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Handegord, G. O.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000808
Canadian Building Digest, 1966-01

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 73

Moisture Considerations in Roof Design

Originally published January 1966

G.O. Handegord

Please note

The evolution of roofing systems has been largely influenced by the requirements for control of rain penetration, but in modern roof design other sources and effects of moisture must be considered. As part of a building enclosure the roof is vulnerable to water vapour from inside the building, and in winter excessive condensation may result in problems as obvious as those from rain leakage. Even small quantities of moisture from condensation or the entry of moisture during construction may seriously affect the components of the roof system and lead to structural damage, deterioration of materials, decreased thermal effectiveness, or subsequent rain penetration. Proper design must therefore be concerned with the control of moisture from all sources, with due regard for the interrelation of control measures. This Digest discusses the principles involved and their application to conventional designs.

Control of Rain Penetration

Rain leakage occurs when there is water on a surface, openings through which it can flow, and forces acting to move it inwards. If any one of these conditions is eliminated, water cannot enter. Obviously, if the roof is never wet, rain penetration is not a problem. Similarly, if there are no openings, leakage cannot occur. But it is also true that, even with water on the roof and openings through which it can pass, rain penetration can be prevented if all the forces acting to move it inwards are controlled (**CBD 40**).

Sloped roofs with shingled or tiled surfaces seldom leak despite their many openings because there is no net force acting to move water inward. Overlapping the shingles limits the direct entry of rain drops by impingement and gravity acts to move water outward down the slope, counteracting the air pressure difference that tends to drive moisture inward. The magnitude of the gravitational force is determined by the vertical height of the shingle lap. As the slope of a roof is decreased, the resistance of gravity to inward flow becomes less and the inward air pressure is also reduced. Leakage through shingled and tiled roofs occurs when the height of rise provided by the slope and overlap is insufficient to produce a hydrostatic pressure greater than the inward air pressure drop. Leakage can also occur when the gravity flow on the surface is interrupted by snow, ice or other accumulations to cause water damming.

Control of rain penetration through flat or low slope roofs can only be accomplished by the use of a continuous watertight membrane. Perfect watertightness is not only difficult to achieve, however, it is even more difficult to maintain. If the roof is designed to be level, the situation is further aggravated because "ponding" of water is inevitable. Not only will this lead to accelerated deterioration of the roof membrane, but the water retained on the surface will act as a reservoir to supply any leak that develops and thus increase the quantity that enters the roof system. Even if intentional ponding of a roof is required, it is important that provision be made in design for adequate drainage.

Control of Water Vapour Entry

The vapour pressure and moisture content of the air within a heated building in winter are almost always higher than those of the outdoor air. A difference in vapour pressure tends to move water vapour into and through the roof construction. It is also true that under almost all conditions in winter the inside air pressure near the top of a building is greater than that outside, a situation that promotes air leakage. There are therefore two forces acting to move water vapour from inside a building into the roof structure. If this water vapour is allowed to enter the roof system and it comes into contact with surfaces at a temperature below the dew-point temperature, condensation will occur. With intentional humidification, both the forces causing flow and the amount of vapour transported will increase. The roof system must therefore be designed to prevent the entry of water vapour by both diffusion and air leakage, or must be capable of removing the vapour by ventilation or of dealing with the moisture formed as a result of condensation.

Complete protection against any vapour migration into a roof system is virtually impossible with conventional roof designs. Any reduction in the rate of vapour flow, however will ease the problem, provided the measures taken do not interfere seriously with moisture removal.

Moisture Entry During Construction

Moisture in the materials used in a roof may also be a source of future difficulties and precautions should be taken to ensure that they are dry. Even if they are dry when delivered to the site, they must be protected from rain, snow and dew. Hygroscopic materials such as insulation and felts must also be protected from prolonged periods of humid weather, which will increase their moisture content because they tend to come to equilibrium with the high relative humidity of their surroundings.

Materials that cannot be kept in a dry warm shelter on the site should be wrapped in a waterproof, vapour-resistant covering such as polyethylene. This protection must be carried under the materials to prevent moisture pickup from the ground, moist concrete, or humid air.

Precautions must also be taken to protect partially installed roofing from rain, snow or dew, and to prevent their application over wet materials. Moisture even in cast-in-place concrete or residual moisture in other deck and insulation materials can eventually migrate into the outer portions of the roof system.

Absolute dryness of the materials used in construction and complete protection against moisture entry are difficult if not impossible to achieve in practice. Provision for removal or control of this moisture is therefore a necessary requirement in design.

Ventilated Roofs

The sloped, shingled roof is inherently well equipped to control moisture. Resistance to air and vapour flow can be incorporated into the ceiling structure below the insulation and the attic space vented to outside. Moisture that enters the attic space through air or vapour leakage from inside the building, or through slight defects in the roofing, has an opportunity to escape by vapour diffusion through the roof or by intentional ventilation of the attic space.

Small amounts of vapour entering the attic space may move directly to the outside primarily by air movement through the vents. It is probable that at times the rate of transfer to the attic will exceed that from it, and that some condensation will occur. At other times, because of heat gain to the attic, this condensed moisture will tend toward a temperature above that of the outside air, and its vapour pressure will consequently be high enough to promote evaporation and sublimation. If it has formed on the under side of the roof sheathing, as is most probable, its rate of evaporation will sometimes be increased, owing to the heating of the roof by solar radiation, and the rate of removal correspondingly increased.

The temperature of the roof may be lowered below the attic dew-point temperature through radiation to the clear night sky, thus inducing condensation of moisture from the attic air, but both the quantity of condensation and the duration of this effect will usually be small in comparison with the effect of solar radiation during the day.

