Energy File

CONDENSATIO

and how to avoid it

CI/

**Condensation is widespread and is costing millions in remedial measures, yet the architectural profession has paid little attention to the relevant moisture properties of its buildings.
There are no instant answers. This article by PETER BURBERRY provides the latest available information for architects to understanc why condensation may occur in their buildings (this supersedes earli AJ articles on condensation).**

Significance for architects

2 - JA

Condensation—a growing problem

Condensation has not always been an acute problem in dwellings or buildings generally. But now very large numbers of dwellings, often of relatively recent construction, are being affected and as energy becomes more expensive measures to save fuel are likely to increase the incidence and intensity of condensation problems.

The nature of activities within buildings and patterns of use on one hand and the nature of building fabrics and installations on the other are the two determinants of whether condensation will take place. Occupants of buildings vary greatly in the ways in which they use the facilities. At the extremes of behaviour there is no practical design provision which could avoid condensation, but the majority of occupants could reasonably expect to find their buildings so designed that normal use will not result in condensation problems.

Condensation in dwellings

Is the cause of the relatively recent increase in condensation problems in dwellings their changing patterns of use and occupancy or changes in design, construction and installation? The main change in occupancy over the past 30 years is that dwellings are increasingly left unoccupied during the day. A consequence of this is the tendency to shut windows for security purposes and to limit heating to actual periods of occupation. This might not be of major significance for condensation were it not for changes in buildings.

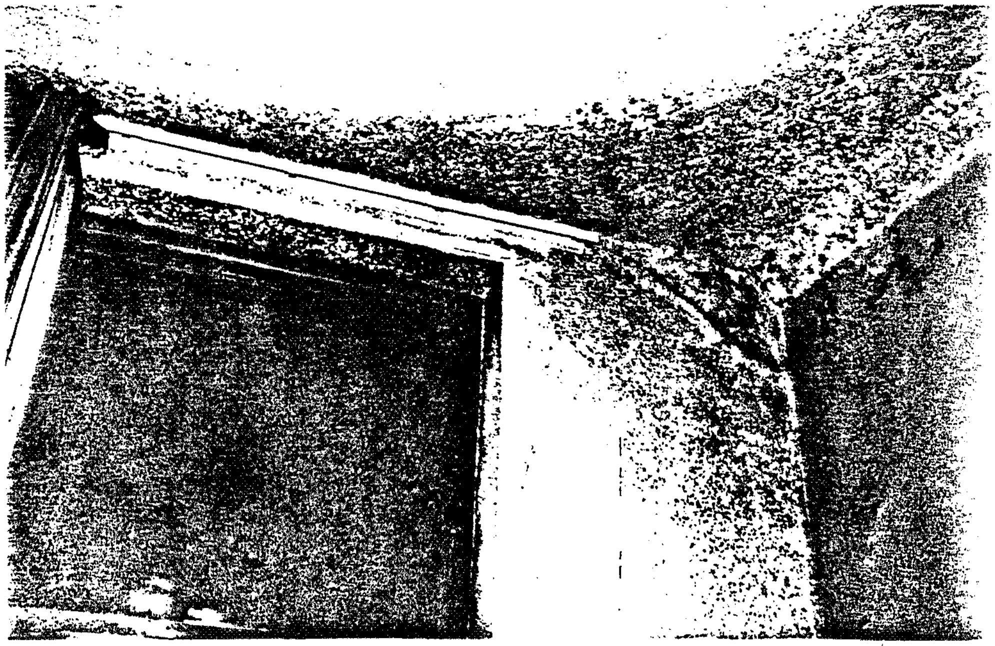
The period has seen the abolition of requirements for flues a permanent ventilation in habitable rooms. Windows now of provide better sealing and night ventilators, which used to b standard domestic provision in windows, are frequently n used. Fast-responding heating installations, which allow f economy with intermittent use, are a normal mode provision. Some types of construction have very high therm capacity and high vapour resistance. New constructior systems sometimes create unexpected cold bridges. M dwellings being built at present contain several of th features and the general tendency in their construction a equipment is towards increased condensation risk.

Future trends

The future need for increased energy conservation is likely result in reduced ventilation and periods of heating. Th factors increase condensation risk as can the provision insulation in inappropriate locations or without effect vapour barriers.

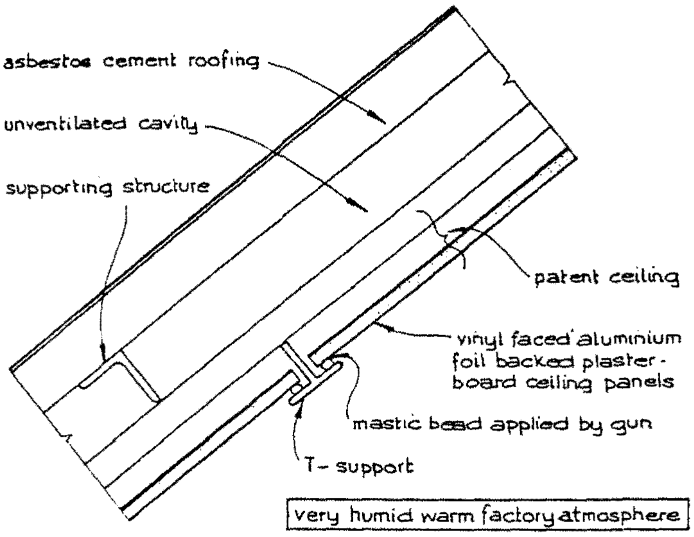
Design responsibility

Building design has a critical part to play in adequat reducing condensation risk. Consultants rarely fi condensation problems arise as a result of some error in otherwise adequate approach to design. When a condensat failure occurs, very often little or no account whatever been taken of condensation.

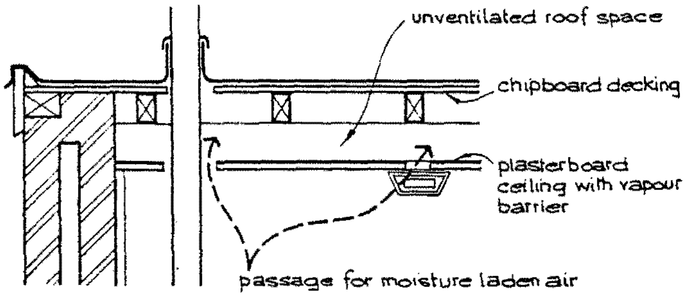


Such condensation is becoming more common. Condensation problems of some sort probably affect more than 20 per cent of new dwellings.

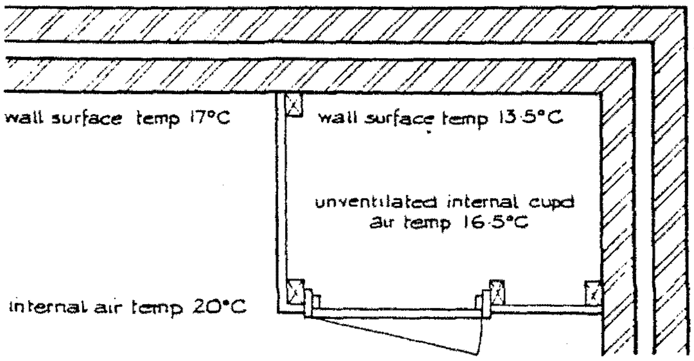
Case studies



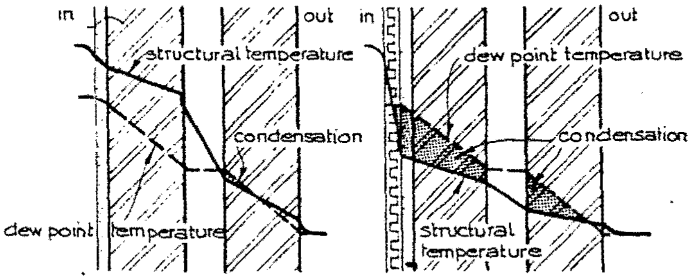
1 *It would be optimistic to think that the mastic bead would have provided an adequate seal even if workmanship was perfect. However, due to late delivery of some equipment a substantial area of the plasterboard ceiling panels was left off until pipes and flues were installed. The condensation which resulted was probably responsible for the initial softening of many of the plasterboard panels, which deformed and destroyed what integrity remained in the mastic bead seals. Very large quantities of condensation affected the lighting and electrical installations and caused acute inconvenience to workers and operators below.*



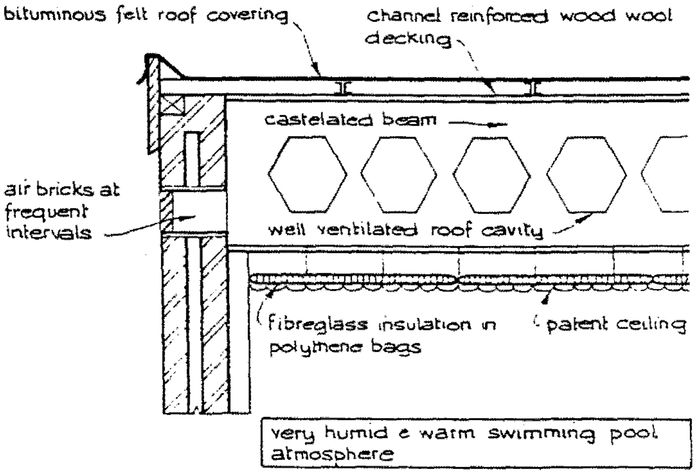
2 *In this case condensation might have been anticipated in the roof void in any case, due to lack of roof space ventilation and discontinuous vapour barrier. But the vapour barrier was pierced by pipes and electrical wiring and moisture-laden air was able to add to the amount of condensation. Pipe ducts can also convey warm moist air into roof voids if they are not sealed at the top.*



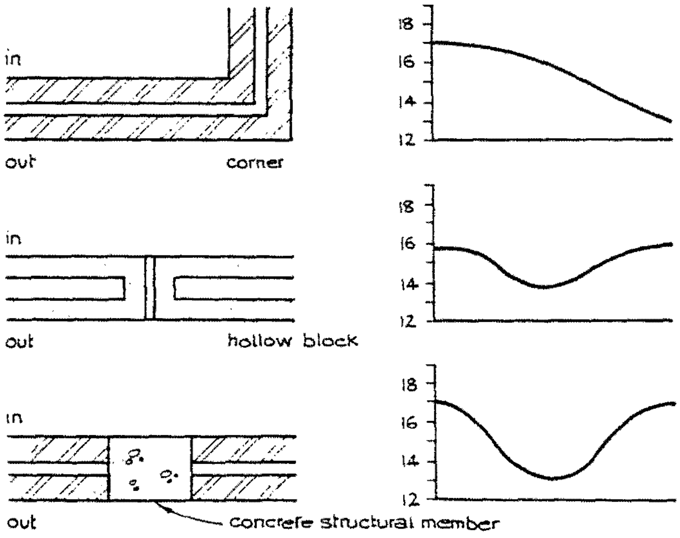
3 *Unventilated cupboards can reduce wall surface temperatures within their enclosure while having little effect upon humidity levels. Thus condensation can occur on or in an external wall behind a cupboard where elsewhere along the wall there is no similar condensation problem.*



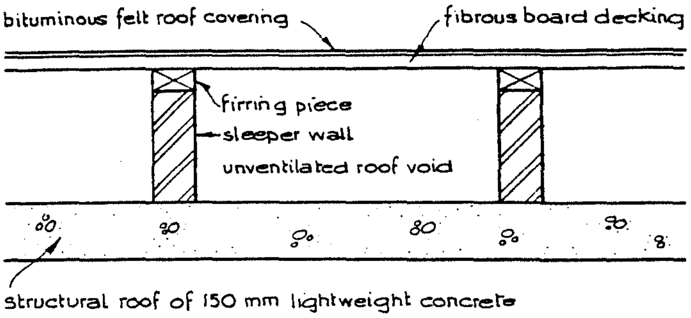
4 *Many acoustic absorbents and thermal insulation materials have high thermal resistance and low vapour resistance. The use of these materials on the inner face of an external wall will, therefore, reduce the structural temperature through the wall without affecting the moisture conditions. This results in increased condensation risk.*



