AVOIDANCE OF CONDENSATION IN ROOFS

J P Cornish, BSc, PhD, AFIMA and I W L Hendry, AIST

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This paper sets out in general terms the design principles for avoiding condensation in roofs, pitched and flat. It reviews existing information and describes the application of research results to practical situations.

Building Research Establishment
Building Research Station
Scottish Laboratory
Kelvin Road
East Kilbride   Glasgow   G75 0RZ

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INTRODUCTION

Most roofs are not troubled with condensation but when problems arise they can be very costly to correct and roofs should be designed to minimise the risk of condensation. Textile mills, swimming pools, laundries and other buildings with high internal humidities are more at risk than less humid buildings, and in the 1940s and 1950s industrial roofs received a good deal of study at BRS. Design principles for avoiding roof condensation were set out by Pratt [1] and Dick [2], and these principles have been widely applied to industrial roofs. Reasonably good estimates of internal humidities can be made for such buildings, as a basis for calculation.

Pitched roofs gave little trouble at that time, but constructional techniques and materials have changed, and some new types of roof have given trouble. For instance it is now commoner to use impermeable roof coverings or undertiling materials. Moisture vapour entering the roof structure from the house can condense on the underside of this layer. One estate of 500 houses built 10 years ago with pitched roofs covered with bitumen felt in place of tiles was badly troubled with condensation, and remedial work had to be carried out 18 months after the houses were erected at a cost of £70 000. It is worth while to consider the condensation risk in all roof types including those previously regarded as free from trouble.

The basic design principles are well known. Roofs have to be designed so that in adverse conditions, ie with a low external temperature and a high internal humidity, the temperature within the structure does not fall for long below the dewpoint. (Some temporary condensation can often be accepted on absorbent surfaces if it later evaporates and there is no long-term accumulation of moisture.) In a structure without airflow into or out of the air spaces, steady-state calculations can be made using the methods set out for instance in BRE Digest No 110 [3]. When there is airflow into roof spaces from the building, or from the roof space to the outside, the equations set out in National Building Studies Research Paper No 23 [1] can be applied. They apply to steady-state conditions, with constant internal and external temperatures and humidities.

In practice temperatures and humidities are not constant, but, as a design procedure, steady-state calculations can be made for the most adverse daily-mean values of external and internal temperature and humidity. Such calculations will indicate whether there is likely to be an accumulation of moisture at any point in the structure; if so the structure should be redesigned to avoid this. This procedure should suffice in structures incorporating absorbent materials, but not in roofs where temporarily deposited water is likely to drip off and cause trouble. For roofs with metal decks or tiled roofs with polythene or pvc sheeting below the tiles, it would be better to make calculations for the worst conditions likely to occur during short periods of time. Steady-state calculations are valid for short-time values of temperature and humidity in lightweight roofs, ie most roofs except concrete roofs.

If data are available these design procedures can be applied to any type of roof, pitched or flat. Unfortunately however data are not generally available on such matters as ventilation rates in roof spaces, leakage rates of moist air from buildings to roof spaces, or even typical internal humidities in dwellings, and statistical information on such matters is needed.

DESIGN PRINCIPLES

Before carrying out detailed calculations the general principles of roof design to avoid condensation have to be considered.

The simplest roof is no more than a rain shield but most present day roofs also include an inner lining or ceiling, commonly separated from the rain shield or 'cladding' by an air space and insulation. The main measures which can be taken to reduce the risk of condensation within the structure are:

(a) To provide a rain shield that is permeable to water vapour

(b) To provide a vapour barrier at the warm side of the structure, eg at or near ceiling level, to prevent moisture from the building entering the roof structure

(c) In roofs with air spaces, to ventilate the air space to the outside and thus reduce the concentration of water vapour in it, or alternatively to blow 'dry' air into the roof space by a fan and thus prevent moist air entering the roof space.

