internal surface of an element. A vapour control layer should be of appropriate vapour resistance and should be situated on the warm side of the insulation.

In practice it is extremely difficult to construct a layer which is totally impermeable to water vapour. The performance of a vapour control layer depends upon the vapour resistance of the material selected, the practicability of the design and the standard of workmanship involved in its installation. Any unsealed holes, fixings, pipes, electrical fittings, etc. which pass through the vapour control layer, will downgrade performance; methods of avoiding such penetrations should be considered in the design stage.

Side and end joints in a flexible sheet vapour control layer should be kept to a minimum. Joints should be made over a solid backing member or substrate, lapped not less than 50 mm and sealed with an appropriate sealant. Similarly, tears and splits should be repaired using the same material, jointed as above. If polyethylene sheeting is used, it should be protected from heat and sunlight to reduce the risk of degradation occurring.

Where a vapour control layer is incorporated in a rigid board or on a profiled metal liner sheet, joints between adjacent boards or sheets should be sealed to avoid mass transfer of water vapour due to air leakage. These seals should be designed to accommodate thermal or other movements which may occur during the design life of the building.

A vapour control layer can also act as an air leakage barrier, which, by reducing air movement, has the added benefit of reducing the heat lost by convection. This is an increasingly important consideration as the incorporation of greater amounts of insulation into the building fabric reduces heat loss by conduction.

Values of vapour resistance for various materials are given in Annex C, Table C.1 and Table C.2. **A1**

8.3 Walls

8.3.1 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 have implications in dealing with the other four sources.

Design guidance on differing types of wall construction is given in **8.3.2, 8.3.3, 8.3.4, 8.3.5, 8.3.6** and **8.3.7**. Other, more unusual wall constructions, such as curtain walling, walls of cold stores, breathing walls or traditional constructions, such as cob walls, are not covered; specific advice on the performance of these should be sought. However, the following factors should also be considered.

- a) To prevent surface condensation, the thermal resistance of the wall should be sufficient to maintain the inner surface 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 **7.4**.

The relationship of the insulation to the detailed structure at openings or junctions of elements, which could contain dense high thermal transmittance materials, should be considered so that thermal bridging is minimized.

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 might not always be practicable as 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 material or layer.

Service openings through a vapour control layer should be avoided. Where this is not possible, they should be kept to a minimum and any openings taped and/or sealed.

Vented air spaces should have openings to the outside air of not less than 500 square millimetres per metre length of wall. 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 to avoid rainwater penetration. A nominal mesh/grill size of 4 mm is recommended, to avoid excessive airflow resistance.

Where external claddings require the use of a membrane to avoid rainwater penetration, or where such a membrane protects the insulation, this should be a breather type meeting the requirements of BS 4016.

c) During the drying out of the building, the risk of surface and interstitial condensation (including reverse condensation) will be higher 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.

If the above recommendations are followed, the risk of decay to timber components will be minimized. Nevertheless, for practical reasons, it might be advisable to increase the durability of structural timber components by preservative treatment.

NOTE Timbers rated moderately durable or better (see BRE Digest 296 [1]) and which contain no sapwood do not normally require preservative treatment (see BS 5268-5).