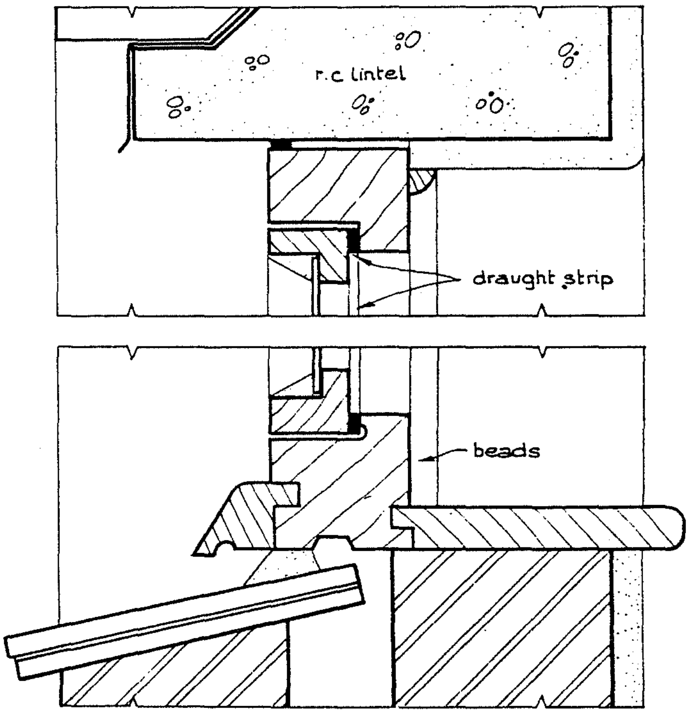
5 *The roof cavity is well ventilated and the mechanical warm-air heating to the swimming pool is designed to maintain a positive pressure in the pool area to avoid any cold draughts. Individually, both these measures are excellent. In combination, however, the path of least resistance for the pressurised pool air is through the ceiling and the roof cavity. Large quantities of moisture-laden air caused extensive condensation in the roof space and corrosion compromised the structural stability of roof and ceiling.*



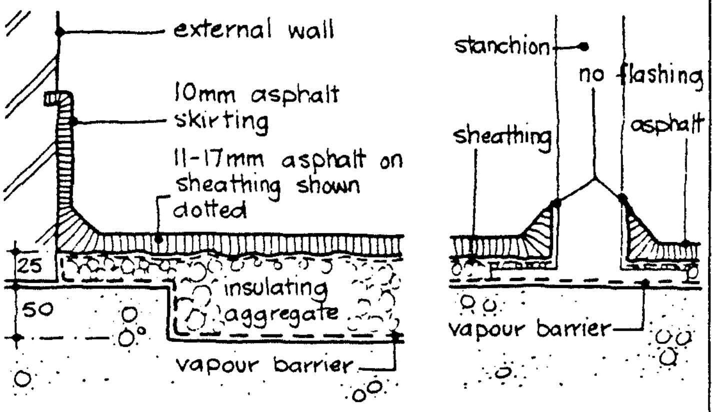
6 *It is common for condensation to occur in corners, which represent particular types of cold bridge. Some typical instances are shown above with the temperature variation of the internal surface near the cold bridge under steady state conditions. Most evaluations of condensation risk are made for central wall locations rather than at corners or other cold bridges.*



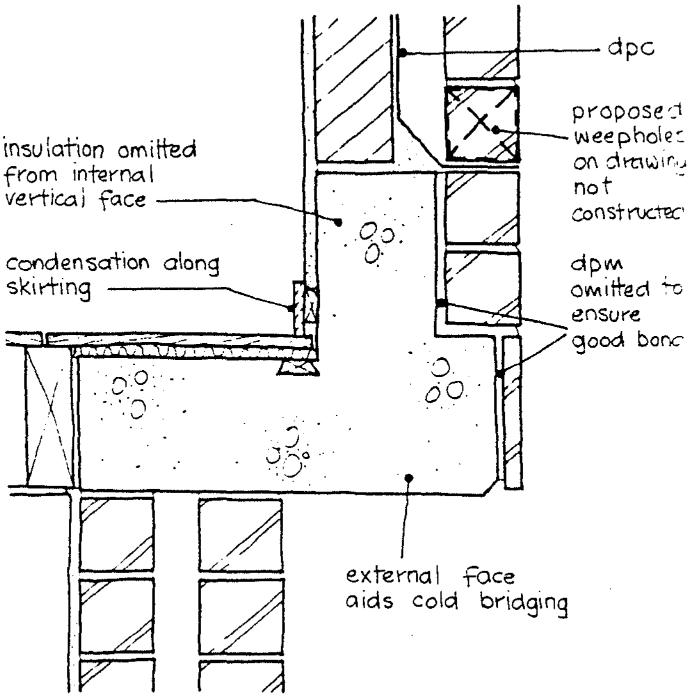
7 *Condensation on the underside of the felt and in the decking caused the decking to disintegrate. Ventilation of the roof void would have prevented this. It seems likely, however, that the designer considered 150 mm of lightweight concrete to be an adequate vapour barrier. In fact it is hundreds of times less effective than the three-layer bituminous felt roof covering and vapour would make its way through into the roof void. The lightweight roof covering is, however, heat resisting to a considerable degree and consequently the temperature in the roof void will be very low.*



8 *In association with the installation of new central heating in a dwelling a number of energy-conserving measures were undertaken including draughtstripping of windows. The consequent restriction of infiltration resulted in acute condensation and mould growth on kitchen walls.*



9a *Access gallery at Smalley Road (AJ news coverage, reference on p739). Thinner insulation at wall and stanchion base may promote condensation in rooms below.*



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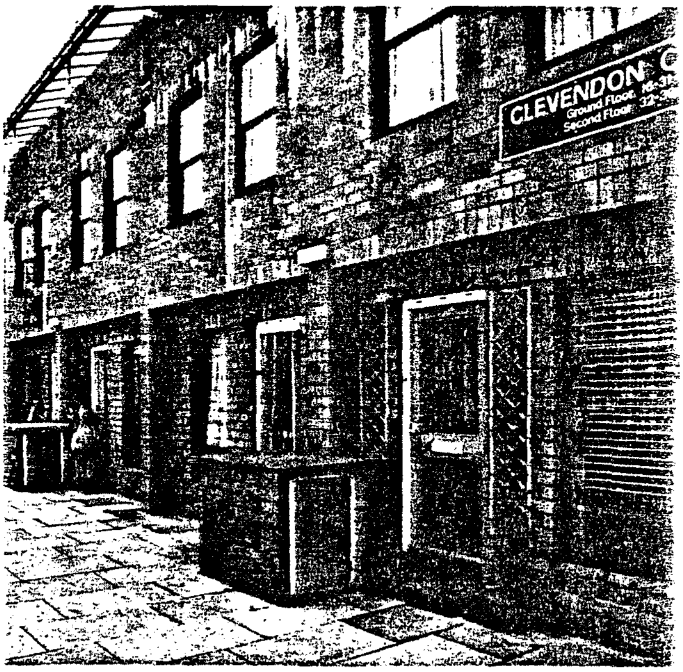

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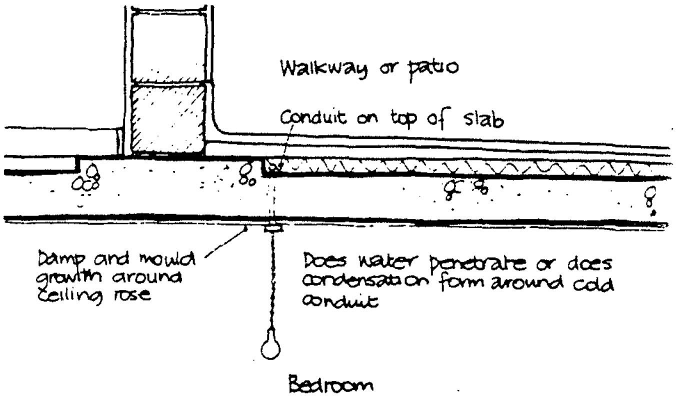
9b, c *Recessed ground floor wall with floor above supported on a concrete edge beam. The face and soffit of the concrete are both uninsulated, providing a cold bridge to the interior.*



9d *Insulation stops short of wall providing cold bridge. The conduit has not been dug out for investigation but may also brid the insulation.*

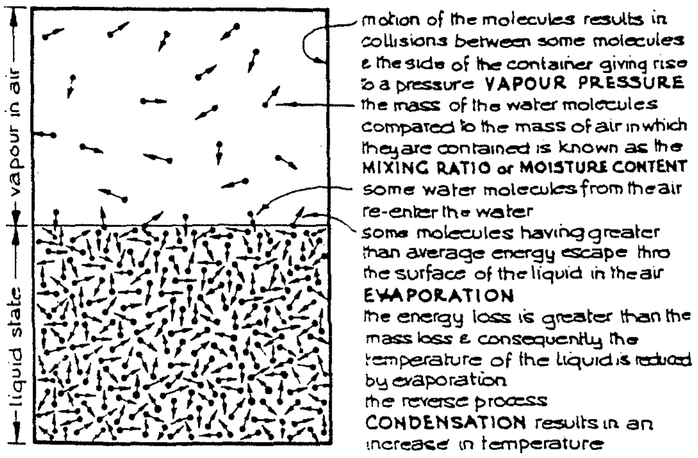
Water and water vapour

Condensation involves both thermal behaviour, which has recently been much discussed, and moisture considerations, which are relatively neglected. The analytical and numerical techniques described later (p732) cannot deal with many buildings so architects will have to design from first principles.

Condensation

Air normally contains water vapour. Its capacity to do so increases as the air temperature increases (3·7 g of water vapour can saturate 1 kg of dry air at 0 °C while 14·4 g is required at 20 °C). If air containing water vapour is cooled so that the quantity of vapour it contains is greater than the amount required to saturate it at that lower temperature, then liquid water is precipitated. This type of cooling of air can take place in buildings. It is almost always the result of air coming into contact with cold building materials and the moisture is deposited as condensation, either on the surface or within the construction itself as interstitial condensation.

The fundamental principles of how water changes between vapour and liquid phases are illustrated in **10** and **11 a, b**, defining basic concepts. The 'dot and arrow' symbols represent molecules in motion.



10 *Liquid and vapour states. In a closed container, half air, half water, at atmospheric pressure, equilibrium will be reached where the number of molecules escaping from liquid to air equals the number returning. In this condition the vapour is described as* SATURATED. *The amount of vapour required to saturate dry air varies with both barometric pressure and temperature. For saturated air these are known as the* SATURATION VAPOUR PRESSURE *and the* DEWPOINT TEMPERATURE.

Definition of vapour properties

The moisture content of air can be quantified in several different ways, all of which are important to some aspect of condensation prediction.

Mixing ratio (or moisture content or absolute humidity). The weight of water contained in a kilogram of dry air (unit kg/kg or g/kg). It enables amounts of water to be summed to give consequent overall mixing ratios.

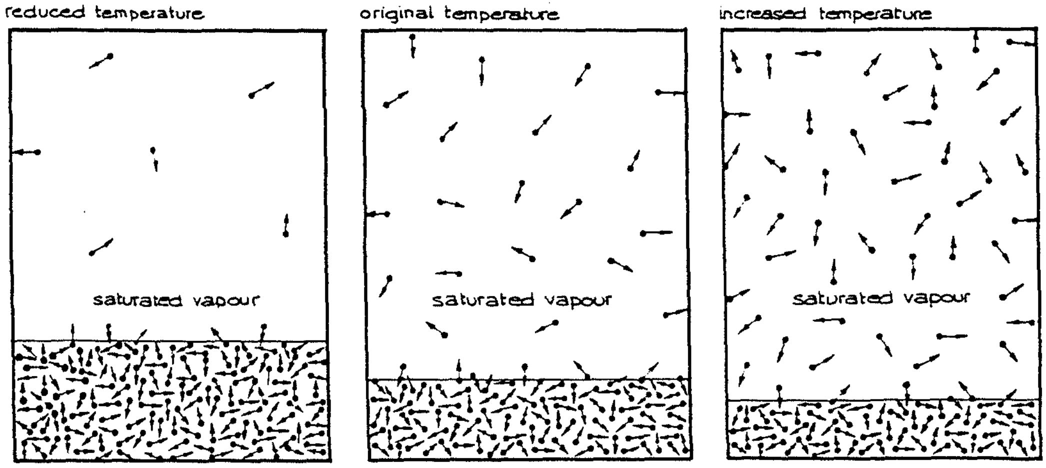
Vapour pressure. The pressure exerted by the molecules of vapour contained in air (unit MN/m^2 or more usually millibars, mb. 1 mb = 100 N/m^2). It enables the rate of diffusion of vapour through construction materials to be estimated.

Dewpoint temperature. Temperature at which a sample of air with given moisture content becomes saturated (unit °C). Used in calculations.

Saturation vapour pressure. Vapour pressure which would be given by saturated air at a specific temperature (units MN/m^2 or mb). Used in calculations.

