CONSTRUCTION RISKS AND REMEDIES CONDENSATION

Several areas of building design and construction exhibit recurring problems. Construction Risks and Remedies is a new occasional series that focuses on these problem areas. The articles will give examples of the most important problems, and will discuss how they are caused and how they can be avoided or resolved.

We begin with condensation, looking at the risks this week and at the remedies next week. Other articles later in the year will be tackling problems associated with thermal insulation and the subject of timber decay.

Part 1: The risks

We should like to thank the following people for their help in the preparation of this article: Lyall Addleson, consulting architect; Dr William Bordass, consulting building scientist; Professor Peter Burberry, UMIST; Keith Darby, architect, Feilden & Mawson; Ecclesiastical Architects' and Surveyors' Association; Peter Falconer, architect, Falconer Partnership; Kenneth Johnson, Pilkington Brothers Research & Development; Roger Jowett, architect, Bickerdike Allen Partners; staff of the BRE, particularly J. L. Smith.

Contents: Part 1

1 Condensation processes
1.1 Saturation
1.2 Dewpoint
1.3 Vapour content and structural temperature
2 Water vapour input
3 Water vapour movement
3.1 Diffusion: the uncertainties
3.2 Diffusion rate
3.3 Air movement
3.4 Intermittent heating
4 Conditions for surface condensation
4.1 Walls
4.2 Roofs/ceilings/floors
5 Conditions for interstitial condensation
5.1 Walls
5.2 Roofs

Contents: Part 2 (AJ 16.4.86)

1 Condensation avoidance
2 Humidity control
2.1 Dehumidification, controlled condensation
2.2 Water vapour emission
2.3 Removing water vapour at source
2.4 Ventilation at potential sites of condensation
2.5 Pitched roofs and ventilation
3 Controlling vapour movement
4 Adding insulation
4.1 Surface condensation
4.2 Interstitial condensation
4.3 Condensation in sheeted roofs
4.4 Lead roofs
5 Heating
5.1 Design temperatures
5.2 Heating and insulation: houses
5.3 Intermittency
6 Mould

Any assessment of condensation risk has to start with the question, 'does it matter?' Transient misting of windows and mirrors is usually tolerable. Water collecting at the bottom of a window can be coped with by drain holes, although some occupants will complain of draughts. Condensation in a drained and ventilated wall cavity probably does not matter, although some experts view the long-term effect of saturation of outer brick skin and the freeze-thaw cycle with concern.

Buildings are often more sensitive to condensation now than they were when plaster and brick surfaces were more absorbent. A bit of condensation could be 'stored' in such materials and slowly released when the conditions changed. A thin layer of hard plaster on a concrete wall panel does not do this. Buildings were 'leakier', so there was a higher air change rate, and, for some people at least, there was less concern to save energy. Open fires not only warmed the structure, but ventilated the room.

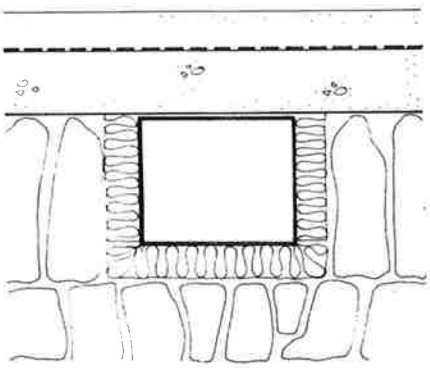
Heating systems now are often used for quick bursts of heat over short periods of the day, which warms the air, letting it take up more water vapour, while having little effect on structural temperature. Condensation risk is greater when the air temperature drops again because of the combination of cold structure and higher dewpoint temperature. Quiet country churches may suffer from this problem just as much as tower blocks.

The acute domestic condensation problem dates from the 1960s, when construction changes were combined with a move to reduce heat lost by ventilation. More recently simple shed-like industrial buildings have been expected to shelter increasingly sophisticated and sensitive operations and equipment without enough being spent on their construction.

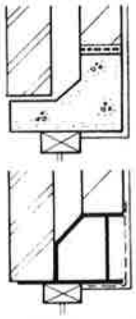
It also depends on an element of informed judgment for which simple adherence to BS codes is unfortunately not an adequate substitute.

RISKS BY BUILDING TYPE

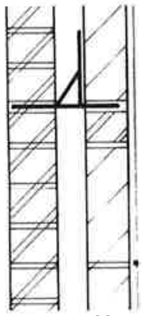
Housing



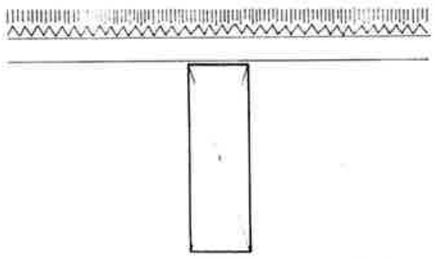
Failure to provide water-protected insulation to underfloor warm air ducts. Condensation caused and water vapour blown round house when system restarts.



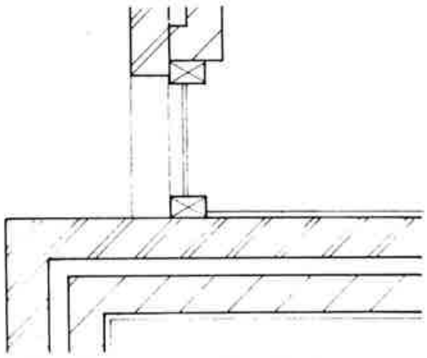
Certain types of lintel act as cold bridge in well insulated walling.



