Roof Design Considerations for Cold Climate Environments

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SYNOPSIS

SPECIAL REQUIREMENTS ARE REQUIRED FOR COLD CLIMATE DESIGN. CONSIDERATIONS SUCH as structural expansion joints, added weight caused by snow loads, vapor retarders, air barriers, insulation requirements and drainage are discussed. Also addressed are system selection, installation guidelines and special specification criteria.

Introduction

As the temperature in the northern climates of North America begins to drop in October towards the very frigid months of winter, design and installation of roofing systems take on new parameters and challenges. Snow, freezing rain, wind chill factors and sub-freezing temperatures are all factors which can have a detrimental effect on the long-term performance of roofing systems.

Cold climate design must incorporate the control of heat flow, moisture flow (vapor and liquid), air flow, snow accumulation and ice formation. It must also consider the proper assembly and construction of the design.

Some manufacturers address cold weather installations of their roof systems while others do not mention it. Knowledge of product installation limitations is vital to designers considering the application of roofing systems during cold temperatures and snowy conditions.

Structural Considerations

Two items come to mind when considering cold climates and structures. One is the additional weight to be considered due to live loads. The other is the movement created by the expansion and contraction of materials due to temperature swings experienced during cold weather periods.

Positioning and inclusion of expansion joints for a given structure will be dependent upon temperature variations and the type of materials used. Since it is not uncommon to see summer highs of 100°F (38°C) and winter lows of -20°F (-29°C), it can be expected that materials will move significantly. Roof composition and the location of the different components within the roof system will have an effect on the extent of movement expected to occur at any given point in the roof structure. Conventional insulated roof assemblies will tend to move less because the deck is located below the insulation layer. The spacing of expansion joints may differ from those required on parking or plaza decks which have no insulation and are subject to extreme temperatures from both the bottom and top side.

If the roofer cannot be reasonably comfortable in the installation procedure, then all the precautions in the world will not help in obtaining a successful installation.

There are no hard and fast rules in most building codes for the location, size and quantity of structural expansion joints. Structural designers draw on their experience and education to incorporate them in the design to accommodate anticipated movement. Other design factors which form an integral part of the structure's design may provide a logical location for the inclusion of an expansion joint. This is quite frequently the case when a low roof area meets a high roof area. The break between these two areas provides an excellent opportunity to include an expansion joint.

Additional weight is the other factor to take into consideration when designing roof structures in a cold climate. Snow will accumulate on roofs and add a significant amount of load to the structure. Freshly fallen snow has a different density than snow which has crusted over for a period of a month. Snow which turns into ice is even heavier. Drifting against high parapets and high roof areas must also be accounted for, since their strata will be different and heavier than the flat

Snow drifting at low roof against wall of higher roof. Drift is approximately four feet at peak. Air leakage has also created a cavity at the base of the wall. During snow melt, water can accumulate in this area and enter behind improperly-sealed flashings.

area of the roof. Code requirements for snow loading differ within North America. The National Building Code of Canada (1990), for example, uses a formula which incorporates various coefficients to determine the total snow load. It takes into account the basic roof snow load factor of 0.8, rain loads, wind exposure, slope and accumulation. The Uniform Building Code (1991) provides a table and requires the designer to refer to the building official for the determination of the snow loads.

As a designer, the added load calculations which are incorporated in a roof structure's design may have some effect on selecting the most economical support system and deck type for a project.

Vapor Retarders/Air Barriers

The use or omission of vapor retarders in a roof assembly is a sensitive issue. Based on their experience, Canadian designers tend to specify vapor retarders more often than not. As a matter of fact, their motto is "when in doubt, specify one." The reason for this is that because our exterior winter temperatures are very low (average -4°F or -20°C for Ontario), there exists a natural moisture drive from the higher vapor pressure interior to the lower vapor pressure exterior. Dew point calculations show that condensation always has the potential to occur at the membrane level when it is located towards the exterior or cold side. In order to prevent condensation from taking place, a vapor retarder is used on the warm side of the insulation. In the case of retrofit roofing where the existing membrane remains in place and where no vapor retarder exists in the original design, the design calculations become even more important. This problem is not as critical in climates where the exterior temperature hovers around the condensation temperature. The potential for condensation may exist one day, followed the next day by a drying cycle if the temperature warms up a few degrees. Wayne Tobiasson's article on "Vapor Retarders For Membrane Roofing Systems" explains in detail the logic on the use of vapor retarders in the U.S.

