#No 2279 AIVC 1647

Building Research Establishment Digest

CI/SfB 1976 (L27)

DIGEST 297

May 1985

2279

# Surface condensation and mould growth in traditionally-built dwellings

*Dampness on the inside surfaces of dwellings is a frequent source of complaint. It may be due to rising damp, rain penetration or a plumbing defect; or it may be due to condensation. Condensation and mould growth are widespread problems in all housing sectors but especially so in tenanted accommodation. In many cases it may be difficult to identify the underlying cause; this can often be complicated by social issues.*

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

*Mould growth varies in severity, causing 'inconvenience' (Fig 1), 'discomfort' (Fig 2) or 'acute distress' (Fig 3).*

*This digest considers the circumstances that lead to surface condensation and mould growth and suggests ways of reducing their incidence in dwellings of traditional construction.*

## Nature and scale of the dampness problem

An estimate of the nature and scale of the dampness problem can be gained from the English House Condition Survey of 1981 — see Table 1.

The interior decoration or furniture was affected by dampness in at least 2.5 million households; 6 million were troubled by condensation on window panes.

The survey contains information on what individual rooms have a dampness problem (though not on the severity and nature of that problem). The numbers of dwellings that have dampness in individual rooms and deterioration of decoration or furniture somewhere in the dwelling are shown in Table 2.

More problems are reported in kitchens than in any other room because the kitchen is generally the major source of water vapour in the house. Mould growth tends to cause immediate concern if it occurs in a room where food is prepared.

Data collected by the Scottish Office indicates that the situation is similar in Scotland, and is likely to be similar in Wales and Northern Ireland.

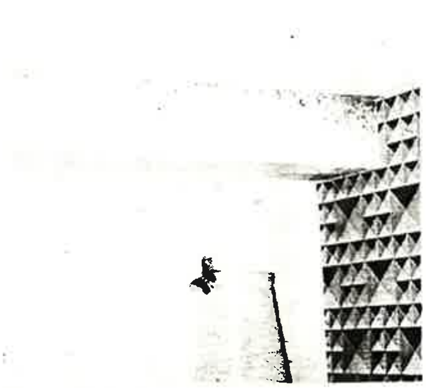

Fig 1 Minimal mould growth causing inconvenience

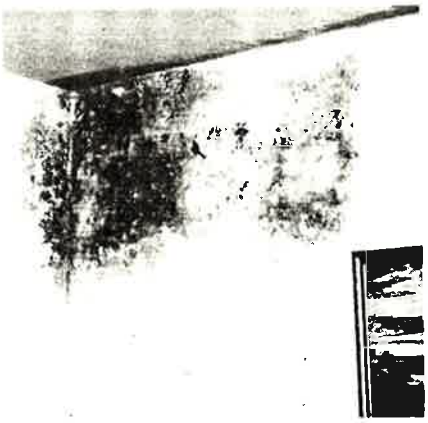

Fig 2 Persistent patches of mould causing discomfort

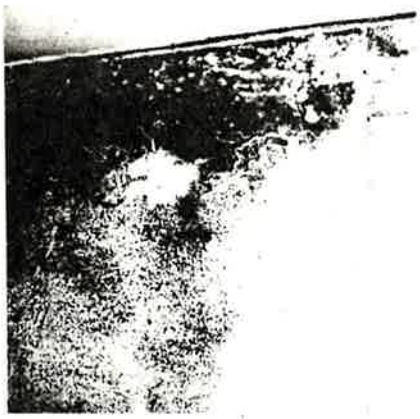

Fig 3 Extensive mould growth causing acute distress

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Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

