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Condensation and its treatment

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This paper outlines the physical basis of condensation and reviews the importance of moisture generation, ventilation, heating and thermal insulation for the incidence and control of condensation in housing. It is stressed that components, particularly flat roofs, should be designed to avoid interstitial condensation. The different mechanisms by which water vapour is transferred from a house to its pitched roof are compared and the effects of ventilation and insulation laid in the roof are discussed.

In recent years damage caused by condensation in houses and their roofs has become one of the major problems facing all those involved with maintenance and management of housing. However, the problems that occur in rooms and roofs are different.

In rooms, mould can grow on walls (Figure 1). It can also occur in cupboards and may spread on to clothing. These are major sources of dissatisfaction, although it is rare for structural damage to occur. The solution to these problems can involve changes in the occupants' life style or major changes in the house's thermal insulation or heating systems and may be very difficult and expensive to undertake. The problems that occur in roofs (Figure 2) can be much more serious; the decay of timbers, rot of sarking boards and corrosion of gang nail plates can lead to structural failure, especially as the problem is unlikely to be noticed until it has reached an advanced stage. Fortunately, in general, the solution to these problems lies in a relatively inexpensive modification to the roof structure with comparatively little disturbance to the occupants.

For mould growth to occur, four things must be present: fungal spores, oxygen, a nutrient medium and water. Fungal spores are always present in houses, they are present in the air and will germinate whenever conditions are suitable: oxygen is obviously present and most building materials provide ample nutrients to support a fungal growth. The vital factor that can be controlled is liquid water and the main source of this, apart from rain penetration and rising damp, is condensation.

The amount of water vapour that air can hold is limited. Condensation occurs if this limit (at which the air is said to be saturated), is exceeded and liquid water appears. As the temperature falls smaller amounts of water vapour result in saturation (eg at 20°C 1 m^3 of air is saturated by 17.3 gm of water vapour while at 0°C only 4.4 gm produce saturation).

There are, therefore, two ways in which condensation can occur:

(a) increasing the amount of water vapour in the air at a constant temperature until saturation is reached.

(b) cooling air containing a constant amount of water vapour until, at the dew-point temperature, it becomes saturated.

Of course, in housing both of these conditions can occur simultaneously.

Houses

Water vapour is produced in houses by the normal activities of the occupants. Typical amounts produced in a five-person household are shown in the table below:

Respiration	3.2 kg/day
Cooking	3.0 kg/day
Bathing, dish washing	1.0 kg/day
Washing and drying clothes	5.5 kg/day

These together produce 12.7 kg/day which equals 12.7 litres or 22.4 pints per day. The amounts will vary depending on the nature and activities of the household. An old person living alone will produce relatively little water vapour while a large family, especially with small children and the consequent washing of nappies, will produce much more. Ideally, clothes should be dried outside, but in winter this is often not possible. Tumble driers, if used, should always be vented to the outside.

Further sources of water vapour, which have become increasingly important with the rise of fuel prices in recent years, are paraffin and unflued bottled gas heaters. These emit over 100 gm of water vapour for every kilowatt hour of heat produced: consequently, if a house is heated entirely by paraffin or bottled gas, a considerable amount of water vapour will be added to that already in the room.

To reduce the risk of condensation, water vapour produced in the house must be removed. The most practical method of removing water vapour is by natural ventilation to the outside air. Unfortunately, in recent years there has been a tendency for ventilation rates in both new and existing houses to be reduced because of the absence of flues and attempts to save energy by weather-stripping around doors and windows. Furthermore, in many modern houses natural ventilation can be provided only by the opening of large windows, which can result in excessive ventilation, and as a result, will not be left open for long periods. Also large windows on the ground floor will not be left opened while the occupants are out of the house. Controllable slot ventilators over the windows are very satisfactory as they do not produce unpleasant draughts. It is, however, necessary to ensure that they are used and not blocked up.

Mechanical extractor fans fitted in the kitchen and bathroom can be very useful if used during cooking and washing since they remove the water vapour when and where it is produced without removing very much heat from the house. It can, however, be very difficult to encourage the use of fans, especially in bathrooms where draughts can be a problem. In the future, sophisticated controllers linked to humidistats or other sensors may be effective, and it may eventually be possible through the provision of mechanical ventilation and heat reclamation to save energy as well.

