Roof Design Considerations in COLD and HIGH ALTITUDE REGIONS



By Steve Bunn

INTRODUCTION

The Rocky and Appalachian Mountains are areas that combine cold winter weather and high altitudes. These regions are not densely populated, so many roof designers are unaware of the special design requirements for roofs within these areas. This paper will address some of the key design elements that are typically overlooked. It will include the following:

- These regions are prone to ice dam formation due to a combination of building heat loss and solar radiation.
- Despite the perception of having dry climates, vapor drive is still a problem, particularly when ice dam protection membranes are installed over the entire roof deck.
- Snow accumulation also requires that snow retention on the roofs be addressed.
- Roof ice melt systems are a critical design component in helping to eliminate ice dams.
- Roof drainage systems must be designed with ice dam formation in mind.

A good roof design will address all of the factors noted above.

ICE DAM FORMATION

Ice dam formation in cold and high altitude regions is caused by building heat loss and solar radiation.

Nature of Ice Dam Formation

Ice dams typically begin to form when the ambient air temperature is 22°F and below. The ice dam begins to form at the drip edge along the roof eave. Snow melt running down the roof begins to accumulate behind the newly formed ice dam. Eventually, the water overflows the initial ice dam, and in the process, freezes over the lower level of ice. This increases the thickness of the ice dam and increases the overhang of the ice dam from the front face of the eave as shown in *Figure 1*. By this process, ice dams can become very large and cause extensive damage to the roof and building structure.



Figure 1: Typical ice dam formation at eave. Notice the eave is not even a substantial overhang.

Ice Dam Formation Due to Building Heat Loss

Heat escaping through the roof can heat the snow to the point that melting occurs. The resultant water from the snow melt starts to drain off the roof. On sloped roofs, the water will run toward the eave, which is typically colder than the remaining portion of the roof. If sufficiently cooled before draining off the roof, an ice dam will form along the eave. Overhanging eaves are the most notorious for ice dam formations; however, the roof eave need not be overhanging to be subject to ice dams. In addition, roof valleys and lower roofs below upper roofs can be prone to ice dam formation.

Contributing Problems

There are a number of factors that contribute to ice dam formation due to building heat loss, including under-insulated roofs, localized heat sources, exhaust stacks, inadequate roof ventilation, and inadequate air barriers.



Figure 2: Severe ice dam formation along eaves and valleys.

Under-insulated roofs allow excessive heat to rise through the roof assembly, resulting in snow melt. A roof in these regions should have a minimum thermal resistance value of R-38.

Recessed lighting within the ceiling is the most common "hot spot" within attic and cathedral ceiling spaces. Exhaust stacks release high temperature gasses that can melt substantial quantities of snow. Chimneys of insufficient height and location on the windward side of a roof will result in localized snow melt and ice dam formation.

Inadequate roof venting is a major contributor to the formation of ice dams and vapor drive problems, which will be described below.

- Air movement within the attic or cathedral ceiling space greatly aids in the removal of latent heat. Sufficient air movement can even make up for other design or installation deficiencies, most notably, vapor drive.
- Poor roof ventilation can also cause premature aging of roof components, such as asphalt shingles.
- Inadequate roof ventilation is typical on roofs with complex configurations, multiple roof valleys, and many changes in plane. These configurations tend to reduce soffit intake required for proper cross ventilation.
- Skylights, chimneys, roof curbs, and other roof penetrations can restrict proper roof ventilation. Provisions for redirection of cross-ventilating flow and addition of specialized venting need to be made.

An inadequate air barrier is also a contributor to ice dams. Air leaks through the air barrier can transport warm, moist air that will help melt snow. In addition, air leaks may short-circuit proper cross ventilation.

Resultant Problems

Ice dams create a number of problems, with the greatest effects seen at roof eaves and valleys as exhibited in *Figure* 2. Ice dams mechanically damage the roofing, flashings, and roof drainage systems (gutters and downspouts). Melting ice dams can create water infiltration into the building envelope, damaging building components and interior finishes. Ice weighs approximately 57 pounds per cubic foot; it can overstress the building structure, particularly gutters and downspouts. Attempts to mechanically remove the ice dams may also result in damage to the roof system.

