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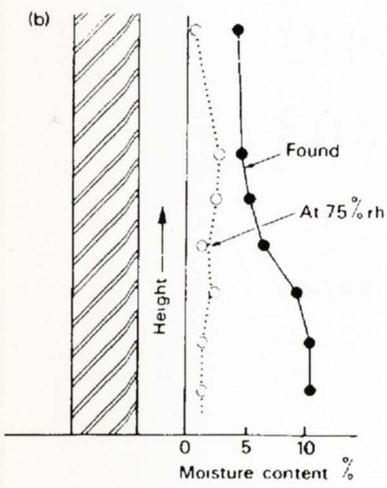

Understanding dampness

Peter Trotman
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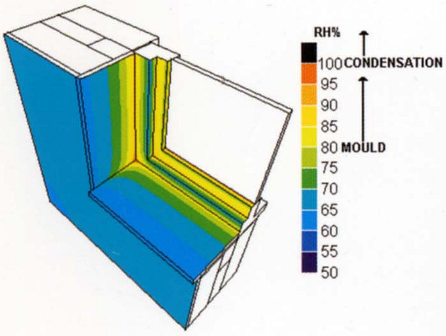

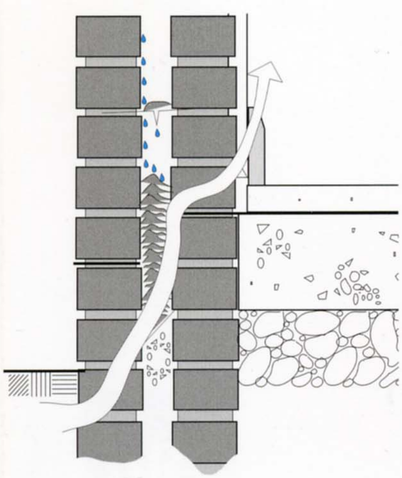

Understanding dampness

Effects, causes, diagnosis and remedies

Peter Trotman, Chris Sanders and Harry Harrison

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Contents

A complete list of contents starts on page 212

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Preface

Many years ago, before the Building Research Station was founded, the British Medical Association asked the Royal Institute of British Architects to investigate the causes of dampness in dwelling houses to help them find the reasons for the prevalence of certain diseases. The RIBA committee found that direct penetration of rain through walls and lack of a damp-proof course (DPC) accounted for nearly two-thirds of all cases; condensation contributed only 2%. The causes may have since changed in relative importance with changes in construction techniques, such as cavity walls and the tendency for houses to be better heated. Unfortunately, though, dampness is a continuing source of distress to occupants. It is possibly a source or a contributor to illness, it encourages deterioration in the building fabric, and it is involved in half of the investigations undertaken over the years by BRE.

As well as damp patches on walls, ceilings and floors, dampness can lead to blistering paint, bulging plaster, rot in building timbers, mould on surfaces and fabrics, and sulfate attack on brickwork. It can also lead to less visible problems, such as reduced effectiveness of thermal insulation or cracking in brickwork as a result of corrosion of embedded metal components. Despite all the technical advice that has been published in the past, there is still a significant set of problems. This book seeks to address them.

Readership

This book is aimed primarily at all professionals involved in the design, maintenance and management of domestic, public, commercial and industrial properties; this includes surveyors, architects, builders and facilities managers. It will also be useful to student members of these professions. Much of the text and many of the illustrations will also be of relevance to householders and other users of buildings.

Scope of the book

The emphasis of this book is on existing buildings with some coverage of the design of new build. It lists the causes of dampness in buildings and explores the consequential effects of that dampness on the fabric, the maintenance of protection against dampness, and the remedies which the detrimental results of dampness will call for.

It is illustrated with photographs of defects from the BRE Advisory Service collection and drawings of construction elements that need careful design and execution. Case studies illustrate some of the more typical problems which have been investigated as well as some interesting but informative non-typical cases, although it must be recognised that it is rare to find two cases which are identical in every detail.

Chapter 1 contains background information. Chapter 2 provides a visual indication of the most common manifestations of dampness to be seen in buildings, tabulated according to building element. When the appearance of the defect under investigation has been matched with the appropriate photograph, a key provides a link to later chapters which give explanations of the physics, further information to confirm the diagnosis, and the remedies which might be specified to put right the defect.

Although this book is mainly about existing buildings, and not specifically about the design of new buildings, it gives some design criteria so that subsequent performance of the completed building may be assessed against what was either required or intended.

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Some important definitions

Condensation: the process whereby water is deposited from air containing water vapour when its temperature drops to or below the dewpoint.

Dampness: used here to cover a wide variety of phenomena relating to the unwanted presence of water or water vapour, whatever its cause.

Deliquescent substance: substance which becomes damp and finally liquifies on exposure to the atmosphere, owing to the low vapour pressure of its saturated solution.

Dewpoint temperature of the air: the temperature at which condensation of liquid water starts when air is cooled, at constant vapour pressure.

Hygroscopic substance: usually applied to solids which tend to absorb moisture from the atmosphere without actually becoming liquified.

Psychrometric: Relating to the measurement of water vapour in the air, including the use of the wet and dry bulb hygrometer.

Rain penetration of walls and roofs: results from water entering the structure to such an extent that the resulting dampness or dripping of water becomes a nuisance.

Relative humidity: the ratio, normally expressed as a percentage, of the actual amount of water vapour present to the amount that would be present if the air were saturated at the same temperature.

Reverse condensation (*old term: summer condensation*): interstitial condensation that can occur when moisture within a wall is driven in by solar radiation on south-facing walls.

Rising damp: normally the upward transfer of moisture in a porous material due to capillary action.

Thermal bridge (*old term: cold bridge*): part of a structure of lower thermal resistance which bridges adjacent parts of higher thermal resistance and which can result in localised cold surfaces on which condensation, mould growth and/or pattern staining can occur.

Vapour control layer (VCL): usually a thin sheet material with a vapour resistance greater than 200 MNs/g, used on the warm side of thermal insulation to restrict moisture which diffuses through the insulation from condensing on any colder outer surface.

Acknowledgements

Unless otherwise attributed, photographs have been provided from our own collections or from the BRE Photographic Archive, a unique collection dating from the early 1920s.

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PMT
CHS
HWH
April 2004

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Chapter 1
Introduction

WHAT IS DAMPNESS?

In many situations the professional investigating the dampness will need an indication of the actual level of moisture within the structure. There is often a perceived need to know when a material is what might be called 'dry', although in absolute terms a porous material in a building will always retain some moisture, either from its own natural properties (for example hygroscopicity) or from the effects of water-absorbing (deliquescent) salts.

Even in a normal 'dry' building, there is always a surprising amount of water present in porous materials, most of which does no harm whatsoever. Although the amount varies widely, depending on the nature of the material and on the humidity of the surrounding air, the following figures indicate the range that may be expected in some common materials:
- plaster 0.2 – 1.0% wet weight;
- lightweight concrete >5%;
- timber 10 – 20%.

These amounts of moisture do little harm to the materials and such moisture is not usually regarded as dampness. That term is commonly reserved for conditions under which moisture is present in sufficient quantity either to become directly perceptible to sight or touch, or to cause deterioration in the decorations and eventually in the fabric of the building.

A building is considered to be damp only if the moisture becomes visible through discolouration and staining of finishes, or causes mould growth on surfaces, sulfate attack or frost damage, or even drips or puddles. All of these signs confirm that other damage may be occurring.

TYPES OF DAMPNESS

A high proportion of dampness problems turn out to be one of the big three:
- condensation;
- rain penetration;
- rising damp.

As these are so common, it is easy to overlook other causes but, before forming an opinion, these other causes of dampness should be investigated:
- construction moisture;
- pipe leakage;
- leakage at roofing features and abutments;
- spillage;
- ground and surface water;
- contaminating salts in solution.

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Condensation

The causes of condensation are quite complex. When making an initial dampness diagnosis, there are several distinctive features to look for:

- ❒ Condensation normally occurs only in the coldest months of the year.
- ❒ Trouble starts on the coldest internal surfaces: external walls, particularly corners, single-glazed windows, cold-water pipes, wall-to-floor junctions, lintels and window reveals.
- ❒ Damp patches sometimes have definite edges on cold spots such as lintels; patches of damp or mould in exposed corners are crescent-shaped.
- ❒ Condensation occurs most often in rooms where large amounts of moisture are produced, such as kitchens and bathrooms, and in unheated rooms into which moisture has drifted.
- ❒ It is common in rooms where flueless paraffin or butane heaters or unvented tumble driers are in use, or clothes are frequently dried.
- ❒ It often concentrates in areas where air movement is restricted, such as behind furniture or inside cupboards on outside walls.

Under normal occupancy of a building in winter, temperature and vapour pressure falls from inside to outside. In multi-layered constructions, the gradients through the wall relating to both these properties depend on the relative thermal and vapour resistances of each layer. Interstitial condensation can result when the main thermal resistance of the wall is on the warm side of the the main vapour resistance. The extreme situation can arise when the outside of a wall has a dense render or an impermeable rain screen cladding, slowing down or preventing the escape of any vapour.

This may not matter; for example, condensation on the the outer leaf of a brick cavity brick wall will be negligible compared to normal wetting from rainfall. However, materials which can be susceptible to moisture, such as timber and timber-based products, or metals which can corrode, are much more vulnerable and can give rise to problems, especially structural members. The studs in a timber framed wall or metal reinforcement of a masonry wall may need special protection from dampness.

Rain penetration

Rain penetration occurs most often through walls exposed to the prevailing wet winds, usually south-westerly or southerly.

Even if rain penetration is certain to be the cause of the dampness, pinpointing the exact route that the rain is taking can be quite difficult. A damp patch on a ceiling could be due to a missing roof tile or to a faulty flashing some distance from the patch. Materials in parapets and chimneys can collect rainwater and deliver it to other parts of the building below roof level, unless they have adequate DPCs and flashings. Blocked or defective rainwater goods can lead to damp patches on walls that appear to be straightforward rain penetration.

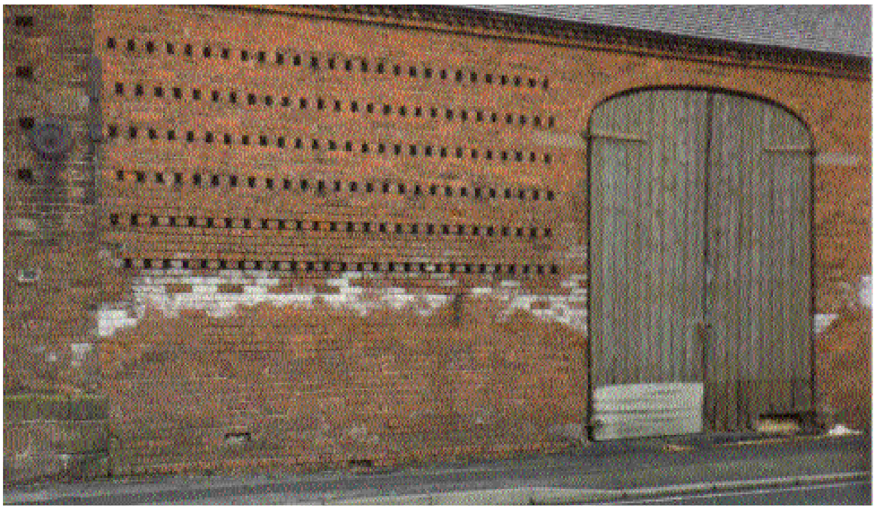
Rising damp

The results of rising damp in walls leave characteristic signs. There is usually a fairly regular, horizontal tide mark, up to a couple of metres above the floor. Below it, the wall is discoloured with general darkening and patchiness; there may be mould growth and loose wallpaper. Hygroscopic salts brought up from the ground tend to concentrate in the tide-mark. In severe cases, it may cause rot in skirtings or dados.

If there is a physical DPC, it is unlikely to have failed. But it could be bridged by pointing or rendering, or by soil, paving or rubbish heaped against the wall outside, or by plaster inside. In a cavity wall it could be bridged by a build-up of mortar droppings.

If there is no DPC, the presence of rising damp must be confirmed by correct diagnosis before deciding to put in a remedial DPC.

Rising damp can affect solid and suspended floors. In solid floors, it is occasionally due to a faulty or missing DPM. Dampness in suspended timber floors often becomes evident by the discovery of wet or dry rot, starting in the joist ends.



Salts show extent of rising damp in an agricultural building

Construction moisture

In a wholly or partly new building, the fabric contains water used in concrete, mortar and plaster. In a typical brick-and-block, semi-detached house, about 8000 litres of water can be used for mixing. This can take a long time to dry out; for example, a 150 mm-thick floor slab may take about a year. In addition, bad weather during construction may have saturated the building before it was closed in. Water can also be trapped in the fabric of older buildings which have been open to the weather during repair.

Leaking pipes

Over time, even a small leak in a water supply, central heating, drainage pipe or rainwater goods can cause extensive dampness, often some distance from the leak. The dampness can easily be mistaken for rising damp, rain penetration or condensation.

Leaks at roofing features and abutments

Blocked valley gutters and downpipes can cause rainwater to pond and overspill the flashings. Parapets and chimneys can become extremely wet and, in the absence of effective damp-proofing, water will drain downwards to other parts of the building, showing as damp patches in rooms below.

Spills

Persistent or recurring spillages can occur from tanks, cisterns, washing machines and dishwashers. Frequent floor washing can also cause problems, for example in kitchens in institutional buildings. Water running through cracks or joints in an impervious floor covering can spread underneath and may reach areas where drying out is either impossible or which may take a considerable time to complete.

Ground and surface water

Water can seep into ground floors or basements from ground or surface water, or from repeated flooding.

Contaminating salts

Walls and floors can become contaminated by hygroscopic salts causing damp patches to form.

Where is dampness apparent?

In some situations, dampness is a surface effect, such as condensation on the underside of pitched metal roof sheets or on single-glazed windows; in other places, the mass of the material can become saturated, such as a floor slab and the base of walls soaked over a long period by a leaking central heating pipe buried in the screed.

Some effects of dampness are easily visible: damaged decorations resulting from long-established rising damp; swollen timber and loss of adhesion of a paint film from a thorough wetting; outbreaks of black mould growth coupled with rain penetration; or a similar mould growth pattern from thermal bridging. Other effects may take time to show: distortion of floor sheeting material by moisture beneath (osmosis effects) and dampness beneath an insulated chipboard floor found only when the chipboard disintegrates.

For many years, BRE has been involved in studying these effects, both when investigators are carrying out short-term site inspections and examining real situations in existing buildings, or are studying phenomena over a long period, such as the drying of mass concrete structures.

There is no universal treatment for curing dampness which has become a nuisance and rarely is it easy. Each problem of dampness must be considered individually and the cause correctly diagnosed before a method to cure the defect can be prescribed. Even when a cause that would appear to account for the dampness has been found, it is wise to continue the examination until it is reasonably certain that there are no other contributory causes. If any of these are missed, the cure for the main cause may accentuate the dampness from these other causes and the treatment will then be regarded as a failure.

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RECORDS OF DAMPNESS RELATED PROBLEMS

BRE Advisory Service records

Dampness in buildings has been a continuing feature over the years. In one form or another it was found to be the main problem in around half of the cases involved in each of three separate analyses, each of over 500 site investigations carried out by staff of the BRE Advisory Service during the sample periods 1970–74, 1979–82 and 1987–89.

Rain penetration

Rain penetration featured in 25% of the 510 occurrences during the period 1970–74; 27% of the 518 occurrences during the period during 1979–82 and 22% of the 520 occurrences during the period 1987–89, an average of about one in four of all investigations.

During the period 1970–1974, of the 510 investigations carried out, about one in five concerned the external wall. Rain penetration was the the defect most frequently investigated. About half the number of cases occurred in cavity filled walls via DPMs and trays, and the other half in solid walls, concrete cladding and other kinds of external wall. Rain penetration actually through windows, as opposed to the window-to-wall joints, also occurred in a significant number of cases.

Condensation

Condensation featured in 17% of the 510 occurrences during the period 1970–74; 15% of the 518 occurrences during the period 1979–82 and 17% of the 520 occurrences during the period 1987–89, an average of about one in six of all investigations.

In 1988, BRE investigators carried out postal and interview surveys in some one-bedroom and bedsitting-room homes. The main aim was to examine problems relating to condensation. Half the homes studied had enough condensation to cause pools of water on the window sills, and one in six had sufficient mould growth to cause damage to plaster or woodwork. Problems reported by occupants were strongly correlated with observations made by interviewers. In these small homes, condensation problems were related to location in the UK (being worse in warmer areas), age of respondent (retired people having fewest problems), household size, insulation standards, home heating (particularly the use of bottled gas) and air movement within the home, but not ventilation habits. Condensation and mould growth certainly used to be widespread problems in all housing sectors, but especially so in tenanted accommodation. In many cases it was difficult to identify the underlying cause; this was often complicated by social issues.

Entrapped water

Entrapped water featured in 5% of the 510 occurrences during the period 1970–74; 3% of the 518 occurrences during the period 1979–82 and 6% of the 520 occurrences during the period 1987–89, an average of about one in 20 of all investigations.

Rising damp

Rising damp featured in 5% of the 510 occurrences during the period 1970–74; 4% of the 518 occurrences during the period 1979–82 and 5% of the 520 occurrences during the period 1987–89, an average of about one in 20 of all investigations.

BRE Defects database records

BRE inspections

In separate studies of the quality achieved in new-build house construction, carried out during the early 1980s, and replicated during the late 1980s, each covering upwards of 1000 dwellings, risk of dampness occurring in one form or another was identified on many of the sites. The resulting database recorded actual inspections by BRE investigators or by consultants working under BRE supervision. The research recorded non-compliance with requirements whatever their origin, Building Regulations, codes of practice, British and industry standards or other authoritative requirements, which could lead to dampness.

In the earlier study, potential weathertightness problems featured in 16% of cases, rising damp in 4%, and condensation in 5%. Entrapped water could not be measured. About one in four of all cases related to dampness.

In the later study, potential weathertightness problems featured in 12% of cases, rising damp in 4%, and condensation in 5%. Entrapped water could not be measured although the investigators were surprised to find extensive mould growth in one brand-new house which had yet to be occupied; it was suspected to have been caused by entrapped construction water. The study showed roughly similar results to the earlier study; this suggested that there had been no change over the intervening eight years. The UK construction industry has always been slow to learn the lessons of its past mistakes – see BRE IP 3/93.

Public sector experiences

In parallel with these studies, public sector building owners were questioned in 1983 and again in 1989 about their experiences of problems with their housing stocks; from the results it was possible to place the problems in order of importance. 115 authorities responded to the invitation.

Tables 1.1 and 1.2 show that dampness related problems were the top five in public sector new-build housing in 1989, and the top seven in rehabilitated housing. There were hardly any changes from the 1983 figures, although there were some differences in the rank order. The more recent experience of the BRE Advisory Service indicates that current problems do not differ significantly from these figures.

House condition surveys

The main source of information on the condition of the UK housing stock is the four house condition surveys carried out every five years in England, Wales, Scotland and Northern Ireland. These are a detailed survey of about 45,000 dwellings in a representative sample, with a follow-up interview with the householders by a market research firm, to establish the ways they use their house, their attitudes to such issues as energy conservation and any problems they experience. The most recently published information is from the 1996 English and Scottish Surveys.

England

The 1996 *English house condition survey* shows that 3.9% of dwellings were affected by rising damp and 6.0% by penetrating dampness. These are both much more common in older buildings which are less likely to have a complete DPC and more likely to have solid walls – Figure 1.1.

Table 1.1 Public sector housing survey: new-build
Rankings in 1989 and 1983 compared

1989	Performance of building element	Number of mentions	% of 115	1983
1	Weathertightness of windows and doors	33	29	3
2	Surface condensation on brick external walls	29	25	1
3	Weathertightness of flat roofs	25	22	5/6
4	Rising damp in brick external walls	22	19	2
5	Weathertightness of pitched roofs	21	18	5/6
6	Surface condensation on windows and doors	19	17	9/10
7	Surface condensation on other external walls	17	15	4
8	Strength and stability of foundations/basements	14	12	9/10
9/10	Durability of windows and doors	12	10	9/10
9/10	Durability of fixtures and fittings	12	10	-
-	Weathertightness of brick/block external walls	-	-	7
	Rising damp in other external walls	-	-	8

Table 1.2 Public sector housing survey: rehabilitated housing
Rankings in 1989 and 1983 compared

1989	Performance of building element	Number of mentions	% of 115	1983
1	Weathertightness of flat roofs	59	51	4
2	Weathertightness of windows and doors	54	47	1
3	Rising damp in brick block external walls	54	47	3
4	Surface condensation on brick external walls	51	44	2
5	Weathertightness of pitched roofs	46	40	5
6	Strength and stability of foundations/basements	37	32	6/7
7	Strength and stability of external brick block walls	33	29	10
8	Weathertightness of brick block external walls	32	28	8/9
9/10	Surface condensation on other external walls	32	28	6/7
9/10	Surface condensation on windows and doors	31	27	-
-	Rising damp in brick block separating walls	-	-	8/9

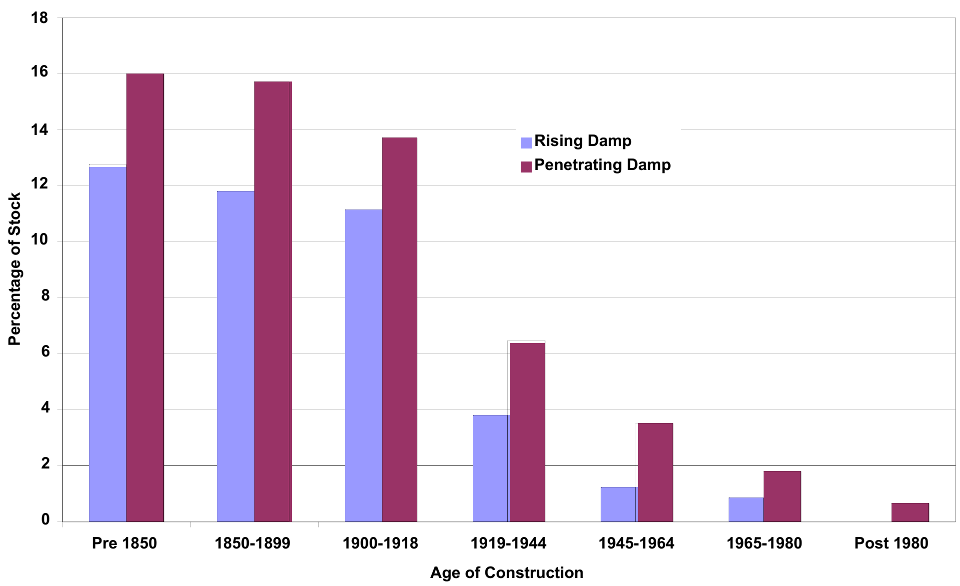

Figure 1.1 Incidence of rising and penetrating dampness by age – *from The 1996 English house condition survey*

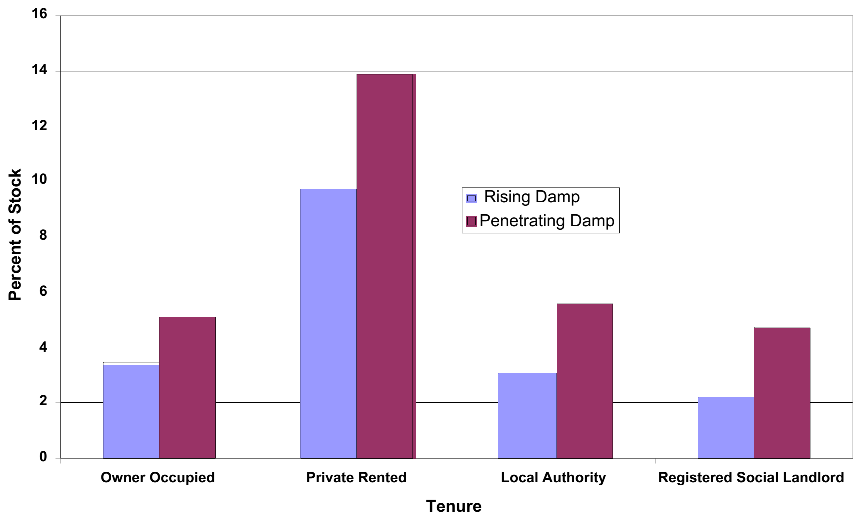

Figure 1.2 Incidence of rising and penetrating dampness by tenure – *from The 1996 English house condition survey*

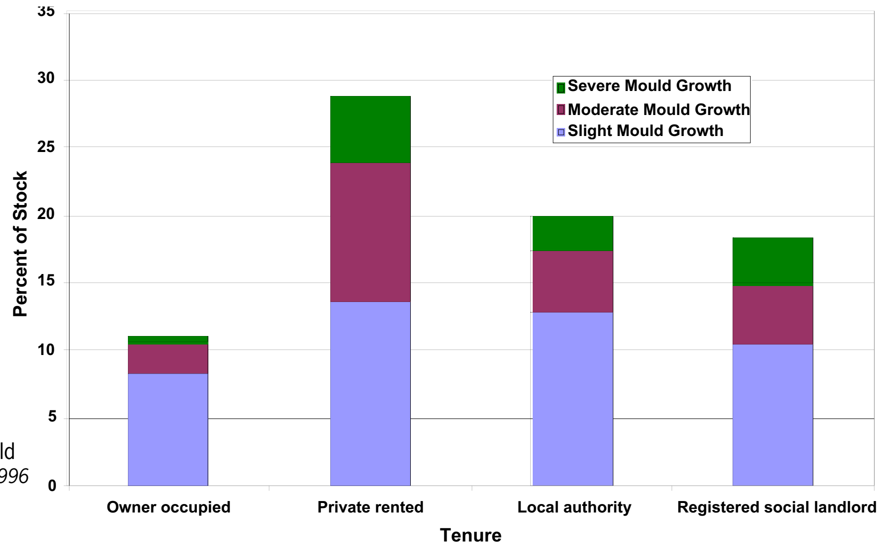

Figure 1.3 Incidence of mould growth by tenure – *from The 1996 English house condition survey*

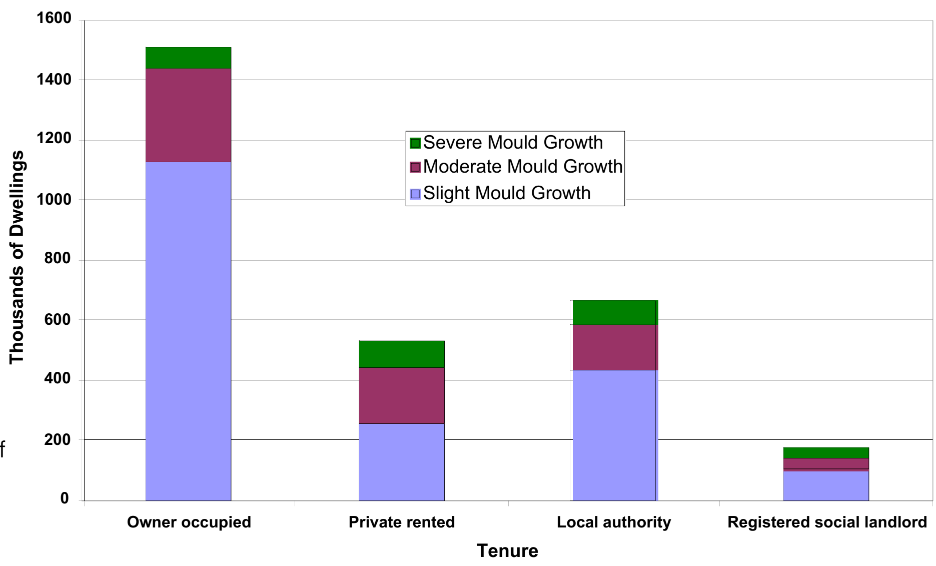

Figure 1.4 Numbers of dwellings with mould growth by tenure – *from The 1996 English house condition survey*

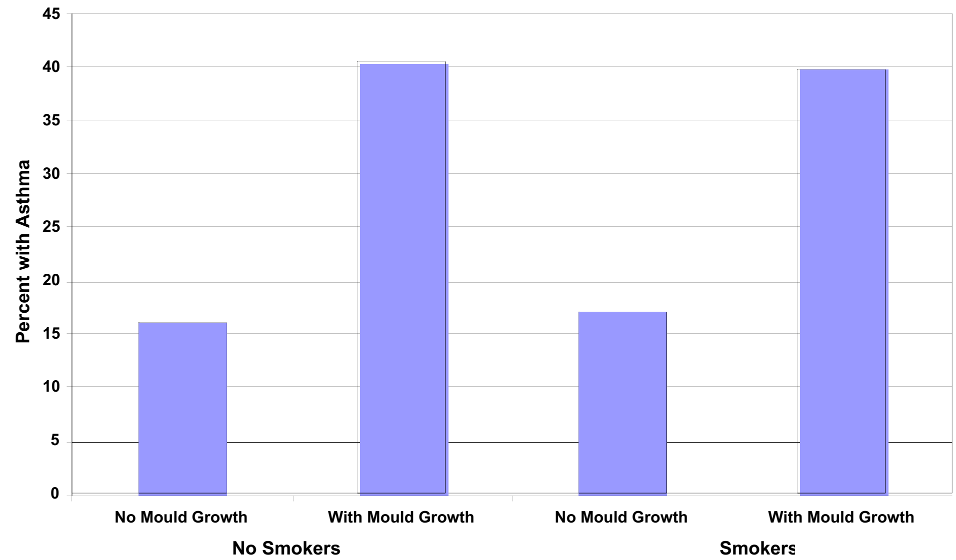

Figure 1.5 Percentage of households with at least one person complaining of asthma, by mould growth and presence of smokers – *from The 1996 English house condition survey*

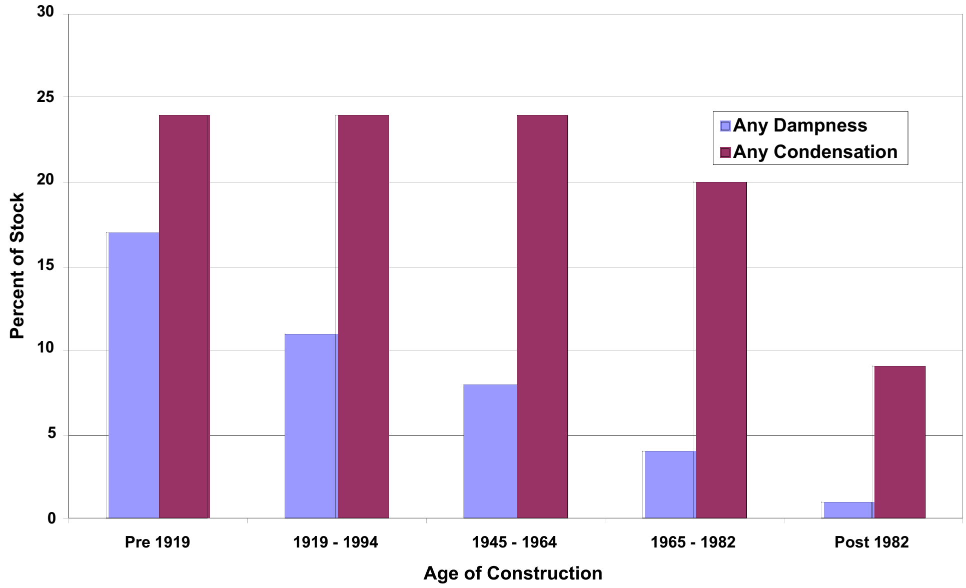

Figure 1.6 Dampness in the older housing stock in Scotland – *from The 1996 Scottish house condition survey*

Problems are also concentrated in private rented housing, which is often older and in poorer repair that the rest of the stock – Figure 1.2.

Altogether, 14.6% of dwellings in the EHCS had some degree of mould growth on the walls of furnishings. Rented housing is more severely affected with the most severely affected part of the housing stock being the private rented sector – see Figure 1.3 – which is older, in poorer repair and occupied by more low income households than the other parts.

Because so many dwellings in England are now owned by their occupants, 52% of mould problems occur in owner-occupied housing – Figure 1.4.

Figure 1.5 shows particularly disturbing evidence of the effect of mould on the health of occupants.

The percentage of households with at least one person suffering from asthma more than doubles in houses with mould growth, even when allowance is made for smoking, the other major cause of respiratory problems.

Scotland

The picture from the 1996 *Scottish house condition survey* is broadly similar; about 25% of dwellings suffered from dampness or condensation. Dampness and condensation affected 4% of dwellings, dampness alone a further 4% and condensation alone 17%. As in England, dampness was concentrated in the older housing stock – see Figure 1.6. The incidence of condensation was more or less constant up to the 1980s, when improved insulation standards should be expected to reduce the risk.

Comparable figures for Wales and Northern Ireland were not available at time of writing.

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CHANGES IN LIFESTYLE AND CONSTRUCTION

Changes in domestic lifestyles

Enormous changes have taken place in domestic lifestyles in the past half-century, especially in heating, the nature and costs of fuels, and a reduction in ventilation rates. In houses heated by open coal fires and those where the building byelaws called for the installation of air bricks, the risk of condensation was low. Following the increases in the costs of fuels, occupiers naturally tried to save money by blocking up ventilation. If the household were out during the day, they wanted instant heat on their return, sometimes using paraffin or LPG-fuelled heaters, with appaling levels of condensation on the cold structure of the dwelling.

There have also been considerable changes with domestic clothes' washing arrangements. Solid-fuelled, open-top wash boilers were still being installed in houses in the early 1950s, and gas or electric boilers were used elsewhere, producing large quantities of water vapour, even steam, within the dwelling. Now, of course, the automatic washing machine is common, and some occupiers have learnt to ventilate tumble driers to the external air.

Changes in external walling practice

Brick walls were almost invariably built in a single leaf until the gradual introduction of cavity walls from early Victorian times. In single-leaf domestic construction, rendering was common until the 1939–45 war, and much of the ribbon housing development of the late inter-war period was still being built in 9-inch brickwork. In areas subject to heavy driving rain it was not unusual to use tile or slate hanging to ensure the wall was watertight.

Damp-proof courses

Damp-proof courses were not common in domestic construction until required by the Public Health Act 1875, and the walls were afforded further protection against dampness by, for example, overhangs and drip moulds which directed rainwater away from the face of the building.

Cavity walls

Cavity walls, at first in twin leaves of brick with facings in the outside leaf and commons on the inside, became standard practice for domestic work only after the 1939–45 war, though they had occasionally been used in certain parts of the country 100 years earlier. Blocks, at first made with coke breeze or clinker aggregates, then gradually replaced the commons in the internal leaves. The main aim of the cavity wall was to improve weathertightness which, provided the workmanship was satisfactory, it did, and the incidence of rain penetration could be reduced. Although it was realised that the thermal insulation value of the wall had been improved, such improvements were marginal when considered in today's terms.

Doors and windows

Doors and windows have improved significantly in performance from the double-hung sashes set into half-brick reveals, both as regards thermal insulation and consequent reduction of condensation, and also in weathertightness and reduction of rain penetration. There was, however, an hiatus in the post-World War II developments, when steel and timber casements became popular, set almost flush with the external face; these were more vulnerable to rain penetration. This seemed to occur more in England and Wales than in Scotland, where the tradition of recessing the windows for better protection was retained. The comparatively recent developments of plastics and other high performance units have, however, given significant improvements both in thermal insulation, reduction in condensation, and in improved weathertightness.

Non-domestic construction techniques

In the second half of the twentieth century, many new external wall techniques were introduced; for example, curtain walling and rain-screen cladding used as new construction or simply to over-clad leaking traditionally-built facades. For the most part, these techniques led to relatively impermeable outer skins of metal, man-made sheet materials, and large areas of glass. Any gaps or holes in this skin could lead to water being pumped through by wind pressures and suctions; any missing thermal insulation could lead to condensation risk. Any misunderstanding on the part of either designer or builder of the required characteristics of these new techniques could lead to potential problems, and the files of the BRE Advisory Service are full of such examples.

Changes in floor construction practice

Many buildings built before the first decade of the 20th century were constructed with solid floors of puddled clay or of quarries laid on ash beds, laid without benefit of DPC. In theory at least, these were vulnerable to rising damp. In practice, however, rising damp was rarely seen.

Suspended timber floors

The risk of rising damp through the floor should have been entirely removed with the introduction of suspended timber floors which became popular in late Victorian times. Some, however, were laid without DPCs on the sleeper walls, leading to rising damp and to consequent rot in the joists. Many domestic buildings built during the inter-war period had suspended timber floors but the shortage of timber in the early post-World War II period led to a change in common practice and a reversion to solid floors.

Solid floors

This change from suspended back again to solid floors on a major scale following the 1939–45 war took place in England, though not to anything like the same extent in Scotland, Wales and Northern Ireland. At this time a variety of floor finishes was used, the most common being magnesite, pitchmastic, mastic asphalt and linoleum laid directly on concrete bases. But with the introduction of thermoplastic tiles around 1946, the use of all except linoleum had disappeared from domestic construction by around 1960. Because thermoplastic tiles and the solvent bitumen adhesives used to fix them were moderately tolerant of moisture rising from below, it was common to lay this type of flooring directly onto a concrete base, usually four inches (100 mm) thick without any DPM or screed. Except on very wet sites, this construction worked well. The provision of DPMs below concrete slabs did not become common until sheet polyethylene became generally available in suitable size and thickness around 1960. Prior to that date, where DPMs were required to protect moisture-sensitive floorings, they were formed by applying various brush or hot-applied tar and bitumen-based products to the top of the base concrete and covering it with screed or board based products. The use of pitchmastic and mastic asphalt as both screed and surface DPM was also common.

It is only within the last few years that precautions have been taken to increase the thermal insulation at the perimeters of solid floors in new construction, with the consequent reduction of condensation risk on the lower temperature of the concrete near to the external walls.

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Changes in roof construction practice

Pitched roofs

Various structures and coverings have formed most roofs in the UK since medieval times and a fair majority of the nation's stock of buildings still have pitched roofs of one kind or another. Maintenance of the weathertightness of the coverings of such roofs is for the most part straightforward. However, in the case of the underlying structure, for example of heritage buildings, there can be problems which need specialist advice.

Sheeted, low-pitched or almost flat roofs have become popular within the last twenty years. These roofs often have steeply pitched tiled perimeters; and they are not entirely without their problems.

In the domestic short-span field there has been an almost complete swing away from the strutted purlin roofs of inter-war and early post-war years towards trussed rafter roofs. These came into widespread use in 1964. Since the mid-1980s, a further noticeable swing in fashion has been from hips to plain gables and back to hips. Provided the construction is satisfactory, there should be virtually no difference in performance so far as dampness is concerned, even considering the potential corrosion of steel trussed rafter plates. What does make a difference, though, is the use of clipped eaves, which offer no protection from rainfall to the wall below.

Another tendency which has become apparent is that of increasing complexity of the geometry of buildings, and more especially of roofs. It is also clear that defects increase in direct proportion to increases in complexity of geometry of the surfaces of buildings; in other words at the intersections of different planes. These intersections provide many situations where the roof continuity is interrupted, and which therefore become vulnerable to rain penetration.

Flat roofs

In the 1920s there was a swing in architectural fashion away from the pitched roof in favour of the flat roof. The flat roof was also the only conceivable solution for some of the convoluted plan forms that were adopted. It is the poor performance of some of these, particularly system-built roofs, coupled with lack of tolerance to thermal and moisture movement of structures leading to cracking of the membranes, that gave flat roofing a bad name.

The real difficulty came with built-up bitumen felt flat roofs which failed in large numbers in the 1950s and 1960s. Particularly when exacerbated by poor maintenance strategies, owners of large building stocks with these roofs, such as county councils and the Property Services Agency, found themselves responsible for substantial costs for their repair. The roofs which failed were largely those using organic felts fully bonded to the deck immediately below them. Consequent thermal movement of the substrate from exposure to solar radiation caused the waterproof membrane to split and break down after a relatively short life.

With the introduction of newer materials and better practice, there should be a progressive reduction of the incidence of defects in newly built flat roofs.

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CHANGES IN LEVELS OF RISK

Some degree of dampness in buildings is probably inevitable, especially considering the effects of the maritime climate of the British Isles, and the amount of water used in constructing buildings, and water vapour generated within those buildings by people breathing, washing and cooking.

You must therefore consider circumstances of individual cases when you assess levels of risk of dampness, and the question must inevitably be faced: what is an acceptable level of dampness? An example to consider is that of rain penetration of an opening window, where acceptance of leakage of a small amount of water onto the sill a couple of times a year will be more acceptable than spending much money on high performance windows which ought to eliminate such leakage. What is acceptable to one person in this situation will be unacceptable to the next, and judgements have to be made. However, even a drop or two of rainwater from a leaky flat roof every time it rains is usually intolerable, especially when it falls on vulnerable soft furnishings, documents or electrical or electronic equipment.

From the point of view of the occupant, penetrating damp is normally regarded as a very serious matter and a sign that something is seriously wrong with the building.

Bear in mind climate change, with possible increases in global warming leading to changes in temperature and rainfall and the winds that carry them around the globe. Already apparent are signs of rises in water tables in the UK, leading to flooding in areas which so far have been relatively free from this risk. More buildings are being built in river flood plains without due attention being paid to the risks involved. Far from reducing in frequency of occurrence, there are discouraging signs that the problems are not being adequately addressed.

BRE PUBLICATIONS ON DAMPNESS

The BRE publications, such as Digests, Information Papers, Good Building Guides and Good Repair Guides which are listed in *References and further reading* at the end of each chapter and at the end of this book make a fairly comprehensive coverage of dampness in all its forms but, since they have been published over many years, they have received only little cross-referencing between them. All these publications have been drawn upon in this book.

Apart from the series of publications referred to above, a number of BRE books examine particular aspects of dampness in buildings. They include the *Housing Design Handbook* BR 253, *Assessing traditional housing for rehabilitation* BR 167 and *Cracking in buildings* BR 292.

There is a considerable amount of information relating to dampness in buildings in the five books in the BRE Building Element series and this has been used here to augment newly prepared material, particularly regarding recent revisions of British Standards. All the case studies are drawn from files of the BRE Advisory Service and the Housing Defects Prevention Unit.

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REFERENCES AND FURTHER READING IN CHAPTER 1

English house condition survey 1996. Department of the Environment. London, The Stationery Office, 1998.

Scottish house condition survey 1996. Scottish Homes. Survey report. Edinburgh, Scottish Homes, 1997.

Public Health Act 1875. London, The Staionery Office.

BRE publications

Potential implications of climate change in the built environment FBE 2

Assessing traditional housing for rehabilitation BR167

Housing design handbook BR253

Cracking in buildings BR292

Roofs and roofing BR302

Walls, windows and doors BR352

Building services BR404

Foundations, basements and external works BR440

Floors and flooring BR460

Information Paper

3/93 Quality in new-build housing

Chapter 2
Visible and hidden effects of dampness

Diagnosis
Visible moisture
Salts
Timber rot
Hidden dampness
Health effects
Mould growth
Frost
Metal corrosion

This chapter gives an overview of the results of excessive amounts of moisture or of moisture in the wrong place. It provides a key to the remainder of the text and shows some of the defects which are more likely to be seen by the reader; these are arranged by building element, outlining the consequential damage to the fabric and, where relevant, to the occupier. A further key links with explanations of the relevant issues, diagnosis and remedies which are described in more detail and illustrated later.

HEALTH EFFECTS OF MOULD AND DAMP

Surface moulds occur on external and internal surfaces of walls and partitions, frequently adjacent to ceilings, usually accompanied by persistent condensation or some other form of wetting. Moulds are unsightly and may also cause premature failure of paint films. As well as being unsightly, mould on internal surfaces is thought to cause respiratory problems in susceptible individuals; some forms of mould are actually toxic.

Mould problems and health

The moulds that grow in housing have long been associated with health problems; the most common are respiratory allergic reactions to mould spores and the faecal capsules of the dust mites that are associated with moulds. Spore concentrations in the air of buildings in which there is actively growing mould are much higher than where there is no indoor mould growth: here, the indoor air spore content is determined by that outdoors, causing great indoor variation day-to-day and seasonally. Indoor spore content ranges from 10% to 50% of that outdoors, and increases transiently with an increase in human activity, vacuum cleaning for example. Mould growth is less common in homes which have better insulation, cavity walls, good ventilation and air circulation, effective heating with no unflued combustion appliances and a generally good state of repair. It is therefore less common in newer homes.

Mould spores affect sensitive atopic individuals, the elderly and the very young, causing asthma, chronic or perennial rhinitis, conjunctivitis and eczema. About 80% of asthmatics in the UK are allergic to dust mites; data from the English House Condition Survey shows that families living in houses with mould are three times more likely to include an asthmatic than those in houses with no mould. There is increasing epidemiological evidence suggesting that moulds which commonly occur in dwellings are producers of potent mycotoxins, which exhibit toxicity to human lung cell linings and can have severe effects on the health of occupants.

More severe, sometimes fatal, illnesses, with names like ‘farmer’s lung’ or ‘maltster’s lung’ have been resulted from exposure to mould spores in the past; however, the evidence is that these are associated with mould species

Table 2.1 Location, timing and possible causes of dampness on building elements

Location	Figure No, Chapter (Ch) and page (p)	Distribution	Timing in relation to weather	Possible cause
All or any surface: walls, partitions, ceilings, floors	2.2; 2.6; 4.4; 4.16; 4.19; Ch 1 p2; Ch 4	Widespread, particularly on impervious surfaces of massive elements or single glazing	Following a sudden rise in temperature and humidity, either of outside air or air of affected rooms	Condensation
All or any surface: walls, partitions, ceilings, floors	6.36; 6.43; Ch 7	Widespread on massive elements only	No relationship	Construction water
All or any surface: walls, partitions, ceilings, floors	Ch 4	Several patches	In muggy weather, dampness; at other times, efflorescence	Condensation aided by hygroscopic salts
All or any surface: walls, partitions, ceilings, floors	6.24; Case study p196; Ch 7	One patch	No relationship	Plumbing leak
External and internal walls	2.5; 2.7; 6.1; 6.15; Ch 6	From floor level upwards with horizontal tide mark	Always present	Rising damp
External walls	4.17; Ch 4	Widespread, but especially when unheated or facing north	In cold weather, but not necessarily wet	Condensation
External walls	2.4; 5.3; 5.49; Ch 5	In patches, often related to exposure to prevailing weather, usually showing efflorescence	After heavy rain, sometimes slow in clearing	Direct rain penetration
External walls	Ch 4	In patches, often related to exposure to prevailing weather, usually showing efflorescence	In muggy weather	Condensation
External walls	5.2; Ch 5	From ceiling of top storey downwards	After rain	Indirect rain penetration, eg defective parapet
External walls	Ch 5	Patches related to rain water goods	After rain	Indirect rain penetration
Chimney breasts	Ch 5	From roof downwards; efflorescence but no brown stain	After rain	Rain penetration
Chimney breasts	Ch 7	In patches, often with brown discolouration	Winter and spring when flue is in use	Condensation in flue
Chimney breasts	2.1; Ch3	In patches, often with brown discolouration	In muggy weather	Hygroscopic salts
Ceilings	Ch 5	Patches	After rain	Rain penetration, leaky roof
Ceilings	Case studies p74 and 76; Ch 4	Patches or widespread	In morning after frosty night	Condensation on underside of roof
Ground floors (solid)	Ch 6	Patches or widespread	Any time, but especially when surrounding ground is wet	Rising damp
	Ch 6	Around edges	When weather turns warm and humid after a cold spell	Condensation
Ground floors (timber suspended)	4.18; Ch 6	Around edges	Any time	Rising damp or condensation

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Table 2.2 Causes and effects of dampness on materials and components used internally

Surface	Figure No and Chapter (Ch)	Observed effects	Cause	Substances involved in addition to water
Any	5.21; C 3	White crystalline growth, sometimes associated with crumbling	Efflorescence of soluble salts and crystallisation of salts within the surface	Akali salts and lime
Paints	Ch 3	Bleaching or change of colour; stickiness; yellow oily runs	Alkali attack	Construction water
		Coloured patches, often protruding slightly; mouldy smell	Mould growth	Organic matter as food
	2.3 5.36	Blistering and flaking	Pressure of vapour and crystallisation of soluble salts	Sometimes soluble salts
Lime plaster	5.49; Ch 3	Softening and crumbling and sometimes blistering	Partial solution and efflorescence	Soluble salts
Cement:sand and cement:lime: sand	Ch 3	Expansion; white specks	Sulfate attack	Soluble sulfates
	5.94; 6.13	Cracking of certain types	Moisture expansion and drying shrinkage	None
Floorings	6.17; Ch 6	Loss of adhesion of impervious coverings	Weakening of adhesive	None
		Rotting of timber and linoleum	Fungal attack	Fungus spores
Wood and wallboards	Ch 2	Warping and buckling	Moisture movement	None
	7.1	Rotting	Fungal attack	Fungus spores
		Delamination of some plyboards	Weakening of adhesive and moisture movement	None
Metals	2.17; 2.18; 2.20; Ch 2	Corrosion	Chemical attack	Air Sometimes salts, especially chlorides, and acids For some metals, eg aluminium and lead: lime Some kinds of timber, especially oak

different from those found in housing and with spore concentrations many orders of magnitude higher. However concerns are now being expressed that severe health problems can be caused by a particular species of moulds, *Stachybotrys Chartarum*, that propagates and grows in the persistently wet conditions following from, for example, a burst pipe or leaking roof. Cases of this, which have led to significant compensation claims have been reported from the USA. This condition may be most important in buildings that have not been adequately dried out after flooding. There is no evidence that any comparable problems have arisen in the UK but, with flooding expected to become more frequent, it is worth watching for the occurrence of this fungus.

DIAGNOSIS

Surveys

Surveys may reveal dampness, perhaps mould, in carpets at floor perimeters or, if there are no carpets, damp stains on the floor surface. This could indicate condensation but rain penetration or run-off from glazing may also be responsible at doors and windows. Inspection below a timber floor finish could indicate the origin of dampness but isolated inspection may not be representative. Where evidence of a problem at floor perimeters is found adjacent to cavity wall construction, you may have to remove a section of the outer leaf to determine the construction and check for cavity bridging. Lifting of floor tiles which extends to the centre of rooms often indicates rising dampness.

Staining

Evidence such as 'puddle staining' on the floor, dampness and mould growth beneath floor coverings or lifting of floor tiles indicates rising dampness. It is important to differentiate between moisture from condensation (at thermal bridging for example) and rising damp: two problems requiring different solutions. If evidence of moisture is concentrated at perimeters, you will have to check for thermal bridging. To check the physical presence of a DPM or the quality of the concrete, trial cores may be necessary. Consider also the ground around the building; a poorly drained site usually increases the risk of rising damp. Signs of dampness from past plumbing leaks and water spillage sometimes confuse diagnosis.

Brown stains on or near a chimney, or where a chimney used to be, are usually due to hygroscopic salts and combustion residues absorbed by the masonry from the condensing flue gases.

Figure 2.1 Peeling paper has revealed stains on a chimney breast

VISIBLE MOISTURE

Condensation

Visible condensation usually first takes place on impermeable cold surfaces, such as single-glazed windows and uninsulated cold water pipes and tanks. Initially, it takes the form of misting, later collecting into beads of moisture, then forming rivulets which run down any sloping or vertical surface under gravity. Puddles of water can form on horizontal surfaces, such as window sills, or on floors under cold rising water mains.

Figure 2.2 Condensation

Many porous building materials, for example timber and brick, take up moisture from the atmosphere: they are hygroscopic. This means that the pores start to fill with water at relatively low humidities; moisture contents may rise high enough to cause problems even though no condensation is taking place. Walls with high thermal capacity, where the surface temperature is unable to follow rapid changes to the air temperature, can often be below the dew-point, and are particularly vulnerable.

While condensation in itself may not give rise to more than a temporary nuisance, the mould growth which often accompanies persistent condensation is much more likely to give rise to serious complaint.

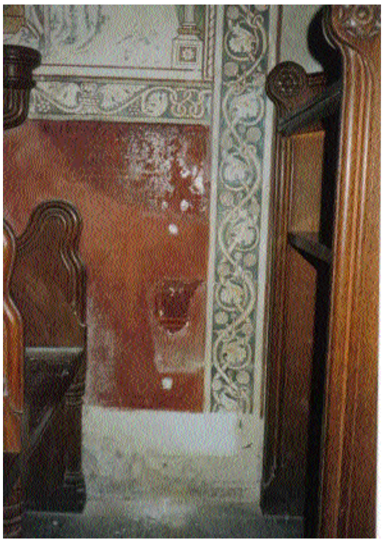

Figure 2.3 Condensation is absorbed into the wall and subsequently evaporates and salts destroy the surface

Rain penetration

Rain penetration usually takes the form of droplets or rivulets of water driven by wind force through gaps under overlapping sheets or tiles on flat or inclined elements, or through faulty joints in vertical elements. These droplets or rivulets may not reach the interior surfaces of the building at expected locations, since the points of entry and the points of emergence can be considerable distances apart. The penetration may also take the form of moisture being drawn through capillaries in the body of adjoining materials, which shows as damp patches at the point of evaporation.

Rising damp

Rising damp usually takes the form of saturation of vertical or horizontal surfaces, initially causing tide-marks with darkening of decoration. The mechanism is via capillaries. Salt crystals may form on the surface or behind decorations at the line of evaporation.

Figure 2.4 Damp patches at the point of evaporation

Figure 2.5 Rising damp

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MOULD GROWTH

Most of the problems resulting from surface condensation are caused by moulds. As well as being unsightly, they are thought to cause respiratory problems in susceptible individuals and are the cause of many complaints by building occupants. They should not occur in any part of a building.

Mould

Relative humidity should be kept below 70%, the level at which moulds can grow on some materials. This can be achieved by a combination of several or all of the following:

- ❒ generating less water within the building, for example in kitchens by keeping pans closed when cooking, and by not drying clothes indoors;
- ❒ ventilating water vapour at its source, for example using extract fans in kitchens and bathrooms, and trickle ventilators in bedrooms;
- ❒ insulating walls to increase the temperature of the internal space and of the surfaces; in the case of massive construction, in buildings which are occupied only intermittently, this may entail fixing internal insulating linings, so that the internal surface heats up rapidly when the rest of the wall is still cool;
- ❒ improving heating;
- ❒ avoiding or correcting thermal bridging on walls where mould may grow.

Minute spores of moulds are always present in the air and are freely deposited on all surfaces. There they can germinate and produce unsightly growths if conditions are suitable. They have two essential requirements: moisture and some form of food for further growth. Food for mould fungi is available in most building and decorating materials, in furnishings, and even in house dust.

Mould growth is therefore likely where surfaces or air are continuously or frequently damp. Such dampness can come from a number of sources: defects in the structure that allow rain penetration; plumbing leaks; rising damp; condensation of water vapour from the internal atmosphere. Of these, condensation is by far the most common.

Figure 2.6 Moulds occur on surfaces such as walls and ceilings. They are normally caused by persistent condensation, due in turn to moist air in unventilated conditions or at thermal bridges

Surface moulds

Surface moulds occur on external and internal building surfaces and are usually accompanied by persistent condensation or some other form of wetting. Externally, moulds are unsightly and may also cause premature failure of paint films. On internal surfaces, as well as being unsightly, mould causes respiratory problems in susceptible individuals.

Algae, lichens and mosses

Algal growths generally occur only on external surfaces where high moisture levels persist for long periods. Like moulds, they can cause problems with appearance and paint failure.

Guidance on the recognition of fungi and moulds in buildings and on remedial treatment is available in two BRE handbooks: *Recognising wood rot and insect damage in buildings* and *Remedial treatment of wood rot and insect damage in buildings*.

Commonly seen on roofs, the resulting appearance of algae, lichens and mosses is often regarded as beneficial. For aesthetic reasons, moderate levels of organic growths can be encouraged by washing the surface with a dilution of cow dung in water. However, these growths can increase the risk of frost damage to coverings such as porous tiles and fibre cement sheets, and they may interfere with drainage; for this reason they may have to be removed. Growths up to 100 mm deep have been reported to BRE, though this is rare. Since the Clean Air Act of 1956, growths have occurred in urban areas as well as in rural. BRE Digest 370 explains how to treat affected surfaces. Even less porous surfaces such as slate are not immune, and growths have been seen to begin in as little as two or three years.

TOXIC MOULD

Toxic mould species can cause a wide range of symptoms in occupants, ranging from headache and flu-like symptoms to serious and possibly permanent health impairment and death. The presence of toxic mould presents a more serious health risk for renovation workers in these buildings. However, not all moulds are toxic to humans.

Normal methods of determining the level of moulds in a building detect only a small percentage (sometimes as low as 1%) of the spores in the air. However, the spores that are unable to grow are still capable of either inducing allergic reactions or releasing water-soluble toxins when they come into contact with the moist surfaces of the human respiratory system. There is a need therefore to detect curable and non-curable toxigenic fungi.

Recent work at BRE has developed a Polymerase Chain Reaction (PCR) protocol, based on a specific marker gene that detects trichothecene-producing fungi. This protocol is highly selective and can distinguish between mycotoxin producing and non-mycotoxin producing isolates of the same species (ie *Stachybotrys chartarum*).

Remedies

Removal

There are several proprietary solutions that will remove growths of these organisms but use only those which have been given a number by HSE. You can use wet brushing or, in the worst cases, hosing with a power jet, provided care is taken not to damage the surface or to drive water between the laps of sheeted or tiled surfaces. Future growth may be inhibited by fitting small diameter copper pipe or wire above the area to be protected but the disfiguring stains that will result may not be visually acceptable. Copper chimney flashings inhibit organic growth only in the areas immediately under the flashing.

HSE Guidance Note EH 36, *Work with asbestos cement*, explains how to clean old asbestos cement roofs. Asbestos cement must not be brushed when it is dry. It must be thoroughly wetted to minimise the release of fibres from the material, and dust masks of the appropriate rating should be worn. Mould growth can be killed by toxic treatment but this provides only a temporary solution; the mould will return unless the source of moisture is removed. An essential first step is to identify the cause of the dampness, and then to remove it.

Do not remove mould growths by dry brushing or rubbing, as heavy growths release large amounts of spores into the air which occasionally induce allergic reaction. Use a vacuum cleaner then dampen the infected area with a 1:4 solution of domestic bleach in water containing a small amount of washing-up liquid. Wipe down the surfaces with a damp cloth rinsed out regularly. Wooden window frames may need several applications. Keep windows open to promote dispersion of spores and moisture and wear appropriate protection.

It is not easy to decide if mould is just growing upon the surface or has penetrated further. Where decorations can be stripped off (distemper, wallpaper, polystyrene tiles, flaking paint) it is often best to do so, but where the growth is slight it may be sufficient to clean down without stripping.

Sterilisation

Before re-decoration, sterilise the stripped or cleaned surface with an approved wash and keep it under observation. At least a week is necessary but longer is advisable. If mould reappears, wash it down again with the toxic wash to ensure sterilisation is thorough.

Clean fabrics and soft furnishings by sponging affected areas with a solution of an approved wash, not bleach. Apply the solution sparingly, first testing a small, insignificant area for any adverse effects; dry thoroughly afterwards.

There are many products for use as toxic washes though not all are widely available. Suitable toxic washes and chemicals which are safe to use include quaternary ammonium compounds and sodium hypochloride. Some yellowing of paints may occur with some treatments.

Use only proprietary products with labels which state that they have been cleared as safe for this use; there is some risk in the use of all these materials. The supplier's instructions and recommended precautions should be carefully observed.

If the toxic wash treatment appears to have been successful, redecoration can be undertaken. Fungicides incorporated into the decorative finish protect only the finish itself and do not obviate the need for the preliminary toxic wash treatment. Some manufacturers supply paints and wallpaper adhesives incorporating fungicides and it is better to use these than to add them on site.

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SALTS

Rising damp can bring salts up from the ground, which are then deposited into the fabric of the wall and remain there even after the original dampness has been cured. When the surrounding air is humid, the salts absorb moisture, and damp patches appear.

Salts can enter the building in various ways: from sea-sand or gravel which has not been adequately washed, or from additives used for frost protection or for rapid setting of mortar or concrete. Other possible sources are magnesite in composition floors, or previous use of the building, such as in a conversion of stables which have been contaminated by faeces or urine.

Figure 2.7 Plaster finish disrupted by salts – *see also page 156§*

Diagnosis

To know where they come from, you must identify what kind of salts are present. This process will frequently need laboratory analysis.

Remedies

Where a wall is thoroughly contaminated with deliquescent salts, there is little hope of removing enough of the salt to prevent dampness appearing in humid weather. Often, however, the salts will be found to have concentrated at the surface, when they can be removed by stripping off the contaminated plaster. For small patches, one old form of treatment was to extract the salts with a poultice of whiting and water. After removing wallpaper or impervious decoration, a layer of whiting and water made up as a stiff paste was trowelled on to give a thickness of about 6 mm. The poultice was left in place until dry, and then removed. The wall was then brushed down, and re-decoration carried out in the usual way. Whiting was the old term for finely powdered chalk, sometimes bound with a small quantity of tallow. More modern techniques for poulticing are in a case study on page 200.

FROST

Building components frequently deteriorate when several meteorological parameters act together. One example is frost damage to porous materials. This occurs when freezing conditions coincide with high moisture content, near saturation. The air temperature at which frost damages walling materials usually needs to be several degrees below freezing since the wall often receives heat energy from inside the building. The wall also has a certain thermal capacity. Furthermore, although water in the largest pores of the materials may freeze at a little below 0 °C, the freezing point in the smallest pores may differ by several degrees. At -2°C air temperature, there will be some freezing in the pores, not necessarily leading to damage, though freezing will take place with some materials rather earlier.

Figure 2.8 Frost damaged brickwork

Factors affecting the susceptibility of a given wall to frost damage include the precise porous characteristics of the material, the speed and duration of freezing, the number of faces frozen simultaneously, the moisture content and its distribution, and the internal strength of the porous brick or other unit and its parts.

Diagnosis

Frost attack occurs most frequently only in relatively new construction using unsuitable materials. After all, if buildings built more than, say, twenty or thirty years earlier were vulnerable to frost attack, there will already have been evidence of repair. It is often those materials which depend on water for setting, such as mortar and in-situ concrete, which suffer deterioration, showing a friable or spongy consistency.

The problem is caused by a poor choice of materials. As an example, facing bricks used for sills and below DPC level, which are in parts of the wall experiencing continuously damp conditions, may not be of M or O quality to BS 3921 and will be more susceptible to frost damage than F quality.

Mild stocks were used internally in many older, especially Victorian, buildings where they are perfectly serviceable, but if they are re-used in external walling they can suffer rapid and severe frost attack. There are implications for using re-cycled materials. Gaults as a class were not particularly durable, but some specimens were. Some of the Keuper marl bricks were not durable. Flettons, of course, are not suitable for the most severe exposures, and the manufacturers offer advice on their specification.

Bricklaying, repointing or concreting should not proceed in the following conditions:

❒ air temperature below or expected to fall below 2°C;
❒ when aggregates are frostbound;
❒ in driving rain.

Frost testing specimens

It has proved difficult to devise a reliable and representative test to assess frost resistance. Any method must select particular conditions which may then not apply to a specific application of the material. For example, freeze and thaw tests on individual bricks are easy to carry out and give rapid results. However, they represent unique conditions which rarely occur in practice in exactly those same circumstances.

There is no current British Standard test for durability to frost damage, but there are RILEM recommendations and British and European standard tests for frost resistance of units and mortars, both based on UK research (eg BS EN 12371 for stone). Even so, there are tests which are well established and quite widely used for similar purposes; for example, salt crystallisation tests are used in the UK to assess limestones and have been used for an overall assessment of durability. They allow prediction of suitability for different locations on a building; and in some cases can be used to determine different susceptibilities to frost attack. Crystallisation tests may be used for other types of stone, although interpretation is less certain.

Remedies

If mortar in new construction has suffered, either through lack of cement or poor quality sand, or insufficient protection from frost, it may be sufficient to rake out the joints to the depth of damage and re-point. It will be a matter for judgement; many supervisors in the past have had no qualms about ordering demolition and re-construction of affected work. If materials have failed, the solution will usually be more radical, and replacement or rebuilding with different materials may be needed.

TIMBER ROT

Types of fungi

There are two types of building fungi: those that cause wood rot and those that do not. Wet rot occurs mainly at the bearings of timber joists in external walls, for example at the sole or head plates rather than in the studs. Wet rot decay of timber and timber based board materials can take place only where these are maintained in persistently damp conditions.

Attack is usually initiated from microscopic airborne spores; it can also occur where pre-infected timber has been used when decay can be rapid in new construction. Under appropriate conditions damage may be rapid and severe and structurally significant. The dry rot fungus, *Serpula lacrymans*, is more devastating, though less common than wet rot, and can infect parts of the structure which are relatively dry.

Figure 2.9 Fruit bodies of *Paxillus Panudides* and decayed wood. This fungus prefers softwoods in damp situations

More information is in three BRE books: *Recognising wood rot and insect damage in buildings*, *Remedial treatment of wood rot and insect attack in buildings* and *Roofs and roofing*.

Occurrence of rot

Roofs

Wet rot can be quite a problem in roofs, though it is more likely to be in evidence in fascias and bargeboards than in the structure. The *English house condition survey 1991* shows that, on average, around one in four houses has faults in its fascias, with the majority of cases probably associated with decay. Age does not seem to make much difference to the rate of occurrence until post-1980 houses show a fall to around one in 10; this is more likely to be due to the time delay required for decay to become significant rather than the growth in the application of preservative treatment or the use of alternative materials, such as plastics.

Floors

Softwood timber is generally used for floor construction and must be maintained in a ‘dry’ condition to avoid rot. Timber floors at ground level are

Figure 2.10 This floor joist was installed in contact with wet external brickwork

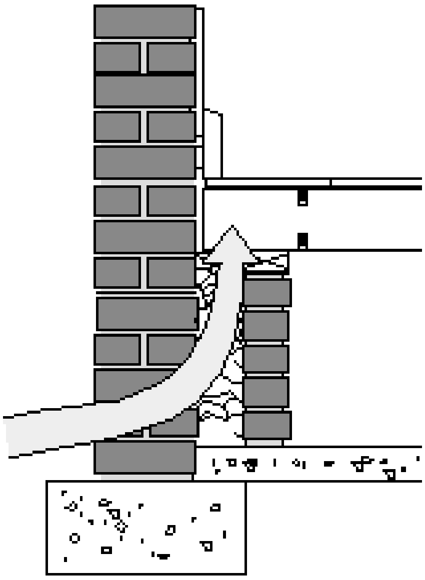

Figure 2.11 Debris or builder's rubbish may bridge the DPC

Figure 2.12 This floor has been devastated by dry rot. Such collapses are quite rare

normally supported on masonry or concrete and protected from rising damp by impervious membranes (DPCs or DPMs). If the membranes are bridged, fractured or deteriorated, rising damp may reach the timber. Additionally, timber floors can become damp if joists have been built in contact with solid external walls, particularly if these are located in an area of high exposure to driving rain – see also page 174.

Although there is a small risk of condensation in a suspended timber ground floor which has been upgraded with thermal insulation, a vapour control layer is not necessary since any small amounts of condensation which form should be vented safely away by air currents under the deck. A vapour control layer (VCL) also might provide a catchment tray for accidental spillages of water which would form a reservoir.

The DPC can be bridged or the underfloor void can flood if the ground or paving around the building is raised. Ends of any joists or boards in contact with solid external walls must be protected or replaced with less vulnerable construction. Replacement DPCs may be needed at these points below wall plates or joists on sleeper walls, and drainage may have to be provided.

Remedies

Replace rotten joist bearings

Rotten joist bearings can be replaced. Figure 2.13 gives one method which has proved to be satisfactory. Where the old joists have been supported from the external wall directly, however, it may be preferable to block the old joist holes and to insert steel shoes to carry the replacements Any adjacent timber that is left after an occurrence of rot must be correctly treated – see *Remedial treatment of wood rot and insect damage in buildings*.

If a timber floor shows signs of distress after repair, the replacement ends may have been inadequately bolted to the sound parts which were retained, or the repaired joists may have rotated.

Specifiers sometimes find it necessary to replace suspended timber floors with solid concrete, for example where access for the disabled is being upgraded. Providing adequate damp-proofing in these circumstances is crucial to subsequent performance.

There are specialist techniques for repairing structural timbers in the floors of heritage buildings. Advice cannot be covered adequately here but guidance is available from BRE or from the heritage organisations.

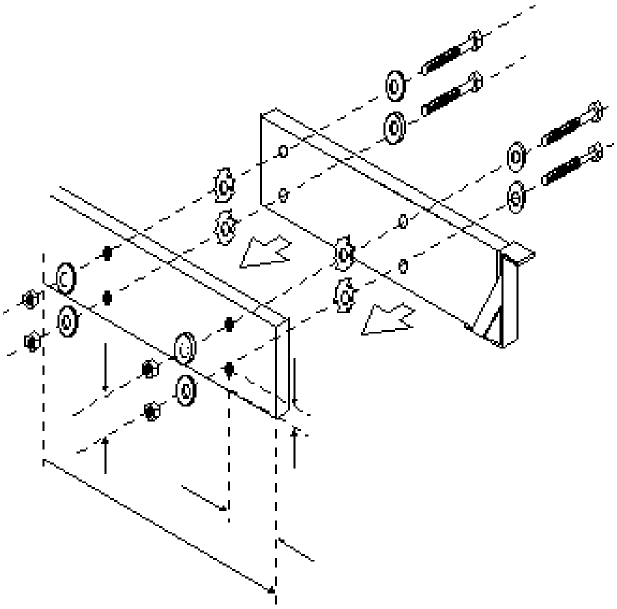

Figure 2.13 Repairing a deteriorated timber joist with a new section

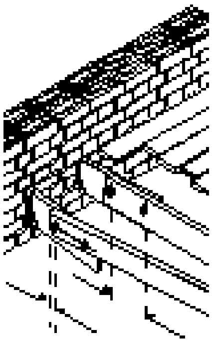

Figure 2.14 Inadequate former repairs of joist bearings

Provide adequate ventilation to suspended floors

Voids under suspended timber ground floors must be ventilated to prevent decay. Existing suspended timber ground floors often have less ventilation than is currently recommended, and the ventilation openings provided may be obstructed by outside ground, pavings or vegetation. Areas of solid floor may impede cross-ventilation to kitchens, sculleries and halls. Building rubbish left under floors can also obstruct ventilation.

Recommendations on the amount of free ventilation area which should be provided have varied over the years. There is little scientific evidence on how much ventilation is required to ensure freedom from deterioration of the timbers. It appears that the provision of air-bricks in subfloor voids in late Victorian times was governed entirely by rule of thumb. The earliest Building Research Station recommendation was just prior to the 1939–45 war, when 1.5 square inches open area per foot run of wall was recommended. This was repeated in 1961 in *Principles of modern building* which also recommended that vents should be provided in at least two external walls on opposite sides of the building, and if possible in all walls. Pipes or ducts were also recommended to provide for air movement around obstructions caused by solid floors and hearths – Figure 2.15.

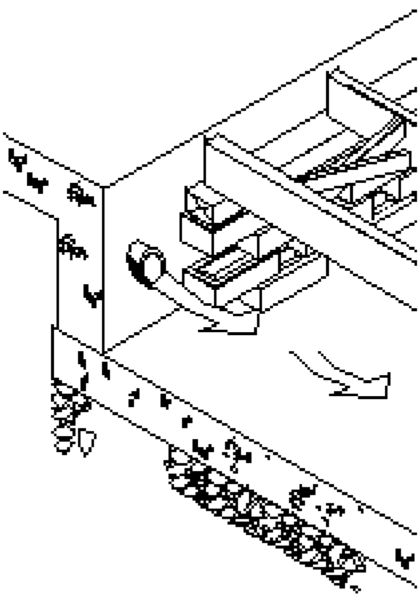

Figure 2.15 Vents inserted to provide cross-ventilation in a part solid, part suspended ground floor

Although it was customary to insert air-bricks under suspended timber floors in buildings built under the old Model Byelaws made under the Public Health Act 1936, the only specific requirement was for a free air-space providing through ventilation of 3 inches if the subfloor was concreted or covered with asphalt, or 9 inches if not so covered. The Building Regulations for England and Wales 1972 increased the void depth requirement for covered subfloors to 125 mm, but still the free area of vents in the external wall was defined only as 'adequate'.

BS CP 102 gave a requirement of 3200 mm^2 per metre run of external wall, whereas the current Approved Document C4 for England and Wales gives in paragraph 1.10(b) a figure of 1500 mm^2 per metre run.

BS 5250 gives a figure of 1500 mm^2 per metre run, or 500 mm^2 per m^2 of floor area, whichever is the greater. In Scotland, Part G of the Regulations applies.

The ventilation rates actually achieved under suspended ground floors vary according to position of the vents and the prevailing conditions. However, provisions in accordance with the building regulations can be expected to achieve adequate ventilation rates. In BRE tests, the ventilation rates actually achieved under a timber suspended floor were measured over periods of two to three days. Several subfloor air-brick locations were tested, although the total ventilation area remained at the level recommended in the then current building regulations. The subfloor ventilation rates measured for this example fluctuated widely, ranging from two air changes per hour (ACH) to over 18. The subfloor temperature remained constant through the day and night, and wind speed had only a limited effect on the subfloor ventilation rate; temperature difference (subfloor/external and internal/external) was far more important.

Gaps between boards in older floors provided additional ventilation in the underfloor space. A problem often occurred if these floors were covered with an impervious material which prevented this ventilation, and decay resulted. Fifty years ago this was widely known as 'linoleum rot'.

METAL CORROSION

Steel reinforcement is protected against corrosion by the alkaline environment of fresh concrete. However, carbon dioxide gradually penetrates from the concrete surface inwards, neutralising the alkalinity as it progresses (carbonation). When carbonation reaches the reinforcement, the steel is much more vulnerable to corrosion and, in the worst cases, rusting can cause the concrete to spall.

Parts of the building at risk

Beam-and-block floors

A typical beam-and-block floor is assembled when the walls are at DPC level. The beams are set on the inner leaf of the external wall, and should not protrude into the cavity. They must be placed on a DPC to prevent moisture and soluble salts moving from the brickwork and ground into the beams. It is particularly important to prevent the ingress of salts which can increase the rate of corrosion of the reinforcement.