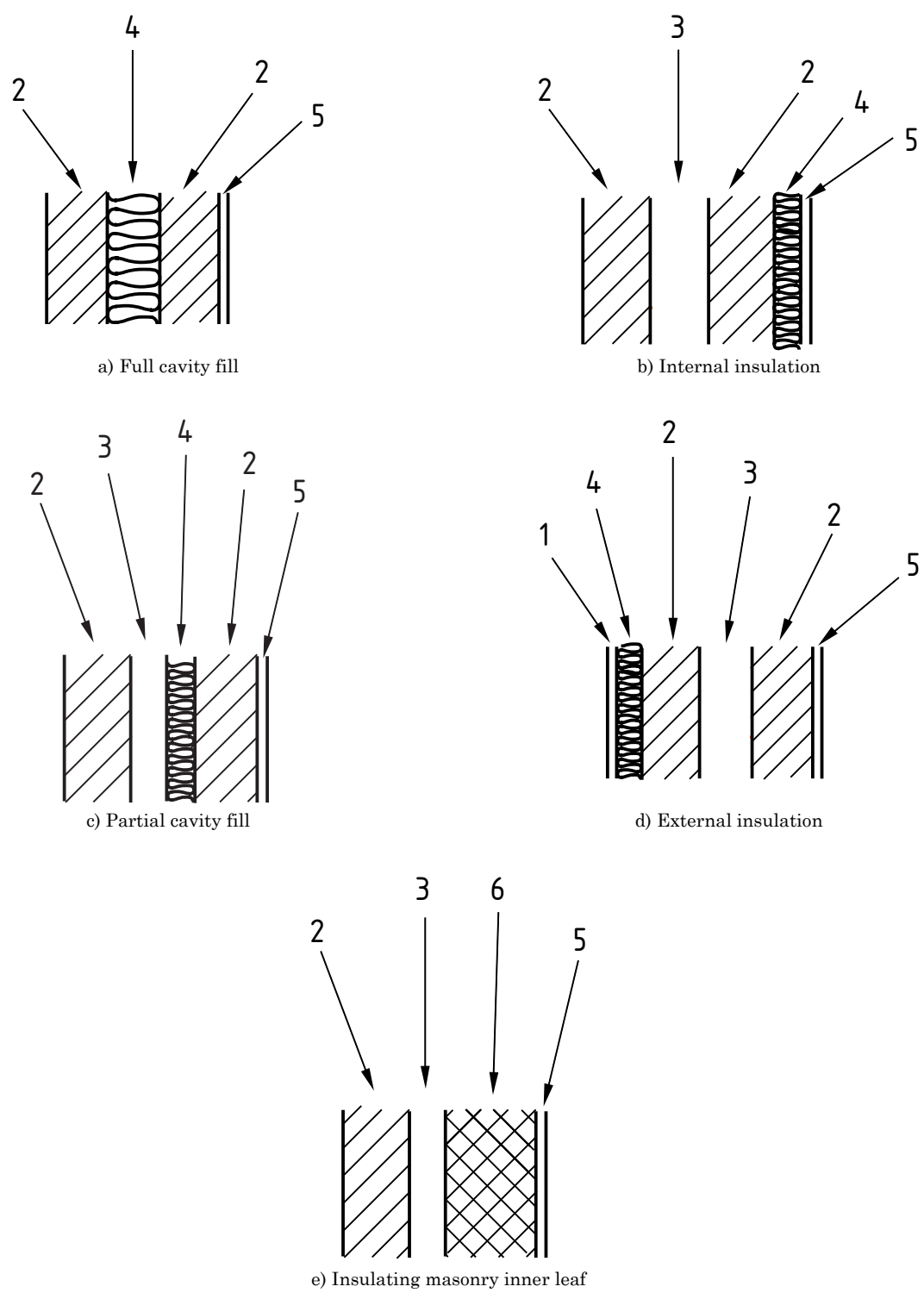
8.3.2 Masonry cavity walls

Masonry cavity walls are shown in Figure 3. The thermal response is slow to medium, except where internal insulation is used [Figure 3b)], and therefore regular low output heating is recommended to minimize surface condensation. Interstitial condensation is likely to occur on the inner surface of the outer leaf but, in general, it will be inconsequential. Careful detailing is necessary at all openings to minimize thermal bridging.

Internal insulation [Figure 3b)] provides a fast response surface, which reduces the risk of surface condensation in intermittently heated dwellings. With this construction it is essential to incorporate a vapour control layer between the insulation and the plasterboard lining to prevent severe interstitial condensation on the inner masonry leaf. Vapour control layers are normally included in proprietary insulating plasterboard products.

External insulation [Figure 3d)] can deal with external surface defects, alleviate rain penetration problems and reduce the risk of thermal bridges causing surface condensation and mould growth. Interstitial condensation is likely on the warm side of an impermeable cladding if a permeable insulation is used; in these circumstances a vapour control layer should be provided on the inside of the wall construction and/or a vented airspace provided on the immediate inside of the cladding.