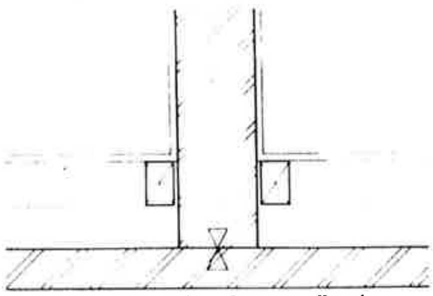
Brick used in blockwork to make up coursing. Local change of U-value results.



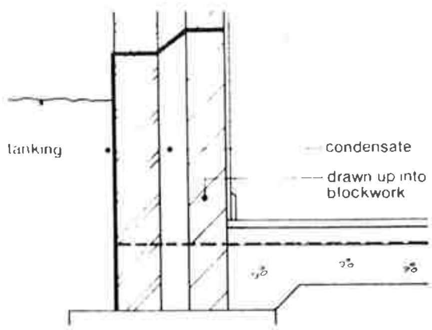
Rubberised carpet underlay prevents stack effect air infiltration through floor construction and forms vapour check. High r.h. caused by construction water or from earth below the floor has caused rot in suspended floor chipboard.



External leaf becomes internal leaf. Mortar bridging cavity or unfilled perpends to blockwork cause condensation staining.



Cold bridge at junction of party wall and external leaf. Structural and fire safety require contact; damp-proofing and insulation require separation.

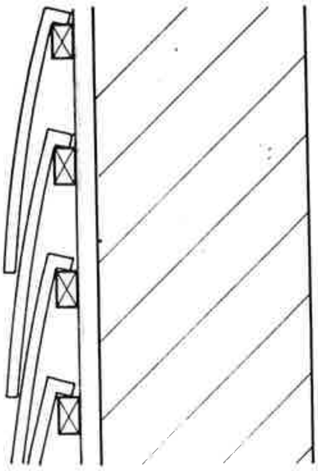


No insulation to the retaining wall. Other examples, for instance failure to continue insulation into eaves, given in BRE Defect Action Sheet No 4, July '85.

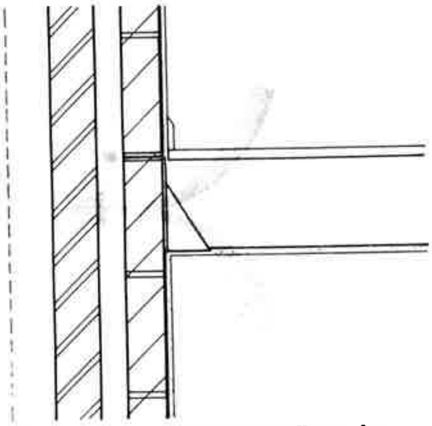
Table I BRE estimate of extent of condensation in English housing*

	Owner occupied/%	*Private rented/%*	*L.A./%*
No condensation/damp	58	48	39
Condensation on windows	33	32	45
Deterioration of paint on sills	9	15	21
Mould or damage to decorations	9	27	23
Damage to floor, carpet, furniture	1	6	3

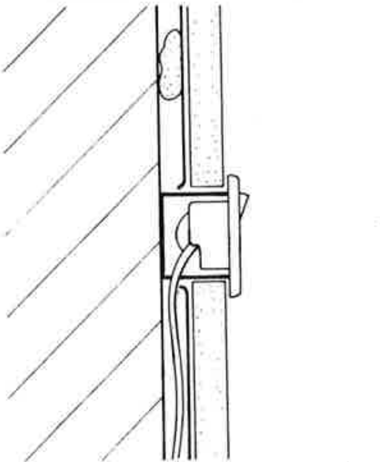
*From BRE Digest 297 May 1985



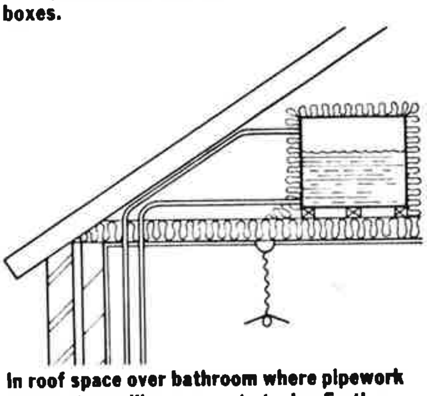
Impermeable material used as sarking behind board or tile cladding. Danger of wall dampness or rot in battens.



Vapour retarder interrupted at floors, for example when using film-backed plasterboard.

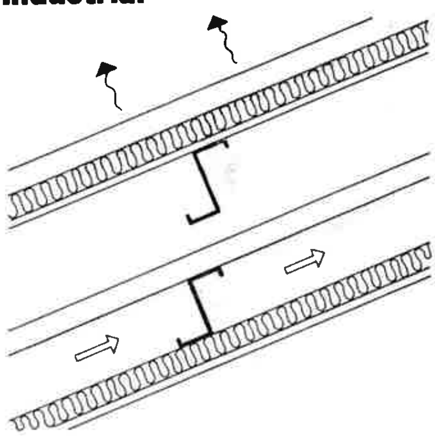


Vapour retarder interrupted in walls, for example by electricity socket and switch boxes.



In roof space over bathroom where pipework penetrates ceiling on way to tanks. Further examples in Defects Action Sheets:
No 1 *Cross-ventilation of roofs* May 1982;
No 3 *Reducing water vapour flow into roof* June 1982;
No 59 *Converting to warm deck flat roof* September 1984.