The recognition of moisture diffusion and its control has been well documented and practiced. The National Research Council of Canada (NRCC) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), however, have both determined that uncontrolled air leakage will cause more harm than uncontrolled moisture diffusion. Holes, gaps and openings in the roof assembly can allow large volumes of moisture-laden air to enter the assembly and potentially condense on the first surface they encounter that is below the interior air saturation temperature or dew point.

In order to put into perspective the relationship between vapor diffusion and air leakage, let's examine the case depicted by Rick Quirouette in NRCC's *Building Practice Note No. 54*. Assume a wall section with a vapor barrier having a water vapor permeance of 5 ng/Pa·s·m^2 (0.087 grains/hr·ft^2·in Hg), is exposed to room conditions of 21°C (70°F), 30% RH and an exterior temperature of -20°C (-4°F). If these conditions were to prevail for a month, approximately 6 grams (0.2 oz) of moisture would accumulate in the wall cavity. This would likely create a thin layer of frost on the surface of the sheeting within the wall.

Taking the same example, assume that an opening exists in the interior wall, say at an electrical outlet which penetrates into the cavity and is equivalent in size to a 625mm^2 (1 sq. inch) hole. Under a pressure difference of 10 Pa (0.2 lbs/ft^2), equivalent to a 15 km/hr (9.3 mph) wind, 2,600 m^3 (91,818 ft^3) of air would enter and exit the cavity over the same month period. This translates into approximately 3,000 kg (6,614 lbs) of air and 14 kg (30.9 lbs) of water. Assuming that only 10% of the air condenses out in the cavity, then air leakage has deposited 1.4 kg or 1,400 g (49.4 oz) of moisture into that cavity. This means that air leakage has deposited 233

Contractor removing snow from deck flutes and right seal area. Installation of vapor retarder and base insulation is taking place. Temperatures are -15°C at this time of the morning.

Preparing a joint for membrane flashing installation. Snow is approximately 3' to 4' deep on the right side of the joint.

lems associated with corrosion of steel decks.

Regardless of the type or thickness of insulation required, the standards of adequate support, staggered joints and tight fitting boards need to be adhered to, whether the design in question is for cold or hot climates. Since condensation can potentially occur at the underside of the roofing membrane in a cold climate environment, the preference tends to be towards a two-layer system of insulation. This allows the joints in the top layer of insulation to be staggered from the bottom layer and minimizes the potential of thermal bridging of fasteners installed in the base layer. Thermal bridging of fasteners is an interesting phenomenon; however, there is not a significant amount of test data available to designers. This data would help to substantiate designs which incorporate mechanical securement of insulation and/or membranes in facilities having high relative humidities.

times the amount of moisture that passed by diffusion only.

It is therefore critical to create air seals within a roof assembly. Although vapor retarders can tolerate some imperfections without drastically affecting their overall performance, air barriers, on the other hand, must be continuous, have low air permeability, must be able to structurally support the pressure difference across them and must be as permanent as the structure and roof system into which they are being installed. Air barriers can be both the vapor retarder and air seal or they may incorporate a combination of materials in order to withstand air pressure.

Thermal efficiency

Trying to manage and control heating and cooling loads within a building is always a great challenge for a designer. In cold climate design, we tend to want to control heat loss more than heat gain since this condition is prevalent for more months throughout the year. In order to put that into perspective, the average of degree-days below 18°C (64.4°F) in Ontario is found to be in excess of 4,000.

Insulation is one of the materials used within a roof assembly to control heat loss. The quantity of insulation used on any structure is dependent on many factors, including code requirements, building use, the location and type of building. Energy conservation quite often plays a factor in the final design. A warehouse will not have the same thermal efficiency requirements as a temperature-controlled museum.

Once a designer has determined the R-value required, several materials are available to suit the roof design. These include low R-value materials such as fiberboard and perlite, medium R-value materials such as fiberglass, mineral wool and expanded polystyrene and a high R-value insulation such as extruded polystyrene and polyisocyanurate. Most of these materials can also be tapered to facilitate construction and improve drainage. Phenolic foams which were also a high R-value material are no longer marketed because of the prob-

Ice column which is approximately 30 feet high has loosened from the wall and is ready to fall onto the roof below.