**Table 1** Estimate of the numbers of dwellings (in millions) in England affected by dampness

| | **Owner occupied (9.6)** | | **Private rented (1.6)** | | **Local authority (4.7)** | | **Total (16.0)** | |
|---|---|---|---|---|---|---|---|---|
| | *No* | % | *No* | % | *No* | % | *No* | % |
| No condensation/damp | 5.6 | 58 | 0.8 | 48 | 1.9 | 39 | 8.2 | 51 |
| Steamed windows | 3.2 | 33 | 0.5 | 32 | 2.1 | 45 | 5.8 | 37 |
| Deterioration of paint on sills | 0.8 | 9 | 0.2 | 15 | 1.0 | 21 | 2.0 | 13 |
| Mould or damage to decorations | 0.8 | 9 | 0.4 | 27 | 1.1 | 23 | 2.3 | 15 |
| Damage to floors, carpets, furniture | 0.1 | 1 | 0.09 | 6 | 0.3 | 3 | 0.5 | 3 |

**Notes** 1 The survey covered only the stock of 16.76 million houses built before 1976.
2 Approximately 0.8 million houses were vacant at the time of the survey
3 Some households experienced more than one problem
4 The number of houses in the sample was 4553

## Diagnosing dampness

The selection of an effective remedy for any dampness problem must start with a correct diagnosis of the cause. The position and appearance of the damage is often directly related to the cause. For example:

(a) Rising damp usually results in a horizontal tidemark with a well defined edge about 600-900 mm above ground level on external walls. The appearance will remain unchanged over long periods.

(b) Rain penetration will occur in localised patches with well defined edges, but not in any particular positon. The patches will increase in wet weather, especially after driving rain, and fade away in prolonged dry spells.

(c) Plumbing defects will cause problems very similar to rain penetration but their occurrence will not be related to external weather.

(d) Condensation problems will lead to damp patches that are more diffuse without the definite edges that occur with the other causes. Impermeable surfaces, such as gloss paint or vinyl wallpaper, can be covered with a film or droplets of water. Trouble starts in areas that are either unusually cold, such as inside exposed corners, wall to floor junctions or solid lintels, or poorly ventilated, such as kitchen cupboards, wardrobes or behind furniture.

Inspection of the building fabric may reveal faults such as a bridged or defective damp-proof course, cracked rendering, blocked rainwater outlets or damaged plumbing and sanitation pipes. Rising and penetrating damp are caused by inadequacies in the building fabric. Consequently the responsibility for any remedial measures lies with the building owner or builder.

Condensation is affected by both the building fabric and the householder's use of the dwelling, and this can lead to disputes as to whether the problem results from poor design or inappropriate use.

## Mould growth

Householders may not be aware of condensation if it is mild and intermittent. But once mould growth is visible, dissatisfaction focuses on deterioration of decorations, a musty smell and possible health hazards.

The spores from which moulds and other fungi grow are always present in the air in houses. Given suitable conditions (a supply of food and oxygen and, most critically, the presence of liquid water) the spores can germinate and grow over a wide range of temperatures, certainly from 0° to 20°C. Some mould spores can germinate at relative humidities as low as 80-85 per cent. If the relative humidity is over 70 per cent for long periods, moulds will spread. The nature of the surface, especially the extent to which it can absorb and retain water and whether it provides particular nourishment, can be very important in initiating and supporting mould growth.

**Table 2** The incidence of dampness* (in thousands) in individual rooms of households that reported damage to decoration or furniture

| | **Owner occupied** | | **Private rented** | | **Local authority** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | *No* | % | *No* | % | *No* | % | *No* | % |
| Living room | 367 | 3.8 | 244 | 15.1 | 441 | 9.3 | 1052 | 6.6 |
| Kitchen | 427 | 4.4 | 295 | 18.3 | 758 | 16.0 | 1480 | 9.3 |
| Bathroom | 367 | 3.8 | 210 | 13.0 | 550 | 11.6 | 1127 | 7.1 |
| Bedroom | 332 | 3.4 | 180 | 16.1 | 638 | 13.5 | 1150 | 7.2 |
| | 9646 | | 1581 | | 4725 | | 15 952 | |

* The incidence of mould in individual rooms cannot be deduced from the EHCS

## Moisture in the atmosphere

Water vapour is one of the normal constituents of the atmosphere: the amount present can be expressed either as the vapour pressure or the moisture content of the air (grammes of water vapour per kilogram of air). The amount of water vapour that the air can hold is dependent upon air temperature. The lower the air temperature the less water vapour is required for the air to become 'saturated': the temperature at which saturation occurs is the dewpoint. Once this is reached, condensation will occur. Internally, this is most commonly seen when warm, moist air comes into contact with a cold window pane and condenses on the surface. In more extreme circumstances it is seen when the air in the bathroom becomes saturated and forms a fog.