The practical difficulties in achieving these measures vary from one type of roof to another. It is easier to achieve a permeable rain shield on a pitched roof, eg by using lapped tiles, than on a flat roof. With present techniques it is easier to form an impermeable membrane as a vapour barrier above a roof deck when working from above, than it is to fix a membrane to a ceiling without leaving gaps when working from below. It is also easier to ensure that the dewpoint of the roof space is below the temperature of the outer layers of the roof if the air space is 'pressurised' by blowing in warm dry air, than if the roof space is naturally ventilated to the outside.

These design principles are now discussed in relation to different types of roof.

SHEETED ROOFS

Sheeted roofs became popular for factories in the 1940s, and were also used on some post-war prefabricated houses. They are pitched roofs with an outer cladding of metal or asbestos cement sheets, an air space, and an inner lining carried on hangers. The lining may be of fibre insulating board or plasterboard covered by a mineral wool quilt (see Figure 1). Moisture entering the roof space from the building by diffusion through the lining or by air flowing through gaps between lining sheets, can condense on the underside of the cladding and drip onto the lining. This problem was studied by Pratt[1] in a series of experimental roofs. If the roof space is ventilated this can alleviate the problem by reducing the moisture content of the air in the cavity. Though nominally unventilated the roof space is usually ventilated to the outside through gaps between sheets. The ventilation rate depends on the width of the gaps between sheets. Pratt demonstrated in experimental sheeted roofs that dripping could be reduced by using spacers to increase the gap between cladding sheets. In practice however it is difficult to estimate flow rates into and out of the air space and to predict the effectiveness of this measure; it may suffice in some roofs, but not in others.

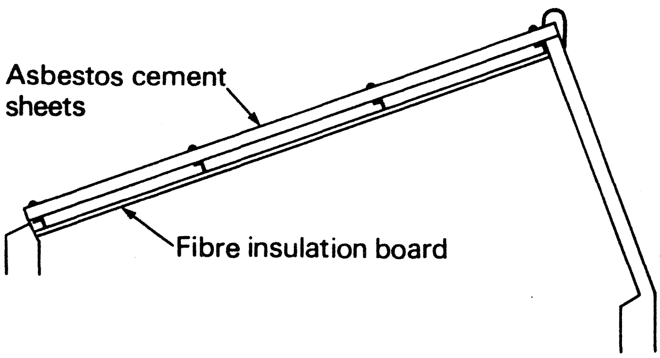

Figure 1 Sketch of asbestos cement sheeted roof

In buildings with intermittently high humidities such as breweries and dye houses, dripping due to intermittent condensation can be reduced by use of absorbent cladding materials. Concrete and asbestos cement have an advantage in this respect over metal, and the surface absorptance of the roofs can be increased by spraying them with absorbent material.

Another method of reducing condensation in a roof space is to prevent moisture from entering it. The best available method of obtaining a crack-free vapour barrier at ceiling level is to spray the underside of the lining with a plastics film - a process known as 'cocooning'. Pratt demonstrated that this treatment effectively overcame condensation problems in the roof of a textile weaving shed. However the treatment is expensive, often unacceptable in appearance, sometimes difficult to apply, and subject to failure where movements in the roof rupture the film.

PITCHED ROOFS

Slated or tiled pitched roofs can provide a permeable rain shield, if not backed by an impermeable undertiling material such as polythene or pvc sheeting. Traditional English house roofs have tiles hung on battens that are on rafters, now generally backed by undertiling bitumen felt to prevent penetration of dust, rain or snow. The gaps between the strips of felt and around the eaves are generally sufficient to make the roof permeable. Recently plastics sheeting has come into use as a substitute for bitumen felt. When laid with large overlaps this can be impermeable and lead to condensation. Cases are known where widespread condensation occurred in tiled roofs with polythene undertiling. Condensation was also observed on the underside of pvc undertiling sheets used with trussed rafters in Scotland. A polythene vapour barrier was used at ceiling level and ventilation openings provided, but these measures were not sufficient to prevent condensation in the roof space.