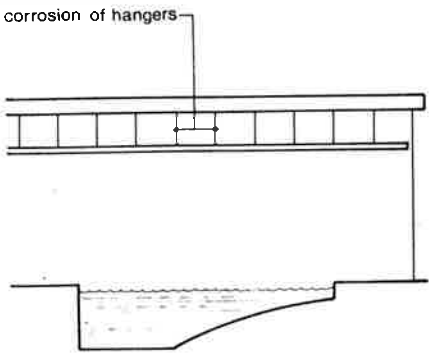
Industrial

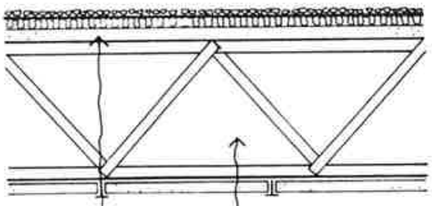


Profiled roof sheeting with insulated or uninsulated lining board. Sheet loses heat by radiation to clear winter night sky, cooling below ambient air temperature. Water vapour condenses, either from factory interior through joints fixings, services and so on or from outside air penetrating from eaves. Ice can form, water collected in/on lining or insulation. Ceiling sags, leaks, falls. Stains may follow line of purlins. Problems from October to April. No obvious difference between steel or aluminium; fibre cement can be affected (see AJ 12.6.85 p73-74), but less so.

Pools

Includes other very humid environments—laundries, knitting and other yarn processing, animal houses.





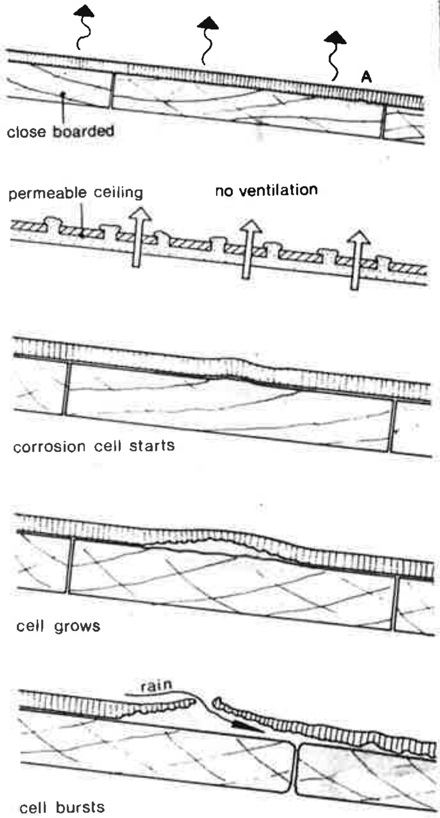
Many failures have occurred in small pools, where conventional built-up felt flat roof relies on natural ventilation. Relative humidity can be 100 per cent inside and condensation occurs on any surface below pool water temperature. Ceiling tiles stain, metal corrodes, chipboard decking and fibreboard insulation sag and rot.

A suspended concrete ceiling over a Swiss pool collapsed when corroded hangers failed.

More sophisticated designs using pressurisation of the ceiling void with heated air have failed when operators reduce temperature, turn off extract fans or reduce flow rates to save energy. If recirculated air is used for pressurisation it has be dehumidified.

Some recent condensation failures have occurred in multi-purpose sports or leisure buildings where the enclosure of the pool part of the building is incomplete. The problems often develop at roof level, where moisture vapour from the pool condenses in the structure of another part of the complex with insulation and ventilation of a lower standard.

Ecclesiastical



The Ecclesiastical Architects' and Surveyors' Association (EASA) is about to publish a report, *Corrosion of lead roofing.* The following is based on its findings. Metal roof to churches are prone to condensation cooling by radiation to the sky. Sometimes condensation on underside of the metal causes corrosion and sometimes rot of the substrate.

Symptoms

- pin holes, usually in groups, may cause patchy damp inside
- hard white discolouration on underside of lead (lead sulphate)
- softer, crystalline, loosely adhering voluminous corrosion product on underside or as soft whitish flakey areas on external, especially vertical, surfaces. Spreads over larger and larger areas, causing leaks.

The first can be a product of the third or a result of external attack or casting sand in the lead. The second is not progressive and forms a protective coat.

Cause

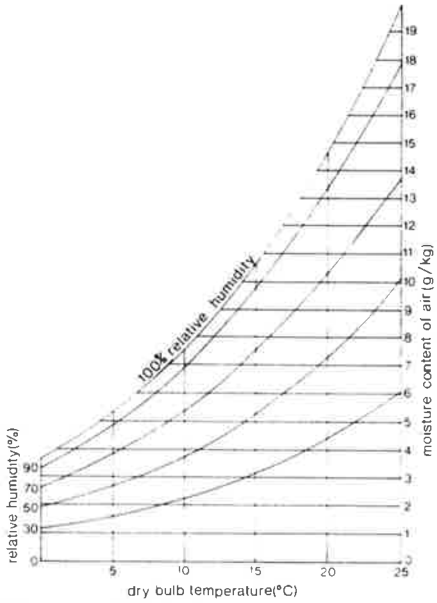
Acetic acid vapour can be emitted from timber, if it is abnormally wet (over 18 per cent moisture content, for example as result of condensation) rate of evolution is aggressive.

Oak is the most aggressive producer of acetic acid vapour, and lead, copper, aluminium and terne-coated stainless steel are all susceptible to it.

The introduction of heating, especially intermittent heating, increases the condensation risk. There is also less ventilation nowadays and, in the major churches and cathedrals where the worst problems have been found, the moisture input has increased markedly because there are so many visitors. The old heating plant was either much more vigorous, with high air flows induced by the flue, or it was on all the time, and did more to warm the structure.

The EASA report suggests that condensation is a key factor. Lead is vigorously attacked by distilled water in the presence of air low in CO_2. If there is little ventilation below the lead sheet, CO_2 in the air may feed the formation of lead carbonate.