Damp-proof courses should be carefully designed, and it is essential that cavity trays should have stop ends. Detailed design should follow the recommendations of BS 8215.



- Key**

 - 1 External render
 - 2 Masonry
 - 3 Cavity
- 4 Insulation
 - 5 Internal lining
 - 6 Light weight block

Figure 3 — Masonry cavity wall

8.3.3 Solid walls: internal insulation

Internally insulated solid walls are shown in Figure 4. This type of construction provides a fast response structure and so surface condensation is therefore unlikely in buildings with adequate heating and ventilation.

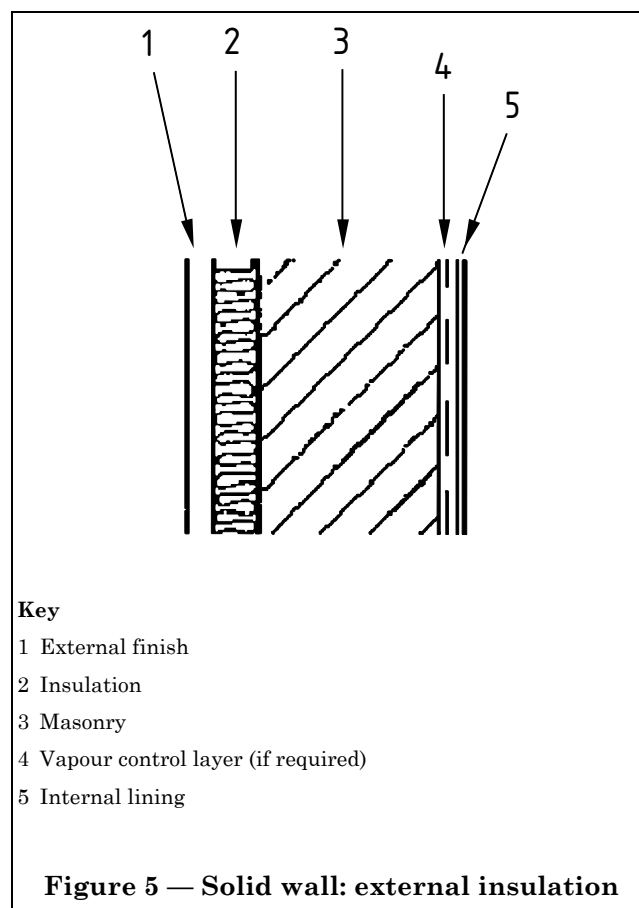
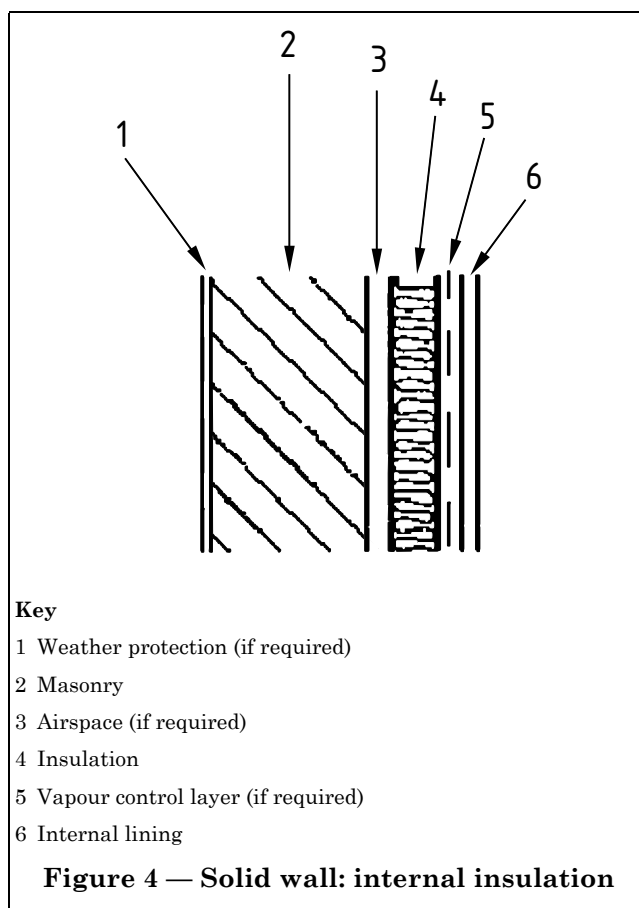
Regular heating is preferable, but infrequent heating may also be used with this construction.