The trussed rafters of traditional Scottish roofs are so designed that the central area of the roof space can be freely used and lateral stability is provided by timber sarking; slates were usually fixed to the sarking. Such roofs are permeable to water vapour even when covered with hair felts. Bitumen felts and tiles are now generally used above the timber sarking to prevent rain penetration. The effects of minor amounts of intermittent condensation have been observed in some roofs constructed in this way. Recently however it has become common to replace timber sarking by other materials such as fibre insulation board. Some roofs of this type have had condensation problems, eg bowing of boards or surface mould, due to accumulation of moisture below the bitumen felt.

Some pitched roofs have recently been constructed with an outer rain shield of impermeable material such as bitumen felt, asphalt, plastics sheeting or metal sheeting, and these are prone to condensation. In a pitched roof design, bitumen felt was spot bonded to chipboard sarking to form a rain shield, and insulation was provided at ceiling level. The chipboard was wetted by condensate deposited between it and the felt, causing some loss of strength and fungal growth. The condensate also drained down the slope making the boards near the eaves wet. Additional ventilation openings to the roof space have been provided to find out whether this will overcome the problem, but it seems unlikely that the entrapped water will evaporate to any extent during the winter.

An adequate vapour barrier at ceiling level prevents roof condensation but is not easy to achieve in practice. For example in a number of prefabricated aluminium bungalows attempts were made to provide a vapour check at the ceiling by taping joints and painting with an oil paint, but the treatment was not wholly successful. In a canteen with roof condensation an attempt was made to provide a vapour check at ceiling level by the use of polythene sheeting, but a gap was left at the junction of the ceiling with the wall which allowed warm moist air to enter the roof space fairly freely. Large pools of condensate formed on the polythene sheeting.

The difficulties of providing a vapour barrier near the ceiling are reduced if it is provided above a roof deck, since an effective vapour barrier consisting of bitumen felt with a mopped on coat of hot bitumen can be formed when working from above. The roof insulation can then be placed above the bitumen layer and capped by another waterproof membrane to provide 'overdeck insulation'.

Pratt demonstrated that this form of remedial treatment successfully overcame condensation within the roof space of prefabricated aluminium bungalows. Since then the Building Research Establishment have advised on the design or remedial treatment of many such roofs. For example, where the pitched roofs were covered with bitumen felt, the condensation was not alleviated by increasing the ventilation openings to the roof space. Overdeck insulation was provided as a remedial treatment, and when defective timbers had been replaced this successfully overcame the problem.

Pitched tiled roofs have also been constructed with a form of overdeck insulation (below the tiles). In this construction bitumen felt is fixed above the rafters and extruded foamed polystyrene insulation (which is unaffected by moisture) is fixed above it, followed by battens and tiles. Any driven rain which gets under the tiles and between insulation boards is kept out of the roof space by the bitumen felt.

The amount of 'overdeck' insulation needed to avoid condensation can be calculated for given temperatures and humidities [3]. The method can be illustrated by the example of a timber deck roof illustrated in Figure 2. The thermal resistance of the insulation is taken as 0.69 m^2 $^oK/W$, which could be provided by approximately 25 mm of mineral wool, extruded or expanded plastic. The surface temperature is assumed to be -4^oC. With these assumptions the temperature of the vapour barrier is 16.4^oC. This is above the dewpoint of the air within the building. Steady-state calculations are applicable since the roof has a low thermal capacity. As a rule of thumb it has been found that condensation in house roofs can be avoided if the majority of the thermal insulation required by Building Regulations is placed above the vapour barrier.