RISKS BY PHYSICAL PROCESSES



1 Psychrometric chart.

1 Condensation process

1.1 Saturation

There is a limit to the amount of water vapour that air can hold, and this varies with temperature (and barometric pressure, although this is not normally significant). When, because it is cooled, a parcel of air reaches this limit (the saturation point), water may begin to condense. In buildings this is most obvious on visible surfaces, but it can also happen inside materials or in construction cavities. In meteorology the same physical conditions produce mist, cloud, rain, dew, fog and other delightful features of the British climate.

1.2 Dewpoint

From the meteorological world we get the term dewpoint, which is another word for the saturation temperature. The dewpoint temperature is that at which condensation can start to appear. It varies with the ratio of water vapour to air. The excess water vapour is dumped instantly as liquid although in practical terms, since cooling is often a surface phenomenon, large volumes of air are not cooled all at once. The rate at which water then condenses out increases according to how far below its dewpoint temperature the cooling surface is. Condensation continues until the amount of water vapour in the air has been reduced to the new limit applicable to the new temperature. The physchrometric chart, *1*, shows how temperature and water vapour content are interrelated.

1.3 Vapour content and structural temperature

Basically condensation risk arises in buildings because the air inside contains more water vapour than that outside, as a result of people or processes inside the building.

Unless this vapour is carried away by ventilation and replaced with drier air, the air in the interior will become saturated, and moisture will condense in and on the fabric and contents of the building wherever the temperature is below dewpoint. Vapour may also diffuse through the envelope to the exterior, although this is a slow process. It can lead to condensation within the cooler parts of the fabric. Air carrying vapour can be drawn through cracks by wind or stack effect pressures into cold parts of the construction.

Thermal insulation, in the right places, can reduce this risk and the likelihood of condensation on internal surfaces by raising the temperature of the fabric. In the wrong place insulation can exacerbate the problem by making parts of the fabric colder. Space heating plays a dual role. By raising the structural temperature, condensation risk can be reduced. However, warmer air can absorb and transport more water vapour to cooler parts of the building and intensify condensation there.

As a rule, naturally ventilated buildings that do not house a moisture producing material or process are not subject to condensation. Condensation *can* happen in these buildings, simply as a result of changes in weather conditions, but in most cases this is a transient and fairly unusual phenomenon (however, see night sky radiation, 5.2 below).

The basic principles are therefore quite simple. Unfortunately, as one moves away from these broad generalisations towards a quantitative analysis of the processes, complexity and uncertainty increase.

2 Water vapour input

On a typical winter's day, outside air at 90 per cent relative humidity (r.h.) and 5 °C contains about 5 g/kg of water vapour. Bring this air into a building and heat it to 20 °C and its r.h. will drop to about 35 per cent. At 20 °C it can hold about three times as much water vapour. Table II shows some estimates for the rate of water vapour emission of a range of (mostly domestic) activities. In non-domestic buildings the main sources of water vapour will be people and any particular (industrial) processes that are carried out inside.

One other major source of water vapour is the mixing water used in many construction materials. A new house may contain 4000 litres of water (see Table I). This is released over a year or more and can upset anti-condensation measures.

The energy required to dry construction water out, in the form of latent heat of evaporation, can absorb a significant part of a heating system's output. Lower room and structural temperatures resulting from this may also add to the condensation risk.

It has to be emphasised that these figures are only estimates, and wherever they are related to the behaviour of the individual there can be wide variations. Figure 4 shows how different values for the moisture content of the air can affect the prediction of condensation risk.

Particularly in houses, where the volume of rooms is small, it is important to try out a range of values for vapour input, and thus relative humidity, when doing condensation risk calculations.

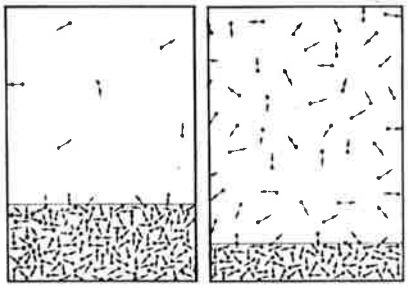
BS 6229, the code for flat roof design, was criticised by all the experts we spoke to, and one of their objections was too close a reliance on specific moisture input rates.

Table I Construction water

Material	*Water in litres/m²*
105 mm brickwork	33
100 mm blockwork	40
150 mm in-situ concrete	30

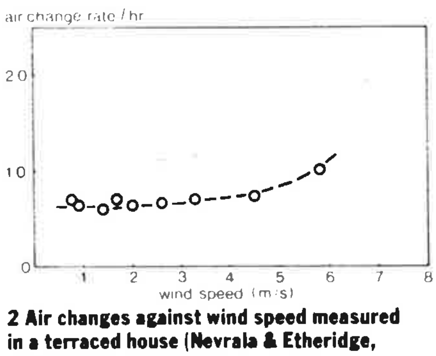
Box 1: Physics and terminology

On the kinetic model, molecules are in constant motion and as the temperature is raised this activity increases. The more energetic molecules in a pool of water can escape into the air above, evaporate, where they contribute to the total atmospheric pressure by an amount called the water vapour pressure. The warmer the system is, the more molecules there are that are active enough to enter the vapour phase, and the water vapour pressure increases. The overall activity of the system—its temperature—determines the maximum number of water molecules that can exist in the vapour phase, and air that is holding this maximum number is said to be saturated. The vapour pressure at that point is the saturated water vapour pressure.



Lower temperature. Higher temperature.

The figures above demonstrate the effect (after Burberry). Some other terms and their units are:
Absolute humidity (or moisture content)—weight of water vapour per kilo of dry air: unit kg/kg or g/kg.
Mixing ratio—ratio of mass of water molecules to mass of air molecules in the sample (essentially the same as absolute humidity).
Relative humidity, r.h.—the quantity of water in air as a percentage of the maximum which could be contained in air at that temperature: units: percentage r.h. at temperature °C.
Vapour diffusivity— the rate of vapour transmission through unit thickness of material under unit pressure differential: units, kgm/MNs or gm/Ns. In practice it is often easier to work in diffusance which is the rate for any stated thickness of material.
Vapour resistivity, r_v—reciprocal of vapour diffusivity: units MNs/kgm or MNs/g.