The inter-relationship of the various factors can be shown on a psychrometric chart where the moisture content of the air is plotted against temperature, see Fig 4.

The curved lines shown the relative humidity; this is the ratio of the actual vapour pressure to the saturated vapour pressure at the same temperature, expressed as a percentage. Relative humidity is the most important factor determining the moisture content of timber and other organic materials and indicating the risk of mould growth.

The conditions of four samples of air are shown in Fig 4.

Air at 20°C and a moisture content of 7.4 g/kg has a relative humidity of 50 per cent (point A). If this is cooled without adding or removing water it will reach saturation at 9.4°C (point B). This is the dewpoint temperature of the air and depends only on the moisture content of the air, not its initial temperature.

If moisture is added to the air at point A at constant temperature until the moisture content rises to 10.3 g/kg, its relative humidity will become 70 per cent (point C) and the dewpoint will be 14.5°C (point D).

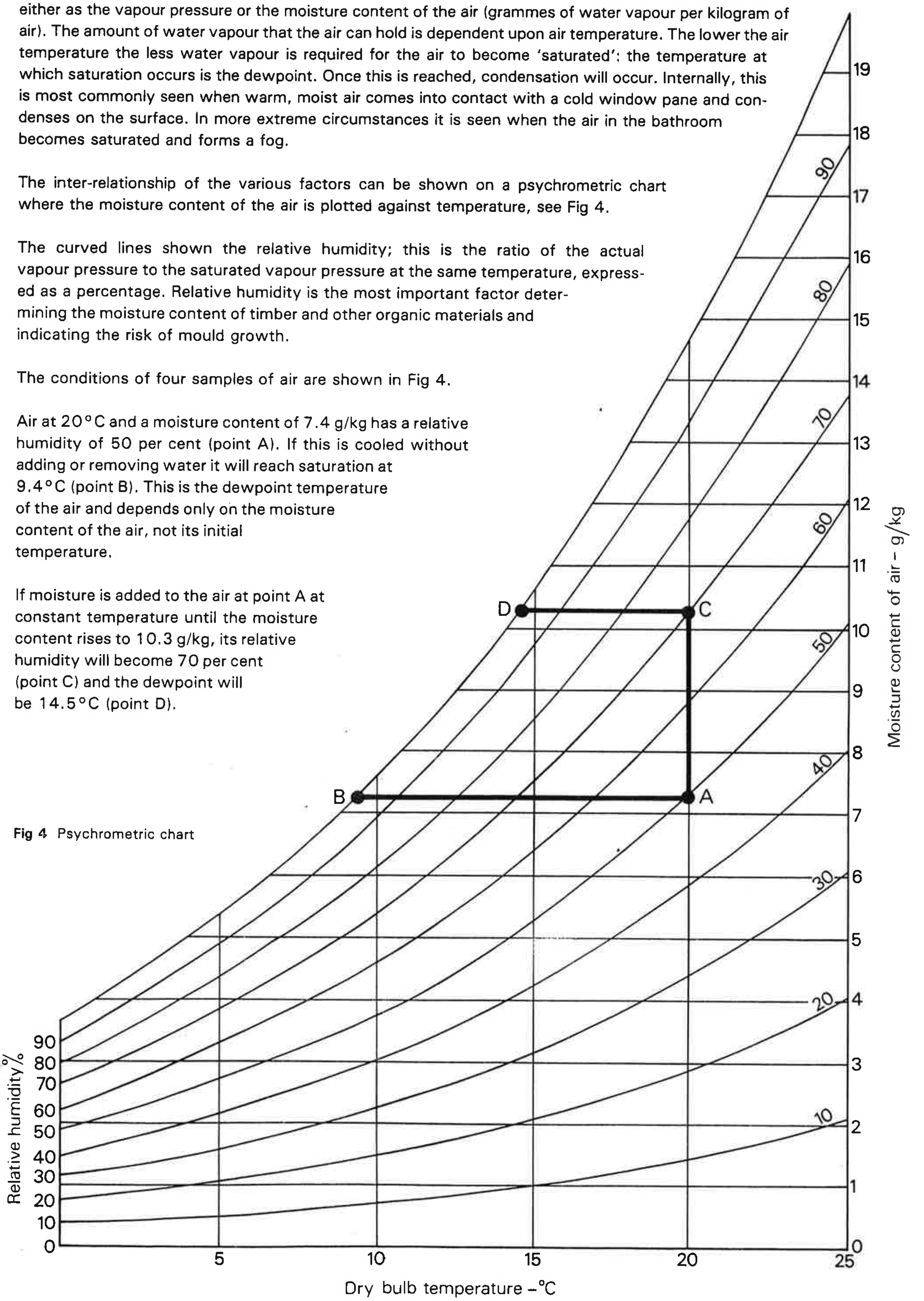


**Fig 4** Psychrometric chart

## Factors affecting condensation and mould growth

The previous section shows how the relative humidity within a dwelling might be reduced, either by increasing the temperature or reducing the moisture content of the air. In practical terms the occurrence of condensation and mould growth is dependent upon a number of factors:

moisture generation;
ventilation;
thermal insulation;
heating;
surface absorption.

**Moisture generation**

Water vapour is produced in all houses by normal household activities. There is a great deal of variation between households, but typical values are given in Table 3.

**Table 3** Range of typical moisture emission rates in a four-person household

| Source: | **Moisture emission per 24 hrs** *litres* |
|---|---|
| Four persons asleep for 8 hr | 1-2 |
| Two persons active for 16 hr | 1.5-3 |
| Cooking | 2-4 |
| Bathing, dish washing etc | 0.5-1 |
| Normal daily total | 5-10 |
| *Additional sources of moisture:* | |
| Washing clothes | 0.5-1 |
| Drying clothes (eg unvented tumble driers) | 3-7.5 |
| Paraffin heater during evening | 1-2 |
| Maximum daily total | 10-20 |