BRE site inspections revealed cases of precast beams projecting into and across external wall cavities, owing to inaccuracies on site. Such projections may give rise to penetrating damp, especially if they later collect mortar droppings in the cavity. The wall DPC should link with the floor DPC or DPM but in more than 10% of cases using precast concrete floors examined by Housing Association Property Mutual, such linkage was unsatisfactory.

Reinforced concrete beams

Cover to reinforcement in most high alumina cement concrete (HACC) beams was commonly less than 20 mm and cracking can occur due to corrosion. Chemical attack may result in further loss in strength where the components are subject to persistent dampness. If the effects on strength are severe, the question of durability is one for a specialist.

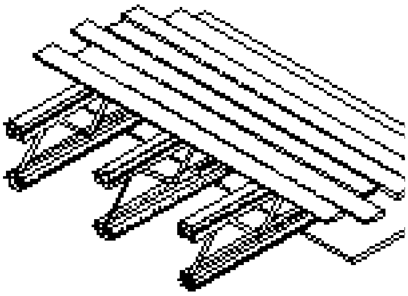

Figure 2.16 A fabricated steel joisted floor. Although the joists in these floors were not always galvanised, significant corrosion in ungalvanised units has been rare

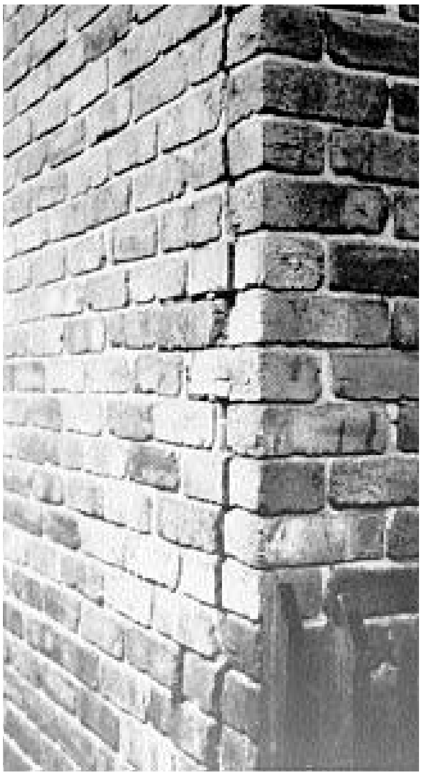

Figure 2.17 Cracked brickwork in a 1920s Dennis Wild system-built house caused by rusting of the corner stanchion

Steel joists, beams and stanchions

With ordinary hot-rolled steel joisted floor beams and fabricated steel floors – Figure 2.16 – whatever the disposition of the steel, strength and stability are rarely compromised by corrosion, and loss of section due to corrosion will be rare. Where it does occur in floors, it will be confined for the most part to the building's perimeter.

Steel roof structures are vulnerable to penetrating damp and condensation.

The corrosion of steel in steel-framed non-traditional housing systems is a more serious problem. The greatest incidence of corrosion of the frame in steel systems examined has been observed in areas with high driving rain. The problem may be exacerbated in dwellings where there is a clear line of sight to open country. Most steelwork paint protective systems examined were deteriorating but this does not automatically mean that such coatings need renewal. It depends what service life is required from the dwelling.

BRE site observations of the corrosion rates of steel in low-rise systems indicates typical rates of 3 mm in 20 years for steelwork in contact with wet cladding. The expansion caused by the rusting exerts considerable force on claddings, sufficient to crack brickwork – Figure 2.17.

Some Presweld steel-framed system-built houses had fully galvanised frames, but these houses were in a minority – see case study on page 78. The ground floor elevations of British Iron and Steel Federation (BISF) System houses, Dorlonco System houses and Crane System houses, are prone to cracked renderings following carbonation of the render and loss of galvanising to the mesh backing.

Although some rusting of rolled steel angled columns and beams has been observed by BRE in most steel framed systems, no dwelling had to be taken out of service because of structural considerations. Pressed sheet steel sections have less steel content and, once the protective coating has disappeared, there is less steel to survive. Trusteel System-built dwellings, particularly the Mark II, need careful examination. In most cases, this means exposing a corner column. However, even nearly complete rusting away of a column at its base will not necessarily mean that failure of the complete frame is imminent. Normally there was some redundancy in the frame, and load sharing seems to take place. Corroded structural steel sections, other than lattice sections, are not difficult to cut away and replace, but it does mean opening up the structure – Figure 2.18.

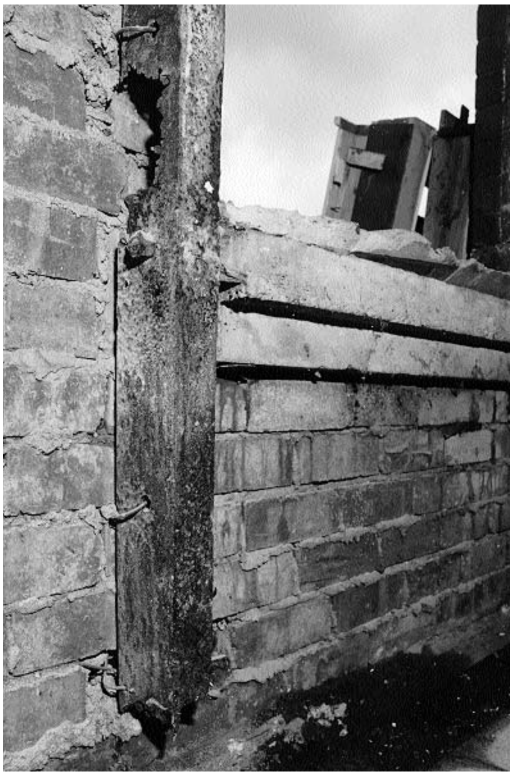

Figure 2.18 The internal leaf has been removed to reveal a badly corroded steel column. In this case there has been some load sharing, and the brick outer leaf is now supporting the column

Dorlonco System-built houses have concrete floors and ceilings, and reinforcement had deteriorated following carbonation of the concrete. In some Dennis Wild System-built houses, the external walls have bulged following corrosion of wall ties.

No problems with loss of integrity of the structural frame have been reported on Atholls and Telfords, though some BISFs have had serious corrosion of stanchion bases. Corrosion of the sheeting rails on BISFs from condensation within the cavity leads to protrusion of hook bolts.

Extensive corrosion of sheeting on Atholl System-built houses built post-1945 has occurred to a much greater extent than on interwar examples. Some Atholls also had timber framing in the external wall which is at risk if rainwater penetrates. The structural frames of Open System dwellings were galvanised; this is a comparative rarity in dwelling systems, although less of a rarity in other building types. In Livett-Cartwright System-built houses the jointing material has deteriorated, allowing rain penetration.

All systems in this category had some breakdown of protective coatings to the structural steel components, though in no case had this progressed sufficiently to allow more than superficial corrosion of the steel. However, the situation was rather different with steel sheet claddings, where some severe corrosion was found.

Sheet steel floors next to the ground

Where steel decking is used as permanent shuttering, and as part of the structure of a floor next to the ground, no further damp-proofing arrangements are normally required. Neither is ventilation of the underfloor void normally provided. Consequently, the underside of the deck may be subjected to long-term corrosion risk from the relatively high humidities, if it is inadequately protected. Table 3 in Section 2 of BS 5493: Part 6 refers to steelwork in dry interiors, and BS 5493: Part 7 to wet or damp conditions. Ventilating the void will reduce the risk of accumulation of moisture, but will not remove it altogether.

Concrete rafts

Raft foundations are engineered floors in which the condition of the steel and concrete affects the performance of the whole building. Corrosion of steel reinforcement may occur where steel is close to the top surface of the concrete and therefore vulnerable to dampness, for example at perimeters of rafts – Figure 2.19.

Steel in roofs and roofing

Corrosion of steel sections, sheets and fixings in roofs can be anticipated where the original protection has disappeared, though most corrosion of steel in these situations seen by BRE has been superficial – Figure 2.20. Most examples of steel framed roofs in non-traditional housing have already survived for their design lives but should be capable of giving further service. The most vulnerable will be those where thin steel sheet has been

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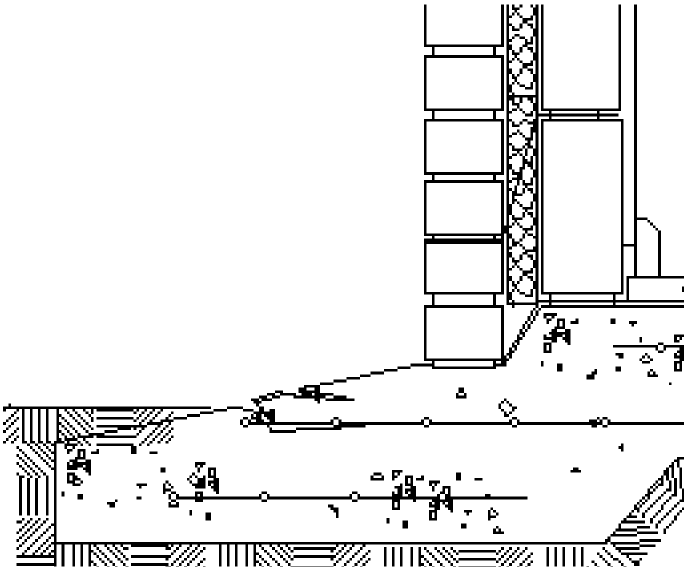

Figure 2.19 The toe of a raft is vulnerable where it extends beyond the perimeter of the building

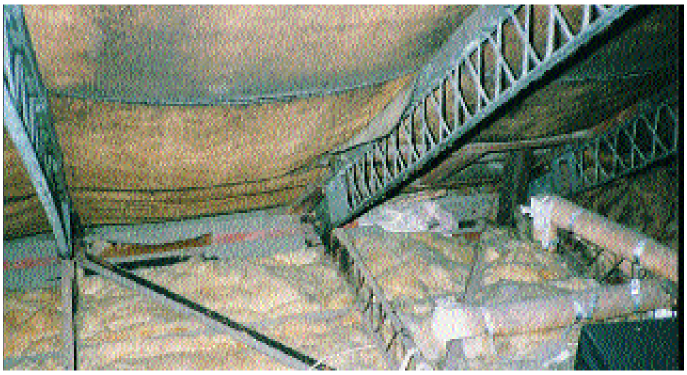

Figure 2.20 Inside the roof of a Hills System house. Some of the principal rafters and ceiling ties are galvanised, but others are not. Though the steel units are beginning to show corrosion, it is superficial and there is no immediate cause for concern

folded to form the loadbearing members: where the surface protection has gone, there is comparatively little steel left to corrode. Particular attention needs to be paid to those systems which made extensive use of thin metal fabricated sections, for example Trusteel System-built and Hills System-built – see *Steel framed and steel clad houses: inspection and assessment.*

Red rust corrosion on truss connector plates, as well as the more common zinc oxide (or white rust) has been seen on BRE site inspections; this raises questions of future durability. Occasionally, a roof has been found in a totally unsatisfactory condition owing to corrosion of the plates. Following a special survey on trussed rafter roofs, BRE published Current Paper 5/83 in 1983. It concluded that corrosion of metal plate fasteners was not a significant problem generally, though the situation might be exacerbated by preservative treatment with CCA (copper-chromium-arsenic) salts or by proximity to the coast. That is still true but, where the thermal insulation covers the plates, there is a risk of the insulation becoming saturated from condensation or from leaks in the outer covering; the poultice effect of the insulation will create conditions favouring corrosion, and so accelerate the process.

Short-span concrete deck roofs usually give visual warning of deterioration before danger of collapse is imminent, but longer spans may be more problematical, especially with roofs of box construction where the corrosion can proceed unseen.

Nail sickness

With older slates and tiles, it is the fixings which usually give problems before the units themselves deteriorate. Since there is no nib on slates or peg tiles to provide extra purchase on the batten, corrosion of the nail or rot of the peg will let the unit slip. This ‘nail sickness’ can be quite widespread in roofs over about 50 years of age, depending on the specification of the original nails and the pollution which the roof has experienced.

Diagnosis

Floors

Reinforced concrete floors may show defects on routine inspection which call for further testing. Such visual evidence includes cracking, corrosion and spalling, disruption of anchors in post-tensioned structures, and any evidence of water penetration at external wall bearings. Load tests on completed structures or parts of structures may also be called for by the structural engineer, and assessments carried out on cracking and recovery of the structure from deflection.

Roofs

Visual evidence of the results of dampness includes cracking, corrosion and spalling, disruption of anchors in post-tensioned structures, and water penetration. Radar can detect the presence of water in roofs but it will not provide useful information on the presence of corrosion of reinforcement; other test methods may be appropriate and further advice should be sought. The structural engineer may require load tests on completed structures or parts of structures, and assessments on cracking and recovery of the structure from deflection.

Swimming pools

It is particularly important that the metals used in the roofs and walls of swimming pools are separated because the corrosive atmosphere will accelerate corrosion of the less noble metals in contact with other metals. However, BRE has found comparatively little corrosion of the metal indoor roof cladding in swimming pools. The main risk is where profiled sheeting is manufactured with uncoated cut edges; in humid conditions these edges will corrode leading, initially, to staining of the sheet and, if neglected, underfilm corrosion causing blistering and detachment of the protective organic coating.

Wall tie corrosion

Ferrous wall ties in cavity wall construction are vulnerable to corrosion from rain penetration of the external skin. Regular horizontal cracks indicate expansion caused by advanced wall tie corrosion. A 'belly' in a wall might indicate lack of restraint, lack of buttressing, lack of wall ties or, more usually, wall tie failure by corrosion.

The problem of wall tie corrosion could eventually affect virtually all cavity walled structures built with galvanised steel ties. Those built before 1981 are likely to fail earlier because the standard specified a thinner layer of galvanising than it did post-1981. Wall tie corrosion is not confined to cases of poorly-made ties, to aggressive mortars, nor to conditions of extreme exposure – it is just more rapid in those circumstances.

Austenitic stainless steel and duplex coat, zinc-plus-epoxy or zinc-plus-pvc coated mild steel ties generally suffer little deterioration. Copper alloy (bronze) ties may suffer minor dezincification, indicated by a salmon-pink colour on the surface. The only other material widely used for ties is polypropylene (plastics) which is unlikely to suffer chemical deterioration provided light is excluded, but might be subject to vermin attack.

BS 5628-3 requires the use of corrosion-resistant materials for fixings (including wall ties) above three storeys. Specifying an appropriate austenitic stainless steel for wall ties effectively removes any risk of corrosion. Site practices, other than the substitution of inferior wall ties for those specified, will then have little, if any, bearing on the risk of tie corrosion.

Galvanised ties are at risk of corrosion; most at risk are in walls:
- ❒ built in black ash mortars;
- ❒ exposed to severe weather, especially in marine or industrial environments;
- ❒ built between 1900 and 1940;
- ❒ built with vertical twist ties during the shortages which followed the 1939–45 war, or during building booms, especially in the early 1970s;
- ❒ where the ties' galvanised coating has exceeded its predicted life; this depends on thickness but in most cases will be 35 years for vertical twist ties and 20 years for wire ties;
- ❒ built with galvanised ties supporting the outer leaf of brick-clad timber frame construction where the protective coating has exceeded its predicted life; this depends on its thickness and the in-service conditions, but in most cases will be 15 years.

If the first two conditions above are combined with any of the others, surveyors should be particularly vigilant and remedial action will be required.

The surveyor's first need is to be certain that the wall is of cavity construction. Next, the outer leaf should be examined for regular horizontal cracks at about 300 – 450 mm spacing; they are usually more evident in the upper parts of the wall and likely to be more clearly delineated on a rendered wall. Remember that cracks may have been repointed or the wall re-rendered.

The cracks are distinguishable from the otherwise similar cracks caused by sulfate attack on brickwork or rendered brickwork since they occur at vertical wall tie spacing intervals rather than in every bed joint. Corresponding cracks in the inner leaf are rare but some may occur where cross walls are bonded to cavity walls. They may also be found in the inner leaves of walls enclosing unheated spaces.

Cracks in the external leaf are virtually certain to have been caused by vertical twist ties because wire ties have too little bulk to generate a significant volume of corrosion product unless the mortar joints are very thin. If wall tie corrosion is suspected, it is fairly simple to locate a tie and to remove a brick from the outer leaf to look at the tie. Digest 401 gives guidance on sampling.

Another way is to insert an optical probe through strategically drilled holes – Figure 5.35. However, corrosion occurs mainly on the part of the tie that is bedded in the outer leaf close to the cavity face. Absence of corrosion on the part that spans the cavity cannot be taken as firm evidence without some sampling and direct examination of parts bedded in the outer leaf. Other, generally more expensive, inspection techniques are described in Digest 329.

If there is wall tie corrosion, consider the possibility that the accompanying expansion has unacceptably distorted the wall or transferred to the outer leaf loads intended to be carried by the inner leaf (for example, roof loads). Be aware also that cavity ties can be used where there is no cavity; for example, in some cross-wall housing, separating walls are projected beyond the face of the building and their ends cloaked by a half-brick skin carried up to the full height. Stability of the brick skin can depend wholly on the integrity of the ties.

The most common technique for locating ties is to use a metal detector, a specialised device designed to find metal within a range of about 100 mm. 'Treasure locators' are not suitable, and stainless steel needs specialised devices. Infra-red thermography can be used for detecting wall ties. The method is a smaller-scale version of that used on whole buildings to detect heat losses; in this case, it is the action of ties as thermal bridges that is used. The test is non-destructive and theoretically can be used on any form of cavity wall construction that uses metal wall ties.

Do not mistake rusty streaks caused by iron-bearing aggregates for corrosion of reinforcement, wall ties or fixings: corrosion is usually accompanied by cracking.

Remedies

Protecting embedded steel

Metals perform best in a clean, dry environment but it is rarely possible to achieve these ideal conditions. The design should prevent, as far as possible, dirt, dust and moisture lodging on the external surfaces. This, in general, means avoiding horizontal or near-horizontal surfaces.

The conditions under which the building is required to maintain weathertightness become more onerous as height increases. The construction must be sufficiently weathertight so that joints and inadvertent crevices in the design do not allow corrosion to occur unseen. It is wise to assume that there will be some moisture ingress, to check for water entrapment, and to ensure that any frame material is adequately corrosion-resistant or corrosion-protected, particularly at high levels.

Thermal insulation within the cavities of the structure could also complicate matters as moisture can collect in some materials and be retained within a poultice in contact with a frame material prone to corrosion. It may seem that the major risk is from rain penetration but do not discount the possibility that condensation can increase the risk of corrosion, both to any frame as well as to the internal face of any metal cladding. Ventilating the cavity is the best way of reducing this risk but there should be no inadvertent reduction of thermal insulation.

With the exception of stainless steels, ferrous materials are normally insufficiently durable externally, and require additional corrosion protection. This can either be in the form of a metallic coating, such as zinc, or an organic coating, such as PVC, or a combination of both (a duplex coating). The life of ferrous metals is related directly to their protective coatings.

The most common metallic coating is zinc, applied by galvanising or sherardising, although other electro-plated or hot-dipped coatings, for example of aluminium zinc alloys, and aluminium, are available.

Protecting sheet steel exposed internally

The long-term performance of metallic roofing components is dictated largely by their resistance to corrosion. It is common practice for the protection on the underside of composite metal sandwich sheets to be of much lower specification than that on the upper surface. If there is any serious risk of condensation forming on the underside of profiled sheets, the underside will need suitable extra protection. Consult the manufacturer to identify a compatible coating. If the complete roof is built up in situ from

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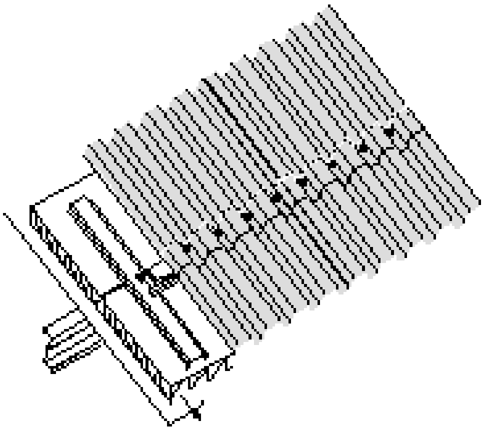

Figure 2.21 A liner tray under profiled metal roofing with separate thermal insulation

separate linings, thermal insulation and outer sheetings, take care that no thermal bridges are formed within the construction – Figure 2.21. The risk of condensation forming on the underside of the outer sheet depends on the integrity of the inner lining acting as a vapour control layer.

Thermal insulation immediately below a roof covering can also complicate the situation as moisture can collect in some insulation materials and be retained within a poultice in contact with the frame. As with embedded steel already mentioned, it may seem that the major risk is from rain penetration but consider the possibility of condensation increasing the risk of corrosion, both to the structure as well as to the internal face of the metal roofing; in some circumstances, condensation can be a significant risk.

Under normal conditions in a swimming pool building, ferrous metals with an organic coating (paint or bonded plastics) should perform satisfactorily; bare metal must not be exposed. Under more severe conditions, for example over flume pools, organic coatings alone are not suitable and the continually humid atmosphere means that repainting is not a lasting solution.

Protecting steel frames exposed internally and in wall cavities

Maintenance of a steel frame is unlikely to be needed, unless the cladding can be stripped to allow corrosion protection to be restored.

Plain mild steel frames need some protection; the main options are hot dip galvanising or organic coatings, or both. The required thickness of a zinc coating is determined by the required life of the frame; the size, chemical composition and method of manufacture of the component members of the frame determine whether it is possible to achieve that thickness. BS 5493, the Code of practice for protective coatings of iron and steel structures against corrosion, is relevant: Part 6 refers to steelwork in dry interiors, and Part 7 to wet or damp conditions.

Protecting aluminium exposed internally

Aluminium, normally used in construction in the form of an alloy, is relatively durable. An oxide skin forms when it is exposed to the atmosphere, providing a natural protective layer. Select an appropriate alloy to meet the wide range of service conditions; copper-bearing aluminium alloys are not suitable. Depending upon service conditions, aluminium can be further protected by plastics coatings or by anodising.

Replacing wall ties

Digest 329 describes the techniques for reinstating cavity walls by inserting new wall ties without recourse to demolition.

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HIDDEN DAMPNESS

Dampness can seriously affect parts of the building that are not immediately visible. Hidden dampness must be discovered because it can lead to severe deterioration in timbers or metals, and can result in structural problems. Sometimes there are visible signs of hidden damp.

Diagnosis

Systematic measurement of moisture contents can provide vital clues of hidden dampness.

Moisture meters

Moisture meters are useful for revealing sudden changes in moisture content in such materials as wood, plaster and screeds. This points to possible problems and the need for more detailed investigation; for example, a sudden change in the readings along the length of a skirting board could indicate dampness in the wall behind it or in the floor beneath.

Moisture meters can also help to discover the boundaries of damp areas. However, it can be difficult to interpret the significance of the actual measurements and it is important to use them only for detecting differences in moisture contents.

Optical inspection

The optical probe or ‘borescope’ is useful for diagnosing damp patches on unfilled cavity walls or walls with partial fill. This is the only non-destructive way of looking inside the cavity to see if it is bridged by mortar droppings or other debris.

The cause of dampness in solid floors can sometimes be difficult to detect. A simple method for distinguishing between rising damp and condensation is to use a sheet of kitchen foil. Place a piece of foil about half a metre square on the floor, under the carpet/underlay if there is one, and seal it firmly round the edges with adhesive tape. Inspect it the next day: if moisture has collected on the underside of the foil, there is dampness in the slab. If the moisture is on the upper surface, it is condensation.

Signs of hidden dampness

- ❒ blistering and flaking paint;
- ❒ softening and deterioration of plaster;
- ❒ expansion or cracking; this can indicate moisture movement or sulfate attack;
- ❒ loss of adhesion of impervious floor coverings on solid floors;
- ❒ sagging ceilings or timber floors;
- ❒ fungal attack in timber floors;
- ❒ warping, buckling or deteriorating wood-based sheet materials;
- ❒ cracking caused by corrosion of metal fixings;
- ❒ corrosion of steel wiring.

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Check lists

When you are diagnosing the causes of dampness, ask:

❒ when was it built ?
❒ what is the construction ?
❒ has it been unoccupied or unheated ?
❒ what type of occupation: family, single person, institutional ?
❒ is it exposed to severe rainfall and wind, and from which direction ?
❒ what was the weather recently ?
❒ when did dampness first appear, and how long did it last ?
❒ was there any liquid water on surfaces or dripping from the window heads or ceilings ?
❒ what colour and shape are the damp patches; is there a stain, tide-mark, mould growth or salt deposit ?
❒ where are the patches in the room: wall, ceiling, floor, corner ?

REFERENCES AND FURTHER READING IN CHAPTER 2

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Roofs and roofing BR302

Current Paper
5/83 Trussed rafter roofs

Digests
329 Installing wall ties in existing construction
370 Control of lichens, moulds and similar growths
401 Replacing wall ties

British Standards Institution
BS 3921: 1985 Specification for clay bricks
BS 5250: 2002 Code of practice for control of condensation in buildings
BS 5493: 1977 Code of practice for protective coating of iron and steel structures against corrosion
BS 5628-3: 2001 Code of practice for use of masonry. Materials and components, design and workmanship
BS EN 12371: 2001 Natural stone test methods. Determination of frost resistance
BS CP 102: 1973 Code of practice for protection of buildings against water from the ground

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Chapter 3
Measuring moisture

Instruments for measuring moisture
Laboratory tests for salts
Instruments for measuring humidity

INSTRUMENTS FOR MEASURING MOISTURE

Measuring accurately the dampness in materials, or strictly speaking the moisture content of walls, is fraught with difficulty. We often need to know when a material is 'dry', although in absolute terms a porous material in a building will nearly always retain some moisture, either from natural hygroscopicity or from the effects of deliquescent salts contained in the material. Here we briefly describe the most commonly available methods of determining moisture content. Other methods are available but they are used mainly in laboratory and specialised applications.

The ideal method of measuring moisture contents in materials would be:

- ❒ non-destructive;
- ❒ independent of the substrate (no need for calibration);
- ❒ equally sensitive at all moisture contents;
- ❒ independent of the presence of soluble salts;
- ❒ independent of temperature;
- ❒ independent of surface texture;
- ❒ capable of giving values for moisture profiles;
- ❒ capable of being restricted to the required sampling area;
- ❒ capable of use when only one side of the material is accessible;
- ❒ capable of being connected to data logging devices (useful for experimental purposes);
- ❒ quick, giving an immediate read-out;
- ❒ inexpensive.

No current method possesses all these characteristics. Measuring moisture in building materials is complex and, in spite of a great deal of research over a long period of time, a method which comes close to the ideal still eludes us. In the meantime, it's 'horses for courses' – selecting the method most appropriate for individual cases, and recognising the drawbacks. None of the available methods has overcome the need for calibration for different materials. In some circumstances it may not be possible to identify the particular type of stone or brick on site and this can lead to inaccuracies in measurement of its moisture content.

Sampling

Sampling areas must be defined. For drying walls on an experimental exposure site, the wall can be built on a weighing machine or a load cell. Moisture gain and loss can then be established for the whole structure, but the moisture content of bricks on the weather side of the wall cannot be compared to the sheltered side. Masonry materials can be variable in their pore structure so an average reading, taken from several small areas, can be more useful than individual readings.

Electrical resistance moisture meters

A method commonly used relates the effect of water on the electrical or magnetic properties of the material. Several manufacturers have developed equipment including the *Aquatrace*, the *Portatrace* and the *Protimeter*.

The presence of water can significantly alter the electrical properties of porous materials: this seems to offer the basis for an accurate method of measurement. It is convenient to make a distinction between resistance, capacitance, inductance and microwave methods, but in practice the dividing line is not always well defined.

BRE has found many cases of systems intended to combat rising damp installed in buildings where rising damp is not occurring. The common reason is that high readings obtained from an electrical moisture meter have been misinterpreted.

Using a meter

The meter measures the resistance between two metal pins which are pressed firmly into the surface of the material. The value is read directly from the calibrated scale of an ammeter. Moisture is measured in the surface layer although shielded probes can be used in drilled holes to establish moisture content deep within the material. The value obtained can be influenced by surface pressure applied to the pins, material which is not homogeneous and the action of salts.

The absolute moisture level may not be particularly important; it may be exceptionally high in a building that is drying after it has been wet. However, when moisture contents are compared over time, it is the regular drop that is important. The electrical resistance meter is a particularly useful tool for monitoring the rate at which moisture content is changing.

The electrical resistance meter is useful for measuring the moisture content of timber but readings must be taken at appropriate locations. For example, if there is water penetration or condensation within a roof space, the moisture contents should be measured across the whole roof area, not simply around the area where moisture is apparent. A measuring programme using this example is described in the box opposite.

Where timber elements are not so easily accessible, for example the sole plates or studding of a timber framed building, you can take deep probe measurements. In planning a measurement strategy, a comprehensive picture of the overall level of timber moisture is essential, so take measurements from several locations around the building.

Interpreting results

Care is needed to understand the readings. BRE experiments with sand-faced Fletton bricks prepared with known moisture and soluble salt contents have shown large errors in readings. For a meter reading on the arbitrary scale of 80 – 90% of full-scale deflection, the actual moisture content could be anywhere between 5% and 22%.

Moisture meters are useful on timber and can show when a masonry wall is dry, but a reading on ‘wet’ masonry cannot distinguish between the presence of soluble salts or actual moisture content.

This surface reading may not be representative of the overall moisture content of the component. Naturally occurring mineral salts, timber preservatives and embedded metals can affect the electrical resistance and, therefore, the measured moisture content. Preliminary investigation or laboratory tests may be needed to quantify this level of interference.There are two principal components in interpreting moisture data from timber components:

❒ the actual level of moisture (% volume reading);
❒ the change in this moisture level over time.

There will be seasonal variation in moisture content. Consider, for example, timber rafters and purlins within a conventional ventilated roof-space and the timber studs within the external walls of a timber framed house. The moisture content rises during the wetter, winter months. But moisture contents reduce in spring and summer. In some situations, moisture contents above 20% may be tolerated provided they are not sustained for more than a few weeks. These figures should be used simply for comparison rather than as key reference data – see Good Repair Guide 33.

Where moisture content measurements are repeated over a period of time (such as long-term monitoring of historic buildings), it is the changes in moisture content, not the absolute level, which are significant. For example, moisture contents rising, rather than falling, during spring and summer suggests that there is some form of moisture storage within the building fabric. Moisture stored within the masonry may evaporate during the warmer months and find its way into the colder roof space where it condenses.

Higher moisture content levels towards the outer face of the wall suggest wetting from wind-driven rain. As the outer face is wetted, and remains wet for some time, moisture is absorbed further into the the wall creating a reducing moisture content through its depth. If staining on internal surfaces is suspected to be caused by rainwater penetrating the thickness of the wall, the moisture content profile across the full depth of the wall is likely to be relatively flat, but at a high moisture content level.

The extent of exposure to wind-driven rain can be determined by comparing the moisture content profiles up the height and across the face of a building. Take into account the protection afforded by such details as window sills, copes, and overhangs. In general, the moisture content of the outer parts of the fabric increases with height up the building and is generally higher towards the outer edges of each facade. A reverse in this

Measuring moisture content of a trussed rafter roof

By carefully planning a measuring pattern across the roof area and repeating the measurements every few weeks, it should be possible to determine:

❒ the extent of any moisture within the roof timbers;
❒ if the moisture pattern is localised or influenced by orientation;
❒ whether the roof timbers are wetting or drying;
❒ whether the moisture is penetrating rain or condensing vapour.

Select three measuring locations: a truss at each end of the roof (say three trusses in) and a truss in the centre of the roof. Take moisture contents 250 – 300 mm from the end of each structural element (rafter, joist and web). At each location, take readings about 25 mm from the outer edge of the element. In the rafter, take measurements 25 mm from any sarking material. If the sarking is timber boarding, also take measurements in the boarding. This gives a moisture profile across the whole roof.

pattern may indicate localised moisture, such as rainwater splashing back onto the wall at low level, damaged rainwater pipe or rising ground moisture.

Take care when interpreting exceptionally high moisture contents towards the outside of the wall. A recent period of high rainfall could produce a moisture level three or four times that of the remainder of the wall but this would be a transient effect. When it becomes warmer and drier, the wall will dry naturally over a few days. Meteorological data for a period prior to the sample collection is an important part of the investigation.

Increased moisture levels towards the inside of a building generally indicate extreme cases of surface condensation but ensure that other sources of moisture are not influencing the measured results. Leaking water services, hygroscopic salts, wetting following flooding or rising ground moisture can provide similar results.

Higher moisture contents towards the middle of the wall are typical of most masonry walls during the spring/summer drying phase. During the winter, the overall moisture content of the wall and, in particular, the outer portions, would be expected to rise owing to wind-driven rain and condensation. From March to September, the drier months, the moisture content of the wall reduces as moisture evaporates from both the inner and outer faces.

Resistance gauges

These measure electrical resistance between electrodes embedded in a porous sample material which is in turn embedded in the test material. They do not directly measure the resistance of the test material itself but do so indirectly by absorption of moisture into the gauge material. They are more accurately described as absorption/resistance gauges.

There are problems with calibration. Although resistance varies uniquely with moisture content and temperature, the gauges are not equally sensitive at all moisture contents. Furthermore, distribution of water between the ancillary equipment and the test material depends on pore size distribution of the test material and on its moisture content.

Alternating current measuring instruments are sometimes used and several have been marketed for this purpose but they are essentially a research tool, rather than devices that can be used by a surveyor. Their life has been questioned but some inserted into a limestone wall at Gloucester Cathedral were found in excellent condition after not being used for 12 years.

Microwave techniques

Certain methods of moisture measurement depend on changes in the dielectric properties of porous materials with changes in the moisture content. Capacitance methods use the technique but microwave techniques use the propagation of electromagnetic radiation.

Equipment consists of a signal generator and receiver placed either side of a wall, although reflection methods allow tests only from one side. Commercial equipment is available, although performance claims are often optimistic. Good correlation between moisture content and attenuation can be obtained with homogeneous materials and, with careful calibration, results can be used with confidence. However, with non-homogeneous materials, such as the more usual sample of brick/mortar walls, the results are disappointing.

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Capacitance methods

Dielectric properties of porous materials can be measured using conventional electrical circuitry and devices based on two electrode capacitors. Meters have been available for a long time and have been used on loose materials and for conveyer belt monitoring.

Commercial instruments for the building industry use a small, flat-plate measuring head with two conducting rings connected to a separate unit containing the circuitry. Examples include the *Aucon* and the *Sovereign* meters. Examined in tests similar to those used for resistance meters, reasonable results were obtained for pure water and low concentrations of salts with a flattening of the curve at high moisture content readings indicating insensitivity as saturation approaches. Meter readings are of little value with significant salt contents.

A further problem is with their use on rough surfaces. As well as giving spurious readings, there is a risk of damage to the measuring surface. BRE has made much use of this type of meter looking for dampness behind apparently dry wallpaper, when it was suspected that water has crossed a cavity fill material to wet the inner leaf.

Physical sampling by independent cores

This is relatively specialised. Using a diamond-core cutter, a 25 mm core is drilled from the wall; a rubber collar is then placed over both ends of the core so that it can be slid back into its original position. Before it is inserted, a wire is passed around the back of the core to facilitate subsequent removal.

The sample is usually taken to the laboratory, where it is sliced up, weighed and dried to provide a moisture content profile through the wall. The sample is then re-assembled and reinserted into the wall and left for a period of time. At intervals, the sample can be removed, re-weighed and the moisture content determined.

This is a quick and accurate way of determining moisture content but can be used only where moisture movement is perpendicular to the faces of the structure, such as rain penetration or drying out. It can be carried out on most masonry materials, is suited to the more technical or academic applications and is useful for long-term monitoring of historic buildings. The cores must be assembled carefully to ensure that there are no air gaps between the core slices and as small as possible between the core and the surrounding material. Any air gaps would prevent the core sample behaving as a component part of the structure. BRE experiments demonstrate that equilibrium is established fairly readily between the core and the wall even though the core and the wall are not in close all-round contact.

Drilled samples

The basis of this method is to drill out damp masonry or mortar and measure moisture content and hygroscopic moisture content. Walls may contain considerable quantities of hygroscopic salts so hygroscopicity should be measured to see whether the wall could have absorbed from the atmosphere the quantity of water found in the samples. On-site moisture content can be established by using a carbide meter, a commercial piece of equipment where the damp drillings and carbide are mixed in a pressure vessel. A gauge measures the pressure generated and the calibration is directly related to moisture content. If several samples are taken, it is more convenient to test in the laboratory and establish both moisture content and hygroscopic moisture content.

The advantages of the method are:

- it is independent of salts;
- it measures moisture content within the material rather than only in the surface layer;
- a moisture profile can be established by drilling in stages;
- measurements are made from only one side of the wall;
- it can be used on a wall where previous preparations, such as building in probes, is not possible;
- the equipment is inexpensive and may be already available, for example a chemical balance and desiccator (or a carbide meter can be purchased).

Samples can be gathered through the full depth of a masonry wall. In particularly thick walls, drillings at 25 mm or 50 mm increments can create a moisture content profile through the depth of the wall. Drilling is stopped 5–10 mm short of the inner face of each leaf to prevent penetrating the cavity and losing the dust sample. This staged drilling technique can be achieved by marking along the length of the drill bit or by using a depth gauge attachment.

The main disadvantage is that the method is semi-destructive, requiring at least a series of 9 mm holes or, if the wall is plastered, a chase cut out to locate the mortar joints. In practice, building owners are usually content for samples to be taken so that a definitive diagnosis can be made.

Figure 3.1 Equipment used in drilling

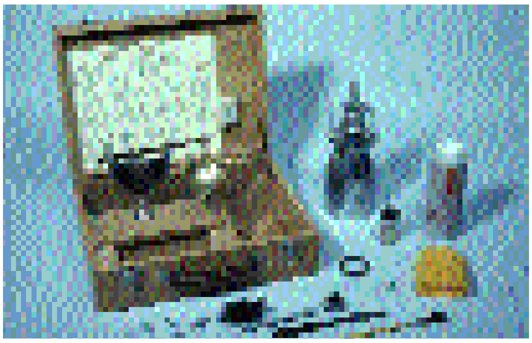

Figure 3.2 The complete calcium carbide kit including scales for weighing samples and pressure vessel *(right hand side)*

Drilling method

The technique is generally used on masonry materials such as brick, stone and concrete blockwork walling. It requires some basic equipment on site: a standard percussion drill, a 9 – 12 mm masonry drill bit, a device to catch the drill dust (some form of chute), a scraper and small bottles with stoppers in which to collect the dust sample – Figure 3.1.

It is better to drill into the mortar because the bricks will have a lower moisture content. Collect the sample in a stoppered bottle for subsequent laboratory tests. About two grams is sufficient, or six grams if the carbide meter is to be used. Take successive samples up the height of the wall and plot a graph of moisture content against height.

Measuring by calcium carbide technique

This is a quick and relatively accurate way to determine moisture content on site. By inserting individual samples with calcium carbide into a pressurised vessel, an almost instant reading of moisture content can be produced – Figure 3.2. Moisture in the drilled sample reacts with the calcium carbide to produce acetylene gas. The subsequent gas pressure indicates moisture content.

Measuring by weighing

For most situations, hygroscopicity can be measured at 75% relative humidity; for most walls the effective relative humidity is less than 75% and it is easy to provide a relative humidity of 75% by using a saturated solution of common salt (NaCl). Place a closable vessel containing the sample over, but not in contact with, the solution of common salt. A desiccator or an enclosed space similar to that shown in Figure 3.3 is suitable.

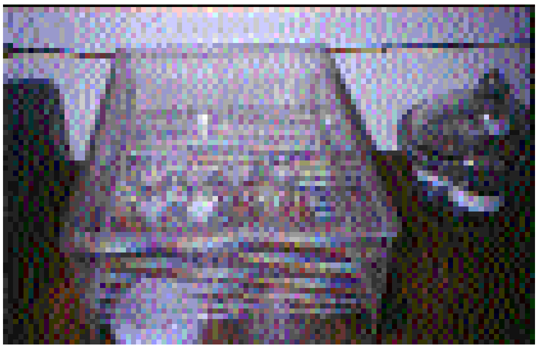

Figure 3.3 Weighing sample

Using a balance:

1 Collect the samples in stoppered bottles.

2 Shake the bottle well before removing stopper.
Spread about 2 grams of the sample from the bottle onto a previously weighed Petri dish or watch glass about 40 mm diameter (weight W_o) and weigh immediately (weight W_w).

3 Place immediately in enclosure at 75 per cent relative humidity.
Leave for a time: overnight is sufficient if the layer is only 1 – 2 mm deep.

4 Reweigh (W_{75}).

5 Place in an oven at about 100°C for about one hour. Remove and allow to cool.
Reweigh soon after cooling (weight W_d). Plaster samples must not be dried out above 35°C.

6 Calculate:

Hygroscopic moisture content at 75 per cent RH (HMC) =

$$100 \quad \frac{W_{75} - W_d}{W_{75} - W_o} \quad \% \text{ wet wt}$$

Moisture content of sample when found (MC) =

$$100 \quad \frac{W_w - W_d}{W_w - W_o} \quad \% \text{ wet wt}$$

This procedure cuts down weighing to a minimum; if the moisture content is required more quickly, leave part of the sample in the bottle or put it on an additional dish and find the moisture content by weighing and oven drying.

The formal procedure is specified in BS EN ISO 12572.

Accuracy of the methods

A series of tests compared the drilling method using oven drying techniques and the carbide meter. The tests also demonstrated that the heat produced by a sharp drill bit does not cause evaporation of water from the sample, provided the material is not too hard.

This method satisfies more of the requirements of the 'ideal method' than any of the other techniques; it is sufficiently accurate for experimental work and can equally well be used for site investigations.

Calculating results by laboratory weighing

The method outlined above gives moisture contents expressed as % wet weight and is the convention commonly used in the damp-proofing industry.

The moisture content can also be expressed as % dry weight using:

$$\frac{(\text{Wet weight - dry weight}) \times 100}{\text{dry weight}}$$

Subtract the weight of any sample bottle from the wet and dry weights.

The calculated figure represents the moisture content by weight of the dry material. The moisture content of materials is often expressed 'by weight'. However, when comparing the moisture content of different materials it is generally more appropriate to express the moisture content 'by volume'. The moisture content by volume is calculated using:

Moisture content by weight x specific gravity of material

Calculate specific gravity by dividing the density (kg/m^3) by 1000.

Table 3.1 gives typical specific gravities for common building materials.

Table 3.1 Typical specific gravities for common building materials

Material	Specific gravity
Lightweight concrete	0.6
Medium density concrete	1.1
Dense concrete	2.2
Common brick	1.8
Engineering brick	2.0
Plasterboard	0.9
Plaster	0.8
Render	1.5
Sandstone	2.0
Slate	2.7
Limestone	2.2
Reconstituted stone	1.7
Concrete roofing tile	2.1
Clay roofing tile	1.9

Moisture contents (%) at which action may be required

When dampness is suspected, accurate measurement of the moisture content of materials which may be subject to deterioration is essential. With these measurements, you may be able to reach a decision on whether remedial action is necessary and, if so, form some idea of the urgency with which the work should be undertaken. Table 3.2 gives a selection of values for typical materials, although their situation within a building will have some bearing on whether action will be necessary.

Table 3.2 Typical action points based on moisture content of building materials
Timber was measured by electrical resistance, the remainder by % volume

Material	Damage unlikely	Action required	Damage likely
Timber (electrical resistance)	<18	>20	>24
Brick (calcium silicate)	< 8	>9	>15
Brick (engineering)	< 4	> 6	> 8
Brick (commons)	<10	>14	>20
Brick (facing)	< 8	>10	>20
Concrete block (high density)	< 8	>12	>15
Concrete block (low density)	< 6	>10	>12
Render	< 3	> 5	> 8
Plaster	< 2	> 3	> 4

LABORATORY TESTS FOR SALTS

Most masonry materials contain soluble salts; quantities are usually low but they can be moved around by moisture and can be concentrated at the surface as the wall dries. This is most obvious where new brickwork is soaked by rain and then dries leaving a white deposit on the external surface: this is efflorescence. Some is washed off the next time it rains, then the cycle is repeated until the levels of salts in the brickwork are reduced. Further salts can be taken into the wall by long-term rising damp, accidental pollution, such as splashing from road salt or where a building has been used for storing agricultural chemicals.

Contamination by salts may not result in damage to the materials but the effects of salts can render useless some methods of moisture measurement.

Procedure

These are simple tests to determine the presence of soluble salts in soils, masonry and efflorescence, all of which may be significant in the examination and identification of dampness-related problems in buildings.

All glassware must be washed in distilled water because the salts in tap water can influence results. Boil the sample in distilled water, cool and filter it into three test tubes, and use one each for the following tests:

Chlorides

Acidify the solution with 10% nitric acid. Add silver nitrate; if chlorides are present, a flocculent white precipitate forms.

Sulfates

Acidify the solution with 10% hydrochloric acid. Add barium chloride; if sulfates are present, a flocculent white precipitate forms.

Nitrates

Add ferrous sulfate to the filtrate. If it goes cloudy, acidify the solution with a little dilute sulfuric acid. Then, with great care, pour concentrated sulfuric acid down the side of the test tube. If nitrates are present, a brown ring forms at the interface of the two liquids.

Typical salts contents

Twenty-two different samples have been tested covering a limited number of representative materials and including samples both in their 'unused' condition and as taken from buildings of various ages – Table 3.3. A list of samples covering all possible variations of material, history and exposure would be almost limitless. These anions are found to some extent in most masonry materials but larger concentrations of nitrate and chloride are often associated with contamination from external sources and the presence of hygroscopic salts.

INSTRUMENTS FOR MEASURING HUMIDITY

Many materials are hygroscopic; the amount of water they absorb depends directly on relative humidity. This can cause dimensional changes or affect the electrical properties of the material.

Thermohydrograph

The thermohydrograph has been used for many years and still has a role. A hair or plastics strip lengthens as it absorbs water in high humidities and shortens in dry conditions. This length change is translated by a series of levers to the movement of a pen on a rotating, replaceable chart calibrated in relative humidity. A second pen connected to a bimetallic strip records the temperature. Calibrated regularly and kept in a reasonably stable environment, thermohydrographs are reasonably accurate and give an immediate visual record of conditions in the room. It is difficult to use the output to calculate parameters such as vapour pressure or dewpoint.

Table 3.3 List of typical materials tested and soluble salt analysis

Description	Source	Water soluble salts Chloride ion content (% Wt)	Nitrate ion content (% wt)	Sulfate ion content (% wt)
Stock brick	Unused	0.005	0.002	0.177
Fletton brick	Unused	0.001	0.001	0.855
Fletton brick	From a now unused flue	0.041	0.019	0.914
Red clay brick	Exposed brick	0.039	0.015	0.092
Sand lime brick	Unused	0.003	0.004	0.024
Sandstone	Exposed wall	0.007	0.001	0.006
Limestone	From exposed seaward elevation	0.109	0.033	0.340
Granite	From exterior of medieval building	0.009	0.002	0.062
Aerated concrete	Unused	0.015	0.004	0.383
Lignacite	Sample from recent construction	0.003	0.001	0.051
Dense concrete	Unused but several years old	0.004	0.001	0.010
Forticrete	From outer leaf of 8 year-old building	0.005	0.003	0.095
Cement floor screed	Good quality sample about 3 years old (1:4 mix)	0.001	0.002	0.069
Cement mortar	From recent cavity wall (1:1:6 mix)	0.004	0.000	0.080
Lime mortar	From interior of medieval building	0.116	0.111	0.062
Lime mortar	Victorian terraced housing	0.166	0.280	2.757
Lime mortar	Second sample	0.068	0.212	2.962
Plaster undercoat	Cement-based (1:5/6) applied after DPC work	0.072	0.264	0.521
Plaster skim	Lightweight gypsum applied after DPC work	0.675	0.424	2.042
Plaster undercoat	Lightweight gypsum applied after DPC	3.724	1.407	0.194
Plaster skim	Renovating plaster from converted stable block	0.069	0.798	4.031
Plaster undercoat	Renovating plaster from converted stable block	0.293	2.940	2.545

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Electronic sensors

These sensors contain elements whose electrical properties depend on the absorption of water vapour in proportion to the relative humidity of the air. From a thermistor, they can give a direct read-out of relative humidity and temperature on a hand-held meter or which can be recorded with a data logger. With regular calibration they are accurate up to about 95% relative humidity provided the atmosphere is clean and dust free; above that, they become saturated.

Compact data-loggers about the size of a 35 mm film cassette incorporate a humidity or temperature sensor and a data store. They can be set to record at a wide range of time intervals, for example hourly readings over 80 days, and can be installed in the area under investigation. They are robust enough to be sent by post for down-loading and analysis. Software will calculate vapour pressures or dewpoints from the measured temperatures and humidities.

Wet bulb and dry bulb thermometers

When water evaporates from a surface, heat is required to achieve the change of state from a liquid to a vapour and the need for this 'latent heat' cools the surface. This is the principle of the wet and dry bulb thermometer; it contains two thermometers, one has its bulb covered with a wet wick. If there is sufficient flow of air over the wick, the evaporation cools the wet bulb several degrees below the dry bulb. The relative humidity and dewpoint of the air can then be found from tables or with standard software. Two methods are commonly used to achieve sufficient airflow:

❒ the whirling hygrometer holds the thermometers in a frame much like an old-fashioned football rattle, which is spun round manually;

❒ the aspirated psychrometer contains clockwork or electric fans which suck air over the thermometers; used carefully, this is the most accurate practical method of measuring the humidity of the air in the field.

Dewpoint sensors

Very accurate measurements of humidity can be achieved by chilled mirror dewpoint sensors. They contain a mirror which is cooled until condensation forms on it; the onset of condensation is detected automatically by the scattering of a light beam. Instruments are expensive and are mainly used for calibrating other equipment.

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REFERENCES AND FURTHER READING IN CHAPTER 3

BRE publication

Good Repair Guide 33 Assessing moisture in building materials *(in 3 parts)*

British Standards Institution

BS EN ISO 12572:2002 Hygrothermal performance of building materials – Determination of moisture content by drying at elevated temperature

BS EN ISO 13788:2002 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods

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Chapter 4
Condensation

This chapter includes a simple explanation of the physics of condensation and interstitial condensation, conditions for growth of moulds, domestic condensation, roof construction and condensation, thermal bridges, and surface condensation on floors and on water pipework. There is further mention of condensation in relation to floors in Chapter 6 because of the potential confusion with rising damp in certain situations.

WATER VAPOUR

Behaviour of water vapour in the air

At any temperature, air is capable of containing a limited amount of moisture, normally as an invisible vapour; the warmer the air, the more water vapour it can contain before it becomes saturated and liquid water appears – Figure 4.1. The amount of water vapour present can be expressed as vapour pressure of the mass of water per mass of air, kg/kg. The psychrometric chart – Figure 4.2 – shows two important parameters of water vapour in the air:

- ❒ The relative humidity, shown as the curved lines, is the ratio of the actual amount of water vapour present to the amount that would be present if the air was saturated at the same temperature; this is normally expressed as a percentage. At point +, air at 20 °C is saturated with a vapour pressure of 2.33 kPa. If the vapour pressure is only 1.40 kPa, only 60% of water vapour is present, therefore the relative humidity is 60% as shown by point O. Relative humidity is important because it determines the absorption of water by porous materials, governs the growth of moulds and other fungi and is the basis of many systems for measuring the water vapour content of air. Relative humidity depends on both the temperature and the vapour pressure of the air and may therefore be modified by changing either or both of these.
- ❒ At the dewpoint temperature of the air, condensation of liquid water starts when air is cooled, at constant vapour pressure. For example, if the air at point O, at 20 °C and 60% relative humidity, is cooled with vapour pressure constant at 1.4 kPa, it will become saturated at 12°C; this is the dewpoint temperature. Although the dewpoint is expressed as a temperature, it depends only on the vapour pressure; warming or cooling the air makes no difference to the dewpoint.

A relative humidity of 100% is necessary for condensation to occur with deposition of liquid water, for example on single-glazed window panes on winter mornings. However, moulds can grow on an internal wall surface when the relative humidity at the wall surface is only 80%. This means that while the air at point O has to be cooled to 12°C before condensation to start, it has to be cooled only to 15.5°C, before moulds will grow. This has important implications for detailing insulation to avoid thermal bridges that are common sites of mould growth.

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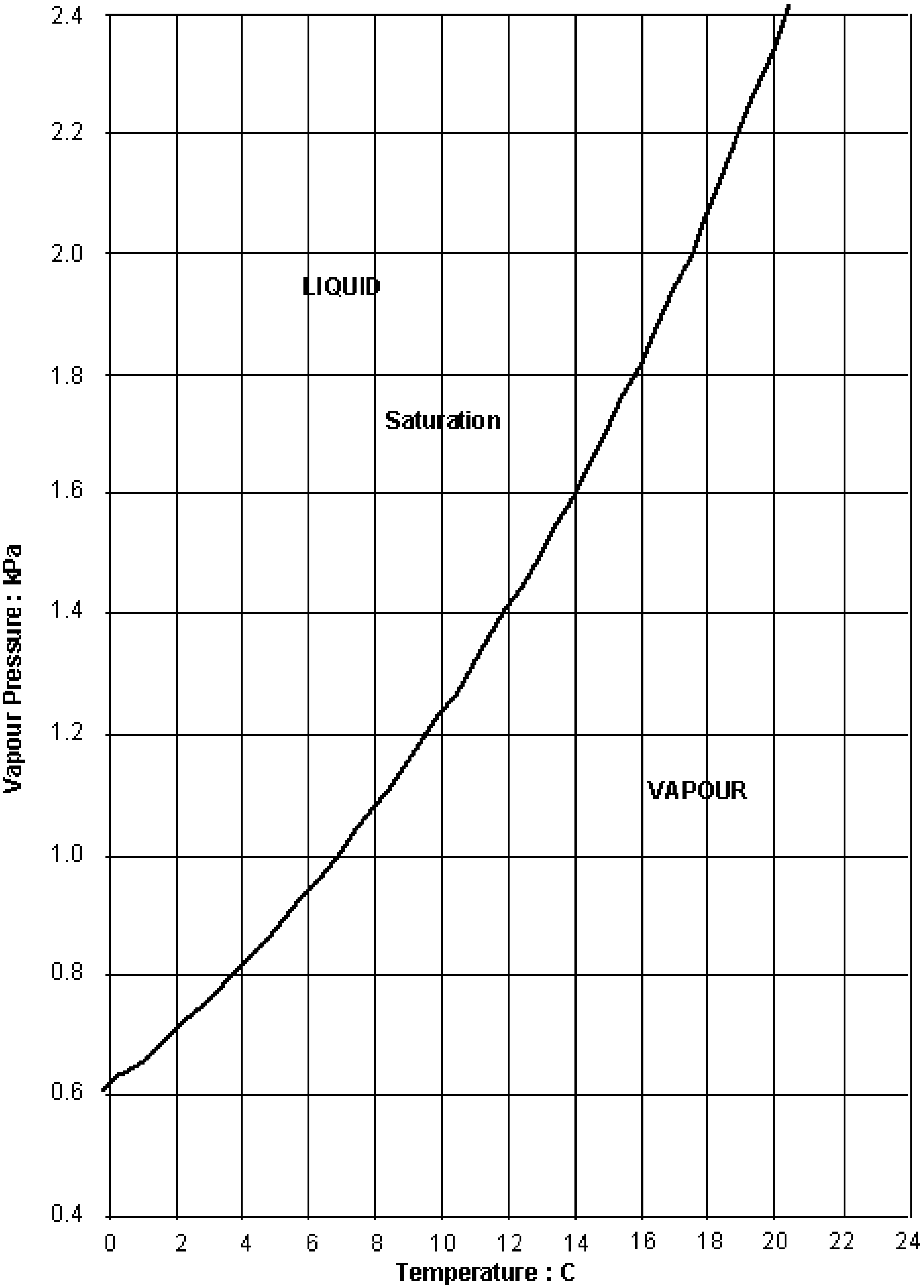

Figure 4.1 Saturation of air as a function of temperature

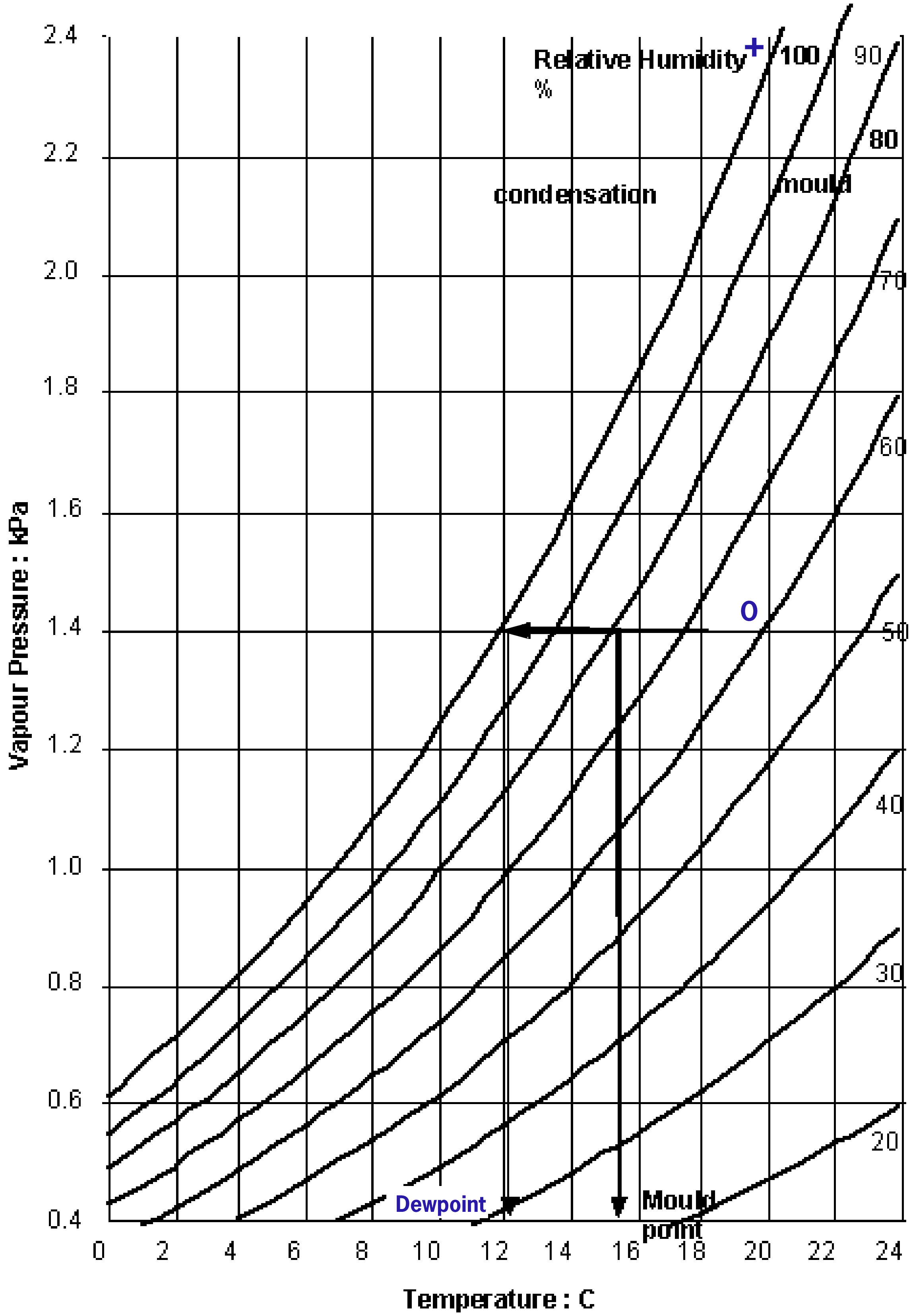

Figure 4.2 Psychrometric chart showing relative humidity and dewpoint

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In winter, the internal surfaces of external walls are colder than the air in the room, with the temperature drop depending on how well the wall is insulated. The relative humidity at the wall surface will, therefore, be higher than in the room. As a general rule, we assume that to achieve the 80% necessary for mould growth at the wall, the relative humidity in the room should be above 70%. This is used for designing heating and ventilation to avoid mould growth in housing and other buildings.

During winter, although it may feel damp outside, the vapour pressure will be much less than within a heated building. Figure 4.2 shows that at 0°C, even if the relative humidity is 100%, the vapour pressure will be only 0.6 kPa, compared to 1.4 kPa, within a building at 20°C and 60% relative humidity. The advantage of this vapour difference is that ventilation can be used to remove water vapour but it also acts as the driving force for interstitial condensation.

Production of water vapour within buildings

Virtually all activities within buildings generate water vapour, which raises the vapour pressure in the internal air above that outside. Table 4.1 shows typical amounts produced in dwellings.

Table 4.1 Moisture generated during household activities

Activity	Moisture rate
People:	1.2 kg/person/day
Cooking:	
Electricity	2 kg/day
Gas	3 kg/day
Dishwashing	0.4 kg/day
Bathing/washing	0.2 kg/person per day
Washing clothes	0.5 kg/day
Drying clothes indoors	1.5 kg/person per day, eg using unvented tumble drier

In addition to these amounts of moisture, substantial amounts of water vapour can be produced by unflued heaters, such as portable LPG appliances or paraffin heaters. Providing 3 Kw for eight hours produces 2.4 Kg of water vapour. When investigating cases of condensation, bear in mind the possibility of other unusual sources of water vapour, such as tropical fish tanks or a home bakery.

There is less quantitative information on moisture generation in non-domestic buildings but they can be classified in terms of likely humidity loads.

Table 4.2 Likely humidity loads

Humidity load	Building type
Low	Storage areas
increasing	Offices, shops
to	Sports halls, kitchens, canteens
High	Special buildings, eg laundry, brewery, swimming pool

Swimming pools particularly need special design to take account of the high internal temperatures and humidities.

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EFFECTS OF CONDENSATION

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

Condensate on surfaces

Condensate frequently occurs on:

- ❒ single glazing in bedrooms overnight or in kitchens and bathrooms at any time;
- ❒ double glazing, especially near the frames, in rooms with relatively high humidities;
- ❒ on WC cisterns or cold pipes in bathrooms or kitchens;
- ❒ on the walls of hallways 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 but more serious consequences can result from, for example:

- ❒ condensate from glazing promoting decay in wooden window frames or condensate running from sills onto the wall below, damaging decor;
- ❒ condensate dripping from roofs onto food preparation processes or sensitive electronic equipment;
- ❒ condensate on certain floor types making them slippery.

Sometimes, condensation can be dealt with by drainage or by mopping it up before it collects and runs to vulnerable areas. Persistent severe condensation on glazing, especially double glazing, in many rooms suggests that excessive moisture is being produced or ventilation within the dwelling is inadequate; these can lead to more serious problems.

Figure 4.3 Mould growth on clothing which has been stored in a damp environment

Mould growth

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

Mould spores exist in large numbers in the atmosphere; to germinate, they 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. Oxygen is always present so mould growth is particularly dependent on moisture conditions at surfaces and the length of time these conditions exist. Moulds do not need water but can germinate and grow if the relative humidity at a surface rises above 80%. This is considerably less severe than the 100% required for surface condensation to occur. As the internal surfaces of external walls are 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. But as a guide, it can be assumed that the relative humidity at the external wall surfaces will be high enough to support the growth of moulds if the average relative humidity within a room stays at 70% for a long period of time.

Moulds and mildews can occur on furniture, curtains, carpets and clothing, especially leather jackets, shoes or suitcases, if they are 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.

Mould growth on thermal bridges

Thermal bridges are areas of the building fabric where, because of the detail or the presence of high conductivity materials, there is significantly higher heat loss than through surrounding areas. Besides leading to increased energy use, they lower the internal surface temperature and are therefore potential sites for condensation and mould growth.

There are two types of thermal bridges:

❒ Repeating thermal bridges, for example timber joists, mortar joints, or mullions in curtain walling. They have a significant effect on heat loss, and must be taken into account when calculating of U-values; they are rarely severe enough to make surface temperatures fall low enough to cause surface condensation or mould growth.

❒ Non-repeating bridges, which commonly occur around such openings as lintels, jambs and sills and at wall/roof junctions, wall/floor junctions and where internal walls or floors penetrate the outer building fabric. They can add 10–15% to the total heat loss from the building.

Figure 4.5 shows an example of a severe thermal bridge caused by a dense concrete floor slab extending through an internally insulated cavity wall to form an access balcony.

Figure 4.4 Signs of condensation and mould growth on a thermal bridge

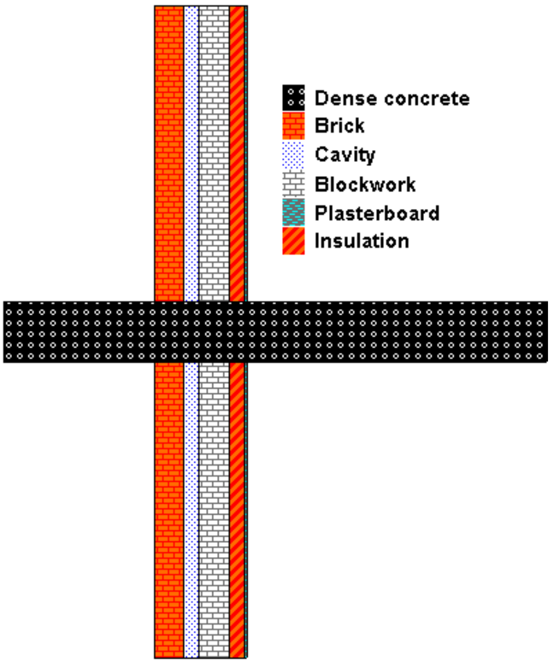


Figure 4.5 Balcony acting as severe thermal bridge

Figure 4.6 shows the surface temperatures calculated with internal and external temperatures of 20°C and 0°C respectively. While the surface temperature of the insulated wall is 19.1°C, the floor slab is falling to 13.6 °C near the wall and as low as 8.9°C in the corner. Figure 4.7 shows the relative humidity at the surface, calculated assuming a relative humidity of 60% within the room; there is a risk of mould growth on the ceiling adjacent to the wall and surface condensation is likely in the corner.

Figures 4.8 – 4.11 show examples of common thermal bridges in housing. If the floor of a house with internally insulated masonry walls is insulated below the concrete slab Figure 4.8, a diagonal heat flow path will lower the surface temperatures and raise the surface humidities sufficient to promote mould growth on the floor in the corner. Including perimeter insulation around the floor Figure 4.9 avoids this.

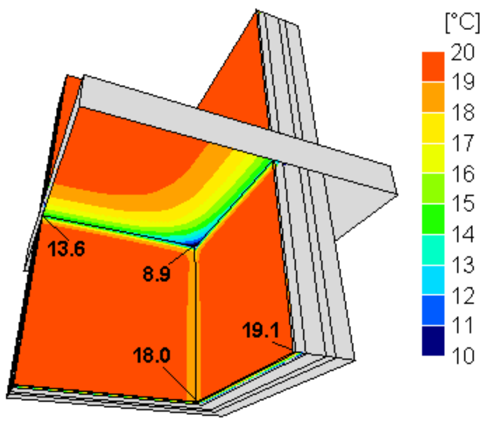


Figure 4.6 Calculated temperatures with Ti = 20 °C and Te= 0 °C

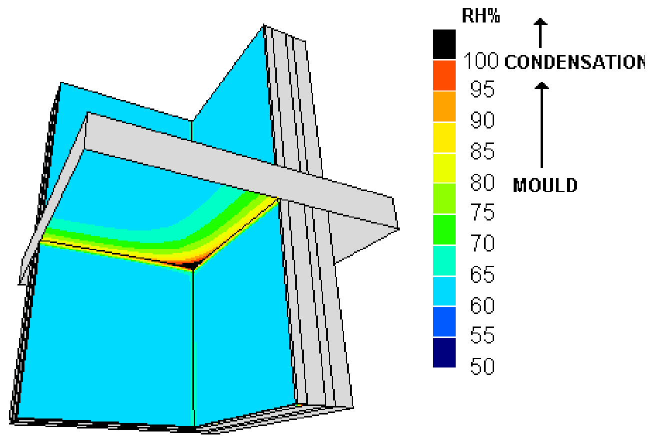


Figure 4.7 Calculated surface relative humidities with internal RH = 60%

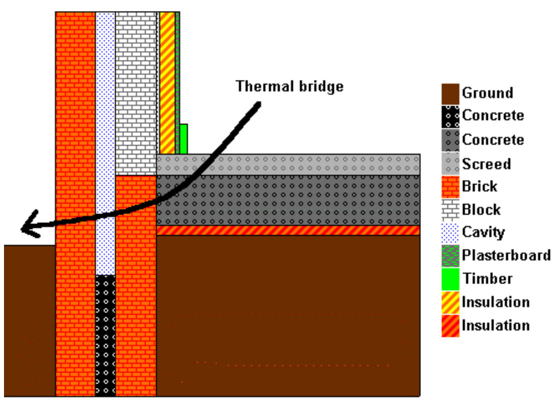


Figure 4.8 Insulated floor with no perimeter insulation

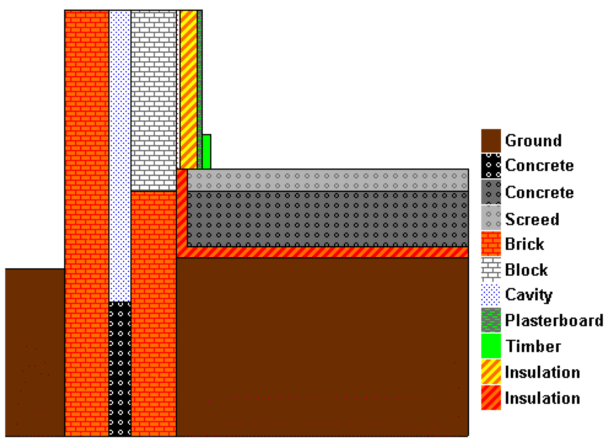
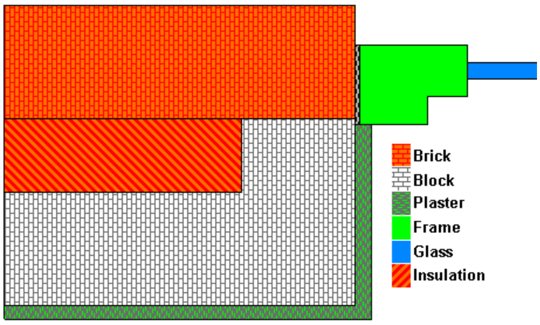


Figure 4.9 Insulated floor with perimeter insulation



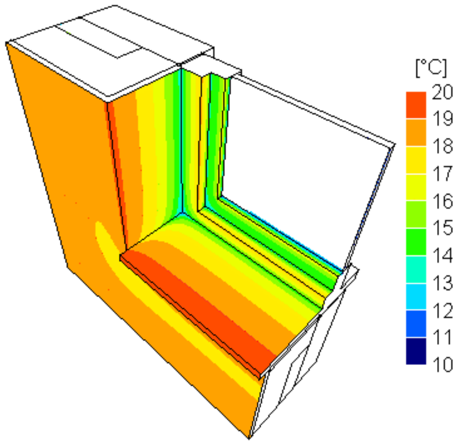
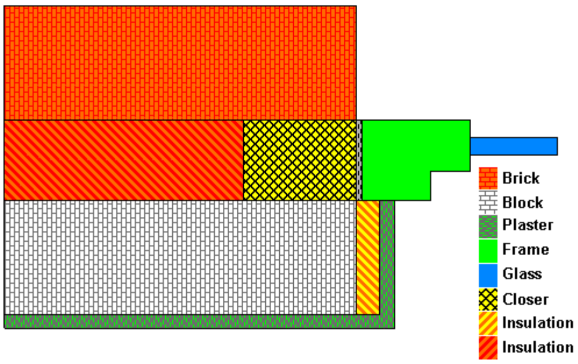


Figure 4.10 Uninsulated window jamb, with window frame set forward



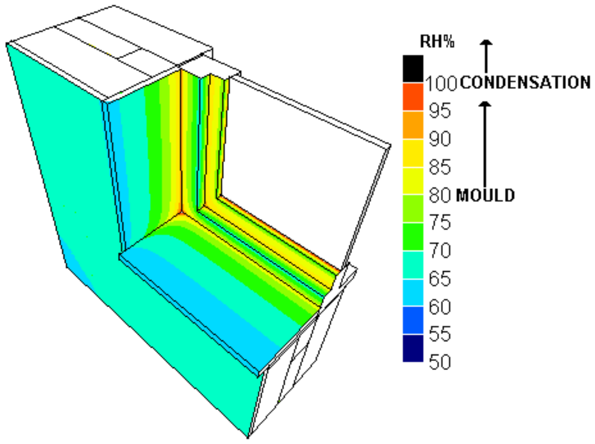


Figure 4.11 Insulated window jamb, with window frame rebated

Figure 4.10 shows a window jamb with the window set forward on the outer leaf, which is common practice in England; the jamb is uninsulated. This leaves a thermal bridge which is difficult to remedy unless the widow is rebated; this is common in Scotland to improve protection from driving rain; the jamb is insulated as shown in Figure 4.11.

A surface temperature of at least 15°C, with internal and external temperatures of 20°C and 0°C respectively, is sufficient to avoid mould growth, given the range of conditions in UK buildings and the UK climate.

Good attention to detailing of junctions between elements and around openings such as doors and windows is necessary to avoid thermal bridging. The surface temperatures on any thermal bridge can be found from either thermal bridge catalogues or by calculation. Thermal bridge catalogues contain a representative sample of building details, identify possible problems and cover a representative sample of typical building details, identifying possible problems and giving recommended solutions. They are simple to use and cover most common constructions. The most comprehensive examples in the UK are the Energy Efficiency Office Good Practice Guides 174 and 183 , which cover new and existing housing respectively, and the *Guide to Robust Construction Details* published in association with Approved Document L of the Building Regulations. There is a wide range of software packages to carry out the appropriate calculations with two or three-dimension thermal models.