2 Air changes against wind speed measured in a terraced house (Nevrala & Etheridge, British Gas).

Table II Water vapour emission rates*

Source	*Rate*	
People (respiration):		
resting or asleep	0·04 kg/hr/person	
sedentary activity	0·05 kg/hr/person	
active, sweating	0·2 kg/hr/person	
Combustion in flueless appliances:		
gas	0·81 kg/m³ of gas or 0·64 kg/hour of use for a typical domestic cooker	
paraffin heater	1 kg/litre of fuel	
Laundry:		
clothes washing	2 kg/day	
clothes drying	12 kg/day	
Washing:		
bath	0·05 kg/bath taken	*roughly* 1 kg per day in a five-person house
shower	0·23 kg/shower taken	
dishwashing (3 meals/day)	0·5 kg/day	
Cooking and preparation (excluding combustion)	2·5 kg/deg	
Kettle, boiling	0·03 kg/minute	
Pot plant, respiration and watering	0·84 kg/day	
Wetted surfaces*, pools or tanks: 16 × wetted surface area (m²) × (SVP at water temperature − VP of surrounding air) gives evaporation rate in g/hr		

*after Millbank of BRE.

3 Water vapour movement

Bulk air movement is the main means by which water vapour is distributed. Besides mechanical air-handling, air movement results from pressure effects caused by the wind or by 'stack effect' differences of air density.

Water vapour is not emitted uniformly throughout a building and absolute humidity will vary from room to room. These differences mean that the water vapour pressure (see box 1) is different from place to place. The imbalance creates a driving force, causing diffusion of the vapour. Diffusion is akin to heat conduction and is relatively easy to explain under steady state conditions. A vapour pressure difference causes vapour molecules to move at a rate which depends on the pressure gradient and the permeability of the medium. The movement does not require air movement, as only the water vapour moves.

Work by British Gas and others including Trada, John Laing and Pilkington Brothers, has shown that, in winter, the stack effect is a very important means of ventilation in houses, *2*. Its absence in flats is one reason why they may suffer more serious condensation than maisonettes or houses.

Although design calculations for condensation risk and its removal need figures for ventilation rate and diffusion rate, there is still a great deal of uncertainty in this area. Computer programs and design methods are available, for example in BS 5250 (the code on condensation in dwellings) and BS 6229 (the code for flat roof design), but they are based on assumptions that might not be appropriate to the problem.

3.1 Diffusion: the uncertainties

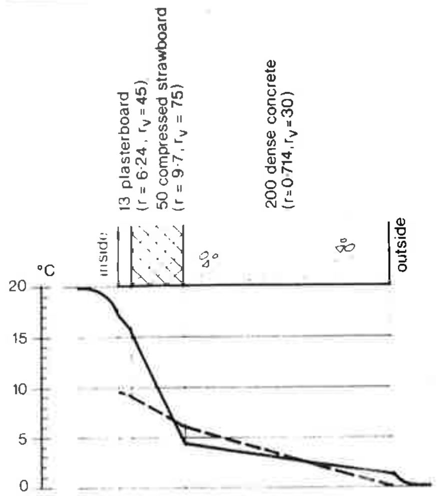
The accuracy of BS 5250 calculations to check the risk of condensation is very limited. A good computer program based on the BS may help, not because it is more accurate, but because it allows several 'what if' calculations to be done to test the sensitivity of the design. Very few programs are based on more sophisticated principles of calculation.

Consider some of the potential inaccuracies in just one factor—the vapour pressure differential across a piece of construction, a roof or external wall that is used for condensation risk calculations.
It assumes:
- interior design temperature
- water vapour content of interior air
- exterior temperature and r.h.

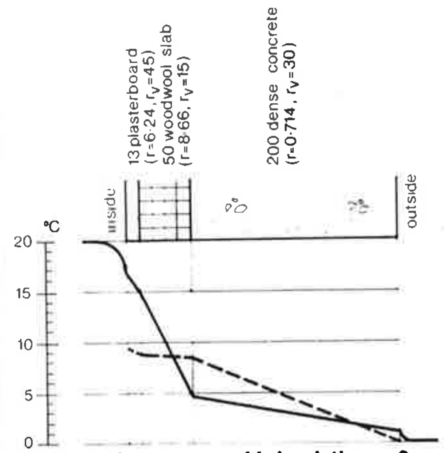
Temperature
Design temperature and actual temperature may differ because of inaccuracies in heat loss calculations, heating system control performance, building occupants' use of the controls, occupants' activities differing from design assumptions, or differences between design and construction. The steady state assumption that internal and external temperatures are constant is also inaccurate.

Water vapour content
The water vapour content of the interior air depends on vapour emission rates which are highly variable both in the short term and over longer periods, according to occupants' behaviour. It also depends on the ventilation rate and the way vapour moves around the building. These factors vary tremendously according to wind speed and direction, whether windows and doors are open, and on the background leakiness of the building (the small cracks and openings that are not designed), *5*.