Relative humidity. Quantity of water contained in air expressed as a percentage of the maximum which could be contained in air at that temperature (units percentage rh at temp °C). Relative humidity varies both with moisture content and with temperature which means that it is not a convenient quantity to use in calculations. It is, however, important in moisture studies since physiological reactions of people and the moisture content of building materials are governed by relative

11a *Effects of temperature changes on vapour conditions where originally, as shown in the centre diagram, there is some liquid water available (container closed but not airtight, at atmospheric pressure).*

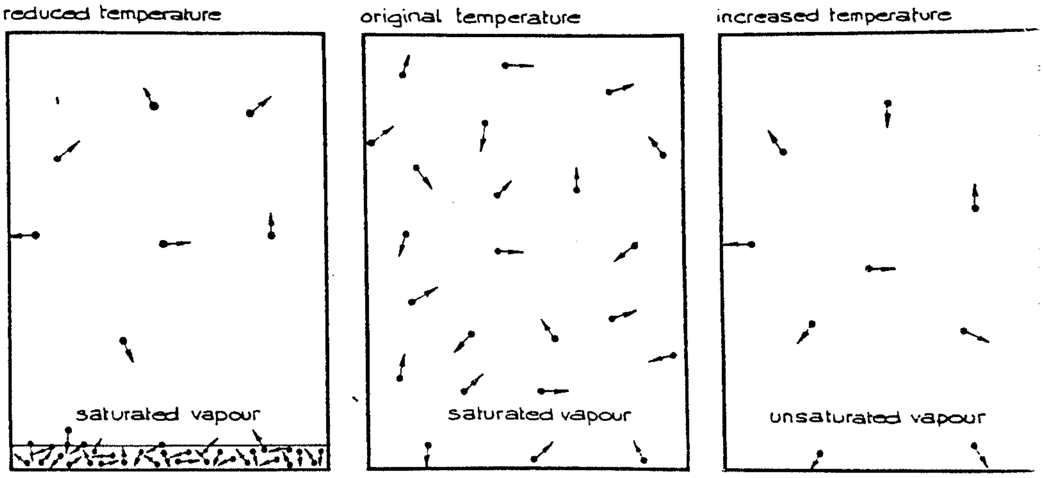


Reduced temperature reduces activity of molecules. A proportion of the molecules in vapour return permanently to water. The concentration of molecules in air is reduced (lower mixing ratio/moisture content, lower vapour pressure) but the air remains saturated. The lower the temperature the less vapour the air can contain.

Original conditions.

Higher temperature increases activity of molecules. More molecules enter the vapour phase from water. The concentration of molecules in air is increased (higher mixing ratio/moisture content, higher vapour pressure) but the air remains saturated. The higher the temperature the more vapour the air can contain.

11b *Effects of temperature changes on vapour conditions where originally, as shown in the centre diagram, there is no water.*



Saturation as in **11a**. *Some vapour molecules associate to form liquid molecules,* CONDENSATION. *The moisture content (mixing ratio) of the air and its vapour pressure are reduced as the temperature falls.*

Original conditions.

At increased temperature both air and vapour expand in proportion: molecules are less densely spaced but the mixing ratio (moisture content) remains the same. Activity of molecules increases so vapour pressure remains the same. Bu the air is not saturated now: RELATIVE HUMIDITY is said to be reduced.

humidity, not by any of the other factors related to absolute humidity. It is also the most easily measured property.

Psychrometric chart

The relationship between these defined factors is given in the psychrometric chart, **12**: its use is described under prediction techniques on p734.

Vapour sources in buildings

Condensation in buildings would not generally be significant if no further moisture were added to the internal air. In practice significant amounts are added and one of the crucial aspects of design to avoid condensation is an appreciation of the scale and nature of increases in moisture and the ways in which the moisture is circulated round the building.

People contribute substantial quantities of moisture by evaporation of sweat and transpiration from the lungs. Also significant are cooking, baths and showers, clothes and dish washing, unflued heaters and water heaters. The combustion products of oil, gas and paraffin are rich in water vapour. Some manufacturing processes clearly put large quantities of vapour into the air. Wetted surfaces will give rise to rapid evaporation and a consequent increase in vapour in the air.

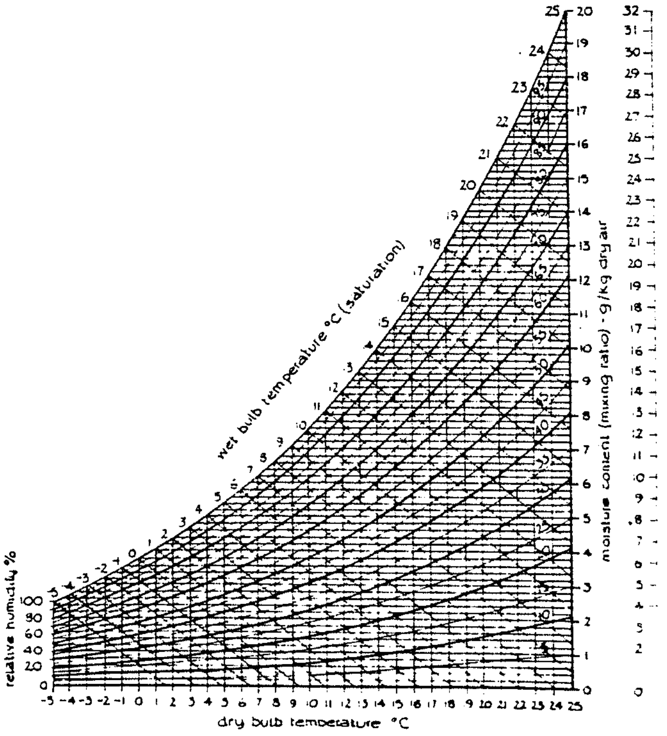
Table III, which appears with prediction techniques on p732, gives typical rates of moisture increase from domestic activities and wetted surfaces. It would be difficult to attempt a detailed estimate of vapour input in every case and the BRE has suggested typical additional mixing ratios to represent conditions in various types of environment, taking into account both typical vapour inputs and typical winter ventilation (table IV p733).

Ventilation and air movement

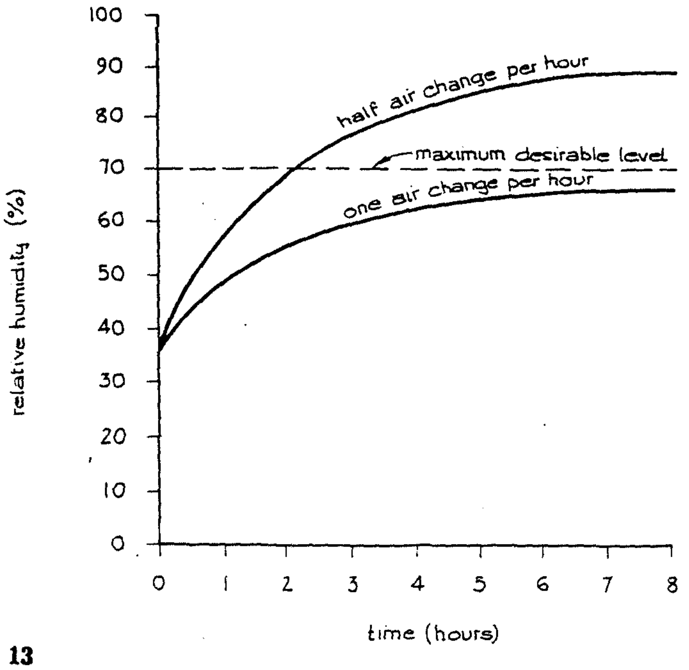
Ventilation. This is critical to condensation. Low ventilation rates may give rise to moisture concentrations, hence increased condensation risk. Diagram **13** shows increasing relative humidity in a bedroom over eight hours, for two ventilation rates. The lower rate, which is quite likely in a bedroom with closed windows and doors, gives totally unsatisfactory conditions.

Air leakage. Many cases of condensation are due not, as is ofte supposed, to diffusion of moisture through materials but to ai movement through cracks and through holes round service which can convey substantial quantities of vapour into col areas such as roof spaces and cavities (see case study 2, p724)

Control of air movement. Apart from a desire to reduc excessive infiltration to improve comfort and energ conservation, there has been comparatively little interest in th architectural profession in ventilation and air movement an there is no easy way of designing buildings to control eithe infiltration or internal air movement. Architects must attemp to achieve standards of workmanship which limit air leakag and also provide means for the occupants to control thei ventilation effectively over a range of ventilation rates.



12 *Psychrometric chart. This complex looking design aid, explained later, may be used to predict condensation.*



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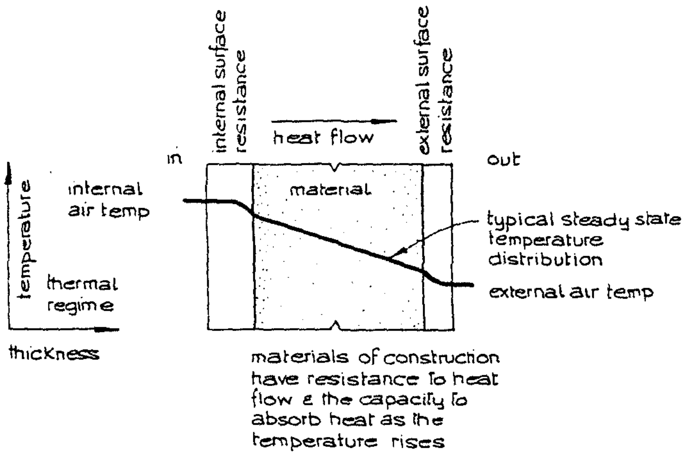

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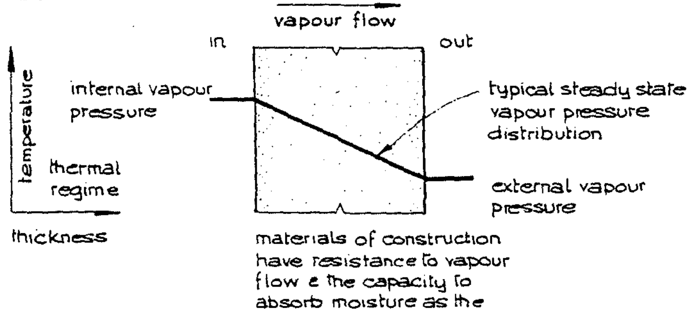

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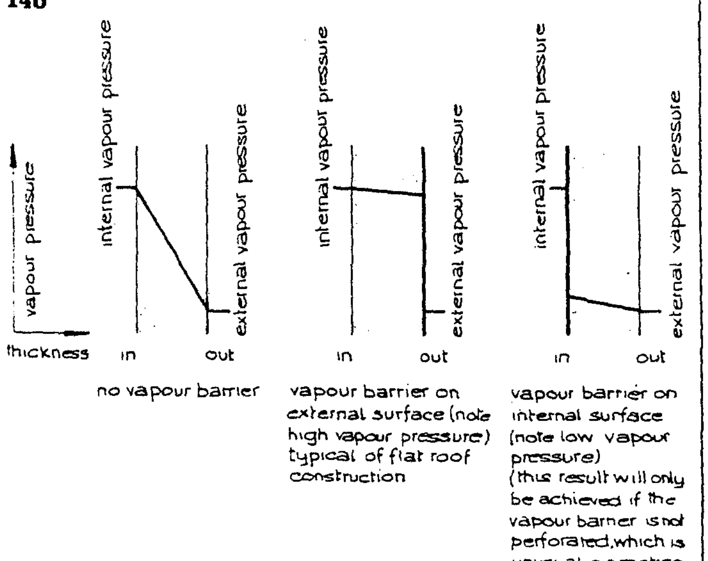

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Heat loss. Air movement through cracks and holes will also allow heat to escape. Apart from the waste involved this does not have the same undesirable consequences as movement of moisture. Ventilation can usually be effective in dissipating excessive moisture levels without major thermal consequences, provided the rate can be controlled.

Vapour transmission through building fabric

Building materials have moisture properties very analogous to thermal ones. Vapour will pass through materials at a rate depending on the resistance of the material and the vapour pressure difference between the two sides of the material. As with heat flow and temperature difference, the rate of vapour flow through a given sample of material is directly proportional to the vapour pressure difference, **14a, b**. The significant vapour properties are:

Vapour diffusivity. Rate of vapour transfer through a material resulting from a vapour pressure difference (unit gm/MNs). Note that this represents the rate of transfer in grams per second through 1 m^2 of material 1 m thick under a vapour pressure difference of 1 meganewton.

Vapour resistivity. The reciprocal of diffusivity and, in effect, the resistance of 1 m^2 1 m thick (unit MNs/gm).

Vapour resistance. The resistance of a given thickness of material to vapour flow (units MNs/g). Resistivity × thickness in m = resistance. The resistance of composite roofs, etc, is expressed in these terms.

Moisture content. Building materials can contain moisture absorbed into their pores and absorbed as thin films on internal surfaces of suitable form. Apart from contributions by condensation, the quantity contained depends more upon the surrounding relative humidity than upon vapour pressure. The main effect of moisture content is to influence the thermal properties (unit: percentage by weight). *IHVE Guide* section A3 deals with the effects of moisture on thermal properties.

Vapour capacity. Only used in very sophisticated calculations. Usually taken as the vapour capacity of the air spaces in the material (unit g/kg or g/m^3).

Vapour barriers

Some sheet materials such as metallic or plastic films have very high resistance to the passage of vapour (vapour barriers) which can, in principle, control the vapour distribution through building elements, **15**. In practice they are not always advantageous. When placed on or near the warm inner surface of walls or roofs the vapour pressure outwards from the vapour barrier should be very much reduced and the risk of condensation reduced. In practice it is difficult to make vapour barriers which do not have open joints and gaps as the materials are often damaged during construction.