Thermal bridges at external wall/floor junctions, should be minimized and insulation and vapour control layers, 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 that can wet timber studding or insulation in contact with the wall. 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 can create a risk of reverse condensation on its outer surface. If this is likely to be severe enough to cause damage, a vented airspace should be provided on the cold side of the insulation and/or a weatherproof surface finish to the wall (see 5.3.3).

Alternatively, an external weather protection of low vapour resistance should be applied to reduce rainwater penetration. This, in turn, reduces the risk of damage to parts of the construction and the risk of reverse condensation.

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



8.3.4 *Solid walls; external insulation*

Externally insulated solid walls are shown in Figure 5. 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. Particular attention should be paid to wall/roof and wall/floor junctions.

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

If the external insulation system incorporates high vapour resistance cladding, interstitial condensation is likely to occur. A vapour control layer should be provided on the inside of the wall construction and/or a vented airspace provided on the immediate inside of the cladding.

8.3.5 *Timber framed walls*

Timber framed walls are shown in Figure 6 and Figure 7. If thermal bridges are avoided, this type of construction provides a fast response structure. Surface condensation is therefore unlikely and, while regular heating is preferable, intermittent heating may be used.

Thermal bridges should be minimized, particularly at external wall/floor and external wall/roof junctions. While timber studs cause repeated thermal bridges that have to be taken into account when calculating heat loss, their effect on internal surface temperature is not sufficient to increase the risk of condensation.

A vapour control layer is essential on the warm side of the insulation to reduce the risk of damaging interstitial condensation on the inner surface of the sheathing. Service penetrations should be avoided; where this is not possible, they should be kept to a minimum and the openings sealed.