Even if ventilation keeps the amount of water vapour in a house relatively low, condensation will still occur unless surface temperatures are kept above the dewpoint. Two factors are necessary to achieve this:

a) Heat must be provided within the house by means that tenants can afford, and

Figure 1: *severe mould growth caused by condensation in a living room*

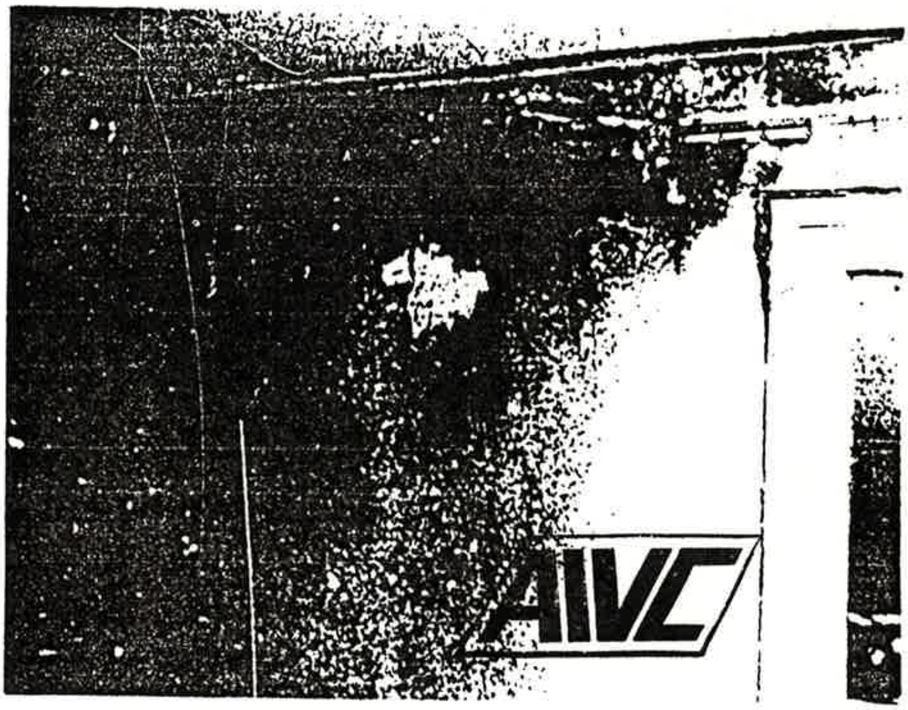
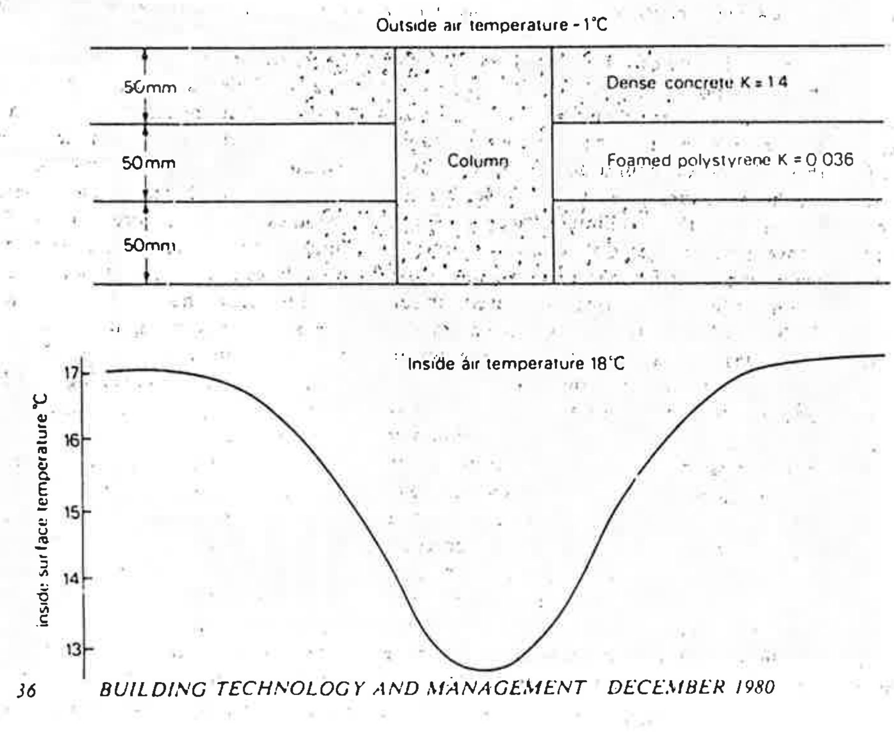