There is a base level of moisture production even in single-person households, but the amounts produced are related to household size. Unvented tumble driers are a major source of moisture. Paraffin and unflued bottled gas heaters should not be used in dwellings with condensation problems; the heat they produce does lower the relative humidity in the room where they are used but this benefit is offset by the moisture they add to the house.

A source of water vapour in new dwellings is the drying of the structure. It is estimated that a typical three-bedroomed house built of traditional masonry contains about 7000 litres of construction water. Most of this is usually dispersed during the first heating season.

**Ventilation**

This is the major route for removal of water vapour from the house. Dwellings have become less well ventilated recently where open fires have been replaced by electric heating and gas systems with balanced flues. Closer-fitting doors and windows and draughtproofing to conserve energy have further reduced fortuitous ventilation.

In most dwellings there is little need for specific steps to be taken in living rooms: the fortuitous ventilation is usually adequate to cope with the small amounts of water vapour usually produced. More definite provision for ventilation is often needed in kitchens and bathrooms which have greater moisture generation and in bedrooms which are usually less well heated. As moisture production is related to family size it may be helpful in future to provide ventilation according to the number of occupants rather than the size of the dwelling, although these are often related.

Some loss of heat through ventilation is inevitable but this can be minimised by the use of extract fans in the main moisture generating areas such as bathroom and kitchen. Automatic humidistat control, which runs the fans only when needed, can further improve their effectiveness, although maintenance may be a problem in the longer term. It is important that provision for a limited amount of natural ventilation is included: controllable slot ventilators, openable quarterlights and similar fittings which can be made secure give better control and are more likely to be used than windows with large openable areas.