If vapour barriers are located near outer cold surfaces of walls they tend to maintain the full internal vapour pressure on the inside right up to the barrier. Since they are near the surface, however, the temperature is low and condensation is encouraged. It might be thought that this type of construction would rarely be used but most flat roofs are of this form.

13 *Increasing relative humidity through the night with two people in a bedroom each contributing 0·05 kg of moisture per hour. Half an air change is inadequate (internal temperature assumed to be a steady 15°C, external 0°C at 100 per cent relative humidity).*

14 *Comparison of heat,* **a**, *and vapour movement,* **b**, *through building construction. The resistance of surfaces and cavities is ignored in vapour calculations. A pressure across elements of construction, especially if cracks are present, can increase vapour transmission dramatically.*

15 *Effects of vapour barriers on vapour distribution through building elements.*

Condensation in buildings

Condensation will occur whenever the temperature of the surface or interior of building materials falls below the dewpoint of the air at the point in question. A complex range of factors governs the temperature that will exist at any point and a similarly complex range covers the vapour pressure that will be reached and consequently the dewpoint temperature. But provided sufficiently accurate predictions of temperature and vapour pressure variations can be made, prediction of condensation itself is simple. Table I sets out briefly the factors directly involved.

Effects of condensation

Condensation, involving a change of state from vapour to water and the release of latent heat, can affect the properties and condition of the materials on and within which if takes place. For the key immediate effects and their consequences see table II.

Consequences fall into two main categories: deterioration of materials and thermal changes. Deterioration of materials must be avoided in buildings. Local temperature increases due to latent heat tend to reduce condensation in principle and can be ignored in calculations. The decrease in thermal resistance may be important in cases of long-term build-up of condensation in durable materials (where there is no capillary path to less durable materials eg in the outer leaf of brick wall), but usually conditions which would give rise to significant variations in thermal conductivity will be regarded as unacceptable in any case.

Design standards

British practice is to predict the incidence of condensation by steady state methods using peak conditions of risk. Continental practice, although not universally consistent, is to use the same techniques but to employ seasonal average values for external temperatures and moisture contents. Any incidence of condensation indicates that a progressive build-up of moisture will take place. It is a very much less stringent test than the peak value analysis and the method is limited to fairly massive construction not affected by transient condensation. In this type of construction even a progressive build-up of moisture may take several years to reach a critical concentration. But short-term condensation may still deposit unacceptable amounts of moisture, particularly if there is free access for internal, moist air to the place where condensation is taking place.

For lightweight construction, of fast thermal response, steady state calculations give reasonable predictions. For heavier construction they can still serve a useful purpose. There are several performance standards which can be selected:

- keeping the relative humidity to less than 70 per cent
- ensuring that no condensation at all is predicted
- allowing condensation to occur occasionally, in place where it will do no harm either to the materials themselves o by migration to other parts of the construction, provided ther is no progressive build-up.

Limitation of relative humidity to 70 per cent

Relative humidities of over 70 per cent in rooms ar unacceptable for comfort and clearly give rise to acute risk condensation occurring in the materials of construction. A one time it was thought that mould growth would occur whe relative humidities reached 70 per cent or more. At present is thought that some liquid water must be deposited to allo mould growth. The chances of this are clearly high when th relative humidity of the air generally exceeds 70 per cen Organic materials may also deteriorate, either directly as result of moisture content resulting from high relativ humidity or because of actual condensation, so this 70 per cer relative humidity criterion may still be of value.

Avoidance of condensation

Where organic materials are involved, or where materials no in themselves affected by moisture are in direct contact wit decorations or other less durable materials, then it is clear desirable to ensure that no condensation is precipitated.

Deposition of transient moisture

In the case of durable materials, where the possible run-off lines of capillary movement would not give rise to problems, is possible to allow condensation to occur for a limited peric provided the liquid can dry out between the periods condensation. Estimates must be made of the likely duration condensation to ensure that there is adequate drying time an of the amount of moisture to be deposited, to ensure that th material does not become saturated leading to substanti water run-off and changes in thermal properties. If th moisture is making its way to the position of condensation means of diffusion, it is easy to estimate the rate at whic moisture can pass through the construction and consequent the maximum rate of condensation (see calculations, p738). moisture is conveyed by air movement it is very much mo difficult to make any estimate of the condensation rate.

It is interesting to see that, all other factors remaining equa the risk of condensation increases as external temperature ris between 0 °C and 10 °C because the air's capacity to take moisture increases and, in humid conditions, the dewpoi temperature can be increasingly above the structu temperature, **16**. Diagram **17** shows condensation predicted

Table I Factors which govern the incidence of condensation

Factors	*Thermal*	*Vapour*
External*	Air temperature Radiant condition	Mixing ratio
Fabric*	Thermal resistance Thermal capacity	Vapour resistance Vapour capacity
Internal*	Internal air temperature Internal air condition	Vapour gains Air movement within building Infiltration and ventilation rates
From these factors it should be possible to predict for any given point and time	Structural temperature	Vapour pressure

*These conditions vary continually with time.

Table II Consequences of condensation

Effect of condensation	*Consequences*
Run-off of liquid from surfaces	Deterioration of decorations anc materials Surface mould
Increase of moisture content due to absorption of run-off or interstitial condensation (note that the water deposited may be quickly distributed through the building material by capillary movement)	Decrease in thermal resistance material Deterioration of organic materi plaster, etc Corrosion of metals (very large increases in moisture content affect air and vapour permeabi of materials)
Release of latent heat	Local temperature increase

hybrid computer, taking into account actual weather conditions and variations; condensation occurs during warmer periods.

Occurrence in buildings

Condensation without specific moisture input

The external air cannot contain moisture above its saturation level. Internal structural and air temperatures in buildings will not normally be below outside temperatures and condensation therefore will not take place unless additional vapour is added to the internal air. There are some exceptions to this rule. In massive buildings, when warm damp weather follows a cold spell, transitory condensation can take place on floors and walls. Roofs exposed to the cold night sky can be cooled by radiation heat losses and condensation may take place. Cold pipes and ducts and the walls of cold rooms may all be at temperatures below the dewpoint of external air.

Moisture increases

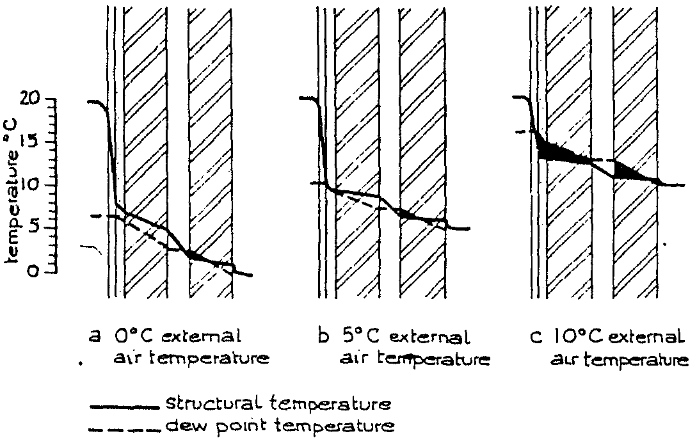
Adding moisture to the air of buildings is a primary cause of condensation. Occupants of buildings and many processes, including bathing, cooking and washing, all contribute moisture to the air which raises its moisture content. The concentration of moisture ultimately reaches equilibrium as the rate of input is balanced by the vapour lost by ventilation. If the air, with its moisture content, comes in contact with cold materials condensation will result. The condensation is not limited to internal surfaces. Cracks in inner linings can allow air to penetrate to wall and ceiling cavities making their mixing ratio (moisture content) the same as that inside. Most elements of construction have some degree of permeability to air which will convey vapour into apparently solid materials but the principal mechanism of moisture movement into building materials is diffusion of the vapour itself, due to vapour pressure difference. The difference in vapour pressure between the interior of a building at 22°C and 50 per cent RH and the exterior at 0°C, 50 per cent RH, would be over 10 mb (or 1 kN/m^2) which represents a substantial driving force. So it is apparent that design for avoiding condensation in buildings must be governed by two major considerations:

- reduction of vapour pressure
- increase in structural temperatures.

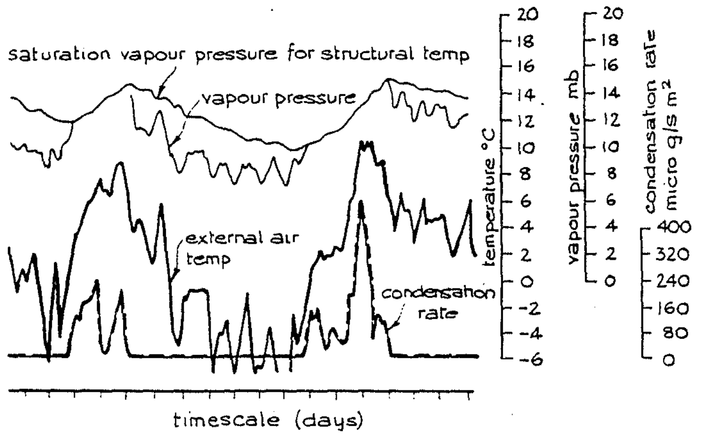
Vapour pressure

There are three main building design variables which govern the vapour pressure at the surface and through the materials and elements of building construction:

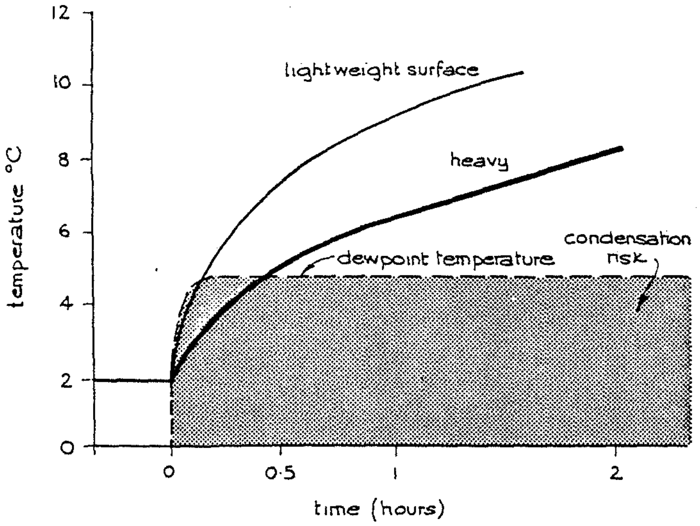
- the vapour input to the interior spaces by people and processes must be kept to a minimum or extracted, where



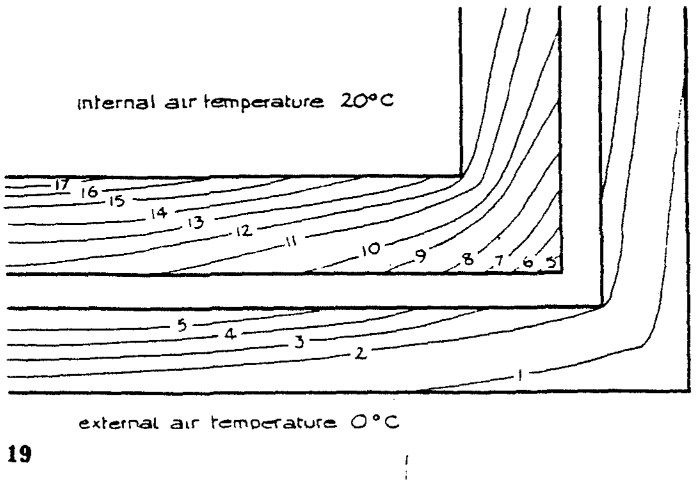
16 *Condensation risk with 0°C, 5°C and 10°C external saturated air and a 20°C internal temperature. The diagrams use a graphical method of prediction (explained later, p736) which shows risk of condensation when the dewpoint temperature is above the structural temperature. This is more marked at higher temperatures. In some houses increased ventilation might occur, reducing risk. The key point remains, however, that the greatest risk does not occur at the conventional design temperature of 0°C externally.*



17 *Variation of dewpoint temperature with air temperature, demonstrating that the worst condensation does not always occur at the lowest temperature: compare external air temperature curve and condensation rate.*



18 *Build-up of wall surface temperature and dewpoint in a domestic kitchen. Surface temperature of heavyweight construction rises much more slowly than dewpoint temperature (diagram Alex Loudon, BRE News 20, summer 1972).*



19 *Temperature distribution at the corner of a brick cavity wall, mapped in °C.*

possible, at source

- the ventilation and infiltration rates (which govern the concentration of vapour) should be considered in relation to the vapour concentration thought acceptable in:

a rooms
b roofs and wall cavities (see vapour sources in buildings p727)

- permeability of building materials and elements to allow:

a diffusion of vapour under the influence of vapour pressure differences
b air movement which can convey vapour.