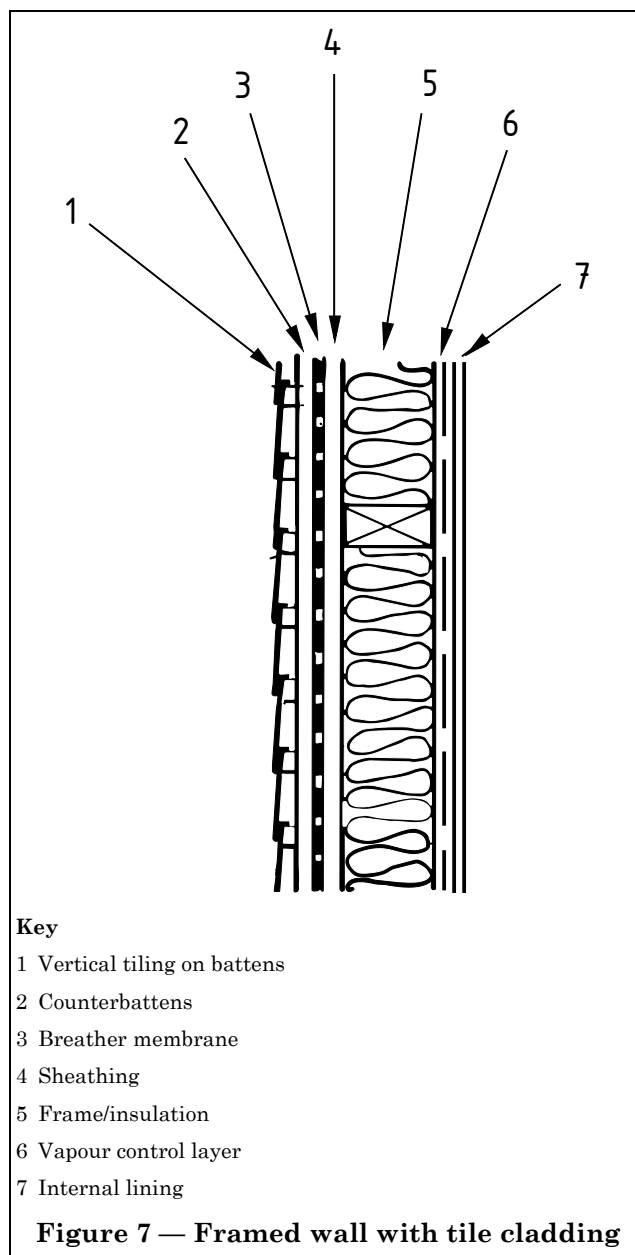
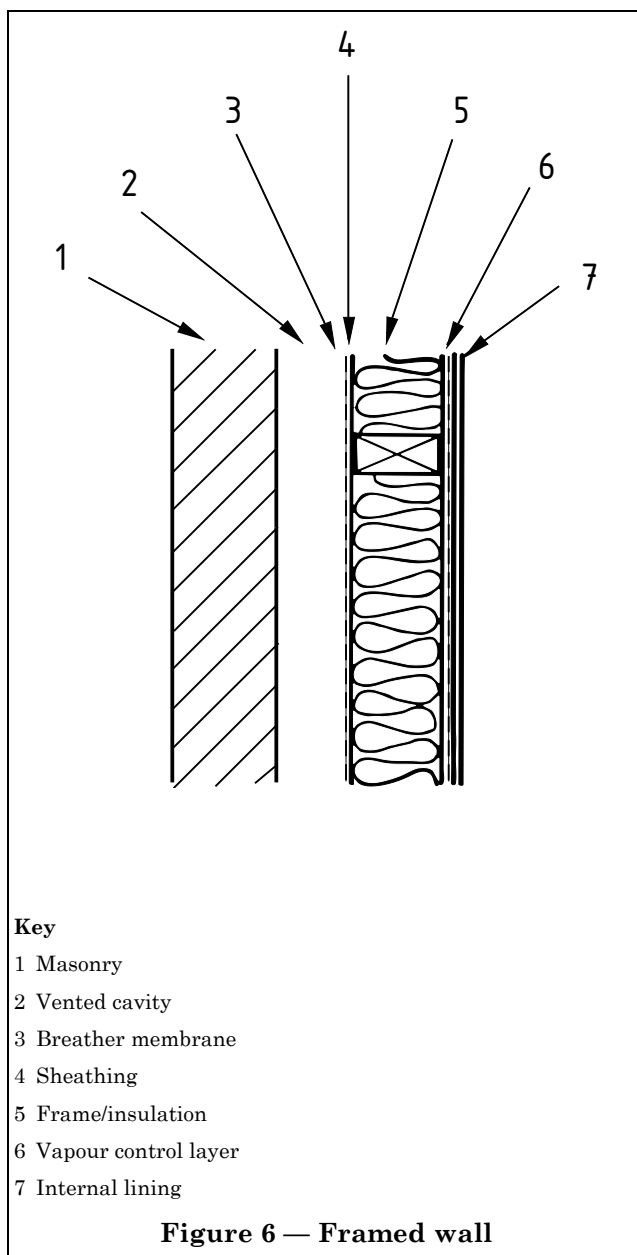
Because of the risk of interstitial condensation occurring on the inner surface of the cladding, it is essential that the construction be vented, preferably by a cavity. If the cladding is of high vapour resistance material, e.g. metal or plastic, a drained cavity is essential. Where the cladding also functions as the sheathing, a vented airspace is recommended. If this is not possible, the cladding should have as low a vapour resistance as possible or have open joints at horizontal laps.