Extent of ice formation on exterior walls caused by lack of perimeter drainage system.

Drainage

Drainage must meet the requirements of the prevailing building code. Interior drainage is often preferred in cold climates because water in drain pipes and leaders will not freeze when it is tempered by the interior heat of a building. In areas of high interior relative humidities, condensation can form on piping carrying very cold water run-off from the roof. A simple solution is to insulate the piping. Another benefit of interior drainage is that natural heat loss at the interior drains helps them to remain clear and free of ice and snow.

Cost is often an issue raised by the building owner. This can lead to poor design considerations on the part of the designer. Perimeter drainage in a cold environment can lead to serious problems. Gutters and downspouts are often specified to collect the water at the perimeter edge. When used, they must be heated with heating cables to prevent the formation of ice. The gutters must also be well anchored to the structure to resist the tremendous amount of stress caused by the additional loading resulting from snow and ice accumulation.

At times, designers may choose to allow water run-off to simply flow over the edge of the roof. Perhaps the facility is heavy manufacturing which is located in a desolate area where control of water run-off is not a concern. The results of this choice can be devastating. Ice columns created by the water run-off during warming spells can form to become as large as 2 to 3 feet in diameter across the face of the building. This creates a hazard to the occupants, the roofing system itself and the equipment located on the roof.

System Selection

Most roofing systems marketed in the northern portion of North America can withstand the rigors of the changing climate to varying degrees. The practical considerations of the installation of a roofing system in cold weather can pose significant problems which will ultimately reduce the long-term performance of a given system. The manufacturer's literature seldom addresses the potential installation problems experienced when installation takes place at temperatures of -15°F and possibly -25°F with the wind chill factor. It is important for designers to consider all aspects of a system as well as the manufacturer's printed limitations for the system prior to specifying it for the project. The usual design criteria, including cost, code requirements, performance, weight, appearance, maintenance and so on, all apply. The decision process for the selection of the roofing system, however, must take into account the added criteria of cold weather installation. The question must be answered on whether the selected system can be adequately installed under the prescribed climatic conditions. This will surely have an effect on the final selection.

The method of attachment, for example, may preclude some systems from being considered. If a fully bonded system is being considered, then fully adhered single plies utilizing weather sensitive adhesives (which can become very viscous or freeze at low temperature) cannot be used. Perhaps one may consider torch-applied systems, since they tend to tolerate cold temperatures better. If snow loads are very heavy in a particular area, a design which incorporates a smooth roof surface with no ballast may benefit the owner since snow removal throughout the winter may be required.

All aspects of the design must be considered prior to making the final decision on a system. This will ensure that the proposed system can be properly installed during the expected weather conditions.

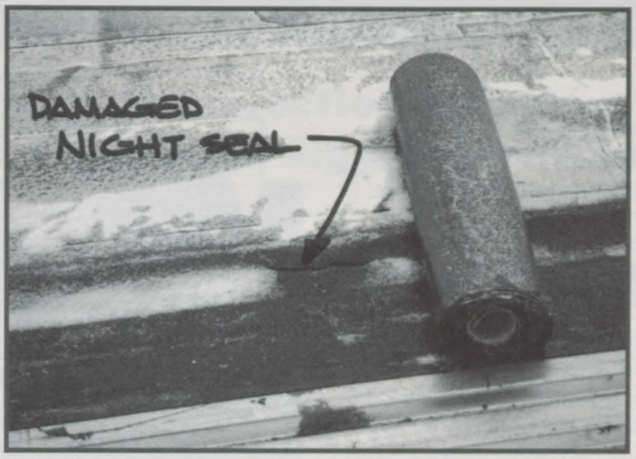
Specification Considerations

Presuming that the roof assembly has been selected and the specification is taking form along with the details for the project, are there any special requirements which should be included in the document to deal with winter conditions? Yes. The following suggestions do not deal with the physics of the roof assembly but rather with the practical considerations which help make the installation a success.