DESIGN TO CONTROL CONDENSATION

Controlling condensation by design depends upon obtaining a satisfactory relationship between air conditions (internal and external air temperatures and humidity) and the properties of external elements of construction (thermal and vapour resistance).

The objectives are to:

- ❐ prevent harmful surface or interstitial condensation;
- ❐ prevent mould growth;
- ❐ economically reduce nuisance condensation.

Condensation control should be considered part of the design process. Successful control depends on such factors as prevailing wind, 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 should be considered carefully; to a greater or lesser degree, they are interdependent, so should be considered together.

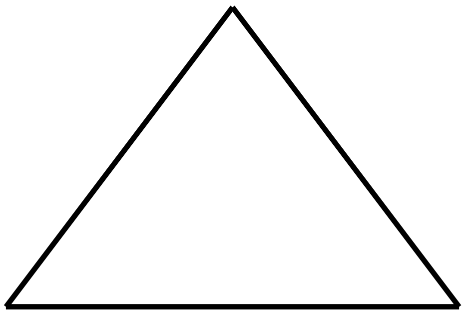


Figure 4.12 Balance of factors

The fundamental principle in designing to minimize condensation is to maintain a balance of the three factors shown in Figure 4.12 in order to achieve either low vapour pressure and/or high structural temperature.

INTERSTITIAL CONDENSATION

Surface condensation and mould growth produce immediately visible problems on the inside surface of buildings. Interstitial condensation is more insidious; before it becomes visible, it can already have caused severe structural damage.

Water vapour generated in a building creates a vapour pressure difference which drives the vapour through the material of the walls and roof. This causes a gradient of vapour pressure, and therefore dewpoint, through the structure, which in turn depends on the relative vapour resistances of all the materials in the wall. At the same time, there is a gradient of temperature through the wall depending on the distribution of thermal resistances. If the main thermal resistance is on the warm side of the main vapour resistance, the temperature falls faster than the dewpoint, until a point is reached where they are equal: condensation then occurs. The dewpoint becomes fixed equal to the temperature, and condensation continues.

Figure 4.13 shows a cross-section through a timber famed wall which does not have a vapour control layer (VCL). Almost all the thermal resistance of the wall is made up of the mineral wool insulation; most of the vapour resistance comes from the plywood sheathing, on the colder side. The temperature falls rapidly in the insulation and becomes equal to the dewpoint on the inside surface of the sheathing, where severe condensation occurs. Given the assumed conditions, about 30 g/m^2/day of water will be deposited, enough to raise the plywood moisture content high enough to promote rot and eventual structural failure. There is another plane where condensation occurs, but only at about about 0.2g/m^2/day, on the inside surface of the outside brick cladding. This is much less than the amounts of rain that will hit the cladding from the outside, so is not significant.

Figure 4.14 shows the profiles that result when a complete VCL, for example 500 gauge polyethylene, is incorporated between the plasterboard lining and the insulation. This has effectively no thermal resistance, so that the temperature profile is unaffected; however, as almost all the vapour resistance of the wall is now on the warm side of the insulation, the dewpoint falls well below the temperature at the VCL and remains below through the whole wall.

Effects of interstitial condensation

In some circumstances interstitial condensation is unimportant; for example:

❐ condensation commonly occurs on the outer leaf of masonry cavity walls, but in small amounts compared to the effect of wetting by rain;

❐ condensation can occur overnight as a fine mist on the underside of the outer sheet of metal roofs; this usually clears rapidly; problems arise only when so much condensate accumulates that it starts to drip or run into areas where it can cause damage.

In many circumstances, severe damage can result from sustained condensation. 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 tends to evaporate. It is difficult to calculate the rate of this evaporation but it should be borne in mind when assessing whether or not condensation is harmful.

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

Although interstitial condensation usually occurs when water vapour is diffusing out from the interior of a building, there are circumstances in which the interior is cooler and drier than outside; water vapour will then enter the structure from outside. An example is an air-conditioned building in warm, humid weather. There have been many cases of severe damage in air-conditioned buildings in the Middle East or the southern states of the USA, which have impermeable linings such as vinyl wallpaper.

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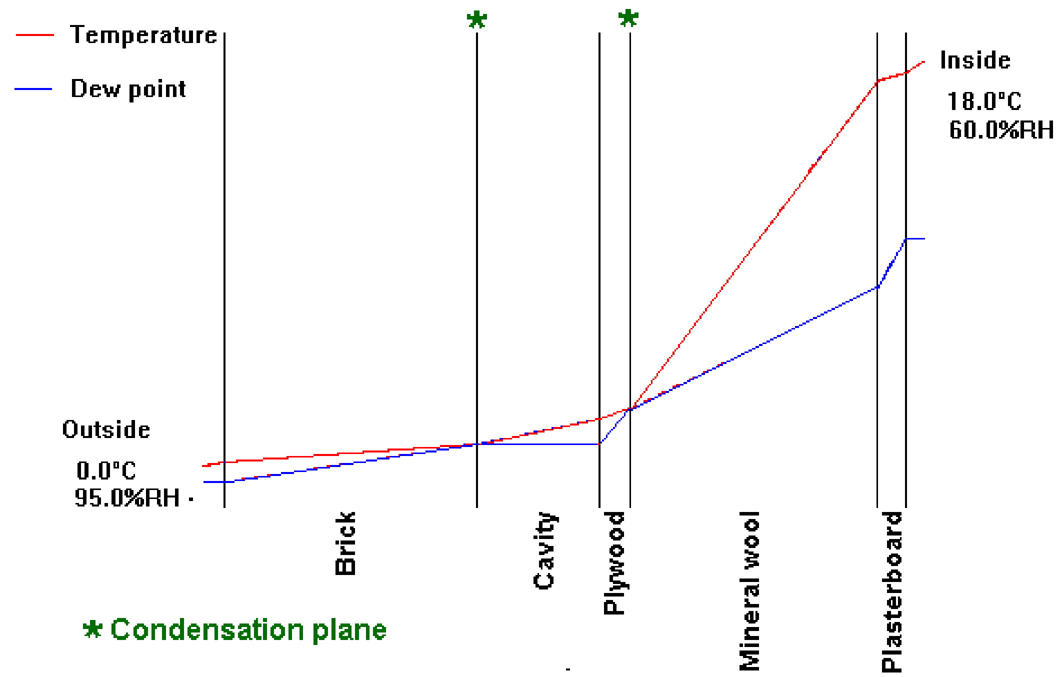

Figure 4.13 Profile through a timber framed wall with no vapour control layer

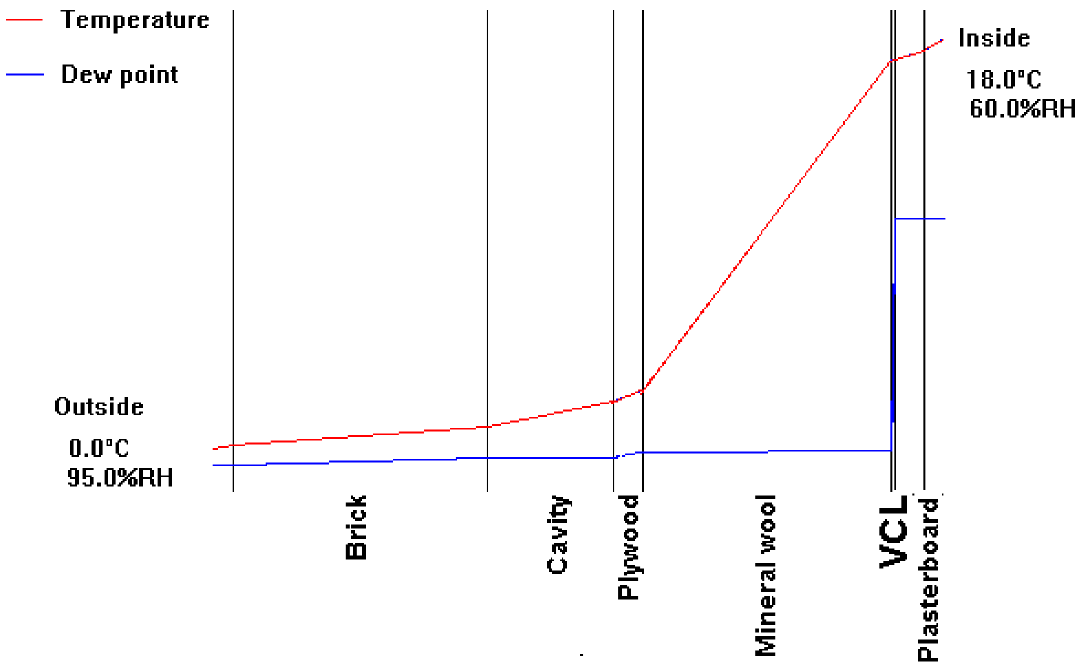

Figure 4.14 Profile through a timber framed wall with a vapour control layer

Controlling interstitial condensation

To minimise interstitial condensation, do one or more of the following:

- Reduce the vapour pressure within the building by ventilation and/or reduced moisture input; this is the driving force for interstitial condensation. An additional benefit is a reduced risk of surface condensation or mould growth within the building.
- Use materials of high vapour resistance near to the warmer side of the construction, for example the polyethylene VCL within the timber framed wall shown in Figure 4.14.
- Use material of low vapour resistance near the colder side of the construction; replacing the high resistance plywood sheathing with a

low-resistance fibreboard sheathing could eliminate the need for a VCL in a timber framed wall.

- ❐ Include a ventilated cavity on the warm side of the main vapour resistance; for example, if an impermeable sarking felt, such as a 1F felt is used in a pitched roof, the loft space must be ventilated to prevent severe condensation on the felt.
- ❐ Use materials of high thermal resistance near to the colder side of the construction; external insulation to walls keeps the whole structure above the dewpoint and eliminates the risk of condensation.

VAPOUR CONTROL LAYERS

Although interstitial condensation is usually caused by water vapour diffusing through solid materials, much larger amounts of water vapour can be carried into the structure by air leakage through cracks or joints. Vapour control layers should always be tightly sealed at joints and edges, and where they are penetrated by services, to prevent air entering. This is especially important in such facilities as operating theatres, clean rooms or breweries, which are operated at a pressure higher than that outside. A VCL, of appropriate vapour resistance, should be situated on the warm side of the insulation. Placed within the insulation, a VCL will be colder and therefore a possible site for condensation in a high humidity environment.

Construction

Take great care in the design of different construction elements and the connections required between different materials and a VCL. Side and end joints in a VCL should be kept to a minimum and it should extend over the whole internal roof and wall areas.

It is very difficult to construct an impervious layer in practice; while a VCL laid above a roof deck can be constructed with a high vapour resistance, this is certainly not the case when the same material is fixed to the soffit. The performance of a VCL depends on the material selected, workmanship and buildability, taking into account the design life of the building. Any holes around fixings, pipes, or electrical fittings will downgrade performance.

Joints

Joints in a flexible sheet VCL should be lapped at least 50 mm, sealed with an appropriate sealant and made over a solid backing member or substrate. Similarly, tears and splits should be repaired using an overlay of the same material. If polyethylene sheeting is used, it should be protected from heat and sunlight to reduce the risk of degradation. Where a VCL is incorporated in or on a rigid board or profiled metal liner sheet, joints between adjacent boards should be sealed with an appropriate sealant or tape, or otherwise closed to avoid mass transfer of water vapour due to air leakage.

Performance

The performance of a VCL depends on the design life of the materials, and identifying at the design stage the position of vapour seals, workmanship and buildability. Avoid penetrations if possible but, where they are necessary, they should be suitably framed with upstands to allow the installation of vapour seals. Any holes for electrical connections or pipes should be sealed during construction or designed to allow installation of vapour seals later. Failure to suitably seal penetrations or connect the VCL to other elements will seriously downgrade the performance of the VCL. Joints in VCLs should be minimised and, where practicable, secured with clamps or battens.

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HYGROSCOPIC MATERIALS

Materials affected

Most building materials are hygroscopic, that is they have a porous structure that absorbs water vapour from the air, even before interstitial condensation occurs. Water is, therefore, built into a construction by:

- the water of hydration in cement, concrete or mortar;
- the inclusion of hygroscopic materials which have been stored outside undercover in humid conditions: 25 mm plywood stored at 90 % rh will hold almost 3 kilograms of water in every square metre;
- rain during construction before the weatherproof layer is placed. 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 the structure under temperature and humidity gradients by a mixture of vapour diffusion and liquid flow through the pores; it will 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 may cool by night sky radiation.

Effects of temperature

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 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 a roof that apparently leaks only in hot dry weather.

Reverse condensation

Reverse condensation is an excellent example of moisture movement in hygroscopic materials under temperature gradients. Most frequently observed when the sun shines on damp walls, the moisture in the wall is vaporized by the heat of the sun. The result is a pressure difference that drives the water vapour towards the inside of the building. If there is a VCL in the construction, interstitial condensation can occur on the outside face where it can run down to affect vulnerable materials.

This is most likely if solid walls are improved thermally by adding internal insulation. The prevalence of the problem is unknown but it is more common in thin masonry walls, absorbent walls or exposed walls that remain saturated. A weatherproof treatment or system can reduce the moisture content of a wall and the consequent risk of reverse condensation. Weatherproofing should have a low vapour resistance or it should be vented; it is applied to the outer surface of the wall.

Do not confuse this type of reverse condensation with the problems of interstitial condensation that can occur in building elements, for example in cold stores or air-conditioned buildings, where the internal conditions are colder and drier than outside.

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Complex phenomena, such as liquid water movement under temperature gradients, are becoming better understood and computer models that give reliable performance predictions are currently being used by consultants. They are being standardised and a formal protocol for assessing structures is under development.

INCIDENCE OF CONDENSATION

Case studies of surface condensation

Condensation and mould growth problems are greatest in the domestic sector, though the underlying physics is the same for all building types. Condensation is a function of four factors: heating, ventilation, insulation and occupant activity; correction or enhancement of any one of these will not necessarily reduce the problem. An example is a poorly heated dwelling in which the occupants routinely dry washing indoors. All four factors need to be under control to eliminate condensation and mould growth: reasonable heating and ventilation provision, no thermal bridging, and the occupants persuaded not to produce excessive amounts of moisture.

In 1988, BRE carried out postal and interview surveys in one-bedroom and bedsitting-room homes. The principal aim was to examine problems relating to condensation. Half the homes had enough condensation to cause pools of water on the window sills, and one in six had sufficient mould growth to damage plaster or woodwork. Problems reported by occupants were strongly correlated with observations made by interviewers. In these small homes, condensation problems were related to location in the UK (worse in warmer areas), age of respondent (retired people having fewest problems), household size, insulation standards, home heating (particularly the use of bottled gas) and air movement within the home, but not ventilation habits. Condensation and mould growth were widespread problems in all housing sectors, but especially in tenanted accommodation. It was difficult to identify the underlying cause but in many cases it was complicated by social issues.

Surveyors carrying out the Scottish house condition investigations concluded there was no major change in the occurrence of condensation between 1991 and 1996. Almost one in three households reported some level of condensation, steamed-up windows being the most common complaint. About one in six households reported other more serious problems, including mould growth on walls or carpets. As expected, the worst affected houses were those with no central heating system or which were heated by methods other than gas or electricity.

Up to 1982, the proportion of dwellings in Scotland which suffered from condensation, about one in three, is not related to age. It is only in dwellings built later that the proportion falls to 9%.

Comparable figures for England, Wales and Northern Ireland are not available at present.

On walls

Surface condensation is most common on solid 225 mm-thick masonry walls. Such walls do not generally suffer from interstitial condensation but under certain prevailing temperature and internal environment conditions, surface condensation can be a considerable problem. Mould growth is often an indication of surface condensation. Investigations carried out by the BRE Advisory Service between 1970 and 1974 showed there were roughly twice as many cases of surface condensation as interstitial in external walls. By

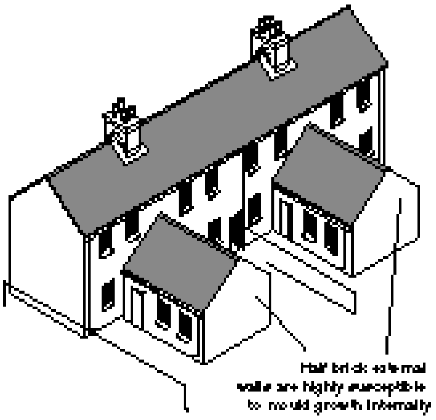

Figure 4.15 Projecting back rooms in 'byelaw' housing may have half-brick solid external walls. They are often subject to condensation

Figure 4.16 Condensation on the glazing and floor of industrial premises. Condensation is rare in building types other than dwellings

1987–1989, cases of condensation were fewer than in earlier years, though Advisory Service records indicated that the number of investigations had begun to rise again.

Reduced wall thicknesses (and hence reduced insulation) are found in porches, previously bricked-up openings and where fireplaces have been removed. Half-brick solid walls, often found in projecting back rooms to 'byelaw housing', are highly susceptible to surface condensation and mould growth – Figure 4.15.

At reveals

At window and door reveals, there may be places where the wall is thinner. Condensation can be a nuisance here and can be indicated by corroding metal corner beads around window or door openings. Impervious external wall coatings may prevent or restrict water vapour from drying out from the wall and lead to dampness and an increased risk of condensation. Changes in heating, ventilation or occupancy patterns can often lead to condensation and mould where there had been no problems previously. For more information on condensation on walls and its treatment see *Walls, windows and doors*.

On windows and doors

Just under two-thirds of all dwellings in England have double glazing on some or all windows; 30% have all windows double glazed. Older dwellings are less likely to have double glazing: more than two-thirds of dwellings built before 1919 have no double glazing; this is probably because planning considerations demanded the retention of such architectural features as wooden sash windows with slender glazing bars, or steel casements, neither of which will take sealed double glazing units.

It is commonly thought that single glazing acts as a 'dehumidifier' and that replacing single glazing with double glazing can exacerbate problems. In fact, the amounts of water vapour that condense on single glazing are small compared to the amounts produced within the house every day. It is more likely to be due to the reduction in ventilation caused by replacing old, leaky windows.

In the colder climate in Scotland, nearly two-thirds of dwellings in 1996 had full double glazing, compared with just over-one third in 1991 – a phenomenal growth – *Scottish house condition surveys*.

In roofs

Pitched roofs

There are about 14 million houses in England with pitched roofs; about one in 50 showed signs of condensation in the roof space (*English House Condition Surveys*). The age of the property makes little difference to the

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Figure 4.17 Mould growth on ceiling perimeter where insulation is missing

incidence of condensation. About one in 50 dwellings built before 1944 had condensation in the roof space; this drops to about one in 85 for those built after 1980. This is probably because of blockage of the eaves ventilation in cold-deck roofs insulated to higher standards. Unintended air movement within the roof void may also carry water vapour to areas where condensation can cause problems.

The most important way to reduce the risk of condensation in pitched roofs is to prevent warm air carrying water vapour moving from the living space into the loft via gaps in the ceiling, up wall cavities or behind dry linings. The main routes through the ceiling are the hatch cover (householders sometimes leave the loft hatch open in cold weather to reduce the risk of pipes freezing) and where pipes or lighting cables pass through. Recessed downlighters have recently become more common, especially in bathrooms and kitchens; the heat from them can cause substantial amounts of air to flow round them into the loft.

Where insulation is laid on a horizontal ceiling with a large loft space above, it has been the practice, since insulation levels increased after the energy crisis in the 1970s, to ventilate the loft via the eaves and possibly the ridge. As insulation levels have increased, especially in low-pitched roofs, it has been difficult to insulate the ceiling adequately up to the wall head without blocking the ventilation paths at the eaves. Drawing the insulation back to free the eaves can leave cold areas on the ceiling where mould can grow – Figure 4.17. There are proprietary devices which allow a free flow of air over the insulation, some of which cannot be installed retrospectively.

High vapour permeability membranes have been introduced recently as an alternative to the vapour-tight undertiling felts used traditionally. Less loft ventilation is needed, making it easier to insulate the ceiling. The batten space between the membrane and tiles must be adequately ventilated.

Flat roofs

Cold-deck flat roofs present a high risk of condensation, whatever the form of heating in the building; these roofs should be converted to warm-deck wherever possible. In existing roofs, especially flat roofs where the

Figure 4.18 Condensation on suspended timber floor perimeter

diagnosis of the cause of dampness is complicated, it may be worth calculating the risk of condensation using the procedure outlined in BS 5250. *Roofs and roofing* has more information on the occurrence and treatment of condensation in roofs.

On floors

Location

The insulation value of many kinds of floor can be degraded by thermal bridges where high thermal transmission materials penetrate layers of low thermal transmission material. This can occur at thresholds, sleeper walls or even at other points near external walls – Figure 4.18. Thermal losses due to thermal bridges are often ignored in calculations, especially where thin sections are involved, but these and other materials, such as concrete floor beams, become more important as thermal insulation standards increase. Some thermal bridges are also important because they produce inside surface temperatures below the dewpoint of the air, leading to selective condensation on parts of the flooring.

The most common situations in which condensation occurs on floors are:

- ❐ Adjacent to exterior perimeter walls where there is a loss of heat from the floor to the outside via a thermal bridge.
- ❐ On floors with high thermal capacity where the floor temperature is unable to follow rapid changes to the air temperature, and can often be below the dewpoint. This particularly affects floors in warehouses or in concourses open to the external air, when a cold spell is followed by a warm front.

Floors and flooring includes more information on condensation and its avoidance in floors.

Solid floors

Massive stone floors in unheated buildings are subject to condensation in exactly the same way as concrete floors, for example when a warm front follows a cold spell.

Solid ground floors are at risk of condensation at their perimeters. Many floors have a thermal bridge at the floor edge due to proximity to low external temperatures and the fact that dense concrete has poor insulating properties. Raft construction is particularly at risk.

Although *Principles of modern building* suggested that the incidence of condensation at the edges of slabs was low, it did point out a need for edge insulation with certain kinds of detail where the external wall was thin, such as with light cladding or curtain walling. This is still true.

A floor perimeter is likely to suffer surface condensation where the slab edge is exposed to the exterior, or abuts a solid exterior wall or the outside leaf in a cavity wall. Depending on the detailing, condensation problems may occur locally below door thresholds, full height windows or infill panels. It can also occur if there is a large accumulation of mortar droppings in a cavity wall allowing thermal bridging across the base of the cavity.

Evaporation from a concrete slab

BRE has inspected domestic properties where the occupants are convinced that the concrete slab and screed are damp and that evaporation from the surface is the cause of condensation on walls and other surfaces. Calculations have been made using the heat and moisture software MATCH to calculate the evaporation from the top of a saturated 100 mm-thick concrete slab. To give realistic temperatures in the slab, it sat on 2 m of soil at 8°C, the annual mean temperature at this level in southern England. A range of temperatures and humidities was used within the room. The calculated numbers do not take account of air flowing over the surface, which would increase the evaporation rate. In a furnished room the air speeds are very small and have a negligible effect. The calculated evaporation rates are:

Internal conditions

Temperature °C	**Relative humidity %**	**Evaporation g/m^2/h**
10	40	0.10
10	60	0.07
15	40	0.14
20	40	0.19
20	50	0.17
20	60	0.13

The largest of these represents evaporation of 36 g/day into an 8 m^2 room. This compares with values of 10,000 g/day for moisture release by normal household activities. Since it is unlikely that a slab will be saturated, the figure will be even smaller and occupants' claims cannot be substantiated.

Warm-front condensation

Cases have been reported to BRE where condensation has occurred on floor slabs after periods of cold weather followed by a warm front. Users of main railway stations will be aware of this phenomenon; where the slabs are open to the atmosphere, condensation ensues, and warning notices appear – Figure 4.19. But the condition has also been seen adjacent to thresholds in houses, where carpets can become quite wet. It is also a common problem in warehouses and other unheated buildings, though it tends to be transient. With this form of construction, unless it is necessary to remove the slab for other reasons, the only practical method is to add a layer of insulation over the slab. The decision on whether or not this is worthwhile must be taken in the light of all the other work on skirtings, floor finishes, doors and staircases which might become necessary as a result.

Figure 4.19 The floors of large concourses open to the weather often suffer from condensation

If the floor finishes and screed can be taken up, however, it may be possible to fit in a thin layer of thermal insulation within the existing depth, using for example a board finish instead of a screed. Figures 4.20 and 4.21 show acceptable forms of construction.

Alternatively, it may be possible to replace the screeds with a flowing screed; this is based on gypsum or cement plus additives, laid in much thinner layers on insulation than traditional sand and cement screeds. Lay a thin layer of thermal insulation before replacing the flooring.

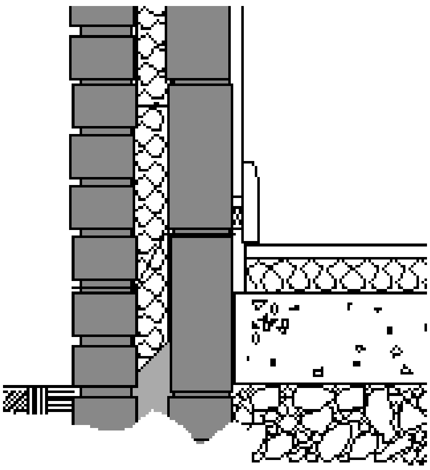


Figure 4.20 Protecting the perimeter of moisture sensitive flooring

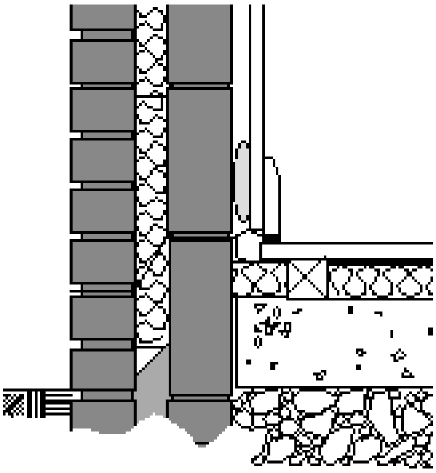


Figure 4.21 An alternative method of protecting moisture sensitive flooring with a polyethylene sheet

If the floor has a layer of thermal insulation over the whole or part of its area and the wall insulation is of a high standard, condensation might occur at thermal bridges where the slab passes into or under the external wall. Avoid the risk of condensation occurring at thermal bridges by making sure that the continuity of insulation is unbroken, especially at the floor/external wall interface, but also at the interface of the floor with internal walls occurring within 1 m of the external wall.

Condensation can occur under platform floors laid on solid bases at ground level, particularly at the perimeters adjoining external walls. If the surface of the concrete is below dewpoint and warm, moist air from above comes into contact with it, and condensation results. Additional insulation in the external wall cavity may be straightforward. But remedial action to the floor itself presents a problem: inserting thermal insulation without a VCL above it will not be effective, and continuity of a VCL is not possible because of the pedestals. Treating the void as a plenum and providing heat to the cold slab in some way may be the most practical solution, but we do not know if this has been tried in practice.

INVESTIGATING AND CURING CONDENSATION

Measuring temperature and humidity by data-loggers

When you assess a condensation risk within a building, it is important to use some form of environmental monitoring to reinforce the moisture data. With all moisture assessments, a history of the building which is as complete as possible is extremely useful. In particular, determine periods when the building fabric has been exposed to severe wetting (for example, flood waters, rainfall through defective roofing or walling, and leaking water services). Wetted building materials can take a long time to dry out.

Environmental monitoring involves installing a number of sensors which relay measured data on temperature, relative humidity, air movement and moisture to a remote logging device, normally a laptop or desktop PC.

There are several different systems which deploy either integrated or detachable sensors. Integrated devices incorporate individual sensors, for example temperature or relative humidity, within a single, easily installed unit. They are usually no bigger than a 35 mm film canister – Figure 4.22.

Figure 4.22 Integrated temperature and humidity sensors

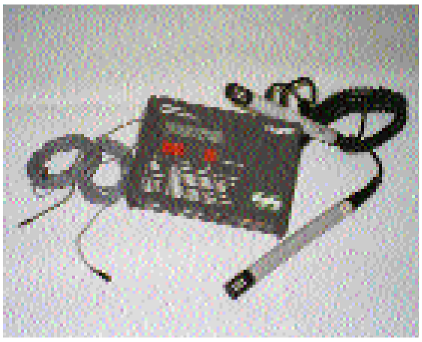


Figure 4.23 Dedicated logger with separate temperature and humidity sensors

Separate units for monitoring individual conditions are required at each location. In contrast, systems which deploy detachable sensors incorporate a logging interface to which a variety of sensors can be attached – Figure 4.23. Individual sensors can be installed at each location and connected to a single logger.

Both techniques must be interrogated at intervals by a computer in order to download stored data. This data, the amount of which can be considerable, must also be manipulated by computer software, which can either be dedicated or a conventional spreadsheet.

These techniques are particularly useful when looking at trends in environmental data over time, for example when trying to establish causes of moisture problems. Determining moisture content can establish the presence and levels of moisture but provide no indication as to their possible causes. Environmental monitoring can establish external influences on the building and what effect any wet components may be having on the internal environment of the building.

Following severe wetting of the building fabric (for example from flooding), it is not uncommon for there to be high levels of surface condensation within the building. As the building dries out, the evaporating moisture simply condenses on colder internal surfaces. Moisture content measurements may indicate that the building fabric is drying out, but there may still be severe moisture disruption, possibly condensation.

Environmental monitoring can provide accurate information on the trends and extremes, giving a detailed picture of what is actually happening.

The principal disadvantage of these techniques is the relatively high cost of the sensors and loggers and manipulating and interpreting the captured data may need specialist training.

Diagnosis

There is much to be said for a careful investigation of problems relating to condensation. Only rarely is the diagnosis straightforward, since there are other sources of dampness which can easily cause confusion.

You should:

- ❐ diagnose the source of dampness;
- ❐ look at the factors;
- ❐ identify the cause – Figure 4.24
- ❐ select the remedy;
- ❐ apply the remedy;
- ❐ follow up.

Most porous building materials retain some moisture; the amount varies widely but if is not apparent on the surface, there should be no cause for concern. You should always investigate excessive dampness if it shows on the material or component. Possible causes which you must eliminate include: leaks of all kinds, retained construction water, hygroscopic salts on walls resulting from earlier rising damp or inundation or from animal contamination.

Figure 4.24 A careless use of textured paint has effectively blocked the below floor ventilation grille

When you establish that excessive dampness is caused by condensation, your next step is to study the occupancy conditions of the building, in particular what the heating and ventilation regimes are which might lead to the generation of condensation. Causes of condensation could include:

- ❒ too cold: inadequate heating, heating too expensive to run, underused heating, inadequate thermal insulation, or too much ventilation;
- ❒ too wet: high moisture-emitting appliances, poor layout of dwelling, poor household management;
- ❒ poorly ventilated: too little or too much.

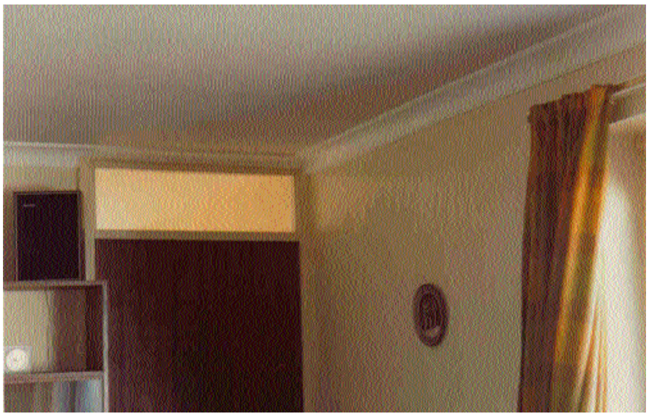
Remedies to these causes include increasing heating, increasing thermal insulation, reducing fortuitous ventilation (air leakage), increasing controllable ventilation, and reducing moisture content of fabric by improvements in domestic management.

Mild cases of mould growth often yield to simple changes in the heating and ventilation regime in the dwelling or to cosmetic treatments of redecoration, perhaps with fungicidal paint. In more severe cases of mould growth, fungicidal treatments may be little more than a useful holding operation if major rehabilitation is not possible for some time. They usually require improvements to thermal insulation, greater heat inputs and reappraisal of ventilation (either natural or mechanical) of the actual dwelling.

BRE has always found it necessary to follow up site investigations of condensation to determine whether recommended measures have actually been carried out and, perhaps more important, whether the occupants understand the part they must play to control it.

CASE STUDY — Condensation in a terraced bungalow with ceiling heating

Condensation occurred at the tops of internal walls when the electric ceiling heating was switched on; it was so heavy that it ran down the full height of external walls. BRE was asked to investigate the cause.



Construction

The L-shaped bungalow was exposed to flat, open fields to the east; the site was frequently damp and foggy. Cavity wall construction was 4-inch hollow block inner leaf, finished internally with a backing coat of 1:4 cement:sand with a Sirapite top coat. The outer leaf was dapple light facings, some external faces were finished with tyrolean stucco. Trussed rafters were at 405 mm centres and $22\frac{1}{2}°$ pitch with interlocking concrete tiles on 44 x 22 mm battens on roofing felt. Ceilings were 9.5 mm plasterboard with stipple finish. The single-glazed wood-frame windows had top-light openings. Floors were thermoplastic tiles on concrete.

The heating was a ceiling system with heating elements in a polyethylene sleeve, laid directly on top of the plasterboard. Glass fibre insulation 75/100 mm thick was laid over the heating mat. Temperature control was by room thermostats, one in each bedroom, living room and dining/kitchen; the hall/bathroom operated from the same thermostat; there were no time clocks.

Investigations

The preliminary visit was in September, too early in the season for the heating to be in full use; on the next visit, one month later, two recording thermohygrographs were set up in the lounge. When the instruments were collected, tests eliminated other sources of moisture that could have been adding to the trouble. A further visit was primarily to measure conditions within other bungalows of the same and different floor plans; as it was colder than on previous visits, a full set of temperature and RH readings were taken in the bungalow.

Measurements were taken of wet and dry bulb temperature using an aspirated hygrometer. Using tables, the RH, dewpoint moisture content and vapour pressure were obtained. Condensation was most severe in the living room and, unless otherwise stated, measurements refer to conditions within that room.

The following table shows time, location and temperatures before and during heating warm up in the lounge which had been well aired. Condensation occurred at head of wall in areas shown in blue.

Time	Dry bulb °C	Relative humidity %	Dewpoint °C	Vapour pressure mbar
11.37				
Below ceiling	15.0	68	9.2	11.65
Wall			13.0/13.5	
12.25				
Below ceiling	19.5	62	12.2	14.17
Wall			13.0/13.5	
12.40				
Below ceiling	27.6	68	**21.3**	25.5
Wall			**14.5/15.0**	
13.10				
Below ceiling	31.2	70	**25.1**	31.87
Wall			**17.5/18.0**	
14.10				
Below ceiling	36.0	40	**20.9**	24.64
Wall			**19.0/19.5**	
14.40				
Mid-room	25.1	54	15.3	17.35
Wall			17/17.5	

A thermohygrograph placed at high level recorded for one week in October diurnal readings of 15° to 22°C and 56 to 68% RH. Another, at low level, recorded readings of 13°C and 58 to 82% RH, but with more variability.

The heating was switched on at 12.25; at 12.40 readings at the same level were taken again. The dewpoint temperature was above the wall surface temperature so condensation was occurring, though it was not until 13.08 that moisture was seen on the walls. This continued with the dewpoint temperature remaining above the surface temperature of the tops of the walls.

Condensation soon started to run down the surface of the walls and reached skirting level. The walls in all bedrooms and the lounge, on outside, inside and party walls, were all stained by this water. There was condensation on the inside surface of the glazed area because dewpoint temperature of the inside air was above the surface temperature of the glass.

There was a net gain in moisture content throughout each set of measurements. Gains were small and consistent with there being three persons in the room at all times, and sometimes five. About 7.2 kg of moisture are generated each day by domestic activities so it must be realised that, unless means are taken to get rid of this moisture, high humidities and condensation are inevitable.

The level of heating seemed reasonable but the electricity consumption was well below that predicted by the local supplier for this type of property. With lower temperatures, the fabric of the building will become colder, so when the heating is switched on, condensation is more likely.

The major part of the lounge extended beyond the main part of the building with external walls on two sides, the third being a cavity party wall. The heat loss from this lounge could be expected to be quite high. Both the kitchen and bathroom were on the west side and the action of the prevailing wind would tend to move moisture across the building rather than out through the windows. An extract fan was later fitted in the kitchen; this helped to remove the moisture at source.

Air movement in the lounge was tested using smoke: there was little with the windows and doors closed, smoke released at ceiling level stayed close to the ceiling, just rolling backwards and forwards with no particular pattern. The windows were tight fitting and the patio door was sealed with adhesive tape. Even with reasonable natural ventilation, the close proximity of the door and windows meant that there would be little inducement for air in the far corner of the room to move. The patio was surrounded by a high wall, which further inhibited natural ventilation. A smoke test carried out with the top light windows open showed that the influence of these windows in ventilation was limited.

Conditions measured in January gave a dry bulb temperature of 9.3°C, RH of 84%, indicating a dewpoint of 6.5°C. So when the temperature of the roof drops in cold weather, condensation is bound to occur.

Conclusions

The first problem is the roof; the movement of moisture vapour from a high vapour pressure zone below the ceiling into the left space, coupled with inadequate loft ventilation, results in high levels of humidity. The roof temperature drops during the night, and condensation forms on the underside of the felt.

The second problem of condensation on the tops of all the walls is again caused by air dewpoint temperature being above the wall surface temperature. As the wall temperatures are not at an unreasonable level, the way in which the ceiling heating establishes a layer of high humidity air just below the ceiling must be the cause of the problem. Levels of moisture within the rooms are slightly above levels that were quoted as normal in British Standards current at the time, but possibly of more consequence is the general level of heating. This was well below that recommended by the local electricity supplier. Certainly a good level of background heat would enable more moisture to be held by the air and then carried out of the room through natural ventilation.

It appeared that there was insufficient natural ventilation to remove this moisture laden air. Owing to the design of the bungalow, moist air from the bathroom tended to move towards the bedrooms. The kitchen, with its extract fan, was not badly affected, though such effects as heat gain and convection currents set up by the deep freeze and refrigerator would help to reduce the problem.

Remedial treatment

Adequate heating and moisture removal at source are necessary to prevent condensation on the walls at ceiling level. An extract fan in the bathroom will help. This, and the kitchen fan, should be left running for a time after moisture-producing activities have ceased.

Brief flow visualisation tests showed that air movement caused by the direct electric heating systems was minimal and air change rate was low. Any solution must ensure that ventilation is not excessive, otherwise draughts would cause discomfort and expensive heat loss. With this type of heating, warm-up of the air is rapid, resulting in air temperature levels that are acceptable whilst the building fabric is still cold; under these conditions condensation can rapidly become a problem. People rarely use ceiling heating on its own and usually achieve a better level of heating by topping up with another type, such as an electric panel heater or small fan heater.

If the wall cavities are filled with insulation, the temperature of the walls would improve only slightly; on its own, insulation would not cure the condensation problem. However, the benefits gained in heat saved should help to offset the additional heat required for increased ventilation.

CASE STUDY | ## Water dripping from the ceiling in a fine-art store-room

Condensation had been a problem in the picture store extension of this building since its completion, so much that the room could not be used. BRE was asked to inspect the extension and suggest remedial measures.

Construction and history

The new construction was a first floor extension running the width of the building which was approximately 25 m at the north end.

The walls were generally of solid 337 mm brickwork with some panels of 300 mm cavity brickwork. A course of soldier bricks extended round the perimeter of the building about 1 m below roof level. Above this level the wall was solid 225 mm brickwork faced with Darley Dale stone about 100 mm thick. Just below roof level, a continuous massive stone cornice projected about 225 mm beyond the face of the building. The parapet wall, above the flat roof, was 112 mm brickwork faced with 100 mm of stone. A weathered stone coping approximately 400 x 150 mm on a lead core DPC topped the parapet wall.

The flat roof consisted of 100 mm precast concrete plank units with foamed cores, the units spanning between 400 x 150 RSIs. Black sheathing felt had been applied to the planks before laying a lightweight screed, which was in turn finished with 20 mm asphalt. The lightweight screed had been laid to falls; generally the screed was at its thinnest at the perimeter walls. The roof was pierced by the large double-glazed gable-end roof lights carried on cast in situ concrete kerbs.

The extension could not be used as a picture store because of drips from the ceiling principally over triangular areas (sides approximately 7 m) at the north-east and south-east (exposed) corner of the room. Condensation had also occurred in the roof lights and work had been undertaken to cure this problem.

Having failed to find leaks in the roof some years before the BRE visit, the owner considered that the problem was most likely to be condensation. It was therefore decided to improve the thermal insulation of the roof so a suspended ceiling of 25 mm thick insulation panels with specially taped joints was installed. No further problems were experienced until the onset of cold weather the following winter. At this time, and subsequently, the north-east and south-east corners of the room were again troubled with drips of water, this time running down the walls. Ceiling panels in the affected areas had been removed for inspection, and beads and runs of water had been observed on the underside of the concrete planks.The panels had subsequently been replaced and retaped.

The condition of the air within the storage room was controlled at 20.5°C and 56% RH, dewpoint 11.7°C, vapour pressure 13.8 millibars: a mixing ratio of about 8.6 gm/kg dry air.

Site observations

The weather on the day of the visit was damp and cold, with conditions improving slightly during the day. At 15.30, outside air conditions were dry-bulb 10°C, wet-bulb 8.6°C, RH 83%, vapour pressure 10.2 millibars.

Using an aspirated hygrometer, air conditions were measured at 11.00 at eight positions round the room at about 1.5 m above floor level.

Dry bulb °C	Wet bulb °C	RH %	Dewpoint °C
19.5	14.6	58	11.3
20.1	14.7	55	11.2
By installed thermohygrograph			
20.5	15.0	54	11.4
20.1	14.8	56	11.4
20.1	14.8	56	11.4
19.4	14.5	58	11.3
At ceiling level			
19.9	14.6	56	11.1
Hole through suspended ceiling into roof void			
15.2	12.0	68	9.8

Wall surface temperatures in the storage were measured using a digital thermometer. The readings were taken about 1.8 m above floor level.

❒ Section at upstand by roof lights where insulation panel is bonded to concrete:

$U = 0.75\ W/m^2{}^\circ C$

temperature of concrete interface 1.8°C, so condensation probable.

❒ At corner near parapet:

$U = 0.5\ W/m^2{}^\circ C$

temperature of brick or concrete in ceiling void approximately 4.4 °C so condensation probable.

❒ At roof light and exposed brick wall:
temperatures are above dewpoint.

If the screed is wet for any reason, for example as a result of inadequate protection during construction or subsequent damage, the temperatures will be lower than those calculated and condensation will be more likely.

Calculations confirm that the condensation and dampness in the roof results from low surface temperatures owing to inadequate thermal insulation, particularly near the outer edge of the roof slab.

There had been some trouble with condensation on the underside of the roof lights; however, work in this area was in hand at the time of the visit and it is understood that a satisfactory solution had been found.

Conclusions

The pattern of dampness and condensation in this extension indicated that the problem resulted from the presence of 'cold' surfaces (surfaces below the dewpoint of the ambient air) exposed to the air within the picture store. Condensation occurred on these cold areas, resulting in runs or drips of condensate. The insulated suspended ceiling had improved the overall U-value of the roof and ceiling structure considerably but had failed to eliminate the condensation problem. Condensation was originally occurring on the cold undersurface of some roof planks. Since the insulation panels were good thermal insulators, the air above the panels was at a much lower temperature than the conditioned air in the store and the underside of the planks was at an even lower temperature than before. Any warm air passing into the ceiling void would condense on the underside of the roof planks. It is practically impossible to seal a suspended ceiling sufficiently well to prevent air percolating through the system. *This is a general observation and not a criticism of this particular installation which was well up to standard.*

Rain penetration and water trapped in the roof screed were not thought to be the cause of the trouble but it was recommended that the roof asphalt was opened up at a number of points to ensure that the construction was dry before any other remedial work was undertaken. Although vents had been installed in the corners of the roof, the area over which they are effective is not known.

Remedial work

After ensuring that the existing asphalt and screed are sound, thermal insulation should be applied over the asphalt. In reducing the heat loss from the roof, this will raise the temperature above dewpoint of the room side of the planks. To be effective, a generous amount of openings are introduced into the suspended ceiling to allow the warm air of the store room to warm the roof structure. With the building continuously heated, conditions for preventing condensation should be favourable.

Calculations indicated that applying 30 mm of extruded polystyrene over the existing asphalt should keep the roof planks above the dewpoint of its conditioned air in the store rooms. Polystyrene would have to be applied over the whole roof, including the areas at present covered by the vents. Failure to insulate these areas would result in local thermal bridging and local condensation. It may be worth using thicker than 30 mm to improve the U-value of the roof and so reduce heating costs and the polystyrene must be protected for three reasons:
❒ buoyancy of the boards;
❒ wind uplift;
❒ UV degradation.

It is usual to lay a minimum of 50 mm washed gravel on top of the polystyrene. The manufacturer of the insulation material will give more details and it is advisable to consult a structural engineer about the ability of the roof to carry the additional imposed load of the gravel.

With the additional insulation installed, the surface temperature of the concrete planks (room side) should be only about 2 °C lower than the room air temperature.

Additional insulation should be applied to the surface of the brick wall exposed in the void between the suspended ceiling and the concrete planks.

CASE STUDY

Condensation in an infants' school

BRE was asked to investigate problems of condensation and efflorescence at a school in the north-east.

The first area investigated was a teaching space. A ceiling tile was lifted at the edge of the ceiling adjacent to the outside wall: the lowest point of the ceiling. It was evident that the construction of the ceiling VCL and insulation was not as described in the letter of commissioning where it was stated that the ceiling was of proprietary board tiles overlaid with a polyethylene VCL and topped with 75 mm glass fibre quilt thermal insulation. In large areas 'as constructed', the polyethylene sheet had been installed over and not under the insulation. The polyethylene was not overlapped at the edge of the sheets, nor did the polyethylene butt against the brickwork at all points. Even where the polyethylene was under the glass fibre, it would have failed by leakage at joints and edges.

The construction was also incorrect in another teaching area, with the polyethylene sheet above the insulation. At the edge of the roof space on the north wall, the glass fibre quilt and polyethylene sheet had been turned up,

leaving a gap of 100 – 150 mm along the wall; electrical wiring had been attached to the wall in this area. In a number of places there were gaps between adjoining sheets of polyethylene; there were many gaps between the polyethylene and glass fibre and the perimeter brick walls.

At eaves level there was a timber plate at the head of the brick wall on which the roof deck was carried. The timber was stained and wet, indicating that condensation had run down the roof deck. The VCL had done little to stop the flow of warm, moist air from the classrooms into the roof space. The brickwork exposed in the roof void would probably have been sufficiently cold, from time to time, to promote condensation on its surface. There would have been a steady leakage of moist air past the edges of the polyethylene sheet where it should abut the brick wall.

The pattern of efflorescence was not consistent with having been produced by drying out of the brickwork, even though the brickwork stood exposed to the elements for some time before the roof was constructed. The condition of the building suggested that rain was repeatedly penetrating into the brickwork. Parapet walls are always a potential weakness and these were no exception. Brick-on-edge is certainly not a suitable construction for copings. The number of joints is large and, where the coping is long, there is always a considerable risk of movement and cracking of joints. With no drip or weathering, the head of the wall tends to become very wet. In this case, the DPC under the brick-on-edge did not extend the full width of the wall and had been pointed over; the lead flashings also gave some cause for concern. At the lower ends of the parapet walls there were some dark stains on the brick wall below, indicating a heavy water run-off. Much of the water was probably entering in the parapet wall areas.

There was also some efflorescence at window openings; probably the vertical DPCs were incorrectly installed.

There are two ways of treating the roof condensation:

- Prevent the room air (at say 20 °C, 70% RH) reaching the roof deck or other parts of the roof where the temperature could drop below the dewpoint (about 14.5 °C) of the room air. This could be achieved by applying an effective VCL on the warm (room) side of the ceiling tiles. A proprietary plastics cocooning material would be suitable and would be expected to have a life of about ten years before some retreatment was necessary. This tends to be expensive and would have to be carried out when the school was unoccupied. The system might not be effective owing to moist air leaking from the school rooms into the cavity walls and then into the roof.
- The preferred solution is to ensure that all points of the roof with which the room air can come into contact are kept above the dewpoint of that air, about 14.5 °C.

To achieve these conditions, thermal insulation is added over the existing roof decking, topped by a metal or plastics rain shield. When a roof is improved by adding thermal insulation, a VCL is required on the warm side of the insulation. In this case, the VCL should be placed on the existing decking. A black polyethylene film coated with a self-adhesive rubber and bitumen compound is suitable. Fixings should be sealed with a bitumen compound where they pass through the VCL.

Roof cladding falls to its lowest temperature on cloudless, calm, frosty nights in winter. The cooling effect of the low outside temperature is intensified by the roof radiating heat to the sky, which in these conditions has an effective temperature of about -45 °C for radiation from the earth.

With low thermal capacity roof cladding, such as single-skin metal sheeting, the temperature of the inner surface drops rapidly as a result of a sudden drop in the effective outdoor temperature: the cladding may be about 5°C below the outdoor temperature for several hours. The U-value of the existing roof and ceiling system is about 0.4; a similar value should be maintained after the remedial work.

The thermal conditions assumed in the supporting calculations for insulation and condensation purposes are:

internal air 20°C;
RH 70%;
dewpoint 14.5°C;
outside air -5 °C.

The performance of the roof system depends to some extent on the amount of air allowed to filter from classroom to roof void.

- With 50 mm of new fibre glass insulation, assuming existing fibre glass has no effect, U-value is 0.6.
- With 50 mm of new fibre glass insulation, assuming the existing fibre glass has effect as if it were 25 mm thick, U-value is 0.22.
- With 100 mm of new fibre glass insulation, assuming existing fibre glass has no effect, U-value is 0.33.
- With 100 mm of new fibre glass insulation, assuming the existing fibre glass has effect as if it were 25 mm thick, new dewpoint is 13°C; this corresponds to air at 20°C at 64% RH. This is probably adequate.
- With 75 mm of fibre glass on top of the deck, assuming existing fibre glass has no effect, U-value is 0.4.

If the existing fibre glass behaves as if it were 25 mm thick, the new dewpoint will be 11.5°C: this is inside the condition of 20 °C, 57% RH, and is too low for safety.

It appears that 100 mm of new overdeck insulation is desirable, and it is suggested that the rooms are freely ventilated into the roof space. This probably involves removing some of the existing ceiling tiles and replacing them with suitable ventilation grilles. The existing glass fibre quilt and polyethylene film would have to be removed in these areas, but it should avoid the removal of all the ceiling tiles and glass fibre with its attendant disruption within the building.

A major cause of the efflorescence was water entering the brickwork at high level so the most important remedial work is to the parapet walls when the overdeck insulation and new decking is being installed. The height of the parapet walls should be reduced as much as possible, and a purpose-made coping with a good drip should be installed to shed the water clear of the brickwork.

CASE STUDY

Condensation in steel-framed houses

Complaints of excessive condensation and dampness were made to a district council by tenants of some of the 140 houses on the site. As is common, pressure for an investigation came from a local councillor representing a group of tenants, in this case 99 people.

Following an original enquiry to BRE on condensation, some twelve months later the chief technical officer asked BRE to inspect and report on the problem.

Construction and history

On the estate were120 Roften prefabricated houses and 20 prefabricated bungalows, constructed in the late 1960s. Types varied from one-bedroom, two-person bungalows to four-bedroom, six-person houses.

The terraced houses were from four to 10 units erected on a concrete slab. An edge strip of 20 mm expanded polystyrene some 225 mm wide was shown in the NBA appraisal certificate as floor insulation, with a 20 mm cement mortar screed over the rest of the floor, but this was not found on site. The floor finish was thermoplastic tiles.

Gable and party cavity walls were of 65 mm woodwool slabs in steel channel frames with a 50 mm cavity. Storey-height panels were bolted together and to vertical wall post channels. Cover plates were rivetted to the vertical channels and 5 mm thick semi-compressed boards were rivetted to the cover plate. The void was filled with 5 mm-thick foamed polystyrene sheet.

Front and rear walls were a braced wind girder at first floor level, with a breather paper and 25 mm-thick polystyrene insulation fitted behind the 10 mm Weyroc panels. Pressed steel ship lap panels were fitted externally, with single glazed metal windows with side-hung opening lights. In some, the windows extended the full width of the house except for one opaque panel. Construction of this panel on the external surface was 7 mm fully compressed asbestos board backed by 15 mm polystyrene and 7 mm semi-compressed asbestos board. Sills were metal channel sections with polystyrene insulation.

Floor and roof were pressed trough sections from 22-gauge mild steel. The roof decking was shown as 12.5 mm Canadian Douglas Fir plywood (sheathing quality) surface-coated with a mastic preparation. Weathering membrane specified was bituminous felt covered with a butyl membrane topped with 10 mm washed gravel 25 – 50 mm deep bonded to the membrane with a bituminous binder. Aluminium angle trim was used on the edges. The ceiling at roof level was 5 mm asbestos insulation board fixed with self-tapping screws through asbestos packing to the metal trough section. A 75 mm-deep softwood coving covered the wall-to-ceiling junction. The first floor metal trough sections were similarly clad with 12.5 mm plywood and 5 mm asbestos insulation board. A 75 mm softwood section was used for both skirting and ceiling level coving, retained with self-tapping screws. The NBA certificate illustrated a similar construction but with 12.5 mm rigid polyurethane/polyethylene laminate on polyurethane pads for the ceilings at roof level.

The roof was pierced for a rainwater pipe, soil vent pipe and extractor fan housing. A galvanised decking insert was welded into the roof trough section and a galvanised upstand slid over the pipe. The butyl weathering membrane was worked up the sides of the upstand section.

Services for the houses were incorporated in a factory-assembled core unit. Heating was by a gas warm-air unit with an asbestos-cement flue pipe. Hot water was provided by an immersion heater; a cold-water tank and flushing cistern were plumbed into the core unit. Soil and vent pipes and internal rainwater downpipes were of PVC. Gas and water services were plumbed in copper pipe. The core unit was situated in the kitchen against the party wall in some houses but in others it was built-in between the kitchen and the hall.

Structural steelwork was protected by hot-dip galvanising and further protected in gable wall and roof by one coat of heavy bituminous paint on all surfaces.

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Complaints

- ❒ Excessive condensation;
- ❒ dampness;
- ❒ loss of heat due to lack of insulation, leading to excessive heating bills;
- ❒ extractor fan vents in most kitchens not connected to the ducting;
- ❒ in winter months, occupiers had to scrape frost off the upstairs windows and window frames.

Not all of the ten houses visited suffered.

Repairs

Repairs had been made to some of the dwellings, including lining the walls with thin polystyrene and fitting slot ventilators above bedroom windows. Quarter-round timber beading was glued to some internal window sills in an attempt to prevent condensation from the windows running down the internal linings. This retained the water long enough for occupiers to mop it up the following morning. Unless this was done, the water could evaporate during the day and making conditions worse the following night.

Site visits

Sections of the wall linings removed from two houses showed the construction on site differed in detail from the documents provided to the investigators. In a second visit, a floor section and ceiling panel were also removed.

House A Most of the condensation showed as mould growth on the ceilings of the upstairs bedrooms. The position of the metal roof trough sections and the studs in the metal wall frames were outlined in mould growth on the ceiling and wall boards. Electric heating was used: a fan heater in the main bedroom and an electric fire in the lounge. A disused paraffin heater stood in the lounge. It was claimed that the gas-fired warm-air unit was too expensive to run. Some tiles under a window in the hall were lifting and a carpet in the bedroom was damaged by water. A section of wall lining was removed in the rear small bedroom revealing the 25 mm polystyrene insulation clamped within the metal frame. This had been stuck to the wall board by adhesive dabs. Part of the insulation was removed to expose the frames and the breather paper. Insulation filled the metal channel section which acted as a window jamb. The mastic sealing the wall panels appeared in good condition. There was no trace of corrosion on the metal frames but there was some slight rusting on the bolt heads that secured the panels together.

House B Conditions were similar to House A, though a section of rainwater gutter had been placed under the window in the main bedroom to channel condensation into an old oil drum standing in the bedroom.

House C Mould growth was apparent in all bedrooms. The gas heating was not used and an unvented tumble drier was in use. There was no trace of deterioration of the fabric in the cladding opened for inspection.

House D No problems were reported. The gas heating was used and the bills were not excessive.

House E No complaints about mould growth. Decorations were in excellent order. There was some rainwater penetration over a ground-floor window.

House F The house was in poor decorative order with signs of condensation. The heating system was not used.

House G Even though the heating system was used, there was condensation in upstairs rooms, there was rain penetration in the roof membrane, and repairs were unsuccessful.

House H Even though the heating system had been used, condensation had ponded under the kitchen floor covering.

House J In good order, with no evidence of serious problems. Removal of the inner boards showed there was no thermal insulation in the wall but there was some in the party wall. A section of plywood flooring was removed to expose the metal sections; no trace of corrosion was found and the protection was in good condition.

House K The kitchen was in the middle of the house with the dining end adjacent to the windows. There was one extract fan in the house at roof level, serving the bathroom and kitchen from the same vertical duct. A smoke puffer showed minimal drift towards the kitchen grille even when smoke was released only inches from the grille.

Roofs

One corner of the roof was opened. Edge trims were partly removed from the eaves of one house and the rubber turned back. The felt was lifted and two 30 mm holes were drilled through the plywood. There was no trace of insulation below the ply, just a void through which the metal trough section could be seen. Wood, felt, metal sections and roof cover were all in good condition. At some locations the chippings had been pushed back from the edge by wind getting under the material and lifting it. The rainwater outlet and the fan on the roof appeared in good order, though the fan and housing were quite dirty.

Discussion

Problems on this estate generally appear to involve condensation, though there was evidence of rain penetration in two properties. In these houses, as there are thermal bridges formed by the metal channels behind the wall board, condensation will occur on the surface of the wall in these areas. In some houses, particularly where paraffin heaters were used, this condensation was sufficient to encourage and maintain mould growth.

The pattern of window use meant that the side-hung windows could be opened on the first catch but, after this, friction hinges were relied on to give a wider opening. After ten years, the hinges either required adjusting or had failed. None of these windows had a top-light opening, so if draughts were felt from the only openable window, it would probably not be used. Ventilation at high level would give less trouble from draughts and the slot ventilator in some bedrooms would help. However, the outlet from this was behind the fascia, so the effect would be small.

The heating system provided a reasonable level of comfort, though some supplementary heat was used. This form of heating has a disadvantage that the room air can be rapidly warmed up without heating the building fabric. The air can, therefore, support a high level of moisture which condenses when it reaches the relatively cool walls.

There was rain penetration in two houses above the lounge window but with no clear point of entry. Other tenants pointed out marks on the ceiling from where water was said to have dripped. The most likely explanation is condensation on the screws fixing the ceiling boards. There did not appear to be any correlation with rainfall; if there had been rain penetration through the roof, it would have been expected to run off the ends of the roof trough sections to wet the flank walls. No trace of this was seen.

There was little condensation in bathrooms indicating that the extract fan was effective in removing moist air. The same fan was also ducted to the kitchen and appeared unable to move the air from rear to the extract grille, let alone other parts of the kitchen. The lack of a door to the kitchen/dining room would encourage moisture migration to the upstairs room.

Conclusions

Condensation in bedrooms occurred mainly on the windows but in some rooms has resulted in mould growth which outlined the pattern of the metal wall panels. The panels were fabricated from metal channel sections and these acted as thermal bridges. In some houses the polystyrene had been omitted from the wall giving a poor U-value for the section. Elsewhere, condensation had occurred on ceilings, again outlining the metal trough sections in some houses; in other houses there was an overall mould growth.

Rain penetration had occurred on a small scale above windows but there was no large-scale leakage of roofs or wall cladding panels.

Remedial work

Though the U-values calculated for the walls and cladding (where the insulation was included) were not unreasonable, the thermal bridge effect of the metal channel sections was causing concern. Accordingly, a dry lining system for front and rear walls was recommended. Dry lining could be applied to the ceiling but an over-deck insulation system would be less disruptive on these flat roofs.

U-values of 0.45 for the flank and party walls were perfectly adequate for the time and there could be no justification for spending large sums of money on further insulating these walls. There was some thermal bridging but mould growth was not severe on flank walls.

An important consideration for occupiers is that condensation on single glazing is probably inevitable and even double glazing would not entirely remove the risk.

Ventilation to bedrooms could be improved by providing top-hung lights. Ventilation to kitchens might also be improved but, if a fan were considered, it should not interfere with the air supply to the gas heating.

Postcript

On 15 November 1978, the national press announced that the whole estate of 140 houses was to be demolished over the next six years. Repairs were costed at just under £6000 for each property but as the consultant could not guarantee that the modifications would be successful, the council rejected the plan. Although the demolition costs would probably be covered by the scrap value of the steel, as a final irony the council would have to pay for 20 years or more the annual loan charges on the capital borrowed to build the estate. Traditional brick built, pitched roofed properties can now be seen on the site.

REFERENCES AND FURTHER READING IN CHAPTER 4

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Floors and flooring BR460

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Chapter 5
Rain penetration

This chapter tells you how to assess the risk of specific designs in actual locations in the UK using the driving rain index, and deals with rain penetration in solid and cavity masonry walls, cavity wall insulation, cladding systems, DPC detailing principles and well-tried details, rain penetration of pitched and flat roofs, parapets and leaking windows.

Figure 5.1 A disfiguring deposit of carbonate from rain penetrating the sloping brickwork parapet

Figure 5.2 Although much of this results from condensation, there is also some rain penetration

There are regional construction differences throughout the UK as a result of local experience and practice as well as available materials. In more exposed locations, walls may be sand:cement rendered and slate or tile-hung in Cornwall and Scotland. Pitched roofs are given a second line of defence with a sarking material of felt or plastics. In Scotland, boarding is used as the sarking. Windows in Scotland are usually inset to give protection; other parts of the UK use a narrow sill with the window much closer to the line of the outer leaf.

DRIVING RAIN

In the Building Regulations, control of moisture is a functional requirement and the building must be designed to adequately resist such penetration – see Approved Document Part C and Part G.

An International Council for Research and Innovation in Building and Construction (CIB) *Working Commission on Rain Penetration* meeting in the 1950s adopted a definition of rain penetration:
By rain penetration is meant that rainwater penetrates into a wall either through the surface of the wall, or due to leakage at windows or similar installations. It is not necessary that water penetrates so far that it may be discernible on the inside of the wall. More information is in *Rain Penetration Investigations - A summary of the findings of CIB Working Commission on Rain Penetration - Oslo 1963*.

Rain penetration in modern cavity walls tends to show as a well-defined roughly circular area on internal finishes. Sometimes surface salts will define the outer limits of such wetting. If the wetting persists, most of the wall may become visibly damp. In older, solid wall buildings, wetting may not be visible because successive coats of emulsion paint or vinyl wallpaper have masked the effects. The extent of the dampness, or if dry the salts which define it, can be traced with a moisture meter.

Figure 5.3 Severe wetting from driving rain on an exposed wall

Moisture can be deposited on external surfaces in several ways:
- ❒ Gentle rain or drizzle normally falls vertically and will accumulate on flat surfaces. Some splashing may wet adjacent surfaces.
- ❒ Driving rain, which is heavy rain blown by a strong wind on to horizontal and vertical surfaces. Water can also be blown uphill on sloping surfaces.
- ❒ Snowfall and wind-blown snowdrifts have little effect at the time but when the snow melts, it can cause severe wetting, particularly very fine snow blown into pitched roofs.
- ❒ Fog wets external surfaces but in small quantities and has little effect.
- ❒ Condensation can occur on outside surfaces in tropical climates, particularly with air-conditioned buildings. Storms in these climates are more likely to be a test of weathertightness.

Figure 5.4 The base of these walls has been wetted by splashing

Wind-driven snow

Wind-driven wet snow will collect in small quantities, for example on ledges and hood moulds, but is not known to cause problems. However, fine powdered snow can penetrate gaps in roofs and walls which may not leak water. Keeping out this snow will depend on the integrity of the air seal.

Driving Rain Index

Hourly measurements of rainfall amount, wind speed and direction have been made at meteorological sites throughout the UK and are held on a computer archive. Wind-driven rain maps have been produced from analysis of the 33-year period 1959 to 1991. BRE has produced the UK exposure map on page 86 with which the local exposure of any particular site can be assessed. The assessment is for walls up to 12 m high and will give a zone in the range from 1: Sheltered to 4: Very severe. The zone can be modified to allow for local knowledge and practice or these two features:

- ❒ add to the map zone where conditions accentuate such wind effects as open hillsides or valleys where the wind is funnelled onto the wall;
- ❒ subtract from the map zone where walls are well protected by trees or do not face the prevailing wind.

When you have established the exposure zone, examine Table 5.1 and determine the maximum recommended exposure zone for insulated walls.

You can calculate the driving rain index more accurately using the method given in BS 8104 and then interpreting using Table 5.1. The procedure and a worked example are given in the box on page 88.

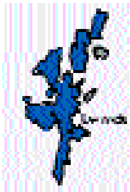
Protection given by overhangs

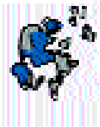
It may be thought that in high winds, water dripping from projections is quickly blown back on to the wall a short distance further down. In fact, air close to the wall forms an almost still boundary layer and, to the extent it moves at all, it flows parallel to the wall surface. Droplets shed from projections tend to fall vertically downwards to the ground. Again, a generous sill projection of at least 25 mm should be provided.

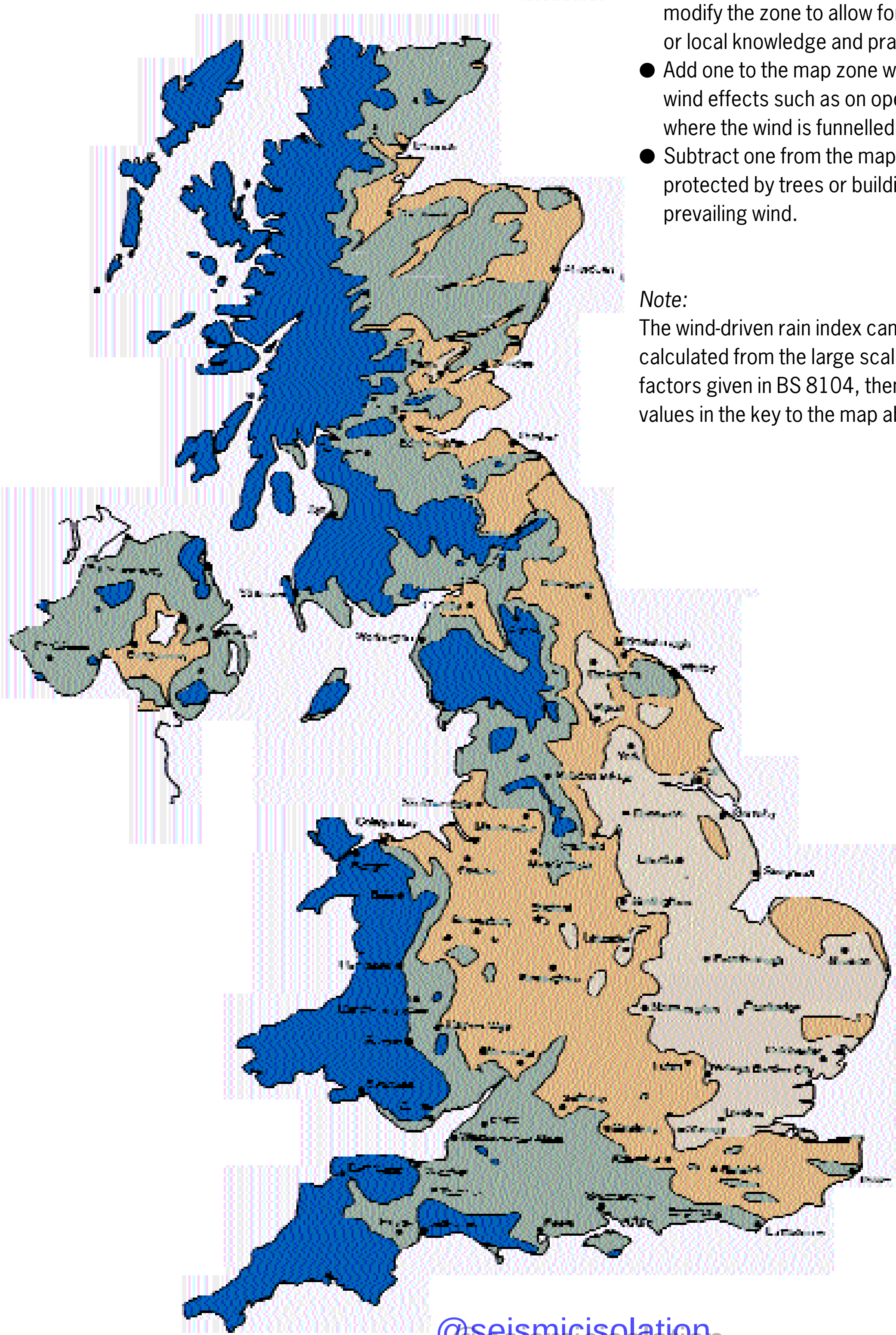
The protection given by projections at the top of a freestanding wall, or with flat roof overhangs at verges or eaves, is much less certain because air

	Exposure zones		Approximate wind-driven rain* (litres/m^2 per spell)
	1	Sheltered	less than 33
	2	Moderate	33 to less than 56.5
	3	Severe	56.5 to less than 100
	4	Very severe	100 or more

* Maximum wall spell index derived from BS 8104







UK exposure zones

Determining the suitability of proposed wall constructions

- Determine the national exposure zone from the map on this page and apply it to Table 5.1. Where necessary, modify the zone to allow for the features given below, or local knowledge and practice.
- Add one to the map zone where conditions accentuate wind effects such as on open hillsides or in valleys where the wind is funnelled onto the wall.
- Subtract one from the map zone where walls are well protected by trees or buildings or do not face the prevailing wind.

Note:
The wind-driven rain index can be more accurately calculated from the large scale maps and correction factors given in BS 8104, then interpreted using the values in the key to the map above and Table 5.1,

Table 5.1 Maximum recommended exposure zones for insulated masonry walls. See guidance notes below

Wall construction		Maximum recommended exposure zone for each construction						
Insulation method	Min. width of filled cavity or clear cavity (mm)	Impervious cladding: Full height of wall	Impervious cladding: Above facing masonry	Rendered finish: Full height of wall	Rendered finish: Above facing masonry	Facing masonry: Tooled flush joints	Facing masonry: Recessed mortar joints	Facing masonry: Flush sills and copings
Built-in full fill	50	4	3	3	3	2	1	1
	75	4	3	4	3	3	1	1
	100	4	4	4	3	3	1	2
	125	4	4	4	3	3	1	2
	150	4	4	4	4	4	1	2
Injected fill not UF foam	50	4	2	3	2	2	1	1
	75	4	3	4	3	3	1	1
	100	4	3	4	3	3	1	1
	125	4	4	4	3	3	1	2
	150	4	4	4	4	4	1	2
Injected fill UF foam	50	4	2	3	2	1	1	1
	75	4	2	3	2	2	1	1
	100	4	2	3	2	2	1	1
Partial fill								
Residual 50 mm cavity	50	4	4	4	4	3	1	1
Internal insulation								
Clear cavity 50 mm	50	4	3	4	3	3	1	1
Clear cavity 100 mm	100	4	4	4	4	4	2	2
Fully filled cavity 50 mm	50	4	3	3	3	2	1	1
Fully filled cavity 100 mm	100	4	4	4	3	3	1	2

Build quality
- Where the construction quality cannot be relied on or guaranteed, consider reducing the maximum recommended exposure zone by one category.

Climate change
- Where there is concern over the increased incidence of wind-driven rain, particularly with full or partial cavity fill, consider increasing the map zone value by one category, ie a location currently assessed as zone 3 (Severely exposed) could be considered as zone 4 (Very severely exposed). This modification should only be considered where there is increased local exposure, eg hillside location, urban fringe or multi-storey construction. Alternatively, provide additional protection in the form of rainscreen cladding to the outer face of the wall.

External insulation
- External insulation systems, which incorporate 65 mm or more of insulation or incorporate a 50 mm clear cavity and an effective external cladding, are generally suitable in all exposure categories. However, reference should be made to manufacturers and any third-party certification guidance on exposure suitability.

Cavities
- Cavities to be not less than the stated width and free of obstructions which will transmit water towards the inner leaf.

Solid masonry
- Internally insulated masonry walls to be at least 328 mm thick if of brickwork, 250 mm if of aggregate blockwork and 215 mm if of autoclaved aerated concrete blockwork with a notional cavity between the masonry and the insulation.

Overhangs
- Sills, copings, string courses and drips below cladding or render to project at least 50 mm and incorporate a throating. Flush sills and copings give no protection to the wall below.
- Overhangs at eaves and verges to be at least 50 mm and incorporate a throating. The greater the overhang, the greater the protection.

Stop ends
- Watertight stop ends to be secured at the ends of all cavity trays or lintels which are intended to act as cavity trays to prevent water discharging from the ends into the cavity.
- For complicated situations, building sequence to be considered and clear drawings, preferably isometric, provided to obtain pre-formed cavity trays and stop end profiles.

Cavity trays
- Cavity trays to be provided:
  - — at all interruptions which are likely to direct rainwater across the cavity, such as rectangular ducts, lintels and recessed meter boxes,
  - — above cavity insulation which is not taken to the top of the wall, unless that area of wall is protected by impervious cladding,
  - — above lintels in walls in exposure zones 4 and 3 and in zones 2 and 1 where the lintel is not corrosion-resistant and intended to function as its own cavity tray,
  - — continuously above lintels where openings are separated by short piers,
  - — above openings where the lintel supports a brick soldier course.
- Cavity trays to rise at least 140 mm from the outer to the inner leaf, to be self-supporting or fully supported, and have joints lapped and sealed. The rise across the cavity should be at least 100 mm.

Weepholes
- Weepholes to be installed at not more than 900 mm centres to drain water from cavity trays and from the concrete cavity infill at ground level. When the wall is to be cavity filled, it is advisable to reduce this spacing.
- At least two weepholes to be provided to drain cavity trays above openings.
- Provide means of restricting the entry of wind-driven rain through weepholes in walls in exposure zones 3 and 4, including at ground level.