Figure 2: *mould growth on sarking boards in a pitched roof*

Figure 3: *the effect of a cold bridge in a sandwich panel construction on the inside surface temperature*



which do not increase the amount of water vapour within the house.

b) The house must be sufficiently insulated.

Neither of these factors is adequate alone. However well a house is insulated, temperatures will remain low unless some heat is introduced. Even if a house is adequately heated some condensation will occur on single glazing which has a high 'U' value and if the condensed water runs over the sill onto the wall below this will cause problems. Proper design of the sill, which can include weepholes to the outside, should prevent this.

Two other aspects of the heating system are particularly important in relation to condensation. First, in many houses heating is provided only in the living room so that the bedrooms remain cold. Water vapour which is produced in the kitchen and bathroom easily migrates to these cold rooms where condensation is likely to occur. A low level of heating in bedrooms can keep the wall temperature above the dewpoint and thus prevent condensation. Second, it is most important that the response time of the heating system is matched to the thermal response of the wall structure. Traditionally, coal fires heated houses all day, keeping the wall construction above dewpoint. Today, when houses are often empty all day, fast response heating such as warm air systems used in conjunction with heavy wall constructions can cause large variations in air temperature and dewpoint while the wall remains cold. These problems may be overcome either by the installation of a more responsive lining such as plasterboard on battens, or by the provision of a low level of continuous heating.

Even though the insulation in a house may be generally satisfactory, small breaks in the insulation will form cold bridges through the wall and condensation is likely to occur on them causing major problems. Figure 3 shows the inside surface temperature of a section through a sandwich panel construction around a structural column. It can be seen that at the gap in the insulation caused by the column the surface temperature is much lower than at adjacent areas. Concrete lintels and ceiling or floor slabs extended to form balconies or walkways, are particularly at risk here. These problems can often be difficult to overcome because dry-lining or external insulation can be difficult to apply.

So far only surface condensation has been discussed. However, it is important to realise that if the temperature falls below the dewpoint within a wall or roof, interstitial condensation will take place and can cause severe damage before the deterioration is noticed. In general, interstitial condensation will occur if the main thermal resistance is inside the main vapour resistance. Care, therefore, must be taken, particularly when insulation standards are increased, about the location of vapour checks in wall constructions which are particularly vulnerable to damage from condensation. The correct installation of a

... vapour check can solve the pro- ... ough care must be taken to seal the ... r check at joints and at gaps where ... ces pass through the wall. A cladding, ... ich while resistant to liquid water is permeable to water vapour, will allow the vapour to diffuse out through the wall safely, preventing any build-up of condensate.

Roofs

Flat roofs are particularly vulnerable to condensation problems. The presence of a weatherproof membrane and the low ventilation rates in the roof void mean that any water that enters the roof structure will not be removed easily. The position of the insulation is crucial in this case. In a warm deck roof, with insulation placed above the deck, the vapour check may be combined with the weather proof membrane. Satisfactory performance of a cold deck roof, with the insulation below the deck, depends, however, on a vapour check at the ceiling and adequate ventilation of the roof void, which are both difficult to achieve.

The number of reports of damage due to condensation in pitched roofs has been increasing in recent years. During the past two winters, which have been relatively severe, the number of complaints received by BRE has been very high. The types of damage that occur depend largely on the roof construction. In Scottish type roofs, where the traditional timber sarking is being replaced by composite boards such as fibre board or chipboard, mould growth can occur on the boards when they become wet due to condensation (Figure 2). English type roofs which have no sarking boards, but instead have an impermeable undertiling felt, present a different problem. In this case no damage is found where the condensation occurs on the sheet, but the condensed water can cause damage by running and dripping on to the ceiling or roof timbers.