The potential for moisture removal is progressively reduced with lower temperatures especially in northern regions where sunshine hours are limited. Not only is the time for removal reduced, but the rate of evaporation or sublimation of condensation is much less. Consequently, it becomes particularly important to provide as complete and impervious an air and vapour barrier as is possible for buildings in northern areas. Here, forced venting of the attic space can sometimes be used to advantage.

The vertical height of the attic space has an influence on the capability of the roof system for moisture removal. For a given temperature difference between the attic space and outside the rate of ventilation by chimney action will vary with the height between inlet and outlet vent openings.

As the slope of the roof is decreased, the rate of ventilation by natural convection will decrease. In a flat roof system moisture removal can only take place by diffusion and wind-induced ventilation, and the effect of both mechanisms will probably be small. Additional practical difficulties also present themselves when this method is applied to other than residential roofs. Ducts and pipes are usually located in the loft space in such buildings. This makes it difficult to achieve an air seal at the ceiling, and requires that the ducts and pipes in the cold ventilated space be insulated. In multi-storey buildings the potential for air leakage resulting from chimney effect is also increased (**CBD 23**) and if a ventilated loft system is considered the tightness of the ceiling air barrier becomes extremely important, particularly if the buildings are humidified.

For smaller buildings of this type consideration might be given to seasonal control of ventilation. Roof vents would be closed in winter and opened in summer, but for this to be satisfactory the air barrier at the ceiling and the closing seal at the vents would have to be very good to limit air leakage. The system would need sufficient storage capacity to hold any small amounts of moisture that penetrated during the winter until ventilation could be provided in the summer.

It is also possible that pressurizing roof spaces by mechanical means, using outside air might provide a method of venting that would prevent air exfiltration from the interior to the roof space. Very careful design, however would be required for such a system.

Unventilated Roofs

Roof designs that provide no ventilated space between insulation and roofing present a more difficult problem of moisture control. Sloped roofs may allow some vapour loss to outside if the surface is shingled or tiled. In low sloped or flat roofs the roof membrane is a vapour barrier, in some cases more impermeable and more complete than any provided on the warm side of the insulation. Removal of any moisture that was initially in the system or any that subsequently enters is extremely difficult. With sloping decks the vapour barrier may provide a secondary roof for emergency control of water from rain leakage, but in flat decks even this feature is eliminated. In flat roofs, removal of moisture to outside involves lateral migration to special roof or perimeter vents by forces that cannot be controlled or predicted with any degree of certainty.

If moisture remains trapped in a relatively air- and vapour-tight compartment, such as between layers of felt or between the roof membrane and continuous deck, substantial pressures may be developed in spring and summer under the action of solar heating. These pressures will be many times those developed by volumetric expansion alone, and are the chief cause of blister formation on built-up roofs. Although lateral venting may reduce the possibility of blister formation, it is very unlikely that it will provide a positive means for moisture removal.

Ridging of moisture-sensitive felts can result from quite small amounts of moisture contained in hygroscopic insulations or trapped between impervious insulations. Such ridging is usually associated with lack of protection at the insulation joints and absorption into the felts of moisture that migrates to the joints.

Evaporation of Moisture to Inside

The seasonal reversal of temperature gradient in roofs offers a basis for moisture control in some designs having impermeable exterior cladding. These systems utilize an insulating deck, such as foamed concrete, or a non-structural insulation, such as asbestos fibre, that have a high moisture storage capacity and are exposed to the interior of the building. Under winter conditions moisture accumulates in the insulation and is held until re-evaporation to the interior is possible. If condensation occurs as water, capillary action may induce a counter movement to vapour diffusion and limit the rate of moisture accumulation. The material used must be capable of holding moisture without dripping or permanent damage to the various components involved until conditions for removal occur. The possible increase in heat loss through the wetted insulation must be recognized and allowed for in design. Because of the difficulty involved in predicting all factors affecting their performance, such systems are normally employed only in heated buildings having low inside humidity.

Summary

Consideration of the sources, movement and effects of moisture in conventional roof designs suggests that certain principles of design are necessary if trouble from moisture in the wrong places is to be avoided. The materials are rarely at fault, the manner in which they are assembled by the designer and builder is more usually the factor that determines the success of the roof.

The principles might be stated briefly as follows:

1. Excess moisture must be controlled.
2. Moist inside air must be prevented from reaching cold surfaces.
3. Vapour traps must be avoided.

Control involves being aware of moisture sources and dealing with them by protection drainage, venting or isolation. Materials must be protected during storage and application. Roof surfaces must be sloped to allow for adequate drainage of precipitation. Construction moisture from wet finishing operations from curing of materials, and from temporary heating equipment must be disposed of by ventilation. Crawl spaces must be drained and provided with ground cover and ventilation. Moisture generating sources due to occupancy must be isolated or controlled by ventilation.

Critical interior surfaces can be kept warmer than the dew-point temperature by using sufficient insulation on the cold side. Moist air from within the building can be prevented from reaching colder surfaces in the roof system by a vapour and air barrier. The tolerance to high indoor relative humidities can be improved if thermally effective materials are kept away from the warm side of the vapour resistant components.

Two vapour resistant components can constitute a vapour trap, however, and this is so in many conventional built-up roofs. Water vapour within the system must be able to escape through the cold side by means of air vapour paths and vents. In some cases a vapour barrier may be omitted and absorbent materials used that can hold transient condensation harmlessly for short periods if conditions are such that the moisture can be re-evaporated at another time.