**Thermal insulation**

Increased insulation brings internal surface temperatures closer to the air temperature in the dwelling and thereby lessens the risk of the surfaces falling below the dewpoint. The reduced heat loss from the dwelling means that household temperatures are on average higher since the dwelling cools more slowly overnight when heating is off. Additionally, occupants will spend less on fuel to achieve comfort and will be more likely to use the heating system provided. The effect of improving the fabric transmittance (ie the sum of the products of the U-values and the area of the different elements) is illustrated in Fig 5. This is taken from a survey of some 1800 local authority dwellings; each point is the mean for at least 20 houses. The data can be expected to be representative of many types of households. As would be expected for the average users, the fuel use falls with higher levels of insulation. However consumption by the lowest 25 per cent of users is independent of the fabric transmittance. Field studies support the implication that when insulation is improved in these households the benefits are taken as increased temperatures (perhaps 3 or 4 °C) and reduced risk of condensation.

While the walls may be adequately insulated overall, there are often localised areas (thermal or cold bridges)

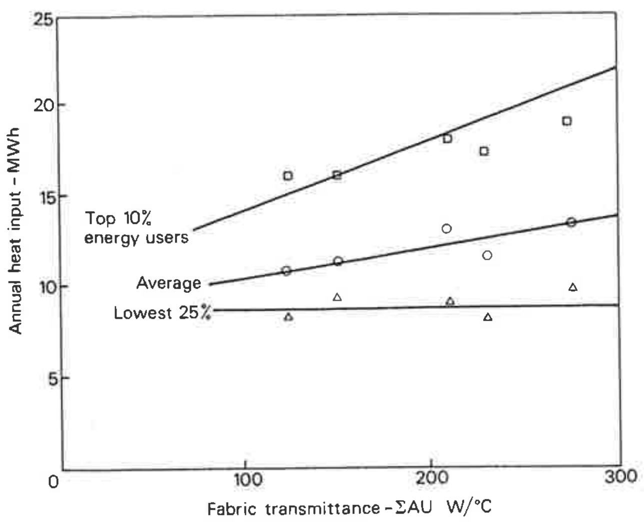


**Fig 5** Effect of improving fabric transmittance — data from survey of fuel use in local authority dwellings

where the insulation standard is much lower. The internal surfaces will be much colder in these areas, often leading to severe localised mould growth. Thermal bridges in traditional construction are typically caused by lintels, window reveals or gaps in roof insulation.

**Heating**

In the United Kingdom, 60 per cent of houses have some form of central heating; the remainder mostly have heating only in the living room. In two-storey properties, heat flow from downstairs can often warm up unheated bedrooms, but in flats and bungalows which have no heat gain from below, bedrooms can remain very cold. The provision and use of full central heating can eliminate many problems. In tenanted properties, a low level of heat provided under landlord control can reduce the likelihood of condensation. However, metering and charging arrangements for the fuel need to be resolved at the outset.

**Surface absorption**

Absorption of condensate will affect the extent of harmful condensation and associated mould growth. When moisture production is intermittent, the absorption and later evaporation of moisture by an absorbing surface may reduce the incidence of harmful condensation. Research is being done to quantify this effect, to see how mould growth is influenced by the nature of the surface and to see what recommendations can be made about surface absorption properties to reduce the incidence of mould growth.

## Inter-relationship of factors

Condensation is always caused by air becoming saturated when it meets a cold surface, but the circumstances under which it may occur in dwellings vary considerably. Broadly speaking, condensation is dependent upon three interacting factors: the environmental conditions within the building, the building structure, and the natural climatic conditions outside the building.

In heated dwellings, where the humidity is not very high, surface condensation is not normally a problem. Intermittent heating of dwellings, whether they are 'lightweight' or 'heavyweight', may lead to problems of surface condensation. In dwellings which have a highly responsive structure, such as dry-lined walls, problems may be encountered once the heating is turned off and surface temperatures fall quickly. In high thermal capacity construction, such as plastered solid brick walls, condensation may occur when moisture generation is increased at the same time as heating is switched on. In both these circumstances it may be necessary to provide continuous heating in cold weather to reduce or eliminate condensation. Traditionally this need was met by coal fires burning continuously at a low level. However, as insulation standards increase the difference between lightweight and heavyweight structures is likely to become less significant.