It is also important to realise that because the moisture content of hygroscopic material depends on the relative humidity of the surrounding air, timbers in a roof where the high relative humidities persist will take up water even if no actual condensation takes place. One possible source of water vapour within the roof is uncovered water tanks, especially header tanks for central heating since they can occasionally become warm: these tanks should be covered at all times.

The main source of water vapour is the dwelling and water vapour enters the roof from the dwelling space by two means. First, the vapour pressure difference between the house and roof causes water vapour to diffuse through the plasterboard ceiling. From the published diffusion coefficients for plasterboard and the measured vapour pressure difference between the house and roof, it is possible to estimate that about 10 gm per hour enter the roof by this means. This may be reduced to about 1 gm per hour by the installation of a vapour check, usually a sheet of polythene stapled

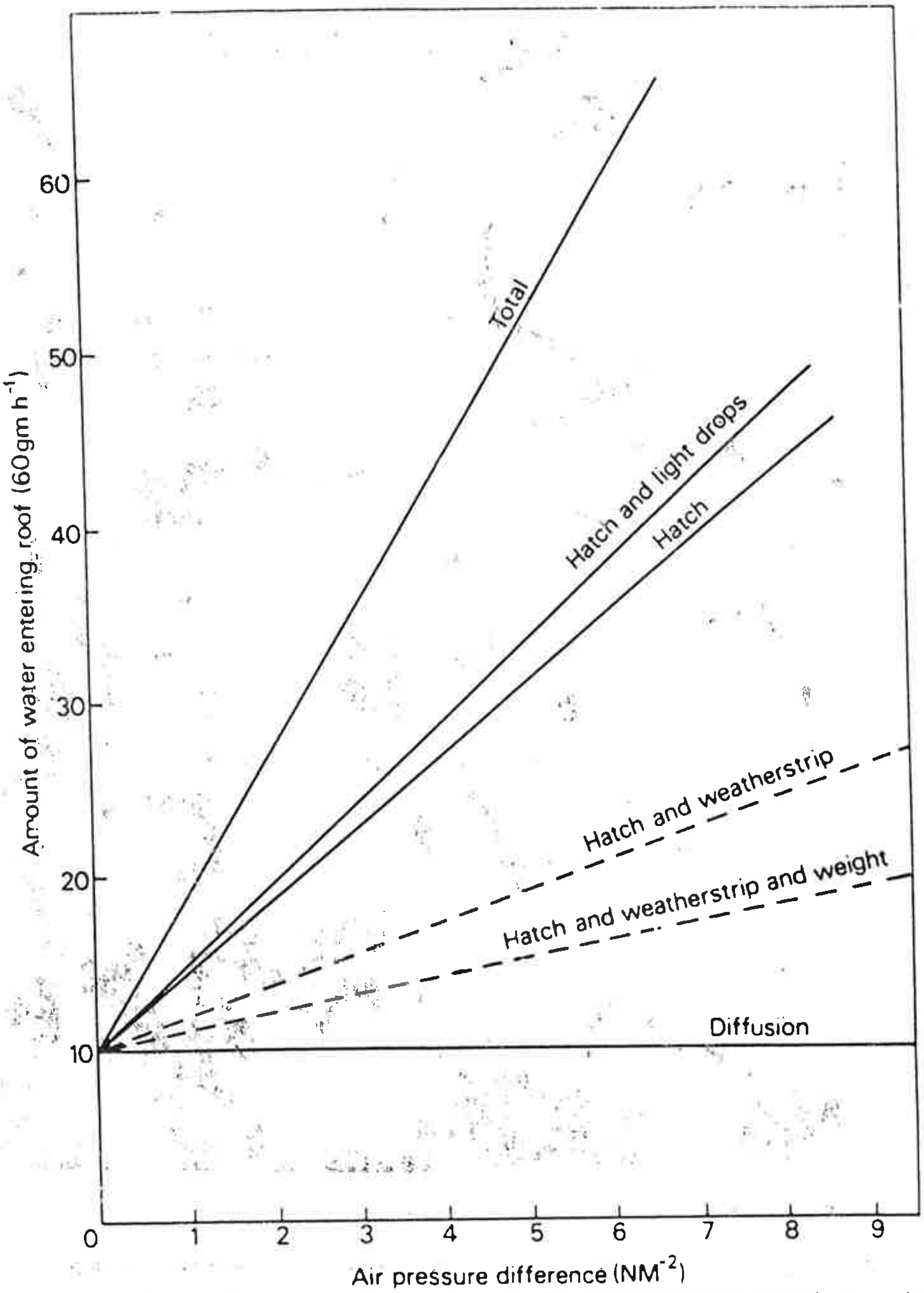


Figure 4: *the amounts of water vapour that enter a roof by diffusion and air motion through gaps in the ceiling*

to the underside of the ceiling joists before the plasterboard is fixed.

Secondly, the water vapour enters the roof by air movement. When the wind blows through cracks around doors and windows on the windward side of the house, the air pressure in the dwelling space is raised above that in the roof, and air carrying water vapour is forced through gaps in the ceiling. With all the windows closed, about 20% to 30% of the air which enters the house leaves via the loft, carrying water vapour into the roof void. With windows open on the windward side of the house and shut on the downwind side, substantially more air can go into the roof. This is similar to the case of single aspect flats which have only a door to an access corridor on one side. As much as 60% of the air entering this type of flat has been observed to leave via the roof. From measured air flow rates and the vapour pressure difference between the house and roof, it is possible to estimate that for a typical two storey house about 50 gm of water per hour enter the roof by this means. This is much larger than the amounts that are diffused through the ceiling even without a vapour check. The vapour check is being by-passed by this airflow and rendered virtually ineffective.

Studies of the moisture content of the roof timbers and of temperatures and relative humidities in roofs, both with and without vapour checks, have shown that the vapour check has made no significant difference to the condition in the roofs. Consequently, blocking holes in the ceiling should have a higher priority than the installation of a vapour check.

Tests have shown that the major routes by which air flows from the house into the roof are around the hatch cover, through light drops and through holes where pipes pass through the ceiling, which can be large, especially if they are concealed in cupboards. Figure 4 shows the contributions to the total water vapour transfer of diffusion and air motion through the in-