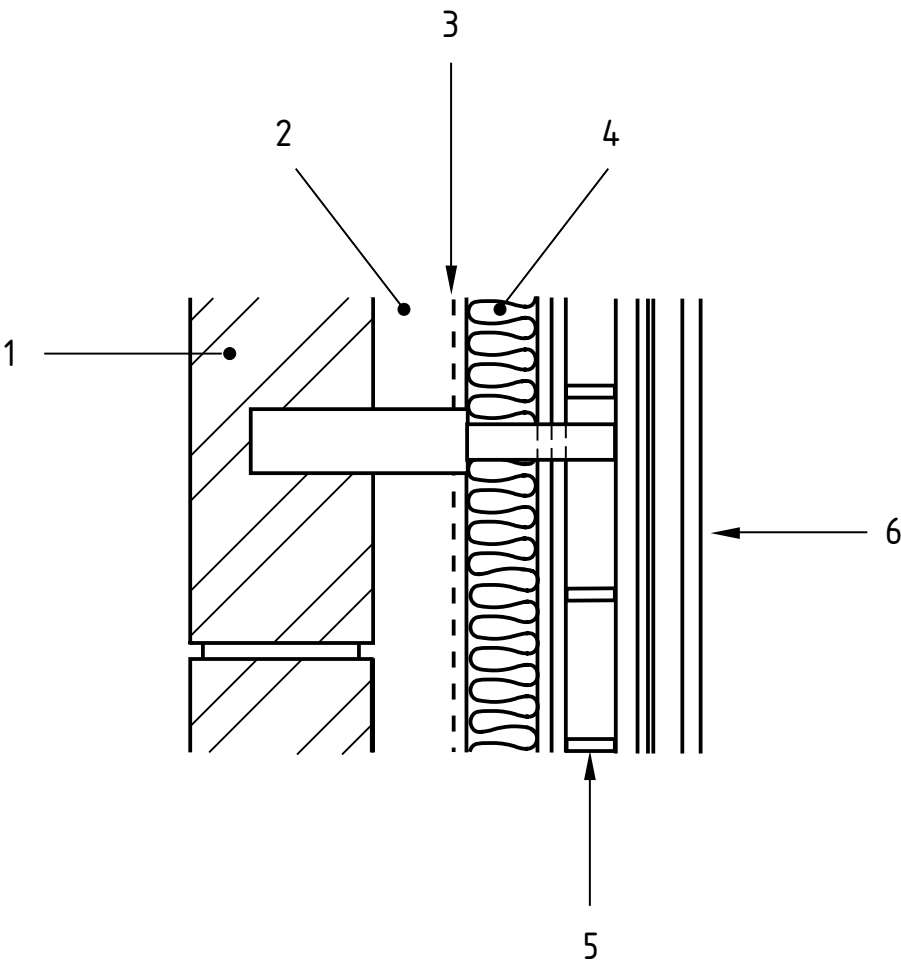
8.3.6 *Metal framed walls*

Metal framed walls are shown in Figure 8 and Figure 9. This type of construction provides a fast response structure. Surface condensation is therefore unlikely and, while regular heating is preferable, intermittent heating may be used. However, detailing should ensure that insulation is positioned in such a way to avoid significant thermal bridging through the metal.

Two types of construction are common.