Where snow accumulates during the installation of the roof system, it will need to be removed prior to installation. The consultant should specify who is responsible for the removal of snow. If it is to be the roofing contractor, then have a section dedicated to the costs associated with snow removal. It is also important to specify the degree of cleanliness desired as

Inadequate storage of insulation and membrane. Rolls should be stored in a warm environment while insulation should be covered with breathable tarpaulins. Factory-applied shrink wraps do not serve this function.

it relates to snow removal. Steel decks are natural traps for ice and snow because of their shape. Designers must insist that snow and ice be removed from the flutes of the deck in order to prevent trapping moisture within the new assembly. Wood decks can become saturated from prolonged exposure to the elements. It must be made clear that the decks be dry prior to the start of roofing. Concrete decks can surface freeze during curing, thereby causing a frail and dusty surface. These surfaces must be properly prepared by sandblasting or shotblasting prior to roofing. Concrete also has the ability to hide a thin frost film in the early morning which will change to water as the day warms. This will result in poor bonding of the roofing materials.



Night seal has been damaged and is now allowing snow to enter the newly-installed system. If this conditoin is undetected, many squares of roofing can be damaged by moisture.

Storage of materials is always a contentious issue with the contractor. Be specific on where and how all materials should be stored for the project. Most insulation materials will be affected by moisture; therefore, they must be protected from the elements. Specify proper tarps that will protect against snow and rain, yet breathe to prevent sweating. Polyethylene and factory-applied wrappers do not provide adequate protection.

There seems to be a belief that snow is not water. If snow-covered surfaces are roofed in, problems will occur in the future. Snow is simply another form of water.

Asphalt kegs and rolls of felt must also be stored to prevent moisture intake. In the case of asphalt, ice and snow can create a significant safety risk when introduced into a hot asphalt kettle. Applying wet rolls of felt or modified bitumen will only build moisture into the system. This can cause blistering and reduce the long-term performance of the system. Modified bitumen rolls are considerably thicker than felt and will become stiff and boardy. Their installation becomes more difficult and the potential of causing wrinkles and fishmouths is enhanced.

Adhesives, sealants and certain flashing sheets used on single ply membranes should be kept in a heated trailer on site or in a hot box on the roof until ready for use. This procedure keeps these materials at the right viscosity and temperature, ensuring a better installation. Certain single ply manufacturers recommend the use of heat guns to assist in the installation of flashing materials, but not to speed up the cure of adhesives. Adhesives must be allowed to have solvents flash off at their own pace in order to perform properly, thereby increasing the time required to execute a proper seal. Most manufacturers recommend that surfaces which are to receive the roof system need to be free of dirt, dust, oil, grease, snow, ice and any other contaminants. These will have an adverse effect on the adhesion of the components in the system.

Night cut-offs are always risky when they are not properly installed. In the case of a snowy area, a night cut-off could become a monthly cut-off and be subjected to a tremendous amount of snow. It is imperative that cut-offs be stringently specified and properly executed in the field. Many squares of otherwise good roofing could have to be replaced due to a failed night cut-off.

Discussion about design considerations and the treatment of materials and systems for low temperature installations have been expressed in this article. It is the writer's opinion that the ability of the roofing mechanic to install the systems at low temperatures is as critical as the considerations given to material selection. If the roofer cannot be reasonably comfortable in the installation procedure, then all the precautions in the world will not help in obtaining a successful installation. One manufacturer has made recommendations regarding the installation of roofing systems during cold weather. The suggestions pertain to the installation of materials; however, they can also be applied to the workers. They are as follows:

"Minimum working temperatures: It is recommended that when temperatures remain below -10°C (14°F) for mopping applications and below -18°C (0°F) for thermofusible applications, operations should be suspended. Minimum working temperatures should take into account a factor for wind chill.

"Wind Chill temperature (°C) = air temperature (°C) - [windspeed (km/hr)/2]

"Daily forecasts should be followed to determine commencement of work or to anticipate possible suspension. For example, if forecasts indicate temperatures will be dropping quickly below the minimum, no work should commence. Conversely, with indication of rising temperatures during the day, slightly lower temperatures on starting are acceptable."

The recommendations help the installation of a roofing systems during cold weather because they provide definite guidelines to work within.

Summary

Since designing roofing systems in cold weather is different from the norm. The designer must be aware of all the forces acting on the building envelope. Recognition and understanding of the effects that snow, ice, cold winds, high interior humidity and cold temperatures can have on a roof system will help to avert the problems commonly associated with cold climate roof designs.

The practical issues of the installation of the system must also be considered along with the design. The assembly as a whole must be able to resist all the forces to which it is subjected, but also be able to be built efficiently, properly and in real time.

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