With heavy structures, rapid changes in weather can cause condensation in poorly heated rooms. When warm, damp weather suddenly follows a cold spell, the fabric may remain comparatively cold for some hours: very thick walls may not warm up for a day or possibly longer. When the warm, moist incoming air comes into contact with these surfaces which are below its dewpoint, water will condense upon them; as the walls warm up and eventually exceed the dewpoint, condensation ceases and the moisture already condensed evaporates. Unlike other forms of condensation, this is not confined to external walls but it rarely persists long enough to promote mould growth.

The inter-relationship between different factors can be shown using a theoretical model that calculates internal temperatures and relative humidities. Figure 6(a) shows the variation of internal temperature with ventilation rate for a mid-terraced house of brick/cavity/brick construction (built to the pre-1975 Building Regulations standard) for typical January conditions with a heat input of 2 kW. The effect of thermally improving the house (to the post-1983 Building Regulations standard) by installing cavity fill and roof insulation is illustrated on the assumption that the heat input remains at 2 kW. Additionally, the effect of doubling the heat input to the original house to 4 kW is also illustrated. Not surprisingly, increased ventilation leads to lower internal temperatures.

Figure 6(b) shows the corresponding relative humidities based on the assumption that seven litres of moisture are generated per day. In the original house with an energy input of 2 kW the humidity remains above the 70 per cent RH limit for all ventilation rates. With the higher heat input or with improved insulation the relative humidity is brought below the 70 per cent RH level for ventilation rates in excess of 0.5 ac/h. The minimum relative humidity occurs at a ventilation rate of about 1 ac/h. No improvement in relative humidity is achieved with higher ventilation rates.

The curves in Fig 6 show that:

(a) increased ventilation leads to lower internal temperatures which may result in discomfort to occupants;

(b) with low levels of heating and insulation, increasing ventilation will not prevent condensation and mould growth;

(c) to avoid condensation and mould growth some ventilation is essential, even with higher heating and insulation standards.

Figure 7 illustrates the calculations of conditions in a double bedroom in a well-insulated (post-1983 Building Regulations standard) flat and house. If the bedroom is in a flat with no heat input other than the 90W from each occupant, the humidity is well over 70 per cent for all ventilation rates despite the high insulation standard. When the bedroom is over a heated living room, as in a two-storey house, the humidity is brought down close to 70 per cent with about one air change per hour. If only 0.25 kW of heating is supplied in the bedroom, the humidity is brought down well below 70 per cent for all reasonable ventilation rates, even with no heat gain from below.

This would indicate that problems of condensation and mould growth in bedrooms will mainly be solved by improved insulation in two-storey houses because of the heat input from other parts of the dwelling. In flats and bungalows additional heat will be required in the bedroom to avoid high relative humidities.

Problems in kitchens in most cases do not arise from low heat inputs as in bedrooms but from short-term large moisture generation rates. These can lead to problems of severe condensation on glazing. The ventilation rate needed to prevent condensation occurring on windows during cooking is shown in Fig 8, which shows the increased moisture load from a gas cooker. Such high ventilation rates are difficult to achieve, even with mechanical extraction, and are likely to result in unacceptable internal conditions. In practice mechanical extract fans which run during and for some time after the high moisture generation periods adequately deal with the situation.