Mortar and render
- A mortar mix whose strength is compatible with the strength and type of masonry unit must be specified to minimise cracking, especially for concrete and calcium silicate units.
- Tooled mortar joints, either bucket handle or weathered, to be used. Recessed or raked joints to be used only in exposure zone 1 with 50 mm clear cavity, or zone 2 with 100 mm clear cavity.
- Render to be appropriately specified and applied to the correct backing material to minimise cracking.

Third-party certification
- Built-in cavity fill must have third-party certification and be installed in accordance with manufacturers' instructions.
- Injected cavity fill must have third-party certification and be installed under an approved surveillance scheme.
- External insulation must have third-party certification for use on solid walls in specified exposure zones.

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How to assess exposure to wind-driven rain

There are two methods of assessing exposure of walls in buildings to wind-driven rain: the local spell index method, used for driving rain assessments, and the local annual index method, for the weathering and staining of facades. A spell is defined as a period or sequence of periods of wind-driven rain on a vertical surface of given orientation. A spell is of variable length and can include several periods of wind-driven rain interspersed with periods of up to 96 hours without appreciable wind-driven rain.

Using the maps in BS 8104 – Figure 5.5 – any place can be related to a subregion and located within the contour bands for a geographical increment – (i). This is in steps of 1 up to 6, and in steps of 2 above 6. The spell rose gives twelve values – (r) corresponding to different orientations around the compass. The direction of the worst weather can be confirmed by examining the spell rose.

You may also have to make assessments for:

- Terrain Roughness factor ranges from 1.15 for land offering no effective shelter to the wall to 0.75 for built up or well wooded areas.
- Topography factor ranges from 1.2 for valleys or grouping of buildings liable to produce a funnelling of the wind to 0.8 where steep-sided valleys are sheltered from the wind.
- Obstruction factor varies from 0.2 where the obstruction is between 4 m and 8 m from the wall to 1.0 where the obstruction is greater than 120 m from the wall.
- Wall factor ranges from 0.5 at the top of a two-storey house with gable to 0.2 at the foot of the same wall.

The calculation to give the Spell Index for the required location can be set out in tabular form:

Location:	Near Poole, Dorset
Grid reference:	–
Orientation:	S
Map subregion:	SY2

	Spell index	
Geographical increment	i	= 0
Rose value	r	= 27
Map value (i + r)	m	= 27
Airfield indices (table 1 -BS8104)	D_S	= 143
Terrain roughness factor (table 3 -BS8104)	R	= 1.15 (within 8 km of coast)
Topography factor (table 4 -BS8104)	T	= 1.0
Obstruction factor (table 5 -BS8104)	O	= 1.0 (obstruction < 120 m)
Wall factor (table 6 -BS8104)	W	= 0.4 (average for two-storey gable)
Wall indices (D,, = D, x R x T x 0 x W)	D_{WS}	= 65.7 l/m^2 per spell

This wall, with a south orientation, is therefore in Exposure Zone 3: Severe

The property in question – Figure 5.6 – had suffered severe rain penetration and the south-facing gable wall had been tile hung from DPC level to the gable peak. A calculation for the adjacent west facing wall gave a value of 35.9 l/m^2 and was within the moderate exposure zone. Guidance now available indicates that the south-facing walls with a 50 mm cavity were not suitable for full cavity fill. Poor workmanship was found and included incomplete fill and missing stop ends to cavity trays – Figure 5.7.

The calculation can be modified to take account of change of local ground height and the effect of steeply sloping topography – see Appendix A of BS 8104.

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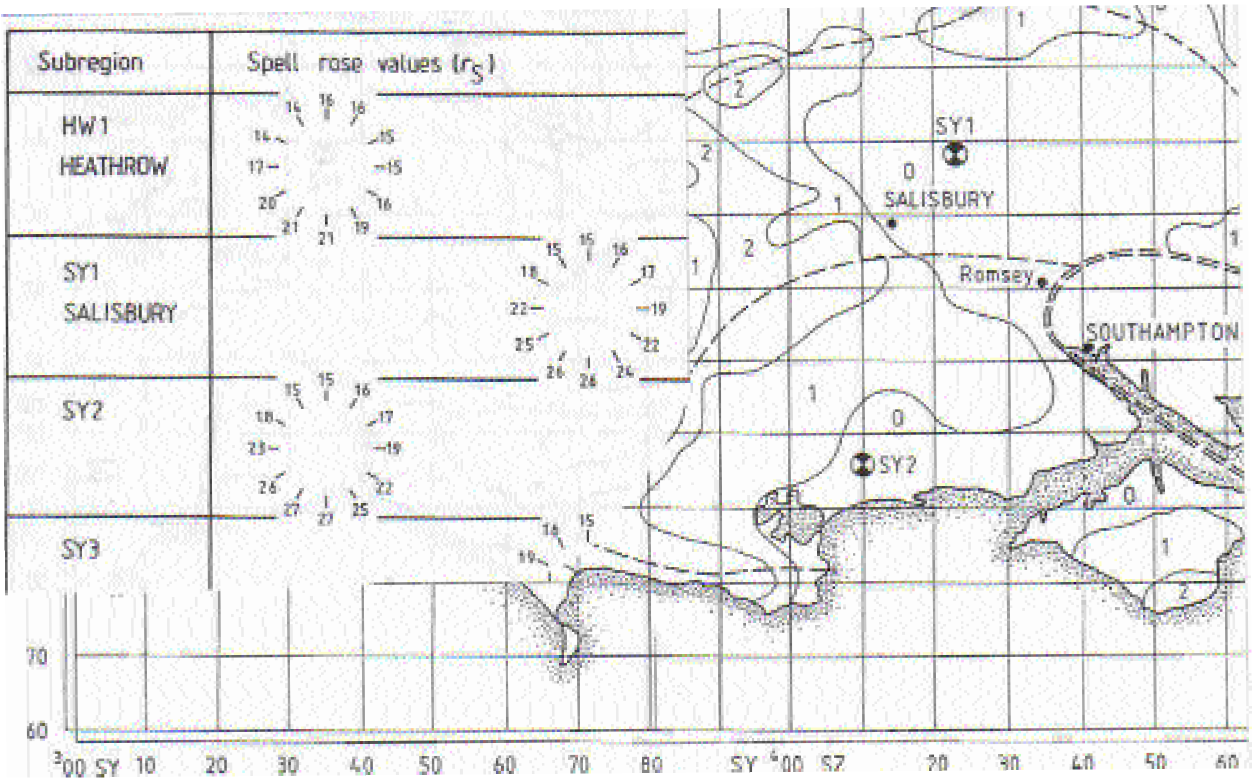

Figure 5.5 Part of the map from BS 8104

Figure 5.6

Figure 5.7 Stop ends were omitted causing internal dampness

movement is more turbulent at the top of a wall. In strong winds, rain droplets may even be moving upwards so projections may become counter-productive. There is little quantitative information on this issue but BRE has carried out tests on a rig 2.25 m high with a flat roof and positioned near the top of an escarpment 10 m high – Figure 5.8. Overhangs of different depths were fitted at the top and half way down the exposed test face.

Some of the results are shown in Figure 5.9. All the lower overhangs provided significant protection to the wall beneath but the pattern of protection afforded by the upper overhangs was significantly different. Below these overhangs, rainfall catches could be several times greater than for a wall with no overhang. The simplified explanation for this can be seen in the wind directions indicated in Figure 5.8, where the upper overhang was situated in the predominantly upwards air flow. An analogous although less

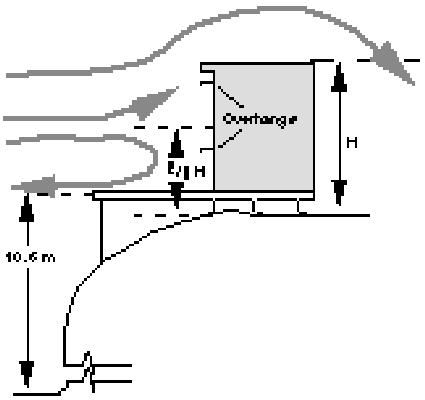

Figure 5.8 Overhangs: comparison of maximum daily catch of driving rain for wind speeds between 16 and 20 m/sec

pronounced effect could arise for verge overhangs on pitched roof gables.

Eaves overhangs to pitched roofs can provide significant protection to the wall below, provided the roof pitch is greater than about 25°. This is because, in terms of wind flow patterns, the roof acts as equivalent to an increase in height of the wall. The eaves projection is in effect positioned some distance from the top of the equivalent wall and is less likely to be in a region of wind uplift.

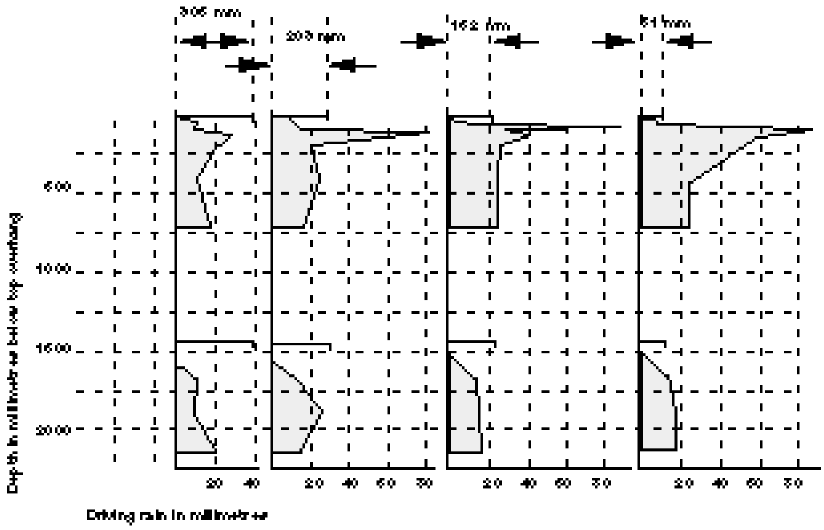

Figure 5.9 Overhangs – cross-section of rig showing airflow patterns

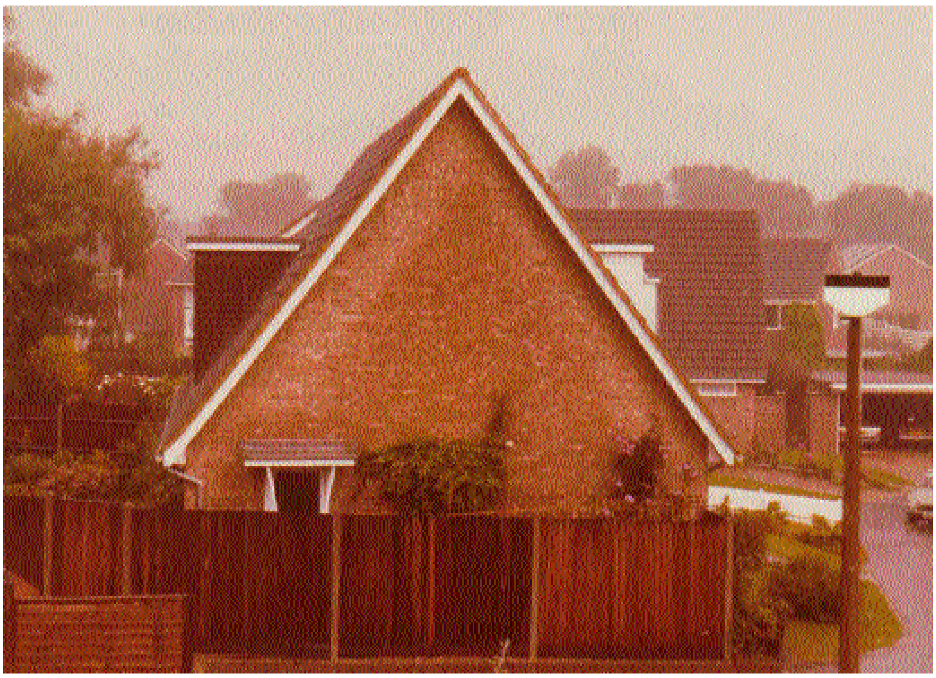

Figure 5.10 The shelter from rain falling nearly vertically which is provided by this projecting verge is clearly apparent. The protection will however vary with wind direction and intensity

Figure 5.11 Wind has caused these rainfall patterns

RAIN PENETRATION IN WALLS

The mechanisms

Water moves into or through a wall under the action of several forces including capillary action, diffusion, wind, gravity and sorption. Wind can give rise to the effects of turbulence which increase speed and change the direction of its influence. Pressure difference across a building can result in negative pressures in a cavity or void which will suck water into that area.

A wide variety of materials have been used for walling and with varying levels of resistance to driving rain. The concept is introduced of 'raincoat' construction where the surfacing material is intended to shed water, and the 'overcoat' effect where water absorbed into the masonry evaporates before penetrating the full thickness of the wall. For both these effects the resistance to rain penetration of a single-leaf wall depends on its thickness – see Table 12 in BS 5628-3.

Brick or stone walls comprise masonry units bound together with a mortar; both vary in porosity and suction. If the mortar is strong, it shrinks away from one side of the vertical joint and minor cracks develop. When rainwater hits a wall, it is first sucked into the wall material. If rain falls at a rate greater than the effect of the suction, a water film forms on the wall and run-off occurs. Some of this can enter cracks being also sucked into the bricks or stone. When the storm ceases, drying occurs by evaporation from

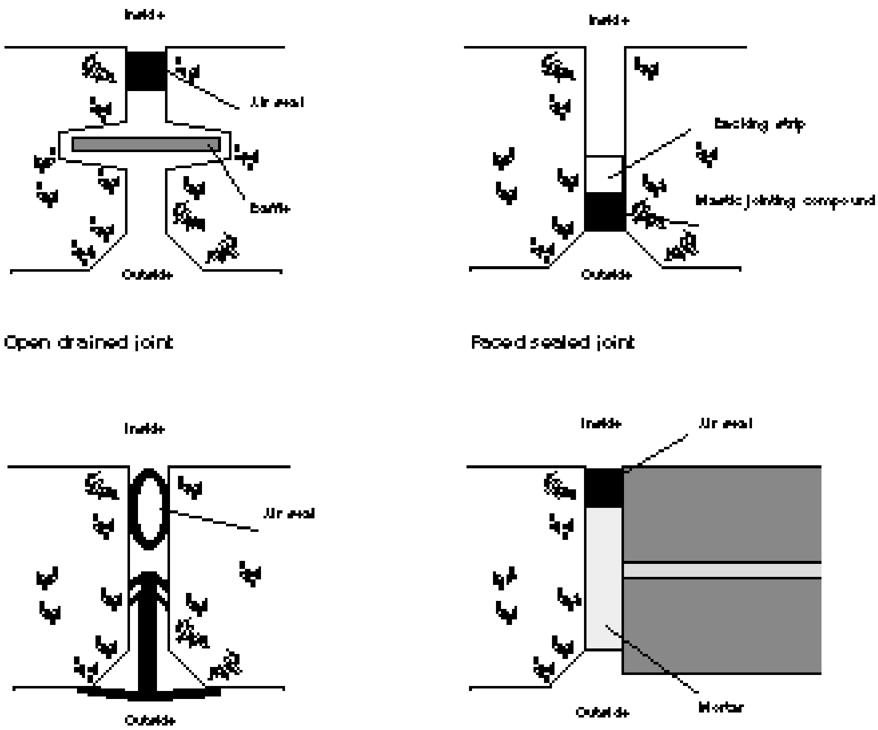

Figure 5.12 Four types of joint in large panel construction

the external surface. If rain falls for a long time, the wall is likely to become saturated with the pore structure full of water. This is the 'overcoat' effect.

The opposite is the 'raincoat' effect where impervious materials shed the water with little or no absorption. Such materials include glass, metal claddings, polished stone, and concrete which has some degree of porosity but will become saturated only during very severe storms. Walls may leak because of failure of the joints. In glass and polished stone walls, a sealant set between the edges of the sheets provides the weathering. Pre-cast concrete units for walling have incorporated a wide variety of designs to exclude rainwater – Figure 5.12. The open drained joint relies on an air seal to stop the wind driving water through and a baffle to encourage water to run downwards. Maintenance on many of these has converted them to face-sealed joints but with inappropriate sealants they have failed. Another design has an air seal at the rear edge of the panels with a cover strip at the front.

Run-off

Once rain has wetted the whole surface it begins to run off, frequently in streams, sometimes driven sideways by wind flow. It is these streams which seek out imperfections in the seals, leading to penetration, and the paths of these streams are difficult to predict. It does not follow that all the water runs down in contact with the facade. Even on smooth, unbroken surfaces water flow is not necessarily cumulative. Much bounces or splashes off, to be carried away in the air stream and, depending on the geometry of the surface, usually falls as a curtain of large drops some 300 – 600 mm away from the facade.

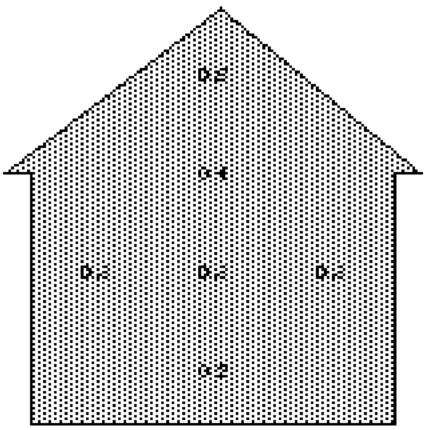

Figure 5.13 Distribution of rainfall over typical two storey gable wall. Shown as a proportion of rainfall in equivalent free space)

Because the shapes of buildings vary so much, there is an uneven distribution of rainfall intensity across wall surfaces. Even simple shaped elevations have uneven distribution – Figure 5.13 – and larger walls tend to receive less rainfall per unit area than smaller walls in the same environment.

Winds tend to drive run-off sideways across the facades of buildings; in consequence the water load on vertical joints is not necessarily any lower than that on horizontal joints – Figure 5.14. Vertical ribbing of the surface will, to some extent, divert sideways flow – Figure 5.15 – but this cannot be quantified into simple design rules. However, water flows are bound to be concentrated at vertical or inclined ribs, where the run-off rate can be many times the average.

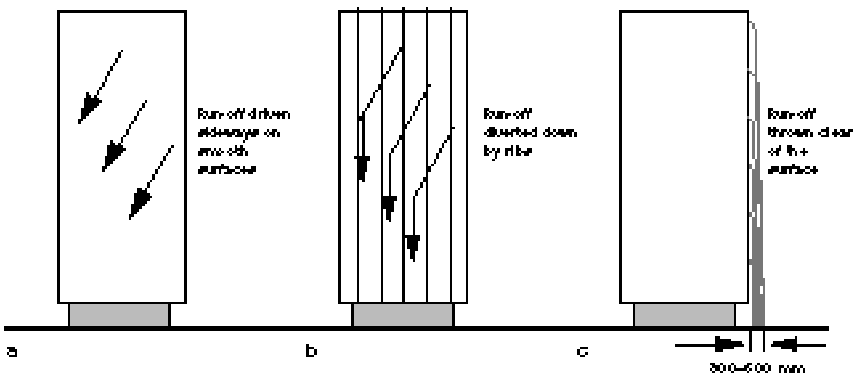

Figure 5.14 Rainwater run-off on vertical surfaces

BRE research in the 1970s showed that the percentage of driving rain which runs down the wall decreases as the intensity of driving rain increases. With driving rain intensities of up to 3 mm per hour, nearly all the water striking the wall runs down it. This decreases rapidly with increased driving rain intensities and appears to stabilise at about 30% for intensities of 20 mm per hour or more. Flow down roughly textured wall surfaces is similar to that on gloss-painted surfaces although texturing does reduce side flow.

Figure 5.15 Rainwater collects from roof and wall and runs down the inclined rib to discharge over the brick wall below

Small horizontal projections have a sheltering effect which can clearly be seen from wetting patterns which show externally during rainfall or as pattern staining internally. Projecting sills, string courses and door hoods have long been incorporated as protective features for walls.

Calculating run-off

If a wall is non-absorbent or if it may have become saturated, expect run-off lower down the wall than is usual. Calculate this by taking the average wall factor above that level, use this average value to determine the wall index, and then multiply this index by the height of the wall above the level concerned. As an example, on an exposed two-storey gable wall in, say, the Birmingham area, the run-off at the bottom of the wall during a once-in-three-year storm is approximately 165 litres per metre width. For a 10-storey block, run-off would be about 412 litres per metre width.

Surface effects

Surface texture and minor surface features can influence significantly the behaviour of rainwater run-off. Water on smooth surfaces, such as finely textured concrete or smooth renders, tends to find preferred run-off or streaming paths, leading to unsightly surface staining. Heavily textured finishes, such as roughcast rendering, can break up streams of water and give a more even wetting pattern. Textured or ribbed surfaces are also better able to prevent surface water blowing sideways, an effect which can produce heavy local loadings on cladding joints.

Some design features tend to concentrate water on certain areas of the wall, in effect increasing the exposure in those locations. An important example of this is a flush window sill. Rainwater collected from the whole area of the window is shed onto the wall below – Figure 5.16. Hence a spandrel of absorbent brickwork in a sheltered area can have an exposure equivalent to an area of the country with over ten times the driving rain index. It is quite common to see frost damage in bricks located under flush sills, while bricks in other parts of the wall are in perfect condition. A sill projection of at least 25 mm, with a drip to allow run-off to fall clear of the wall, should be provided in such circumstances – Figure 5.17.

Saturation of walls

Penetration through unit masonry invariably occurs preferentially through cracks at the brick/mortar interfaces. Tooled joints generally perform best in resisting rain penetration, and raked or recessed joints worst. Experimental work has shown that over 90% of leakages of running water

Figure 5.16 Rain water collected from the whole area of the window is shed onto the wall below

Figure 5.17 Run-off from the impervious window has not cleared the wall, leading to a different appearance of the painted surface below

Figure 5.18 Benefits of a well-repointed wall clearly visible

occurs through interface cracks; these cracks may have an average width of only about 0.01 mm. This applies not only to poorly built walls but also to walls which are well built with good standards of pointing for the external joints. Inevitably, some of these cracks are downward sloping channels, and the hydraulic head of water is sufficient to drive it through the wall.

The likelihood of a wall becoming completely saturated so that water begins to stream down the external face obviously depends on the type of brick or block, but nevertheless is thought to be relatively rare. For example, only twice during working hours in a period of 25 years was it observed to occur on a particular three-storey wall built in London Stock brick at BRE.

The most satisfactory solution to rain penetration of a wall is to identify and correct the underlying defect. But where dampness is widespread and correction is difficult, it may be better to improve the water resistance of the outer surface. Available methods include repointing, application of a masonry waterproofer, painting, rendering, cladding and tile hanging.

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Solid walls

Brickwork

Facing brickwork has a long history and has performed well both in grand houses and Victorian terraces, although repointing may be required eventually and bricks may have to be replaced when they are frost damaged. Much of the walling from the 1920s onwards was rendered externally to improve rain resistance and internally to contain any dampness. For older, solid walls, which account for about 9 million dwellings in the UK, some of which may need remedial work, there is usually no complete water barrier at any point through their thickness. Rain penetration, therefore, tends to be in a state of equilibrium with evaporative losses. The possibility of penetration is reduced by a number of traditional design features, such as large overhangs, external rendering, string courses, which tend to throw off rainwater streams, coupled with the use of dense internal renders. When the building is occupied, heat and ventilation inside also help to prevent dampness appearing. If such buildings are unoccupied for significant periods, dampness is likely to migrate further towards the indoor surface.

Figure 5.19 Buttresses affording support to a structurally defective wall can lead to rain penetration. The bed joints of the brickwork slope inwards

Solid brick walls generally give satisfactory protection against rain penetration in the drier half of Britain. When water does get through the wall, penetration is often linked with certain building features. Any of these can be a source of trouble:

- ❒ cracked or detached rendering or defective cladding details;
- ❒ deteriorated pointing;
- ❒ unweathered ledges, for example, steps in unweathered chimney stacks, piers or projecting courses;
- ❒ defects such as cracks in sills, out-of-level, insufficient projection, blocked or absent throatings;
- ❒ inadequate, damaged or blocked rainwater goods;
- ❒ unprotected joints round windows, doors, air bricks and other components;
- ❒ changes in exposure of the wall, for example adjacent building demolished or shelter trees removed.

The degree of rain penetration of solid one-brick (225 mm) walls depends on the exposure and the type and condition of the bricks and mortar; many of these walls continue to perform reasonably well in the drier areas of the country, or where exposure to driving rain is not severe. Before the widespread use of cavity walls it was common, particularly in exposed conditions, to render walls to improve weathertightness. If the render is too strong, it may crack and lead to rain penetration, so weaker renders often perform better. Solid half-brick (112 mm) walls are not weathertight.

As some of the alternative solutions which may be adopted, the Building Regulations call for external walls in situations of severe exposure to be at least 328 mm thick and of solid brickwork (equivalent to one-and-a-half bricks), or at least 250 mm of dense concrete blockwork, or at least 215 mm of autoclaved aerated concrete blockwork; all to be protected by a two-coat render at least 20 mm thick – see also BS 5628-3.

Concentrations of moisture can occur where there are barriers to downward migration, such as dense concrete lintels and DPCs.

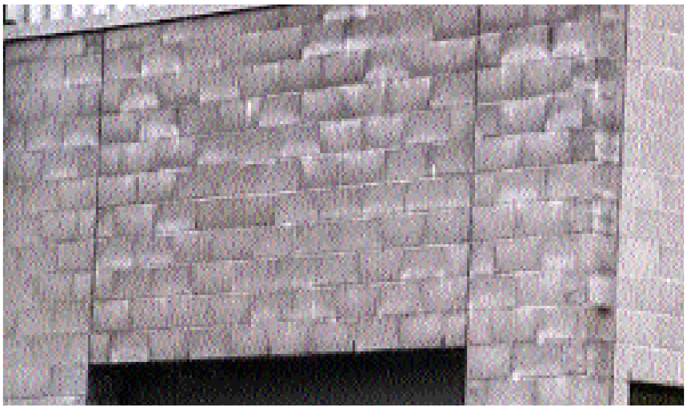


Figure 5.20 Rainwater has caused this staining

Concrete blockwork

Blocks range from dense units to autoclaved aerated concrete (AAC), also known as aircrete. Where the blocks are left fairfaced, pay careful attention to detailing and handling of water run-off if disfiguring staining is to be avoided – Figure 5.20. Blocks are obviously not as easy to handle as bricks so buttering of the vertical face can be poorly carried out giving a badly filled perpend. Coupled with the possible shrinkage of both the block and the mortar, this results in a vertical joint which offers little resistance to driving rain. Blocks are sometimes laid without bond where again the continuous vertical joint increases the risk of damp penetration.

Stone

The mechanism of rain penetration through stone is similar in many ways to that of brick, particularly where the stones are absorbent and relatively small in size. Softer stones, such as some of the limestones, absorb rainwater, then allow release by evaporation when conditions permit. The harder and less porous stones, such as granite, although relatively impervious as a material, tend to allow rainwater through imperfect joints. Flint depends almost entirely on the quality of the mortar joint. Once water has entered the thickness of the wall, it will drain down through voids and cracks within the core of the wall to reappear internally or on the face of the wall, often leaving a disfiguring deposit of white carbonate – Figure 5.21.

Figure 5.21 Deposits of white carbonate are exuding from the wall surface

In-situ concrete

Monolithic dense reinforced concrete is vulnerable to shrinkage cracking and in addition, cracks may occur at daywork joints. When rainwater runs down the outer face of such walls, even where they have been rendered, cracks provide paths for rain penetration into the building.

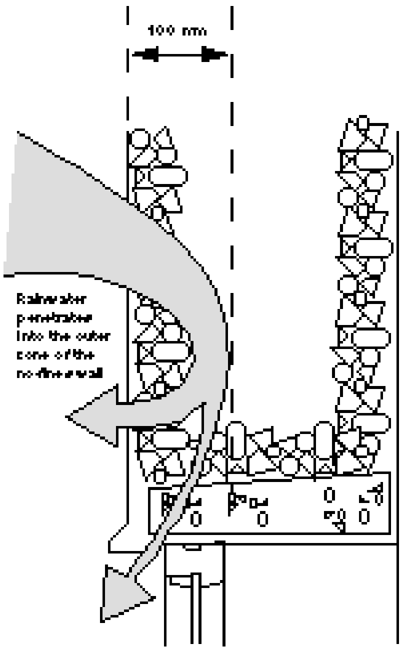


Figure 5.22 Rainwater penetrating cracks in the external render tends to find its way out again without penetrating through the wall thickness

On the other hand, no-fines concrete is not subject to cracking in quite the same way. Voids do occur through the material but rainwater penetrating through cracks in the rendering normally percolates down through the no-fines just behind the render – Figure 5.22. There is some evidence that the porosity of the aggregates slightly affects the weathertightness. Where shrinkage of the render has been severe, particularly along the bellmouths over windows and doors, it has been necessary to strip the render and re-coat, in order to preserve weathertightness.

Earth, clay and chalk

A wide variety of materials and methods can be included under this heading so we recommend you consult with a local specialist. Earth walls must not be allowed to become too wet otherwise there is a substantial risk of collapse. Cob walls can be rendered with an earth-and-lime mix and finished with lime-wash. In some villages, this was done only to the front elevation. Other elevations, and particularly barns, were just left as built. Weathering does occur and stones and straw will be seen proud of the earth, but material loss, even after centuries of exposure, is minimal.

The greatest dangers are from deterioration of the roof at the head of the wall – Figure 5.23 – and from the misconception that modern cement-based renders used externally will keep the weather out. Although they may be laid over chicken wire, pinned to the surface, the cement-and-sand render invariably cracks. Rainwater enters through these cracks and concentrates at the base of the wall. Evaporation of moisture will be at a slow rate and in the wetter parts of the country the walls are at risk of collapse.

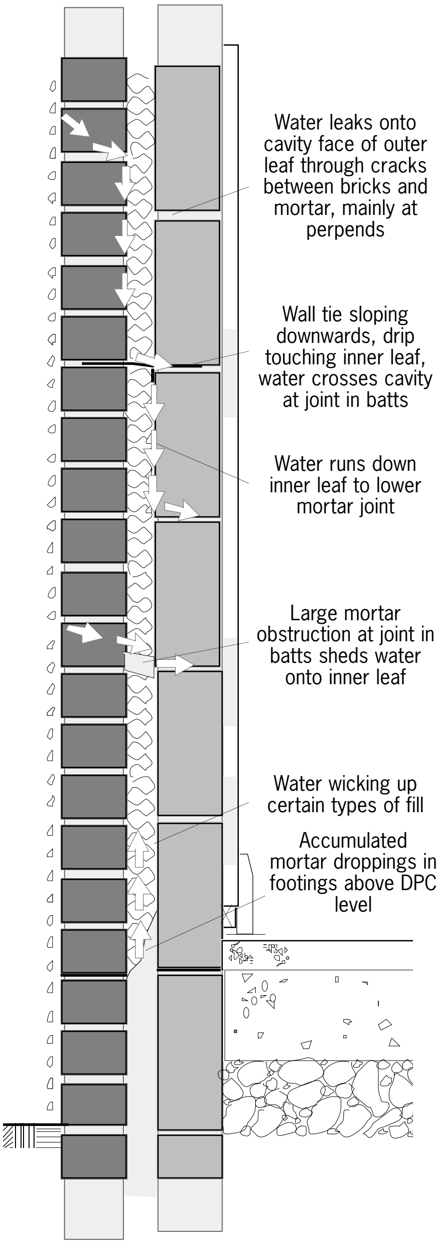
Figure 5.23 Deterioration of the roof at the head of the wall
photo courtesy Larry Keefe

A similar problem arises from the 'improvement' of rural buildings by erecting a single-brick skin against the existing cob or clay lump wall. The brick wall will not resist the passage of driving rain and so may cause the whole wall to fail.

Masonry cavity walls

Unfilled and partially-filled cavities

A properly constructed cavity wall should prevent rain penetration. However, existing construction may be imperfect in respect of the separation between the two leaves, the cavity width, cleanliness of wall ties and the method of draining any rainwater which penetrates the outer leaf. Present information indicates that around one in five external walls has significant bridging of cavities, potentially leading to penetrating damp – Figure 5.24.



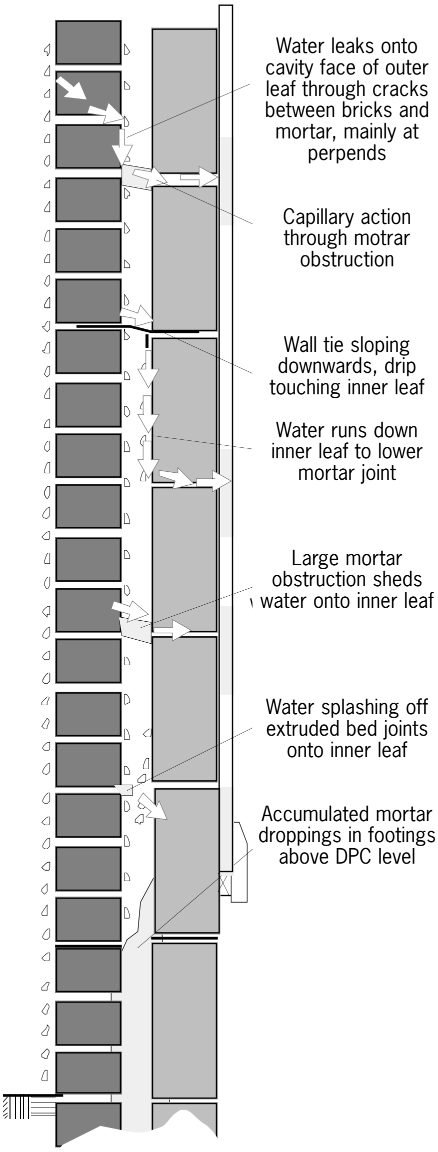


Figure 5.24 How rain can cross filled and unfilled cavities

Rain penetration is much less common in cavity walls than in solid walls, and is usually due to a fault in construction. The single-skin outer leaf does not totally resist the passage of driving rain but when water gets into the cavity it should drain freely downwards. Water can cross to the inner leaf only if it is deflected inwards.

There are several defects which can cause this to happen and these can often be identified by the location of damp patches on the inner leaf:

- ❒ Dampness at wall tie locations indicates ties sloping the wrong way, mortar droppings on the ties or other debris in the cavity.
- ❒ Dampness at the base of the wall can indicate that the cavity is blocked above the DPC by mortar droppings.
- ❒ Dampness at window reveals can indicate that window jamb DPCs are defective or absent.
- ❒ Dampness in the wall above or around openings or junctions may indicate that the cavity tray is missing or inadequate, for example it is too short or has no stop ends, or that there are insufficient weepholes.

The likelihood of penetration into the cavity is affected by the type of pointing. ‘Flush’, ‘bucket handle’ or ‘weather-struck’ pointing offer the best resistance to driving rain. ‘Recessed’, which allows water to pond on the exposed ledge, can result in a very wet outer leaf and heavy rain penetration of the cavity – Figure 5.25.

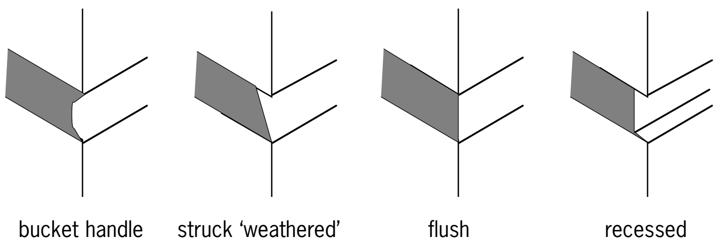


Figure 5.25 Mortar joint profiles

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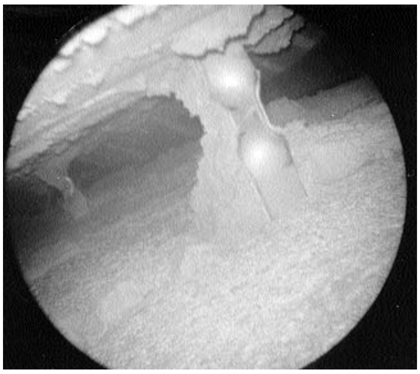

Figure 5.26 Taken from underneath a strip tie through an optical probe, this shows a massive mortar snot caught on the tie; there is a high risk of water being conducted across the cavity

More water is likely to enter the cavity if the outer leaf is built of low-absorbency bricks, or when there are hairline cracks between the bricks and mortar, or poorly filled perpends. If there are defects in the cavity, the risk of penetration through the inner leaf is greater. Even with well-built walls with clean cavities, water which enters the cavity in severe driving rain can be blown across to the inner leaf.

In walls with partial cavity fill, problems can arise if the boards or batts are incorrectly fixed and project into the cavity or even fall across the cavity. This can lead to isolated, irregular damp stains.

Similarly, mortar trapped between lifts of cavity batts can also cause dampness, seen largely as horizontal stains. Cavity trays should be installed over the top edge of the highest course of batts.

If a cavity wall is to be retro-filled, its condition must be checked to assess its suitability. The Building Regulations call for such filling to be in accordance with a current Agrément certificate, or with BS 5617, BS 5618, BS 6232-1 and BS 6232-2.

It is very common to find mortar collected on wall ties, cavity trays and at the base of cavities resulting in potential routes for moisture penetration – Figure 5.26. Around one in four cavity walls with partial fill that were inspected during 1991-1994 had inadequate provision for restraining the insulation, which could also bridge the cavity.

Cavity widths less than 50 mm increase the risk of rain penetration, as do wall ties which slope downwards towards the inner leaf of the wall, recessed pointing and inadequate projection of sills, copings, verges or eaves. Stepped DPC trays may lack stop ends at abutments, and may have unsealed laps or comers.

Figure 5.27 Applying a solution of fluorescein dye to the previously wetted outer leaf to highlight water leakage paths through the cavity wall

Site experiments on built cavity walls have shown that, after saturation, the outer leaf can quite commonly allow over 20% of incident rainfall to flow into the cavity. Rates of up to 80% have been observed in some wetting tests, especially with low absorbent bricks – Figure 5.27.

Fully-filled cavity

Full cavity fill accentuates the role which poor construction plays in rain penetration, particularly when it involves dirty or sloping wall ties, mortar snots protruding into the cavity or debris lodged in the cavity. Water may also cross to the inner leaf through gaps or fissures in the fill material.

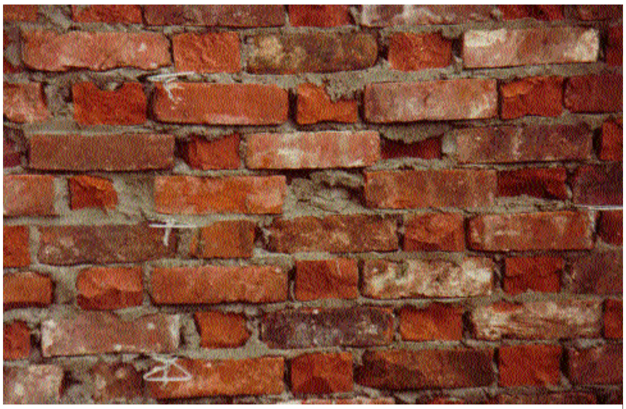

Figure 5.28 Cavity side of outer leaf built in simulated Flemish bond with snapped headers (inner leaf has been removed)

In a survey of some typical failures in walls that had been filled some time after construction, BRE found that in most cases the pre-fill inspection had failed to identify existing defects in construction, or that the building was in an area of high exposure and was unsuitable for filling – Figure 5.28.

There have been more cases of rain penetration in new housing with full cavity fill than in existing buildings that have been subsequently filled. Again, this is almost always due to faults in construction – Figure 5.29.

Figure 5.29 Mortar on the top surface of insulation. A tray should have been fitted

Filled or partly filled cavities provide adequate resistance to rain penetration if proper attention is paid to design and workmanship and if certain constructions are avoided in areas of the country with the highest exposure to wind-driven rain. Guidance is given in the *Thermal insulation: avoiding risks* and BS 5628-3. Cavity wall insulation, either as insulation batts built-in during construction, or blown into the cavity post-construction, should have been installed in accordance with a relevant Agrément Certificate or, for foam, with BS 5618.

Panelled walls

In many non-traditional buildings, the walls are in panels of impervious or nearly impervious material with special joints between. If rain penetrates the wall, it usually does so at these joints, which open and close as a result of thermal and moisture movements of the panels or of frameworks to which they are attached.

Concrete panel

High-rise blocks clad with reinforced concrete panels are vulnerable to increased exposure to driving rain. Problems have been reported with most systems. Rainwater leaking through the joints of large concrete panels seems to have been a major factor in deciding to overclad. Repair or refurbishment of the original design to restore raintightness has often been tried and has failed.

Single leaves of limited thickness can be expected to leak rainwater through to the cavity under driving rain unless protected externally with a rain-resistant cladding. Water must be prevented from reaching the frame or inner walls by suitable detailing of copings, DPCs, cavity trays and flashings. Defects characteristic of the class include rain penetration and draughts through defects in the original cladding, particularly in conditions of high exposure. Poor drainage will also take its toll.

The actual rainwater load on a building is a product of its geometry as well as the incident rain and wind. The water does not necessarily run down in contact with the facade; as already mentioed, much falls as a curtain some 300 to 600 mm away. The wind tends to drive run-off sideways. Water flows may be concentrated at vertical ribs, increasing run-off to many times the average.

Water load on joints

Cladding should resist the penetration of rain and snow to the inside of the building and the cladding itself should not be damaged by rain or snow. To satisfy this requirement, the cladding may:

- ❒ be a lap-jointed, moisture-resisting outer layer (for example similar to tiles);
- ❒ be backed by a moisture-resisting inner layer;
- ❒ be backed by a clear cavity across which rain will not penetrate.

All joints, sealed or open, should be designed to prevent rain and snow reaching the inside of the building.

Rainwater drops carried in the air stream will enter the front of vertical joints in direct proportion to the open area of the joint. However, since most flows will be at an angle to the surface of the building – Figure 5.30 – the depth of the joint, together with the topography of the opposing faces, will directly influence the amount of water reaching the back. This is why, in concrete-panel open-drained joints, if the air seal remains intact, most of the water never even reaches the baffle. On any kind of open joint, the greater the depth of the joint faces, therefore, the lower the water load on the interior of the joint. When considering any open-joint design for overcladding systems therefore, those with returned edges perform best, other things being equal. Sharp angles are better than rounded for encouraging water to flow down rather than across, but a minimum radius of 2 mm should normally be specified where applied finishes are specified, as angles sharper than this encourage thinning of applied finishes, with reduced durability.

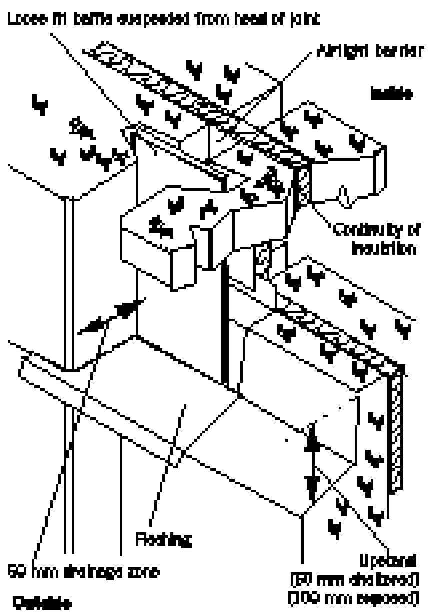

Figure 5.30 Provided the air seal remains intact in concrete panel open drained joints, most of the rainwater never reaches the baffle

When rain penetration through panel joints does occur, its source can be particularly troublesome to diagnose, as the water can percolate down through the many cavities in the external envelope before appearing on the inside of the building, perhaps some distance from the point of entry. Water trapped within the existing external envelope can cause serious damage to the fabric of the building, causing steel reinforcement to rust as well as saturating insulation and hence degrading its thermal properties.

In any face-sealed system of cladding, the jointing products used in them, for example sealants and gaskets, will be subject to movements which must be accommodated. There are exacting raintightness requirements for such joints; they must be virtually perfect. Rain water will be drawn in by capillary action if any gap is less than a millimetre or so, and any gap above that will have water pumped through it by differential air pressure.

It may become necessary to provide cavity trays and weep pipes within cladding of this kind to allow rainwater penetrating the facade to escape without percolating to the interior of the building.

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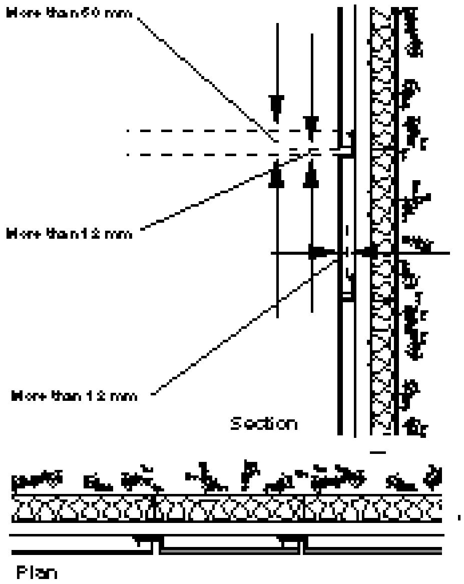

Figure 5.31 One design of edge profiling which gives reasonable protection against driving rain entering the joint. These minimum dimensions reduce the possibility of rainwater filling the channels

Rainscreens

Rainscreens are sheaths designed to keep the majority of driving rain away from buildings. In their simplest form, they were often used in agricultural buildings, where timber slats spaced apart provide a degree of ventilation, yet exclude the majority of driving rain.

In other building types, rainscreens can protect materials used in the inner layers of external walls which may be vulnerable to wetting, such as thermal insulation. Screens can take many forms, from fine mesh only slightly larger than the size of the average raindrop, to continuous sheet with open joints. The joints between jointed sheets can be profiled to give protection against rain being driven sideways, as well as to provide for the discharge of vertical flows to the sheet below – Figure 5.31.

The design of a satisfactory rainscreen enclosure is not easy, a high degree of accuracy in assembly and particularly over joint widths is essential – see box right. Once correctly designed and installed however, there is less worry about accommodating movements and durability of jointing products than with single-stage or face-sealed joints.

Curtain walling

For conventional curtain walling, that is not designed to act as a permeable rainscreen, where reliance is normally placed on the provision of an impermeable skin to resist rain penetration, the joints between the framing and the infilling are very important. Even a pinhole in a mastic seal can admit copious amounts of water when under pressure or suction high up on a facade. It is much better to give it some further protection.

When curtain walling first became popular in the late 1950s and early 1960s, BRE carried out a series of case studies on curtain walling and light cladding; they showed that many examples suffered rain penetration. Many examples placed considerable reliance on oil-based mastics to provide seals between frames and infilling. Such seals could, at best, tolerate only limited movements in service, and typically broke down after about three or four years service. When the investigation team re-visited some of the sites several years later, they found that some buildings had been re-sealed several times with the identical materials which, of course, had again broken down. No attempt had been made to rectify the defect causing the problem. No wonder that curtain walling got a bad name in the early days!

Things may not have improved much in the intervening years. A study by Taywood Engineering reported in April 1997 revealed that two-thirds of curtain walls failed to keep out water when first installed – see *The Hole Truth* published in *Building*. Unfortunately, there is still much wishful thinking on the ability of inexpensive sealants to accommodate large movements.

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The rainscreen principle

A rain-screen essentially is a relatively thin open-jointed screen spaced away from an inner wall. In its simplest form, the rainscreen can be sheet materials spaced apart, which allow rainwater to drain down the back face of the sheets, with run-off dripping from one edge to another over the horizontal joint. The cavity is fully ventilated and not limited in size to enable rapid drying of any water crossing the cavity. This is known as the ‘drained and back ventilated’ method.

In a more sophisticated version of the rainscreen, attempts are made to equalise air pressures both within and outside the cavity by carefully controlling the sizes of both the cavity and the open joints. There must also be a complete air seal at the back of this cavity. The rain-screen skin catches most of the droplets; for those few drops which get past the screen, because the cavity is open to the external air though limited in size, the pressure inside and outside is practically equal. There is therefore neither energy nor air stream available to drive the droplets across it to the inner face.

The width of joints must be accurately controlled, especially where catchment trays at the rear of both vertical and horizontal joints are dispensed with. The widths of these trays are directly related to the width of the joints, and BRE measurements give a basis for determining their dimensions. It may be possible to combine the tray with the vertical members of the support system. Unlapped horizontal joints – Figure 5.32(a) – are unlikely to fill with water, and air pressure inside and outside the cavity is therefore more or less the same. Lapped horizontal joints need sufficient upstand such that they are not likely to fill with water – Figure 5.32(b). It is also important that vertical joints do not fill with water, especially at the foot of tall buildings which have continuous vertical joints, since there is a risk that water will overflow inwards instead of outwards, as a result of blocking the ventilation slots.

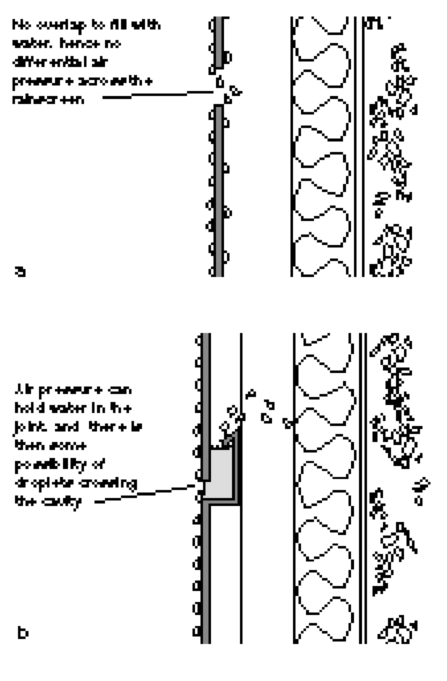

Figure 5.32 The rainscreen principle

Water will run down the back of some designs of rainscreen panels and any stiffening or damping applied to the back of the screen will get wet. This will also affect fixings on the back of the screen and the underlying insulation, depending on the design; this could be protected by a breather membrane.

Since wind action on a rain-screen-clad building will produce both positive and negative pressures, the cavities must be closed at the corners of the building so that pressures and suctions operating on different faces of the building do not interfere with each other. The size of such cavities must be restricted near external corners: a maximum horizontal dimension of around 1.5 metres is usually specified. In any case, from the point of view of minimising wind loads on the cladding, it is better to close the cavity at the corner. It is a good idea too to limit the extent of cavities within plane facades; BS 8200 suggests 5 m maximum. Within reason, the smaller the better.

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Timber frame walls

The joint between frame and nogging in old structures is vulnerable to rain penetration. Clay daub would, of course, swell on wetting to give a reasonably tight joint but a lime mortar joint would not. Ad hoc solutions may sometimes be encountered – Figure 5.33.

The bituminous felt membranes used between the wars and in some later systems have minimal water vapour transmittance. Any vapour transmission occurs mainly through the lap joints. However, inspections have shown little evidence of high moisture content or decay in the timber structure of systems where bituminous felt has been used. These dwellings generally had minimal insulation and indoor ventilation rates were relatively high. An efficient breather membrane was therefore less essential.

In some dwellings where there is no sheathing, the bituminous felt has disintegrated at the foot of the external wall. Such disintegration of the felt is particularly likely where mortar droppings have accumulated in the wall cavity. Breather membranes have decayed locally where a defective detail has caused persistent rainwater leakage.

Inspections indicate that in many older dwellings the aluminium foil which was used as a VCL has corroded and become ineffective as a vapour control layer. However, there is little evidence of resulting high timber moisture contents. The polyethylene VCLs used in some post-1966 systems were generally in good condition when inspected; some layers had lost some flexibility but this is less important if the cavity is undisturbed.

Modern timber frame constructions are a variant of the cavity wall with the benefit that the breather membrane provides drainage to control any water that crosses the cavity. Care is needed during erection that the membrane is not damaged – figure 5.34.

Some properties have had cavity insulation retrofitted. Although there is little evidence that a dampness problem has followed, some building societies refuse to grant a mortgage until the fill is removed. Cases have been recorded where this has involved taking down the outer leaf to enable complete removal of the fill: at considerable cost and with little justification.

Figure 5.33 Timber hood mould protecting a vulnerable horizontal joint

Figure 5.34 Damage to breather membrane by panels dragged across rough ground. Repairs are rarely effective.
The DPC has also suffered, and the sole plate will be at risk of rising damp from the torn DPC

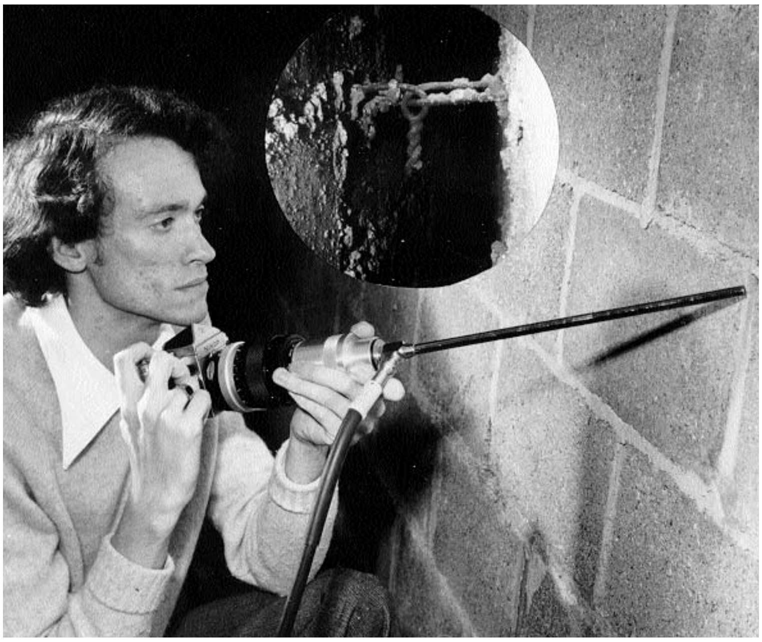

Figure 5.35 Using an optical probe. Inset is a typical field of view with a camera connected to the probe. The wire tie in the cavity is relatively uncontaminated with mortar droppings

Figure 5.36 Salts have dried and destroyed the paint film. Removal of the block revealed a corner of the bat turned over

Signs of rain penetration

- Damp patches following heavy rain. If the patches appear immediately, the cause is probably hygroscopic salts, often seen on chimney breasts or where there has been local salt contamination.
- Patches on the inside of external walls exposed to the prevailing weather, usually showing efflorescence. They can be related to faults in the wall itself or to defective rainwater goods or parapets.
- Dampness round window and door openings is usually due to incorrect installation of DPCs and cavity trays.
- In ceilings, damp patches usually point to a leaky roof or faulty guttering.

Survey methods

Finding out exactly what kind of wall construction has been used in a building is often not easy, and some destruction in the interests of diagnosis of a problem may be inevitable. It will be a matter for professional judgement in balancing the severity of problem with the consequences and costs of making good any damage.

Optical probes may be useful because they keep damage to a minimum but our experience is that they must be used with caution, since the field of view is restricted – Figure 5.35.

Diagnosis

Before taking any remedial action against rain penetration, exclude all other possible sources of dampness. Visible effects often dry out fairly rapidly although repeated wetting will mark decorations and may leave a deposit of salts at the furthest limit of the damp – Figure 5.36.

Outlining and dating the extent of wetting is a useful reminder of what has been experienced. If circular patches have occurred in a fully filled cavity wall, dirty wall ties may be the problem. However, opening up the wall may not be conclusive and drainage of water through poorly installed fill materials is more difficult to quantify. A spray test using a sparge pipe is useful in confirming rain penetration and subsequent opening up of the cavity should help to identify the way the water is reaching the area of dampness. More guidance on diagnostic methods is given in *Rain penetration through masonry walls: diagnosis and remedial measures*.

The main symptoms of rain penetration through walls are summarised in the box below.

If rain penetration is correctly diagnosed as the problem, it can be difficult to pinpoint the exact route the water is taking. A damp patch on a ceiling could be due to a missing tile some distance away; masonry in parapets and chimneys can collect rainwater and deliver it to other parts of the building below roof level; blocked gutters can lead to damp patches on walls that appear to be rain penetration.

Remedies: external

Of the many recommended treatments for walls that have become damp from direct rain penetration, some are applied to the outside, some to the inside surface and some can be used on either surface. The advantage with external treatments is that they keep the body of the wall dry, and so help to improve both durability and warmth.

Figure 5.37 Tile hanging in progress. Unfortunately the 'breather' membrane is not a breather membrane at all but is a polyethylene sheet. This forms a vapour control layer on the cold side of the thermal insulation with a risk of condensation inside the polyethylene

Tile or slate hanging

The most effective of all external treatments is tile or slate hanging. It is durable, especially if any timber used in fixing is pressure-impregnated with preservative. Tile or slate hanging has an advantage over most other treatments in that it is able to shed most of the rain failing on it without impeding evaporation of any moisture that may still find its way into the body of the wall by indirect paths.

Provided tiling or slating is constructed without obvious faults, the wall should be weathertight for all exposures of driving rain, although wind may lift tiles or slates, as it can with roofing. A suitable breather membrane to BS 4016 – Figure 5.37 – is important; more information is in *Roofs and roofing*.

Renderings

External renderings in cement, lime and sand mixes are next in effectiveness to tile hanging. They are particularly useful in preventing direct penetration through cracks between mortar and bricks or blocks. Applied to a nine-inch one-brick wall, they can be expected to keep the internal surface of the wall dry except when it is exposed to severe driving rain. This may also occur towards the end of an abnormally long spell of wet weather when there has been little opportunity for evaporation.

A remedial measure for rain penetration in a two-storey house is to provide a render to the first floor level only (including the gable), with a bellmouth finish at the lower edge. This is often cosmetically more acceptable, and cheaper, than complete cladding or render. The mixes usually recommended for render are cement:lime:sand 1:2:9 or 1:1:6 These produce finishes that are porous, absorb water in wet weather and permit free evaporation when the weather improves; the action is rather like that of a thick layer of blotting paper. Full details for the choice of mixes are given in Good Building Guide 18 *Choosing external rendering*.

A dense, impervious rendering might seem preferable but is often less efficient than a porous one. To be effective, dense rendering must be free from cracks, a condition difficult to ensure. If cracks form, rain water running down the face drains through the cracks into the body of the wall and becomes entrapped behind the dense rendering; this impedes subsequent evaporation. Consequently, the moisture travels inwards, much of it evaporating from the inner surface, causing familiar signs of dampness, such as efflorescence and staining. Penetration through cracks in a dense rendering is most marked where the rendering has a smooth surface. Such finishes as roughcast and pebbledash shed much of the water that falls on them and are less likely to cause dampness in this way; they are particularly suitable where the exposure is severe, for example near the coast.

Renderings are often used to increase the weather resistance of a basic wall material; however, the more exposed the wall, the more restricted is the choice of render. The factors involved are:

- ❒ Rendering can increase the exposure rating to wind-driven rain of a wall by one or two categories: a wall which would otherwise be suitable only for sheltered exposures can be upgraded to severe or very severe – see *Thermal insulation: avoiding risks*.
- ❒ Exposure to marine or polluted environments may lead to attack on the cement content of renders or increase the rate of corrosion of metal lathing.
- ❒ Rendered walls exposed to driving rain and pollution may streak differentially. Flint or calcareous dry dashes have the best self-cleaning properties though some flints contain iron, which can lead to staining.

Renders have a significant effect on reducing rain penetration into walls but their effectiveness may be variable:

- ❒ 1:1:6 and $1:\frac{1}{2}:4\frac{1}{2}$ renderings are effective in reducing the passage of water into brick backgrounds and this is improved further by adding a dry-dash finish. Performance can be significantly reduced by cracking or loss of dash by erosion.
- ❒ Rendering does not reduce the passage of water into aerated concrete backgrounds as much as it does on clay brick backgrounds. It does, however, help to prevent rain penetration through the joints.
- ❒ Evaporation rates are generally much lower than absorption rates but there is usually no significant build-up of water within the materials.
- ❒ Rainwater absorbed intermittently is usually lost by evaporation before it can penetrate deeply.

Timber boardings and PVC-U sidings

Timber feather-edged shiplap is comparatively weathertight provided it does not rot, warp nor split. Traditionally, the timber is painted or treated both for appearance and for protection. PVC-U sidings are unlikely to suffer too much from these if they are not vandalised but there can be surface deterioration. Traditional paints can reduce impact resistance so special products have been formulated – see Digest 440.

Vertical boarding spaced apart to allow ventilation is frequently seen on agricultural buildings. Provided the joints are not too wide, little driving rain will enter the building, especially when it comes at an angle inclined to the wall. Wind-driven fine dry snow, however, is another matter.

Paints and other coatings

Paints have been used on stucco for centuries, generally successfully. The main problem is that the paint film may crack and allow water to wet the masonry or render behind. Drying is inhibited by the paint film and can lead to an accumulation of water and potential frost or sulfate damage. Cement paint coatings are particularly good at shedding water under severe exposure. Weather resistance is improved only if the wall has no major cracks or defects that allow water to penetrate behind the paint film.

Aerated concrete blocks or panels must be coated to resist rain penetration. Investigations by BRE on different coatings for water penetration, vapour resistance and durability demonstrated the significant influence of coatings on moisture content gradients across the wall. There were persistent high levels or even penetration to the inner surface under some conditions,.

Oil, bitumen and tar paints were traditionally used to coat the plinth at the base of the wall. They give an almost impervious surface coating, so they should be used only on walls where there is no risk of indirect penetration of moisture through parapets, sills, etc, nor any likelihood of a build-up of condensed moisture at the back of the paint film.

Solidly bedded tiling

As with any comparatively impervious finish which is prone to cracking, the weathertightness of a wall covered with solidly bedded tiles depends on the absence of cracks which allow rain water run-off to penetrate the finish. It may not easily find a way out, and frost action can then occur.

Colourless waterproofers and repellents

These treatments can improve weather resistance. They are clear and at worst will give only a slight sheen to the wall. Although water-repellent treatments do not completely seal the pores of the surface, some closing of the surface is inherent. The principle is that a greater quantity of water is turned away from the surface than is prevented from evaporating. Run-off from the surface will be increased so vulnerable details which might leak are at greater risk.

BS 6477 describes test methods for water-repellent treatments but they do not take into account either the crucial influence of mortar joints or the effect of water applied with forces similar to wind-driven rain. BRE tests on clay and calcium silicate brickwork using BS 6477 methods showed silicone-based treatments to be the most effective; treated masonry did not leak and the moisture content of the walling remained low. Polyoxoaluminium stearate treatments were moderately effective but one based on acrylic polymers was poor.

Colourless waterproofers make a wall surface water repellent and less porous, without much change in appearance. Like paints, they should be used with discretion; in particular, make sure that the dampness is not due wholly or in part to some cause other than direct penetration through the wall. If it is, the attempted cure may cause more trouble. The permanence of the protection is variable and depends on the type of waterproofer and on the condition of exposure. Periodic renewal will probably be necessary.

Repointing

Repointing should be the only maintenance required on a durable brick; its frequency depends on the mortar, the finish of the joint, and the degree of exposure of the wall; a life of at least 30 or 40 years ought to be expected. Hand-raking the old mortar wherever possible is preferred to mechanical equipment. Disc cutters can cause considerable damage.

Leaking mortar joints should be deeply raked out and repointed using a mix compatible with the existing mortar and type of masonry. It can be difficult on site to sort out the various designations of mortars, so there is something to be said for the use of a 'general use' mortar, which can resist all but the most severe exposure, and can accommodate minor movements. Such a mix is 1:1:5½ Portland Cement: hydrated lime:Type S or G sand plus an air-entraining agent.

Pointing technique can play havoc with durability and can alter the character of a wall. Recessed joints, for example, can lead to reduced weathertightness so should be used only in the most sheltered locations.

Remedies: internal

If you cannot be certain that direct penetration of rain is the sole cause of dampness, internal treatments have obvious merits. They may help to combat dampness due to rising ground moisture, indirect rain penetration or contamination with deliquescent salts. A further advantage is that they are applied to a more accessible surface. External treatments could aggravate this sort of dampness, unless they are porous.

Dry lining

The traditional way of preventing moisture reaching interior wall surfaces was to batten out (strap) and fix wallboard, t and g or lathing out of direct contact with the wall. All timber used for plugs and battens was pressure-impregnated with a non-staining inodorous preservative. Where they are in contact with plugs or wall, battens should be painted with a bituminous paint to reduce transmission of moisture, or a slip of bitumen felt should be inserted between the wall and batten. If possible, the space behind the lining should be ventilated.

An alternative was to fix corrugated bitumen impregnated sheet to the wall and render or fix plasterboard over. This has now been replaced by plastics dimpled sheets with the options of similar finishes. Both methods need ventilation behind the impermeable sheet. They take up an appreciable amount of space and sometimes present difficulties at openings.

Dense internal renderings

These were commonly used in the 1920s and 1930s with solid brick walls and can be equally suitable as a remedial treatment for damp walls. A dense cement and sand rendering, often with an integral waterproofer added, is used; such a rendering impedes the passage of moisture to the inner surface but it also slows down the rate of deterioration of the decorative coating. It does not prevent all penetration but can, in favourable circumstances, reduce it to an acceptable level.

The suitability of an internal rendering depends largely on an alternative escape for any water that enters the wall. This water must be allowed to evaporate elsewhere. If the body of the wall and any external covering is a porous material, the internal rendering is likely to have a significant effect. If, on the other hand, evaporation from the outside surface is likely to be difficult, little benefit can be expected. This can be because the wall itself is dense or there is a dense rendering on the outside.

The value of dense renderings used in this way depends to some extent upon the nature of the decoration. Finishing coats of calcium sulfate plaster and decorative coatings of oil paint, distemper and wallpaper are all sensitive to dampness. Where circumstances permit, there is much to be said for omitting the finishing coat plaster and applying cement paint directly on the cement rendering.

Internal waterproofers

Another internal treatment for damp walls is to apply an impervious coating of bitumen or similar material; this is followed by blinding with sand and plastering or by lining with wallboards. The adhesion of the impervious coating to the wall is critical and can be lost if the wall is wet when the waterproofing is applied. This treatment can be successful but BRE's experience is insufficient to assess the risk of failure in any given circumstances.

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It is sometimes thought, mistakenly, that 'sealers' applied to a damp wall will prevent the dampness reaching the inner surface and spoiling the decoration. The principal function of most proprietary sealers is to reduce suction and so facilitate application of a decorative coating. No doubt they reduce the porosity of the surface plaster, but they cannot be expected to make it waterproof.

The same is true of alkali-resistant primers. They guard against attack on a paint film by alkalis in the surface of the wall. They will not prevent other effects of dampness, such as blistering, loss of adhesion and efflorescence.

Workmanship

Unfilled and partially-filled cavity walls

The precise location of the dampness must be pinpointed before any defect can be remedied. You may have to remove areas of paint or wallpaper and use a moisture meter to locate the boundaries of damp patches. A wetting test will confirm that the dampness is due to rain penetration.

Pinpoint the location, then remove a few bricks from the inner or outer leaf and inspect the cavity using a mirror and a torch with a narrow beam. Alternatively, use an optical instrument such as a borescope.

You can remove small obstructions in the cavity, such as mortar droppings on ties, from holes drilled in the inner or outer leaf. Other faults, such as misplaced DPCs, may also be diagnosed by looking into the cavity.

Some types of metal detector are useful for finding the position of wall ties. If the position of a tie corresponds to a damp patch, it is worth removing a brick or block at that point for detailed inspection.

All these methods are possible for unfilled walls and for those with partial cavity fill. For more details, see *Rain penetration through masonry walls*.

Fully-filled cavity walls

It is quite difficult to identify the cause and location of rain penetration in a fully-filled wall; a special investigation may be needed.

A wetting test is necessary for some fills; simply opening up the cavity without artificial wetting can be deceptive. Penetration through built-in fibre batts usually occurs at joints between batts rather than through the batts themselves. Mortar bridges or other minor installation faults can be corrected quite easily, and the joints re-formed before closing up. For injected fills, injection of more material sometimes cures the problem.

Repointing can help if mortar joints are cracked or in poor condition.

In exposed areas, or if the dampness is widespread, one of the remedies for solid walls described above is probably best.

Renderings

It is extremely difficult to repair a cracked dense rendering satisfactorily. Even if all precautions are taken to undercut a groove, wide enough to fill on the line of the crack, and then to fill it carefully with a cement:sand or a cement:lime:sand mix, a new crack will probably form at the side of the filling within a year or so. Although narrow at first, the new crack might be filled satisfactorily by a cement paint treatment but, sooner or later, the major repair of cutting out and filling with mortar will be needed again. There is much to be said for making a thorough job of the repair by removing the whole of the dense rendering and replacing it with a less dense mix of cement:lime:sand. This more porous rendering is less likely to develop large cracks and should not cause entrapment of moisture within the wall.

Panelled walls

There is no strong case for an overall treatment of a wall of this nature where the joints, rather than the panels, have allowed rain penetration. Filling the joints with a suitable mastic, which can accommodate small movements, will often prevent further moisture penetration. The mastic will of course, need periodic renewal.

Assessing repairs

Make adequate allowance for the time required for heavy masonry construction and concrete to dry out; a year may be too short a period if the material itself is very dense (good quality concrete for example) or if the wall is covered with an impervious skin of tiles, dense rendering or paint. Efflorescence may continue to appear on the surface during the whole of the drying out period

There may also be deliquescent salts present in the damp wall; while it is drying, they will be brought to the surface, possibly in sufficient quantities to cause damp patches. Further local treatment will then be necessary.

Damp-proof courses

Purpose and performance

Damp-proof courses (DPCs) are formed from impervious materials introduced to prevent the passage of liquid water from one part of the construction to another. This usually means attempting to keep the inner skin free from absorbing moisture and therefore 'dry'. Chemical DPCs are used specifically for remedial work at the base of the wall. DPCs in solid walls are normally found at the base of the wall and in parapets. One example was formed from lead and was through the full width of a parapet wall. But there was an inherent defect: the flashing was on top of the DPC and the lead was perforated and required replacement – Figure 5.38 and page 146.

Requirements for DPCs become more critical within the cavity wall. The risk of failure is high unless the concepts are understood and material selection and workmanship carefully approached. BRE Advisory Service has been involved in many hundreds of cases of DPC failure and the remedial work can be costly – Figure 5.39. Demolition of whole sites has been necessary in some cases. The introduction of pre-formed components has reduced the incidence of failure but has not eliminated it.

Figure 5.38

Figure 5.39

Location

Figure 5.40 shows situations where DPCs are required and where they can be omitted.

A DPC is needed:

- ❐ in both leaves of external cavity walls to prevent rising damp; it should be positioned at least 150 mm above adjacent ground levels to guard against rainwater splashing the wall from the ground – Fig 5.41
- ❐ beneath internal partition walls; this prevents a wet slab drying out into the base of the wall;
- ❐ beneath sills and copings which are formed of jointed units to prevent penetration of water to the wall below – Figure 5.42.

A DPC should be installed in a parapet wall to provide continuity of the weatherproofing with the roof covering. It should be not less than 150 mm above the roof finish to lap over any cover flashing to the roof upstand. Some designers feel that taking the tray outwards leads to unsightly staining running down the outer face of the masonry. There is the option to drain the tray towards the roof but this concentrates water at a vulnerable junction. If the cavity is filled, the tray should always drain to the outer leaf.

Where a masonry chimney penetrates a roof structure, one or two DPC trays with appropriate flashings should be provided. If the capping is jointed, a DPC is required below – Figures 5.43 and 5.102.

Openings in cavity walls need protection with integrated vertical and horizontal DPCs to deflect water away from the inner leaf – Figure 5.44. Vertical DPCs are needed at the jambs of openings where the cavity is closed; horizontal DPCs are also needed at the head to bridge the cavity in the form of a tray. A DPC is necessary where the sill is jointed.