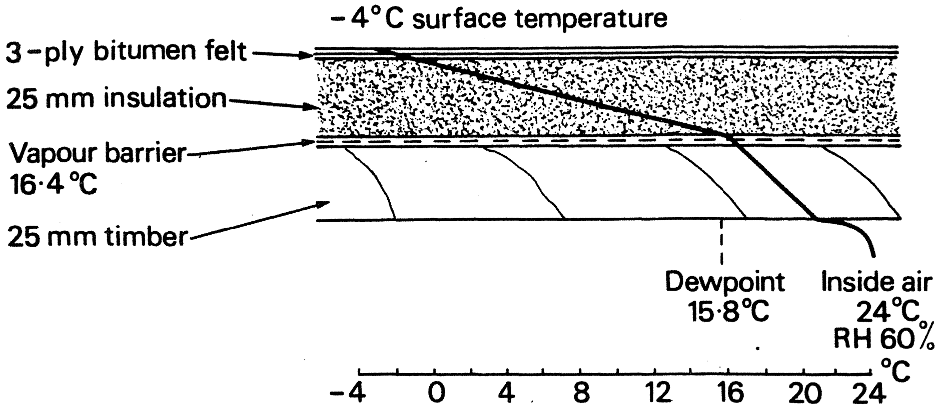

Figure 2 Roof with vapour barrier and overdeck insulation

FLAT ROOFS

Flat roofs have to be covered with an impermeable layer of, for example, asphalt or bitumen felt to exclude the rain, and as with sheeted and pitched roofs if the impermeable layer is on the outside there is a risk of condensation. Air spaces in pitched roofs can be ventilated, but it is more difficult to obtain adequate ventilation in the air space in a flat roof.

A timber deck roof of the kind illustrated in Figure 3 contains a series of narrow air spaces between joists. They can be ventilated through grilles or gaps at each end of each air space, ie between each pair of joists, but there is a fairly high resistance to airflow in these long air spaces, particularly if they are obstructed by stiffeners. When the roof overhangs the external wall, ventilation openings can be provided on the underside of the projection, but when the roof is flush with the external wall, ventilation openings have to be in the plane of the wall and they can be unsightly.

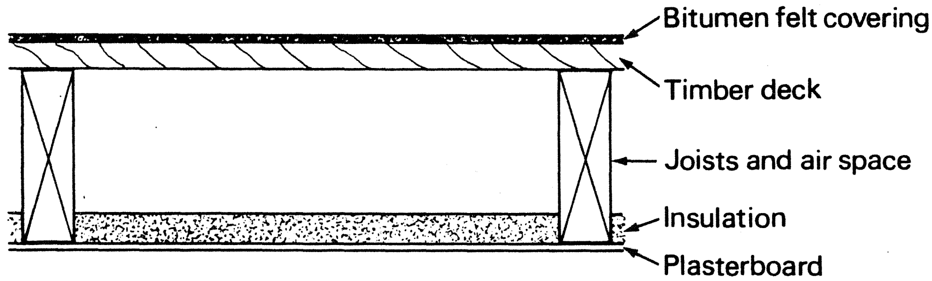

Figure 3 Sketch of shallow timber deck roof

Concrete is another material commonly used as a structural deck for flat roofs. There are many types of concrete roof. Dense or lightweight concrete, or dense concrete with a lightweight screed - either cast in situ or placed as slabs - can be used. They are usually covered with a waterproof layer of bitumen felt or asphalt.

Concrete roofs can perform well if they are dry before they are covered and if the internal humidity in the building is low. If not they are at risk from condensation on the underside of the covering. Constructional water is present in cast-in-situ concrete and concrete screeds, and moisture may also be present in concrete slabs if they are allowed to get wet before they are erected. If the air in the building is humid it can diffuse through the concrete, or any cracks in the concrete, and condense on the underside of the covering, even if the concrete is initially dry. Condensed water can flow along the space between the underside of the covering and the concrete and drip down through joints or cracks in the slab. The condensate may be darkened by bitumen emulsion and cause unsightly staining of ceilings or walls, or drip into the room below.

Breather vents are sometimes fitted to allow water to escape from the outer side of the concrete, sometimes in conjunction with a pressure releasing layer beneath the waterproof covering. If properly designed these can be effective in avoiding blistering of the covering, but they are not always effective in preventing trouble from condensation.

Condensation can be avoided if overdeck insulation is used, provided that its thermal resistance is high enough. Because of its high thermal capacity there can still be intermittent condensation on the underside of the concrete slab when the building is intermittently heated; this can be avoided by using a suspended ceiling of low thermal capacity which warms up quickly when the heating is turned on.