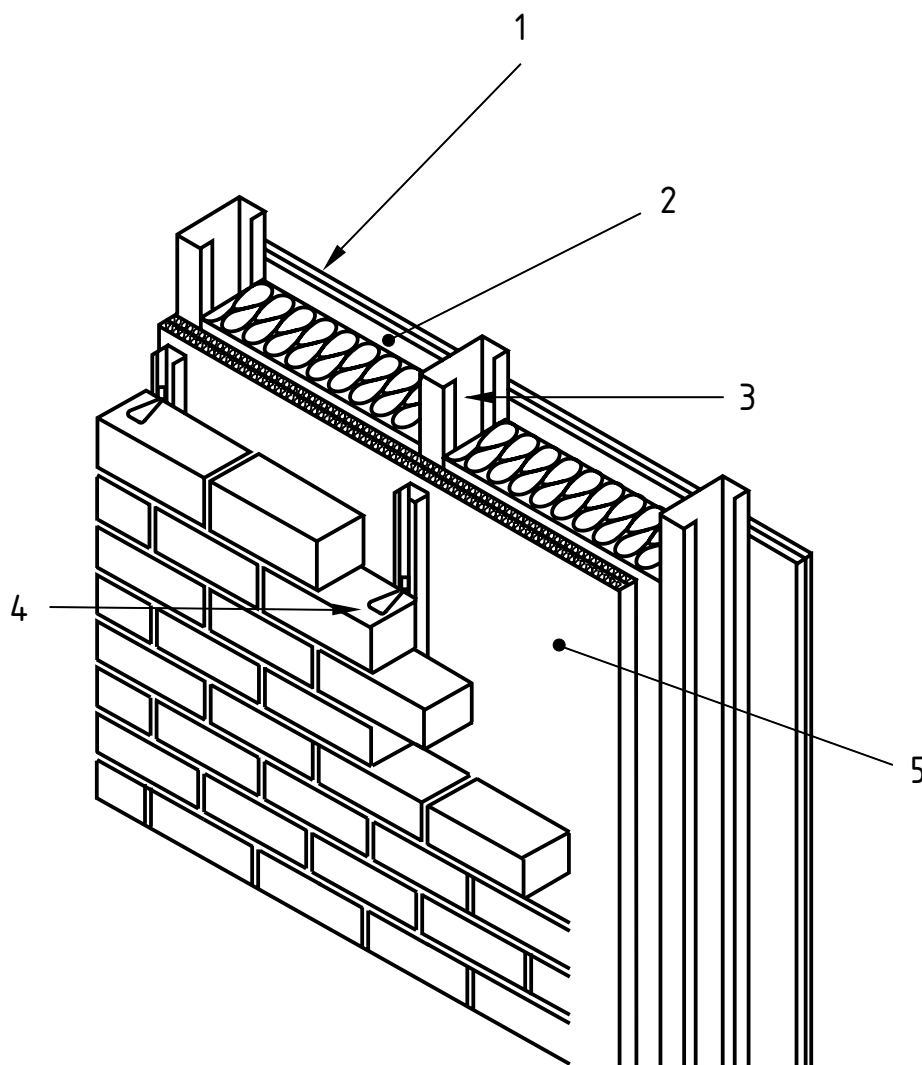
- a) In the warm frame construction, the entire steel frame is on the inside of the insulation layer (see Figure 8). This means that the steel is kept above the dewpoint so there is no need of a vapour control layer. Some interstitial condensation will occur on the external cladding but, if the cavity is vented, this will be inconsequential. A breather membrane should be included on the face of the insulation to repel any water that penetrates the cladding.
- b) The other type of steel-framed wall has the frame within the main insulation layer with an insulated sheathing outside (see Figure 9). As the steel is bridging part of the insulation layer the thermal sheathing must be designed to provide sufficient insulation to avoid the risk of interstitial condensation. A vapour control layer is necessary on the warm side of the insulation to reduce the risk of damaging interstitial condensation on the inner surface of the sheathing and unacceptably high humidities causing corrosion to the frame.





- Key**
- | | |
|---------------------|-------------------|
| 1 External cladding | 4 Insulation |
| 2 Vented cavity | 5 Steel frame |
| 3 Breather membrane | 6 Internal lining |

Figure 8 — Warm steel frame wall

**Key**

- | | |
|---|------------------------------|
| 1 One or two layers of plasterboard | 4 Wall tiles |
| 2 Vapour control layer | 5 Insulating sheathing board |
| 3 Light steel studs with mineral wool between | |

Figure 9 — Steel frame wall with frame within the insulation**8.3.7 Profiled metal walls****8.3.7.1 Site assembled metal wall**

Site assembled twin skin systems (see Figure 10), in which the principal thermal insulation layer is placed at or immediately inside the internal lining, result in the external profiled sheeting being substantially colder (in winter) than the interior of the building. A vapour control layer should be included at or immediately inside the internal lining. This may be achieved by sealing the side and end lap joints of metal liner sheets or by the use of a vapour control membrane with sealed joints.

To alleviate any condensation where high internal humidity is predicted, the void between the insulation and external profiled sheeting should be through-ventilated to the outside air.