Possible Solutions

A conventional roof system utilizing Uniform Building Code venting minimum ratios of 1:150 or 1:300 (for cross ventilation) typically do not have sufficient ventilation in these climates to prevent ice dam formation due to building heat loss. In addition, some code jurisdictions unwisely reduce the ventilation code requirements. For example, Summit County in Colorado does not require any roof ventilation because the climate is "dry." With the excessive use of ice dam protection membranes installed over the entire deck, projects are developing severe

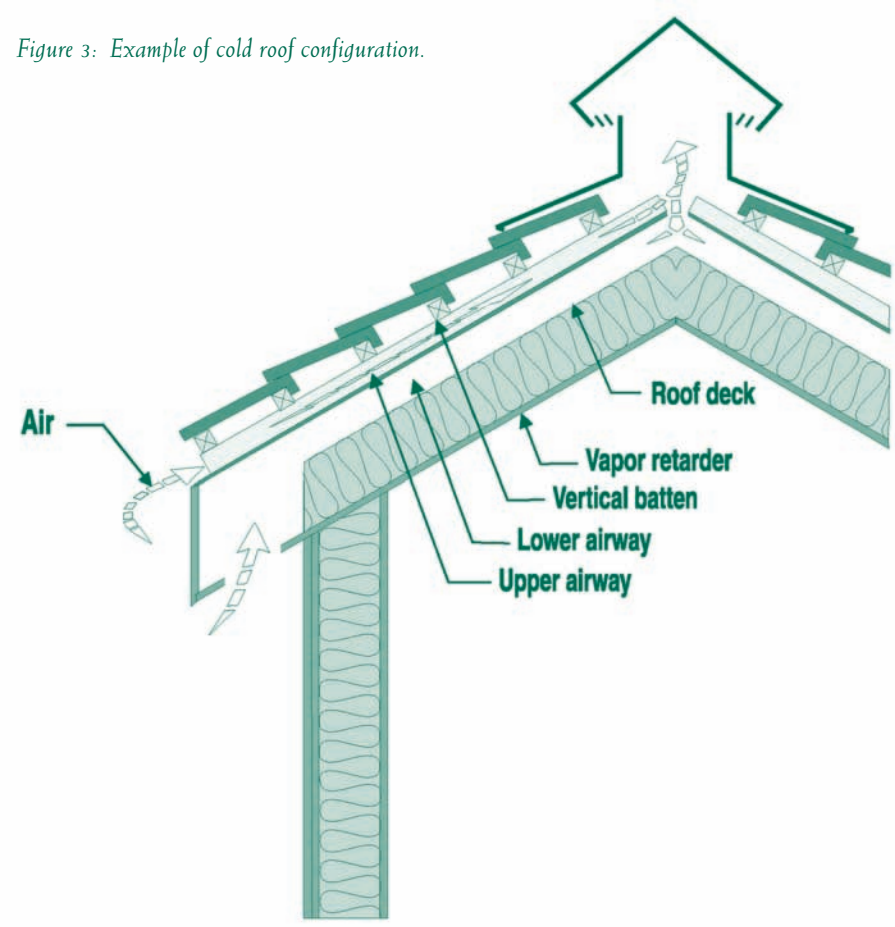


Figure 3: Example of cold roof configuration.

problems with condensation due to vapor drive. Simply following local code requirements does not guarantee the success of a roof design.

Super-insulated roof systems have been designed to control ice dam formation. A super-insulated roof system has insulation with a minimum thermal resistance of R-45. While super-insulated roofs help reduce ice dam formation due to building heat loss, they do not address ice dam formation due to solar radiation. As a general rule, super-insulated roofs are not ventilated. While they typically include a vapor retarder, many have roof decks that are entirely covered with impermeable ice dam protection membranes such as "Ice and Water Shield." With little or no roof ventilation, these roof systems can have severe problems with condensation due to vapor drive.

Cold roof systems are good for preventing ice dam formation caused by building heat loss. Cold roof systems incorporate increased roof ventilation beyond that required by code. They include good roof insulation (R-38 minimum) and ventilate the attic or cathedral ceiling space above the roof insulation. Cold roofs keep the temperature of the roof deck and roofing systems close to that of the exterior air temperature.