This is particularly important through gaps between sheet materials where critical quantities of vapour can be transported into roof and wall cavities. Cracks in solid walls can also allow significant amounts of air to pass. The vapour pressure in the cavity may thus rise to be the same as that in the room, increasing the risk of condensation while, if condensation occurs, it will be able to proceed at a very high rate because of the rapid supply of airborne vapour.

Materials of high vapour resistance positioned towards the inner faces of walls will reduce the vapour pressure in the rest of the wall. It is also apparent that materials of high vapour resistance on the outer, cold, surface of walls will result in high vapour pressure being maintained across the whole thickness of the wall and thereby increase the risk of condensation. Flat roofs generally suffer from this particular problem which diagram **15** illustrates.

Increasing structural temperature

Insulating materials towards the outer surfaces of walls will raise the structural temperature through the wall. Locating the insulating materials on the inner face will reduce the structural temperature through the wall and increase the risk of condensation. A number of good insulating materials are also very low in their vapour resistance and consequently the internal insulation must be very carefully considered. It is possible to produce condensation on a wall previously not subject to condensation simply by applying insulation with low vapour resistance to the inner surface. There are a number of factors, which are not immediately apparent, which can nevertheless affect structural temperatures.

Intermittent heating. Where additional vapour input coincides with the start of heating after a break, the time lag in warming up the construction may give rise to condensation. Diagram 18 shows the general pattern though there is no easy way of quantifying this.

Cold bridges and corners. There may be situations in an otherwise well insulated wall or roof where solid construction members bridge the insulation or where the increased heat loss at the corner will give rise to reduced structural temperatures. In brick walls, a variation of 3°C in the internal surface temperature of the wall is not unusual, **19**.

Cupboards and similar enclosures. Closed cupboards usually resist the flow of heat more readily than the flow of vapour. They therefore act in a manner similar to an insulating material with high thermal and low vapour resistance. Cupboards of this type on an external wall can reduce the temperature of the wall while having little effect from the vapour pressure. The risk of condensation is therefore increased (see case study 3).

Checklist of building factors in prediction of condensation risk

Factor		*Means of reducing condensation risk*
Moisture input	From occupants ablutions washing/drying cooking processes flueless heaters	Moisture input from occupants cannot be controlled. In the other cases the following actions might be appropriate: 1 change process to generate less moisture (eg electric cooker instead of gas) 2 reduce wetted area surrounding wet activities 3 select apparatus with built-in exhaust 4 extract moisture-laden air near point of moisture input.
Internal temperature	Of air and environment	Although relative humidity varies with air temperature it is absolute humidity (ie moisture content of the air) which governs condensation and this is not affected by temperature changes. Internal temperatures, however, govern the structural temperature in walls, floor and roofs. Increases in air temperature are not normally possible since temperatures are governed by comfort considerations. If heating is intermittent, however, more continuous heating will raise structural temperatures and thereby reduce condensation risk.
Ventilation	Of rooms	Increased ventilation results in reduced levels of moisture in the air. A very effective way of reducing condensation risk.
	Of cavities in walls and roofs	Unventilated cavities present a barrier to heat flow but not to vapour; they therefore increase condensation risk in the outer skin. Small amounts of ventilation can be effective in reducing moisture concentration without excessive heat loss.
Structural temperature	Of walls, floors and roofs	Increases in structural temperature reduce condensation risk. This can be achieved by increasing the internal air temperature, making heat more continuous or by providing insulation towards the outer face of the wall (note that insulation on the inner face, if not associated with a vapour barrier or inherently vapour resisting itself, increases condensation risk). Wall surface temperatures in external corners can be as much as 3°C less than those in the centre of the wall and cold bridges in construction may also create areas where structural temperatures are very much lower than on the wall generally. Cupboards and fitted furniture can also reduce wall temperatures while not affecting vapour pressure.
Vapour pressure	On walls, floors and roofs	Reducing vapour pressure will reduce condensation. Increased ventilation achieves this. Vapour barriers towards the inside surface can limit the diffusion of vapour pressure. Note that problems arising from inadequate jointing of sheet type vapour barriers are frequent. Flat roofs, which have an effective vapour barrier on the cold side, present a critical condensation problem since the internal vapour pressure will be maintained all the way through the construction and condensation on the cold underside is very common. The most effective remedies are either to provide insulation outside the vapour barrier or to provide ventilation in the roof cavity.
Pipe and trunking temperatures	Cold rooms etc	In winter, water from the mains will often enter buildings at temperatures about 5°C. Condensation on exposed pipes is likely in many places, particularly kitchens and bathrooms. Cold pipes or trunkings conveying chilled water or cold air may be at temperatures below the dewpoint for considerable periods and will inevitably be subject to condensation. Vapour barriers on the outside of the insulation will limit the rate at which the condensation can take place but the effect cannot be avoided.

Existing buidings

Design possibilities

Condensation may take place anyway or be promoted by changes during rehabilitation or installing new services. Although there may be limits to running trunkings for mechanical ventilation, services are usually comprehensively revised during major renovation. Windows can often be modified or replaced to improve ventilation. The fabric, however, is expensive to change so remedial measures are often confined to the addition of insulation and vapour barriers, either internally or externally.

Building fabric

External vapour barriers are almost always undesirable. External insulation is generally a very good idea in relation to condensation although it needs protecting with a weatherproof but ventilated covering such as tile hanging. Costs are clearly considerable.

Internal finishes have to be renewed often so insulation can be added internally relatively cheaply. But to do so may give rise to increased condensation risk since vapour régimes may not be affected while structural temperatures are reduced (see p728, **15**).

Vapour barriers will, theoretically, correct this but their performance in practice is disappointing due to problems of jointing and workmanship. A ventilated cavity may offer a solution if it can be arranged without excessive sacrifice of space or complex details.

Since changing the fabric performance is difficult in existing buildings, heating and ventilation are relatively much more important. Decisions on these need making early on, with decisions about fabric performance: an integrated approach is more critical than usual.

Measurement

Existing buildings allow measurements to be taken which can generally give much more precise information than prediction techniques. Not to take measurements could well be regarded as professionally careless in the case of any subsequent problems, whether or not they could have been anticipated from the measurements.

Ease of measuring

The main environmental factors relevant to condensation which can be measured are:

- air temperature
- surface temperature
- relative humidity
- ventilation rate.

Measurement presents problems. Quick measurement of temperatures and humidities is always worthwhile and can indicate undesirable conditions even in summer but this does not predict winter conditions, so it is necessary to wait for the heating season before taking measurements. Even during the heating season, variability of weather and patterns of occupancy make it difficult to isolate critical conditions. Continuous recording is very desirable.

In the case of ventilation measurements, provided windows and doors are controlled as in winter conditions, it is less critical at what time of year the measurements are taken.

Measuring instruments

Major electronic data logging systems are, of course, very expensive and require experts to install, calibrate and interpret the results. Experts are also needed for complex or critical situations. However, there are some simple instruments which are economically and technically practicable for any office working with existing buildings. They are:

- *whirling hygrometer* for immediate air temperature and relative humidity determination and for the calibration of thermohygrographs, **20**
- *thermohygrograph* for continuous recording of air temperature and relative humidity, **21**
- *electronic thermometer* for temperature measurements and especially for surface temperatures, **22, 23.**

Air movement

Ventilation rates and air movement are critical to condensation but not easily measured. The most usual method in the UK is to mix a small quantity of nitrous oxide with the atmosphere of a room and with an *infra-red gas analyser* record the rate at which gas concentration decays or increases in other areas, **24.** This establishes local ventilation rates and broader air movements. The equipment for these analyses always requires expert operation.

Experts are needed too for *infra-red gas thermography* which gives an immediate and graphic indication of surface temperatures and consequently the rate of heat loss through a building envelope. An example of infra-red thermography is given in next week's AJ for ABK's Felmore housing, Basildon.

Future developments

Some development is needed. At present few architects commission surveys of thermal and moisture régimes but with energy conservation designs tending toward increased condensation risk, measurement of conditions is likely to become more important. Offices should familiarise themselves with measurement techniques so that they will be able to use them in the future.

Methods of prediction

Standards for calculations

British Standard 5250 : 1975 proposes conditions for calculations related to condensation.

External air temperature

Roofs −5°C.
Walls −3°C.

These are to take account of air temperature and loss to the cold night sky. Note from **16** and **17** that greatest condensation risk may not coincide with lowest external temperature.

External air humidity

90 per cent.

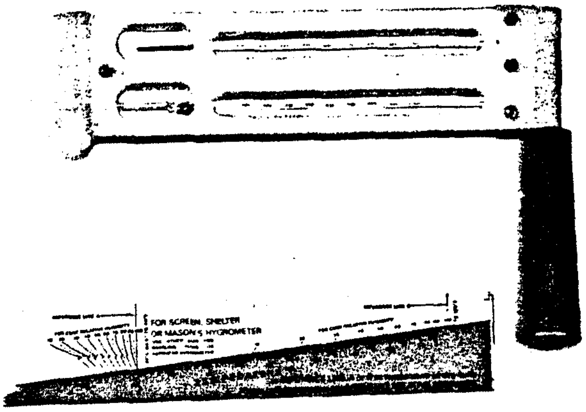
Internal air temperature in dwellings

Occupied rooms 20°C.
Unheated areas, day or night 10°C.
Internal humidity (except kitchens and bathrooms) 10·7 mb.

Recommendations of added moisture content (mixing ratio) for various building types are given in table III and, for different activities, in table IV.

Table III BRE vapour-design standards

Types of building or occupancy	*Mixing ratios to be added to external air mixing ratios*
Schools, offices, shops, hospital wards, public meeting places, dry industrial processes	1·7 g/kg
Dwellings	3·4 g/kg
Large kitchens and humid industrial atmospheres	6·8 g/kg



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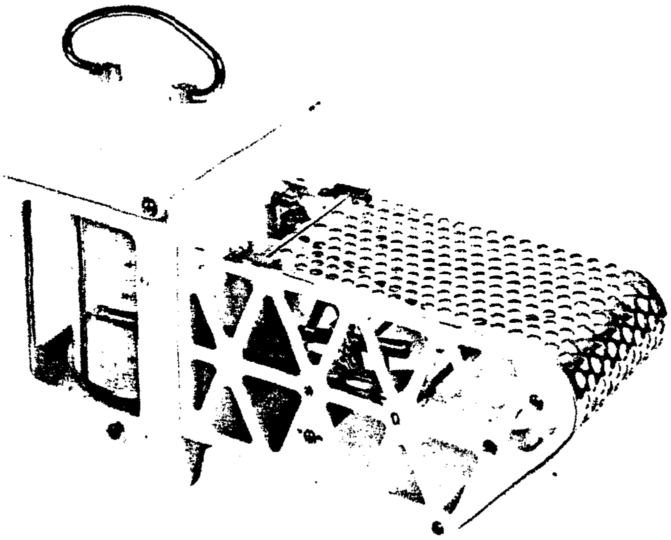

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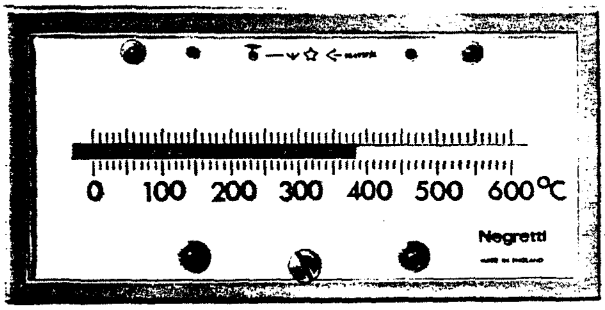

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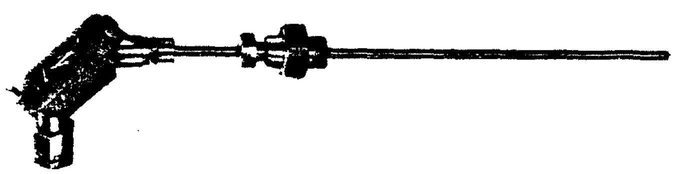

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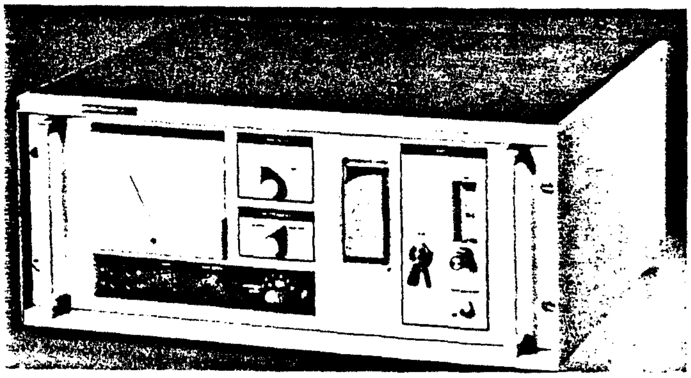

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Table IV Vapour inputs to buildings

Source	*Rate of input*
People: at rest	0·04 kg per person per hour
secretary/moderate activity	0·05 kg per person per hour
very active	0·2 kg per person per hour
Gas: cooking and flueless heaters	0·81 kg per m^3 gas (typical quantity for one day's domestic cooking 3·0 kg)
Oil: flueless heaters	1 kg per litre of paraffin, 0·1 kg per kWh
Bathing and showers	0·25 to 0·5 kg/hr, say 1 kg per day for a five-person household
Dishwashing (by hand)	0·08 to 0·15 kg/hr, say 1 kg per day for a five-person household
Clothes washing and drying (hand or machine)	May be up to 5 kg for typical dwelling where clothes are dried indoors or washing machines are not vented to exterior

Wetted surfaces

The moisture input from swimming pools and a number of industrial applications comes from the surface of the water, or from wetted areas of floor. Millband of BRE has suggested the following equation for prediction of the rate of evaporation:

$$\text{Evaporation rate (g/hr)} = 16 \times \text{Area of wetted surface (m)} \times \text{SVP* at water temp} - \text{VP* of surrounding air}$$

* SVP = saturation vapour pressure. VP = vapour pressure.