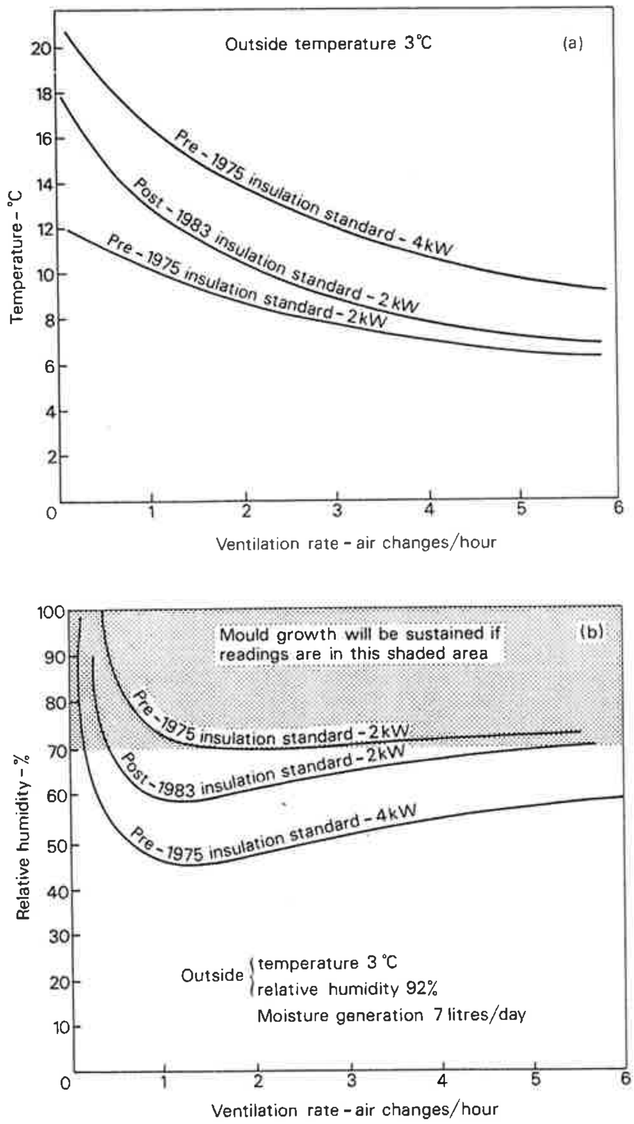


**Fig 6** Effect of ventilation on house temperatures and relative humidities for different insulation standards and energy inputs

## Selection of remedial measures

There are short and long-term measures that can be taken to solve a condensation problem. Short-term measures alleviate the immediate problem and assist the occupants; long-term measures affect the environmental conditions in the dwelling and may lead to a permanent solution. In many cases, both will need to be taken.

### Short-term measures

**Advice to the occupants: written and verbal** Many minor problems can be alleviated by careful attention to the heating and ventilation of the house. Quite trivial changes in living habits may bring major improvement. In the case of rented accommodation, discussion with tenants can often reveal the true nature of the dampness complaint; it may, for example, be as much a focus for general dissatisfaction with their dwelling as any specific condensation problems. A number of leaflets are available, from the Department of the Environment or local authorities, explaining the nature of condensation problems and outlining steps that householders can take. Films and videos are being developed that will play a useful role.

**Fungicidal washes and paints** A number of chemical treatments are available to kill mould fungi growing on walls. These may have little lasting effect where mould has been severe, but they are often useful to clean up an affected house at the same time as other remedial measures are carried out. Anti-condensation and fungicidal paints can be longer lasting. Their effect is, however, negated if they are subsequently covered with wallpaper or ordinary paints. Simple redecoration with ordinary paint may satisfy tenants at relatively little cost.

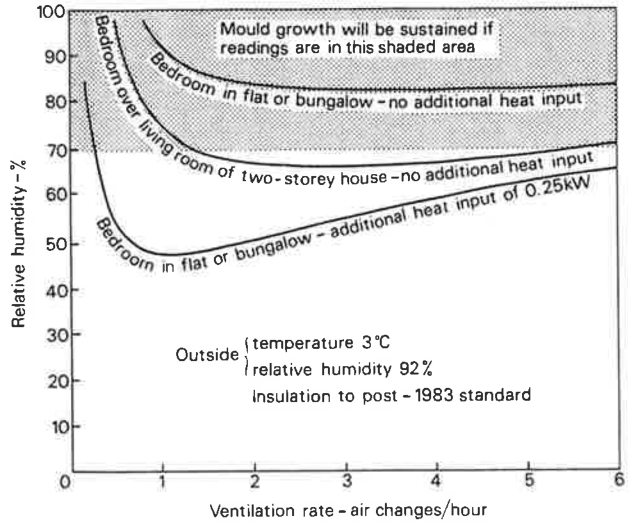


Fig 7 Relative humidity and ventilation rates in a bedroom in a well insulated dwelling

**Long-term measures**

These measures can be more expensive. Careful consideration must be given to the amount that it is necessary to spend to cure any individual problem as well as to the likely effectiveness of the remedy.