Cold roof systems may provide ventilation entirely under one roof deck or two ventilation paths underneath an additional cold roof deck installed over battens over the lower roof deck as shown in *Figure 3*. For concrete and clay tile roof systems, the second air passageway can be created by installing sleepers underneath battens, which also improves drainage over the roof underlayment. On complex roofs with many valleys, there may be insufficient air intake at the soffit to provide adequate air movement in areas of the cold roof. As a result, heat tracing or another roof ice melt system may be required in valleys. A cold roof system will not address ice dam formation due to solar radiation.

Roof ice melt systems can be used to address ice dam formation not remedied by the roof systems noted above. Roof ice melt systems typically consist of heat tracing, heated metal extrusions, or heated roofing such as heated roof shingles. Roof ice melt systems are typically required at roof eaves and valleys. They should primarily be used to address ice dam formation due to solar radiation, not building heat loss.

Proper detailing and use of vapor retarders and air barriers is beneficial in eliminating ice dams. Typically, a vapor retarder will be a good air barrier if properly installed. The converse is not always true. Vapor/air barriers are not typically installed in a manner that meets theoretical performance criteria. Unsealed laps, mechanical attachment through the vapor/air barrier and ceiling board, unsealed penetrations, and improper tie-ins to the wall vapor/air barrier greatly reduce the effectiveness of these systems. Vapor/air barriers should be well sealed to penetrations with either tape or expanding foam. The laps of the vapor/air barrier should be taped or sealed to prevent air leakage or vapor transmission. In addition, the vapor/air barrier should be tied into the wall vapor/air barrier.

ICE DAM FORMATION DUE TO SOLAR RADIATION

Contributing Factors

Solar radiation melts snow in sunlit areas, and the resulting water easily refreezes in shaded areas. Chimneys, gable roofs, and other roof projections that create shadow lines are key areas that promote ice dam formation due to solar radiation. Sunlight can melt snow adjacent to these areas, and the resultant water can easily refreeze once it enters a shaded area since the air at high altitudes does not have sufficient insulating properties to moderate the temperature extremes between sunlit and shaded areas.

The north and east elevations of a roof are most prone to ice dam formation due to solar radiation. Roofs oriented north and south have the worst problems with these types of ice dams. To reduce the likelihood of ice dams, roofs should be oriented east and west to promote even heating and cooling of the snow.

Resultant Problems

The resultant problems are identical to those described in ice dam formation due to building heat loss noted above.

Possible Solutions

The three different roof systems (conventional, super-insulat-

ed, or cold roof) noted above will not remedy ice dam formation due to solar radiation. Control of shadow lines, roof pitch, and roof ice melt systems will help eliminate these types of ice dams.

Roof orientation relative to north should be considered carefully. East and west facing roofs have fewer problems with ice dams. In addition, the location and sizing of gable roofs, chimney stacks, and other roof projections should be reviewed for effect on shadow lines that may promote ice dams.

The roof pitch also affects ice dam formation due to solar radiation. Steeper or shallow roof pitches can reduce the formation of ice dams; however, other design considerations must be evaluated before ultimately deciding on the roof pitch to be used.

Roof ice melt systems are the most common method for addressing ice dam formation due to solar radiation. The other solutions noted above may not be feasible, requiring the use of roof ice melt systems. While these systems are effective in reducing ice dams, they require electricity, increasing energy costs.

VAPOR DRIVE

A Summary of Vapor Drive

In cold and high altitude climates, outward vapor drive is greatest during the winter heating season. The warm air within the interior holds more moisture than the cold air outside. Moisture contained within the air creates a vapor pressure. Accordingly, the warm, moist air on the inside creates a higher vapor pressure than the cold, dry air outside. While the relative humidity does correlate to the amount of moisture within the air at a given temperature, a direct comparison of relative humidities at different temperatures does not immediately indicate which has the most latent moisture. In other words, room-temperature air at 30 percent relative humidity has a higher vapor pressure than 20-degree air at 80 percent relative humidity. The differences in these vapor pressures results in a directional drive, whereby moisture will migrate from areas of higher vapor pressure to areas of lower vapor pressure.