The 'inverted roof' operates on the same principle as overdeck insulation, but uses materials which are unaffected by moisture, such as foamed glass or extruded polystyrene, above the waterproof covering. These slabs are not covered with a waterproof layer as with 'overdeck insulation', but are simply weighted down by gravel.

ROOF INCORPORATING A PRESSURISED ROOF SPACE

Sometimes a suspended ceiling is specified to provide a roof space to accommodate machinery, or for appearance, or for acoustic absorption. This introduces an air space (Figure 4) which must be taken into account in assessing the condensation risk. For instance the thermal insulation of an acoustic ceiling may be high enough to reduce temperatures within the structure below the dewpoint of the air within the building.

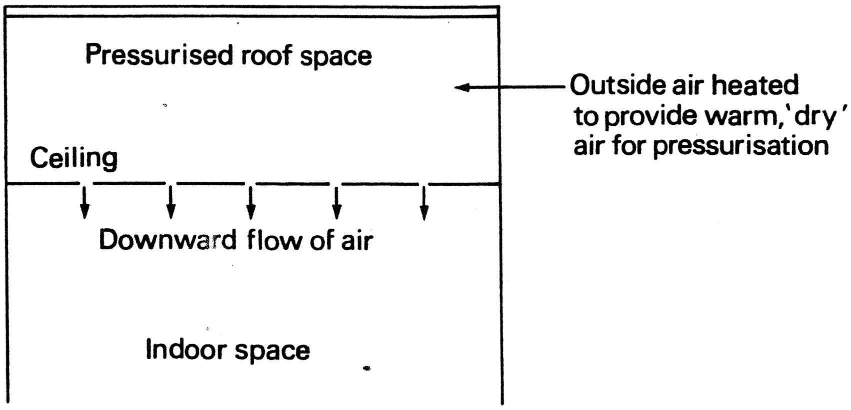

Figure 4 Sketch of pressurised roof space

No condensation occurs if the roof space air is maintained at the indoor air temperature of the building and if the roof has overdeck insulation as illustrated in Figure 2. However overdeck insulation is not always acceptable to designers; it may be difficult to construct with the roof construction considered, or the appearance of bitumen felt may be unacceptable. In such cases warm 'dry' air can be blown into the roof space to ensure that the dewpoint of the air within it is kept below the temperature of any part of the structure. The air pressure in the roof space has to be high enough to prevent entry of water vapour from the building, and ensure downward flow of air through gaps. It is desirable to incorporate a vapour check at ceiling level to reduce the diffusion of water vapour into the roof space and to reduce the gaps. The excess pressure should be kept to a minimum to save on the cost of fans.

Dick [2] developed a general theory for this form of construction and successfully put it into practice in a factory roof space. The Building Research Establishment has given advice on the use of pressurised roof spaces in swimming pools, and this has been applied successfully.

CONCLUSIONS

The basic design principles for avoiding condensation are the same for all types of roof. They should if possible have an impermeable inner layer to prevent moisture from entering the structure, and - since this can seldom be perfect - a permeable outer layer.

The only means of removing moisture which enters the air space of a roof with an impermeable outer layer is by ventilation. The ventilation requirement to avoid condensation depends on the roof design, including the amount and distribution of the insulation. Although theoretical methods are available for assessing this, data have not been assembled in a convenient manner for practical use, nor have the means of achieving a given ventilation rate been set out. Such questions are being investigated by the BRE Scottish Laboratory, initially in relation to pitched roofs. The diffusion of moisture through ceilings and leakage of moist air from the building to the roof space has a bearing on the ventilation requirement and this also is being studied in housing.

'Overdeck' insulation is effective in avoiding roof condensation if sufficient insulation is placed above a good vapour barrier, eg bitumen felt mopped with hot bitumen. The 'inverted roof' is an adaptation of the 'overdeck insulation' principle, and is used extensively on the Continent.

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