**Ventilation** As shown in Fig 6, a limited amount of ventilation is essential to keep relative humidities below 70 per cent. This may be achieved by the installation of trickle ventilators in bedrooms and extract fans in kitchens and bathrooms. Automatic controls, such as humidistats, can improve the effectiveness of fans at little extra cost. Care should be taken in the installation of fans to make them as unobtrusive as possible, both in visual and acoustic terms. Systems that transport air via ducts can provide adequate ventilation; they can incorporate heat recovery. Figure 6 also shows that above about one air change per hour, increased ventilation brings lower temperatures but little reduction in relative humidity. If a house with a condensation problem is reasonably ventilated further provision of ventilation is not likely to help.

**Dehumidification** Electric dehumidifiers that work on a closed refrigeration cycle both dry and heat the air. As some latent heat is released when the water condenses, the heat output is 10-30 per cent greater than the electricity consumed (typically 200-300W). An essential feature of all dehumidifiers is that the amount of water they extract is very dependent on the temperature and vapour pressure of the air. They are much more effective in warmer dwellings where condensation problems are caused by high vapour pressures, than in the more typical condensation prone houses where problems are caused by low temperature. They tend to be fairly obtrusive and too noisy to run in bedrooms overnight and are not acceptable to all householders. However, their portability means they can be used on a trial basis and moved elsewhere if need be. Some dehumidification systems can be mounted in the loft or a cupboard, but that makes the installation much more expensive.

**Insulation** As well as increasing surface temperatures, insulation can improve comfort conditions in the dwelling and reduce the cost of heating. Improved insulation therefore brings a number of benefits and should always be considered at the same time as other improvements such as installation of central heating. The most appropriate method of insulating depends on the construction. Where climatic exposure and construction permits, cavity fill is relatively cheap and its installation causes no disruption to the occupants. Provided the external leaf and any render is in good condition there should be little risk of rain penetration. Where there is no cavity or it is thought necessary to improve the thermal response of the wall structure, internal insulation (dry lining) can be used. A plasterboard-insulation composite board (with an integral vapour check) is a much better insulator than simple plasterboard and the extra cost is small. There will inevitably be a considerable amount of disruption in the household and some loss of floor area. Insulation may be better applied externally than internally to overcome localised condensation problems caused by thermal bridging. Materials and installation costs are high, but the effective cost will be much less if it replaces damaged rendering that would have had to be repaired anyway, or improves the external appearance. Rainwater pipes and drainage stacks may have to be repositioned but these may need to be replaced as part of normal repair work. Care is needed to prevent rain penetration around door and window openings.

**Heating** If insulation is to be effective in reducing the risk of condensation some heat must be provided. Unheated bedrooms gain some heat from below in two-storey houses, but this is not the case in flats where bedrooms are located above each other. Running cost and acceptability to tenants are just as important as the capital cost of a heating system. The best designed system will have no effect if it is not used.

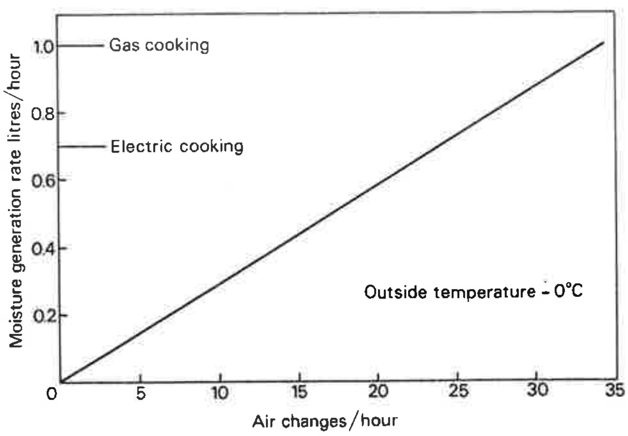


Fig 8 Ventilation rates needed to prevent condensation on kitchen windows (single glazed)

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*For the occupant*

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