20 *The whirling hygrometer consists of a dry bulb and a wet bulb thermometer. It gives a direct indication of air temperature and, with the use of a table or chart, enables the relative humidity to be determined. The whirling motion required for the use of the whirling hygrometer is to ensure a minimum velocity of air movement across the wick of the wet bulb thermometer, since mor accurate determinations can be made in this way (Airflow Developments).*

21 *The thermohygrograph is a clockwork operated recording instrument which will give a daily or weekly record of conditions. Air temperature and relative humidity are recorded on a drum-mounted chart. The air temperature is sensed by a bimetallic strip and the relative humidity by a bundle of horsehair. While the instrument is not very accurate in absolute terms it is well able to provide useful data for decisions about condensation. The whirlin hygrometer is used to calibrate the thermohygrograph at intervals (Airflow Developments).*

22, 23 *Electric resistance thermometer. It is difficult to measure surface temperatures. This type of thermometer,* **22,** *can be fitted with a special lightweight probe,* **23,** *and equipped with silicone grease which enables a good thermal contact to be made between the probe and the surface (Negretti and Zambra).*

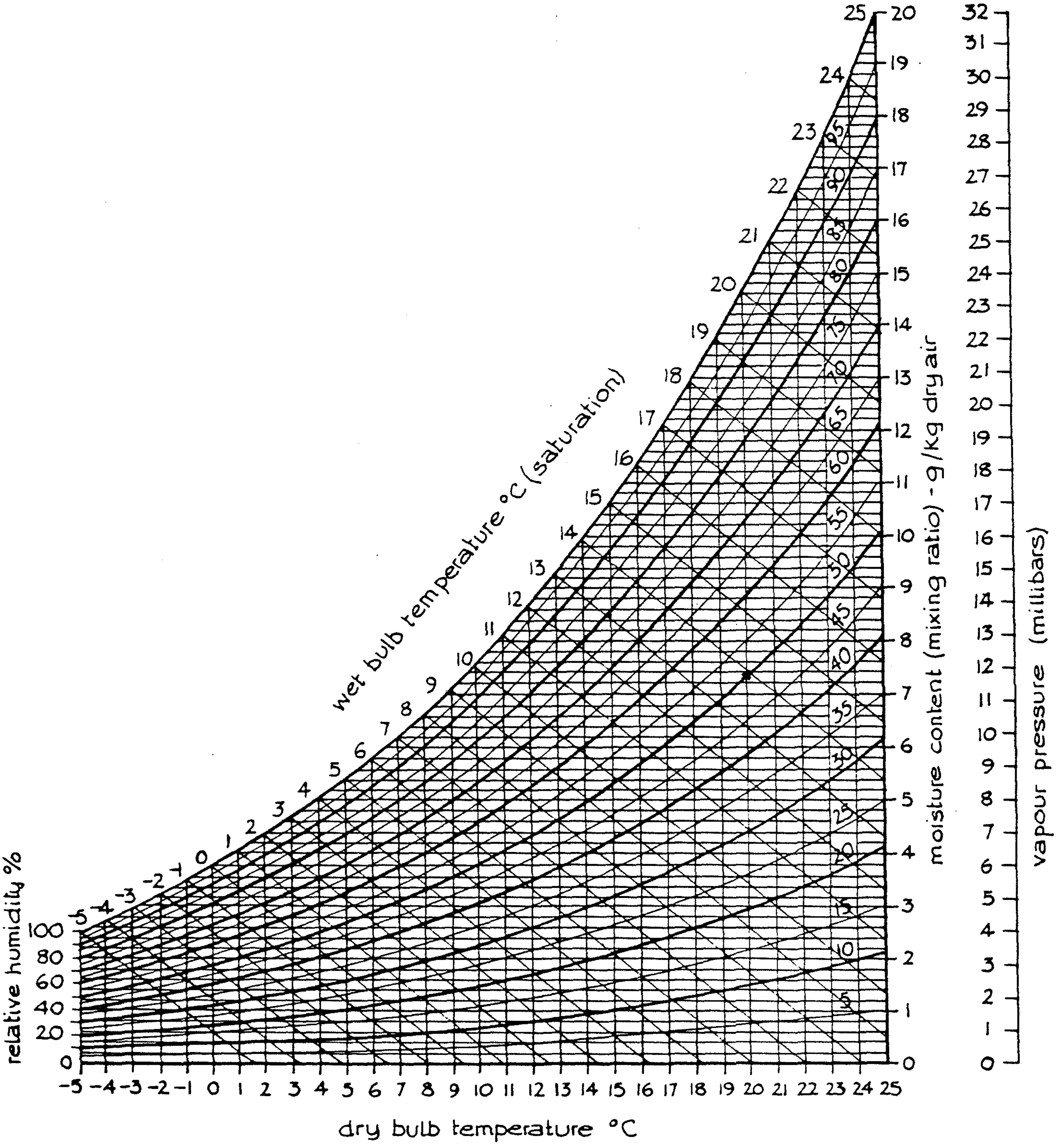
24 *Infra-red gas analyser. Ventilation rates are a critical factor condensation problems: measurement of ventilation rate is difficult. It is normal to release tracer gas into the air of a room being considered and to measure the rate at which the concentration decays. From this decay curve the rate of ventilati in the room can be determined. The most usual tracer gas used f ventilation purposes is nitrous oxide. The picture shows an infra red gas analyser suited to the determination of the presence of ve small proportions of nitrous oxide in air. Designers will norma have to consult laboratories possessing this type of equipment a the expertise to use it, when they wish to determine ventilation rates. In the past very few determinations of ventilation rate h been made and this lack of information may well have contribu to the increased incidence of condensation in recent years (G. P Instrumentation).*

Note on British Standards
These standards are for dwellings : modify them for other building types.
For moisture prediction it appears undesirable to use 90 per cent relative humidity at temperatures of −3°C and −5°C. These temperatures represent the effect of radiation losses on walls and roofs, whereas those losses do not affect relative humidity. And the difference in vapour pressure of air at 90 per cent relative humidity between the conventional external temperature of 0°C and −5°C is considerable: 5·3 mb and 3·6 mb respectively. So it seems appropriate to use 0°C for the moisture part of calculations.

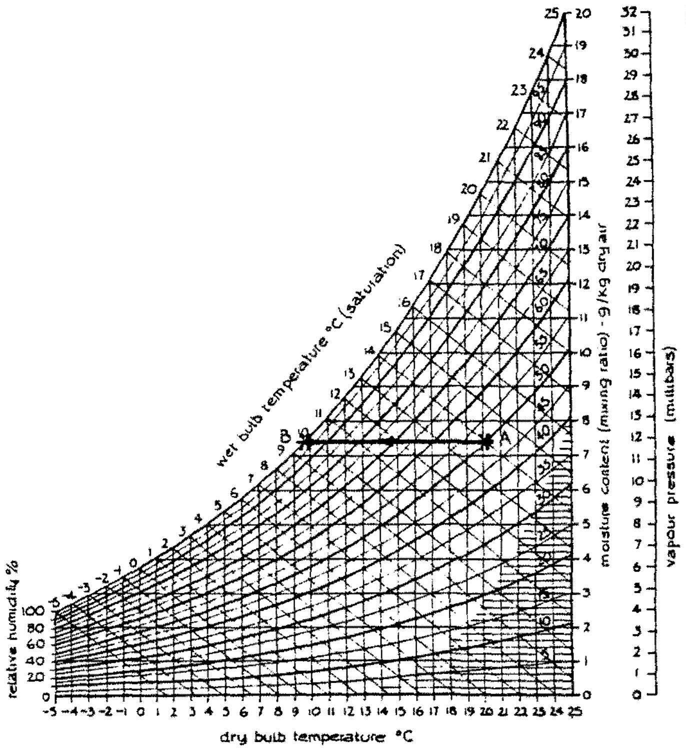
Psychrometric chart

The relationships between various properties of moist air are shown in the psychrometric chart. This allows some predictions of condensation to be made by relating changes in relative humidity to the temperature and moisture content of the air. Although values are affected by barometric pressure, for condensation in buildings a standard pressure of 1013 mb can be used for all purposes.

Use of the chart
For current purposes ignore the right-hand vapour pressure scale (which relates vapour pressure to moisture content of the air) and the diagonal straight lines (used for interpreting whirling hygrometer results, **20**). The following examples are on small-scale charts but, for accuracy, use a copy of the large one, **25**. The chart relates dry bulb temperature (air), wet bulb temperature (ie dewpoint temperature), moisture content of the air (mixing ratio) and relative humidity. Relationships between them can be made by drawing lines horizontally or vertically across the chart.
Example 1. If the internal air in a room has a temperature of



25 *Psychrometric chart that can be photocopied for use in predictions of condensation conditions.*

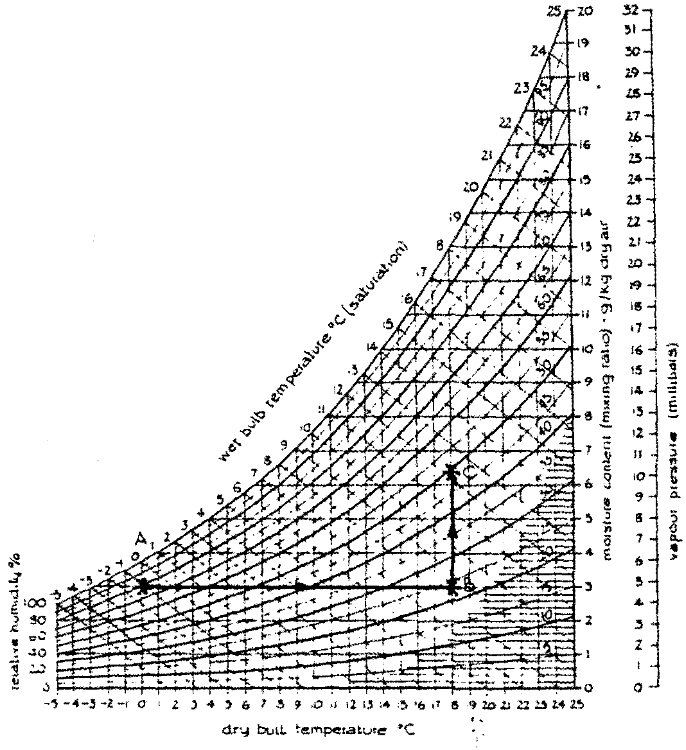


26 *Example 1.*

20°C and 50 per cent relative humidity, at what temperature will condensation take place?

First, mark the initial point, 20°C and 50 per cent relative humidity at A, **26**. For condensation, ie 100 per cent relative humidity, draw a line horizontally to B, on the 100 per cent curve. This is the temperature, 9·5°C, at which condensation will take place.

Example 2. BRE recommends adding a moisture content (mixing ratio) of 3·4 g/kg to the moisture content of external air to give typical domestic humidity levels. This is the moisture input expected from people and domestic activities (table IV). If the external air is at 0°C and external relative humidity 80 per cent, what will the internal relative humidity be at 18°C?



27 *Example 2.*

First, mark the initial point, 0°C and 80 per cent relative humidity at A, **27**. Draw a line horizontally to B at the internal room temperature of 18°C. This point B for 18°C is at a relative humidity of about 23 per cent. This would be the internal humidity level if no moisture were added by occupants and domestic activities. In fact, these add water in a proportion of 3·4 g per kg of air. So at B read off the moisture content on the right hand axis: 3·0 g/kg. Add to this 3·4 g/kg to give 6·4 g/kg and draw a line vertically to C at 6·4 g/kg. Read off the relative humidity here by interpolating between the curves—say 49 per cent. This is the relative humidity in the room at 18°C.