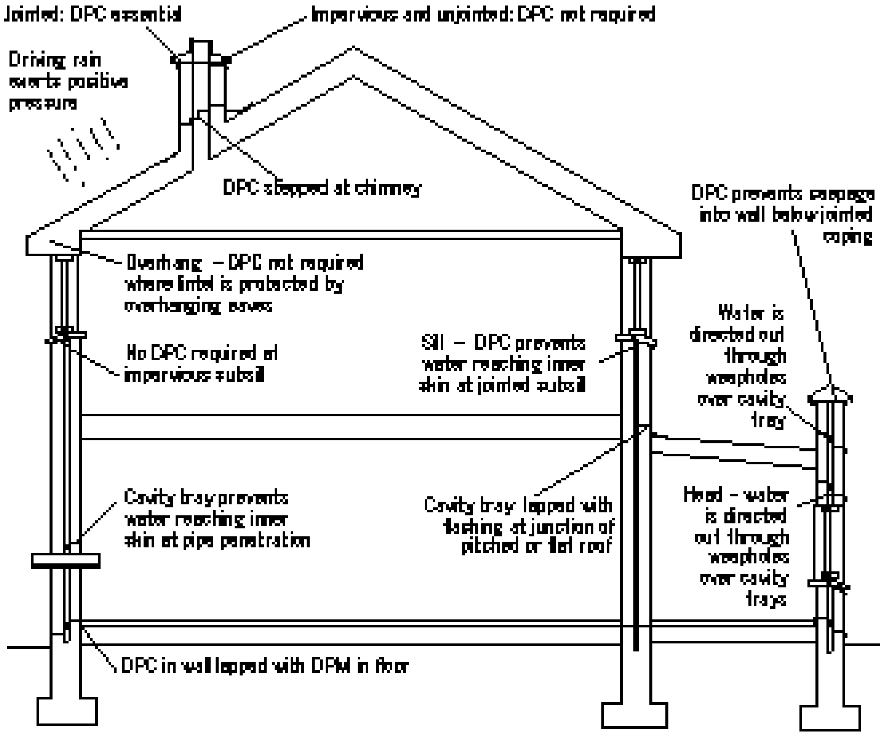

Figure 5.40 Positions where damp-proof courses may be required

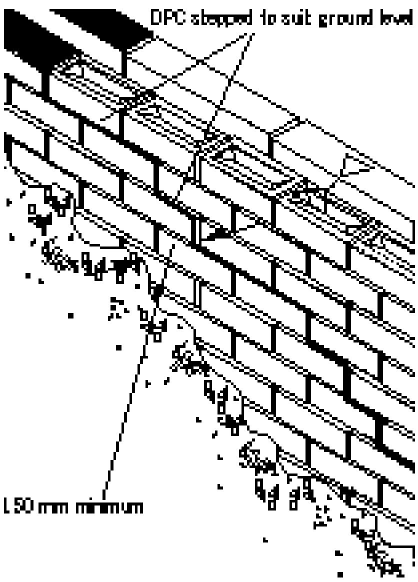

Figure 5.41 To prevent rising damp

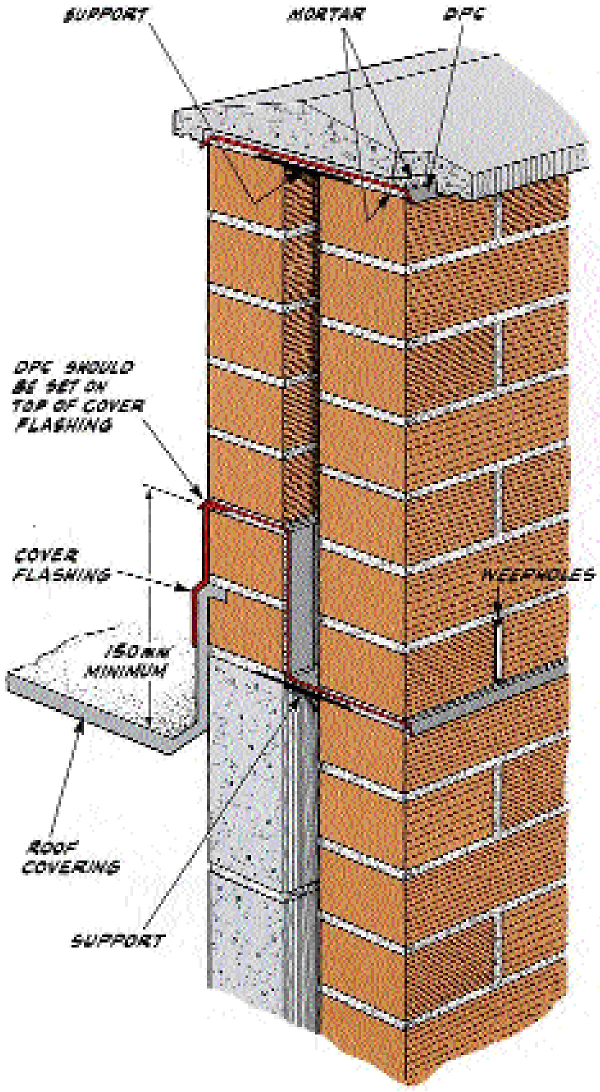

Figure 5.42 Beneath copings

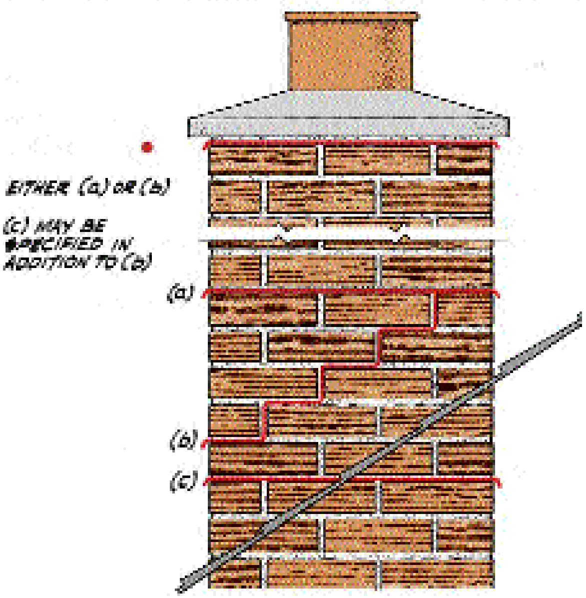

Figure 5.43 Masonry chimney penetrating a roof

Abutments to cavity walls need a tray across the cavity to prevent water reaching the wall within the building at a lower level. A carefully detailed series of stepped trays is needed; components with integral flashing are available – Figure 5.45. The cavity tray may be omitted where there is tile hanging or cladding provided run-off cannot drain into the wall below.

Materials and installation

Three main types of materials are used for DPCs:

❒ flexible materials such as sheet lead and copper, bitumen, polyethylene, bitumen and pitch polymer;
❒ semi-rigid materials such as mastic asphalt;
❒ rigid materials such as dense bricks and slates.

Not all materials are suitable for all situations so consider each application in detail. Flexible sheet materials can span cavities and accommodate minor movements. Sheet lead can be worked into complex shapes on site but, unless protected by bitumen, may corrode in contact with mortar. Dense bricks or slate (once a common material for the DPC at the base of the wall) provide a barrier only to capillary rise of moisture. While the prime function of a DPC is moisture control, other factors must be considered when selecting materials. They include resistance to compressive stress, shear stress and flexural stress. Table 5.5 gives details of products and their suitability for various applications.

Workmanship plays a particularly important part in the installation of DPCs so pay careful attention to the following recommendations:

❒ A DPC must be laid on a full, even, bed of fresh mortar. A further course of masonry should be laid, including a full bed of mortar over the DPC. If protection is needed against corrosion, apply it to both sides of the DPC and allow it to dry before laying.
❒ The DPC must cover the full width of the masonry and project 5 mm beyond any external face. At the base of the wall, the DPC should not create a ledge within the cavity.

TABLE 5.5 PHYSICAL PROPERTIES AND PERFORMANCE OF MATERIALS FOR DAMP-PROOF COURSES

Material	Minimum mass kg/m²	Minimum thickness mm	Durability	Remarks
Lead to BS 1178	Code No 4	1.8	Corrodes in contact with mortars. Protect with bitumen or bitumen paint of heavy consistency applied to the corrosion-producing surface and to both surfaces of the lead.	Can be worked easily to required shape but this is a slow process.
Copper: C 104 or C 106 of BS 2870 0 grade	Approx 2.28	0.25	Highly resistant to corrosion. If soluble salts are present, protect as for lead.	May stain masonry. Not easy to work on site, so unsuitable for cavity trays.
Bitumen with:				
Hessian base (class A of BS 6398)	3.8	–	The hessian or fibre may decay but efficiency is not affected if the bitumen remains undisturbed. Classes D, E and F are best if building is to have a very long life or if there is risk of movement.	Unroll materials carefully; in cold weather, warm before use. When used as a cavity tray, the DPC should be fully supported. See Appendix A of BS 6398.
Fibre base (class B of BS 6398)	3.3	–		
Asbestos base (class C of BS 6398)	3.8	–		
Hessian base and lead (class D of BS 6398)	4.4	–		
Fibre base and lead (class E of BS 6398)	4.4	–		
Asbestos base and lead (class F of BS 6398)	4.9	–		
High bond strength asbestos base	2.2 –	–		See Appendix C of BS 6398.
Low density polyethylene to BS 6515	Approx 0.5	0.46	No evidence of deterioration in contact with other building materials.	Accommodates considerable lateral movement. If used as a cavity tray, may be difficult to hold in place and may need bedding in mastic for full thickness of outer leaf to prevent rain penetration. Unsuitable where compressive stress is *minimal*.
Bitumen polymer and pitch polymer	Approx 1.5	1.10	Unlikely to be impaired by any movements normally occurring up to the point of failure of the wall.	Accommodates considerable lateral movement. If used as a cavity tray, preformed cloaks should be used, eg at changes of level and junctions.
Mastic asphalt to BS 6577 or BS 6925	–	12	No deterioration.	To provide mortar key, beat up to 35% grit into asphalt immediately after application and leave proud of surface, or score surface while warm.
DPC brick to BS 3921	–	Two course, laid to break joint, bedded in 1:3 Portland cement:sand	No deterioration.	Particularly suitable if DPC is required to transmit tension eg in free-standing walls. Does not resist downward movement of water.
Slate to BS 743	–	Two course, laid to break joint, bedded in 1:3 Portland cement:sand	No deterioration.	–

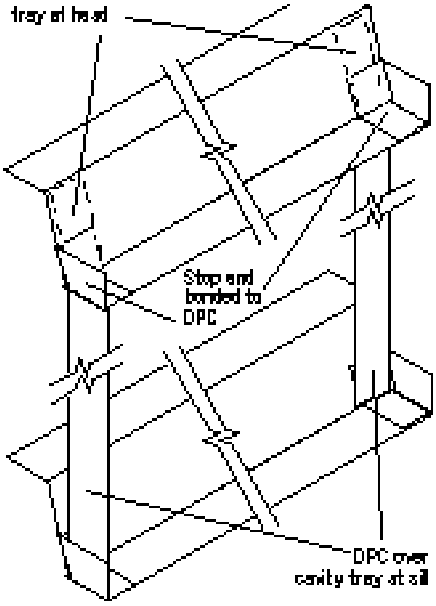

Figure 5.44 Cavity between vertical or horizontal DPCs around openeings

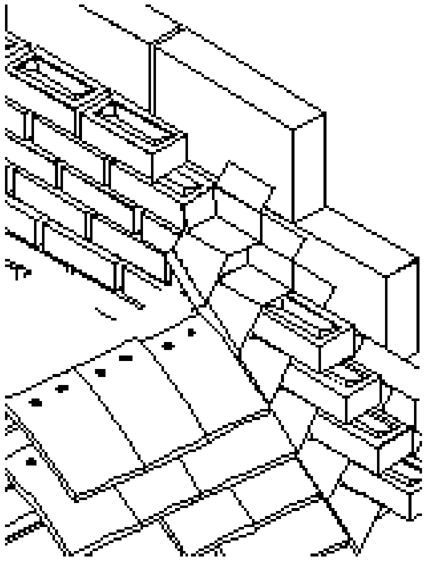

Figure 5.45 Cavity trays

- ❒ A render should be stopped at DPC level and the bottom edge finished with a bellmouth casting. Internal plastering must be finished just above DPC level.
- ❒ Lay vertical laps in DPCs so that the upper one laps the lower. This is particularly important around openings where the DPC or tray at the head of a door or a window should lap over the vertical DPC at the jambs and extend beyond it by at least 25 mm. The vertical DPC should extent at least 25 mm into the cavity beyond the closure and seal properly with any frame set in the opening.
- ❒ Lap horizontal joints in DPCs a minimum of 100 mm and seal where they resist the downward movement of water, in parapets for example.
- ❒ A cavity tray should step up not less than 150 mm from the outer to the inner leaf. Although the Z-section is commonly drawn, it is better to take the tray horizontally across the cavity and provide support. In practice it is difficult, or even impossible, to achieve a fully sealed joint using a flexible material if there is no support to work against. Such joints often leak.
- ❒ A cavity tray fitted above a lintel should extend at least to the ends of the lintel. Where there are frequent openings separated by short runs of masonry, it is often convenient to run a cavity tray as a continuous feature along the whole elevation or perimeter of the building. If trays are not continuous, provide stop ends that are fully sealed to the ends of the tray – Figure 5.46.
- ❒ Internal and external corners require complex three-dimensional details which any designer should draw out properly. All too often the drawing shows the easiest section and leavesit to the man on site to sort out the difficulties. Consider using the widely-available preformed trays for this situation.
- ❒ Water in cavity trays must be allowed to drain; proprietary weep tubes are a convenient way of achieving adequate drainage. Provide at least two over every opening, not more than 1 m apart – see BS 5628-3.

RAIN PENETRATION AT OPENINGS

Windows

If a window is not weathertight, surrounding materials and finishes may become damp and deteriorate. Windows positioned close to the building face may leak air and water around the backs of frames if they are not provided with a properly housed joint – see Figures 5.46 and 5.47. Damaged, cracked or inadequately projecting sills can result in penetration under a window. Cavity wall construction without a vertical DPC or cavity tray can be at risk of penetration at the window head or sides. Failed glazing compound or beads may allow water penetration around glass and into the fabric of a door or window.

Figure 5.46 Replacement windows have been fitted close to the external face of the wall ...

Figure 5.47
... with consequent leakage through the window to wall joint

Selecting performance characteristics

Wind and rain are more severe in some parts of the UK than others and it is important to choose windows that have appropriate weathertightness. Windows can be classified on weathertightness performance by testing in accordance with the appropriate British Standards (eg BS 5368). Windows are classified in an 'exposure category', defined in BS 6375. The exposure category for any particular location in the UK is related to the wind speeds during the most severe storms in the area. It is expressed as a wind pressure in Pascals (Pa) and there are five exposure categories: less than 1200 Pa, 1200 Pa, 1600 Pa, 2000 Pa and over 2000 Pa. The two lowest categories differ only slightly in the degree of resistance to rainwater penetration and cover most windows in buildings up to three storeys high, in built-up areas and sheltered countryside. The 1600 Pa category applies to windows in low-rise buildings on exposed hillsides, high ground and in open country. The two highest categories apply only to low-rise buildings in extremely exposed locations which experience the most severe storms and driving rain conditions in the UK (eg some south-west facing coastal areas).

The concept of 'driving rain' and 'driving rain index' for a site is not relevant to specification testing and performance of windows, which is concerned with shorter period gusting of wind. When rain water is in contact with joints, such pressure fluctuations may make windows leak by overcoming seals or pushing water over upstands. The driving rain index concept is for absorbent masonry walls where longer period spells of wind and rain combined may saturate masonry, causing penetration.

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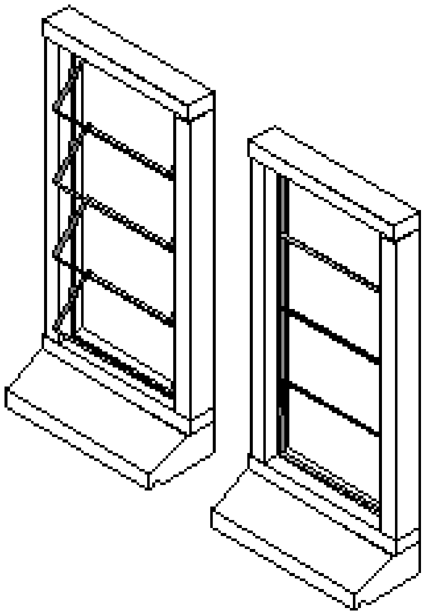

Figure 5.48 Some early louvred windows leaked

To ensure windows are adequately weathertight, purchasers of replacement windows should check that samples have been tested in accordance with the appropriate British Standards and given an ‘exposure category’ which matches the area where the windows are to be used –see Digest 377.

Some of the first louvred windows on the market did not perform well when subjected to driving rain and had high air leakage, even in the closed position; later versions with improved blade seals performed better in situations up to severe exposure – Figure 5.48.

The window-to-wall joint

The problem

Leaks at window-to-wall joints – Figure 5.49 – can be due to sealant failure, poor installation of the vertical DPC and a design that cannot accommodate the DPC and although these points were recognised by BRE in the early 1970s, little has changed apart from the introduction of cavity closers. Site inspections about ten years ago showed that nearly half the vertical window to wall joints were deficient in weathertightness and lack of provision for stop ends to lintels occurred in about 40% of cases – Figure 5.50.

In recent years, requirements for increased thermal insulation in walls and a reduction in air infiltration have encouraged the use of the insulated cavity closer. Previous practice was to return the inner leaf blockwork by pieces of block, though sometimes cut with a trowel. This gave a rough line to hold

Figure 5.49 Effects of water penetration at a window reveal

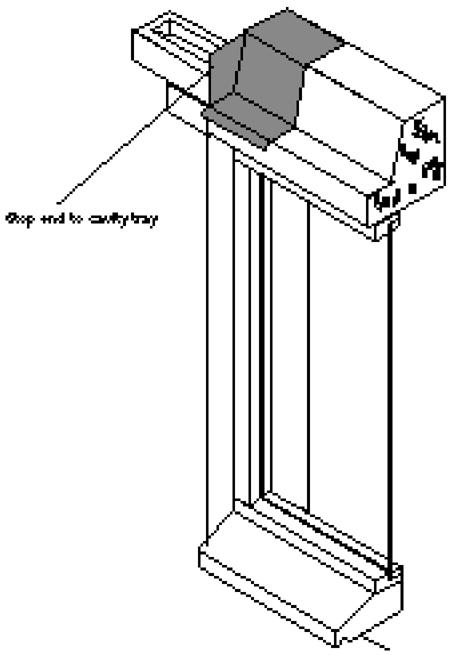

Figure 5.50 Lintels in cavity wall construction need stop ends to the cavity tray to prevent rainwater penetrating the outer leaf and saturating insulation in the cavity

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Figure 5.51

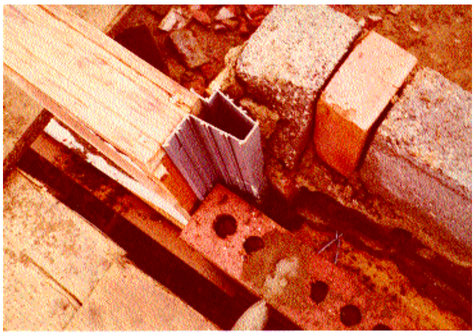

Figure 5.52 A window-to-wall joint in a cavity wall under construction. Thermal insulation is deficient, in spite of the plastics closer; an insulated closer is better. The solid brick in the inner leaf may make little difference in the presence of unfilled perpends and deficiencies in the cavity fill

Figure 5.53

the vertical DPC against the outer leaf. The subsequent insertion of the window frame into the opening did not allow for proper sealing of the DPC to the frame, even assuming the DPC was in the correct place – Figure 5.51. The preferred method is to use a preformed cavity closer and seal the front and back of the frame – Figure 5.52.

The front sealant will be difficult to apply if the brickwork joints are recessed – Figure 5.53. Remember that this sealant will reduce draughts and direct penetration of water but the masonry may become saturated and water could be running down the back corner of the bricks. Ribbing in the cavity closer and on the window frame should encourage this water to drain down into the sill cavity tray.

Two-stage joints

Two-stage joints can be formed in both single and two-skin walling. The underlying principle is that the water and air barriers are separated. Provided water is prevented (by design and by having an air path past the water barrier) from reaching the air seal at the rear of the joint, performance can reasonably be assured – Figure 5.54. Two-stage joints are more likely to tolerate variations in workmanship than are single-stage joints.

Whether the wall is single or multi-skin, window-to-wall joints should be sealed at the back and have some kind of overlap or mechanical protection at the front, effectively creating a two-stage joint – Figure 5.55.

Single-stage joints

Commonly-used in some types of curtain wall construction, single-stage joints usually have mastic or gasket seals on the outer face; a single mechanism provides protection against both air and water penetration,. Face-sealed joints in window-to-wall masonry should be lapped rather than butted wherever possible to protect the seal – see Figure 5.56.

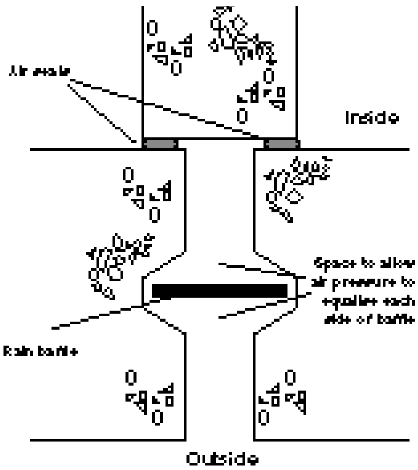

Figure 5.54 Separation of the functions of water and air exclusion

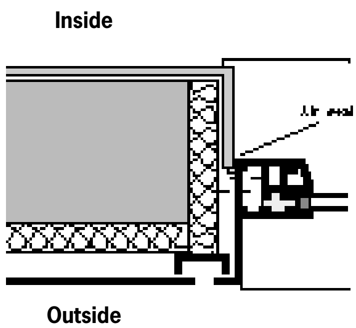

Figure 5.55 Two-stage joint, with air seal on the inside, and an overlap on the outside to shed rainwater

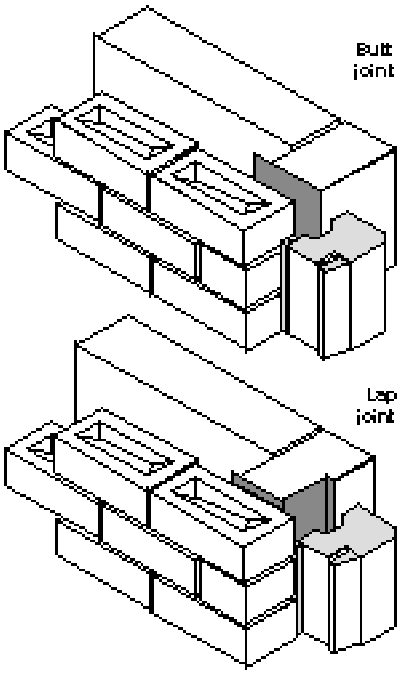

Figure 5.56 Face sealed joints should be lapped rather than butted

Each joint design will have a maximum and a minimum dimension over which its performance can be assured. Such ranges depend on the individual characteristics of edge profile of the joined components and jointing product material and dimension. Figure 5.57 shows these limits. If corrections of positioning or other deviations are not feasible, choose alternative designs.

Window sills

The window sill is often a weak feature in modern construction. Many consist of several sections of cast concrete or natural stone with rigid mortar pointing between. This mortar invariably cracks, and water running off the window above is fed into the cracks. If it is not possible to insert a DPC beneath the sill, it is advisable to point with an appropriate mastic.

String courses and hood moulds

String courses and hood moulds over windows and doors were a traditional method of reducing the water load by encouraging run-off to be shed clear of the general surface of the wall. But if they are not properly detailed, they provide extra catchment areas for water. Horizontal surfaces, in particular, are likely to be troublesome; these surfaces must be either covered with a flashing or isolated from the body of the wall below by a DPC.

Doors and thresholds

Doors

Laboratory measurements, using the same test methods as for windows, have shown doors to be generally much less resistant to leakage than windows – Figure 5.58. It is difficult to design an inward opening door in an exposed situation which meets a high standard of resistance to leakage without making it difficult to open and close, or without providing additional protection such as a canopy or a porch. Outward-opening doors

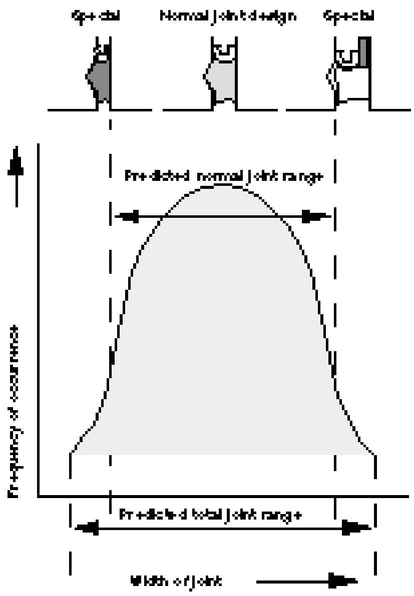

Figure 5.57 Normal (Gaussian) distribution indicating upper and lower limits for normal joint performance

Figure 5.58 Asphalt not properly keyed beneath a door threshold

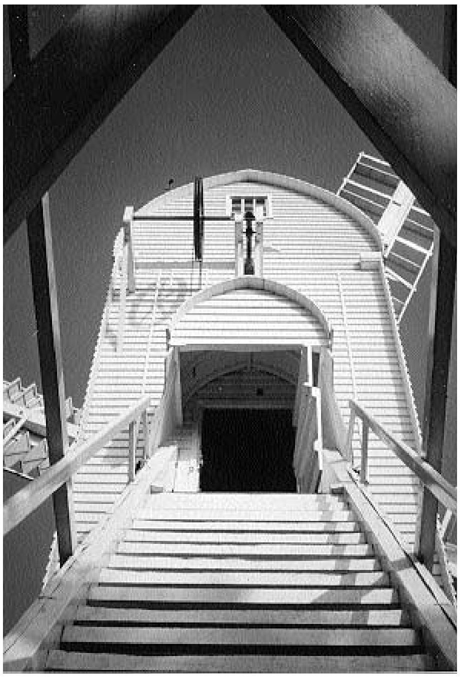

Figure 5.59 Stable-type door opening outwards – Saxtead Windmill, Suffolk

Figure 5.60 This water bar is fitted in front of the rebate, so that water running down is directed to the interior

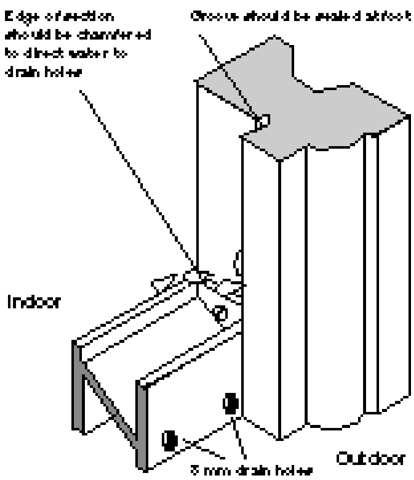

Figure 5.61 Some proprietary trough sills may lead water inwards

are much easier to make weatherproof, but even these may need the extra protection of a porch in the most exposed situations – Figure 5.59

Inward opening doors may lack a weatherbar or weatherboard, and door frames may lack adequate, correctly positioned drainage channels. Sills and sub-sills may lack a drip or throating on the underside of projections. If a door is not weathertight, surrounding materials and finishes may have become damp and deteriorated. Diagnosis of a weathertightness problem is often complicated by condensation. Some simple principles can be used to improve weather resistance are:
❒ rain check grooves at least 6 mm deep;
❒ water bars fitted inboard of the rain check grooves or rebate; the door should also be rebated – Figure 5.60;
❒ trough sills with adequate drainage holes that do not allow water to track across their stop ends – Figure 5.61

Thresholds

Dampness on the floor near the threshold might indicate that there is no weather-bar in the sill, the rebates drain to the indoor side of the weather-bar, or there is no weather-board or, if there is, it is not throated. In severe conditions, the only solution may be to build a porch.

Though most designs conforming with previously relevant codes and standards for weathertightness seem to have worked reasonably well, some conventional raised thresholds have proved to be inadequate in resisting driving rain in exposed areas of the UK.

The higher the upstand, the better the detail can resist water being driven over it by air leakage. If there is no air seal at the foot of the door, and therefore nothing to resist the passage of an air stream carrying water over the threshold, even upstands of 25 – 50 mm will be vulnerable to rain penetration. This detail is now unacceptable in new buildings owing to access problems for the disabled – see *Good Building Guide 47*.

The design should provide for a water load on paved areas of 50 mm/hour – see BS 6367.

Other ways to reduce the water load on the area to be drained are:
❒ a shelter, such as a porch;
❒ a drainage channel or gutter in front of the threshold;
❒ permeable paving.

Any of these should reduce the chances of leakage to an acceptable level for most of the UK. Porches need cheeks that project at least 750 mm to prevent driving rain blowing in sideways and reaching the threshold, but it will obviously depend on the direction of the prevailing winds.

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Figure 5.62 A level threshold is where the external walking surface is level with the door threshold and the internal floor finish

Waterbars

Waterbars can reduce, if not entirely prevent, rainwater penetrating a threshold. There are two kinds:

- ❐ Placed at the foot of the opening leaf, creating an upstand against which the leaf closes. It must resist impact and wear, and it must be positioned correctly: placed too far forward, leakage will run down the rebates and so fall inside instead of outside the bar.
- ❐ Those that prevent water being drawn through the horizontal joint between the underside of the threshold and the wall into which it is set. Being protected, this can be more flexible than the other type.

Some experiments were carried out by BRE in the 1970s, involving a variety of sections of stainless steel, aluminium, neoprene and PVC waterbars cast into concrete beams, and tested in the laboratory.

The tests were severe, the first creating a 10 mm pond of water adjacent to the bar continuously for 24 hours, and the second a conventional pressure box test. Only seven out of 34 cases showed any leakage in the ponding test; the pressure box tests however, showed, as expected, that the height of the waterbar to a large extent governed its performance. None was high enough to entirely resist the flow of water carried in the air stream, emphasising the importance of an effective air barrier in resisting water penetration – Figure 5.64.

Some of the neoprene and PVC waterbars developed a kink at one end after a period of hot weather, since they had been cast in tightly. The kink remained after cooling. In the aluminium and steel sections, the expansion had taken place without apparent distortion. It is prudent therefore, to ensure that the built-in ends of non-metallic waterbars are wrapped so that the ends can slide, in order to provide some degree of protection against kinking, particularly when cast into concrete which shrinks on curing.

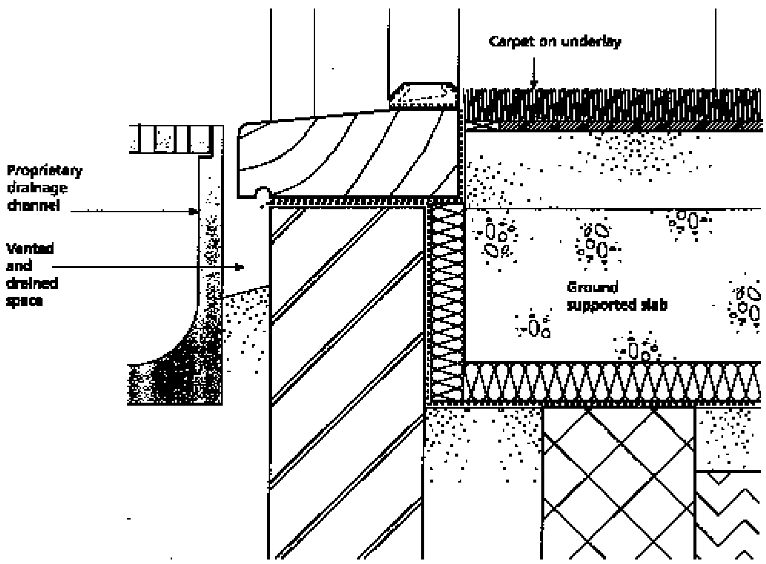

Figure 5.63 Drained and ventilated space adjoining timber sill. Reproduced from *Accessible thresholds in new housing* by permission of The Stationery Office Ltd

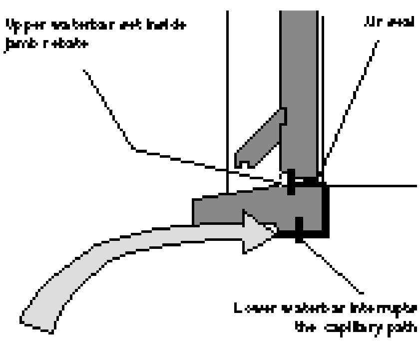

Figure 5.64 Alternative positions and functions for waterbars incorporated into door thresholds

Figure 5.65 Long-term water ingress has resulted in failure and subsequent replacement of wall plate and new metal ends for joist

Figure 5.66 A torched roof leaking owing to capillary action

Figure 5.67 The wall below will become saturated if water flow is not properly dealt with

RAIN PENETRATION IN ROOFS

Although vertical light rain is unlikely to result in much wetting of the masonry, it is obvious that all rain tests the weathertightness of the roof covering. Flat or shallow-pitched roofs rely on a waterproof membrane which must be sealed at all joints in the material. Where the flat roof meets a vertical surface, such as parapets, chimneys and walls, measures are needed to ensure that no water can overtop the upstand. Tiled or slated roofs are assembled from relatively small units; a membrane of thin felt or plastics is usually laid beneath the roof battens although this was not done in older roofs.

Pitched tiled and slated roofs

Rain penetration through a tiled roof can result from something as simple as a slipped tile or a leaking valley gutter but, if not repaired, persistent wetting will encourage wood rot with expensive consequences – Figure 5.65.

Torching

Roof tiles and slates rely on overlapping the sides and ends to keep the water out. Where leakage was unacceptable, mortar was applied to the underside joints; this was known as torching – Figure 5.56. More recently, a bituminous felt or perforated plastics sheet, known as sarking, is fitted beneath the battens to improve performance.

Flow of rainwater

The natural flow of water on a pitched roof is governed mainly by gravity – Figure 5.67. The ridging of double lap tiles and the vertical rolls of pitched metal roofs help to direct water flow downwards. In plain tile and slate, verges can be canted upwards to help divert water away from the verge. This also has the effect of countering an optical illusion of sagging where the roof surface runs through without such canting. However, where relatively smooth surfaces are used, wind can and will blow water sideways across roofs. Given the right conditions, relatively large quantities of water can be moved sideways under wind pressure – see IP 90/74. In metal-covered roofs with standing seams or batten rolls, water is driven sideways until it encounters the seam or roll, where it is diverted downwards. The water load on the joint is considerable. In areas with the highest driving rain indices, therefore, it may be necessary to evaluate the risk of sideways flow, the potential use of the building and its proximity to walkways, and even to provide verge gutters.

On a large-span pitched roof, considerable quantities of rainwater can reach the eaves. Asymmetrical gutters with large upstands on the outer rim can prevent rainwater overtopping the gutter, though they may have to be specially fabricated. BS 6367 provides for discharge weirs at the ends of gutters to direct overload run-off where the flows exceed the design rate.

Pitch and lap of tiles and slates

The relatively small units on most domestic roofs depend for their effectiveness on two main factors: the pitch of the roof and the amount of the end and side overlap. In general, the flatter the pitch the greater the overlap required, though there are exceptions. Pitch may also have an effect on durability: some porous tiles may take longer to dry out on the flatter pitches with an increased risk of freezing in winter. Natural slate is relatively non-porous and weathertightness depends primarily on adequate lap and gauge rather than material thickness.

Recommended pitches for tiles vary enormously; it is not practicable here to list different types and their performance at different pitches so follow manufacturers' recommendations. As a general rule, plain tiles should not be used on pitches of less than 40°. Laps should be not less than 65 mm, or 75 mm in exposed areas. Single-lap tiles should not be laid at pitches of less than 35°, though they have been laid on pitches down to 30° with anti-capillary clearances built into the design. Modern designs of single-lap tiles may be laid at lower pitches than 30° (some are claimed to perform adequately even down to 12.5°), but we suggest you test or get evidence of performance of tiles at these low pitches before specifying them.

Figure 5.68 A slated roof with no sarking showing signs of water penetration, particularly on the encastred wall plate. The ceiling has been stripped and plaster removed from the one-brick wall below prior to rehabilitation

Recommended pitches for slates have traditionally been lower than for tiles, and many old roofs have pitches of less than 35°. In those areas of the UK where heavy, thick tilestones are used, pitch may be as low as 25 – 30°. Where light, thin tilestones are used, pitches should be steeper – at least 45° and preferably steeper.

We have seen a large proportion of cracked tiles and concrete slates on the shallower pitches particularly, presumably as a result of work on chimneys and television aerials, leading to greater risk of slippage and rain penetration.

Overhanging eaves

Overhanging eaves may be ‘closed’ or ‘open’, meaning that the rafters are boxed in with fascia and soffit, or left exposed with the wall surface carried up to the underside of the roofing. There is no inherent difference in weathertightness provided the detail and workmanship are satisfactory.

To achieve adequate weather protection to the wall below, we recommend an overhang at eaves of at least 300 mm irrespective of the kind of roof covering and angle of pitch. It has been estimated that a pitched roof with a pitch greater than 20° and an eaves overhang of 350 mm gives approximately the same protection to the wall below as if the wall were rendered or clad. There is a presumed advantage if the overhang can be provided with a drip: say a tile with a sharp arris to the under-surface. The underlay should be continued into the gutter – Figure 5.69 – with a strip of DPC material

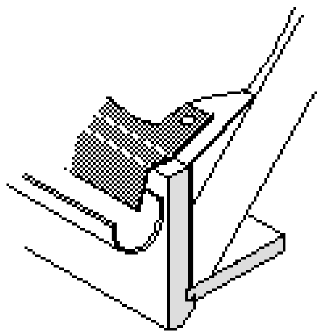

Figure 5.69 A strip of DPC material should be dressed into the gutter

However, the large overhang can be something of a mixed blessing. Under some conditions of driving rain in exposed areas, water load reaching the wall under the eaves can actually be increased – see

Figure 5.70 Rebuilding sprocketed eaves following deterioration of the timbers. The beam-filling above the wall plate carries the sprockets. The open eaves have no soffit. (When the photograph was taken, the ladder was, correctly, tied to the building, but the roofer should have been wearing a safety harness.)

Figure 5.71 A good projection was given to this single-lap tiled verge, and the tiles were neatly clipped

Figure 5.72 A double undercloak on a deep verge. The pointing mortar was probably too strong leading to shrinkage cracks above the lower course

Current Paper 81/74. But over the whole range of conditions, generous overhangs do seem to reduce water loads on walls.

Large overhangs at both eaves (especially those involving sprockets) and verges should be securely anchored back to the roof structure. Some examples have been seen on site where sagging in eaves and verges has occurred, so reducing weathertightness.

With some kinds of roof structure over thick external walls, and roof pitches steeper than 45°, it may be difficult to obtain good overhangs at the eaves and adequate clearance for the window heads. This may have been the reason for the use of sprockets, cantilevered from the rafters, to give a suitable overhang with flatter pitch at the eaves. The fixings of these sprockets seem to be the first part of these roofs to show distress. Nailing or bolting sprockets to the sides of rafters, where the fixings operate in shear, would probably give better reliability than those nailed to the tops of rafters, where the strength of the fixing relies only on the resistance of the nails to pull-out – Figure 5.70.

Clipped eaves
BRE does not recommend the use of so-called clipped or flush eaves. The reinforced BS 747 class 1F felts that were commonly used in this situation as an underlay disintegrate after a few years' exposure to external conditions, leaving the detail vulnerable to rainwater blown back by the wind on to the head of the wall. More satisfactory, from the point of view of durability, for overhanging eaves as well as for clipped eaves are those in which the detail has a strip of better quality material lapped under the sarking felt and dressed into the gutter. Defect Action Sheet 9 suggests a strip of DPC-quality material – Figure 5.69.

Mortar bedded verges
Verges should oversail the wall or bargeboard by 50 mm, and should be undercloaked with a durable and compatible material – Figure 5.71.

Pointing between the undercloaking and the tile above should not exceed 35 mm; more than this is likely to crack. The use of tile inserts as a form of galleting between the tile surface and the undercloaking, similar to the dentil slips used on ridge tiles, helps to minimise the appearance problems caused by cracking. Another way is to use a double undercloak – see Figure 5.72.

Plain tiles should not be used for undercloaks on roof slopes below 30°.

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The appearance of plain tile verges is enhanced by tilting the verge tiles inwards. A small amount of tilting does not affect performance. Single-lap interlocking tiles should not be used in tilted verges because their performance will be affected.

Dry-laid verges

Dry-laid verges are an alternative to ordinary verges; the specially shaped tiles form a downstand similar to a bargeboard. Potentially this form of verge will be more weatherproof than the mortared-and-pointed verge, provided the fixings are secure.

Bargeboarded verges

A bargeboarded verge gives more protection to the wall than a verge set on the wall head – Figure 5.73 – but ensure that:

- ❒ the underfelt is carried over the top of the bargeboard to meet with the undercloak;
- ❒ the inboard edge of the ladder is securely fixed to the rest of the roof;
- ❒ the cantilever effect of the tiles does not impose too great a load on the bargeboard.

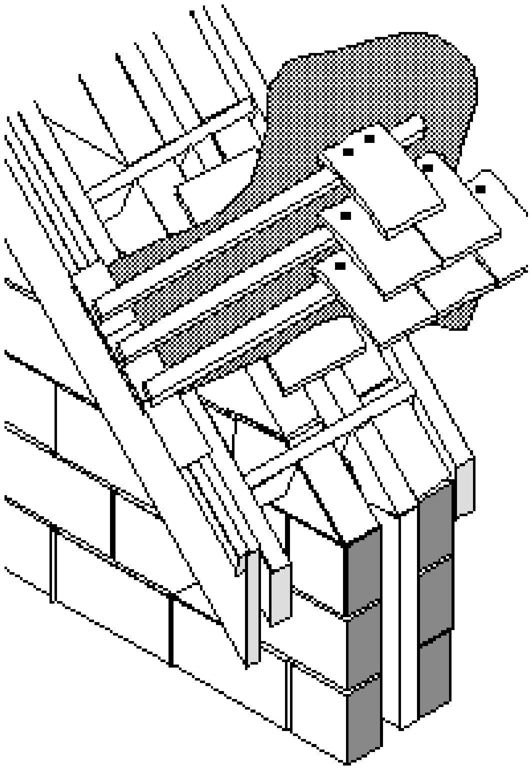

Figure 5.73 A bargeboarded verge with gable ladder

A verge detail common on pantile roofs in Suffolk is a section of timber nailed to the top of the bargeboard, overlapping the verge tiles – Figure 5.74. This serves the dual function of providing a reasonably weatherproof side lap for the verge tile and a positive fixing to resist suction in that part of the roof which is most sensitive to wind. Durability is the main problem because the section can be painted underneath only by removing it.

Figure 5.74 Common verge detail in a Suffolk pantile roof. The timber cappings shown are prone to decay since it is impossible to repaint the underside without removal

Abutments

Where a lower roof abuts a higher one, an external wall becomes internal below the roof – Figure 5.75. A completely impervious sheet material must be provided because masonry alone is inappropriate. Lead was traditional and especially effective where it was protected by bituminous paint; many other materials, such as copper and bituminous felt, are satisfactory, or sandwiches of thin sheets of these materials. Other materials are described in BRE Digest 380.

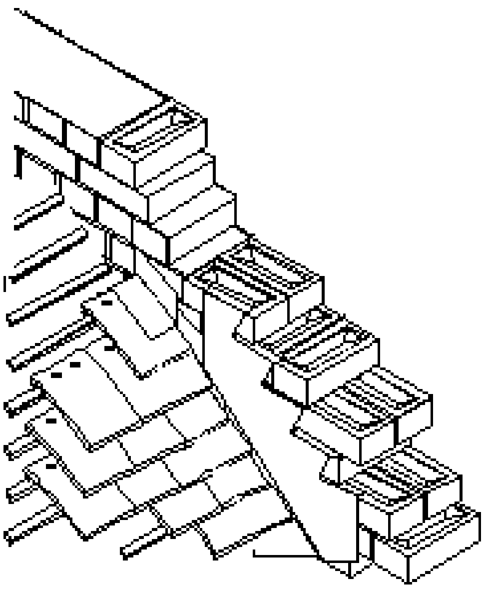

Figure 5.75 A DPC, cavity tray and flashing is needed to prevent rainwater percolating down a wall: not easy when the pitch of the roof differs from the rake of the bond

Sarkings and underlays

Rain and snow can be forced past the edges of lapped tiles and through the joints by wind. In theory, at least, tiled and slated roofs with boarded sarking, as is common in Scotland, will be at less risk of rain penetration than roofs having flexible sheet sarkings since the boarded sarking performs much better as a wind barrier. Sarking membranes should have a vapour permeability in the range 0.1 – 2.0 MNs/g.

On one-third of building sites visited by BRE, the installation of sarking felt underlays was faulty in various ways. In particular, sarking felts were not fitted closely around soil and vent pipes, nor properly lapped nor dressed out to eaves gutters and bargeboards.

If the space underneath a layer of tiles is not sealed, there is a risk of fine snow being blown between the joints, even though water may not penetrate. The current Scottish boarded sarked roof can be expected to perform much better than the English counterpart. The unsupported underfelt used in a traditional English roof can billow in the fluctuating wind pressures of a snow storm, allowing the snow to be pumped through the gaps in the covering.

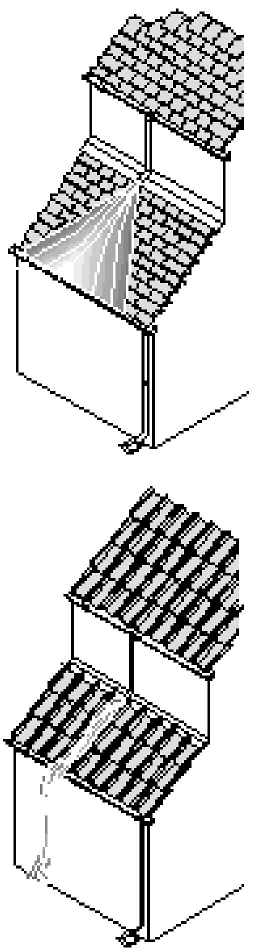

Figure 5.76 Patterns of discharge from rainwater pipes over plain and profiled tile roofs

Gutters and rainwater pipes

Although thatched roofs that have a wide overhang are not normally fitted with gutters, most other roofs have a system of gutters to catch the water running off the roof. Downpipes then lead the water for disposal. At the extremity of the eaves of a pitched roof, the shape characteristics of the covering have an influence on the positioning of the rainwater gutter. The ideal profile of the covering (from the point of view of rainwater disposal at the eaves) is for the upper edge to be rounded and the lower edge to be sharp to provide a drip. The raindrops will then have less chance of being blown back up the underside of the slope. The minimum projection into the eaves gutter is about 50 mm. BS 6367 shows the normal trajectory of droplets from drips of various profiles. Further protection to the eaves can be given by overlapping the lower edge of the sarking felt (or a substitute, a more durable felt strip) into the gutter.

Gutters are not usually designed for storm conditions and maintenance is frequently neglected; the system is ineffective if outlets are blocked with leaves. The worst cases are valley gutters where the discharge of the increased water load from large areas of roof completely overspills the eaves gutters, soaking the wall beneath.

It is common for rainwater pipes to discharge over lower roof slopes. On a roof of plain tiles or slates there is usually no problem since the discharge fans out before reaching the lower gutter – Figure 5.76 – but this is not so with heavily profiled interlocking tiles. The profile confines the whole of the run-off to a single valley and there is risk that the tile laps will leak. The discharge at the foot will almost certainly overshoot the lower gutter in all but the lightest rainfall. The tiles will also be preferentially stained.

Proprietary precast concrete gutters often have been fitted at the head of walls where the roof is of fully supported felt construction; in the past they have also been used on pitched roofs covered in different materials, and as permanent shuttering for lintels carrying the eaves and wall plates over first-floor windows. Originally lined with bitumen felt, they were, in our experience, a continual source of leakage caused by splitting of the linings which were fully bonded to the concrete, the joints of which had opened.

Flashings

Loose flashings allow rain to penetrate behind; especially at abutments, flashings may need additional clipping. We have seen an example where, on a severely exposed site, the contractor had applied a silicone sealant between the brickwork and the lead in an attempt to keep water out – Figure 5.77.

Figure 5.77 A silicone sealant between the brickwork and the lead in an attempt to keep water out.

Flashings should be chased a minimum of 25 mm into brickwork. Particularly vulnerable is the change of slope in a mansard where the flashing and the first row of tiles above it can be stripped by wind action. The heavier the weight of flashing, the more it can resist wind action; the lower edges of thinner flashings in this position should be held down with strip tacks. Code 5 is more appropriate than Code 4 for lead flashing without tacks. Poor detailing of sarkings is common with tears in sarkings leading to problems with rain or melting snow.

Valleys

About two-thirds of roofs of new houses built between 1991 and 1993 had valley gutters. Before this most valleys were formed by inserting a metal lining into the valley and cutting the tiles to shape over. There was much clumsy cutting, with appearance compromised. Better solutions, though seen more rarely, used purpose-made valley tiles of various configurations. Valleys formed from plain tiles may be swept or laced, either to a radius or to an acute angle – Figure 5.78.

Figure 5.78 A swept valley in plain tiles. The camera viewpoint has foreshortened the tiles, exaggerating their apparent irregularity. The parapet capping has not succeeded in throwing rainwater run-off clear of the wall

A double thickness of sarking felt is needed in valleys, lapped at least 600 mm over the centreline of the valley. Tiling battens must be properly supported where they abut valleys.

Our experience is that the design of valley gutters is frequently defective. We have seen drawings that specifically state that the design of gutter systems should be left to the site staff to sort out! Valley gutters slope much more shallowly than the pitch of the roofs they join; they are particularly prone to leaking on pitches of less than 20°.

Incidence of defects

In a large sample of new housing in 1992 – 93, we found that almost 20% had unsatisfactory weatherproofing at abutments and that in about 10% the bottom course of interlocking tiles had been tilted upwards at the eaves; the tiles had not interlocked satisfactorily, so making the eaves more vulnerable to rain penetration.

As can be expected, there are many different kinds of weathertightness faults in older roofs. Some of the more common ones we found in older pitched tile roofs include:

- absence of sarking and torching;
- strips of sarking tacked to battens between rafters, leaving rafters unprotected;
- many cement fillets cracked and displaced;
- flashings working out of joints;
- clay roof tiles delaminating;
- replacement tiles overhanging eaves gutters too far, so rainwater run-off overshoots;
- rainwater from long valley gutters overshooting undersized eaves guttering.

Windows set vertically within the slopes of mansard roofs sometimes present problems. The vulnerable point is where protrusion changes to inset – Figure 5.79.

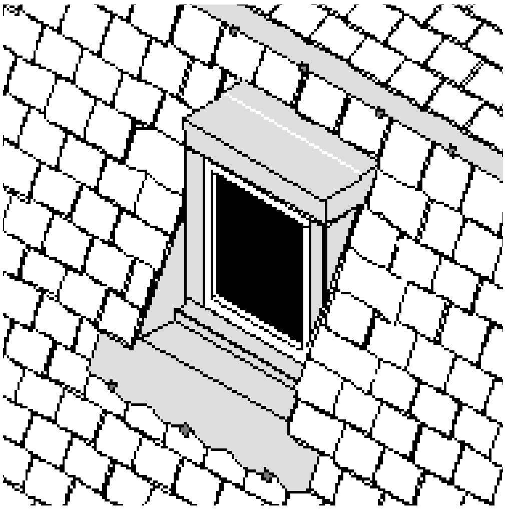

Figure 5.79 Windows set in mansard roofs need careful detailing

Problems are common in late Victorian terraced houses where local byelaws required that separating walls were built to project through the roofs. Many houses with this feature can now be found 'flashed' with cement fillets or flaunching. There is no real substitute for a metal flashing over a secret gutter, or soakers, but if a cement flaunching is preferred, it should include a gritty fine aggregate with some lime in the mix.

The copings of projecting separating walls for the most part rest on kneelers on the slope or footstones at the eaves, and are bedded in mortar up the slope. Most are in good condition though there are reports of more recent attempts to emulate the detail, usually at gables, without using kneelers or footstones, where the copings have slid down the slope as a result. Damp-proof course materials such as slate should be capable of adhering to both coping and masonry below, or it may be possible to use special fixings. If sheet materials provide a slip plane, there is a risk of the copings dislodging in high winds. Mortars here could have a bonding agent.

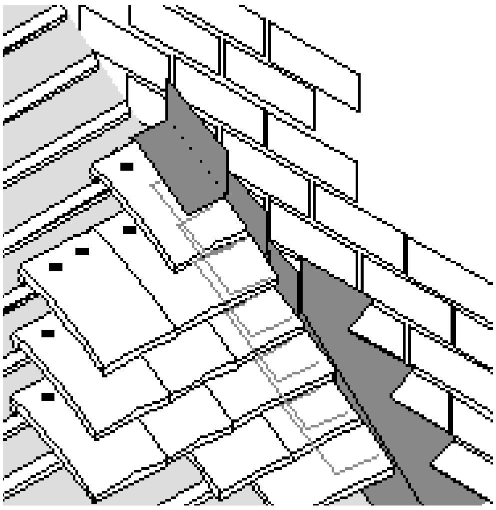

Figure 5.80 Soakers and stepped flashings

Cavity trays, soakers and secret gutters, with associated flashings, can cause problems where there are steps in levels between adjacent buildings – Figure 5.80. Problems seem not so much with design as with execution, but the preformed cavity tray with attached flashings performs satisfactorily.

Where a pitched roof abuts a stepped-and-staggered separating wall, part of the roof becomes an external gable, and the outer leaf of masonry becomes an inner leaf below roof level. Ensure that rainwater is prevented from reaching the interior. Soakers for plain tiles should be 175 mm wide minimum to give an upstand of 75 mm against the wall, and a lap of 100 mm under the tiles. A cover flashing then laps the soakers by at least 50 mm, preferably more. For interlocking tiles, use a stepped flashing dressed over the tiles; soakers cannot be used because they would interfere with the interlock. A secret gutter is feasible. Lead should be of Code 4 thickness for soakers (Code 3 is sometimes specified, but it is less

Weathertightness inspections

When we inspected site work on new roofs over masonry construction, we found the following items relating to weathertightness occurred most frequently:

- ❒ sarking missing or torn and not repaired;
- ❒ sarking stretched too tightly across the slope to allow passage of water under the tiling battens;
- ❒ sarking felts not dressed up around SVPs – Figure 5.81.
- ❒ no tilting fillet at eaves, so sarking allows ponding of rainwater;
- ❒ sarking not turned up under outer layers at dormer cheeks;
- ❒ sarking does not project to overlap into gutter;
- ❒ tiles broken or missing;
- ❒ flashings at steps in terraces defective;
- ❒ flush (sometimes called clipped) eaves used on exposed sites offering little protection to walls below;
- ❒ mortar flaunching used as flashing on new construction;
- ❒ lowest courses of tiles lifted too high by tilting fillets: tiles almost level will lead to rain penetration;
- ❒ lead slate (or other shaped material) round SVPs not large enough to lap adequately with tiles – Figure 5.82 .
- ❒ undercloaking mortar fillets cracking and falling out;
- ❒ tiles laid to incorrect laps (nibs not engaging); the worst case we found was 50 mm where 75 mm was actually required;
- ❒ flashings with insufficient upstand: 50 mm instead of 150 mm;
- ❒ tiles laid at too low a pitch;
- ❒ cement fillets only covering joints between re-roofed properties and adjacent original roofs;
- ❒ sprayed treatment of undersides of roofs, completely 'wet poulticing' the battens, possibly leading to rot.

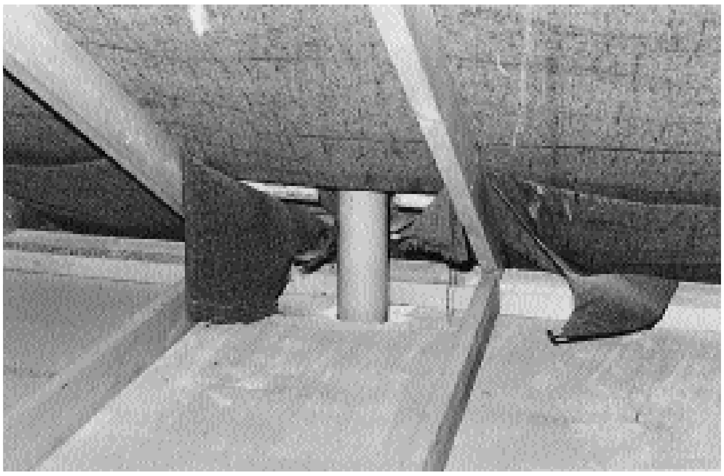

Figure 5.81 Torn sarking around a soil and vent pipe. If this had occurred underneath the example in Figure 5.83, it would have leaked immediately

Figure 5.82 An undressed (and therefore totally inadequate) lead slate round an SVP on a newly built house. The tiles have been roughly cut and, even if an attempt had been made to dress the lead over the cuts, gaps would have been left; the sarking felt would then provide the only line of defence against rain penetration

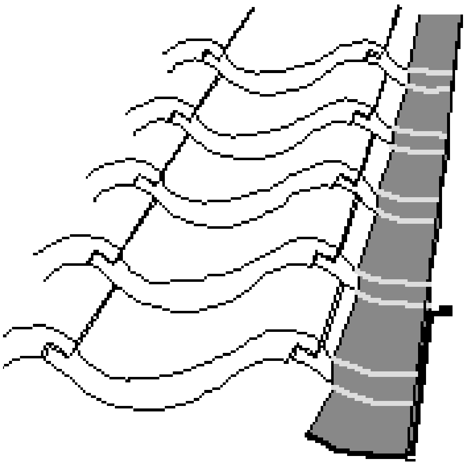

Figure 5.83 An abutment of profiled tiles with a dormer window. The flashing ends on an upward slope, making the detail vulnerable to rain penetration

durable) and Code 4 also for trays and flashings, but Code 5 or 6 on exposed sites, especially where tacking is not specified. Lead flashings should be protected with bitumen or patination oils where built in to any masonry. BRE Defect Action Sheet 114 provides further information.

Take care with the abutments of profiled tiles with dormer windows. We have met cases where the flashing or soaker against the vertical cheek of the dormer is too short to master the roll of the tile, leaving the detail vulnerable to rain penetration – Figure 5.83.

Diagnosis

Key questions are:
- ❒ Are the pitch and lap of the existing covering suited to the exposure conditions?
- ❒ Does the roof have sarking or other means of excluding rain and wind-blown snow?
- ❒ Are the eaves, verges, ridges, hips and valleys adequately detailed and soundly constructed?
- ❒ Are all abutments with other elements adequately flashed?

Leaks can also result from Incorrect sarking felt details, including insufficient lap, torn felt round soil vent pipes, and felt not properly supported and dressed out over eaves, gutters and barge-boards.

Other pitched roofs

Thatched roofs

Thatch is normally laid in layers to total thicknesses of around 300 – 600 mm with rainwater run-off occurring in a zone some 50 mm deep from the edge of the eaves. While it might be possible to design rainwater gutters to catch most of the run-off from thatch, the gutters would need to be much wider than those normally used on other kinds of pitched roofs to catch all the water running within the thickness of the thatch. Guttering might also spoil the appearance of the roof, and presumably that is why gutters are normally dispensed with in the majority of thatched roofs.

A generous overhang at the eaves is essential if rainwater blowing back on to the external walls is to be reduced to a minimum. Generous drainage gutters on the surface of the ground or paving underneath the eaves are also needed, and rainwater splashing on to the lower surfaces of walls can be minimised by channelling or broken surfaces.

Whatever pitch is determined for a thatched roof (the steeper the better for watertightness and durability), the stalks or stems which form the covering lie at shallower angles than the roof pitch because of the method of laying – Figure 5.84. To keep out the rain, thatch operates on two principles: first, that there are a great number of stalks in the path of any droplet penetrating the outer layers, and second that droplets penetrating the outermost layers of the stalks will track a greater distance horizontally than vertically. So, unless wind blows the droplets back up the slope, drainage is assured.

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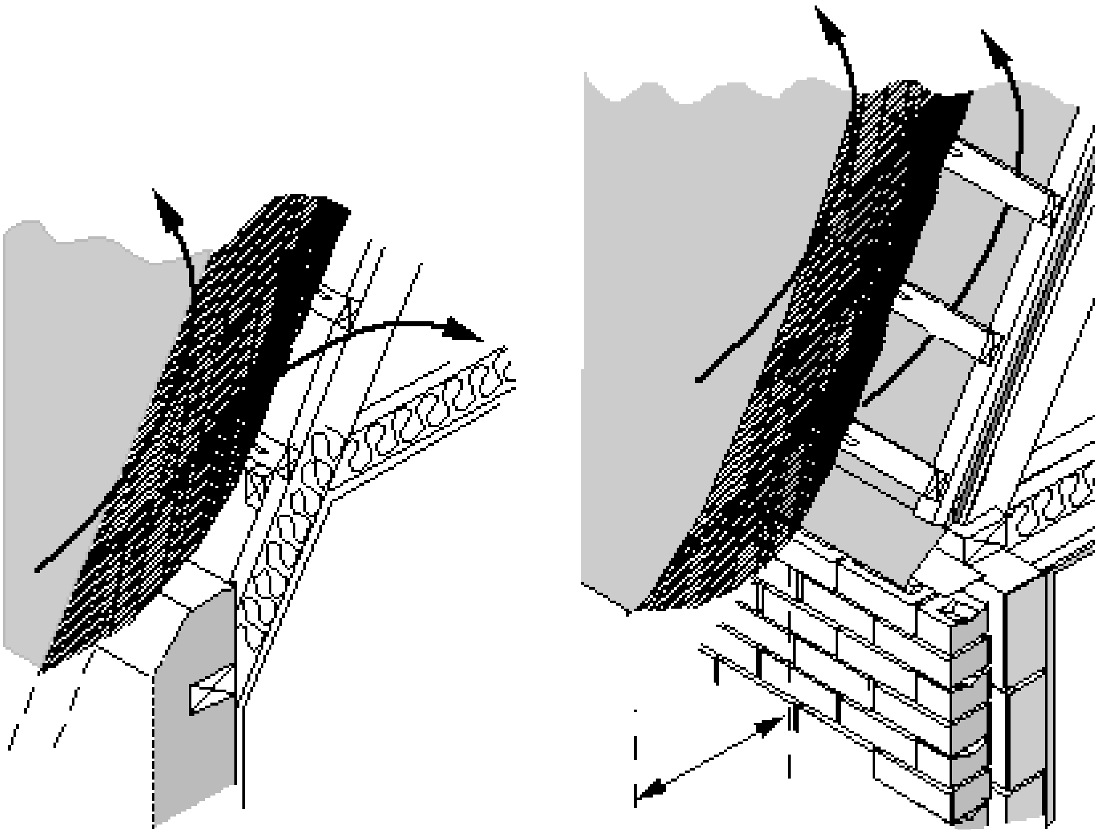

Figure 5.84 Eaves details: traditional English and lowland Scots and ... underdrawn with fire resistant boarding

A check that drainage is still satisfactory is best made under the **leeward** eaves after a rainstorm: the thatch at the wall head should be reasonably dry. Wet underfelt may be a sign that the rain has penetrated that far and the covering needs attention, although the wetness might be caused by summer condensation.

Abutments and chimney stacks provide the greatest problems of weathertightness. Stacks should preferably be on the ridge so that complicated back gutters and their associated flashings or drips can be avoided. Where the stack is on the slope, the back gutter to the stack should be slightly wider than is normal with tiled roofs so that it has a larger overhang of the thatch.

Shingled roofs

Shingles depend largely on their taper in thickness to create an air space and so minimise capillary attraction of rainwater between the units.

Traditionally, shingled roofs have been laid without felt underlays to help the free flow of air essential for moisture removal. However, there is less risk if counterbattens are used, and underfelting will then be beneficial. If closeboarding is used, the sarking should be laid on this then the counterbattens laid before battening. If sarking felt is used alone without closeboarding, the felt should be laid over the rafters and then the counterbattens immediately over the top of the rafters.

Shingles laid to pitches over 30° should have a gauge of at least 125 mm. With conventional shingles around 300 – 400 mm in length, this will give a covering of not less than three thicknesses of the material. Flatter pitches should be laid to a gauge of 90 mm or so which should give a thickness of not less than four layers over the roof.

Riven shingles are better at resisting rain penetration than are sawn shingles because the surface fibres suffer less disruption; consequently the grain of the wood tends to shed water quicker.

Sheeted metal roofs

Sheeted roofs are usually overlapped at the side by one complete undulation of the sheet; this lap should be away from the direction of the prevailing wind. The lap should be sealed in areas of high driving rain.

There may be a problem with rain penetration of side as well as head laps and, in some cases, for example with pitches below 10°, it might be better to seal the side laps as well as the head laps. The problem may be exacerbated by the build-up of detritus in the valleys where it can form a dam causing rainwater to overflow both head and side laps – Figure 5.85 .

Head laps are vulnerable to rain penetration and capillary action. On a sheltered site, if the head lap is at least 200 mm and the pitch is greater than 15° it may not be necessary to seal the joint. Otherwise, especially on exposed sites, two seals in each lap are recommended: one above and one below the fixing to the purlin – Figure 5.86.

Where pollution levels are high, run-off from curved or rolled eaves can stain the wall surfaces. A gutter above the change of pitch reduces this risk.

Metal covered roofs are prone to problems from entrapped water, and from moisture being pumped through the joints.

Enclosed voids in roof constructions which provide only limited and perhaps inadvertent contact with the outside air (as in a roof constructed with a welted seam sheet material) may be subjected to pressures and suctions

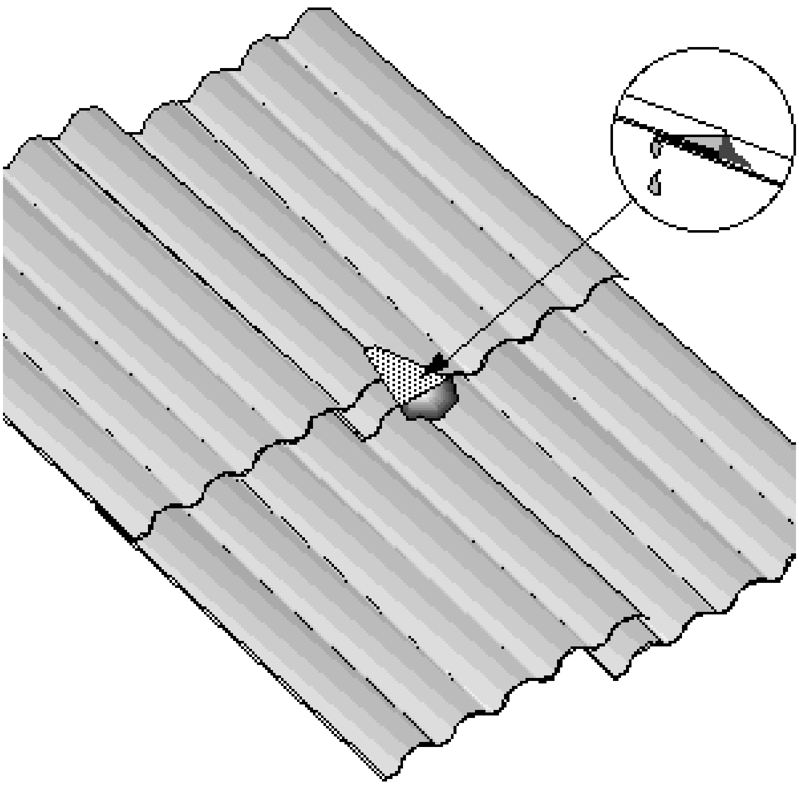

Figure 5.85 Detritus can build up in valleys of sheeting and lead to water penetrating to the interior of the building

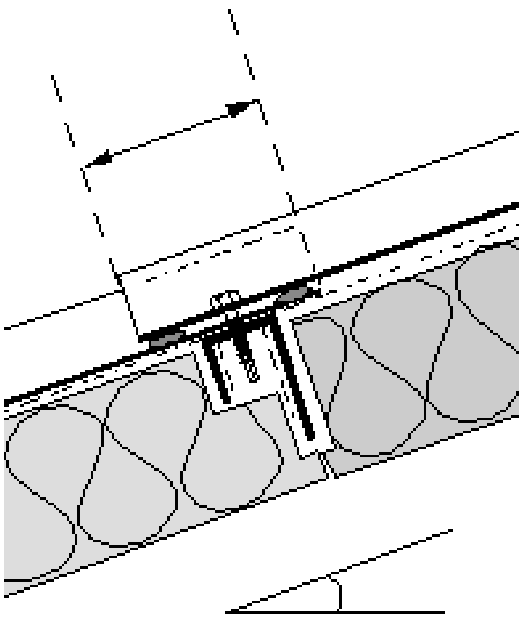

Figure 5.86 Seals above and below the fixing to the purlin to prevent water penetration

which take up water lying against the open edge of the welt and transfer it to the inside of the roof. In addition, water vapour in the atmosphere may similarly be transferred to the roof interior and condense on relatively cold surfaces near the outside of the structure. Loosely referred to as 'pumping', this is attributed to two main mechanisms:

- ❒ external wind pressures and suctions forcing air to and from the inside of the roof void (this tends to occur, given appropriate conditions, where the voids are relatively large);
- ❒ temperature changes affecting the air inside the void (tending to occur, given appropriate conditions, where the voids are relatively small).

In both cases, the resultant movement of air through the gaps carries with it some liquid water or water vapour from outside to inside which cannot then easily escape if the void is not ventilated. Significant volumes of water can be transported; enough indeed, to wrongly diagnosis the cause as rainwater penetration through holes or other damage to the covering.

Where the problem has been correctly diagnosed, there are effective remedies: for the first mechanism, by providing better air seals at the welts or joints, effectively making them less responsive to external air pressure; for the second mechanism, by better ventilation to the immediate underside of the membrane via special weatherproof vents situated away from the joints. This should remove water vapour without admitting rain. You may need specialist advice.

When specifying fully supported metal roof coverings, ensure that there is some ventilation over the top of the thermal insulation and underneath the outer sheeting on its deck. Otherwise, the sheet can deteriorate through inadvertent rainwater penetration to its underside. It then fails because solar heat expands and expels the trapped air; when it cools during rainfall, a partial vacuum is created which can suck in rainwater over the top of any vulnerable standing seams. Prevent this by fitting small shielded ventilators penetrating the roof covering.

Lead is particularly susceptible to deterioration in this way, other metals less so. Stainless steel and copper sheets are inherently more durable than other metals but there is always the risk of rainwater deterioration of any timber supporting structure.

Metal lined gutters are prone to leak, especially if they are blocked by snow and ice (snow boards are needed). They may also be a source of condensation on the underside of the metal, leading to deterioration in the gutter soles.

Weirs are a common requirement to provide upstands at vulnerable joints across the sheets. They must be checked for signs of lifting after strong winds, especially if of lighter gauge materials.

Patent glazing

The original intention of patent glazing was that it did not involve putty. The preformed strip or cord underneath the glass was not the primary weather seal, merely the inner air seal on a two-stage drained system of jointing. Over the years, this simple principle has to some extent been disregarded and now the weathertightness of some so-called patent glazing seems to depend on adhesion of the seal between bar and glazing. Many types of seals have been used, including tapes, cords and strips in solid and cellular form, and gun-applied mastics. British Standards are available for gun grade materials of certain polymer types though not for tape sealants. BS 5889 is obsolete but European standards are being prepared.

A second line of defence with patent glazing bars is the shape of the channel formed in the section at each side of the bar underneath the seating for the glazing. The route to the outside must be kept open for any rain penetrating the outer cover and running down the channel in the bar.

If the glazing is to be replaced at any time, take care that the deflection characteristics of the bars are appropriate to the kind of glazing to be specified or damage could result.

Snow guards to BS 6367 should be fitted above patent glazing. Rainwater pipes should not discharge over patent glazing – Figure 5.87 – for two reasons:

❒ all the water load will be concentrated on a narrow section of gutter at the foot of the patent glazing with the risk of overshooting in all but the lightest of rainfall;
❒ the glazing will quickly become streaked with dirt.

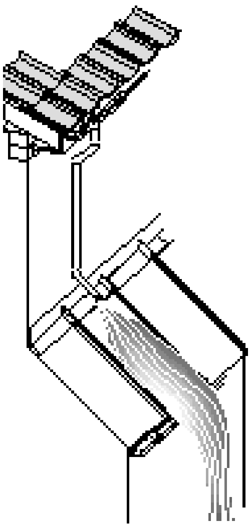

Figure 5.87 Rainwater discharging from a RWP over patent glazing will leave deposits on the glass and overshoot the gutter

Flat and low-pitch asphalt and bituminous felt roofs

Theoretically, the materials in built-up roofing provide a continuous and impervious barrier to rainwater and there should be no problems provided the surfaces are not perforated. However, damage has been caused to felted roof surfaces of comparatively low pitch during maintenance, for example when fixing aerials on chimneys.

About half the failures in bituminous felt roofs are due to splits produced by localised movements of the substrate. Rain can then penetrate and cause local damage on the ceiling below and will also, of course, damage the deck material. Splits can usually be repaired but the membrane must be isolated from building movements – more details are in Defect Action Sheet 33.

The other main cause of rain penetration in flat roofs is poor detailing at abutments and upstands: an angle fillet must be provided where the felt turns through 90°; the upstand must be at least 150 mm high and well lapped by secure flashings. In a parapet cavity wall, the DPC tray must be lapped over the cover flashing.

When BRE surveyed rehabilitated housing, many of the older roofs covered in three-ply built-up felt had problems of rainwater penetration. Many were patched. Roofs using organic fibre felts over boards of high moisture or thermal expansion have not generally been specified since the mid-1970s. Although there were fewer cases of leaks in asphalt roofs, they were invariably found in the oldest of these roofs.

Water penetration of single-ply membranes has been due usually to inadequate joints in the membranes.

Flat roof perimeters

The treatment of the perimeter provides difficulties for the designer; the main options are a parapet, low or higher for safety, if there is access to the roof or just to fit a trim to secure the edge of the membrane. Both have their drawbacks and are likely to be the type of roof detail which is most likely to fail.

Abutments

Abutments, where the roof meets a vertical wall or a parapet, are a common source of problems. The main requirements are for a tilting fillet to turn the roof covering from horizontal to the vertical in 45° increments and well tucked in flashings beneath any cavity trays. The parting of asphalt upstands from their adjoining abutments and parapets is one of the commonest problems with asphalt coverings. The unsupported lead flashing above a valley gutter – Figure 5.88 – was a risky venture; sagging of the lead and not properly sealing the joints encourages early failure. Overflowing of the gutter behind the flashing must be avoided. Fit a weir at the gutter end and ensure that debris never blocks the outlets.

It may be worth installing an automatic leak detection system. One of these works on the principle of a change in electrical conductance in a grid of metal tapes buried beneath, and insulated from, the outer surface of the covering. Water penetration is monitored by a microprocessor so the source can be pinpointed and dealt with.