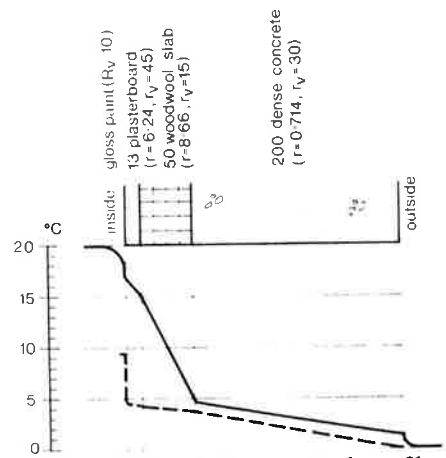
Permeability
The permeability of the construction is another factor on which information is



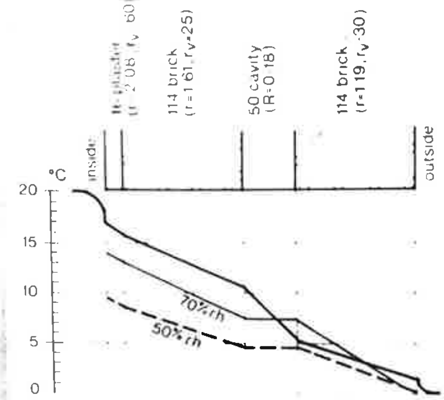
3a Condensation risk example.



3b Effect of more permeable insulation on 3a.



3c Effect of gloss paint vapour retarder on 3b.



4 Effect of different r.h. assumptions.

scarce, divergent and probably inaccurate. The standard permeability tests were devised for use on packaging materials, and the conditions and size of sample may not be appropriate to the environment of buildings. Cracks, openings and variations in material porosity combine with these uncertainties to make it pointless to rely on the accuracy of calculations involving permeability (or resistivity, see box 1). One expert we spoke to said that where low permeability seemed to be important—where a vapour retarder was needed, for example—he tested the calculation to see what was the effect of reducing the resistance of the supposed 'barrier' by a factor of 10. The Swedish-Finnish Timber Council has used the same factor to represent a poor or damaged vapour check. However the methods available are able to sort out the safe from the totally unsafe designs. Figures *3*, *4* show how condensation risk assessment is sensitive to some of these factors.

3.2 Diffusion rate

Bearing these qualifications in mind, it is possible to make an estimate of the rate at which water vapour diffuses through the building envelope to outside air.

The expression used is:
vapour transmission rate kg/s = area of material (m^2)
× vapour pressure across material (N/m^2)
÷ vapour resistance (MN s/kg).

(It is sometimes expressed in g/day).

For composite construction with layers of different materials, the sum of the vapour resistances of the layers is used. There are surface resistances to vapour flow like those used in heat flow calculations, but they are unimportant, given all the other approximations made.

The water vapour pressure difference between air at 22°C and 50 per cent r.h. and outside air at 0°C and 50 per cent r.h. is about 1 KN/m^2. Water vapour will penetrate the slightest weakness in any would-be vapour barrier.

Diffusion is too slow a process to offset most of the vapour emitting processes. For example, diffusion alone might account for the loss of roughly 3 g/hr water vapour through a 225 mm external wall of permeable brick of 6 m^2 area. A person sleeping in the room would produce about 40 g/hr of vapour.

3.3 Air movement

Water vapour can be moved much more rapidly by bulk air movement than by diffusion. In the example in 3.2 above, where diffusion could not cope, the r.h. could be maintained at 60 per cent by introducing air from outside (0°C, 100 per cent r.h.) at less than one-third air change per hour.

Unfortunately, if air movement is the main mechanism of water vapour transport, the risk of condensation is much harder to estimate than if diffusion rules. This is because, as already explained, natural ventilation is highly variable. Nevrala & Etheridge* found that at low wind speeds (up to about 4 m/s when ambient temperature is 20°C) stack effect dominates air movement, *2*, but above that 'large changes in ventilation rate due to changes in wind speed and direction are likely to occur often'. However, work on natural extract systems for houses using the stack effect (discussed in detail next week) has shown that it is possible to design a self-regulating system that functions at low wind speed without being draughty when it is windy.

3.4 Intermittent heating

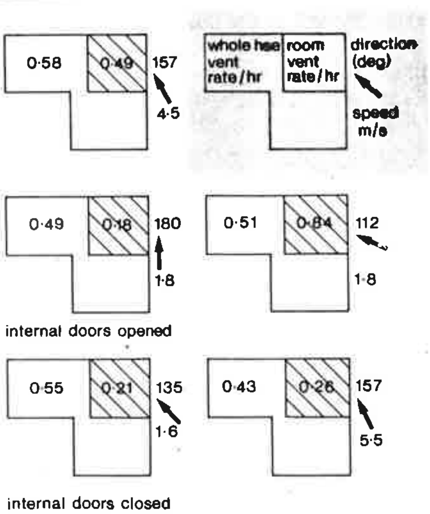
Design based on steady state heating with an unchanging temperature profile through the structure can be misleading, as figure 6 shows.

Ventilation of domestic buildings, No 6 in Energy Efficiency Studies series paper by Nevrala & Etheridge.

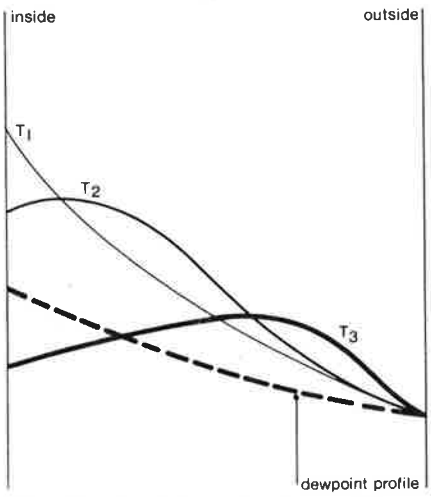
Table III Water vapour resistivity—examples of the range of values*