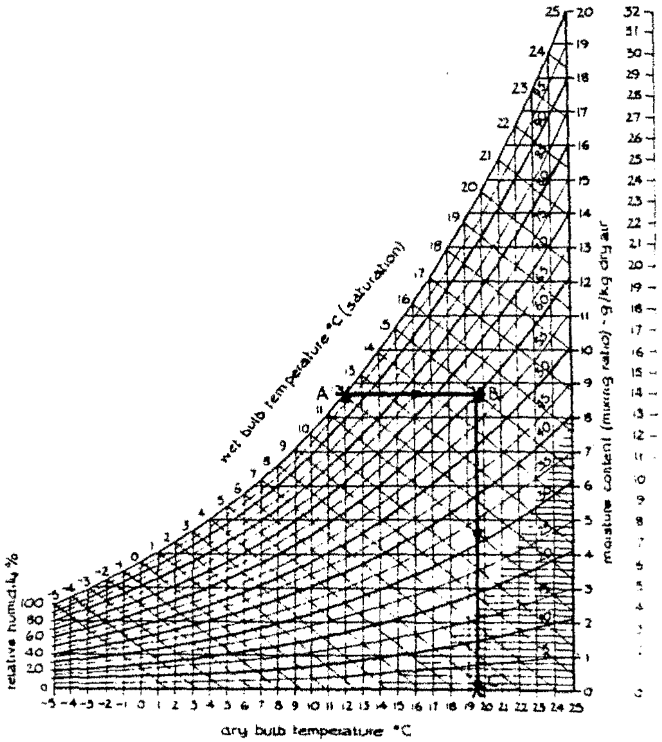
Example 3. If condensation has just taken place on a surface at 12°C, to what temperature must the surface be raised to reduce the relative humidity in the vicinity of the surface to 60 per cent?

If condensation is taking place, 12°C is the wet bulb (dewpoint) temperature. So mark the initial point of 12°C, 100 per cent relative humidity at A, **28**. Draw a line horizontally to B to meet the 60 per cent relative humidity curve. The temperature at which this occurs can be seen by reading off the value at C. This temperature, needed to reduce humidity to 60 per cent, is 19·5°C.

Condensation through building elements

Methods for predicting condensation

The accurate prediction of condensation through construction elements is too complex to be undertaken during normal building design. Simple steady state methods can be employed. They give useful results for constructions which respond rapidly to thermal and moisture changes and helpful indications of the degree and location of risk in other circumstances. The method employed is to calculate the temperature and vapour distribution across the wall or roof being considered and, by means of converting the temperature to its corresponding saturation vapour pressure or by converting the vapour pressure to dewpoint temperature, to compare the temperature and vapour regimes to see whether condensation will be taking place. The process can be carried out graphically or arithmetically. There are considerable advantages in the graphical method since it offers, in a very simple way, the opportunity to determine what variations in temperature or resistance would overcome the condensation.



28 *Example 3.*

Graphical method for condensation prediction

This process can be carried out by means of three diagrams. First, a sketch of the construction is prepared and the data on the performance of the materials and the external and internal conditions are assembled.

Second, a diagram is prepared where the widths of the materials are represented in proportion to their vapour resistance and a straight line will represent the distribution of vapour pressure.

Third, a similar diagram is prepared of the thermal distribution across the construction being investigated. The data on vapour distribution from the second diagram now enables a line representing the dewpoint temperature to be drawn on the thermal diagram. Condensation is possible wherever the structural temperature falls below the dewpoint temperature. The method is best explained by an example, shown is diagrams **29**, **30** and **31**.

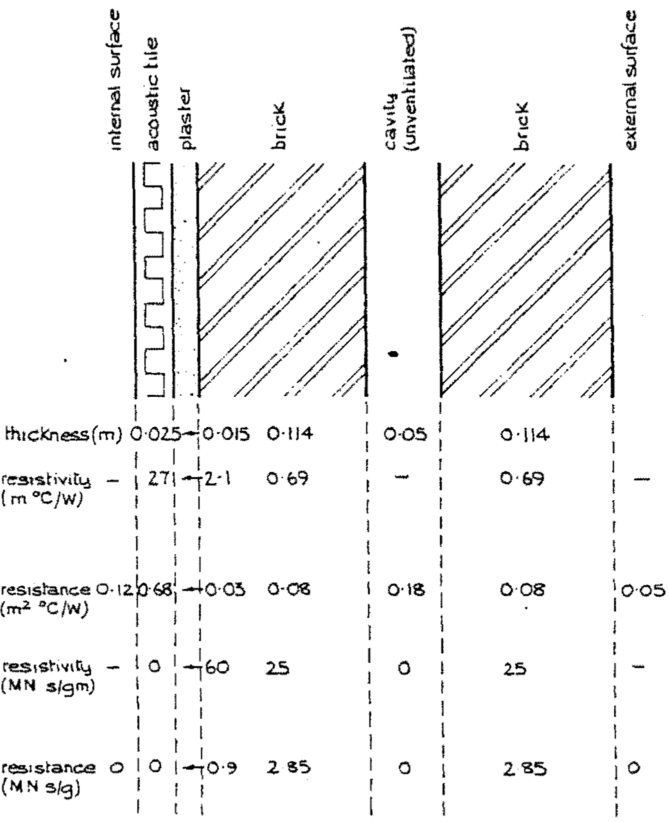
Notes on the graphical method of condensation prediction

Use of the diagram to overcome condensation

It is apparent from **31** that it is immediately possible to determine what increase in the internal temperature or what variation in assumption about external temperature would raise the structural temperature line to a point which should clear the saturation temperature line and thereby eliminate condensation. It is also possible to discover what value of external insulation would be required to raise the structural temperature line above the saturation level and, in the case illustrated, rather surprisingly the decrease in the amount of internal insulation which would also have the effect of raising the temperature to a level above the saturation temperature throughout the wall (it may seem surprising that a decrease in

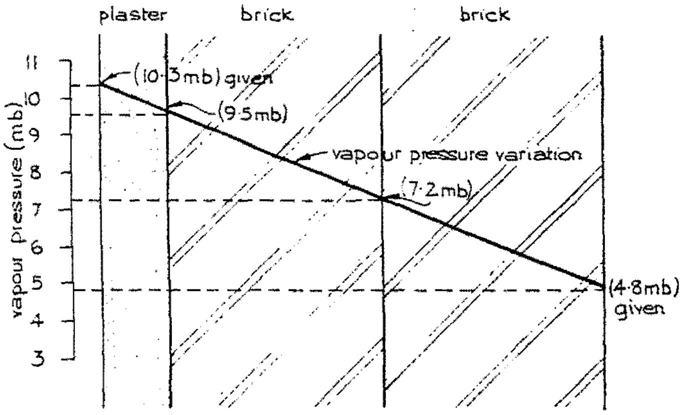
29 *Construction and basic data.*
i Sketch a section of the construction.
ii Mark thickness of each element in m.
iii Mark thermal and vapour resistivity of each element from tables V, VI and VII.
iv Mark thermal and vapour resistance for each element (resistance = resistivity × thickness in m, or fixed value as shown for surfaces and cavities—see table VIII).
v Note basic conditions, eg internal and external temperature and relative humidity.
In this example external relative humidity is 80 per cent for air at 0°C. Internally air is 18°C with an increased moisture content (mixing ratio) of 3·4 g/kg contributed by occupants and their activities.

30a, b *Moisture regime.*
i Draw a section with widths of elements in proportion to their vapour resistance (any scale will do—20 mm per MNs/g is often convenient). The acoustic tile and cavity do not appear because they have no vapour resistance, **30a**.
ii Draw to any convenient length a scale of vapour pressure. The range of vapour pressures can be derived from a psychrometric chart. The same basic conditions were covered earlier in example 2, **27**. *The points representing external conditions, point A, and internal conditions, point C, from* **27** *are reproduced in* **30b**.
iii For external and internal conditions, A and C in **30b**, *rule horizontally to the right hand vapour pressure scale. The external and internal vapour pressures can be read off: 4·8 mb and 10·3 mb respectively. Draw a straight line (shown solid black) connecting these two vapour pressures on the section,* **30a**.
iv For each junction—plaster/brick, brick/brick—read off the vapour pressure on the left hand scale of **30a**; *in this case 9·5 mb and 7·2 mb respectively.*
v On the psychrometric chart mark each of the vapour pressures—10·3, 9·5, 7·2, 4·8—on the vapour pressure scale and rule horizontally to the left (draw as broken lines) to the wet bulb temperature line: these are the corresponding saturation temperatures. In this example they are 7·5, 6·2, 2·5, −3°C.

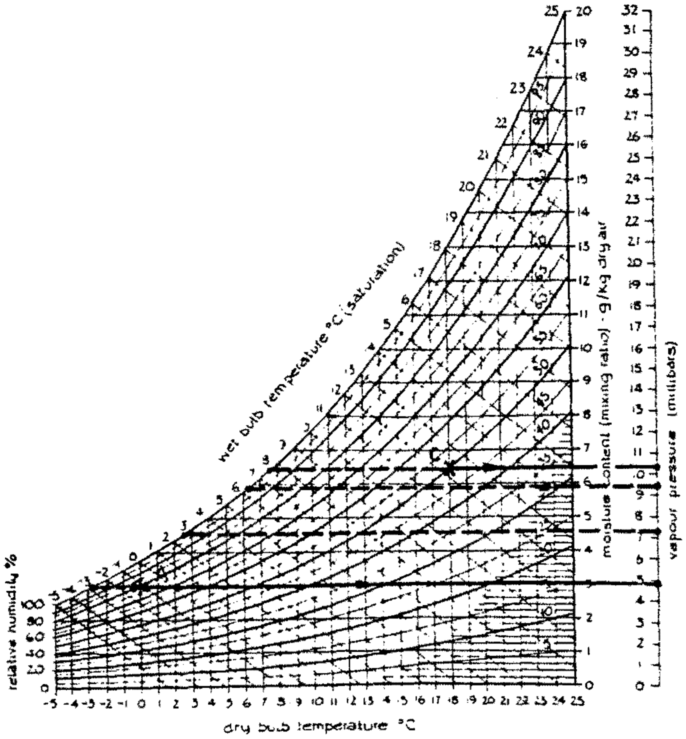


	internal surface	acoustic tile	plaster	brick	cavity (unventilated)	brick	external surface
thickness (m)		0·025	0·015	0·114	0·05	0·114	
thermal properties: resistivity (m °C/W)	–	27	2·1	0·69	–	0·69	–
thermal properties: resistance (m² °C/W)	0·12	0·68	0·03	0·08	0·18	0·08	0·05
vapour properties: resistivity (MN s/gm)	–	0	60	25	0	25	–
vapour properties: resistance (MN s/g)	0	0	0·9	2·85	0	2·85	0

29



30a



30b

Table V Thermal and vapour resistivities

Building material	*Thermal resistivity (m°C/W)*	*Vapour resistivity (MN s/g m)*
Aluminium	0·0045	—
Asbestos cement	2·8	1600
Asbestos insulation board	9·5	(18)*
Asbestos, sprayed	21·0	(60)
Asphalt	2·0	(100 000)
Brick (see table VI for more details of masonry)	0·84	25-100 (45)
Clay tiles	1·2	270
Chipboard	9·2	(500)
Concrete, ash aggregate	1·6	(55)
Concrete block, Lignacite solid	2·0	36
Concrete block, Thermalite aerated	5·3	56
Concrete, cinder aggregate	1·4	(55)
Concrete, dense	0·69	30-100 (50)
Concrete, exfoliated vermiculite aggregate	8·6	(60)
Concrete, foamed slag aggregate	4·1	(40)
Copper	0·0025	—
Cork, granulated	25	(10)
Cork slab insulation	20·4	(75)
Cork tiles	12·5	250-330 (300)
Ebonite, expanded	24	10 000-60 000 (30 000)
Fibreboard	20·0	15-60 (45)
Glass	1·7	(100 000)
Glass, expanded	16	(100 000)
Glass wool blanket	24·0	(18)
Glass wool quilt	28·6	(15)
Granite masonry	0·34	(400)
Hardboard	5·0	450-750 (600)
Hollow tiles	1·8	(270)
Lead	0·028	—
Limestone masonry	0·65	(150)
Linoleum	5·5	(1000)
Marble	0·4	(200)
Mineral wool felt	27·0	6
Mineral wool slab	20·4	8
Plasterboard	6·25	45-60 (55)
Plaster, gypsum	2·0	59
Plaster, lime	1·5	60
Plaster, vermiculite	5·0	(60)
Plywood	7·25	1500-6000 (3000)
Polystyrene expanded slab	30·0	100-600 (350)
Polyurethane foam	40·0	closed 1000 open 29
Render, cement mortar	1·88	100
Sandstone masonry	0·77	(150)
Slate	0·53	(250)
Steel	0·02	—
Stramit	10·8	45-75 (60)
Terrazzo	0·57	(250)
Thatch	8·6	(15)
Timber, hardwood	6·25	50-70 (60)
Timber, softwood	7·2	50-75 (60)
Urea formaldehyde, foamed	29	23-30 (25)
Vermiculite, exfoliated	16	—
Wood wool slab	11·0	4-15 (6)
Zinc	0·0085	—

* Brackets indicate typical values.