Figure 5.88 Unsupported lead flashing above a valley gutter

Figure 5.89 A defective abutment detail on a canopy to a doorway. A fillet has been provided at the junction between the canopy and the wall but there is no flashing

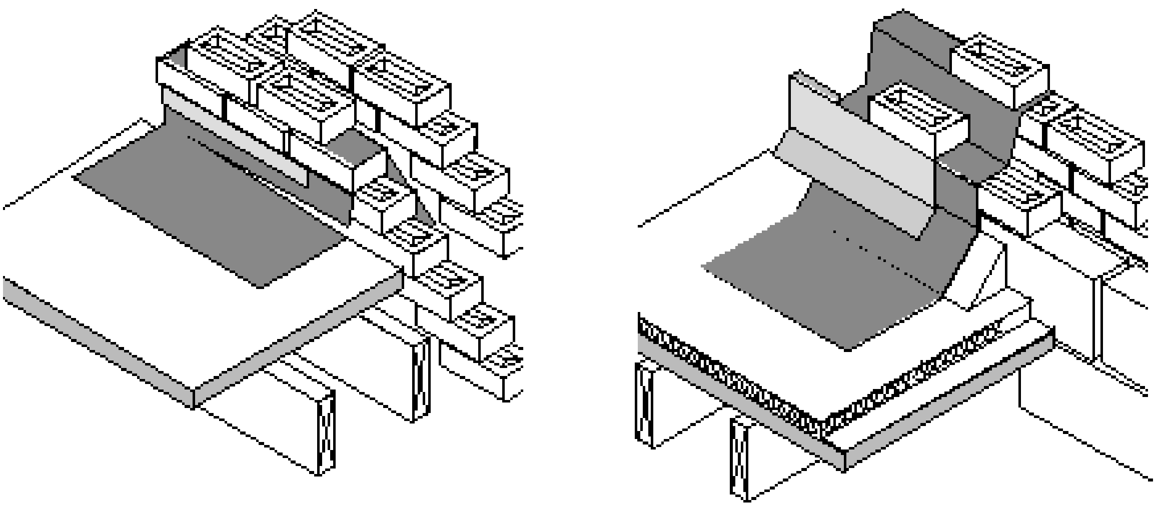

Figure 5.90 Defects found at built-up felt abutments (left) and how they can be avoided (right)

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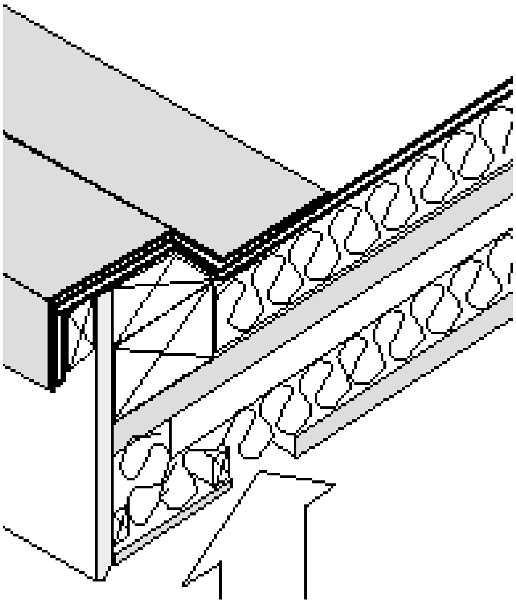

Figure 5.91 Detail of eaves in the timber deck of a warm roof. The external wall in not shown

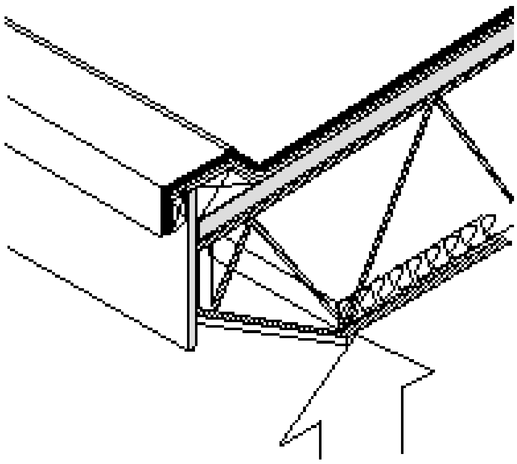

Figure 5.92 Metal trim at eaves of a mastic asphalt cold roof

Figure 5.93 This eaves trim was not securely fixed down to the deck. Consequently outward movement has torn the built-up felt. The shorter the length of metal or plastics, the less will be the thermal movements. Fixing should be made at both ends of lengths, close to joints in the trim

Eaves

The simplest way of finishing the roof edge when using felt is a welted drip at least 50 mm in depth and projection. These welts are normally fixed over a preservative-treated timber batten – Figure 5.91

Mastic asphalt roofs are finished with a metal trim securely fixed as closely as practicable on both sides of each joint in the lengths of trim – Figure 5.92.

Metal or plastics trims are also used with felt or membranes. They must be fixed carefully, or thermally-induced size changes can initiate a tear or crack in the membrane under each joint in the trim, with obvious consequences of a roof leak – Figure 5.93. Water does tend to run off at the junction of the lengths of trim and this should be set forward of the face of the wall to prevent staining.

Asphalt upstands parting from their adjoining abutments and parapets is one of the commonest of problems seen with asphalt coverings.

Parapets

The origin of this detail must be castle battlements where the avoidance of water penetration to the room below was well down on the list of requirements. The damage that can arise from long-term leakage and the consequential high repair costs has already been shown – Figure 5.94.

Rather draconian, but thought worthy of including as a marginal note in BRE Digest 89 was a point made by LB Perkins, speaking at a symposium on Modern Masonry, held in the USA, 1956. He said: "*In our office today, anyone who wishes to put a parapet wall into one of our designs may do so coincident with his resignation*". The guidance in the Digest was to suggest that parapets were to be avoided unless copings had generous overhangs and adequate drips, and were provided with DPCs at roof level. Other recommendations were aimed at minimising the risk of sulfate attack. Attack can cause expansion of the mortar which can arch the coping to a parapet producing wide cracks through which water can obviously enter.

Where a parapet bounds a metal-covered flat roof, melting snow may be a cause of water overflow. The problem arises where ice or snow blocks the gutter so creating a dam; the resultant ponded water overtops the upstands – Figure 5.95. The problem can be solved in part by using snow boards to keep the gutter and outflow clear.

Figure 5.94 A leaking joint in the coping has led to failure in the render

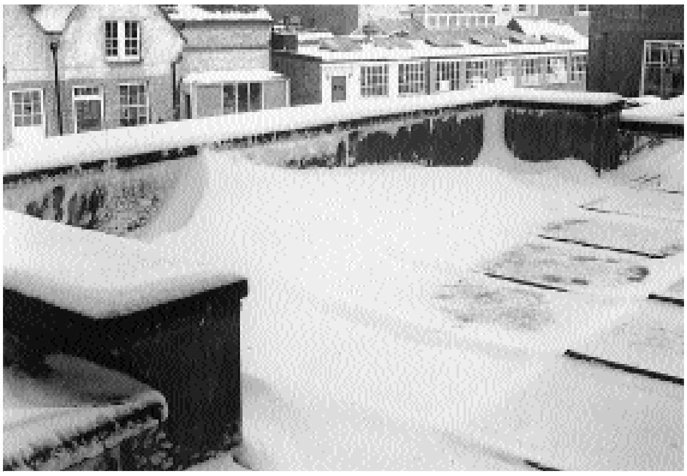

Figure 5.95 Drifting snow on a lead roof behind a parapet

Figure 5.96 Perforation of a waterproof layer – for example for services, machinery and cleaning cradle rails – needs particular attention and careful detailing. Indeed there can sometimes be more perforation than roof !

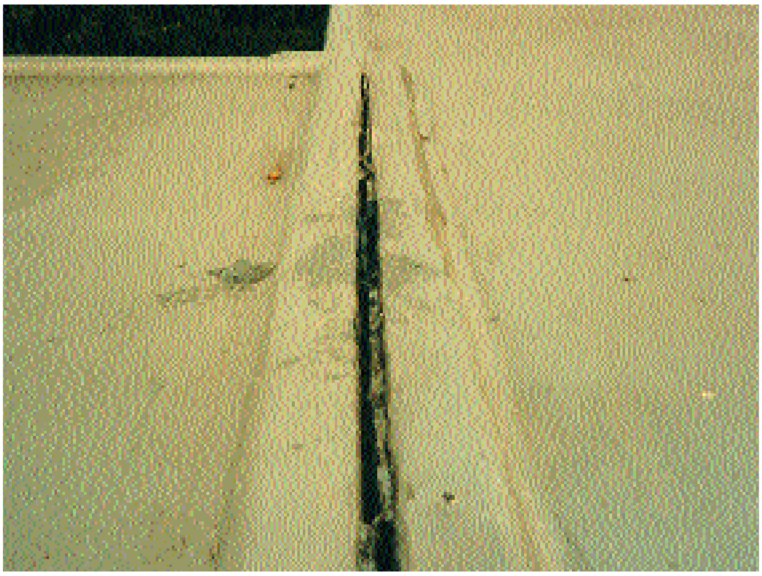

Figure 5.97 A movement joint on a concrete slab roof. The jointing material has completely failed to accommodate the movements in the slab. We have often seen this type of failure in specification

If there is access to a roof, the weathertightness of the roof covering is often not easy to maintain around handrail standards which perforate the waterproof layer. In general, the top of the upstands should be at least 150 mm above the surrounding roof, and the standard should be sleeved with the capping overlapping the upstand. If holding-down bolts are needed to fix, for example, cleaning cradle rails, they should be seated on washers of neoprene or a similar material and covered with a suitable non-hardening mastic – Figure 5.96.

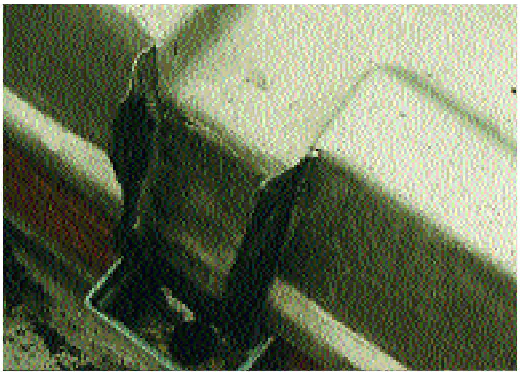

Figure 5.98 The kerb at this hopper head is too small to prevent overtopping in heavy rain

Rainwater entrapped during construction has been encountered frequently. Before the roof is enclosed by the weatherproof membrane, both construction water and trapped rainwater should be allowed to evaporate, or the roof should be vented to the external air through hooded ventilators.

The design and detailing of kerbs, particularly those protecting movement joints – Figure 5.97 – are crucial to the exclusion and disposal of rainwater; they should be high enough not to be overtopped in a storm – Figure 5.98.

Green roofs

The different kinds of green roofs range from thin layers of growing medium to support grass or other plant life, to relatively thick beds of earth to support plant life in a roof garden – Figure 5.99.

Whether pitched or flat, the aim is to provide sufficient water-retentive capacity on the roof to even out the adverse effects of intermittent natural rainfall, at the same time providing adequate capacity for rainwater disposal after saturation during heavy rain. All this is in addition to providing the extra performance characteristics which such roofs can provide. Rain penetration into the building below must be avoided; additional layers of organic medium could provide a more stable regime for the waterproof layer in terms of protection against UV or thermal gains or losses.

Figure 5.99 A green roof

Moisture retention, therefore, is desirable in a roof garden. In fact, ordinary earth or topsoil covering the structure will vary between waterlogged and slightly damp for long periods at a time. Water necessary for plants can be introduced by natural (rain) or artificial (sprinkler) means. The waterproof layer should normally consist of asphalt laid in three coats to total thicknesses of 30 mm on horizontal surfaces and 20 mm on vertical (BS CP 144: Part 4). It may be possible to substitute an alternative, such as a polymer modified felt, provided that mechanical damage during the installation of the roof will be avoided. Above the waterproof layer is a drainage zone of a no-fines material, such as fired clay or sintered pulverised fuel ash (PFA).

Above the drainage zone, a geotextile sheet is needed; this is of woven plastics material which allows water to percolate but which retains the fines from the earth.

Inverted roofs

A possible problem with an inverted roof design is the creation of thermal bridges under certain conditions. Rainwater percolates and lies between the joints of the thermal insulation boards, so giving rise to thermal bridges and the risk of condensation under the waterproof layers – Figure 5.100. This effect is localised, intermittent and independent of insulation thickness and occurs in lightweight decks where temperature swings are more rapid than in heavyweight decks. The reduction in thermal insulation value of the whole roof can be compensated for, in the longer term in new designs, by making an additional allowance of about 20% to the thermal insulation underneath the main layer. Laying the thermal insulation in two layers to break joint is unlikely to help much since the risk is from cold rainwater filling the joint. In new construction, a thin layer of insulation (a material of 0.15 m^2K/W) under

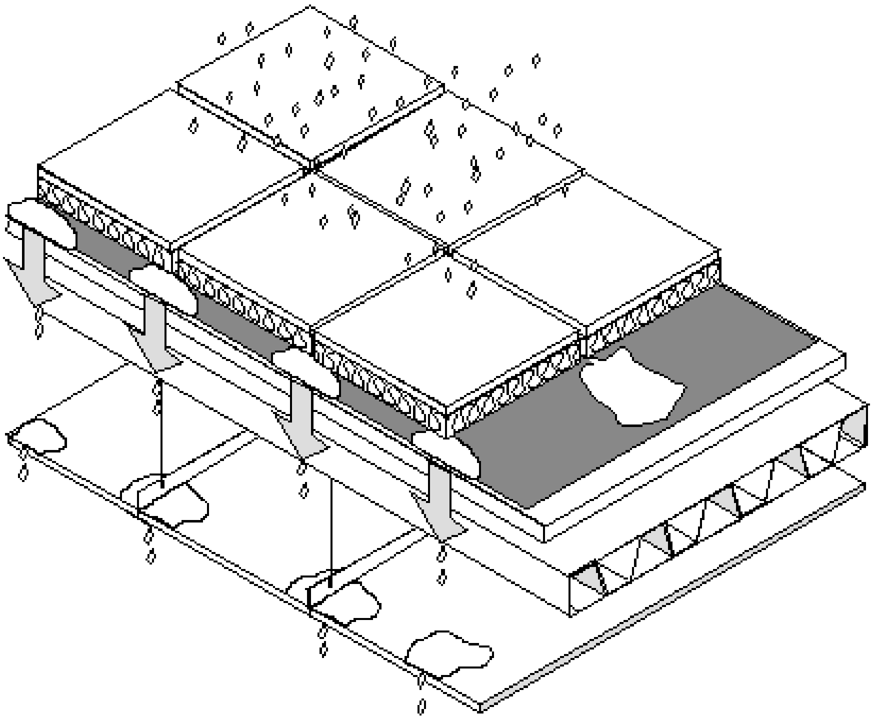

Figure 5.100 Thermal bridges caused by rainwater percolating between slabs of insulation on an inverted roof over a lightweight deck can lead to condensation on the ceiling beneath

the waterproof layer is beneficial. Remedial work to reduce the risk of condensation, however, is hardly practicable without taking up the ballast and existing insulation.

One main disadvantage of the inverted type of roof is that the weatherproof layer cannot be inspected easily. This may make tracing the source of leaks even more difficult than usual. Detritus may be washed down to become trapped between the insulation and the weatherproof layer. In time, constant movement can cause the membrane to perforate, especially if it is thin. A porous textile membrane installed immediately under the ballast layer can filter out the detritus and help to protect the weatherproof membrane.

Rainwater disposal

Rainwater disposal from mastic asphalt roofs is normally via hoppers through a parapet or, occasionally, via gutters attached to the eaves. Normally the top of the slope at an abutment will have an upstand; the flashing over the upstand must not be in tight contact with the asphalt to avoid capillary attraction of rainwater under the apron.

Repairs

Liquid applied membranes, some of them reinforced with a glass-fibre or polyester base, may be used in remedial work to provide a temporary cure for small leaks, though compatibility of the new material with the old roof should be ascertained from the manufacturer. Choosing a product which has been granted an Agrément or other third party certificate is advisable.

Splits in felt can be repaired satisfactorily provided the methods or workmanship which led to the original error are not repeated. Faults in the structure itself which lead to splitting should be corrected. The first strip is

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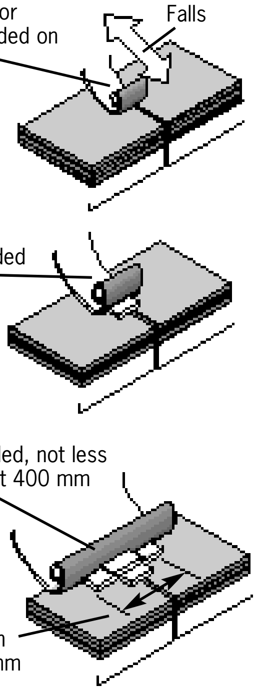

Figure 5.101 Repairing a split in a felt roof

either not bonded, or bonded only at one edge. Subsequent layers may be fully bonded provided the minimum dimensions shownn in Figure 5.101 are observed.

Precast concrete eaves gutters built into the head of the wall can be relined. A rubberised plastics sheet is used; this is hot-air welded on site to form a lining in one sheet the whole length of the gutter, including rainwater outlets. The material is flexible and since it is not fully bonded to the gutter, the risk of splitting is reduced.

Bays and porches

Gutters are not always installed on porches and bay windows; this may not matter if the drips cause no inconvenience to the occupants but it is less acceptable for doorways.

Roofs on bays or porches are often built to a lower standard than the main roof, or they may have a different type of construction from the main roof with inadequate rainwater drainage and poor detailing.

Diagnosis

In looking for possible routes for rain penetration, key considerations are:

- ❐ Is the bay or porch of single-skin masonry construction?
- ❐ Is the roof properly detailed?
- ❐ Is penetration due to failure of protective cladding or render?
- ❐ Are details for rainwater shedding and disposal adequate?
- ❐ Is the junction with the main structure watertight?

Chimneys

The problem

Dampness is common around chimneys. They should have a capping, a flashing to prevent rain passing between the chimney and adjacent roof covering and, in exposed locations, one or more DPCs built into the chimney. The bottom one should be at the lowest intersection between roof and chimney. Rain can penetrate into the stack through eroded pointing or through cracked or detached rendering on the outside of the stack.

There must be adequate provision for damp-proofing a masonry chimney stack where it penetrates the roof line – Figure 5.102. Not all old chimneys were fitted with a DPC and some of these chimneys can be sources of continuous problems. On one old farmhouse house investigated by BRE near the coast in Pembrokeshire, there was a history of damp walls throughout living memory; after many attempts to waterproof the rubble stone walls, the problem was finally diagnosed as no DPCs in the brickwork stacks. Since the fireplaces were no longer in use, the stacks above roof line were demolished, making adequate provision for ventilation of the remaining disused flues. That cured the dampness

Diagnosis

Chimney breasts may become damp as a result of rain penetration through the brickwork from above, or of condensation from the flue gases. Where there is a considerable area of chimney exposed beneath the roof in a part of the building that is not habitable, some penetration of rain can be tolerated because the exposed area will provide an evaporating surface. A

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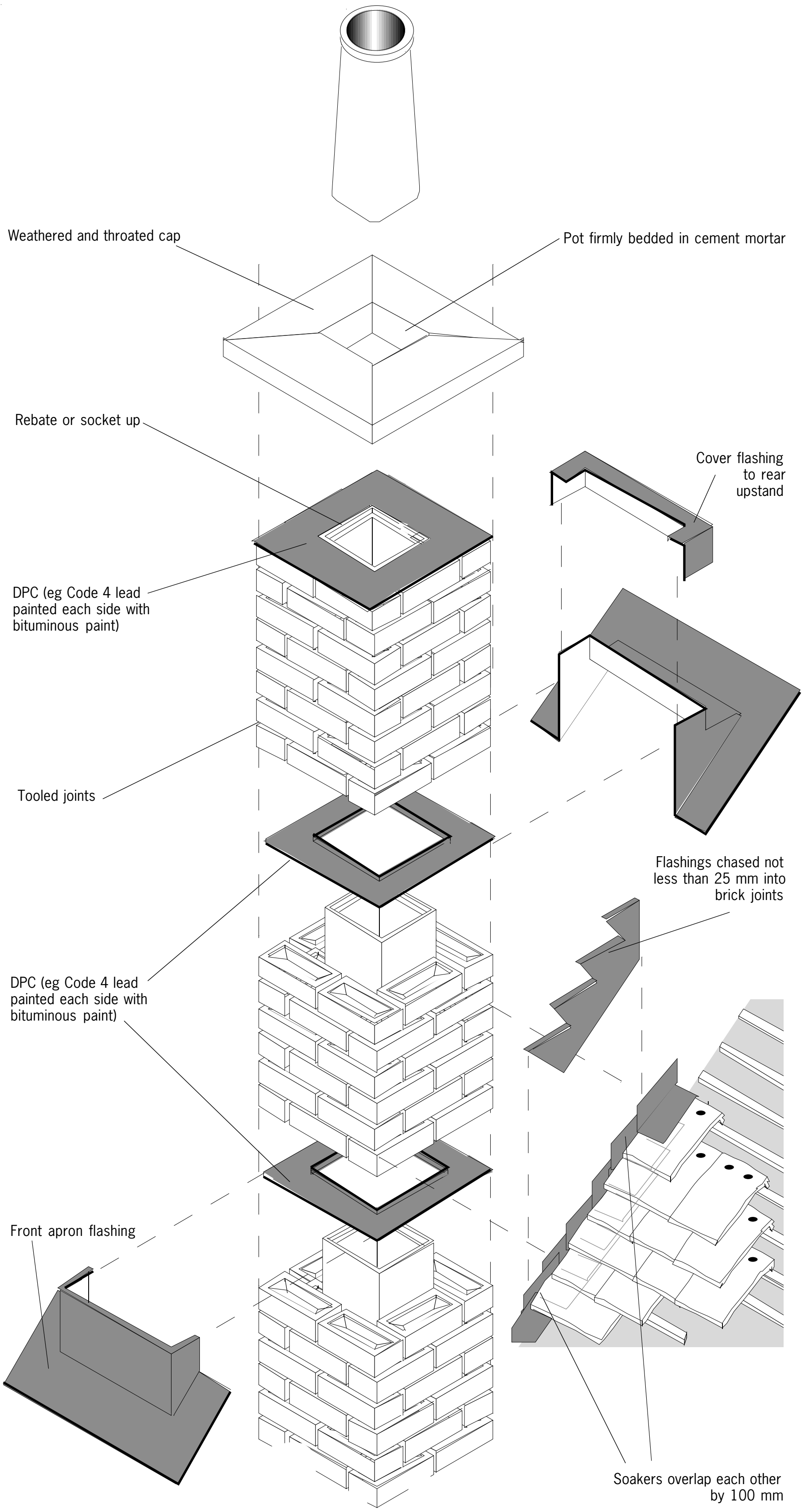


Figure 5.102 A DPC should be provided in a stack, and two may be needed where the chimney is severely exposed or the roof slope steep.

dense rendering on this part of the chimney would be disadvantageous. In certain cases, its removal and replacement by a porous rendering might be a sufficient treatment to stop dampness being apparent in the building.

Remedies

Penetration down through the brickwork can be prevented only by inserting a DPC at roof level. The most satisfactory type is a sheet material, stepped where necessary to follow the slope of the roof. Engineering bricks and slates as a DPC have the disadvantage in this situation that water may penetrate at the vertical joints either by way of porous mortar or through fine cracks between bricks or slates and dense mortar.

CASE STUDY — Water dripping from a bakery roof

Water was dripping from the corrugated asbestos-cement sheet roof. Of those consulted before BRE was called in, opinions were divided between those thought the cause was condensation within the roof void, and those who thought that the roof was not weathertight.

Measurements and observations

Temperature and RH measurements in the building were recorded using a thermohygrograph for the overnight period. The values obtained were below levels quoted in the then current British Standards so roof condensation was unlikely. There was no evidence of water staining from condensation.

The following spot value conditions were recorded in the factory at 10.40 am on a working day:

dry bulb	35.5°C
wet bulb	21.5°C
RH	28%
dewpoint temperature	14.9°C
moisture content	0.0105 kg/kg dry air
vapour pressure	16.89 mbar

The surface temperatures of the roof components were measured using an electrical thermometer:

underside of roofing sheets	25°C
ceiling support T-section	32°C
underside of ceiling	30°C

The timber used to space the asbestos-cement sheets from the Z-type steel purlins was checked from inside the roof with an electrical moisture meter: it was dry. Some of the ceiling supporting T-sections had sprung away from above the purlins, allowing ceiling panels to drop. There were streaking water marks down several of the vertical internal cladding panels on the exterior end wall. External inspection of the roof revealed points where water could enter, and debris within the roof lights revealed the inadequacy of the lap sealing. In the interests of safety, only limited areas of the roof could be examined.

The following points were noted:

- ❒ Eaves closure pieces had fallen out.
- ❒ Translucent panels were distorted (one appeared to have been stepped on at some stage). The insulation material could be pulled out through the gap between the translucent panel and the asbestos sheet. It was wet.
- ❒ One of the translucent roof light panels was loose and flapping in the wind.
- ❒ End laps at some junctions were only 100 mm. A run of sealing mastic could be seen through the translucent panels. Some of the end laps between translucent panels and asbestos-cement sheets were badly fitting and there was an open gap in excess of 25 mm.
- ❒ The crookbolts had not been fitted with caps and were rusty; some of the crookbolts were distorted.
- ❒ There were leaves and twigs between the translucent panel and the ceiling light panel.
- ❒ Some of the side laps had been screwed down with self-tapping screws. It was suspected that an elastomeric filler had been used, and then the areas primed, sealed and patched with a one-coat elastomer waterproof membrane.

Discussion

The adequacy of the roof design and construction was first examined against the requirements of the relevant British Standards. Weathertightness of the roof was in doubt, in particular at end laps. On an exposed site and with a pitched roof, British Standard recommendations were for 300 mm end laps, with side and end laps sealed. The construction did not comply.

Translucent corrugated panels as roof lights had not proved satisfactory. Debris was being blown through gaps and water had leaked through the roof during storms. The water marks seen on the wall panels were consistent with water being driven under barge boards.

If condensation occurs and moisture forms on the underside of the asbestos-cement sheets, the usual signs are of water dripping onto the ceiling boards and running down to the ceiling support T-sections. There was no sign of water at this point; the ceiling panels were not stained at the lower edge, neither were the spacing timbers in the roof wet. The inspection was carried out after a cold night with temperatures below freezing; if condensation were likely, it would have occurred then.

The measured RH trace peaked at 67% for a short time but after particular processing operations had finished it dropped rapidly to 24%. The night-time temperature dropped from 19°C to 15°C with a corresponding rise in RH to about 50%. This is without heating in the unit, during a frosty night outside. When the baking oven was relit at about 6 am, the temperature trace became unstable but RH remained below 50%. As with all sheet roof and wall coverings, the risk of condensation is greatest when the RH and temperatures of the internal air remain above 60% and 18°C respectively for long periods. In this building, these conditions were not exceeded for long periods and it was concluded that the baking operation was unlikely to produce condensation.

Remedial measures

Would roof condensation be likely when the roof is repaired? In a more weathertight roof, there would be less ventilation between the insulation and the underside of the asbestos-cement sheets. The suspended ceiling is not a VCL, so moist air will inevitably drift into the void. This suggests that the roof should be stripped completely and a double-skin insulated construction fitted with a VCL on the warm side.

An alternative is that an extract fan automatically operates if RH rises above the conditions in the British Standard of 60% and 18°C. This still requires the present roof to be repaired with due attention to laps and the replacement of the translucent panels with roof lights more appropriate to the exposure.

Conclusions

It was concluded that that the roof design and construction was poor and took little account of the recommendations of the then current British Standards. The water marks were the result of leakage through inadequate sealing of the roof components and the performance of the corrugated translucent roof panels was unsatisfactory.

Condensation arising from the baking process was not found to be part of the problems.

CASE STUDY **Rain penetration at a medieval church**

BRE was asked to investigate a 12th century parish church that was suffering from severe rain penetration, mainly on the west-facing elevation of the tower.

Construction and history

The church was typical of construction of the time: external walls of solid stone 0.6 to 0.9 m thick, a dense and impermeable carboniferous limestone.

Rain penetration was a long-standing problem, mainly through the west face of the tower. Damp also appeared at times on the north face of the tower. There was no penetration after one day of rain and wind; the first signs appeared at the end of the second day and there was severe penetration during the third day. Heavy rain alone did not seem to lead to water penetration, but when it was wind-driven problems occurred throughout the height of the tower leading to flooding of the floor area at the west end.

The tower was later than the main body, probably 15th century. Major renovation work was carried out in the early 1900s when the bells and a new roof were installed. Some elderly local residents reported that long ago there was some form of covering to the west face of the tower.

In an earlier attempt to prevent water penetration, all mortar joints on the tower were raked out to a depth of 75 mm and repointed with a suitable mortar mix, said to be a 1:1:6 or similar, and the outside of the roof was completely overhauled. This had not solved the problems.

Site observations

Climbing the tower revealed wet internal stonework at every level on the west face. At some points where stonework had been removed internally to a depth of 300 mm or so, damp was plainly visible all the way to the core of the wall. The roof structure itself appeared quite sound, apart from some minor and easily corrected leaks associated with drainage and guttering.

The external stonework was sound with no deterioration visible to the weathered surfaces. The pointing to mortar joints looked in reasonable condition although shrinkage cracks were clearly visible at the stone and mortar interface. Close inspection of external surfaces revealed traces of a white or yellow encrusted layer, possibly the remnants of an old limewash treatment. It was common practice throughout medieval times to apply limewash internally and externally to church buildings, and such treatment regularly carried out would have kept rain penetration at bay. Samples of stone and mortar were collected from the tower and taken to the laboratory for water absorption tests.

Discussion and recommendations

Tested to BS EN 13755, the 24-hour water absorption of stone and mortar were 1.3 and 25.1% wet weight respectively. This is the most realistic measure of the ability of a porous material to soak up water; it is usually around 80% of the total porosity. The figures confirm the low absorption capacity of the stone and the relatively high absorption of the mortar. The stone accounts for the far greater portion of the volume of any given section of walling which means that the absorptive capacity of the wall remains low.

Rain penetration occurs through the cracks between materials rather than through the materials themselves. In a rainstorm, walls built with low absorption materials leak sooner than those built with high absorption materials, simply because the former cannot soak water up as it penetrates the structure. Cracks always develop between mortar and adjacent brick or stone no matter how carefully construction work is carried out and, mainly for this reason, repointing alone is unlikely to cure a severe water penetration problem, although it may reduce it.

Remedial measures

There are two categories: those that affect the appearance of the structure and those that do not:

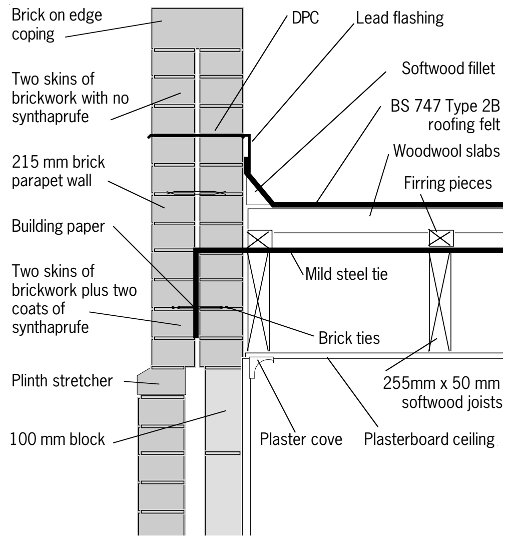
- ❐ Using a form of slate cladding would cure the penetration problems but would probably be unacceptable visually. An alternative is to apply a lime:sand render, finished with a limewash. This would allow any damp to evaporate readily.
- ❐ Second category options are applying a colourless water repellent, pressure grouting, or building a new internal stone skin with cavity at ground floor level.

Pressure grouting the core is an expensive process intended primarily to impart structural stability. Resistance to rain penetration would be increased but there is no track record or testing for this with such treatments. Specialist contractors would have to assess the problem. It would be unlikely that they would guarantee any treatment to cure completely the water penetration problems.

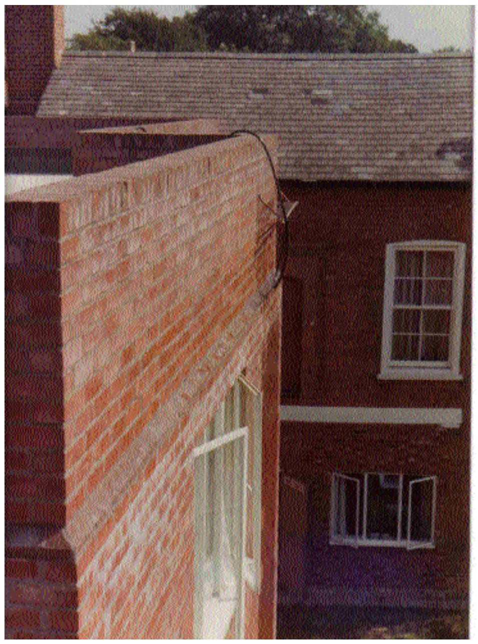
Another alternative would be to accept damp walls in the upper parts of the tower and to construct a new inner skin of matching stone against the west end at ground floor level, incorporating a 50 mm cavity with wall ties and drainage outlets at the base of the existing external wall. This would cure the internal effects of rain penetration in the regularly used section of the building and, in effect, create a modern cavity wall with a free-draining cavity.

CASE STUDY Water ingress through a solid brick parapet

A block of flats was built in cavity construction with the wall continued above flat roof level in solid 225 mm brickwork capped with a brick-on-edge coping. A DPC was set above the level of the roof flashing through the thickness of the wall. The inside face of the outer leaf was painted with a bituminous DPM to stop water ingress at joist ends where the wall was only one brick thick. A plinth stretcher brick at the top of the cavity wall accommodated the difference in wall thickness.



Concern was also expressed with the bricks used in this location. The brick manufacturer suggested that the bricks were usually underfired to produce the required colour and also pointed out that underfired bricks are more susceptible to sulfate attack.



Dampness at ceiling level followed construction and a water-repellent treatment was applied. This did not cure the problem so the BRE Advisory service was commissioned to investigate and report. An initial inspection located water stains down the wall from beneath the ceiling together with some mould growth. A water test was set up initially on the external side and then the roof side of the parapet. Water crossed through the solid brick wall an hour after starting the test, in spite of the water-repellent treatment. Part of the problem was the inadequate tuck in of the lead flashing beneath the horizontal DPC. There was also a back fall on the lead in places. The absence of a DPC beneath the brick-on-edge coping will allow early entry of water to the wall.

Several remedial options were put forward, all involving demolishing the outer skin of the parapet. Reduction in height was recommended together with rebuilding as a cavity parapet with DPCs at roof level and below a concrete coping. A cheaper option was to demolish to roof level and cover with a metal capping, paying particular attention to the joints, although the local planning authority might not agree to this.

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CASE STUDY | **Rain penetration in a Victorian stately home**

An extensive programme of re-roofing had been undertaken on this building but there was further rain penetration of parapets and condensation on the underside of roofs. The client commissioned a BRE inspection of the property.

Construction and history

There has been a building on this site since Roman times; a castle built in the 13th century was followed in the next by a pele tower. Major rebuilding was undertaken in the 1860s; at the time of the inspection much of the slate and lead roof coverings were being replaced. A new flat roof, spanning from ridge to ridge, replaced valley gutters. Drainage falls were revised with flat lead roofs supported by plywood sheets. Some chimney rebuilding had already proved necessary and lead trays were introduced.

Other works at the time included conversion of private rooms beneath the roofs into flats and the installation of a complete new central heating system.

The solid walls have random granite stones as facing, capped with dressed sandstone blocks to parapets. Wall heads are reduced in width, with sandstone blocks to weather the head of the wall. A line of leadwork projects in places, indicating a tray within the thickness of the wall.

The building is exposed down the valley to the south-west with clear views to the sea. High external walls are surmounted with battlements or parapets with the wall thickness being reduced and covered by long stone blocks.

At the time of the visit, works on the roof had been completed although the location of a lead tray and flashings had been investigated by dismantling the stonework of a section of the parapet. BRE's brief covered investigating rain penetration at the parapets, suggesting remedial measures and examining links between rain penetration and condensation on the underside of the slate and lead roofs.

Site observations

The day of the visit was initially dry following heavy overnight rain; a light shower occurred late morning. Parapets, roofs and roof voids were examined for rain penetration and condensation. A small area of the lead was opened up adjacent to the parapet.

There was no pointing mortar in some of the joints. Sandstone cappings to the battlements were dressed flush with infill stonework so there was no overhang nor drips to shed water. Algae and white staining down the face of the wall suggested considerable wetting.

A section of battlement had been dismantled to expose the lead tray. The two leaves of stonework seemed well bedded, though there was voiding within the thickness of the wall. There was no DPC beneath the sandstone cappings. A length of lead tray was exposed; it was thinned and perforated by corrosion in several places. The tray appeared to have a slight slope inwards towards the roof. The flashing had been set incorrectly above the tray rather than beneath it.

Dampness was seen at joist ends in the large roof void above the library where buckets had been placed to collect direct rain leakage. Changes to the levels of flat roofs had resulted in some of the lead trays through the wall being well below the new roof and there was evidence of water discharging down the internal face of the wall.

There was much dampness and staining on the boarding beneath the slated areas of pitched roof. Some of the copper slate fixing nails project through; it was reported that drops of water have been seen hanging on them. New areas of flat roof and valley gutters have been boarded with plywood and mould growth was becoming established on the underside.

The roof void was vented at high level with purpose-made lead tiles with vents. The upstand at the front was low and, although a check would be needed during a storm, there was concern that rain could drive into the roof void. There was evidence of a leaking roof-light.

A lead perimeter flashing was lifted to examine the upstands. A geomembrane fleece between the lead and the ply decking had been taken up the wall behind the upstand. However, the fleece did not extend to the edge of the lead and there was a white deposit on the underside of the lead: corrosion in the form of lead carbonate.

Rain penetration through the roof side of the parapets had previously been tackled by applying a render to the stonework. This was now cracked and in need of repair.

Discussion and remedial measures

Although dampness from rain penetration increases the available moisture for condensation, the two problems can be considered separately. Monitoring temperature and humidity confirmed that conditions existed for surface condensation. In fact, in one roof space, such conditions existed for most of the time that measurements were made. Temperatures were around 9°C but recorded humidities were rather high: around 95%. Underside roof condensation is unavoidable on occasions. Night sky radiation can result in surface temperatures 5°C lower than ambient. Control of condensation is normally managed by ventilation; in these pitched roofs there are only a few high level vents. There are no low level vents or any form of ventilation below the parapet valley gutters. This is understandable because through ventilation is unachievable without piercing the parapets.

An alternative is a fan-assisted extract system, possibly humidistat-controlled, to prevent build up of moist air within the roof voids. This had already been considered. Ducts may be necessary to draw air from stagnant areas.

When the building is heated there would be some fortuitous heat loss to the roof voids. No insulation had been provided to ceilings so this low level of heat should further reduce the condensation risk. It is important that no moisture drifts into roof voids from the living areas below. Most moisture is produced in bathrooms and kitchens where extract fans discharging to outside air are a requirement. Access hatches to roof voids should be sealed with draughtstripping.

The lead valley gutter abutment to the wall was a problem because there was insufficient height available with the remodelling of the gutters. It was proposed on site to form a secret gutter that would enable a low flashing over the tray to be protected by a much deeper cover flashing.The new Code 8 lead upstand might need some further support to prevent mechanical damage and the leadwork contractor would have to be content with lead burning this item to the gutter.

The roof side of the parapets had already been protected and it was proposed to fix temporary polyethylene protection to other areas. If successful, it could be replaced by a proprietary dimpled sheet membrane, together with a render finish. Fixings for the membrane should be at close pitch, otherwise thermal expansion of the plastics can result in cracked renders. Protection by a flashing at the head and provision for ventilation behind the membrane would also be necessary.

Perforation by corrosion of the parapet lead tray was reducing its effectiveness and a chemical injection DPC was initially suggested. These products are intended only to resist capillary rise of moisture. They do not block the pore structure and therefore cannot prevent gravity drainage of water. They are, therefore, unsuitable for use in parapets. Repointing areas of walls would reduce the amount of water getting into the core, and help to prevent leakage through the joints in the capping stones. A sealant is better than mortar for horizontal surfaces subject to thermal movement.

The lead corrosion at the cover flashing probably resulted from the proximity of the lead to a damp area of walling without the protection of the fleece underlay. Further advice is available from English Heritage.

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89 Sulphate attack on brickwork
377 Selecting windows by performance
380 Damp-proof courses
440 Weathering of white external PVC-U

Defect Action Sheets

9 Pitched roofs: sarking felt underlay – drainage from roof
33 Flat roofs: built-up bitumen felt – remedying rain penetration
114 Slated and tiled pitched roofs; flashings and cavity trays for step and stagger layouts – specification

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18 Choosing external rendering
47 Level external thresholds: reducing moisture penetration and thermal bridging

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16/03 Proprietry renders

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BS 5368 Methods of testing windows
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Chapter 6
Rising damp and groundwater movement

This chapter deals with theory and treatments of rising damp in walls and floors. Replastering following rising damp is included and there is a discussion of damp penetration of basements by lateral movement of groundwater.

Rising damp is the result of porous masonry sucking up water from the ground. It rises up the wall, often to a height of a metre or more, and usually leaves a characteristic horizontal tide mark. Below it, the wall is discoloured, with general darkening and patchiness, and there may be mould growth and loose wallpaper.

Three factors affect the quantity of moisture absorbed by the wall and the height to which it rises:
❐ the capacity of the wall material to absorb moisture;
❐ how wet the soil is;
❐ how quickly moisture can evaporate.

The water is bound to contain soluble salts brought up from the ground or dissolved out of the bricks or mortar. As the water evaporates, these salts crystallise out on the wall surfaces, often concentrating in the tide mark.

Figure 6.1 Plaster has bridged the DPC

THE THEORY

Rising damp is normally the upward transfer of moisture due to capillary action. Masonry has a complex pore structure in which the diameter of the pores varies widely and influences the ultimate height to which moisture can rise but it can be over 1 m. Other relevant factors include the degree of saturation of the soil, the rate of evaporation from the wall surfaces and the presence of salts in the wall. Normally, for new construction, a sheet material is incorporated close to the base of the wall to resist the passage of water. In older buildings, there may be no such barrier or the material may have failed. It may also be made ineffective by defects in construction or use where the DPC is bridged.

Saturated ground

For water to rise in a wall, there must be a supply at the base. This is the case if the ground surrounding the wall is saturated but, if not, the soil exerts a suction that opposes the upward capillary pull on the water in the wall. This suction is roughly equivalent to the negative pressure exerted by a column of water whose height extends from the base of the wall to the water table. If the water table falls, the height of the moisture in the wall drops to a new level provided there is sufficient time for equilibrium to become established. Each period of heavy rain on the base of the wall produces temporary saturation; the water level in the wall rises again to a level that depends on the amount of evaporation of water from a wet wall and on the resistance to the flow of moisture up the wall. If resistance is high, as in a material with many fine pores, the effect of evaporation is most marked, but if the wall material has many coarse pores, the height of dampness will be only slightly affected by normal rates of evaporation. Increasing the heat input to the structure increases the rate of evaporation from the wall surfaces. The overall effect of this is to increase the rate of flow of water up the wall but, because of the resistance to flow, this is likely to be accompanied by a reduction in the height to which the moisture extends. In addition, evaporation will occur from deeper in the pores of the plaster so that the rising damp seems to disappear. In summer, hot weather increases the evaporation rate and lowers the water table, so the effect on rising damp can be even more striking.

Soluble salts

Water drawn from the soil usually contains a low concentration of soluble salts; the rising water also dissolves salts from the bricks or the mortar. When the water evaporates, the salt solution becomes more concentrated at the surface and finally the salts crystallise out. This tends to block the pores, reducing evaporation and raising the level of dampness. Being hygroscopic, these salts may also absorb moisture from the air above some critical value of relative humidity so that the surface becomes wet during wet weather. This dampness disappears when the air becomes drier again.

This suggests that, under real, dynamic conditions, rising damp in a wall is in a sensitive equilibrium which may be disturbed considerably by changes in the building's heating and in the level of the water table. The presence of hygroscopic salts obscures any drying associated with such changes by keeping the wall more moist than it would otherwise be. If salts are removed from the surface by removing the old plaster, and the heating is improved, the dramatic improvement in the appearance of the wall's surface probably gives the impression that rising damp has been cured. Against this background, the correct diagnosis of rising damp becomes important.

Rainfall splashing

Rain, whether wind-driven or vertical, is usually expected not to splash up more than 150 mm from horizontal hard surfaces. This is the normal height for siting DPCs above paving as well as for flashings above roofing level. However, detritus carried by splashes has been found on vertical surfaces 300 mm and more above horizontal surfaces or paving – Figure 6.2.

Figure 6.2 Detritus carried to a height of 350 mm on the spandrel of a wooden window above concrete paving

DIAGNOSIS

Failures of existing DPCs

Before anything else, check if there is a DPC. The Public Health Act of 1875 introduced the requirement for a DPC in walls to prevent rising damp. However, the adoption of this into local byelaws took some time. Houses built before then, or with uncoursed walls, such as flint and random stone, are unlikely to have a DPC.

If the building has a DPC, it is unlikely that it has failed: most DPC materials have a long life – Figure 6.3. It has probably been pointed or rendered over, or bridged, inside or out. Raised soil levels or pathways, or rubbish or fuel stored against the wall, or render or internal plaster covering the DPC, all provide possible routes for moisture. In cavity walls, rising damp can occur if the DPC is bridged by mortar droppings at the base of the cavity – Figure 6.4.

Physical DPCs can fail occasionally, particularly those formed by engineering bricks or overlapping slates, following breakdown of the mortar; bitumen felt DPCs can become brittle with age. It is also possible that a remedial DPC system is damaged or ineffective. If a suspended timber floor has been replaced by a solid floor, there can be a difference in the level of DPCs; this leads to bridging. It can also happen where solid and timber floors abut, such as solid floors in the kitchen and timber floors elsewhere, or in a stepped terrace. Partition walls are less at risk than external walls of rising

Figure 6.3 A slate DPC about 20 mm thick with half lap joints in a house built in the 1870s; it is still in excellent condition

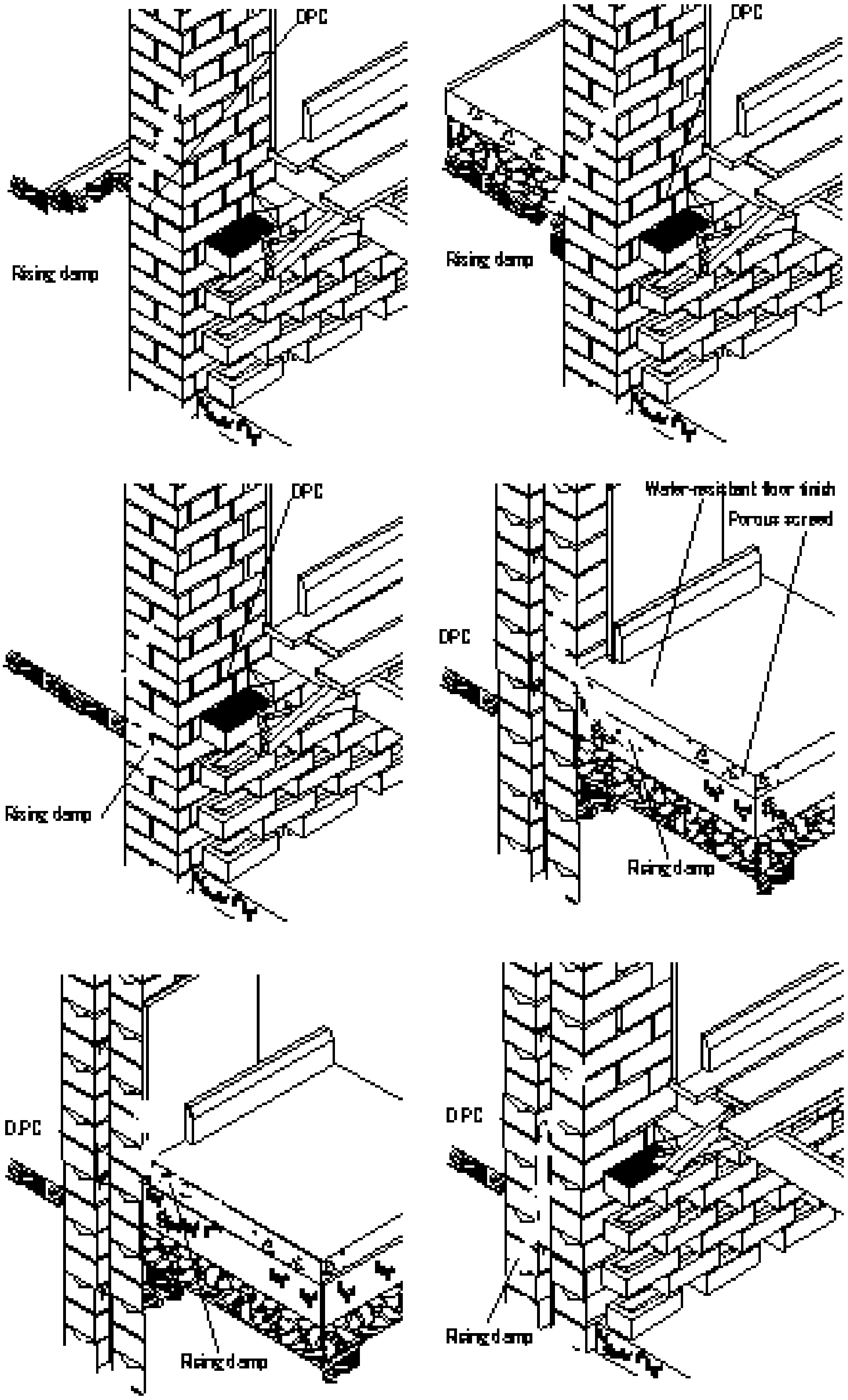

Figure 6.4 Bridging a DPC

damp but, where they meet an external wall, there can be a break in damp-proofing, particularly if the two DPCs are at different levels. As with other walls, the cause is most likely to be bridging of the DPC, caused by plastering, solid floors and abutting external walls. Tanking may be needed.

Range of possibilities

The remedies for rising damp are expensive, so correct diagnosis is absolutely essential before embarking on any treatment – Figure 6.5.

Dampness may result from leaking gutters or downpipes, plumbing faults or persistent spillages. In a new building, it may be caused by construction water. In refurbished property, water can be trapped in the fabric while the building is open to the weather. Soluble salts are usually contained in the fabric of buildings; since they give a high reading on a moisture meter, they can confuse diagnosis.

Salts can be a symptom of rising damp but they can also enter buildings in a number of other ways: from unwashed sea-sand or gravel, or additives used for frost protection or rapid setting of mortar or concrete. They can also be the aftermath of a previous dampness problem which has been successfully cured.

Many of these salts are hygroscopic: they can absorb moisture from humid air, causing damp patches on the wall. So residual salts can cause a dampness problem themselves, regardless of how they got into the building.

Using an electrical moisture meter

Rising damp must, by definition, encourage moisture to rise up the wall; a moisture gradient will be generated in the height and thickness of the wall.

Electrical moisture meters are valuable for carrying out a preliminary survey to identify areas that need further investigation. But they can give an artificially high reading when they are responding to salts in the surface and not to excess moisture. It is not uncommon for meters to give high readings on surfaces which are virtually dry, especially in old buildings.

To obtain more conclusive proof, the best method is to remove a small area of plaster and drill out samples of the bricks or blocks. These can give an accurate measurement of the moisture content of the wall and an indication of the effect of any salts. The drilling method and how to interpret the results are described on page 44.

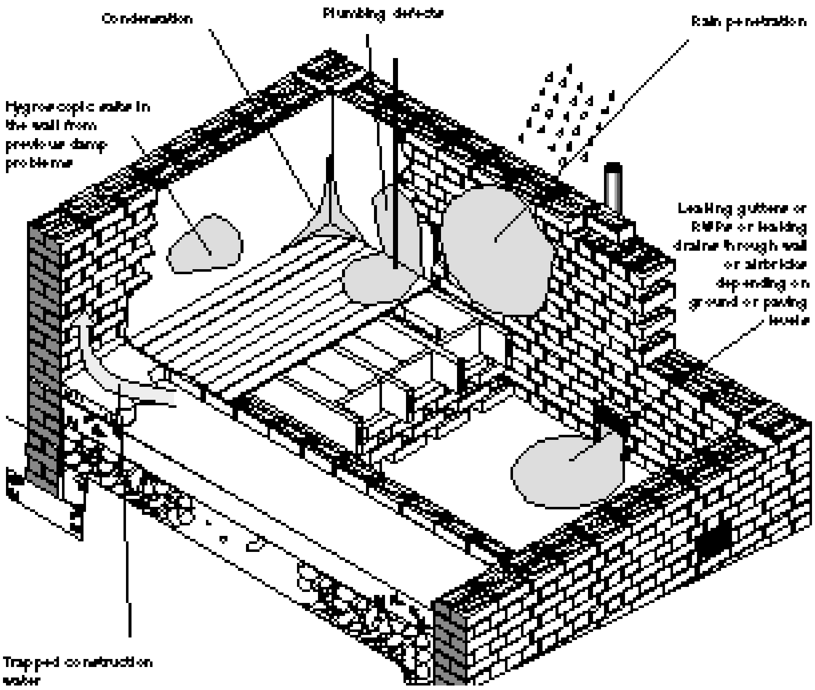

Figure 6.5 Alternative causes of dampness

Many cases have been reported to BRE where a householder has been told that there is rising damp in the walls of his house but where there is no visible damage to decorations. Diagnosis has usually been based on the use of an electrical moisture meter where just the surface of the wall is checked. If there is concentration of soluble salts at the surface, or condensation, the meter will give a high reading even though the walls may be dry in depth. Even if surface readings give an accurate picture, they do not indicate the amount of moisture in the depth of the wall, which must be established to confirm the presence of rising damp.

Where there is a problem there will be other more visible indications, such as a tidemark on the wall surface, peeling and blistering wall decorations, patches of efflorescence and possible rotting and splitting of wood due to wet or dry rot. There may also be a damp and musty smell. All this may be due to bridging of the DPC – Figure 6.5. Indications are that a large proportion of the walls that are claimed to have rising damp do not have any such problem. In the 1970s, BRE carried out an exercise with a major damp-proofing contractor to evaluate their system; great difficulty was experienced in locating sufficient properties that had a rising damp problem.

Drilled samples

A diagnostic method using drilled samples determines a value for the moisture content of masonry and mortar samples. If possible, the drilling should be from the mortar course: this is likely to have more moisture in it than the brick or stone. The samples can be tested on site using a carbide meter or taken back to the laboratory and weighed as found, then reweighed after drying. A further test for hygroscopicity establishes whether any salts contained in the samples are going to pick up moisture and lead to high moisture content values.

Generally, it is unusual for walls with moisture contents less than 5% wet weight at their base to have severe rising damp. Hygroscopicity caused by salts which may have migrated over the years into the plaster and decorations can, however, cause damage. It is useful to plot the results as a graph – Figure 6.6. The 'found' line is also referred to as the total moisture content (MC) and the difference between it and the hygroscopic moisture content (HMC) as the capillary moisture content. In this example, the additional moisture present clearly demonstrates rising damp. In BRE surveys, the samples are invariably tested in the laboratory to obtain the hygroscopic value. One pitfall to trap the unwary is that samples from aerated concrete blocks will have values between 5% and 7%; if the total moisture content is the same or lower, there is no capillary moisture and no dampness problem. If only rising damp is present, there should be a definite moisture gradient from the base of the wall tapering off to a point where the HMC becomes equal to the MC. There is often an increase in HMC at a level where the MC falls off although it is a matter of luck to sample the wall at that point.

It can also be useful to establish the moisture content of wallpaper, plaster and render, although the pitfall of drying plaster above 35°C must be avoided. The figure of 5% at the base of the wall (the floor wall junction) can be taken as an approximate guide to the presence of rising damp. However, even at this low level of moisture there can be a risk of damage to finishes and rot to any timber that may be in contact with the wall.

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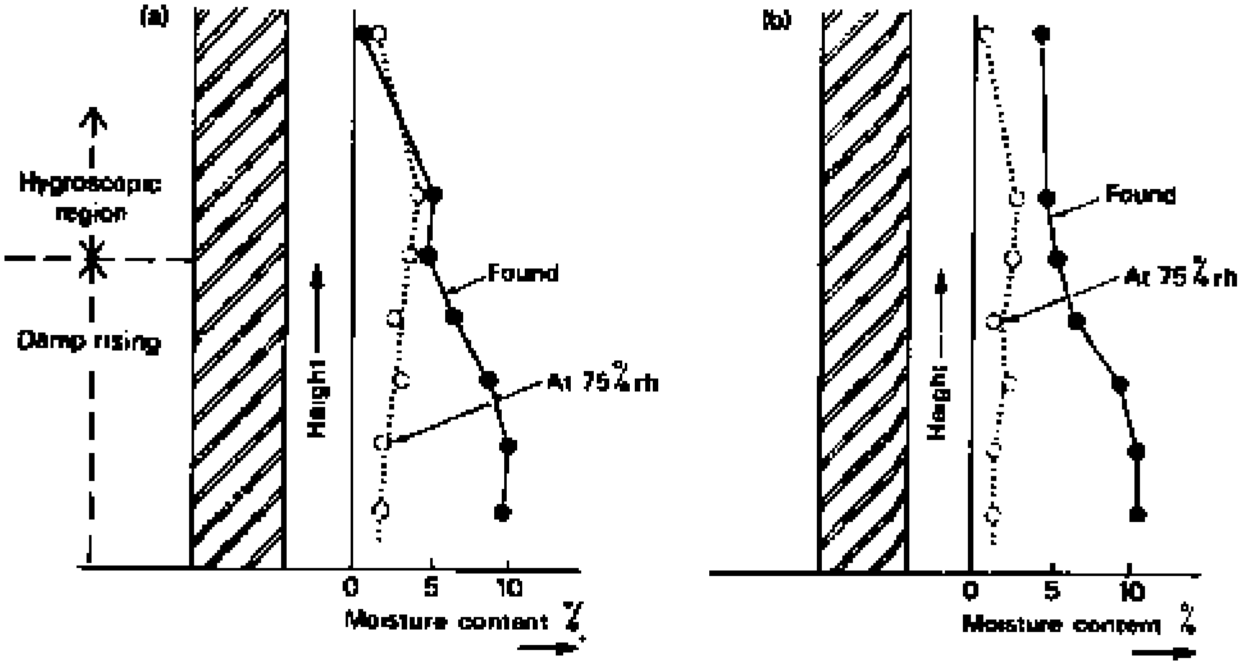

Figure 6.6 Results from typical cases

IN WALLS

The problem

Water which can potentially move from the ground through the base of the wall, or which can be conducted into the remaining parts of the structure from wet external leaves, must be prevented from doing so by effective damp-proofing. For new buildings, there are provisions in Building Regulations and British Standards for continuous DPCs between masonry in contact with the ground and the structure above, in order to meet the functional requirement. For traditional solid walls, DPCs have been compulsory in dwelling houses since the Public Health Act 1875.

Despite widespread concern, true rising damp is not very common. The treatment of rising damp tends to be expensive, so correct diagnosis is important. Alternative causes of the dampness should always be investigated.

Earth, clay and chalk walls

Rising damp is not usually a serious problem with earth walls. A remedial DPC can be installed in the stone or brick plinth if care is taken to avoid structural damage. Myths had arisen about ideal moisture contents of these walls; it has been suggested that cob should not be allowed to dry out too much but BRE has disproved this – see *Dampness in cob walls*. It does not matter how dry the wall is.

Solid masonry walls

Most solid-walled houses built between 1875 and 1950, and some older ones, were built with a DPC in the external masonry walls. Some DPCs may have deteriorated and failed but 'bridging' around the DPC is a far more common cause of rising damp. Buildings with a suspended timber ground floor generally have a DPC located at, or above, the level of the wall plate supporting the floor joists (typically 175 mm below finished floor level), while those with a solid floor will often have a DPC coincident with the top of the structural floor (typically 50 mm below finished floor level). This difference in

Figure 6.7 External rendering has bridged the DPC

Figure 6.8 Plaster has bridged the DPC – see also page 23

Figure 6.9 Bitumen exuding from a DPC

level of DPCs can promote bridging problems when solid floors are substituted for suspended floors, or where solid and timber floors abut (for example solid floors in kitchen or scullery and timber floors elsewhere).

Damp-bridging of DPCs is a common problem caused by external rendering – Figure 6.7, internal plastering – Figure 6.8, raised external ground, solid floors and bonded-in external walls (such as screen or boundary walls). Previously installed remedial DPC systems may be damaged or ineffective; problems are commonly encountered with osmosis, evaporative tube and poorly installed chemical systems. Failure of physical DPCs, particularly those formed by engineering bricks or overlapping slates, may result from breakdown of the bedding mortar. Some bitumen felt DPCs become brittle with age; some can soften in hot conditions and exude from the wall under pressure – Figure 6.9, though this seems to make little difference to performance unless actual fractures occur.

Cavity masonry walls

Few buildings constructed with cavity external walls will have been constructed without a DPC of some kind so, if rising damp is suspected, the cause is likely to be breakdown or bridging of the DPC rather than its omission. Bridging is much more common than failure, as most DPC materials have a long life in the protected inner leaf of a wall. The outer leaf should also have an effective DPC but localised failure here is unlikely to cause dampness internally in the dwelling.

With timber ground floors, the DPC in the wall would normally be below the level of any timbers but with solid floors the DPC may be at any level below the finished floor. With solid ground floors, an overlapping link between the floor DPM and the wall DPC is a key detail in preventing rising damp; there is often no effective linkage; in older properties there may be no floor DPM.

Rising damp can occur if a cavity wall DPC is bridged by mortar droppings which accumulated during construction at the base of the wall – Figure 6.10 – or even by vandalism: Figure 6.11 shows a short piece of scaffold board that has been dropped into the cavity.

Bridging of DPCs is commonly caused by external render, internal plaster, external ground, raised steps, solid floors and external works (such as screen or boundary walls) bonded to or abutting the cavity wall.

Is it really rising damp ?

- ❒ Are there any leaking or sagging gutters or down-pipes? Clues are green stains on the brickwork, or dampness at low levels on indoor surfaces.
- ❒ Is there run-off from sills below large glazed areas or below weatherboarding or non-absorbent cladding? If sills don't project enough, they can feed a lot of water into the brickwork below.
- ❒ Is the building less than five years old? If so, the dampness is probably due to construction water in walls, floors and screeds.
- ❒ Are there leaks from plumbing, waste pipes or central heating systems, including pipes buried in the wall?
- ❒ Is it condensation? Persistent condensation on the perimeter of solid floors can wick up into the plaster and produce a stain that looks like a rising damp tidemark.
- ❒ Has there been any recent flooding, or leaks from a washing machine or dishwasher?

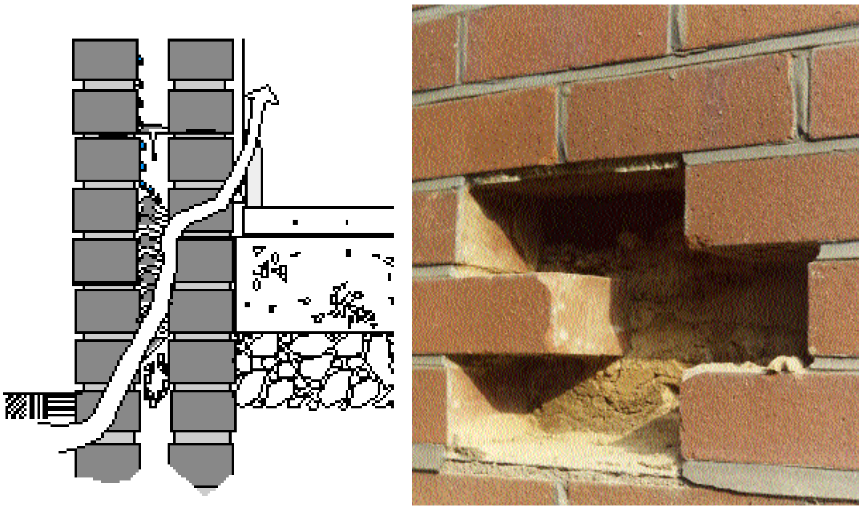

Figure 6.10 Common causes of rising damp

Figure 6.11 Vandals dropped this piece of scaffold board down the cavity

Accumulation of dropped building mortar at the base of the wall cavity can cause bridging. As with solid walls, previously installed remedial DPC systems may be ineffective, particularly osmosis types, those relying on evaporative tubes, and poorly installed chemical systems.

Materials for DPMs and DPCs

Since most forms of masonry allow the passage of moisture upwards from wet ground, some form of protection is needed against rising damp. The moisture barrier usually consists of a membrane laid at a suitable height above the splash zone, and linked with the horizontal DPM. The ideal material for a DPC would be completely impervious to water in both liquid and vapour forms. In practice, not all materials have been effective.

Two courses of slates laid in cement mortars to break joint, and two or more courses of engineering or ‘blue’ bricks, have been widely used in the past, especially in one-brick solid walls; in many cases they have been effective, especially where the vertical joints were left unfilled. However, the materials in the units themselves are more resistant to rising damp than the mortar used to joint them, and it has become customary (though arguably unnecessary) to make sure that the damp-proofing is still effective by adding a replacement.

All materials should be able to accommodate slight movements in the wall. Sheet materials must be carefully jointed, usually achieved by lapping at least 100 mm. The weight of the masonry wall is usually sufficient to seal the lap without additional jointing materials. The organic felts in some DPCs may have perished but this does not necessarily mean that they become ineffective provided they are not disturbed by subsequent movements.

Bituminous felt DPCs can be squeezed out slightly under pressure, especially in hot weather, but the amounts exuded are usually insufficient to compromise their performance and durability. They are relatively ineffective against horizontal displacement, in effect providing a slip plane on which the walling can move quite easily. Polyethylene is common now but plain sheet has low shear bond; the newest types have a moulded pattern to improve shear and flexural bond. Higher performance DPCs are often formulated from a blend of pitch and polymer; they have good resistance to squeezing.

New build

Building Regulations require a DPC at the base of walls. In cavity wall construction on a concrete slab, common practice is to use the inner leaf as permanent shuttering and place the DPC on top of this level of masonry. The screed has to be isolated by a vertical DPM otherwise drying of the screed into the wall may result in rising damp. The DPC in the outer leaf must be at least 150 mm above the outside ground level. If the site slopes, the DPC must be stepped. There are special arrangements where radon is an issue.

Treatment

Treatment for rising damp involves either curing the source of the problem or masking its effects. Curing at source is normally preferable and, as a first step, the building should be inspected closely to ensure that an existing DPC has not been bridged. Remove earth that has piled against external walls and cut back external render and internal plaster to just above the DPC line. Improving the land drainage at the base of the wall may also help. In old houses with suspended wooden floors, the DPC usually runs in the mortar course at the top or bottom of the ventilation grilles set in the external walls. Adequate sub-floor ventilation is most important so clear the grilles of any obstruction. Check suspended wooden floors for wet or dry rot. They may need extensive preservative treatment and cutting out of any decayed timber. In many of these situations, the original DPC will have been completely effective, a fact often overlooked when considering treatment.

The choice of DPCs

The methods for installing a new DPC are described generally as 'traditional' (the insertion of a physical DPC) or 'non-traditional'. We strongly recommend that you consider non-traditional methods only if they have been awarded an Agrément or other third-party certificate. Chemical injection is the only method that currently satisfies this requirement and is the only method which BRE considers suitable where it is not possible to insert a physical DPC. Physical DPCs can only be placed in brickwork or coursed stonework; random flint walls or rubble infilled walls are not suitable. Unusually thick walls can rarely be treated and it can be dangerous to attempt installations of this type for structural reasons if the walls have settlement cracks. Chemical injection systems can be used in most types of structure, although flint walls and rubble infilled walls can be difficult to treat.

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Physical DPCs

Ineffective DPCs are often traceable to bridging by porous materials in contact with the wall. There may be soil on the outside, with a concrete floor on the inside. Treatment can take the form of either digging away the offending material to leave an air space, or of inserting a vertical DPM to prevent contact between the porous material and the wall above DPC level.

The only certain way of introducing an effective DPC is to insert a new physical membrane. Techniques have improved over recent years and cutting an old lime mortar bed joint through the entire thickness of a 225 mm (9 inch) solid wall should present no problems.

A tungsten-carbide tipped chainsaw is usually used and the cut made in short lengths of about 1 m at a time. The membrane is loaded with mortar and inserted; temporary wedges in the remaining gap prevent settlement. Eventually, the cut is back-filled with more mortar. In the standard solid 225 mm brick wall, the entire thickness of the wall can be cut from one side taking care that all water and gas pipes and electrical wiring are moved out of the way. Regardless of type, a new DPC should, if possible, be inserted below the level of an existing suspended wooden floor and as close as possible to the top of the screed of an existing solid floor. Conditions vary enormously in this respect and usually some compromise is necessary in the siting of a new DPC. Any gap between horizontal DPC and solid floor membrane should be closed if necessary with a tanking type of treatment.

The advantages of the physical techniques are that the membrane can be extended internally to form a vertical DPC between any solid floors and the horizontal course, and the membrane (usually flexible black polyethylene) is resistant to all acids and alkalis normally encountered in building materials. The disadvantages are cost, time taken and the disturbance created.

Chemical injection systems

These can be used in most types of structure, although rubble infilled walls can be difficult to treat successfully. There are many installers operating commercially, but specifiers should consider using only those who are members of the *British Wood Preserving and Damp-Proofing Association*.

The systems involve inserting specially formulated products into closely spaced holes drilled in brick or mortar courses along the DPC line. Their efficiency depends on how well the product penetrates the damp structure and its subsequent successful curing. Treatment must be carried out by drilling successively to different depths in anything other than a single leaf wall, or by injecting from both sides of the wall, to ensure penetration through the entire thickness.

Methods of injection are covered in BS 6576; suitability of injection products and the method of installing the remedial DPC are covered by BBA certificates.

Silicone or aluminium stearate water repellents are either injected at high pressure or transfused into the wall under gravity or at low pressure. High pressure systems are generally used with solvent-based silicones and aluminium stearates; transfusion methods are limited to the application of water-based silicones basically in the form of the water-soluble sodium methyl siliconate. The water repellents are pore liners rather than pore blockers and so allow the passage of some water vapour whilst preventing the rise of liquid moisture. The repellents are not intended as a damp-proof barrier against a substantial positive pressure of water and are not suitable in basement areas subject to high water tables and penetrating damp.

Another limitation is that the repellents commonly used are not durable in the long term in highly alkaline conditions and their use is not recommended in newer buildings containing relatively fresh cement mortars. Evidence suggests that high alkalinity is not a problem in older buildings with well weathered lime/sand mortar joints, unless perhaps the walls are exceptionally thick. Once injected, various curing and solvent evaporation processes occur; these result in polymerisation reactions and weak bonding of the cured repellents to the material substrate, serving to keep the injected and cured material in place in the presence of active rising damp.

The success of chemical injection systems depends on the efficiency of the fluid penetration of the damp structure. The repellents are injected or transfused into closely spaced holes in brick or mortar courses along the DPC line. Treatment must be carried out at different depths in anything other than a single-leaf wall to ensure penetration through the entire thickness of the structure – Figure 6.12. The transfusion methods carried out at low pressures with aqueous repellents should, in principle, penetrate more effectively than high pressure systems since they depend almost entirely on diffusion processes which are the only physical processes that can eventually give complete penetration. Since the diffusion processes are extremely slow, there is a danger that the slow-curing aqueous repellent can be carried away in the presence of active rising damp before an effective DPC is formed. In practice, it is unlikely that an injection treatment can create a completely impervious barrier in a truly damp wall. The success of these systems in treating a case of genuine rising damp lies in reducing the moisture flow up the wall to an extent that the problem disappears.

Figure 6.12 Bricks shattered by careless drilling

Figure 6.13 No satisfactory explanation has been found for the line of injection holes across the window head.

All injection techniques are likely to be less effective in non-uniform materials and where moisture contents are quite high at the injection level. Fortunately, in practice, the latter condition is rare: evidence suggests that most cases of genuine rising damp involve low enough moisture levels for an injection technique to have a significant effect. As rising damp is a seasonal effect, injections are best carried out in late summer when water tables are at their lowest and the walls are relatively dry – see also *Injection systems for damp-proofing*.

Recent new products are known generically as creams or gels. The cream is a concentrated viscous silane / siloxane emulsion, inserted by a gun through 12 mm diameter holes drilled at the base of the perpends and at intervals of up to 120 mm along the mortar coarse. No carrier fluid is used so the curing process is claimed to be more rapid. BBA Certificates are available for some products.

Electro-osmotic systems

There are two types: active and passive; neither has been approved by a recognised laboratory. By far the greater number of systems are of the passive kind, where there is no external source of electricity. They have always been something of a controversial issue. On theoretical grounds, it remains a mystery as to how they can work; their effectiveness has not been demonstrated in the laboratory and field evidence is disappointing.

Active electro-osmotic systems use an external source of electricity. BRE has no evidence to suggest that the two types behave differently in practice, though some of the active systems may be rather more susceptible to the effects of mechanical damage and electrochemical corrosion.

Installation is quick and relative simple in practical terms and involves, in principle, the installation of a continuous electrode system in walls at DPC level. The system is either earthed through earthing rods set in the ground (passive types) or a potential is applied between DPC and earth or between DPC and another set of wall electrodes set at a different level (active types).

The claim for passive systems is that a damp wall contains an electrical potential and the earthing of this potential causes dampness to fall. It is true that the existence of electrical potentials in a damp wall can be demonstrated. However, where such potentials are caused by the movement of moisture and salts in the first place, earthing the potentials might be expected to increase rather than reduce the upward flow of moisture and salts.

The installations inspected by BRE were coupled with a replastering system which provided a good barrier to moisture; it is suspected that claimed successes for the system relied heavily on the render and plaster system. As far as is known, the passive system is no longer available, though many thousands of installations still exist. Active systems do attempt to make use of true electro-osmosis: the movement of moisture through finely pored materials under the influence of an electrical field. Site experience is not encouraging and, again, the systems rely on the assistance of a plaster system to contain moisture.

Of the complaints about electro-osmotic damp-proofing that BRE has investigated, some have involved condensation problems that the installation could not be expected to cure; in others there appeared to be at least a partial failure of the system, suggesting that electro-osmotic systems are not effective in preventing rising damp in walls in all conditions.

Porous tubes

Porous ceramic tubes were an early attempt to produce a method of combating rising damp; in the 1920s this technique was marketed by British Knapen. Tests were written up in the Building Research Station Annual Report of 1930: '*There have been tests to determine the effect on the rate of evaporation of moisture of inclined porous clay tubes set in specimens of brickwork and natural stone. Laboratory experiments and field tests have been carried out. Results indicate that no useful increase in the rate of evaporation of moisture results from the use of these tubes.*'

It must be true, of course, that increasing the evaporation rate from a wall by boring holes can only help to reduce the level of rising damp. The function of the tubes is, however, not clear. It is claimed that the tubes draw moisture to them but, if so, they must also draw salts. It is difficult to see how any significant evaporation can take place. If the salts are hygroscopic, the tubes could perhaps feed moisture from the air into the surrounding masonry when external humidities are high. Also, for the tubes to draw moisture from the surrounding structure, they must be more finely pored than the surrounding material. In general terms, the more finely pored a material, the less permeable it is and the lower the evaporation rate from it, unless the material is virtually saturated. In that case, evaporation would take place mainly from the surface and the nature of the material would be of little importance. A couple of installations have been examined but were found to still have effective physical DPCs at a lower level than the new porous tubes.