Material	*Resistivity GN.s/kgn*	*Resistance GN.s/kg*
Aerated concrete	40-54	
Aluminium foil		175-10 000
Asbestos cement	2·08-3·5†	
Brickwork	25-100	
Corkboard	250-333	
Expanded polystyrene	100-600	
Exp. polystyrene bead board (25 mm)		6·7-10·5
Foamed polyurethane, open cell	29-181	
Foamed polyurethane, closed cell	1000	
Foamed ureaformaldehyde	20-33	
Fibreboard	15-60	
Hardboard	500-1000	
Kraft paper		0·22-0·62§
Gloss paint, average		7·5-40
Mineral wool	6	
Plaster	60	
Polythene (0·1 mm)		219-250†
Roofing felt		4·35-100
Plywood	1500-6000	
Woodwool slab (25 mm)	14·3-41·6	0·24-0·32

*From Prangnell R. D., *Materiaux et constructions* no 24, vol 4—Nov-Dec 1971 †Varies according to whether 'dry cup' or 'wet cup' test method is used §Range covers from single ply to five ply paper



5 Ventilation rates vary with wind conditions (British Gas).



6 Consideration of dynamic, as opposed to steady state, heating conditions may show risk of condensation. T_1, T_2, T_3 are structural temperature profiles as the element cools down from design room temperature to cold. Intermittent heating in heavy weight structures can give surface condensation.

4 Conditions for surface condensation

Surface condensation occurs because air that is 'too' heavily loaded with water vapour meets 'too' cold a surface.

4.1 Walls

Table IV lists factors that have a bearing on surface condensation.

4.2 Roofs/ceilings/floors

The general causes of surface condensation are much the same as for walls. Ground floors at the perimeter and projecting upper floors can exhibit cold bridge effects, especially where the latter are in-situ concrete. A similar problem has afflicted ceilings under inadequately insulated external balconies and walkways (AJ 1.8.79 p222). Solid floors with edges that are exposed on the perimeter or concealed only by thin cladding, such as brick slips, also form cold bridges.

Ceilings beneath pitched or flat roofs with voids of significant depth (not solid concrete roofs) are not often prone to surface condensation because they are relatively light and warm up quickly and because they benefit from the insulating effect of the void above (which almost always has some added insulation nowadays).

But serious condensation on surfaces within that void, and especially the underside of the roof, is common. The particular problems of ceiling voids over swimming pools and high humidity industrial processes, and from the night sky cooling of metal roofs, were mentioned in the first part of this article.

BRE Defect Action Sheets 1, 3, 4 and 59 address the condensation problems caused by providing insulation at ceiling level without taking steps to reduce the movement of water vapour into the roof space, and to ensure its removal by adequate ventilation.

4.3 Mould growth

Mould on walls, floors or ceilings is evidence of dampness of that surface and condensation that persists for any length of time will give rise to it. Once established, many kinds of mould can withstand drying out. A relative humidity of about 70 per cent is the minimum level in the atmosphere that will sustain growth. Some surfaces, wall paper beside a window sill for example, can be saturated with condensate running off adjoining construction even though the atmospheric r.h. is below 60 per cent.

Moulds can grow without light. They flourish in or on paint films and on wall paper and wallpaper paste. Vinyl papers, though relatively impermeable, can suffer stains from mould growing underneath them.

There is some evidence that high concentration of mould spores can be a contributing factor in sick building syndrome. Some people are allergic to certain spores. Spore concentrations in rooms with heavy growths will be much higher than normal.

Table IV Causes of surface condensation on walls

Surface too cold: room inadequately heated	Heating can raise the surface temperature of structure and reduce risk, but condensation may become interstitial. If ventilation is not adequate, heating may also promote processes that cause more condensation to occur
Room intermittently heated	Heavy construction slow to heat up, stays or becomes below dewpoint as air temperature rises, especially if ventilation inadequate. If the heated air takes up more vapour there is more chance of condensation on the still-cold structure when the heating goes off because the dewpoint temperature has been raised. Same total amount of heat at lower level, but constant, might avoid condensation
Lack of insulation	Surface resistance to heat transfer means surface temperature always below internal air temperature, if U-value is poor, for example, single pane glass, condensation can occur, though r.h. in room is only 40 per cent. Planned condensation on glass can dehumidify the air somewhat
Cold bridge	Local reduction in insulation or increase in external surface area such as solid lintel, metal window frame or external fin
Local internal insulation	Furniture, curtains and so on reduce heat transfer from rest of room and allow local cooling of surface and air
Radiative losses	Areas such as window reveals can lose heat by radiation through glass to cold night sky, the geometry of corners increases the surface to volume ratio and therefore radiation losses
Relative humidity too high: water vapour emission rate too high	Some activities, see Table III, have particularly high vapour emission rate
Ventilation rate too low	Condensation is bound to be a problem unless average water vapour removal rate is removed as fast as it is being added to the air

Box 2: Identifying condensation

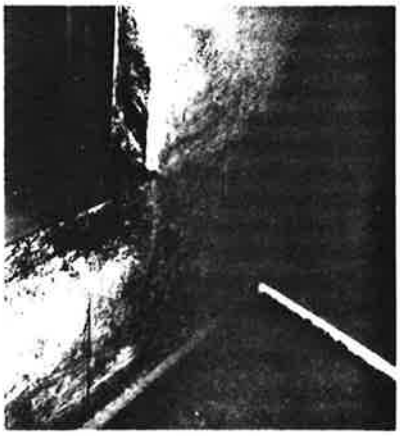
When damp occurs in a building, condensation is not the only possible cause. It could be the result of rain penetration, rising damp or leaking pipes or tanks. How do you tell?

Condensation problems are related to the weather to some extent. They tend to be a winter phenomenon, especially when there is little wind, the r.h. is high, or the nights are clear. If the symptoms coincide with periods of rain, then the chances are that it is a penetration problem rather than condensation. But there are exceptions to this, such as the condensation caused by the flow of cold rainwater in pipes or gutters.