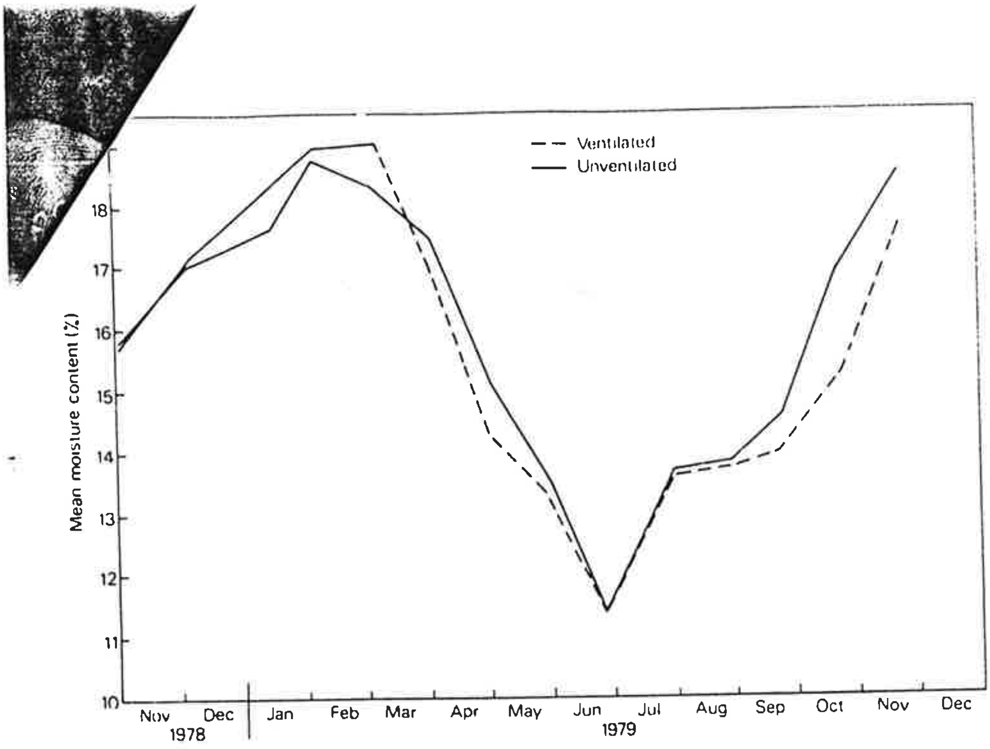


Figure 5: *the variation over a year of the timber moisture content in 20 well ventilated roofs*

dividual holes in the ceiling. While the diffusion contribution is constant, the air flow contributions increase sharply as the air pressure difference increases until at normal pressure differences they predominate. Also shown on Figure 4 is the reduction that results from putting a simple weather strip around the hatch and weighting down the hatch. Similar reductions in the flow round pipes may be affected by filling the hole with a mastic, which will allow for the expansion and contraction of hot water pipes.

Extractor fans also have benefits in the context of water vapour transfer to roof spaces. When an extractor fan is turned on in the kitchen or bathroom, air is sucked out of the house reducing the pressure in the house relative to that in the roof and thus reducing the airflow across the ceiling. At low windspeeds, air can be drawn from the roof to the house. Therefore, not only does the extractor fan remove water vapour from the house at places where it is generated, thereby reducing the risk of condensation in the house, but it also reduces the amount that enters the roof and assists in reducing the risk of condensation in the roof.

Ventilation of the roof space is very important. The situation is complicated and some ambiguity has arisen over advice which has been given in the past since there are circumstances when increased ventilation can lead to increased condensation. On clear calm nights, radiation to the night sky may cool the roof surface below the dew-point of the outside air (this is exactly analagous to the way in which the ground cools at night giving dew in summer and ground frost in winter). Under these circumstances bringing more air into the roof can give more condensation. When the roof warms up again during the day, however, ventilation will increase the rate of evaporation and reduce or prevent the long term build-up of condensate. Thus, even though increased ventilation may make matters slightly worse for short periods on certain nights, it should improve matters considerably in the long term.

The most effective way to improve ventilation in roofs is by the installation of ventilators in the soffit of the eaves on both sides of the roof. Where this is not possible, special ventilators which replace tiles may be used as can ridge ventilators and air bricks in gable walls. Because ventilation is important, care should be taken, when installing insulation at ceiling level, to ensure that it does not cover ventilation openings at the eaves while ensuring that the ceiling is covered up to the wallheads to prevent a cold bridge being formed.

The effect of roof space ventilation on the moisture content of roof timbers has been demonstrated in results from field studies carried out in twenty highly insulated roofs. During March 1979 three ventilators, each 30 cm and 10 cm were installed in the soffit of the eaves on both sides of ten of the roofs. Figure 5 shows the mean moisture content of both groups of roofs. The moisture contents of the roof timbers in the ventilated roofs fell faster in the spring and increased more slowly with the approach of winter.

Thermal insulation laid on the ceiling can have important effects on condensation in roofs. The insulation reduces the amount of heat entering the roof from the house below, but generally has very little effect on the amount of water vapour transferred. Consequently, the air temperature in the roof will drop while the vapour pressure remains constant: this leads to a rise in relative humidity. As noticed previously, the moisture content of wood and other hygroscopic materials depends on the relative humidity of the surrounding air, therefore, the roof timbers with insulation at ceiling level will be wetter than those without. Improved insulation, however, is highly desirable from an energy saving point of view and the slightly increased risk of condensation can in most cases be easily overcome by reducing the flow of moisture into the roof space and ensuring that the roof is adequately ventilated.

