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Baker, M. C.

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Designing Wood Roofs to Prevent Decay

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M.C. Baker

Please note

When wood in roofs or other building elements decays, it is a logical consequence of conditions created in the building system by design and construction rather than an inherent weakness in the materials used. The moisture conditions required for rot development may have been present in the wood initially or may have resulted from poor construction practices, from subsequent leaking or from condensation in the system.

Wood rot need never occur in new buildings. The factors that cause it are well understood and can be allowed for in the design of the various building elements and systems. This Digest will deal mainly with some of the moisture conditions to be considered in the design of wood roofs.

Moisture Content of Wood in Use

The effects of moisture on the basic characteristics of wood and some of the implications of changes in moisture content in service were discussed in **CBD 85** and **CBD 86**; and it was indicated in **CBD 111** that moisture content is one of the controlling factors in the growth of fungi and the rotting of wood.

Moisture content of wood in service varies with the temperature and humidity of the surrounding atmosphere. From laboratory and field measurements of various types of wood and parts of buildings in Canada it has been possible to draw some broad conclusions about the average moisture contents to be expected in particular environments. Figure 1 is such a generalization, and does not represent any particular test. It is intended to show conditions that may exist for most areas of Canada. Out of doors, but under cover, wood may have a moisture content as low as 10 per cent in early summer and as high as 18 per cent in mid-winter. In buildings, in locations not appreciably affected by winter heating (roof trusses in attic spaces), wood can be expected to settle down to about the same moisture conditions as wood protected outdoors.

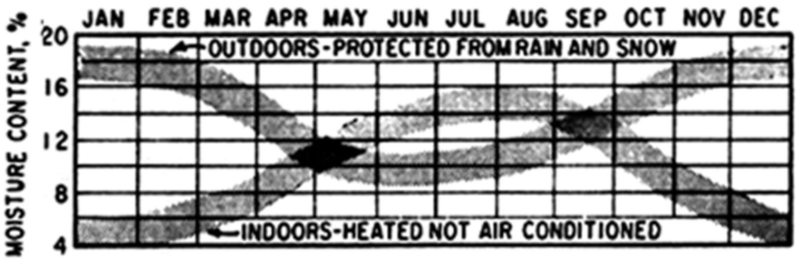

Figure 1. Moisture content of wood in use.

When it is subject to indoor conditions in a heated but not air-conditioned building, wood will have a moisture content varying between about 5 per cent in winter and perhaps 15 per cent in summer. In air-conditioned buildings in which the relative humidity is kept between 40 and 50 per cent, wood moisture content will be about 8 or 9 per cent. Wood components in partial contact with both outside and inside air may vary in moisture content, but it will probably be no greater than 12 per cent at any point.

Some fluctuation in moisture content is inevitable, but problems are seldom encountered as long as the wood at the time of manufacture and installation has a moisture content approximating the average conditions attained in service. Changes in dimension and shape caused by moisture content fluctuations can be allowed for in design.

It should be noted that the usual moisture contents encountered in service are of no consequence in relation to wood decay. They are generally well below the 20 per cent or more required for fungus growth. Values conducive to rotting can be reached, however, when building systems are improperly designed or built, or where maintenance is neglected.

Design

It has been the practice for a number of years to incorporate vapour barriers in wall and roof constructions as close to the inner finish as possible. More recently, it has been realized that the air resistance they provide is more beneficial than their vapour resistance in avoiding condensation. Designers generally have also understood the need for permeable finish materials on the cold side of a vapour barrier, so that moisture penetrating the barrier can find its way to the outside. This is usual practice in relation to walls, but it is often ignored in the design of roofs, where insulations are sometimes sandwiched between a vapour barrier and an impermeable roofing membrane.