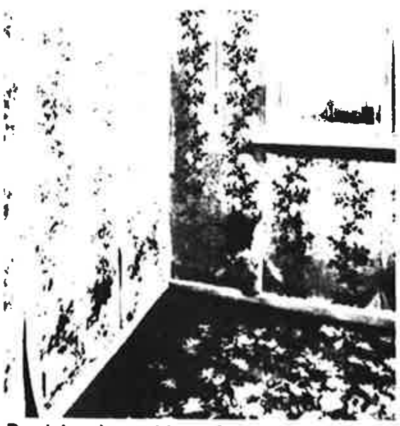
Condensation damp patches tend to be diffuse, *A*, without sharp edges, whereas rising damp often produces a tidemark effect, *B*. Condensation often shows around openings where there are cold bridges (for example, solid lintels) and the possibility of radiation to the outside, or where the external surface area of the wall increases locally so that heat loss is greater.

The upper corners of rooms, especially at eaves level, are very common condensation sites for this reason, and because there is probably less air movement there.

Another sign that a damp problem may be a condensation one is that the markings often have a pattern to them that can be traced to some construction feature, cold bridges due to fixings, for example.



A—typical condensation mould growth in a corner.



B—rising damp tidemark.

5 Conditions for interstitial condensation

As mentioned in section 3, the accuracy of calculations to check the risk of interstitial condensation is severely limited. However, the simple steady state model gives useful information for constructions that respond quickly to thermal and moisture changes, and is a worthwhile indication of the extent and location of possible condensation in other heavier constructions. The point is not to apply these results without reservations.

5.1 Walls

The cases of interstitial condensation in walls that the experts we spoke to have seen were almost all due to breaches in the construction, rather than failure to anticipate the location of the intersection point in the structural temperature and dewpoint temperature profiles. Unsealed openings for services or failure to continue insulation or vapour checks are typical causes.

Many insulation materials have relatively high water vapour permeability and adding insulation to the inner face of walls without a vapour check tends to increase the risk of interstitial condensation. The insulation lowers the structural temperature while making little or no difference to the dewpoint profile, 7. If a less permeable insulant is used, more care is needed in detailing and construction to avoid gaps which would probably cause heavy local condensation.

Metal sheet cladding can be cooled below ambient air temperature by radiation to a clear winter's night sky. The space behind the cladding is often ventilated to the exterior and condensation is possible if the r.h. is high, regardless of conditions inside the building and whether there is a vapour barrier in the wall or not. Theoretically cladding finished in dark colours should be at greater risk, but in practice the differences are minor.

5.2 Roofs

The outer surface of a roof with radiation losses to a cold night sky (with an effective temperature that can be as low as −50°F), it can be the coldest part of the building. In built-up felt and polymeric membrane roofing the outer layers are also of high vapour resistance. There is, therefore, a big risk that water vapour will accumulate below this sort of covering and condense. Added to this is the difficulty of ventilating the spaces between joists of a typical domestic-scale cold deck flat roof.

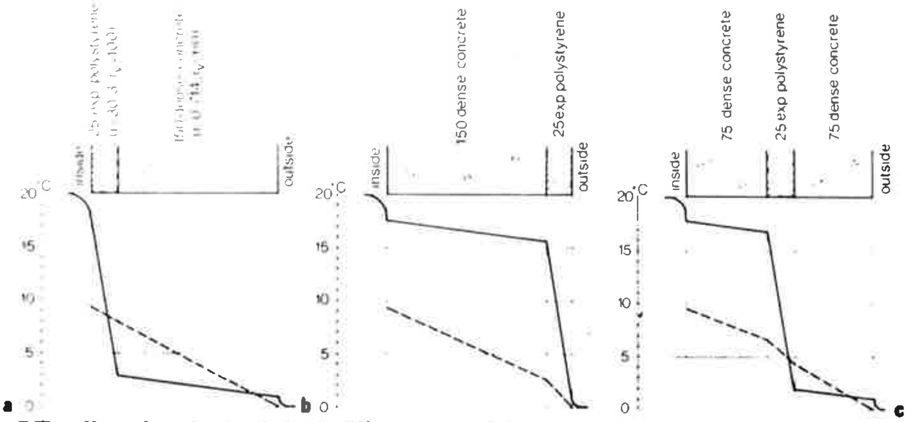
The other widespread cause of roof condensation has been the extra insulation we now install at ceiling level. Experience of insulation above, or at, rafter level suggests that this may be a more certain way of avoiding condensation. The roof space is warm and does not require cross-ventilation, so does not depend on wind to prevent condensation. However, it is more expensive.

Some experts we spoke to would not consider using a flat roof with insulation below the waterproofing layer, because they consider the chances of failure are too high.

In the AJ of 12.6.85 (pp73-74) the increasingly common failure of sheeted industrial roofs was discussed. It is interesting to find that the then Building Research Station investigated the problem in the mid-1950s (National Building Studies: Research Paper No 23 *Condensation in sheeted roofs*, HMSO, November 1957).

There are at least three main features to the industrial roof problem: the impossibility of stopping water vapour penetration into the roof from below, the large and rapid swings in temperature under the metal top sheet, and the large areas of construction involved.

In most cases penetrations of the inner lining boards for fixings and services and the gaps between boards allow vapour free entry to the roof, helped by stack effect and wind pressures. Condensation occurs in or above the insulation, and ice is often formed. This melts quickly in the morning sunshine and in effect concentrates the product of an otherwise slow condensation process. In any large roof it is likely that there will be flaws in the construction to let the water into the building. Fixings also loosen enough with time to let water through.



7 The effect of putting insulation in different parts of the construction; a, on inner face, b; in the middle; c, outer face (after Addleson).