Table VI Thermal conductivity of masonry materials (W/m°C)

Bulk dry density kg/m³	*Brickwork protected from rain: 1 per cent moisture content*	*Concrete protected from rain: 3 per cent moisture content*	*Brickwork or concrete exposed to rain: 5 per cent moisture content*
200	0·09	0·11	0·12
400	0·12	0·15	0·16
600	0·15	0·19	0·20
800	0·19	0·23	0·26
1000	0·24	0·30	0·33
1200	0·31	0·38	0·42
1400	0·42	0·51	0·57
1600	0·54	0·66	0·73
1800	0·71	0·87	0·96
2000	0·92	1·13	1·24
2200	1·18	1·45	1·60
2400	1·49	1·83	2·00

insulation could eliminate condensation but it is important t remember that many good insulating materials have very low vapour resistances and, if they are used internally withou vapour barriers, the effect is to reduce the temperature of th basic wall without significantly reducing the vapour pressure) Diagram **32** shows the method.

Reconciliation of structural temperature and saturatio temperature

It may be thought more realistic to correct the situation show in diagram **31** so that the saturation temperatur does not rise enough to cause condensation, ie limi ing the water input by vapour barriers. This may chang the pattern of vapour distribution, since the vapour pressur will be reduced in areas in which condensation is taking plac involving reworking **30** and **31**. If no solution is possible b this method then it will be necessary to try to reduce th internal moisture content, by increased ventilation o extraction at source, and a new calculation will have to b made.

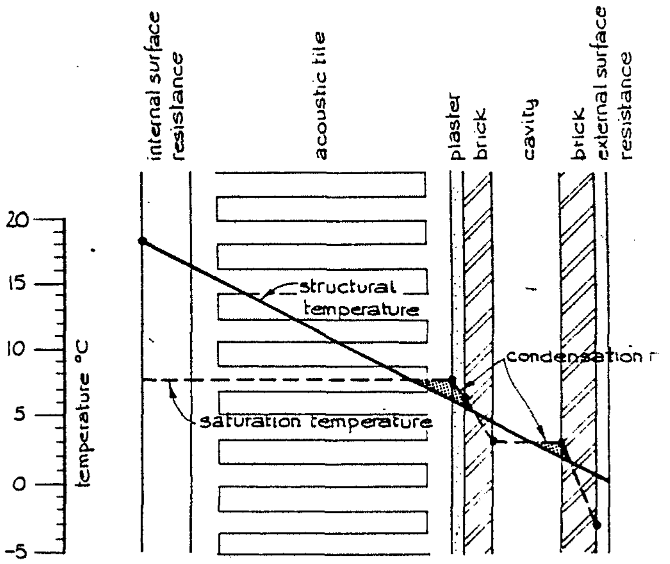
Table VII Moisture factors for masonry materials

Where moisture content is known, thermal conductivity (for the dry stat can be multiplied by the moisture factor to give a more precise conductivit

	Moisture content, percentage by volume						
	1	3	5	10	15	20	25
Moisture factor	1·3	1·6	1·75	2·1	2·35	2·55	2·75

Table VIII Thermal resistance of air layers

		Thermal resistance (m²°C/W)
Wall surface:	inside	0·12
	outside	0·05
Roof surface:	inside	0·11
	outside	0·04
Cavity		0·18



31 *Thermal regime.*
i Draw a section showing elements of the wall with widths in proportion to their thermal resistance (10 mm per 0·1 m² °C/W often convenient).
ii Draw a temperature scale of convenient length.
iii Join with a straight line the 18°C and 0°C points on the extremes of the internal and external surface resistances.
iv Plot the saturation (dew point) temperatures already established (7·5, 6·2, 2·5, −3°C from caption **30a, b** *stage v) the junctions of materials and connect them with a line shown h as a broken line.*
There is danger of condensation wherever structural temperatur drops below saturation temperature.

Arithmetic condensation prediction

This is described in BRS Digest 110 (see references). Its use is described in AJs 19.5.71 p1149 and 26.5.71 p1201.

Rate of condensation

In many cases it will be thought desirable to avoid all condensation. In others some transient condensation may be acceptable and it is desirable to estimate its rate. On surfaces the rate at which condensation can occur will usually be governed by the movement of air bringing fresh moisture since the rate of diffusion of moisture through still air is relatively slow. On windows and other surfaces which will generate convection currents carrying vapour, condensation rates can be very high and difficult to estimate. In cases where surface condensation is anticipated drainage channels should be provided, eg on windows.

The rate of interstitial condensation will be controlled by the rate at which vapour can pass through the construction to the point of condensation. Vapour flows generally from the interior to the point of condensation. There will also be some vapour flow from that point to the exterior. The difference between these is the rate at which condensation accumulates.

$$\text{Rate of flow (from interior)} = \frac{\text{Internal VP*}-\text{SVP at point}}{\text{Vapour resistance}}$$

*Internal VP = internal vapour pressure (MN/m²)

SVP point = saturation vapour pressure at point of condensation (MNs/g)

Vapour resistance = vapour resistance of construction from interior to point of condensation (MNs/g)

Rate of flow in g/m²s.

$$\text{Rate of flow (exterior)} = \frac{\text{SVP at point*}-\text{external VP}}{\text{Vapour resistance}}$$

*SVP at point = saturation vapour pressure at point of condensation (MN/m²)

External VP = external vapour (MN/m²)

Vapour resistance = vapour resistance of construction, from point of condensation to exterior (MNs/g)

Rate of flow in g/m²s.

Values of vapour resistance can be taken from the first diagram of the graphical method described earlier, eg values of vapour pressure (internal or external) and saturation vapour pressure at the point of condensation can be taken from **30a**.

Moisture equilibrium—steady conditions

The rate of ventilation required to achieve a predetermined internal humidity can be calculated from:

$$\text{Ventilation rate } (m^3/\text{hr}) = \frac{\text{Moisture input (g/hr)}}{1\cdot2\left(\begin{array}{l}\text{Desired internal}-\text{external mixing}\\ \text{mixing ratio (g/kg)} \quad \text{ratio (g/kg)}\end{array}\right)}$$

Consider a room with 100 occupants. Moisture input is 0·05 kg/hr per person (table III), a total of 5 kg/hr. External air temperature is 0°C with 90 per cent relative humidity. Internal air temperature is 20°C. The desired internal relative humidity is not more than 60 per cent. From the psychrometric chart, **25**:

mixing ratio at 0°C, 100 per cent RH = 7·5 g/kg

mixing ratio at 20°C, 60 per cent RH = 8·9 g/kg

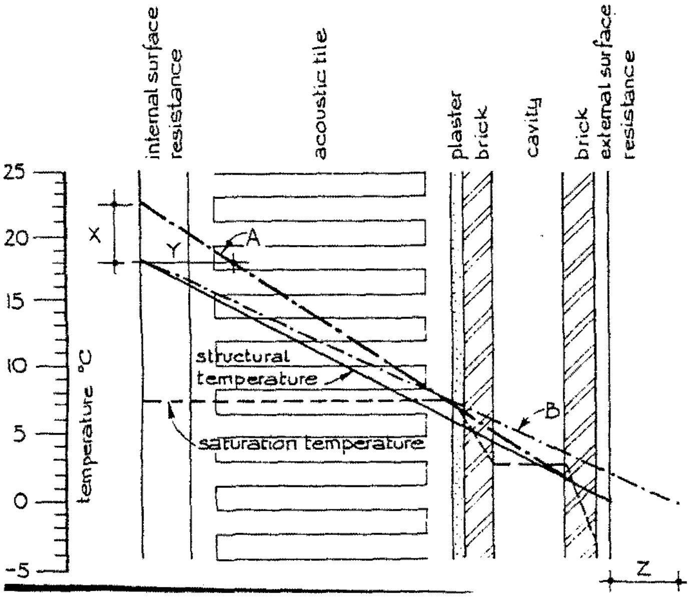
$$\text{Ventilation rate} = \frac{5000}{1\cdot2}(8\cdot9-7\cdot5) = 2980\text{m}^3/\text{hr}.$$

This is similar to the minimum requirement for a place of public entertainment.

Moisture content—unsteady conditions

In cases where vapour input fluctuates a simple graphical procedure can be used. The method can best be described by a simple example.

A lecture room with intermittent use provides a typical problem. Will the moisture from the occupants give rise to excessive humidity levels? Consider a room 50 m² on plan and 3 m high (150 m³ volume) having 50 occupants between 9 am and 10 am, 11 am and 12 noon and 2 pm and 4 pm. It is empty at other times, the infiltration rate is three air changes per hour. The external temperature is 12°C and relative humidity 100 per cent, giving a mixing ratio of 8·6 g/kg (from psychrometric chart, **25**) and the internal temperature is 20°C. At the commencement of the period under consideration the mixing ratio both externally and internally will be 8·6 g/kg, since there is no other source of moisture than the outside air. The internal relative humidity at 20°C and a mixing ratio of 8·6 k/kg will be 58 per cent (see psychrometric chart **25**). During the course of the first hour (9-10) the air in the room will be changed three times (450 m³) by outside air and the 50 occupants will contribute 0·05 kg of moisture per person, a



32 *Three design possibilities to overcome condensation risk. Line A is drawn starting from an unchanged external air temperature but is steeper to clear the saturation temperature of the inner leaf. This shows:*

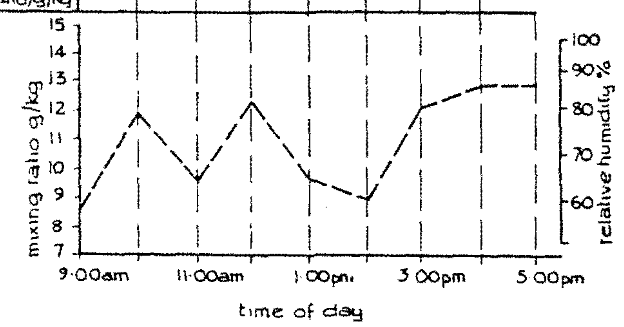
X = the increase in internal temperature necessary to eliminate condensation risk in the inner leaf

Y = the 'reduction' in internal insulation to achieve the same result (overall heat loss of course increased; a disadvantage of this approach).

This shows Z = the additional external insulation (with little vapour resistance) required to eliminate condensation risk.

Line B is drawn starting from an unchanged internal air temperature but inclined to clear the saturation temperature line. This shows Z = the additional external insulation (with little vapour resistance) required to eliminate condensation risk.

moisture sources kg								
occupants	2·5	0	2·5	0	0	2·5	2·5	2·5
original rm air (50 m³/180 kg)	1·6	2·3	1·8	2·3	1·8	1·7	2·3	2·4
ventilation air (450 m³/540 kg)	4·8	4·8	4·8	4·8	4·8	4·8	4·8	4·8
total	8·9	7·1	9·1	7·1	6·6	9·0	9·6	9·7
moisture content (mixing ratio) g/kg	12	9·5	12·2	9·5	8·8	12	12·7	12·8



33 *Hourly relative humidity showing unacceptable conditions, over 70 per cent for much of the time.*

total of 2·5 kg during the hour. The total moisture input for the period will be the sum of:

- moisture content of the air originally present
- moisture content of the fresh air introduced
- moisture introduced by occupants.

Given the density of air at 20°C is 1·2 kg/m^3:

- original air 150 m^3 (180 kg), mixing ratio 8·6 g/kg

water content = 180 × 8·6 = 1·55 kg

- ventilation air is 450 m^3 (540 kg, mixing ratio 8·6 g/kg

water content = 540 × 8·6 = 4·65 kg.

- water from occupants = 2·5 kg

$$\text{Total water content} = 1{\cdot}55 + 4{\cdot}65 + 2{\cdot}5 = 8{\cdot}7\ \text{kg}\ (8700\ \text{g}).$$

To determine the average moisture content of the air assume it is dispersed evenly through the total air, 600 m^3 (720 kg) ie both the 150 m^3 (180 kg) in the room itself and the 450 m^3 (540 kg) in the ventilation air expelled.

For 600 m^3 (720 kg) of air containing 8700 g of water,

$$\text{mixing ratio} = \frac{8700}{720} = 12\ \text{g/kg}$$

From the psychrometric chart, **25**, air at 20°C with a mixing ratio of 12 g/kg has a relative humidity of 81 per cent. This is the internal relative humidity at 10 am.

The process can be applied to each succeeding hour, taking into account the new mixing ratio established in the room. The calculation and the results are best set out in the form of a chart, which can show at the same time not only mixing ratio but also relative humidity. Relative humidity will normally govern the effects of moisture in the air including comfort, fungus growth and shrinkage and swelling of timber. Diagram **33** does this for the case under consideration showing that relative humidities reached are excessive and that the design should be modified from the point of view of comfort, apart from condensation risk.

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