Replastering as a solution

A dampness problem usually leads to damaged internal plasterwork and a subsequent need for some replastering as part of remedial treatment. The main requirement of any new plastering is that it should act as a barrier to residual salts and moisture in a wall. Ideally, it should have as high a vapour permeability as possible to help the evaporation of residual moisture and should be weaker than the background to which it is applied.

Rich cement-based undercoats are effective moisture barriers in their own right but their vapour permeability is low and their strength high. Tests on a typical 1:3 cement:sand undercoat finished with gypsum plaster have shown that the finished surface remains completely dry with an evaporative air flow across it, even with water under a positive pressure behind the system. Although a washed and well-graded sand was used, no waterproofing additives or workability aids were incorporated. Results of this sort demonstrate the possibilities of a basic cement:sand system as a moisture barrier, although the disadvantages of high strength and low vapour permeability remain. High strength may preclude their use direct on very weak backgrounds where lathing is needed to provide a base for the plaster.

Figure 6.14 Replastering did not contain an unsuccessful DPC injection

Renovating plasters should be used only if the cause of the dampness has been removed and if they have an Agrément Certificate.

Ordinary gypsum based undercoats are not effective moisture barriers and should not be used as such.

Dry lining

Rather than attempt to cure the problem the effects can simply be masked. Where treatment of the source is virtually impossible, for example if the insertion of a DPC is too expensive, the alternative is to cover the effects of damp by using some kind of wall lining technique, such as plasterboard on battens or a proprietary lathing system. This has the fundamental disadvantage that such remedies will cut down the evaporation rate from a wall and cause the dampness to rise further. It may be possible to avoid covering the whole wall by terminating the battening at a dado rail. This was common before the introduction of DPCs in external walls and can still be found in many old cottages.

The likelihood of this treatment being a success is best assessed by observing the height to which moisture has risen in the past. The new lining should cover all the affected area and go at least 150 mm higher – more if the finish of the lining or the external surface of the wall is impervious. Ventilating the spaces between wall and lining reduces the risk of excessive rise of moisture in the wall as a result of reduced evaporation from the covered side.

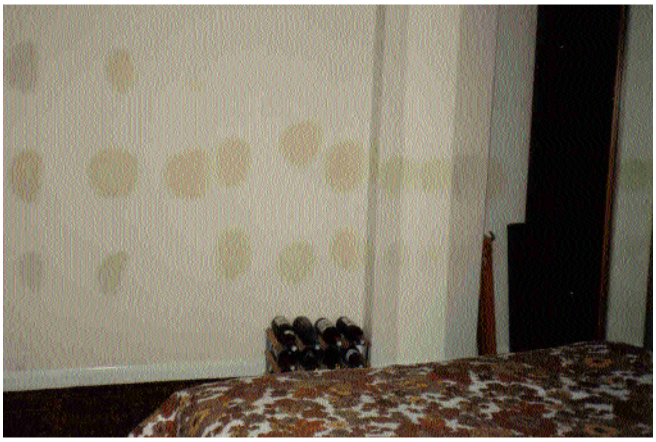


Figure 6.15 Plasterboard on a wall where rising damp has not been cured

One widely-used product was a pitch fibre material corrugated into dovetail keys. Air circulation behind the sheet material encouraged drying of the wall. The finish could be either a render or plasterboard. Products available now are based on a high-density extruded membrane finished in the same way. Such remedies provide a dry interior surface but cut down the evaporation rate from a wall and may push up dampness levels. Rising damp is, after all, a dynamic equilibrium between the rate at which water is fed to the structure via the soil and the rate at which it evaporates away via airflow across the surfaces. Increasing the height and intensity of the dampness could pose serious long-term dangers to such wooden components as window frames.

Monitoring of the behaviour of a replacement DPC

If, after installation, there are doubts about the effectiveness of a damp-proofing system, the system may have to be monitored. If possible, obtain readings above and below the damp-proofing system, taking sets of readings over a period of time. In interpreting the results, remember that in the absence of a DPC walls tend to become wetter in the winter and drier in the summer as the water table moves up and down. A fall in moisture content readings at any one level above the damp-proofing system that occurs between summer and winter is good evidence that the system is having an effect. Conversely, a fall in readings between winter and summer is to be expected and is not evidence of success. Indeed, if the summer readings are the same or higher than those in the previous winter, the damp-proofing is not effective.

Replastering following a new DPC

After installing a new DPC, some replastering will be needed as part of the treatment. When a DPC has been inserted in an existing wall, the wall and plaster above damp-proof level may be contaminated with deliquescent salts from the ground. If the new DPC is effective, removing all plaster showing signs of contamination should be a sufficient safeguard against persistent dampness arising from this contamination.

Damp walls stay damp above DPC level for some time; new plaster must resist this dampness, and the passage of water and salts to the inside surface. It should have as high a vapour permeability as possible to help the evaporation of residual moisture and, ideally, it should be weaker than the background to which it is applied.

Remove old plaster to at least 300 mm above the highest level at which dampness is detectable, and always at least 1 m above the level of the

DPC. Remove residual dust and loose particles and rake brickwork joints to a depth of 10 mm to provide a key.

Use a 1:3 cement:sand undercoat, with a washed, well-graded sand to BS 1199, with a gypsum plaster finish. Alternatively, use one of the proprietary remedial plaster systems which has a third-party certificate. Gypsum-based undercoats (other than remedial plasters) must not be used as they can accumulate hygroscopic salts from the wall. For a weak background, choose the remedial plaster system carefully. In all cases, plastering must comply with the DPC installer's specification.

Check the proposed remedial work to ensure that the new DPC will not be bridged, for instance by new screed or plaster, and that new plaster will not be in contact with a new screed.

Impervious linings

Applying an impervious lining where there is rising damp is sure to drive higher the moisture in the body of the wall. How much higher depends upon the porosity of the opposite surface of the wall, which will then become the only one from which evaporation can occur.

This weakness of the impervious lining treatment must be appreciated fully before deciding to adopt it. Other features mentioned in the section on rain penetration, such as possible loss of adhesion and special requirements for decorating renderings, are equally relevant here and must be considered.

Providing an evaporating area

It is sometimes possible to expose parts of a wall below floor level so that much of the rising damp can evaporate before reaching the decorated part of the wall. This may only involve clearing earth from the bottom of the wall on the outside; sometimes it may involve cutting down through a solid floor and inserting a grating at floor level to cover the hole.

FLOORS

The problem

Rising damp in floors is much less common than in walls; it is often confused with excess residual construction moisture, a common problem in new buildings. In both cases, symptoms are damp patches on porous in-situ flooring, rucking, curling and loss of adhesion of sheet and tile flooring, or expansion and disruption of woodblocks. Lifting and loss of adhesion can also be caused by excessive use of cleaning water.

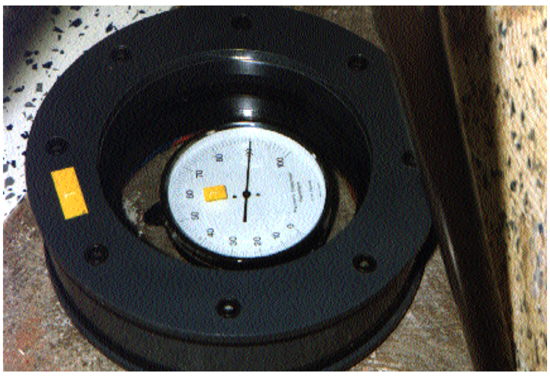


Figure 6.16 Hygrometer box, with thermally insulated lid removed, sealed to a screed on which rubber flooring was bubbling. The reading is 90% RH

Not all floors are subject to dampness problems; those in contact with the ground in basements or ground floors will clearly be most at risk and measurements should be made to determine the scale of any defect – Figure 6.16. But the risk should not be discounted altogether with suspended floors, particularly at bearings on external walls. Information from Housing Association Property Mutual indicates that about one in ten of newly built dwellings inspected by them during the early 1990s were not adequately protected against rising damp.

Characteristics of failure

The form of any failure depends on the flooring material and the adhesive. Such flexible sheet materials as PVC, linoleum and rubber commonly curl or blister, while tiles made from similar materials curl or tent at their edges. The basic defect in most cases is some expansion of the flooring material accompanied by loss of adhesion from the base. Often, any moisture expansion is aggravated by stretching of the flooring material by traffic after adhesion has been lost. Many adhesives soften in the presence of moisture. The adverse effect on flooring and adhesive is often made worse because the moisture is highly alkaline, having derived alkalis from the cement in the concrete base or screed. Timber block and strip floors fail by disruption brought about by expansion of the wood following moisture take up. Carpets and other textile floorings may become debonded and ruck because the adhesive is softened. There is also the possibility that some fibres or backings will rot, especially if they are organic.

Sources of moisture

There are four main possible sources of moisture in floors to consider:

- excess constructional water;
- moisture from outside;
- condensation;
- spillages and leaks.

Excess constructional water

Water is added to a screed or concrete mix to make it workable, over and above that required for hydration of the cement. The additional quantity usually amounts to between half and two-thirds of the water used for mixing. This excess must be allowed to dry out before fixing such impervious floorings as PVC sheet, or such moisture-sensitive floorings as wood or textile – see figure 6.17 and Table 7.1 in Chapter 7.

Floors without a DPM may perform satisfactorily in combination with a moisture-permeable finish and a draughty dwelling. However, the reduced ventilation rates in refurbished dwellings and, particularly, adding a moisture sensitive or impervious floor finish may result in rising damp becoming more apparent and which may therefore demonstrate the need for a DPM. Floor slabs less than 100 mm thick will be more vulnerable to rising damp,

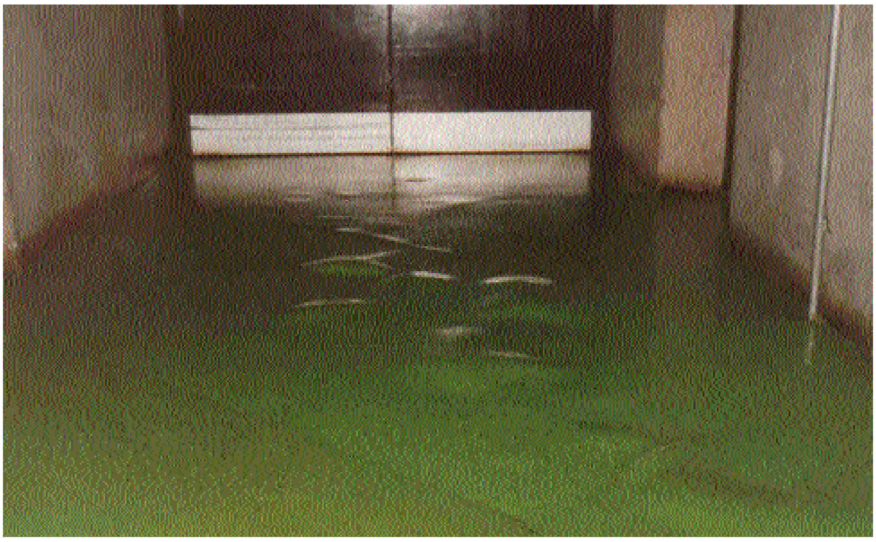


Figure 6.17 Dampness in this basement slab has softened the adhesive and allowed the rubber flooring to lift and bubble

Figure 6.18 There is no effective DPM in this ground bearing floor

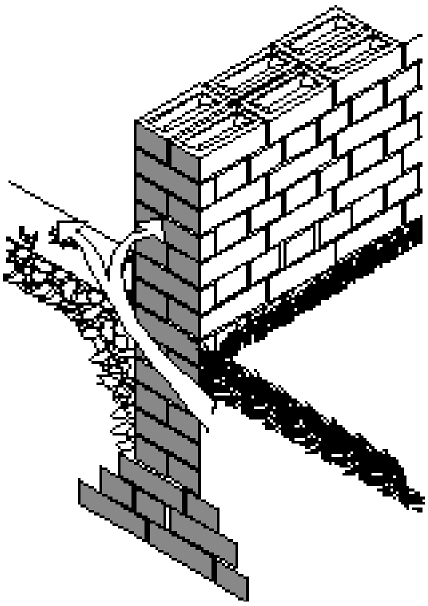


Figure 6.19 An effective vertical DPM is absent at the edge of the slab

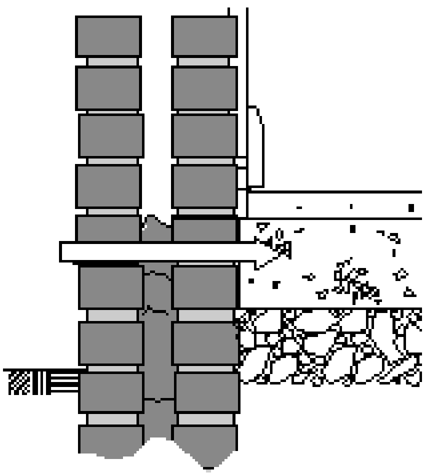


Figure 6.20 A thermal bridge at the perimeter of the building

particularly if the concrete is of low quality. Floors with an asphalt DPM laid above the structural floor as a screed are vulnerable to damage by building works and may require specialist repair or alteration. It may be advisable to protect asphalt DPMs during rehabilitation work. When considering alterations, you will need to consider how to achieve continuity between DPMs and DPCs.

The following points have often been observed during site visits:

❒ dampness may penetrate a floor slab due to the omission of an effective DPM – Figure 6.18.
❒ localised dampness may result from inadequate laps, punctures in the membrane or discontinuities at service pipes;
❒ brush-applied membranes may have inadequate thickness or missed areas;
❒ dampness at perimeters may indicate inadequate linking of floor DPM and wall DPC: don't confuse this with condensation due to thermal bridging – Figures 6.19 and 6.20.
❒ asphalt screeds may have cracked or may be discontinuous where previous works have removed fire hearths or partitions or provided service routes.

Excess constructional water in concrete bases and screeds – Figure 6.21 – must be allowed to dry out before moisture-sensitive floorings (such as carpets, PVC, timber) can be laid A sand/cement screed 50 mm thick laid on a DPM should be left for about six weeks; thicker slabs need much longer.

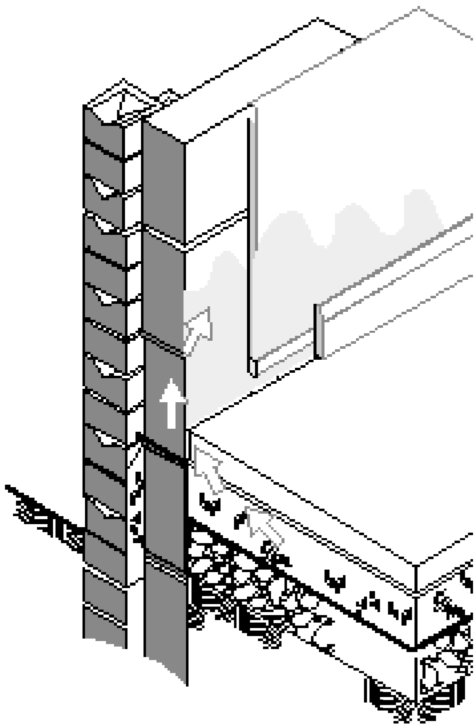


Figure 6.21 Construction water from the slab can seem like rising damp

There are proprietary screed systems which dry much quicker than conventional screeds but they are of little value if laid on concrete bases which are still wet. It is rarely possible to allow sufficient time for concrete bases and screeds to dry to a state which will not induce moisture movement in moisture-susceptible decks such as chipboard. A vapour control layer should, therefore, be placed between the base and the chipboard. Where insulation is interposed between chipboard and base, it is better to place the vapour control layer on top of the insulation – the warm side. With some prefabricated panels, where the chipboard and insulation are stuck together at the factory, this is not possible so the vapour control layer should be placed below the panel.

The vapour control layer should be polyethylene (not less than 500 gauge, preferably 1000 gauge). For bases laid directly on the ground, the vapour control layer is in addition to the DPM.

Moisture from outside

Water which can potentially move from the ground through the base hardcore and concrete, or which can be conducted from wet external leaves of walls to the edges of sensitive construction, must be prevented from doing so by effective damp-proofing. This is crucial in basement floors with high water tables where a tanking sufficient to withstand the hydrostatic pressure is required. Here, it may be necessary to ensure that sufficient mass is available in the building above to prevent flotation of the basement. We cannot here give comprehensive recommendations for the positioning of such damp-proofing, but merely draw attention to commonly occurring deficiencies.

If the base is dry when the flooring is laid, moisture from this source usually takes many months to rise, and failure of the flooring can still occur a year or two later.

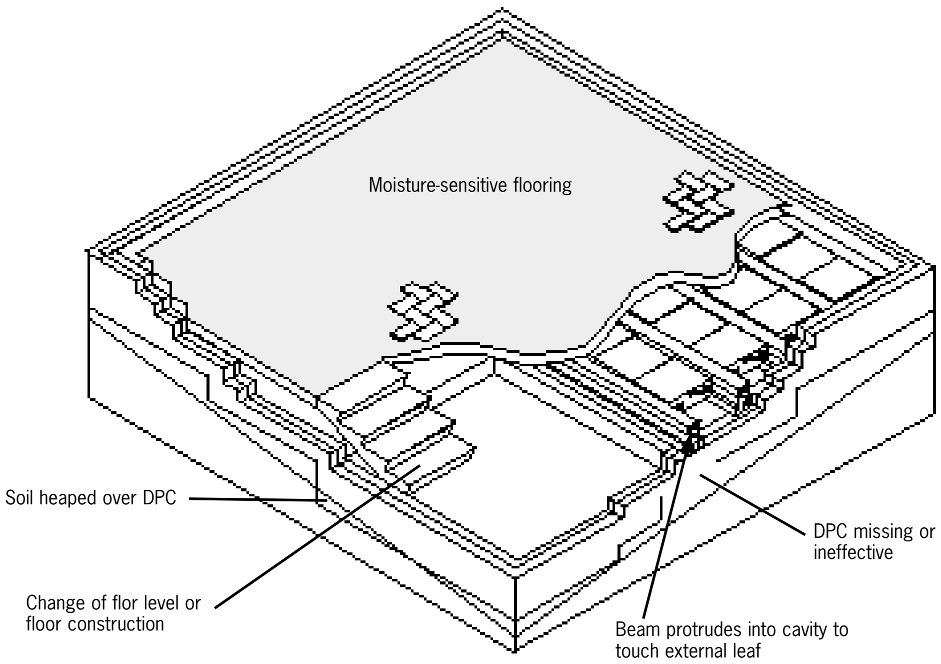


Figure 6.22 Routes for moisture from the exterior to sensitive floor and flooring materials, even where the DPM is present and effective

Condensation

Condensation may sometimes look like rising damp, and must be investigated before rising damp can safely be diagnosed.

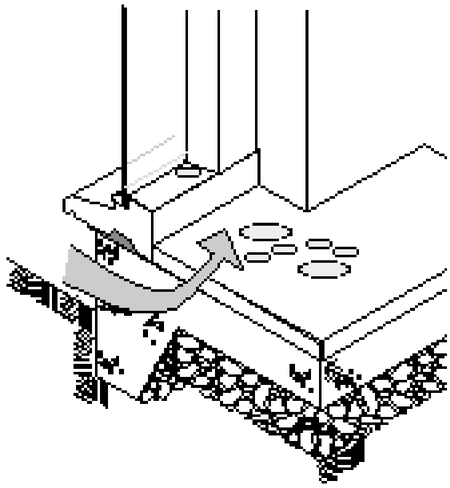


Figure 6.23 Condensation risk on an exposed edge of an uninsulated floor slab adjacent to external walls

Condensation will occur when the surface temperature of the floor is below the dewpoint temperature for a sustained period of time. The dewpoint varies according to the air temperature and the relative humidity. Condensation occurs when the relative humidity of the air in direct contact with the cold surface rises to 100%. The two most common situations on floors are:

- ❒ Adjacent to exterior perimeter walls where there is a loss of heat from the floor to the outside via a thermal bridge – Figure 6.23.
- ❒ On floors with high thermal capacity where the floor temperature is unable to follow rapid changes in air temperature; they can often be below the dewpoint. This particularly affects floors in warehouses or the concourses of railway stations when a cold spell is followed immediately by a warm front.

The presence or absence of an effective vapour control layer (VCL) in the structure should help to diagnose rising damp or condensation. It is not normally necessary to provide a vapour control layer in floors to prevent water vapour ingress downwards, though it may be required for special reasons, for example to prevent water vapour rising through a construction to affect sensitive materials.

Of the various terms that are used, ‘vapour control layer’ is preferred to either ‘vapour check’ or ‘vapour barrier’, to emphasise that the function of the layer is to control the amount of water vapour entering the construction. As the achieved vapour resistance depends at least as much on workmanship as on the design and integrity of the materials used, it is not realistic to specify a minimum vapour resistance to be achieved for the layer as a whole; for the material to qualify as a VCL it should have a vapour resistance greater than 200 MNs/gm.

Plastics films are the most usual materials for a VCL in a floor construction. Keep joints to a minimum, either overlapped a minimum of 100 mm and taped, or sealed with an appropriate sealant; they should be made over a solid backing. Repair any tears and splits. Keep penetrations by services to a minimum and seal them carefully. Draughts of moisture laden air through gaps in vapour control layers are more significant than normal still air diffusion through materials even if there are splits in the vapour control layer; it is, therefore, much more important to provide an air seal than to take elaborate precautions for making a total seal of the VCL.

Spills and leaks

Spills and leaks are frequently the cause of dampness in investigations by BRE – Figure 6.24. Using too much water during cleaning has also been known to cause surface breakdown of sensitive floorings and even to accumulate on DPMs. The water, often carrying residues of corrosive products, passes through joints between impervious coverings, or at the edges of the material under skirtings or external door thresholds.

Figure 6.24 A plumbing leak has caused deterioration of the chipboard deck laid on expanded polystyrene. An unsealed joint in the polyethylene VCL allowed moisture to rise to the surface

Excluding rising damp

Rising damp can occur in older buildings, many of which don't have DPCs in external walls. Fortunately, many of them have suspended floors, only the perimeters of which are at risk. BS CP 102 was for many years the authoritative source of information on construction standards relating to rising damp, and has even now only been partially replaced by BS 8102 and BS 8215.

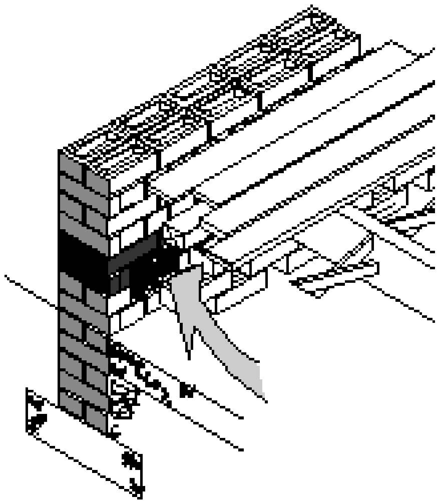
DPMs

The DPM in a groundbearing floor slab can be laid in a variety of positions. With a fully bonded screed, the DPM must be laid under the slab; for an existing screed, a surface DPM can be used. The exception is an epoxy DPM, which can act as a bonding agent and can be laid as a sandwich.

Existing dwellings being rehabilitated will often have solid floors which do not have DPMs. Many houses built between 1950 and 1966 had floors which were finished with thermoplastic tiles stuck down with a bitumen adhesive. This system tolerated moderately damp conditions, so it was common not to provide a DPM in the base. If the flooring is removed, make an assessment of the moisture condition of the base as a DPM may be required before laying moisture sensitive flooring.

Moisture-sensitive materials, such as chipboard, other timber products, flexible PVC, linoleum, or cork tiles, should be laid only on a floor which has a satisfactory DPM. In a survey of rehabilitation in progress, faults included failure to provide a DPM, even in vulnerable situations, and unsatisfactory linking of DPMs with DPCs.

Where timber ground floors have been replaced by solid floors, BRE has been commissioned frequently to investigate rising damp showing on the external, usually solid, wall – Figure 6.25.



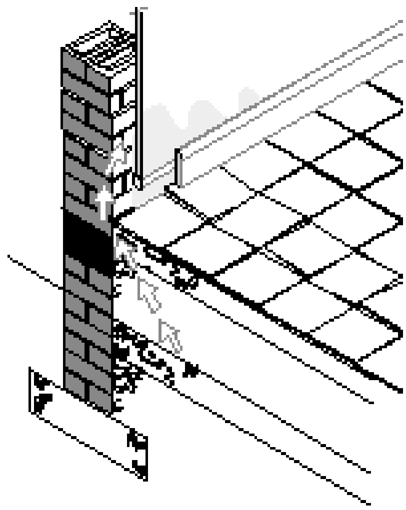


Figure 6.25 There is a risk of rising damp where a solid floor replaces a suspended floor, unless an adequate DPM is installed
(top) before replacement ...
(bottom) ... and after replacement

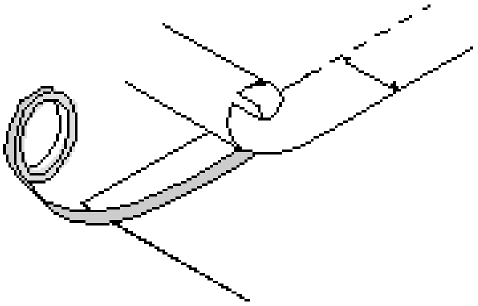


Figure 6.26 Sticking the overlap of a DPM

DPMs must be continuous, above or below the base and linked to the DPC in the walls. Polyethylene below the base should be at least 300µm or 250µm if the product has a BBA certificate or is to the PIFA standard. Where sheet material DPMs are being laid below replacement floor slabs, it is important to ensure adequacy in the joints between sheets. The preferred method of forming the joint is to overlap the sheets by at least 150 mm, and stick the joint with double-sided pressure-sensitive tape – Figure 6.26.

If welts are used to join sheets, construct them in a four-stage operation – Figure 6.27. Hold the welt flat until the slab or screed is placed.

Service entry points can be a source of penetration of damp – Figure 6.28, mainly in buildings built in ground with high water tables, or where persistent dampness is present in the hardcore. When replacing slabs in such locations, it is worth taking care with damp-proofing service entry points – Figure 6.29.

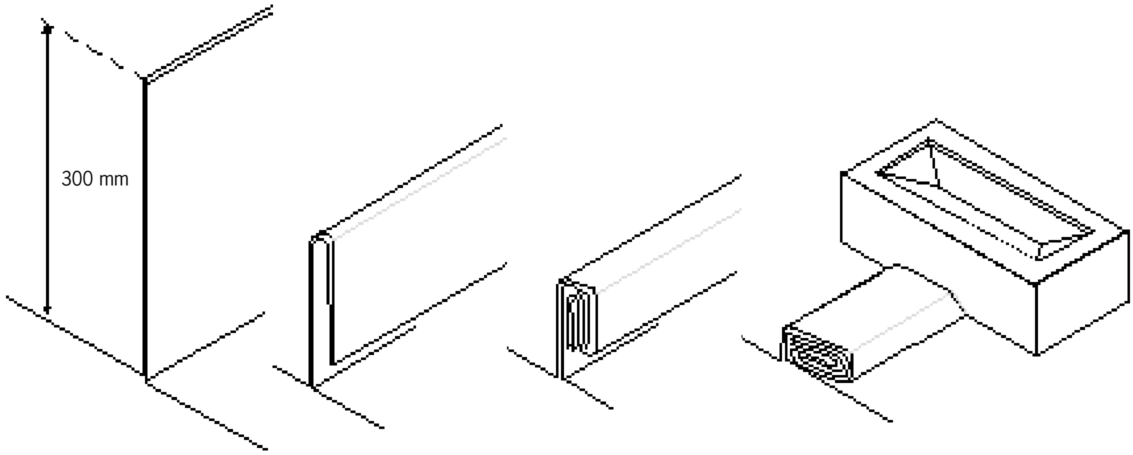


Figure6.27 Forming a welt in a DPM

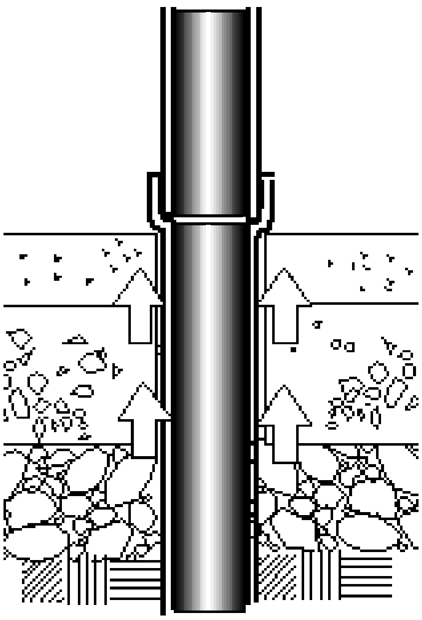


Figure 6.28 Service installations are the most likely points at which rising damp will show

Brush-applied and hot-poured materials are available for membranes laid on top of the base. They should be applied to provide a dry film, at least 0.6mm thick. Take care selecting these materials as some of the solvents may not be compatible with foamed plastics insulants. In any case, allow sufficient time for any solvent to evaporate before covering. Consider the possibility of poor workmanship with brush-applied materials. They must be covered with a sand/cement screed not less than 50 mm thick.

Another alternative is a waterproof flooring, such as mastic asphalt to BS 6925, which will add around 20 mm to the finished floor level; it is laid in accordance with BS 8204: Part 5.

The use of sandwich membranes is restricted to where the whole floor is being replaced; in this case it will be beneficial, given adequate headroom, to install thermal insulation below the slab.

Surface DPMs based on proprietary epoxy resin systems have been available since around 1965. They have a good track record, but have only recently become widely accepted because of their high cost. They are rarely considered

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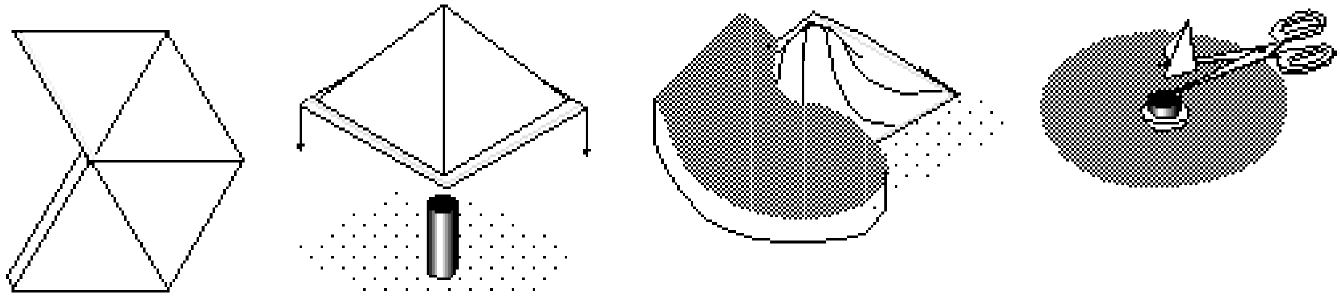

Figure 6.29 One method of protecting a service entry point

Figure 6.30 The base being prepared for casting a raft for a multi-storey building. Column bases are already in position

Figure 6.31 Laying a DPM which also acts as blinding to prevent fines migrating to the hardcore. Taping provides integrity to the seal

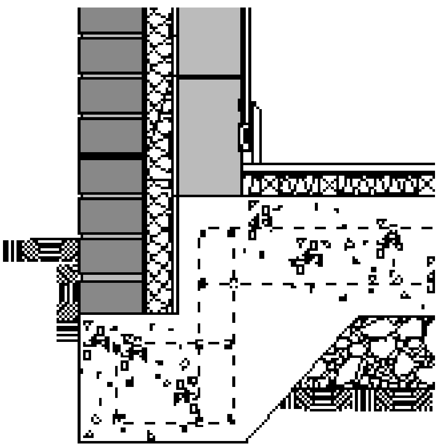

Figure 6.32 Insulation should be started as low as possible at the toe of concrete rafts

for new work but are most useful for renovation and change of use where no DPM is present. They can be applied to clean surfaces of concrete or screed, and should be covered by a latex levelling compound at least 3 mm thick. These surface DPMs are also useful for controlling excess constructional water in thick constructions when it would be uneconomic to wait for them to dry out.

Protection of a raft from rising damp has to be done underneath the concrete, in order to provide continuity. This means that some of the geometry is complicated, particularly at perimeters and thickenings – Figures 6.30 and 6.31

There is a risk of condensation occurring at thermal bridges with this kind of floor. The thermal insulation in the cavity of an external wall cannot be taken sufficiently low to overlap that within the floor – Figure 6.32.

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Magnesite flooring

Magnesite can only be used in dry situations. These floorings are very vulnerable to dampness, and those without adequate DPMs will probably have failed and have been removed long ago if covered by an impervious flooring. If it remains damp, the oxychloride reaction is reversed; the material rapidly loses strength – Figure 6.33 – and in the worst cases may form a mush. The reversed reaction releases magnesium chloride which rapidly corrodes metals and can enter concrete bases and affect reinforcement.

Water can reach magnesite in a number of ways: spillage, plumbing leaks, and construction water during major refurbishment of buildings. However, it was not uncommon for it to be laid in ground floors without any DPM. Any rising moisture can diffuse through the flooring and evaporate away without harm. However, if such a floor is covered by another impervious flooring, such as PVC or rubber-backed carpet, moisture can build up in the magnesite. Bear in mind that such screeds should not be covered with a new DPM either, since in these circumstances they will suffer accelerated deterioration. All such screeds should be completely removed before installing new surface DPMs.

Magnesite can ‘sweat’ in moderately humid conditions. This is characterised by beads of magnesium chloride forming on the surface, and is not the result of condensation. Sweating is to some extent a property of the material since magnesium chloride, an essential ingredient, is very hygroscopic. Because it is in slight excess, it readily takes up moisture from humid air. Magnesium chloride may migrate into adjacent walls and will cause dampness there because of its hygroscopicity.
The slight excess of magnesium chloride also ensures that magnesite flooring is electrically conducting. As a result, moisture meters of the resistance type cannot be used to assess the moisture condition of this flooring. Even when bone dry, most meters give nearly a full-scale deflection – Figure 6.34.

Figure 6.33 Magnesite flooring breaking up following prolonged wetting

Figure 6.34 Full scale deflection of an electrical resistance moisture meter on a bone dry sample from a two coat magnesite floor. Wet or dry, the meter would give the same reading

Thermoplastic tiled floors

Most thermoplastic tile floors were laid on solid groundbearing floors without a DPM. When stuck down with a solvent bitumen adhesive to an initially dry concrete base, the flooring could tolerate moderately damp conditions if the concrete became wet later. However, the flooring could not be considered to act as a DPM – Figure 6.35.

On very wet sites, water rising through the concrete can bring soluble salts with it; on evaporation, these salts are deposited as a white crystalline material along the joints between the tiles. They are mainly sodium and potassium carbonate, which tend to creep inwards from the tile edges to produce white bands up to 25 mm wide along the tile joints. This is often called 'window framing' – Figure 6.36.

They can be removed by careful cleaning. Sometimes, the evaporating solution is absorbed by thermoplastic tiles. Crystallisation pressures set up within the tile are often sufficient to cause delamination and ultimately powdering of the edges of the tile.

Composition block flooring

The flooring is unsuitable in areas liable to dampness, such as kitchens and bathrooms. It should be laid on an effective DPM, though this was not always done.

Some existing floors laid without DPMs were coated with polyurethane seals. Unsealed blocks allows some dispersion of moisture rising from the ground but sealing prevents this. Consequently, moisture builds up in the blocks, leading to detachment of the seal.

Softwood suspended timber ground floors

Softwood timber is generally used for floor construction and must be maintained in a dry condition to avoid rot. At ground level, timber is normally supported on masonry or concrete and protected from rising damp by impervious membranes (DPCs or DPMs). If the membranes are bridged, fractured or deteriorated, rising damp may reach the timber. Timber floors may also become damp if joists have been built in contact with solid

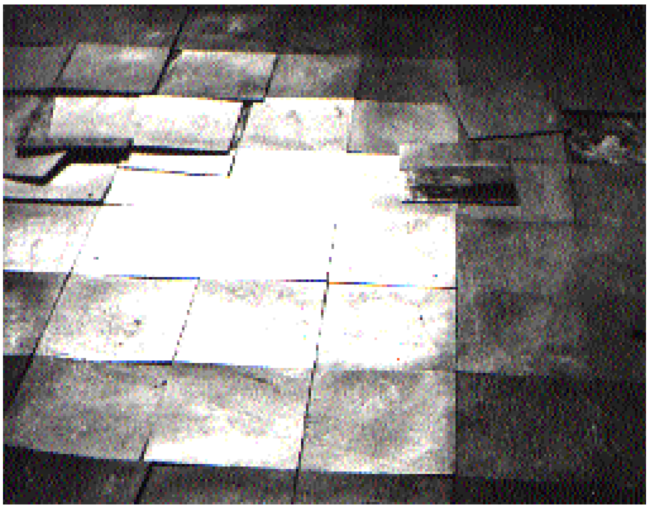

Figure 6.35 Total failure of a thermoplastic tile floor caused by moisture rising from below

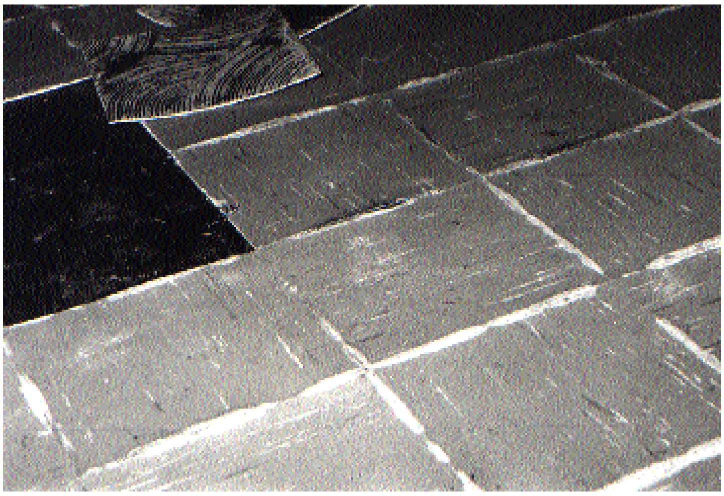

Figure 6.36 Typical 'window framing' on a thermoplastic tile floor caused by soluble salts efflorescing from the base

Figure 6.37 This floor joist was installed in contact with wet external brickwork

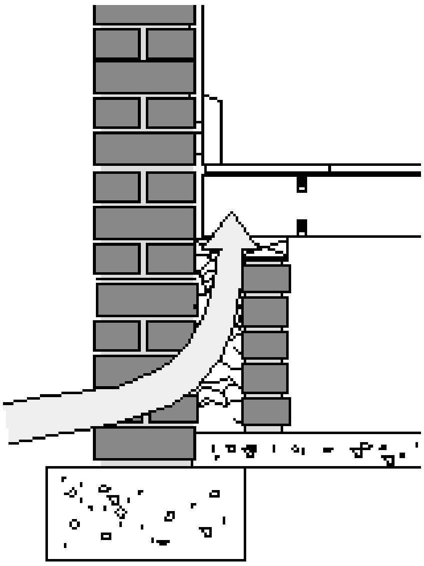

Figure 6.38 Debris or builders' rubbish may bridge the DPC

Figure 6.39 Condensation in the corner of a timber floor

external walls, particularly if these are located in an area of high exposure to driving rain – Figure 6.37 – or where builders' rubble has accumulated – Figure 6.38.

Although there is a small risk of condensation when a suspended timber ground floor has been upgraded with thermal insulation, a vapour control layer is not needed since any small amounts of condensation which form should be vented safely away by air currents under the deck. A vapour control layer might provide a catchment tray for water spillage.

Bridging the DPC, or even flooding of underfloor voids, may occur if the ground or paving around the building is raised. Ends of any joists or boards in contact with solid external walls will need to be protected or replaced with less vulnerable construction. Replacement DPCs may be needed at these points below wall plates or joists on sleeper walls, and drainage may need to be provided for the subfloor void.

Fully or partially-spanning timber ground floors are not usually prone to condensation problems. Warmth from the dwelling will normally maintain the floor timbers above dewpoint and conventional timber floors do not usually include any VCLs where moisture can collect at low temperatures. However, the use of impervious floor finishes, such as PVC flooring, above the timber deck may, under certain conditions, create a risk of moisture accumulation. Shortfalls in underfloor ventilation can result in high humidity in the subfloor void and increase the risk of condensation. The passage of water vapour from the ground into the floor void should be limited by the provision of concrete oversite, asphalt or DPM. Water in a floor void from flooding or long-term groundwater problems will lead to particularly high humidity and condensation on cold surfaces.This needs specific action, either to prevent passage of water through the structure, or to improve drainage or lower groundwater levels.

Experience in Scotland suggests that where buildings are located in a frost hollow, condensation can occur on the underside of timber floors near air bricks on north walls – Figure 6.39.

In ground floors, the durability of timber can be ensured if it is maintained at a moisture content below about 20 – 22%; higher than that, timber will rot. Timber can become damp if DPCs and DPMs are omitted or bridged, or from the accumulation of moisture from condensation. Timber may achieve a high moisture content in service merely by reaching an equilibrium with moist air in a subfloor void where humid air occurs as a result of moisture migrating from the ground: the rate of migration depends on the permeability of the ground surface treatment, which ideally should be concrete or asphalt, and the amount of naturally occurring ground moisture. The humidity depends on how well the subfloor space is ventilated. Ventilation openings and unrestricted cross-ventilation are both important.

Suspended in-situ concrete floors on permanent shuttering

Permanent shuttering is often left in place within the subfloor void. In a heated building, a suspended concrete ground floor is warmer than the ground, so conditions are not favourable to the transfer of water in the vapour phase from the ground via the void to the underside of the floor. This is especially true where the subfloor space is ventilated to the outside. Even so, transient conditions can exist where moisture transfer does occur. These floors should have an integral DPM, particularly where moisture sensitive floorings are to be applied. Providing a DPM beneath a screed also cuts down the drying time, as construction water in the concrete slab does not need to be taken into account: only the screed needs to be dried.

Timber flooring supported by battens fixed into, or onto, an in-situ solid ground floor cast onto permanent shuttering with an unventilated space beneath are vulnerable to rising damp; if there are also groundwater problems, the risk is further increased. Such floors are likely to date from wartime shortages of timber; many have been replaced – Figure 6.40.

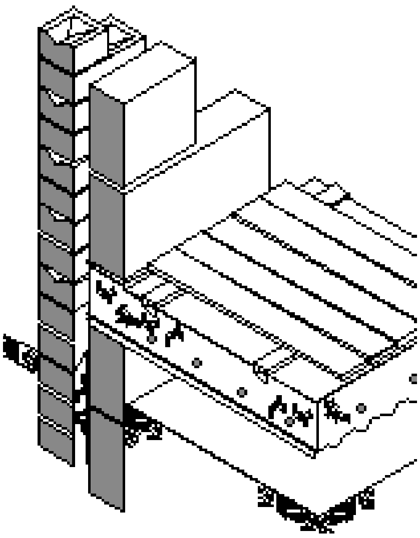

Figure 6.40 An in-situ solid ground floor cast onto permanent shuttering with an unventilated space beneath

DPMs must be continuous under service ducts within the floor. Electricity, water, and gas mains may have to be sleeved to maintain the DPM's integrity.

Most suspended concrete floors allow excess construction moisture to dry both upwards and downwards but floors cast onto permanent metal shuttering can only dry upwards. This is often not taken into account at the planning stage of construction and delays the application of moisture sensitive floorings. Depending on the thickness of the toppings, it can take two to three years for moisture to reach equilibrium – Figure 6.41.

Beam-and-block floors

The various national building regulations require a DPM to be provided under the floor if the ground level under the floor is below the lowest level of the surrounding ground and will not be effectively drained. But since these floors are constructed when the walls are at DPC level, rain can saturate the blocks before the building is made watertight, leading to a long drying time before moisture sensitive flooring can be installed. Completion is delayed and the floor can fail prematurely. It is good practice to place a DPM or vapour control layer between the structural floor and the screed or timber panel to control the transmission of construction moisture. A turn-up to the DPM is essential, otherwise moisture from accumulated rainwater can migrate up the inner leaf of the external wall

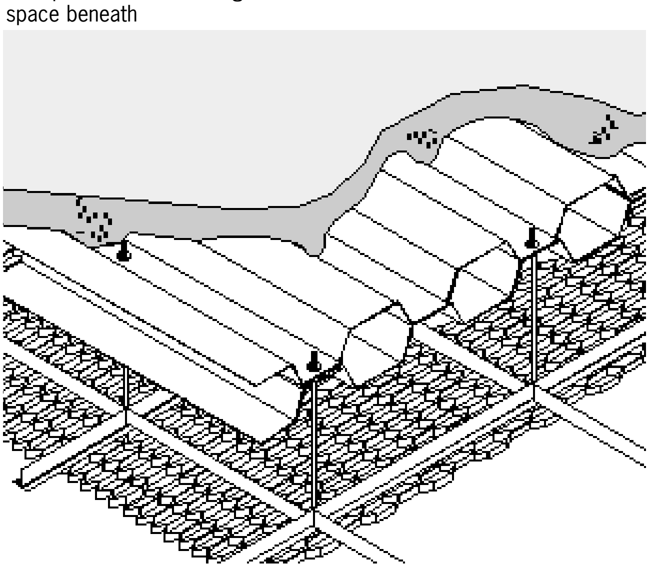

Figure 6.41 Floors cast onto permanent metal shuttering have only one face from which the concrete can dry

A DPC must be placed below any beams or planks to prevent moisture rising up the supporting walls and, more importantly, to prevent soluble salts reaching the components of the floor; salts will induce corrosion of the reinforcement.

BRE site inspections have revealed inaccuracies on site where precast beams have projected into and across external wall cavities. Projections can give rise to penetrating damp, more especially if they collect mortar droppings in the cavity. The wall DPC must link with the floor DPC or DPM; Housing Association Property Mutual found that such linkage was absent in just over 10% of the precast concrete floors they examined.

Materials for DPMs

Although good quality concrete bases laid directly on the ground can be relatively impervious to the passage of liquid water, they cannot be expected to stop all moisture rising from the ground. Some form of damp protection is needed. The usual moisture barrier is a membrane, either laid under the slab or sandwiched between the slab and screed. The ideal membrane is completely impervious to water in both liquid and vapour forms but, although such materials do exist, they tend to be difficult to handle. They must be applied as a fluid and are expensive, such as hot-

Table 6.1 Effects of rising moisture on floor finishes

Group	Material	Properties
A Finish and damp-proof membrane combined	Pitch mastic flooring Mastic asphalt flooring	Resist rising damp without dimensional or material failure
B Finishes that can be used without extra protection against damp	Concrete Terrazzo Clay tiles	Transmit rising damp without dimensional, material or adhesion failure
	Cement/rubber latex Cement/bitumen Composition blocks (laid in cement mortar)	Transmit rising damp slowly without dimensional or material failure and usually without adhesion failure
	Wood blocks (dipped and laid in hot pitch or bitumen	Transmit rising damp slowly without material failure and usually without dimensional or adhesion failure. Only in exceptional conditions of site dampness is there risk of dimensional instability
C Finishes that are not necessarily trouble-free but are often laid without protection against damp	Thermoplastic flooring tiles PVC (vinyl) asbestos tiles Acrylic resin emulsion/cement Epoxy resin flooring	Under severe conditions, dimensional and adhesion failure may occur. Thermoplastic flooring tiles may be attacked by dissolved salts
D Reliable protection against damp needed	Magnesium oxychloride	Softens and disintegrates in wet conditions
	PVA emulsion/cement	Dimensionally sensitive to moisture. Softens in wet conditions
	Polyester resin flooring Polyurethane resin flooring Rubber Flexible PVC flooring Linoleum Cork carpet Cork tile	Lose adhesion and may expand under damp conditions
	Textile flooring	Dimensional and material failure, and usually adhesion failure occur in moist conditions
	Wood block laid in cold adhesives Wood strip and board flooring Chipboard	Acutely sensitive to moisture with dimensional or material failure

applied bitumen. Other materials, like bitumen solutions, bitumen/rubber emulsions and coal tar/rubber emulsions, have been used for many years; polyethylene sheeting has also been used from around 1960. These materials resist the passage of liquid water but are not impervious to water vapour. Some permeability of the membrane can be accepted provided it is less than the flooring material it is protecting. The degree of protection required depends on a number of factors, including the moisture sensitivity of the flooring, the adhesive used to fix it, and the site conditions. Little is usually known in advance about site conditions but the ability of the flooring to resist rising ground moisture is well known – see Table 6.1. Suitable materials for membranes are shown in Table 6.2.

Concrete bases containing proprietary 'waterproofers' are not an acceptable substitute for a properly laid DPM.

Special formulations of epoxy resins are used widely as surface DPMs. They adhere well when applied to concrete that is damp but surface dry. They can be used when the moisture condition of the concrete is up to 92 – 93% relative humidity; this must be measured by the hygrometer method. They are rarely specified for new construction but are used when a building without a DPM undergoes a change of use (for example, factory-to-office and farmhouse conversions) or to control excess constructional water in thick concrete bases when there is not enough time for them to dry.

Mastic asphalt forms an excellent barrier to rising damp. Because its vapour resistivity is also good (not less than 100 000 MNs/g), it is commonly used under moisture-sensitive floorings where there is no other DPM.

Volatile organic compounds (VOCs)

Some flooring products emit volatile organic compounds (VOCs) which, in sufficient concentrations, may be injurious to health. These include solvent naphtha and related compounds from DPM materials, and plasticiser from degraded PVC floor coverings. Information is available about the types and amounts of VOCs emitted that enables specifiers to select suitable products. Tests are carried out according to a guideline drawn up by a working group under the auspices of the EC Concerted Action of Indoor Air Quality and its Impact on Man.

The main sources of VOCs in DPMs are those based on coal tar products, which may contain solvent naphtha. Bitumen adhesives for thermoplastic tiles and semi-flexible PVC tiles traditionally contained solvent naphtha. Gum spirit adhesive for linoleum and cork contained methanol/ethanol; rubber solution adhesive for rubber flooring contained ketones. Because of COSHH Regulations, these adhesives are now being phased out and replaced with water-based adhesives but it is doubtful whether some of the replacements are as effective as the adhesives they replace.

Thermosetting resin floors contain solvents which release VOCs over a period of time. The most common solvents used with particular resins are:

- ❐ toluene with epoxies;
- ❐ xylene with polyurethanes;
- ❐ styrene with polyesters and acrylics.

Seals and floor paints contain similar solvents and some may also contain white spirit.

Plasticised PVC flooring may be a source of VOCs. Plasticisers are liquids

Table 6.2 Materials for membranes

Material	Standard or grade	Position	Comment
Hot applied			
Mastic asphalt	1410: Mastic asphalt for flooring (natural rock asphalt aggregate BS 1076: Mastic asphalt for flooring (limestone aggregate) BS 1451: Coloured mastic asphalt for flooring (limestone aggregate)	Surface	May be used as a floor finish (see BS CP 204). If used as an underlay to a floor finish, the thickness should be not less than 12 mm. A compressible underlay is not recommended but glass fibre may be used
	BS 1097 (limestone aggregate) BS 1418 (natural rock asphalt aggregate)	Sandwich	When loaded, can withstand hydrostatic pressure
Pitch mastic	BS 1450: Black pitch mastic flooring BS 3672: Coloured pitch mastic flooring	Surface	Normally used as a floor finish but may form a surface membrane to protect other finishes. Its indentation characteristics make it less suitable than mastic asphalt
Pitch	BS 1310: Coal tar pitches for building purposes (Grade R & B40)	Sandwich	Should be laid on a primed surface to give an average thickness of 3 mm (3 kg/m^2)
Bitumen	Should have a softening point of 50 – 55 °C. This corresponds to a penetration number of 40 – 50 at 25 °C	Sandwich	Should be laid on a primed surface to give an average thickness of 3 mm (3 kg/m^2)
Cold applied			
Bitumen solutions, coal tar pitch/rubber emulsion, or bitumen/rubber emulsion	Not defined by any BS specification or code	Sandwich	BS CP 102 recommends 0 – 6 mm min thickness but this is for broad guidance only. The solids content will usually have been adjusted to give adequate coverage by two or three coats. The material should not be thinned by dilution or spread in thinner coats than recommended by the manufacturer
Pitch/epoxy resin	Proprietary only	Surface Sandwich	Although applied in thin layers, the material is strong enough and its adhesion to concrete is usually sufficient to make it a satisfactory base for a variety of floor finishes. It cannot tolerate any cracking in the surface to which it is applied
Sheet material			
Polyethylene film	0.12 mm thick (500 gauge) [1]	Sandwich	Joints must be properly sealed; the welting method normally used appears satisfactory. Where there is risk of damage by subsequent screed laying operations, material about twice as thick (1000 gauge) may be used
Composite	Polyethylene and bitumen, self-adhesive;thickness is in excess of 1.5 mm	Sandwich Below concrete	Adhesion simplifies joint treatment and reduces risk of tearing
Bitumen sheet	Bitumen sheet to BS 743	Sandwich Below concrete	Joints must be properly sealed
	Note [1] Polyethylene sheet 120 µm thick (500 gauge) is sufficiently impervious to be used as a DPM but it is easily damaged because it is not robust. Building Regulations (England and Wales) Approved Document C4, Section 3.5, recommends that polyethylene should be at least 300 µm thick (1200 gauge) or 250 µm (1000 gauge) if in accordance with appropriate BBA certificate or to the Packaging and Industrial Films Association (PIFA) standard.		

with a high boiling point low volatility but if flexible PVC flooring comes into contact with strong alkalis, either from the base screed or concrete or from cleaning materials, the plasticiser can be saponified to form a volatile alcohol.

Traditional polishes and dressings contained volatile solvents, usually white spirit and methylated spirit. Except for a few wax polishes for timber flooring, solvent-based materials have been replaced by water-based emulsions. Natural products such as beeswax are emission-free.

Waterproofness of floorings

Some floors must be completely waterproof, especially if the materials are at risk of deterioration, for example in domestic bathrooms and kitchens, or in manufacturing areas where a lot of water is used for cleaning.

Diagnosis

This form of dampness must be distinguished from condensation, which usually occurs at thermal bridges adjacent to outside walls. In solid floors in ground contact, general dampness can result if there is no effective DPM. This is rare in property built since 1967, when Building Regulations first required a DPM in all ground-supported solid floors. Floors laid between 1945 and 1966 may or may not have a DPM; before 1940 they will almost certainly not have had one. Floors without any DPM are the most likely to have rising damp problems.

Suspended timber ground floors can become damp if the DPC in the supporting masonry or concrete is bridged, fractured or deteriorated, or if the joists have been built in contact with solid external walls. Timber flooring supported by battens on a solid unventilated sub-floor is extremely vulnerable to rising damp if there is no effective DPM.

Resistance to water

Principles of modern building pointed out that the effects of moisture probably cause more damage to floor finishes than any other, even abrasion. Experience of the BRE Advisory Service suggests this still holds true. However, it does not normally result from moisture rising from the ground through a groundbearing slab because of a defective DPM although some cases were observed where moisture had risen from the ground because there was no membrane.

Most problems have been where excess constructional water in slab or screed has not been given enough time to dry before floorings are laid. Other sources are spillages, or overzealous or inappropriate use of water for cleaning. Condensation on ground floors is next most frequent.

The European Union of Agrément classification is a useful guide. Table 6.3 shows the E classification indices.

Table 6.3 UPEC E indexes

Index No	Maintenance	Tolerance to wetting
E_0	Dry methods only	Short duration wetting
E_1	Occasional wet methods	Accidental standing water
E_2	Wet methods and washing	Non-prolonged standing water
E_3	Swilling	Prolonged standing water

The G classification applies to plastics floorings. Those classified G1 to G5 have limited tolerance to wet conditions, Gw indicates that a product can tolerate wet conditions, Gws that it can tolerate standing water – see *Directives for the Assessment of Manufactured Plastics Floorings.*

Test methods cover exposure to water and assessment of sensitivity, spread of water under a puncture, resistance to standing water, and dimensional variations when wetted.

Floorings may be wetted by water from above, used in cleaning or accidental spillages. Some finishes may only be able to tolerate accidental wetting of short duration, whilst others can be considered as being immune even to prolonged wettings.

Osmosis

Many kinds of flooring are affected by osmosis: blisters, which contain an aqueous solution under compression, form under the surface of the flooring. It is caused when the concrete underfloor acts as a semi-permeable membrane in an osmotic cell – Figure 6.42.

All self-levelling thermosetting resins can suffer this unusual form of failure when floors laid on concrete become badly blistered. The blisters are usually first noticed up to six months after the flooring is laid. They can range from a few millimetres up to 300 mm in diameter but commonly from 10 to 50 mm and 2 to 5 mm high. Each blister contains an aqueous liquid under pressure which is a mixture of inorganic salts and organic components derived from the resin. BRE research in 1974 suggested that the blistering was caused by osmosis.

Three conditions are required before osmotic blistering can occur:
- ❒ the presence of a concentration of a soluble salt or soluble organic material at or near the surface of the concrete base;
- ❒ a semi-permeable membrane at or near the surface;
- ❒ a source of water in the substrate.

It is only since the mid-1970s that osmosis has been seen in failures of some sheet and tile floorings as blistering or bubbling of the covering. BRE has heard of about 50 cases of osmotic blistering and has examined about half of them. Even though much more is now known about blistering caused by osmosis, it remains a rare and unpredictable event.

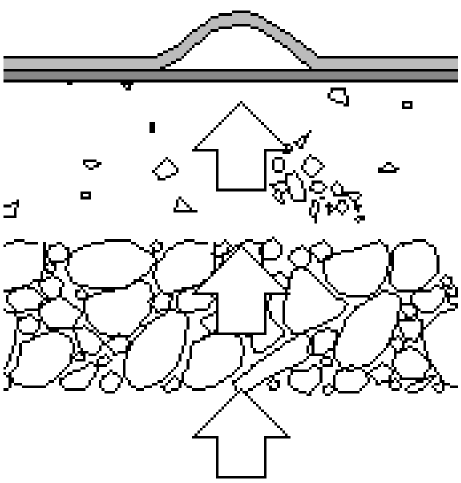

Figure 6.42 The mechanism of osmosis

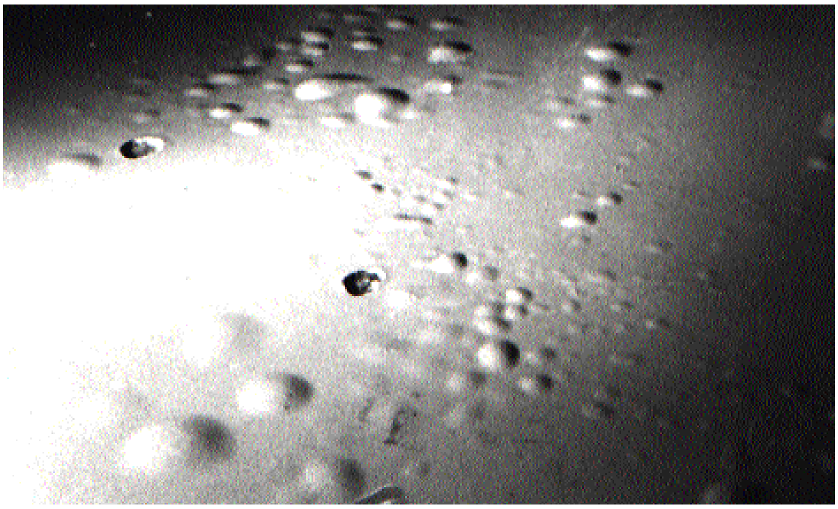

Figure 6.43 The first case of osmosis investigated by BRE in 1971

Osmosis and how it has been observed

Osmosis is the spontaneous flow of water into an aqueous solution or of water from a dilute to a concentrated solution where the two solutions are separated by a semi-permeable membrane; this membrane allows the free passage of water but not the dissolved solute. The movement of the solvent (the water) through the membrane into the concentrated solution can generate high pressure known as osmotic pressure.

Three constituents are required before osmosis can occur in flooring:

- a concentration of a salt or other soluble material;
- a semi-permeable membrane or layer;
- a source of water.

A **salt** can concentrate at or near the surface of concrete in a number of ways, for example from acid etching or the application of surface hardening agents. Salts derived from Portland cement can migrate to the surface where they concentrate as the concrete is drying. Contamination from sources outside the concrete or screed are not usually involved.

In some cases seen by BRE where blistering has occurred, old concrete bases were laid on the ground without a DPM. Over the years, and before the resin flooring was applied, small amounts of water passing through the slabs could have carried soluble salts to the surface; the salts were derived either from the ground or the cement in the concrete. Here they could concentrate, like efflorescence on drying brickwork. Old concrete floors can also be contaminated with soluble salts during previous use; for example, de-icing salts could have been tracked into the building by vehicles.

Analysis of fluid taken from blisters at a number of sites shows that the fluid always contained a mixture of inorganic salts (mainly sodium and potassium sulfates, carbonates and hydroxides) and often organic constituents contained in the epoxy resin hardening systems. Total soluble material concentrations are between 4% and 28% by mass. These concentrations would have been higher before dilution by osmosis occurred.

In some cases of blistering, it has been suspected that the resin constituents have not been thoroughly mixed together. This could leave concentrated pockets of soluble hardening agents adding to the soluble salt. However, there is no direct evidence for this.

A **semi-permeable membrane or layer** allows water-size molecules (but nothing larger) to pass through. Good quality concrete can act in this way. Even if the pore size in the concrete is not small enough to form a semi-permeable membrane, applying a primer coat could reduce the pore diameter at the surface sufficiently for this to happen. Epoxy films can perform as semi-permeable membranes.

The moisture content of concrete is often specified to be below 5% before an epoxy is laid. However, the osmotic force is an extremely powerful one. There is probably sufficient **water**, even in so-called dry concrete of 3 – 5% moisture content, for osmosis to occur. The minimum moisture content for osmosis to occur is not known.

The conditions for osmosis can often exist in a concrete floor covered by an impervious flooring material. The osmotic pressure generated by the movement of water through the semi-permeable membrane is sufficient to cause blistering of the flooring – Figure 6.43.

The size of the blisters depends on the initial concentration of salts, the quality of the semi-permeable membrane formed and how well the flooring is stuck to the concrete.

Blisters can increase in number and size for up to two years; they slow and stop when the ionic activity on either side of the semi-permeable membrane becomes equal due to dilution of the salt concentration and its transfer back into the bulk of the concrete through an imperfect membrane. Blisters opened some years later are often dry: all aqueous fluid and soluble material has probably returned to the concrete through an imperfect membrane.

Blisters can be punctured by internal pressure or the effects of traffic; fluid within the blister then leaks to the surface. Initially this is a pale straw colour caused by the organic components. The water quickly evaporates, depositing the inorganic salts as crystalline material, but the organic component appears to oxidise to a much darker, sometimes nearly black, sticky material. Further solutions may exude from a broken blister until the ionic activity on either side of the membrane becomes equal. This happens for the reasons already given and because soluble material is being lost to the surface.

Blistering in resin floorings caused by osmosis is a rare and unpredictable event. The subject has not been well researched and, although BRE has examined about 20 cases, we cannot predict when osmosis will occur or the precise conditions necessary for the formation of blisters. Nor can we predict whether a replacement floor will blister again; this has happened in a number of cases.

Remedies

Solutions for a defective DPM in a solid floor include:
- ❒ repair it;
- ❒ provide a new one beneath the screed;
- ❒ overlay the floor with flooring grade mastic asphalt;
- ❒ apply a proprietary surface DPM based on thermosetting resins.

With a change of use, it is often found that the existing floor does not contain an effective DPM but the proposed new flooring must be protected from moisture from the ground. Many thermoplastic and vinyl asbestos tiled floors have been laid without DPMs because they could tolerate moderately damp conditions. But if a moisture sensitive flooring is to be applied to one of these floors, one of the following types of DPM is required:
- ❒ A DPM laid and covered with a sand and cement, or concrete, screed at least 50 mm thick.
- ❒ A mastic asphalt screed 18 mm thick which will act both as the DPM and the screed.
- ❒ If the thickness of the floor cannot be increased, a surface DPM based on a proprietary epoxy resin can be used. Some floorings can be laid directly to the resin surface; others require a 3 mm layer of a latex underlayment.

GROUNDWATER AND BASEMENTS

The problem

Numbers of basements

Around 550,000 dwellings out of a stock of around 20 million dwellings in England have all or part of their habitable accommodation in basements. Of these, over three-quarters date from before 1919 – Figure 6.44. Dampness is the most common defect encountered, though it is not quite as common as one might expect, with just over one in 20 of all basements showing some signs of penetrating or rising damp.

Figure 6.44 Typical older domestic basement where the dampness might have to be tolerated

Condensation

Dampness and mould growth are often indications of condensation but can also be a result of penetration of moisture from the ground. The diagnosis of the cause of dampness in basements tends to be complex but dampness in unoccupied buildings is rarely due to condensation. This section deals with penetrating moisture from the ground; condensation, which is linked to ventilation and heating regimes, is dealt with in Chapter 4.

Groundwater

Dampness can be due to penetration of groundwater if the water table is high or the excavation for the basement is in impermeable subsoil. Find out if there is any history of flooding in the basement, and whether or not the water table level ever exceeds that of the basement floor level. Flooding can lead to lifting of waterproofing treatments if they are inadequately loaded. A detailed investigation of the ground may be necessary to establish the water table level and the soil type. It may be possible to lower the water table by improving the drainage system around the outside of the building.

If there is an external light well or cavity, check whether the cavity is bridged by debris, that the drainage is still functioning and not silted up, and that air bricks are not obstructed by soil or vegetation. Examine the floor for signs of moisture penetration. Check any constructions which abut the main structure, such as garden walls and arches under steps, as these are a potential source of dampness. Check also for plumbing leaks.

Floors and walls of basements are often impregnated with hygroscopic salts, particularly if they have been used for storing solid fuel. Lightweight plasters will accentuate any dampness problems.

Remedial methods for dampness in basements are given in *Foundations, basements and external works*, Chapter 3. For walls and ground floors, damp-proofing methods are discussed in *Walls, windows and doors* and *Floors and flooring*.

BS 8102 gives guidance on the level of protection required for new construction. This may be adapted for use in improving the resistance of existing construction.

Level of protection required

For new construction, it is important that the client has a clear idea of what use will be made of the basement. Exclusion or control of moisture and, in some circumstances water vapour, is the chief consideration. BS 8102 lists four grades of basement usage; these are listed in Table 6.4 together with acceptable forms of construction. The grades can also be used for assessing existing properties when refurbishment work is being considered. The proposed use is likely to be different from previous use when dampness was probably of less concern.

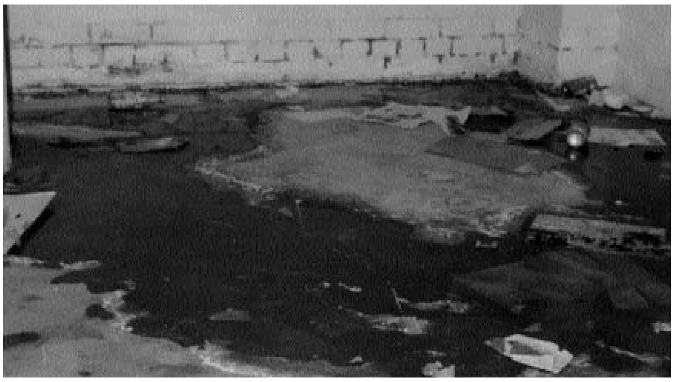

Figure 6.45 Flooding in a basement. The lower courses of brickwork are also saturated

Existing tanking systems are usually of asphalt, a method that has been in general use for many years. The material can accommodate a degree of movement in the structure and, provided the workmanship is satisfactory, it is comparatively rare to encounter a failure.

Table 6.4 Level of protection to suit basement use

Grade	Basement use	Performance level	Construction	Comment
1	Car parks, plant rooms, (not electrical)	Some seepage and damp patches tolerable	Reinforced concrete to BS 8110	Groundwater check for chemicals
2	As above but need for drier environment, retail storage	No water penetration but vapour penetration tolerable	Tanked or as above or RC to BS 8007	Careful supervision Membranes well lapped
3	Housing, offices restaurants leisure centres	Dry environment required	Tanked or as above or drained cavity and DPMs	As above
4	Archives and controlled environment areas	Totally dry environment	Tanked or as above plus vapour control ventilated wall cavity with vapour control and floor cavity and DPM	As above Groundwater check for chemicals

There are three categories of materials used in liquid applied membranes for damp-proofing:

- ❒ bitumen emulsions and solutions, some containing rubber latex;
- ❒ polyurethane compounds;
- ❒ epoxy resins.

All these can provide protection but complete integrity depends on the quality of workmanship.

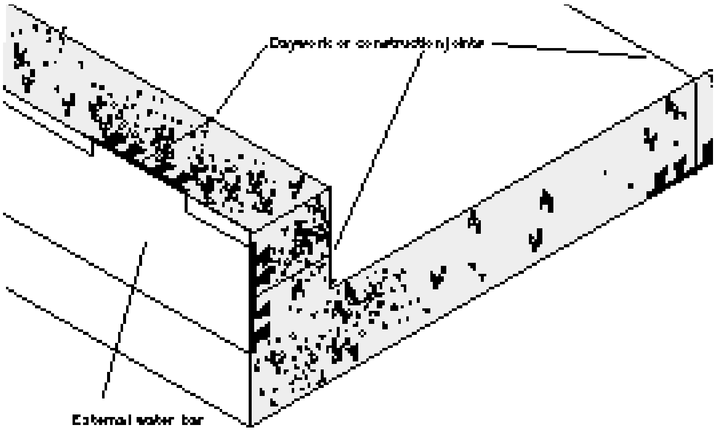

Figure 6.46 Dovetail section rubber or plastics strip cast into the shuttered face of the pour

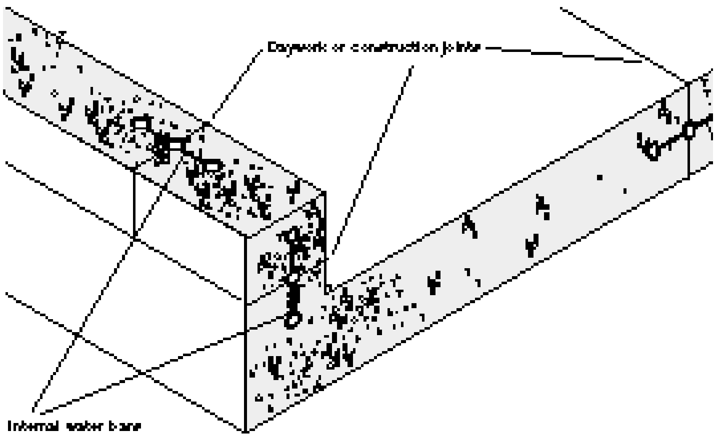

Figure 6.47 Dumb-bell section rubber or plastics strip cast into the open face of the shuttering

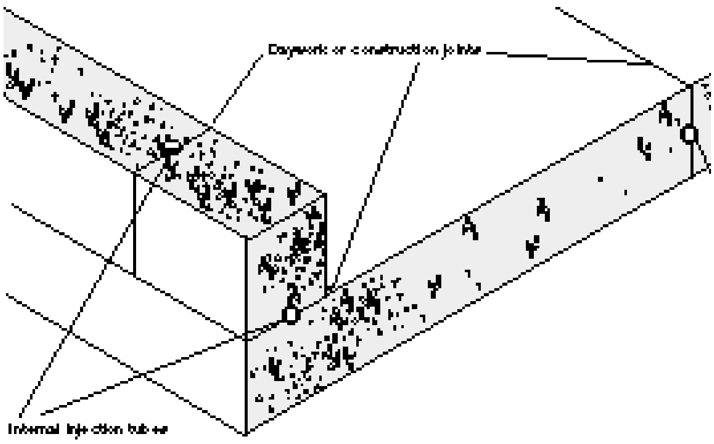

Figure 6.48 Perforated tube cast into the open face of the pour for later injection of resins into the joint

Waterstops

Water stops are needed in in-situ reinforced concrete construction where day joints are to be formed during the casting process and where the structure must resistant water penetration. Several types are available; they prevent the ingress of water in different ways.

Rubber or flexible waterstops

The most common forms are extruded sections designed to provide a continuous barrier to water through joints in the concrete structure. Strips of rubber or plastics, dovetailed on one side, are fixed to the face of the shuttering and cast into the wet concrete. These are external to the structure – Figure 6.46.
If they are used horizontally they must be cleared of debris before placing the concrete. They resist passage of water only from the face on which they are fixed.

Waterstops designed to function in the middle of the wall are difficult to install as successful placing of concrete cannot be guaranteed. Strips of rubber or dumb-bell shaped plastics are cast into the open face of the pour.
These are internal to the structure – Figure 6.47.

Water-swellable waterstops

These function by the sealing pressure developed when the hydrophilic material absorbs water. In strip form, they are placed against the concrete joint before the next pour. They can be attached to rubber or PVC waterstop to provide a combined system.

Cementitious crystallisation waterstops

These are cement, fillers and chemicals mixed on site as a slurry and applied to the face of the concrete before the next pour. Salt crystallisation within the pores and capillaries of the concrete provide the waterstopping.

Post injected waterstops

A perforated or permeable tube is fixed to the first pour of concrete in the joint, leaving the open ends accessible. The second pour is made and, when the concrete is hardened, a polyurethene or proprietary fluid is injected to seal any cracks or fissures in the construction joint – Figure 6.48.