When building materials have been kept dry before and during construction, such systems have usually given reasonable service. There is little margin for error, however, and there is no doubt that many premature roof failures have resulted from water trapped in the system. Under such conditions, eventual failure can take place, even with insulation materials normally unaffected by moisture. Organic materials such as wood and wood products may deteriorate quite rapidly unless preservative treatments have been used to resist decay. Plank or mill decks are systems for which considerable confusion in design seems to exist, and each year several cases of wood rotting in such systems come to the attention of DBR.

Consider such a 4-inch thick wood mill deck subjected to winter conditions assumed to be 73°F inside and -27°F outside, with a clear night sky, and summer conditions assumed to be 75°F indoors and 90°F air temperature outside, with bright sun, the roof finish having a solar absorption coefficient of 0.75. The calculated temperature gradients representing extreme winter and summer conditions are superimposed on the roof sections of Figure 2.

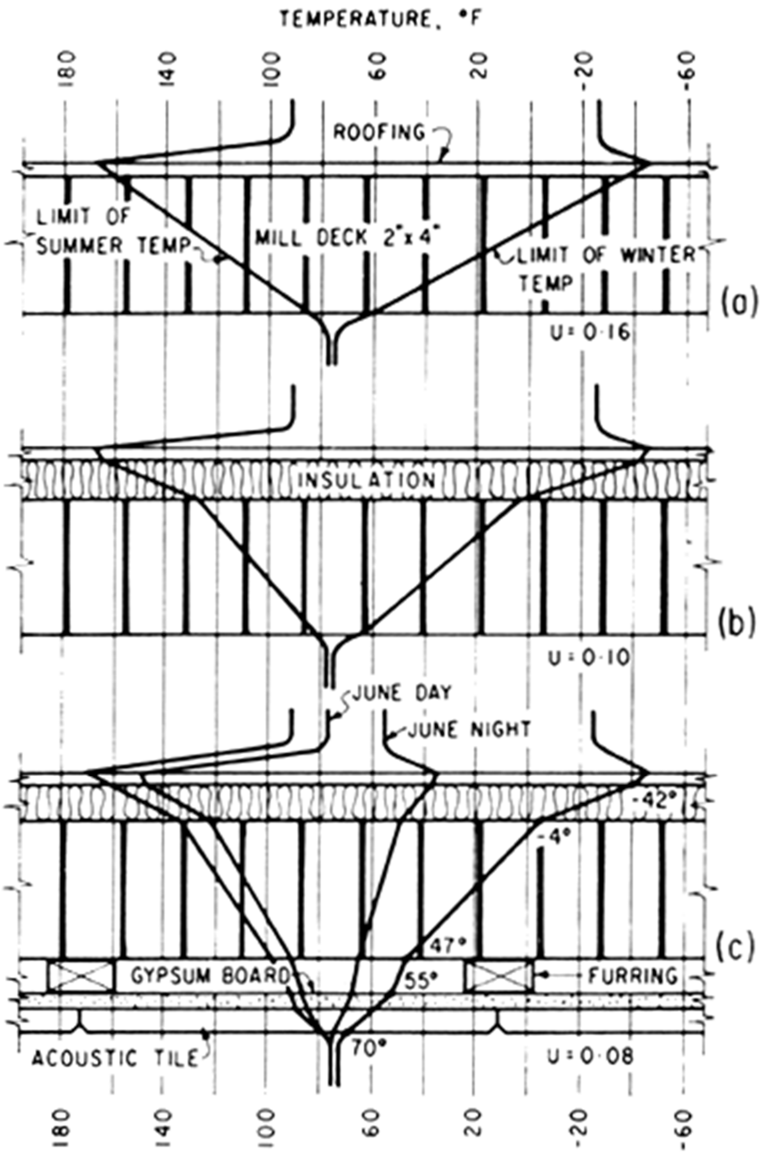

Figure 2. Temperature gradients of wood decks.