Unlike the other problems of dampness in housing, such as rain penetration or rising damp, which are caused almost entirely by physical defects in the house structure, condensation problems are particularly intractable as they depend upon the interaction of the occupants' life style and the house structure. *It is necessary to ensure that occupiers understand how to use their houses without causing problems and for architects and designers to ensure that houses are adequately insulated and can be effectively heated and ventilated.*

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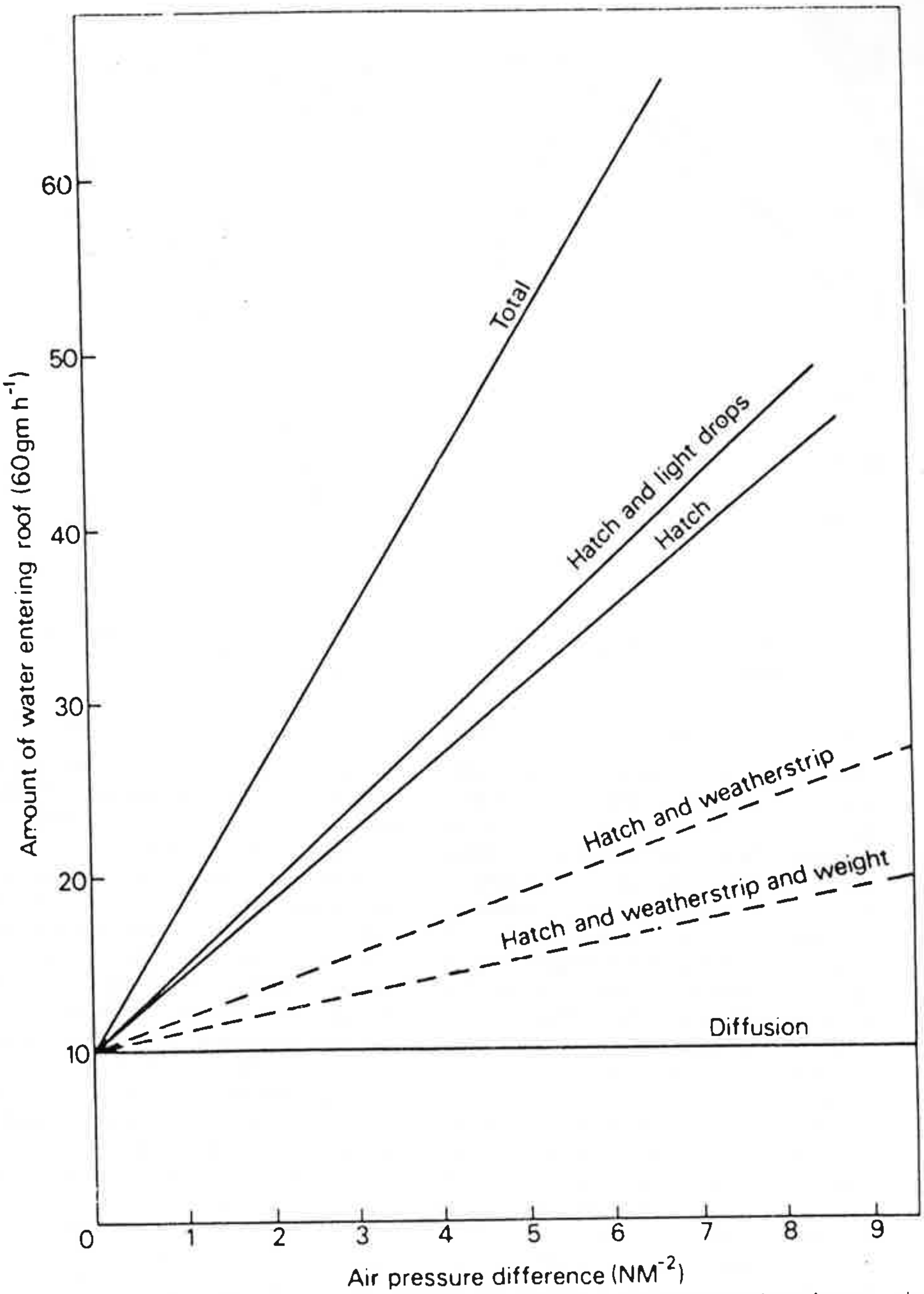

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