Converting basements during rehabilitation

During housing rehabilitation, basements which have been in use only as utility rooms are often considered for conversion to living areas. This change of use requires very careful assessment. They must be protected from penetrating dampness, associated mould growth and moisture-related deterioration of components – Figure 6.49. Evaluate carefully the practicability and cost of conversion, particularly bearing in mind structural implications, risk of flooding and the presence of positive water pressure in

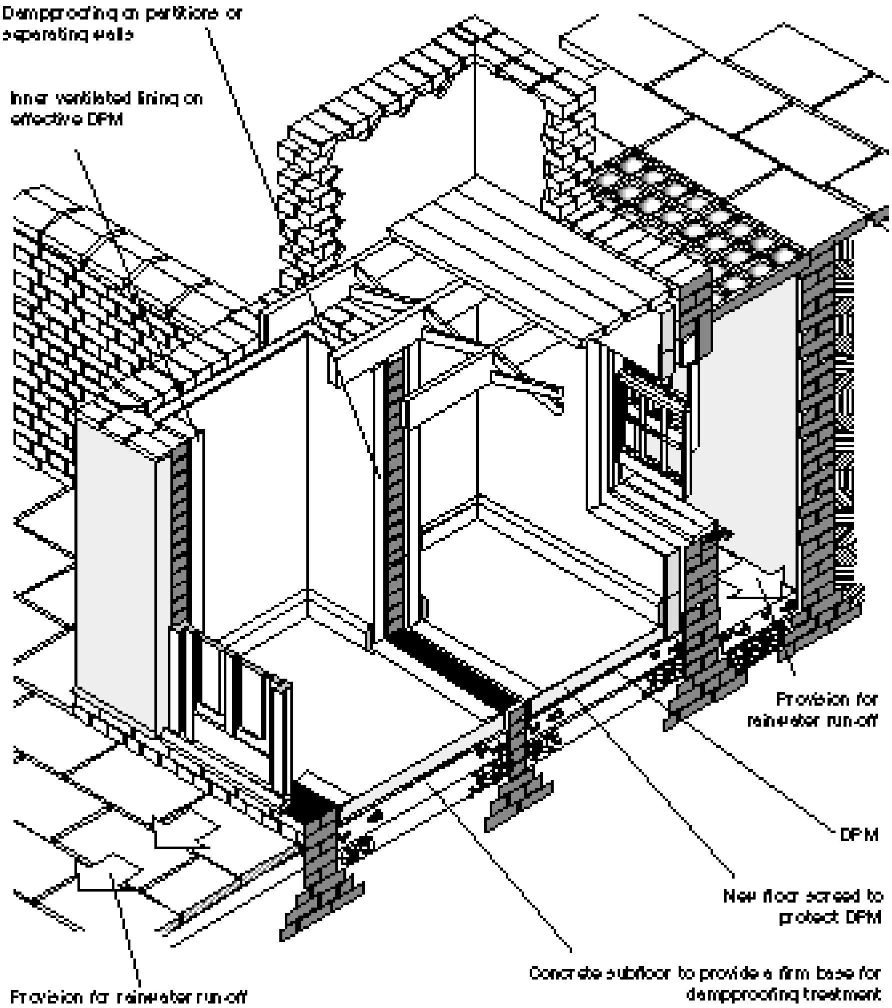

Figure 6.49 A basement in a building built on a sloping site may give rise to problems such as continuity of damp-proofing, and the need to provide DPMs and DPCs for internal walls in addition to floors

the ground related to a high water table. Basements are difficult to ventilate so assess the condensation risk in the finished basement before work starts – see Good Building Guide 3.

There is always a risk that alteration works will exacerbate problems of dampness. For example, lowering the floors to improve headroom, and extensions to increase plan area, present considerable structural and damp-proofing problems. Investigate groundwater levels and the cause of any previous dampness.

Few masonry basement structures had comprehensive external tanking incorporated when built and retrospective installation is often discounted on cost grounds. Specifiers have to decide whether asphalt tanking is required or whether one of the cheaper proprietary waterproofing systems would be satisfactory. Proprietary systems available include waterproof renders containing special additives, paint-on high-build coatings and moisture-resistant lathing materials that allow plastering of damp walls; when considering the use of any of these products, bear in mind that discontinuities in the waterproofing are difficult to avoid and are a common cause of dampness later.

An alternative approach, more of a palliative than a solution, is to improve drainage to lower the local water table around the structure. This is practicable only in some soils.

Penetration of moisture from the ground or from flooding commonly results in surface dampness, salting and timber decay. Structural movement can cause failure of any waterproofing applied internally or externally. Holes for pipes or removal of internal waterproofing for electrical fixings may cause localised leaks. There may be difficulty in providing waterproofing at junctions between internal and external walls and in achieving correct overlapping between vertical and horizontal waterproofing materials. Internal treatments may lift if not restrained. High water table and high wall salt content increase the difficulties of providing waterproofing.

Obvious signs of dampness are visible salting or 'tide marks' on walls or floors and decay of timber components. Estimates of the moisture content of masonry can be obtained using a calcium carbide meter, or by weighing and drying samples of wall material. Moisture content of timber can be checked with an electrical resistance meter but readings are inaccurate if salt content is high. To help the specification of suitable remedial measures, a detailed ground investigation may be necessary to determine the soil type and the position of the water table.

CURING DAMPNESS PROBLEMS

All methods for waterproofing existing buildings aim to provide a moisture resistant envelope to walls and floors. Several types are used, ranging from asphalt tanking to ventilated dry lining. A more traditional alternative is to provide a drained cavity by building a new inner leaf. The remedies in this section are essentially those given in Good Repair Guide 23.

To ensure completely dry surfaces to the walls of basements, the whole of the structure below ground level must be tanked: provided with a continuous membrane of asphalt supported on the inside. A specification is given in BS 1097 and BS 1418.

Applying a dense rendering, even with integral waterproofer added, cannot be expected to provide a completely dry surface. But it may reduce the dampness to an acceptable level, particularly if further decoration is not too sensitive to moisture, cement paint for example.

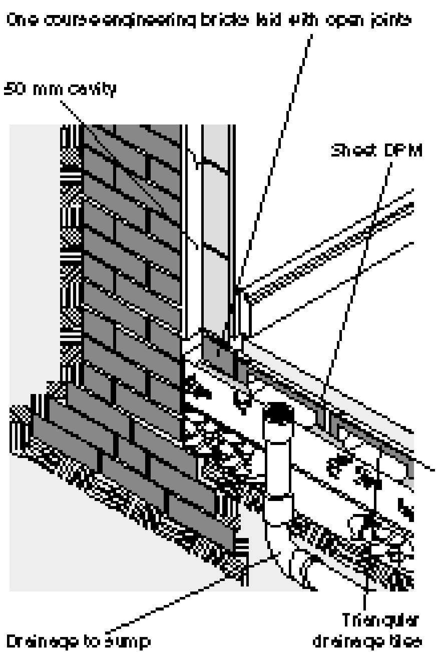

Figure 6.50 Damp-proofing a basement with joined cavities on walls and floors. This method can be used only where drainage is possible. The drained cavity wall and floor construction provides a high level of safeguard. A ventilated cavity and horizontal DPM prevent moisture ingress

Dampness in basements can sometimes be reduced by improving the drainage of the ground in the immediate vicinity or by cutting away earth to leave an air gap around the external wall.

Several of the following treatments result in loss of space because of the additional wall thickness. In each case, there must be a sound concrete sub-floor, at least 150 mm thick, as a stable base.

Drained cavity

This is a tried and tested solution but it does reduce the available internal space, and it relies on effective gravity drainage or installation of a sump and pump – Figure 6.50. The method is not suitable in conditions of high water pressure or high water tables. It can be completed by non-specialist contractors.

Remove wall and floor finishes, together with existing screed or flooring materials. Lay a course of engineering bricks on the slab, incorporating a 50 mm cavity and drainage channel, and leaving perpends open at intervals. Above the brick course, lay a physical DPC and a new blockwork wall, tied into the original wall with stainless steel wall ties at standard spacings. Lay a drainage or sump and a self-draining underfloor layer of triangular drainage tiles and a sheet DPM, to the requirements of CP 102, lapped up the side of the engineering bricks. As an alternative to tiles, use a heavy-grade plastics dimpled sheet, which will also act as a DPM. Finally, lay a new screed at least 50 mm thick, and replaster the walls.

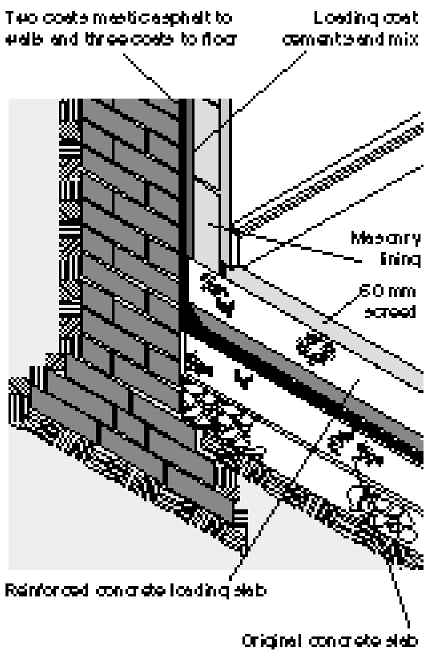

Figure 6.51 Damp-proofing a basement by mastic asphalt tanking. The structure itself does not prevent water ingress, and protection therefore depends on a total barrier system applied externally or internally. The system may also need a vapour control layer, depending on the use to which the basement is put

Mastic asphalt tanking

This is expensive but durable – Figure 6.51 There is a significant space penalty, in terms of area and, usually, height and the system must be installed by specialist contractors.

Remove the existing flooring back to sub-floor slab, ensuring that all surfaces have an adequate key. Rake out horizontal brickwork joints to a depth of 25 mm, and coat with a proprietary high-bond primer. Hack or bush-hammer glazed brickwork. On smooth concrete, wire brushing with either the addition of a proprietary cement:sand slurry with plasticiser or a light application of a proprietary high-bond primer may be necessary. Round off external angles of masonry and concrete.

Build up a two-coat asphalt angle fillet at wall-to-floor and wall-to-wall junctions, and three coats of asphalt to a total of 30 mm on floor slab and 20 mm on walls –

see BS 8102. Stagger joints between successive coats by at least 150 mm on floors and 75 mm on walls. Finally, add at least 50 mm protective sand:cement screed, or build a vertical brick or blockwork lining wall, backfilling against the asphalt with a cement:sand mix.

Cementitious render or compound

Correctly mixed render or compound, properly applied to a stable background, should last for many years – Figure 6.52. Make specific allowance for services if they are to be run in the wall. The cementitious layer is vulnerable to accidental puncturing unless special wall fixings are used, or an inner blockwork wall is added. The method can be used in areas with high water tables, provided extra care is taken; use a specialist contractor to achieve a satisfactory solution.

First, build a cement corner fillet at wall-to-floor and wall-to-wall junctions. Then, apply by trowel three coats of proprietary mix (thinned with clean water). In strict accordance with the render manufacturer's instructions, lap successive coats, and complete the curing. Walls may be skim-coated where necessary. If using cementitious compound, the substrate must be dampened, and two coats applied to manufacturer's recommendations followed by a loading coat and floor screed.

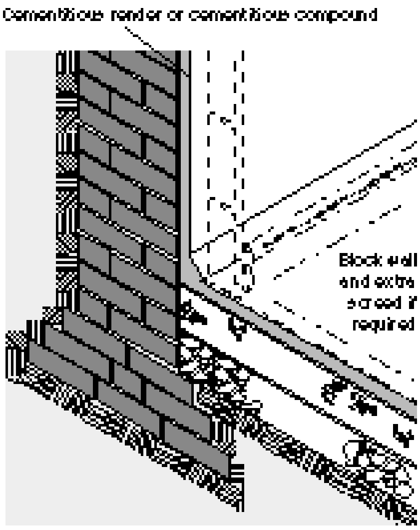

Figure 6.52 Damp-proofing a basement by cementitious render coats

Self-adhesive membranes

They provide a durable solution and a suitable surface for services and fixings, but there is a space penalty. The method can be used in areas with high water tables, and specialist contractors are not usually necessary.

First, clean the brickwork, and remove all flooring down to the subfloor slab. Flush point all brick surfaces, or render if the masonry is uneven – see *Walls, windows and doors* for suitable mixes; clean and dry the concrete slab. Construct wall-to-floor and wall-to-wall fillets, and apply the membrane to dry wall and floor surfaces following the manufacturer's guidance, allowing at least 150 mm overlap at the joints. Protect the floor membrane and build a blockwork lining, progressively backfilling with cement:sand mortar. Finally, add a new floor screed at least 50 mm thick and replaster the walls. Some contractors have suggested that when applied internally, water pressure can cause detachment. Careful workmanship and attention to detail will result in a satisfactory job.

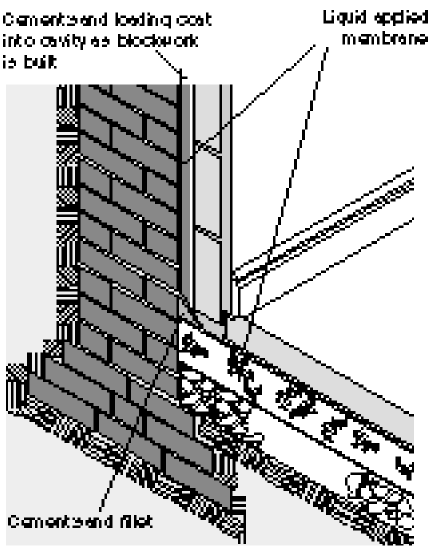

Figure 6.53 Damp-proofing a basement by liquid-applied membrane.

Liquid-applied membranes

They also provide a durable solution and a suitable surface for services and fixings, but with a space penalty – Figure 6.53. The method can be used in areas with high water tables and it is not usually necessary to employ specialist contractors.

Remove all flooring down to the sub-floor slab. Clean and flush point the brickwork, and give a final clean to all surfaces to be coated.

Use all products strictly in accordance with the manufacturer's instructions, particularly any ventilation

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requirements during and after application. The usual procedure is:

- ❒ construct wall-to-floor and wall-to-wall fillets;
- ❒ apply one or more liquid coats and allow to cure;
- ❒ lay a new floor screed;
- ❒ construct a new inner leaf (normally backfilled with cement:sand mortar) with the floor membrane protected from damage during building operations;
- ❒ allow sufficient time for the membrane to dry.

Ventilated dry lining

This has the advantage of only marginally decreasing space in a room – Figure 6.54. However, it is suitable only if dampness is slight, and it does not protect against groundwater under pressure. The plastics sheet is vulnerable to accidental puncturing unless special fixings are used. The linings have a life of 20 years or more. Specialist contractors are not usually necessary.

First, lay a high-density dimpled polyethylene sheet on the floor, turning up the wall by at least 150 mm and overlapping to manufacturer's recommendations. Next, lay a new floor screed at least 50 mm thick. Fix proprietary dimpled plastics sheet to the wall surface by nailing, screwing or special plastics plugs, leaving a gap top and bottom for ventilation. Finally, plaster the wall surface, or cover it with plasterboard, while retaining the ventilation gaps.

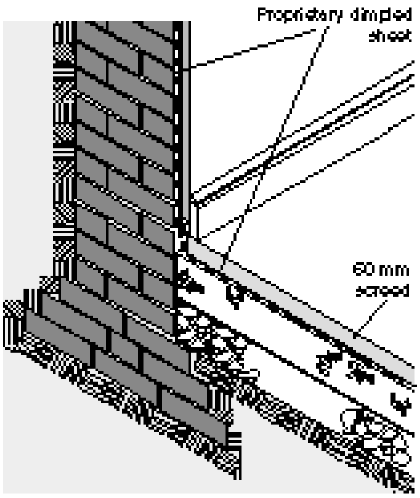

Figure 6.54 Damp-proofing a basement by dimpled sheet dry linings.

Partition walls

Partitions must be damp-proofed, with careful attention to detail. There are three approaches:

- ❒ Completely remove the partition. Install damp-proofing and screed by one of the methods given above, and rebuild the partition. This is normally only advisable for partitions which are not loadbearing and not contributing to the stability of the building.
- ❒ Insert a DPC at the base of the partition, overlapped with the floor and wall damp-proofing. This is usually appropriate only when the partition is not connected to an external wall.
- ❒ Continue the external wall damp-proofing along the partition. This does not prevent moisture entering the wall masonry but stops dampness penetrating to wall finishes. Full protection may be needed, or a ventilated dry lining may be adequate. Protect timber door frames in partitions by continuous damp-proofing around the sides and base of the opening. This may be the only solution where the partition is connected to an external wall and where the partition cannot be removed because it has a structural role.

Basement ceiling level

The damp-proofing system must lap the ground level wall DPC. If this is absent or ineffective, it must be replaced before damp-proofing is started.

Installing lining walls and new ceilings to basements may reduce ventilation around ground floor joists. It may be necessary to improve ventilation to joists and isolate joist ends from walls, where possible, with DPC material or by using joist hangers.

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Door thresholds

Threshold DPCs should be 150 mm above outside ground level and fully lapped with floor damp-proofing. Timber thresholds must be of durable timber or pretreated with preservative.

Door and window frames

The damp-proofing layer must be taken into the reveal to abut the frame. Lining to walls is usually stopped at the edge of the reveal and plaster, or adhesive-fixed plasterboard taken round to complete the reveal. Interior sills, of durable or preservative treated timber, should be fixed to the lining wall.

Sound door and window frames of durable or preservative-treated wood can be retained in position if there is no indication of rot and if they are likely to remain dry. If there is a risk of wetting, frames should be isolated from damp masonry by a physical DPC which laps the wall damp-proofing.

Replacement frames should be durable or treated as specified in BS 5589, and isolated from damp masonry. If excessive wetting is likely, consider using aluminium or PVC-U frames.

Fixing services

If services are run behind ventilated dry linings, use moisture-resistant fittings and provide a waterproof seal at outlets. For cementitious damp-proofing, run services in recesses in the walls. Services can be run on dry internal partitions or inside hollow skirting systems. Basement floors cannot normally accommodate heating and water pipes.

Chimney breasts

If the fireplace is to remain in use, damp-proofing can be taken to the chimney breast reveal; the heating will maintain dryness round the breast and hearth. Otherwise, an envelope treatment is required around the breast. Alternatively, remove the chimney breast, provide new support for the stack and damp-proof the whole basement wall. More information is given in *Walls, windows and doors*.

Built-in timbers

Remove built-in, non-structural timbers which would be vulnerable to rot if sealed behind damp-proofing. With embedded structural timbers, the safest solution is to replace them with materials less sensitive to moisture. Retain structural timbers only if they are sound and of durable material and if dampness can be minimised in the supporting structure. If there is any timber rot, investigate the cause and take preventative measures – information is given in *Walls, windows and doors*.

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CASE STUDY | **Dampness in internal walls in a converted stable block**

There were large areas of discoloured wallpaper on internal walls in the flat. During conversion, an electro-osmotic system of damp-proofing had been installed; BRE was called in following complaints about rising damp.

The living room of the flat was papered in a heavy, flowered paper that had probably been in place since the flat was converted. There was no evidence of dampness from the front wall to the false fireplace but from the right-hand side of the fireplace to the kitchen wall the wallpaper was discoloured with a tide-mark up to 540 mm above floor level. There was no evidence of disruption of plaster, and an electrical moisture meter gave a high reading on this wall. The plaster in the kitchen cupboard was in a good condition, although a small area behind the cooker had blown and was loose..

Findings

BRE made three visits to the flat but the occupiers did not allow any disturbance to the decoration. It was explained to them that all that was required was a couple of square inches of wallpaper and a few 9 mm diameter drilled holes. They claimed that the wallpaper had been stained for many years and they were prepared to live with it. A less than satisfactory solution, but better than none, was to obtain samples from the party wall inside the kitchen cupboard next to the stained wall and beside the cooker.

From the measurements taken within the cupboard, the hygroscopic moisture content values were found to be higher than the as-found moisture content values, indicating a build up of salts over the years although, in an adjacent location, there were some indications of dampness with a lower level of hygroscopic moisture content.

Evidence was not available on the original layout of the stable so diagnosis had to be made from first principles. It is well known that problems can arise during conversion of this type of building, either from salts build-up, from horse urine, from curing bacon or, in more modern times, from the storage of agricultural fertilisers. Without test results to back it up, the most obvious explanation is that the horse loose-boxes were in this middle section and the brickwork was contaminated by urine. There was no reliable evidence on the effectiveness of electro osmotic damp-proof courses. However, re-plastering the walls with a sand:cement render can be demonstrated to contain both dampness and residual salts. The render drilled on this wall was rather weak and was possibly low on cement content; this would allow the passage of salts which in turn will have contaminated the wallpaper.

Dampness in a bedroom wall adjacent to the rear window could be attributed to the abutting high garden wall. The wall was extremely wet and had suffered from some frost attack. The brick coping sloped downwards towards the house wall and run-off would have wetted the upper part of the wall. If it were not possible to have a clear gap between the garden wall and the house, some lead flashing would be needed to divert the water away from the house. To contain residual moisture, internal plaster should be hacked off and replaced with a sand:cement render.

Remedial treatment to the internal walls

It was difficult to be specific about remedial treatments on the scant evidence gathered. Possibly, all that would be necessary is removal of the wallpaper and replacement with new paper, perhaps vinyl. If, however, the render was contaminated with salts, this should be hacked off and replaced with a plaster system. In the kitchen, there was evidence of hygroscopic salts contamination of the plaster; the existing plaster should be hacked off and replaced. There was insufficient evidence of rising damp to justify the expenditure of an injection DPC, and the proposed re-plastering should contain any slight moisture present.

CASE STUDY | **Severe damp and related problems in No-fines houses**

Complaints of severe damp and damp-related decay, including mould growth, had been made by tenants of No-fines houses on an estate in the north-east. BRE was asked to inspect one of the properties.

Construction

Houses on the estate were erected in the 1960s using the Wimpey No-fines system. The house was a two-storey, end of terrace dwelling. The gable wall faced south. On the ground floor was an entrance hall, lounge, kitchen, rear entrance and staircase; upstairs were three bedrooms, a bathroom and landing. The only heating was a gas fire in the lounge. There was a gas cooker in the kitchen.

Inspection

In the presence of client representatives, construction was found to be different from that originally reported. Walls were lined with a cellular-cored plasterboard, rather than being plastered. Moisture content was checked with an electrical moisture meter and pieces of plasterboard were cut out to determine the moisture content in the laboratory.

All rooms were examined. There had been some recent redecoration and little mould growth was seen.

Externally, the main cause for concern were cracks over two-storeys where the front and rear walls met the party wall. External pebble-dashed render was in good condition with no major defects. The heads of some of the windows were damaged with the render detached. This may have occurred when window frames were replaced as there was evidence of the render being patched. The rainwater down-

pipe at the rear of the property was damaged allowing water to discharge down the lower part of the wall.

The moisture contents of internal surfaces were sampled with an electrical instrument by pressing the two points into the wall surface. Values were in the range 35 – 40 on the 0 – 100 scale at all locations.

Plasterboard samples were cut out so that the as-found moisture content could be determined in the laboratory. Sample A was cut from the rear bedroom outside wall next to the party wall. Removal of loose wallpaper revealed a vertical crack in the corner that corresponded with the external crack. At this point the cavity behind the cellular-cored plasterboard was 26 mm wide. The crack in the no-fines wall was 20 mm wide at ceiling height. The plasterboard is restrained top and bottom by timber battens. The moisture content of the top batten was 15%.

Sample B was single thickness plasterboard that formed the window reveal and was cut from the left-hand side. The wallpaper was stained by damp and although not disintegrated was friable where in contact with the window sill. The cavity behind the cellular-cored plasterboard was 28 mm wide and the cavity behind the reveal was 25 mm wide. The inside of the single-glazed window was wet from condensation.

Samples were taken from the rear wall of the lounge. A length of skirting was cut out to examine the lower batten which supported the cellular-cored plasterboard. A moisture content of 15% was measured on the batten. Because there was no cavity at this point, the plasterboard was in contact with the no-fines concrete.

The floor screed was in direct contact with the no-fines. It appeared that the perimeter strip had been filled in with a weak mix after the screed had been laid. A short length was broken out and no trace of any DPC material could be found. Samples of screed and plasterboard were tested in the laboratory for moisture content and hygroscopic moisture content; values were:

Sample number	Material	Moisture content % wet weight	Hygroscopic moisture content 32%	54%	75%	93%
Rear bedroom						
A	Plasterboard Room side	0.96	0.42	0.75	1.24	1.91
Al	Plasterboard Cavity Side	0.96	0.43	0.75	1.26	2.22
B	Plasterboard	0.95	0.43	0.79	1.44	2.00
Lounge						
C	Plasterboard Room side	0.72	0.42	0.74	1.23	2.08
D	Plasterboard Cavity side	0.95	0.44	0.81	1.42	2.42
F	Screed: piece	1.0			1.2	
Fl	Screed: loose	1.7			1.7	

As well as measuring hygroscopicity at 75% RH, vessels were set up for relative humidities of 32%, 54% and 93%. The samples were put into each vessel in turn and left until the weight stabilised. An electrical moisture meter reading was also recorded at each condition.

Discussion

Masonry and wood-based materials contain moisture; the amount increases or decreases depending on the RH with which it is in contact. In dwellings, relative humidities range from 35% for a well heated room to over 90% for a bathroom for a short period of time. It is usually around 55% but is dynamic and depends on living patterns. If the RH remains above 70% for long periods, black mould growth will become established. There is consistency in the samples tested between the as-found values for samples A, A1, B and D of 0.95% wet weight. Sample C is lower at 0.72% which is to be expected from the room-side plasterboard where the room is heated for long periods. All values are low so there is no dampness problem.

The hygroscopic moisture content tests show that at the highest test value of 93%, the moisture content of the plasterboard increases only to values from 1.91 to 2.42% wet weight. These are not excessive and there is no sign of any disintegration of the plasterboard. It is unlikely that a RH of 93% would be experienced for more than short periods in the bathroom and kitchen.

Moisture contents in the screed samples were lower or equal to the hygroscopic moisture content. Values are low, showing that there is no excess dampness.

Further evidence was provided by moisture contents of 15% in timber battens at the head and base of the plasterboard. This is acceptable.

Conclusions

Electrical moisture meters produced mid-scale readings in the plasterboard linings leading to the original concern that damp was present. Laboratory tests established low moisture content values for five samples of plasterboard and two screed samples. Further tests examined moisture pick-up and electrical moisture meter readings at different relative humidities. Even at the highest RH levels, the plasterboard remained stable and no permanent effects remained when it was dried. It was concluded that levels of moisture found in the materials were acceptable and that the property is not damp.

CASE STUDY Moisture in chipboard flooring over foamed polystyrene

BRE was asked to investigate the condition of chipboard floors supported on foamed polystyrene.

Construction and history

The client owned a large number of dwellings in which the ground floor construction was a polyethylene DPM beneath a concrete slab mainly 150 mm thick but increased to 230 mm beneath internal loadbearing walls. At the exterior walls, the slab descended vertically and then horizontally to form a wide plinth for the foundations. The DPM was not continuous with the DPC in the walls.

The concrete slab was then covered with 40 mm expanded polystyrene insulation, followed by a VCL of 1000-gauge polyethylene. This was then overlaid with 18 mm chipboard Type II/III. Since occupation, the floors in a number of properties were damp and the chipboard and overlying carpets were wet.

The client's representatives had inspected a number of properties including some with no apparent problems where the underlying base concrete was found to be visually dry. However, where dampness had been reported, water standing on the surface of the concrete base was found when the floor was taken up. In most of these, there had been water leaks from plumbing in adjacent areas in the same structure.

In a few properties where the floors were damp, no plumbing leaks could be found; it was these that BRE was asked to investigate.

Two single-storey linked properties were selected for detailed investigations. During the winter and spring of the year when the concrete floor slab and footings were cast, the weather was wet, so the floor slabs would have contained a considerable quantity of moisture at the time of closing in. Subsequently, the chipboard flooring in some areas had become saturated and the carpets were wet.

Site examination

The first dwelling was unoccupied. In all areas except the lounge, the chipboard, polyethylene and polystyrene had been removed several days before the BRE's visit to expose the concrete base. It was reported that, except for an area near the kitchen sink, the surface of the concrete base was damp, mostly covered by a thin layer of water. This water had evaporated away and at the time of the visit the concrete base was surface dry.

To ascertain the moisture condition of the exposed concrete base, measurements were made by the method given in the relevant British Standards. Hygrometers in thermally insulated boxes were fixed to the surface of the concrete at four separate positions. These were left in position overnight. Readings next morning were between 90 and 94% RH, indicating that the concrete contained a considerable amount of water within its porous structure. The safe level for laying timber flooring is below the range of 75 – 80% RH.

When the chipboard in the lounge was taken up, the top surface of the polyethylene sheet beneath was dry except in one area where it was torn: the chipboard immediately above this tear was wet. There were some droplets of moisture on the underside of the polyethylene. When this sheet and the polystyrene was removed, there was a layer of water 2 to 3 mm thick on top of the concrete slab.

The other house was occupied. The standard of heating was good and there were no signs of condensation on outside walls. In one area in the kitchen and another in the hall, the carpet was wet in patches. Both areas had been inspected previously. When the chipboard and polystyrene were taken up, a thin layer of water was seen on top of the concrete base.

Air temperatures and relative humidities were measured using an aspirated hygrometer. Surface temperatures of floor, walls and single glass were measured using an electronic thermometer. The outside weather was mild: 11.5 °C in the late afternoon. From the internal conditions measured, no condensation was taking place at the time of the inspection.

The internal partitions were of plasterboard on timber studwork, shot-fired directly to the floor slab. Moisture content of the timber in contact with the slab was above 28% with an electrical moisture meter. The base of the skirting gave a reading of 16%.

Discussion

The chipboard flooring and carpets were wet because moisture was moving upwards through punctures and tears in the VCL from a reservoir of water below. Even if the polyethylene had been intact, the water beneath would have caused such problems as rot in the timber sole plates and rising damp up the brickwork chimney breasts.

There are usually four sources of excess water in concrete ground floors:

❒ Constructional water is the excess water which is added to a concrete mix to make it workable and above that required for hydration. This can take a long time to dry out, particularly with thick slabs where the DPM is underneath. Commonly, slabs 150 mm thick take six

to nine months to dry sufficiently before moisture-sensitive floorings can be laid; those 200 mm thick often take one year. Drying cannot start until the roof is complete and rain excluded.
- ❒ Water from the ground which moves into the base, either because there is no DPM or because it is defective.
- ❒ Water from cleaning, spills, leaks, floods etc.
- ❒ Condensation which occurs if the surface temperature of the concrete is below the dew-point. Significant amounts of water will condense only if humidity is high in the room for extended periods and there is free access for the moisture vapour to reach the slab.

If humidity had been high for long periods, condensation would be expected in other places but there was no evidence of this. Also, the VCL beneath the chipboard would have prevented free access for the moisture vapour to reach the slab. Condensation was therefore discounted.

Following an unusually wet spring, it was about three months between completion of the roof and installation of the flooring. This is insufficient time to dry the slab.

Examination showed that the DPM was not continuous where the slab descended to form the foundations. Water from the ground could easily enter the slab by this route. However, the amount of water found was more than could be expected from constructional water and water from the ground. There must have been another major contribution.

Although no leaks were found, it was likely that the water had come from the plumbing system. It is not uncommon for drain-cocks to be left open or joints to leak when the system is initially filled. These are later turned off and tightened. Water from leaks or open drain-cocks near radiators could run down the pipes through the floor system to the slab below as the VCL is punctured at these points. There would be no visible signs that water had entered by this route and beneath the flooring there would be no sign of its presence until the chipboard became wet where there were gaps in the VCL.

Leaks from plumbing systems have worried the industry for some time. Model Water Byelaws and, later, the Water Regulations require that pipes and other water fittings are not embedded in any wall or solid floor or installed in or below a solid floor or under a suspended floor at ground level unless accommodated in a duct or sleeve. Chipboard floors require ducts or openings with removable covers where there is a change in direction of the pipework.

Conclusions

- ❒ Wetting of the chipboard and carpets was caused by water trapped beneath the polyethylene VCL coming through splits and punctures in this membrane.
- ❒ There was insufficient evidence to pin-point conclusively the original source of the water found on top of the ground floor slab.
- ❒ A contribution was probably made by constructional water and water from the ground.
- ❒ These two sources could not account for all the water so it was concluded that there must have been a leak from the plumbing system at some time, probably during commissioning.

Recommendations

Because it would take a long time to dry the floor slab before chipboard could be relaid, and because the DPM was not continuous, a new DPM was recommended over the concrete base.

Where insufficient time has been allowed for the concrete base to dry out, a DPM or VCL must be laid between the wet construction and the sensitive flooring. Conventionally, a DPM is used on top of the slab, covered with a screed at least 50 mm thick. Applying an epoxy bonding agent, which also acts as a DPM, to the surface of the base allows bonded screeds to be less than 50 mm thick.

Proprietary epoxy resins surface DPMs can be applied to the surfaces of screeds or concrete bases; they are most often used where drying time has been misjudged and the flooring must be laid on a base which is still wet.

All the heating pipes must be taken out of the floor and run around the skirtings or down walls from the ceiling level. If this is not feasible, the requirements of the Water Regulations should be complied with.

The timber studwork in contact with the wet slab must be isolated, preferably by a DPC. Techniques are available for cutting out mortar courses with a modified chain saw. If a membrane can be installed in this way, it should be brought up the sides of the timber and fixed behind the skirtings to protect the timber from a wet screed.

If it is impossible to insert a DPC, the timber sole-plates must be preservative treated.

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CASE STUDY **Dampness from leaking pipes in commercial properties**

The party wall between a health studio and a furniture showroom was lined on the showroom side with gloss-painted, tongued and grooved timber. Dampness had caused the timber to swell and become detached, and the paint had blistered. BRE was asked to investigate the causes.

Close-up of the blisters

History

Both the Victorian properties had been extended at the rear. The furniture showroom had been substantially unaltered for many years and the walls were covered with tongued and grooved vertical planking. The upstairs part of the furniture showroom was behind a flat which had a separate entry from the side alley. The second floor had also been converted into flats. The basement was partly converted to a living room; the rest was used for storage.

The adjacent shop was converted to a health studio two years before the inspections. The entrance area was at ground floor level; the gymnasium behind extended the depth of the building. The party wall was lined with full-length mirrors and the area had a suspended ceiling. The basement housed the sauna at the front of the premises adjacent to the party wall. Beside the sauna was the changing area with showers that extended under the street. Presumably the barrel-roofed areas underneath the street had been used for storing coal. The remainder of the basement at the rear was the changing room and a small refreshment area and lounge. First-floor rooms were used for treatment, sun lamps etc, and the second floor was converted to a flat.

The builders and architects who had examined the timber panelling in the furniture showroom had suggested that the proximity of the sauna was to blame.

Observations

The weather on the day of the first visit was sunny and dry. The wall of the furniture showroom was examined. Several of the boards had been removed previously, so a set of moisture content drillings was taken from the mortar courses. Where the paint had blistered, the timber was saturated, showing a full-scale reading on an electrical moisture meter. When blisters were punctured, water ran out of the blisters and down the face of the board. Away from the blistered area, timber was dry.

Using an aspirated hygrometer, temperatures within the showroom were:
dry bulb: 13.5°C
wet bulb: 11°C
RH: 74%

It was not possible to drill the party wall because it was covered by mirrors and the sauna. The wall at the front of the sauna was drilled from the under-pavement storeroom side. Also drilled was the party wall at the front, which was underneath the pavement, giving 20.8% for moisture content and 1.2% for hygroscopic moisture content at 1500 mm above floor level. It was reported that the barrel roofs under the pavement area leaked water after heavy rain.

The sauna was heated by a 21 kW electric element under special stones and the RH within the sauna could be raised by splashing water onto the stones. There was a large extract fan from the shower area that discharged outside the front of the shop. Both heater for the sauna and the extract fan were switched off at night. In the morning before opening, the temperature had dropped to 19°C within the sauna and the shower room was dry.

At a second visit, drilled samples were taken again from the furniture showroom side. The layout of the drainage within the health studio was examined. The WC on the first floor was against the party wall with the discharge from the pan passing through the floor. Removal of a ceiling tile showed that the vertical stack was set in a channel built into the depth of the wall. The pipe was lead and there were also two small lead pipes; by flushing the WC, it was established that the discharge stack was still in use but it was not possible to check on the smaller pipes.

There was another WC on the second floor directly above the first-floor WC; it appeared that the discharge was taken horizontally through the rear wall before dropping vertically.

There did not appear to be any pipes adjacent to the party wall in the flat above the furniture showroom. One steel pipe behind the plaster on the furniture showroom side proved to be an abandoned gas pipe that ran down to a basement outlet.

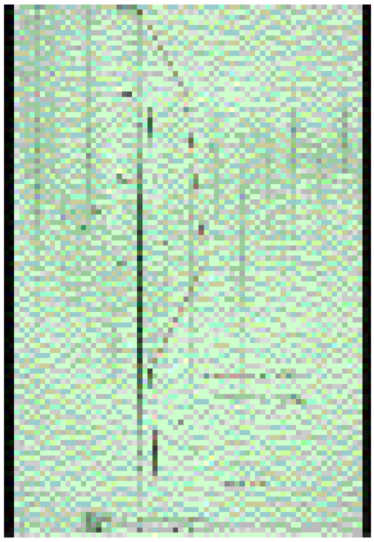
Discussion

No evidence was found to support the theory that the dampness within the wall was caused by the sauna.

Most revealing were the results of the moisture content samples drilled from the wall. They showed that the wall was dry for about the first metre above floor level; it was quite damp, nearly 8%, at the 1500 mm level, and was then dry again just below the ceiling. This suggested that water was getting into the wall and, as there did not appear to be any pipes on the showroom side, the lead soil pipes or the lead water pipes must be the prime suspects.

Remedial treatment

First, the source of the water must be found and plugged. This means removing the mirrors from the health studio wall and exposing the pipework. The timber cladding must be removed from the showroom so that the wall could dry out before refixing. As this wall was quite wet, it would probably take several months to dry out to its residual moisture content. It would be prudent to test by further drilled samples before refixing any cladding.



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CASE STUDY — Damp in a listed building

The listed building was derelict before reconstruction work started four years before BRE was asked to investigate problems with damp. Part of the building was used as an adult education centre. The stable block and the caretaker block contained residential units and were unoccupied, and therefore unheated and unventilated, for some time after the contract was completed.

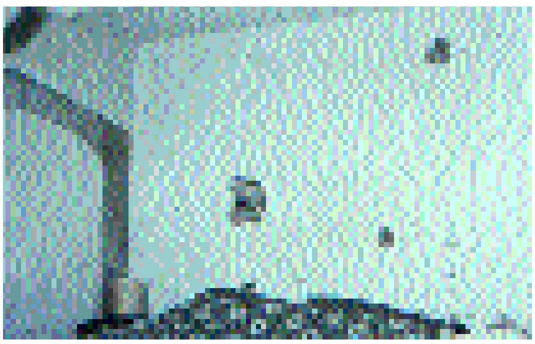
Damp-proof coursing had been carried out using an injection mortar system in rubble-filled stone walls that varied in thickness up to 1.5 m. However, rising damp was still considered to be a problem.

On some of the walls there was heavy contamination of salts, resulting in a large amount of efflorescence and considerable local spalling. It was reported that road salt had been stored in this building at some stage; laboratory analysis of drilled samples confirmed this.

Replastering to some sections of the walls appeared to have been carried out using lightweight plaster and this was wet when the samples were taken. Condensation had also contributed to the general dampness, and there was mould growth on the inside face of some outside walls.

A ground-floor flat

In the main bedroom, the old stone masonry partition wall had been retained and the head of the bed was adjacent to it. This wall had a fairly soft friable render and surface coating which was heavily contaminated with salts, resulting in a large amount of efflorescence and local spalling of the surface. Some small pieces of the coating were lying on the floor at the time of the inspection. Several samples were lifted from the wall surface for



laboratory examination. Deeper drilled samples were taken from the wall to the right side of the bed head. These samples were placed in small phials and sealed for later testing to determine their moisture content and hygroscopic moisture content. Tests with an electrical moisture meter on this wall gave readings of 9 – 10 (arbitrary scale) on the mortar and 8+ (arbitrary scale) on the stone. In this flat, and several others in the building, there was considerable yellowing of the white emulsion paint on the old stone walls. This did not occur on the new work, for example above the newly installed concrete lintels over the bedroom windows. There was an unlit paraffin heater in one of the bedrooms.

Caretaker's ground floor flat

It was understood that the bathroom in this flat had been replastered following a severe water leak in the flat above, and the corridor had also been affected.

Dampness was evident at low level on the outside front wall of the kitchen. The outside ground level was about 200 mm higher than the kitchen floor level.

The windows at the rear of the flat and including in the passageway were poorly installed with a mastic fillet between frame and wall. A thin metal spatula was easily inserted about 75 mm; this gap must provide an easy point of entry for driving rain.

A single sample was drilled in the bedroom from the east wall where plaster had already been removed from the underlying blockwork. This appeared to be where a window opening had been filled in. Moisture meter readings in this area were 2 on the mortar and 4.4 to 10 on the blockwork. Moisture meter readings on the timber skirting board in this room were between 28% and 30% content.

Skirting removed from the short return wall near the outside door had a moisture content of 30%. The wall was plastered right down to the floor screed. When the linoleum floor covering was turned back, the underside was wet.

The floor covering was also lifted near the centre of the room. The surface of the floor was very wet. A surface hygrometer reading of 98% was obtained after one hour.

Samples were drilled from the front wall of the kitchen. The plaster in the area was unusually thick and appeared to be Carlite bonding directly onto the stone. A moisture meter reading on this mortar 140 mm above the floor indicated 8 – 10 on the arbitrary scale. The timber scale moisture meter reading on the skirting was 30%.

Discussion

All drilled samples of mortar showed that the hygroscopic salts present were likely to be the controlling factor in determining the moisture content of the walls. The maximum hygroscopic moisture content was 7.8% and the moisture content was 7.3%. Surprisingly, the moisture content of one wall was less at lower level than at a higher level. Qualitative analytical tests on a sample of efflorescence from this wall showed that the soluble salts were mainly sodium. There was a large amount of chloride, a trace of sulfate and a small amount of nitrate. A large amount of sodium was present with small amounts of potassium (less than 0.02%), calcium (about 0.1%) and magnesium (less than 0.02% on sample). This indicated conclusively that the heavy contamination of the masonry was sodium chloride, common salt. It was likely that the wall had been considerably wetter in the past and that as evaporation of water from the wall proceeded, the salts in solution within the wall have crystallised out, causing spalling of the surface. As the surface of the wall, particularly the mortar was so friable, it was likely that further spalling would occur as more salts crystallise out. The salt concentration in the surface layers was so high that it would be impossible to guarantee the performance of any paint system. Similarly, it was most likely that any stabilising fluid would be ineffective.

Recommendations

The heavy salt contamination and the friable mortar preclude the application of any new plaster system. The only way to remove the salts is to remove the wall itself: an impractical solution. There appeared to be a choice between two alternative treatments. In both cases as much of the loose surface as possible should be removed without further damage to the wall.

Treatment 1 To eliminate further falls of mortar and stone fragments, a layer of glass fibre quilt is applied to the wall surface. The quilt is kept in close contact with the wall by nylon netting attached to timber battens. The glass fibre quilt has a low vapour resistance and allows evaporation of moisture from the wall. A 75 mm-thick blockwork wall is then constructed leaving a suitable cavity between the glass fibre and the blockwork. The cavity is adequately ventilated at floor and ceiling level in a manner similar to that recommended for installing proprietary bituminous lathing. The wall is stopped 5 – 6 mm short of ceiling level to form a continuous slot which is concealed by beading or coving (making sure the occupier does not fill the gap). The cavity could possibly be vented to the roof void.

Treatment 2 Cover the wall surface (after cleaning as above) with a self-adhesive DPM, such as Bituthene, which should adhere adequately and form a VCL. A 75 mm block wall is then built against this; no ventilation is provided. Alternatively, a cavity can be left between the membrane and the blockwork and subsequently filled with a weak concrete with only just sufficient water to make it workable. This has the advantage that the self-adhesive DPM stays in place but one disadvantage: it introduces more moisture into the structure which will have to dry out. This treatment with self-adhesive DPM and block wall is repeated on the opposite face of the wall. As the moisture content of the wall appears to be largely governed by the hygroscopic salts present, and not by rising damp, applying a VCL to both faces seems to be justifiable.

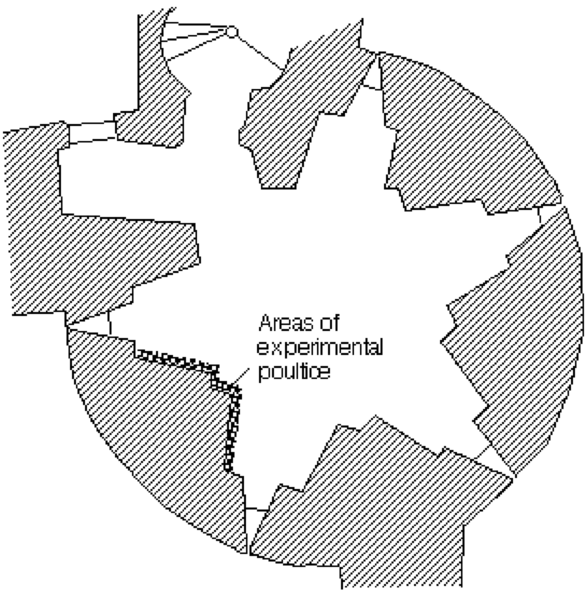
The problem of the yellowing and some flaking of the existing emulsion paint on the stone walls can be treated by removing loose paint and treating the wall surface with diluted alkali-resistant primer to help stabilise the surface. There are two alternative finishes and it is suggested that both systems are tried out on selected areas: flat oil paint and flat emulsion paint.

CASE STUDY

Soluble salt in the Tower of London

For many years attempts have been made to preserve stonework from decay. Usually the treatments involved have been only to the surface, for example lime-wash or silicone water-repellent solution. These treatments have had little effect in arresting decay or even made it worse. In some cases, soluble salts in the masonry have caused decay; when water is present, the salts move to the surface where they dry and crystallise, leading to decay of the masonry. A good example is at the Salt Tower in the Tower of London. This tower was used, in former times, for storing culinary salt (sodium chloride) when it was a more highly valued commodity than it is today.

The ground floor consists of a thirteenth-century, five-sided room with six arched embrasures; the walls are of coursed rubble, and the arches of ashlar quoins and voussoirs. The walls are mainly Reigate quoins and voussoirs with Kentish rag rubble walling.



Ground floor plan of the salt tower

The lower block is part of the Victorian renovations and the upper is an original piece. Assuming that the repair was inserted flush with the faces of the original, it can be seen that since the repair, which was itself beginning to decay, about 20 to 25 mm of decay had taken place in the original.

Since previous surface treatments were unsuccessful, a large-scale experiment was tried, using a poultice to remove the salt. Beginning in May 1972, it continued for four complete poulticing cycles over two years.

The site

Part of the wall of the ground floor was used to monitor the tests. Part had only one face is exposed, another included an outside corner with two faces exposed. Given stone of similar absorbing power, extraction should be more rapid in the external corner than in the straight wall. A water catchment system was installed to take run-off to the nearest drain because the floor level was below outside ground level. It consisted of lengths of heavy gauge polyethylene sheet inserted into a raked out horizontal joint about 300 mm above floor level and held in place with mortar pointing. It deflected the run-off down the wall into a length of guttering which took the run-off to the drain.

Technique

Since soluble salts migrate in masonry only if water is present, the masonry must be wet for poulticing to be effective, so it is first sprayed with water. Wetting continues for up to 14 days, depending on the porosity of the stone, and thickness and construction of the wall.

The absorbent is then applied to the wetted wall. As the poultice and wall dry out, by evaporation at the air and poultice interface, soluble salts are carried across the stone and poultice boundary by the moving water and removed from the stone.

If the poultice is on an outside wall, some form of weather protection is needed to prevent rain from washing the clay away. When to remove the clay is usually obvious: the clay shrinks and will probably lose contact with the masonry. The cycle can be repeated as often as necessary. The wall, however, will still be damp and should not need as much wetting as the first time.

This is the general outline of the technique used but, since a quantitative assessment of the salt distribution was required at the Tower of London, drilled samples of stone were taken from the wall at selected points in the process.

Sampling procedure

Experiment has shown that 15 mm x 25 mm deep drilling provides sufficient weight of stone dust for tests. Samples were taken at various depths in 25 mm steps until the drill broke through the rear face of the block. They were gathered on polyethylene sheet and put into polyethylene bags for return to the laboratory where they were dried at 105 °C and analysed for chloride ion content.

A weighed amount, 8 gm, of dried stone dust was placed in a polypropylene centrifuge tube with 80 ml of de-ionised water. The tube was shaken for about two hours to extract the water-soluble salts. After removing the stoppers, the tubes were centrifuged 10 minutes. Suitable aliquots, usually 20 ml, were titrated by the Volhard method with silver nitrate and ammonium thiocyanate.

Slater type plaster of Paris moisture gauges were installed in the holes in two blocks left by the initial sampling. They were embedded by blowing a slurry of plaster down a PVC tube inserted temporarily behind the gauge. The remainder of the hole was filled by closed-cell polyurethane foam which, when set, filled the hole and ensured that the moisture reaching the gauge did so by permeating the stone block rather than directly down the drill hole. The hole was finally capped with a two-pack polysulfide mastic. Holes from subsequent drillings were left unfilled except by poultice material.

Measurements of moisture were made by connecting each gauge to a Wayne-Kerr Universal conductance-capacitance bridge. As the moisture at the back of the block increased, so meter readings of conductance and capacitance also increased. When the meter readings showed little or no further increase, the wall was deemed wet.

Poulticing procedure

Water was applied at less than 150 litres/hour to the test area from four nebulous fan sprays positioned about 1 m from the wall to give even coverage. Polyethylene sheeting minimised splashing onto the floor and guided excess water into the guttering. For security reasons, spraying took place only during the normal working day but the extra time this entailed in wetting the wall was negligible.

Two materials were tried, both used in industry as filtering media: sepiolite and attapulgite. Owing to its high shrinkage on drying, sepiolite quickly lost contact with the wall; attapulgite proved much better.

The poultice was hand mixed by adding clay to water. A small cement mixer could have been used, again with the water put in first, contrary to normal concrete mixing practice. Mixing and adding clay continued until a consistency rather like whipped cream was achieved.

The clay paste was applied to the wall to about 25 mm thick by hand using steel floats. Chicken-wire was embedded in the poultice and supported on nails driven into masonry joints to keep the poultice from shrinking away from the wall and falling off. The poultice was allowed to dry naturally; it was an inside wall so needed no protection from rain but windows were left open for ventilation. The poultice was left on the wall for five to 15 weeks: the main criterion for removal was the degree of contact, or lack of it, with the wall.

After removing the poultice, it was necessary to allow the moisture (and salt) distribution in depth to re-equilibrate before further samples were taken and before another cycle could be started. As this was an inside site, spraying could take place during the winter months without risk of frost damage.

The initial concentration of chloride in one block was about seven times higher than that in another; it is assumed that salt would be sucked out faster from the higher one. The last two efficiency figures for the lower one of 46% and 43% show that the extraction rate was slowing. If poulticing had continued on the first block, the chloride concentrations should still fall towards 0.07%, giving an apparent overall efficiency of approximately 96%.

Even assuming that 0.07% chloride is the lowest practicable level attainable, it is still not possible to say that this is a safe level which will not cause further decay.

We have assumed that any reservoir of soluble salts is removed or separated (for example by an efficient damp course) from contact with the masonry. These conditions were not met at the Salt Tower, as there was no damp course and the level of salt in the footings and subsoil was unknown. The site was undeniably damp, being only feet above river level, so rising damp is likely to carry any salt in the ground into the wall.

To check this, blocks were resampled, almost one year after the end of poulticing: salt content had increased.

In spite of this, it has been shown that four or five cycles of poulticing can reduce to a low level the salt content of the inner skin of the rubble-filled wall. Only time will tell if this can be maintained. However, this conclusion could not have been reached without sampling by drilling the actual stone and it cannot be assumed that the same number of cycles will be sufficient at other sites. Sampling is essential to minimise labour and materials waste, though the overall cycle time is increased because of the four to six weeks equilibration time. At an outdoor site, spraying and poulticing can be undertaken only at frost-free periods, and shelter from the rain must be provided.

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Chapter 7
More about dampness

CONSTRUCTION WATER AND DRYING OUT

The water introduced in the course of bricklaying, plastering, concreting and decorating may take a long time to dry out. For this reason, signs of dampness appearing during the first year of a building's life should not necessarily be taken as indicating that there is a fault to be rectified. Indeed, in parts of the construction where impervious or nearly impervious surfaces such as glazed tiling or cement rendering have been applied, evaporation can be so slow that several years may be needed before a brick wall, for example, can be considered dry.

Entrapped water

The industry seems only slowly to be learning the lessons of entrapped water, in spite of the detachment of finishes becoming much more prevalent. For example, entrapment of water in floor slabs leading to failure in moisture-sensitive finishes is fairly well documented and most failures can be dealt with by non-specialists. Even so, many practitioners are unaware of the long drying times for thick concrete bases to dry sufficiently to receive moisture-sensitive floorings.

Concrete drying times

Water moves through concrete partly by capillary action but mainly by diffusion: a very slow process. Unless atmospheric humidity is high, in excess of 90% RH, water can evaporate from the surface of a concrete base as fast as it reaches it. Moisture is never visible once the initial surface water has dried off. The surface may look dry, even though there is still a considerable amount of water below the surface.

Figure 7.1 Dry rot in skirtings following replacement of a timber suspended floor by a solid floor

The rate of drying, and therefore the time to dry a base or screed before floorings can safely be fixed, depends on a number of factors; they include mix proportions, amount of mixing water added, temperature of the floor, relative humidity of the air, and the largest influence on the process, the thickness. A rule of thumb often quoted is to allow a day for each millimetre of thickness for screeds. This has worked well for thicknesses up to 75 mm, although many sand and cement screeds laid semi-dry will be sufficiently dry well within the predicted times. A 50 mm-thick sand and cement screed laid on a DPM commonly dries within four to six weeks. There are proprietary screed systems which dry considerably quicker than conventional screeds.

Thick concrete bases where the DPM is positioned below the slab, with or without a screed on top, take much longer to dry than screeds laid directly on a DPM or in sandwich construction. For example, it is not uncommon for bases 150 mm thick to take up to one year to dry.

The rule of thumb method of predicting drying times does not apply to thick concrete slabs. Commonly, 150 mm-thick slabs with a DPM immediately below take between six and 12 months to dry, but there have been cases where they have not been dry even after 18 months. The mix design of the concrete appears to be a big factor, particularly the cement content and the water/cement ratio, but this area has not been well researched.

Table 7.1 Drying times for screeds and bases

Construction		Estimated drying times
Screed:	50 mm	4 – 6 weeks
	75 mm	6 – 8 weeks
Concrete:	100 mm	4 – 6 months
	100 mm plus screed 50 mm with no DPM between	6 – 12 months
	150 mm	6 – 12 months
	200 mm	8 – 20 months

The actual drying time of a screed or slab depends on many factors and this table is for guidance only. Before laying any moisture-sensitive floors, such as PVC, linoleum, wood blocks or carpets, the moisture condition should be checked with a hygrometer – see BS 8203 and Digests 163 and 364.

Rainwater falling onto an uncovered slab can add more water than was originally in the concrete so drying cannot be assumed to start until the shell of the building is watertight – Figure 7.2.

The problem is compounded where screeds are bonded directly to the concrete base. Some drying of the slab often takes place before the screed is laid. However, the slab is intentionally re-wetted at the time of laying the screed to kill off any suction. With this type of construction, the total thickness above the DPM must be taken into account and, for forward planning, the start of drying taken from when the slab was laid.
If it is impracticable to allow sufficient time for the concrete base to dry out, a DPM or VCL must be laid between the wet construction and the sensitive flooring – Figure 7.3. Conventionally this is achieved by providing a DPM on top of the slab and covering it with a screed which, because it is unbonded,

Figure 7.2 Rainwater can find its way onto newly laid floors, particularly if the building is not weatherproof. Here there is a veritable lake in which the columns and the soffit of the ceiling are reflected

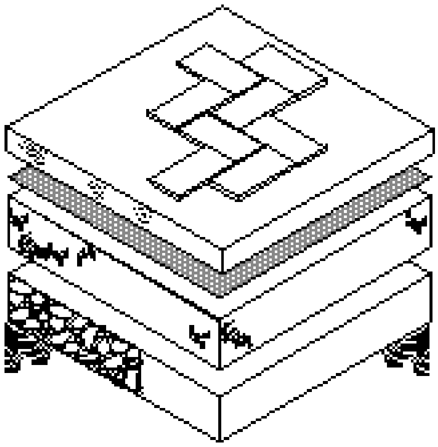

Figure 7.3. If the DPM is placed between base and screed, only the screed needs to be dry

should be a minimum of 50 mm thick. Applying an epoxy bonding agent (which also acts as a DPM) to the surface of the base enables a bonded screed less than 50 mm to be laid.

SURFACE DPMS

Proprietary surface DPMs based on epoxy resins can be applied to the surfaces of screeds or concrete bases. They are most often used where specifiers have misjudged how long a construction will take to dry. Take care that the moisture does not migrate to the edges of the floor to cause damage to unprotected fabric. They are also useful where a building's use is being changed and there is no DPM in the existing floor. In both these cases, solventless epoxy resins have a good track record.

The problem of providing adequate drying time for thick slabs has been known for many years. In 1965, Digest 54 stated that a 150 mm slab would take at least six months to dry sufficiently for a moisture-sensitive finish to be laid and, in 1987, BS 8203 (Clause 11.3), stated that concrete 150 mm thick may require as much as one year to dry from one face only. There is some evidence that industry has still not learned these lessons.

Although there is little experimental evidence one way or the other, BRE experience is that power-floated slabs, having a dense and therefore relatively impervious surface, dry out more slowly than trowelled slabs. Hygrometer readings left in position for at least 72 hours should provide a good indication of the moisture content, even of power-floated slabs.

FLOODING

Immediate action

Immediate action after flood waters have subsided is important in reducing re-occupation times and in minimising repairs and replacement:

- ❒ switch off electricity supply;
- ❒ shut off gas supply;
- ❒ check for structural damage;
- ❒ check drainage system is clear;
- ❒ remove wet soft furnishings;
- ❒ drain cavities;
- ❒ begin the drying process.

Pay close attention to personal hygiene during cleaning because of risk of contamination of flood waters by sewage.

Structural damage

Houses that have been buffeted severely by flood waters or floating baulks of timber may suffer structural damage:

- ❒ undermining foundations on sandy subsoils;
- ❒ compaction of certain soils not previously flooded;
- ❒ in clay areas, ground heave followed by shrinkage as the subterranean water flows and dries out, leading to cracking of masonry;
- ❒ weakened floors affecting the stability of adjacent walls.

Cracks over 5 mm wide, or several narrower cracks occurring together, need further investigation.

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Draining

The building must be drained thoroughly. Although most of the flood waters may have subsided or been pumped away, some might remain:

- ❒ Under ground or basement floors. Lift floorboards carefully and inspect floor voids. The level of the bottom of the floor is usually in concrete but may be earth in older buildings; if it is below the levels of the adjoining ground or paving, water is likely to be trapped. The floorboards may have swollen making lifting more difficult than usual.
- ❒ Under some floors there may be air ducts connecting the floor spaces to the outside; drain and clear them carefully.
- ❒ Within sumps or pits or access to drains. Drain and clear any drains.
- ❒ Old heating ducts or radon ventilation systems.
- ❒ In the gaps between the outer and inner leaves of external and basement walls. You may have to drill holes in the vertical brickwork joints between every fourth brick to allow water to drain away.

Some wall cavities will be filled with insulation material which, although saturated, may not warrant removal of the material. Timber framed external walls or timber framed linings may have to be exposed and dried by taking down radiators and stripping off the internal plasterboard wall linings and skirtings. It is important to maintain essential VCLs, usually of thin plastics sheet, to protect the timbers from condensation.

Cleaning

Scrupulously clear mud and silt and spray the areas. Local authority environmental health officers may give advice.

Inspect the building for signs of trapped mud particularly:

- ❒ Inside wall cavities, taking care to clear the cavity above DPC level. Occasional bricks should be removed carefully and the mud raked or flushed away. If this requires the removal of insulation layers, reinstate them afterwards.
- ❒ Air bricks and vents serving underfloor voids which provide essential air flow to floor timbers. Check balanced flues of boilers and gas water heaters.

Clear mud and other debris away from the base of outside walls as soon as possible. It is vital that the rubbish is cleared away, at least 150 mm below any DPC. Clearance should be rigorous, even when earth has been built up over the years, otherwise bridging of the DPC will cause rising damp.

Drying

Drying out may have to continue for many months before the building can be reinstated completely. The walls, bricks and plaster, absorb large quantities of water during flooding. A solid one-brick wall, for example, may have taken in as much as 55 litres per m^2 and may take more than one year to dry effectively. As the walls dry, efflorescence may appear on the surface. Remove it by brushing when dry taking adequate precautions against breathing the dust. In some cases salts may have been introduced into the walls by sea water which may, over the years, attract more moisture and give similar symptoms to those of rising damp. Here, remove the plaster and replace it with new plaster capable of withstanding the actions of the salts.

Thin walls dry more quickly than thick ones, everything being equal; a thick wall twice as thick of the same material as a thin one, will take four times as

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long to dry. Drying is best effected from the outer surface, though rendered finishes take longer.

Stone walls are likely to dry out more rapidly than those of brick, since they are often less porous. However, rubble cores in the walls may have to be drained just like cavities.

These points are important:
- ❒ keep warm air flowing through the building by heating and ventilation;
- ❒ keep windows and doors kept open to give good ventilation, even when the heating is on; take precautions against housebreaking;
- ❒ remove loose floor coverings and carpets for drying and storage;
- ❒ lift floorboards, especially near walls, to increase draught under suspended floors; this includes upper floors affected by the flooding;
- ❒ strip impervious wallcoverings to help the walls dry out;
- ❒ keep furniture and pictures away from damp walls;
- ❒ keep cupboard doors open.

If the heating system is still operable, set the thermostat to 22° or above, with as much ventilation as practicable.

Inspections

Disconnect and test all electrical installations that have been immersed in water. At the same time, examine and test all appliances: this includes boilers, heaters and cookers. Cables in good condition should not be affected by immersion, but junctions certainly will be.

Open ducts or conduits containing cables to help drain any trapped water. Once the cleaning and drying is completed, arrange for the installation to be tested for earth continuity and insulation resistance as laid down in current IEE Regulations, and issue an inspection certificate. Inspect the electricity installation every month for the first six months after the initial test, and at least twice again in the following six months.

Remedies

Walls

During cold weather, wet walls may be damaged by frost, causing the surface of the brickwork to crack and powder away. Some walls may expand because of the dampness and then contract on drying, producing fine cracks which usually can be dealt with simply by repainting. Some types of wall plaster soften readily when wet and crumble when they dry out again. Others may expand or contract such that replacement is needed.

Timber

Probably the greatest danger caused by flood waters, even months after inundation, is rot in timber. The longer timbers remain wet the more likely they are to rot. It is worth keeping floorboards raised and even introducing special dehumidifying equipment to dry out floors as quickly as possible. Splitting can be minimised by ensuring the timbers dry on both faces, which is helped by removing panelling and skirtings.

All timbers, including door frames, the ends of joists, skirting boards and floorboards, attached to or embedded in damp walls are vulnerable and should be moved away or cut back from the walls. Where joists are embedded in brickwork, supporting metal hangers may be needed instead.

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Salt contamination

Salt contamination from sea water or other sources affects the readings from an electrical moisture meter. If it is possible to accurately measure moisture content of timber, values should be 24% or below when measured from October to May and below 22% for the remainder of the year When the timbers have dried, inspect the underfloor timbers six months later and then again in a year's time. Several types of rot can affect the timbers, which show up as brown or white strands, small orange or white blotches, splitting of the timber and softness nearby and, in extreme cases, the growth of fungus – see *Recognising wood rot and insect damage in buildings* and *Remedial treatment of wood rot and insect attack in buildings.*

Floors

When tongued and grooved floorboards and sheet floor coverings have dried, they may shrink leaving gaps between the boards which may need to be filled or tightened up. Some types of chipboard used for flooring will have swollen during wetting and become permanently weak as a result. The only option here is to replace the material, preferably with one that remains stable when damp.

Wood blocks and other coverings, such as vinyl or linoleum, which have been stuck to floorboards or concrete screeds may have lifted because the adhesive has weakened on wetting. Some materials, particularly wood block and strip, may have swollen and become damaged.

Impervious floor coverings should not be laid until drying out is acceptably complete. Test using a hygrometer: readings should be in the range 75–80%. Valuable timber panelling must be dried thoroughly and not replaced until the backing walls are completely dry. In timber framed walls, take away some plasterboard panels to expose the timber framework and remove the insulation removed as necessary; don't replace the wall linings until drying is complete.

Doors

Panelled doors are unlikely to be affected seriously unless the panels are made of the type of plywood which expands because the adhesive is sensitive to water. Modern flush doors are often more severely damaged and require replacement. Other doors and windows may stick but should not be eased by planing the edges until drying and shrinkage is complete.

Metals

Metals are likely to have escaped serious damage unless seawater flooding has occurred. Steel reinforcement embedded in concrete may corrode and expand causing long-term damage. In other cases, the drying process should leave the metals unscathed, although locks and hinges should be oiled to prevent them rusting and seizing up.

Redecoration

Delay redecoration until the walls have dried thoroughly and use porous coatings, such as emulsion paint, rather than wallpaper. Treat walls with a fungicide if there are signs of mould growth.

Figure 7.4 Persistent leakage from a warning pipe. The warning has gone unheeded

SPILLS AND LEAKS

Spills and leaks are often the cause of dampness – Figures 6.24 and 7.4. Too much water used for cleaning has also been known to cause surface breakdown of sensitive floorings and even, in some cases, to accumulate on DPMs. The water, often carrying residues of corrosive products, passes through joints between impervious coverings, or at the edges of the material under skirtings or external door thresholds.

Diagnosis

When central heating or other water supply pipes leak, water frequently appears some distance away from the source of the leak. Time spent examining drawings before opening up the construction often pays dividends.

Figure 7.5 Vandalism to pipework has led to extreme wetting of the walls and subsequent mould growth

Figure 7.6 Result of frost damage to a plumbing system at first floor level above a cob wall

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CONTAMINATED MATERIALS: SOURCES AND TREATMENT

Animal residues

When agricultural premises are being converted into habitable accommodation, consider the possibility of contamination within the floors and probably splashed up the walls by animal dung and urine. Even though the surface may appear dry and clean, the presence of residual moisture below the surface will tend to migrate to the surface, carrying the salts with it. Any attempt to plaster the walls or to screed the floor without introducing a barrier to resist the transfer of deleterious salts will risk failure. Removing these salts is always a problem and solutions cannot be guaranteed.

Chimneys

Until the passing of clean air legislation, many small domestic chimneys were used to vent solid fuel combustion products. Before the middle of the twentieth century, these chimneys were pargetted internally and sometimes externally with a weak render rather than lined with impervious liners. When the render broke down, or was damaged during sweeping, routes were left for deleterious materials to pass from the flue into the chimney breast or flue walls internally, or the freestanding chimney above roof level. Any future source of dampness, whether it came from inside the dwelling in the form of water vapour, or externally in the form of rain penetration, tended to migrate through the masonry to the external surface of the construction, carrying with it the products of combustion. It is sometimes possible to trace the outline of canted flues on chimney breasts by the resulting discolouration of the surface decorations. In other cases, the deposition of salts on the surface can cause disruption to rendered chimney external finishes and even to the body of porous materials, such as inappropriately used place bricks. Diagnosis is normally fairly obvious from the dark tars or creosotes.

Storage of salts

This problem arises in the conversion of commercial or horticultural buildings to housing. Salts of various kinds were formerly used in small-scale operations to preserve foodstuffs, mainly meat. The residues of these salts, predominantly common salt, can often be found in considerable quantities in the floors and walls. If it is an historic building, removal of disfiguring efflorescence may be a possibility but that will be expensive. The case study on page 198 describes the consequences of failing to line the walls; the case study on page 200 describes attempts to remove some of the salt by means of poulticing the surface.

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COMPLETE LIST OF CONTENTS

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- 3/93 Quality in new-build housing

Defect Action Sheets
- 9 Pitched roofs: sarking felt underlay – drainage from roof
- 33 Flat roofs: built-up bitumen felt – remedying rain penetration
- 114 Slated and tiled pitched roofs; flashings and cavity trays for step and stagger layouts – specification

Good Building Guides
- 3 Damp-proofing existing basements
- 18 Choosing external rendering
- 47 Level external thresholds: reducing moisture penetration and thermal bridging

Good Repair Guides
- 11 Repairing flood damage (in four parts)
- 23 Treating dampness in basements
- 33 Assessing moisture in building materials *(in 3 parts)*

Digests
- 54 Damp-proofing solid floors
- 89 Sulphate attack on brickwork
- 163 Drying out buildings
- 329 Installing wall ties in existing construction
- 364 Design of timber floors to prevent decay
- 370 Control of lichens, moulds and similar growths
- 377 Selecting windows by performance
- 380 Damp-proof courses
- 401 Replacing wall ties
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BS 5493: 1977 Code of practice for protective coating of iron and steel structures against corrosion
BS 5628-3: 2001 Code of practice for use of masonry. Materials and components, design and workmanship
BS 5368 Methods of testing windows
BS 5617: 1985 Specification for urea-formaldehyde (UF) foam systems suitable for thermal insulation of cavity walls with masonry or concrete inner and outer leaves
BS 5618: 1985 Code of practice for thermal insulation of cavity walls (with masonry or concrete inner and outer leaves) by filling with urea-formaldehyde (UF) foam systems
BS 5628-3: 2001 Code of practice for use of masonry. Materials and components, design and workmanship
BS 5889: 1989 Specification for one-part gun grade silicone-based sealant
BS 6232-1: 1982 Thermal insulation of cavity walls by filling with blown man-made mineral fibre. Specification for the performance of installation systems
BS 6232-2: 1982 Thermal insulation of cavity walls by filling with blown man-made mineral fibre. Code of practice for installation of blown man-made mineral fibre in cavity walls with masonry and/or concrete leaves
BS 6367: 1983 Code of practice for drainage of roofs and paved areas
BS 6375 Performance of windows
BS 6398: 1983 Specification for bitumen damp-proof courses for masonry
BS 6477: 1992 Specification for water repellents for masonry surfaces
BS 6515: 1984 Specification for polyethylene damp-proof courses for masonry
BS 6576: 1985 Code of practice for installation of chemical damp-proof courses
BS 6577: 1985 Specification for mastic asphalt for building (natural rock asphalt aggregate)
BS 6925: 1988 Specification for mastic asphalt for building and civil engineering (limestone aggregate)
BS 8102: 1990 Code of practice for protection of structures against water from the ground
BS 8104: 1992 Code of practice for assessing exposure of walls to wind-driven rain
BS 8200: 1985 Code of practice for design of non-loadbearing external vertical enclosures of buildings
BS 8203: 2001 Code of practice for installation of resilient floor coverings
BS 8204-5: 1994 Screeds, bases and in-situ floorings. Code of practice for mastic asphalt underlays and wearing surfaces
BS 8215: 1991 Code of practice for design and installation of damp-proof courses in masonry construction

BS EN 12371: 2001 Natural stone test methods. Determination of frost resistance
BS EN 13755: 2002 Natural stone. Test methods. Determination of water absorption at atmospheric pressure
BS EN ISO 12572:2002 Hygrothermal performance of building materials – Determination of moisture content by drying at elevated temperature
BS EN ISO 13788:2002 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methodsBS CP 102: 1973 Code of practice for protection of buildings against water from the ground
BS CP 144: Part 4: 1970 Roof coverings. Mastic asphalt

About the authors

Peter Trotman served a student apprenticeship with Bristol Aero-Engines Ltd (now Rolls-Royce Ltd), qualifying as a mechanical and structural engineer. He was involved with the provision of facilities for ground running of aero engines. Peter joined BRE in 1967 and spent five years in the Public Health Engineering Section, carrying out research into water services and drainage. He has served on BSI committees dealing with waterproofing of below-ground structures and was a founder member of the Basement Development Group. In 1975 he joined the BRE Advisory Service, and became its Head in 1990, managing programmes of site investigations, lecturing to construction professionals and preparing BRE technical publications. More recently he has become Co-ordinator for the CIB, International Council for Research and Innovation in Building and Construction, Commission W86 – Building Pathology.

Chris Sanders graduated in physics and meteorology in 1973 and worked for BRE in Scotland for 29 years, initially on the risk of condensation and mould in houses and roofs and the assessment of the effects of moulds and mites on health. He carried out the analysis of the condensation and mould data in four English House Condition Surveys. He has produced guidance documents giving advice on avoiding thermal bridging in housing and other buildings and carried out the thermal analysis of the Robust Details that were produced in association with Approved Document L1 of the English Building Regulations. He is Convenor of the CEN Working Groups developing European standards on moisture and climatic data and chairman of the BSI committee revising BS 5250, the code of practice for condensation in buildings. He was actively involved with the UK Climate Impacts Programme and the BRE programme investigating the effects of climate change on future buildings and developing cost effective measures for the repair of housing after flooding. Chris left BRE in August 2003 to become the director of the newly established Centre for Research on Indoor Climate and Health at Glasgow Caledonian University.

H W (Harry) Harrison is an architect. After short periods with a large UK building contractor and a small architectural practice, he joined BRE. He retired 34 years later as Head of Construction Practice Division. At BRE he carried out research into many aspects of the design and specification of buildings and building components, especially of weathertightness, accuracy and jointing. He has served on British and International Standards Committees responsible for putting into practice the results of BRE and other research, and for several years was the secretary of Commission W60, the Performance Concept in Building, of the International Council for Building Research, Studies and Documentation (now the International Council for Research and Innovation in Building and Construction). He was a founder member of the International Modular Group. In later years he became a specialist in building defects, and was responsible for the Housing Defects Prevention Unit and the BRE Advisory Service. In the 1990 Queen's Birthday Honours he was appointed a Companion of the Imperial Service Order for services to building research.

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