No Insulation. Figure 2(a) shows roofing applied directly to the mill deck, with no additional insulation or ceiling finish. The over-all heat resistance for this system is reasonably good. There will be no danger of condensation at the ceiling until the inside relative humidity reaches about 60 per cent, but moist air from inside can penetrate the spaces between the mill deck laminations to cause some condensation close to the cold outside surface. This may cause some wetting of the wood, but it will probably not be a problem because capillarity in the wood, aided by daytime warming, will usually return the water of condensation to the inside. Only under very severe, prolonged conditions of high inside humidity and low outside temperature could there be a build-up of frost in the system; and if the cold were followed by a sudden thaw there could be some dripping of water from the ceiling.

Insulation. An inch of insulation is added to the system in Figure 2(b). This naturally improves the over-all heat resistance and increases the inside surface temperature in winter, thus permitting even higher humidities without surface condensation. The temperature at the under side of the insulation would be about 6°F for the winter extreme, and again there would be a danger of condensation at this location where a vapour barrier is frequently placed. The situation is similar but perhaps not quite as severe as that for the first example.

Some difficulties could develop in insulation covered with built-up roofing. If a vapour barrier were used, any initial moisture normally present in the insulation plus that picked up in storage or during construction would not be able to escape. It would move back and forth across the insulation according to changes in the temperature gradient. Under certain conditions this could lead to concentrations of moisture and rotting of organic material.

If shingles are used as roofing there is some chance for moisture to escape from the insulation through the shingle overlaps. A vented space above the insulation, however, would provide a more positive means of disposing of moisture. This could be accomplished by providing furring or nailing strips over the insulation and fastening rigid type shingles directly. A plywood base fastened to the furring strips could be provided for the nailing of more flexible shingles. The spaces between nailing strips could be vented to the outside, with protection against the possible entry of blowing snow.

Insulation and Ceiling. In some cases the designer may not wish to leave the under side of a mill deck exposed as the ceiling. He may wish to add some other material such as gypsum board and tile or acoustic plaster. Figure 2(c) shows such a construction. It further improves the over-all heat resistance, and temperatures at various points through the system for the winter limit chosen are as shown.

Condensation at the under side of the deck could now take place with 75°F air having a relative humidity of about 35 per cent. This would probably not cause any problem unless the humidity were constantly higher than 35 per cent, as might conceivably be the case in specially humidified rooms. This system can be made nearly equivalent to that in Figure 2(b) if the air space is well vented to the interior.

Ceiling Vapour Barrier. Designers are often tempted to put a vapour barrier on the under side of a wood deck, held in place by the furring strips for the ceiling. If an impervious membrane is used at the top of the deck between the wood and the insulation, this creates two vapour traps - one enclosing the wood deck, the other the insulation. If there is no barrier on top, one vapour trap is created when roofing forms a continuous membrane.

If all materials are dry and no moisture is added during construction, there may still be no problem. Even when materials do get somewhat wet, they may dry sufficiently to avoid problems if time is allowed for the heat and ventilation in the building to dry them before the ceiling is applied. The system, however, has a very large potential for trouble, and even the normal moisture contained in essentially dry materials may, under certain conditions, be sufficient to cause rotting of the wood or other organic material trapped between membranes.

Moisture from Precipitation

It was indicated in **CBD 111** that the moisture required for decay-causing fungus growth to start is in excess of 20 per cent, and that from 35 to 50 per cent is necessary for active growth. As has been indicated, wood stored out of doors in winter may have a moisture content as high as 18 per cent if protected (Figure 1) or higher if unprotected.

Consider a wood deck left unprotected before installation of roofing. If a 2-inch water equivalent is taken as the precipitation for one month, this represents 10.5 pounds of water per square foot of flat roof. A 4-inch thick spruce mill deck having a density of 24 pounds per cubic foot weighs 7 1/4 pounds per square foot. If the assumed precipitation were completely absorbed into the deck, there would be an increase in moisture content of more than 140 per cent. Naturally this is most unlikely; much rain would run off a sloping deck, snow would blow off or remain unmelted, and some evaporation to the air would occur. If even 10 per cent were retained and absorbed, however, it would represent an increase in moisture content of the wood of 14 per cent, bringing the total moisture content as high as 32 per cent. Application of a vapour barrier or insulation and roofing would effectively prevent any rapid loss of moisture to the outside, and the application of ceiling finishes would retard or prevent drying to the inside.

The quantities of water that might thus be trapped are not always appreciated. If mill deck is enclosed at say 25 per cent moisture content, for each 100 square feet having 7 1/4 pounds of dry wood per square foot the total contained moisture would be 180 pounds or 18 gallons.

Moisture Concentration

Earlier DBR papers have explained the movement of moisture within a construction. When there is a temperature difference across a wall or roof section, moisture (originally distributed uniformly within the system) tends to migrate to the cold side under the action of an imposed steady-state temperature gradient.

The patterns of temperature variation in a roof system exposed to natural weather conditions are extremely complex, and when sunshine is involved it is complicated still further by the fact that the temperatures of surfaces exposed to the sun rise above air temperature. Night sky radiation also can cause surface temperatures to fall below air temperatures (see Figure 2).

Figure 2(c) shows additional gradients for a June day and a June night. The temperature limits are mean maximum of 75°F and mean minimum of 55°F for the month. On a sunny day moisture can move inward, whereas at night as the temperature drops it can move outward. To determine the net effect of such fluctuations it is necessary to study the local climate in relation to a specific building and its orientation. In many cases it will be found that daytime conditions in spring and early summer do indeed produce strong inward flow. This may sometimes explain why dripping from ceilings frequently occurs at this time of year, as the vapour which is driven inward by high roof temperatures is condensed on the cooler inner surfaces. Flow of vapour can take place in the wood itself, but for mill deck the easiest path of flow will be the spaces between the laminations.

If a vapour barrier is placed on the under side of a mill deck. it is unlikely that it will touch the surface everywhere and air spaces will probably occur. These can act as an insulating layer and permit the vapour barrier in such spots to be a little colder than the under surface of the deck during conditions of inward heat flow. At such times the barrier could form a condensing surface. The details of the particular roof system will determine what happens to water thus formed. If the roof is sloped, the water may flow to some point from which it can escape from the system. This may act as a protection against wetting of the materials, although dripping may still be a nuisance. If, however, the water moves only as far as some point of obstruction, it may accumulate and be re-absorbed to produce severe wetting of the wood locally. This could lead to decay in such areas since temperatures favourable to fungal growth may exist for considerable periods during summer (Figure 2).

Moisture Produced by Decay

It was mentioned in **CBD 111** that wood-rotting fungi can produce water through the breakdown of cellulose. It is interesting to examine the amount of water that can be produced. It has been estimated by wood pathologists that the cellulose in 1 cubic foot of wood (specific gravity 0.5) rotted to 50 per cent of its original dry weight would produce 0.9 imperial gallons of water. For 100 square feet of 4-inch spruce mill deck with specific gravity of 0.4, assuming advanced rot extending through the full thickness and covering 20 per cent of the area, the moisture produced by decomposition of the cellulose to 50 per cent of its original weight would be 5 gallons. There is also an accumulation of water from the decomposition of pentosans, so that the loss for any actual situation may be something more or less than the 5 gallons. This is a significant quantity of water, and as long as decay continues water is produced.

Conclusion

This Digest has indicated some of the moisture conditions that must be considered in the design of wood roofs. It has shown why wood should not be used in a vapour trap formed between two vapour-resistant components. Successful systems can be designed by allowing moisture in the construction to escape through the cold side by providing air vapour paths by purposeful ventilation; in some instances, when unfavourable and unavoidable conditions are foreseen, it may be possible to use preservative treatments so that the materials used can resist decay. Where moderate indoor humidities in winter and suitable drying conditions in summer can be anticipated, experience has shown that leaving wood exposed to the inside can result in a workable system. The moisture storage capacity of the wood is in the latter case utilized to accumulate some moisture under outward flow conditions with re-evaporation to the interior under inward vapour flow conditions.