Each building material has a unique resistance to moisture vapor transmission. Building components with a resistance (or Reps) of 1 or greater are considered vapor retarding materials. Conversely, components with a resistance lower than 1 Rep are considered vapor permeable materials. Choice of vapor retarder must take into account the vapor resistance of the vapor retarder, plus the resistance of all other building components within the roof assembly. Other building components such as ice dam protection membranes may have a very high resistance to vapor drive, which may adversely affect the migration of moisture within the roof assembly.

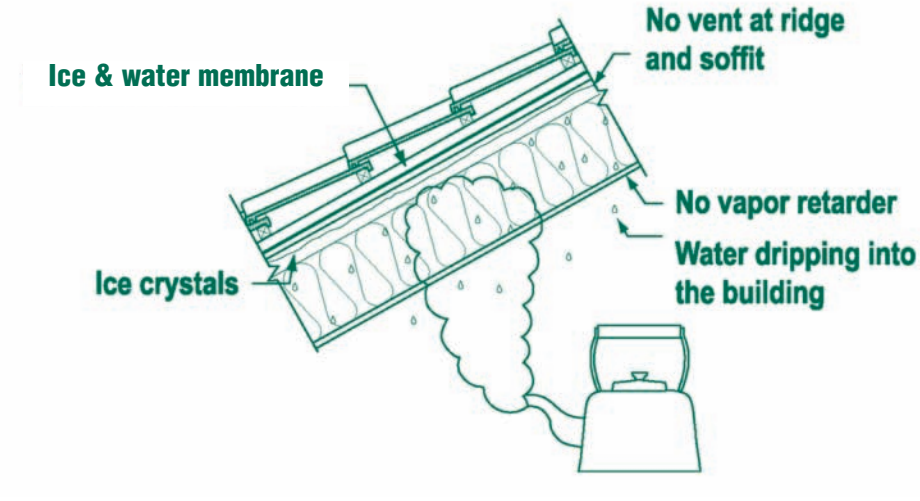


Figure 4: Example of condensation problem with installation of ice dam protection membrane and no vapor retarder.

Contributing Factors

Inadequate or poorly installed vapor retarders are primary factors that result in condensation within the roof assembly due to vapor drive. A 4-mil polyethylene vapor retarder has a theoretical resistance of 12.5 Reps; however, WR Grace "Ice and Water Shield" has a resistance of approximately 200 Reps. Furthermore, the polyethylene is much more likely not to perform as expected due to the propensity for unsealed laps, unsealed penetrations, and penetration by mechanical attachment for the ceiling board. On the other hand, "Ice and Water Shield" is well adhered and continuous, with sealed laps and self-sealing properties around mechanical attachment penetrations. The effect of this problem is shown in *Figure 4*.

Air leakage from the interior spaces into the attic or cathedral ceiling space can also be a major contributor to vapor drive problems. Air movement can transport about 1000 times more moisture than vapor drive alone, which transports moisture by diffusion. Ideally, the vapor retarder will also act as the air barrier. Unsealed penetrations and lack of tying the roof vapor retarder/air barrier into the wall vapor retarder/air barrier create localized air leaks that can result in condensation.

Non-breathing underlayments and ice dam protection membrane can promote condensation within the roof assembly. As noted above, "Ice and Water Shield" and other similar self-adhered ice dam protection membranes have outstanding resistance to vapor drive. In most cases, this is not their intended function, resulting in the greatest potential for condensation on the building component directly underneath, which is typically wood roof sheathing. This is not to imply that ice dam protection membranes should not be used, but careful consideration of their use and placement needs to be exercised. Simply specifying their installation over the whole roof deck, assuming that the result will be a roof bulletproof against leaks, will likely produce an undesirable outcome.

Resultant Problems

The main result of vapor drive problems is condensation within the roof assembly. The condensing water within and on building components can lead to degradation and negatively impact performance. Wood products are commonly used in roof

framing and sheathing. For most species, if the percent moisture within the wood exceeds 19 percent, wood decay will begin. Excessive moisture levels within wood will also promote swelling and warping, as well as mold and fungal growth that feeds on the wood. Mold and fungal growth are also health concerns, which the industry is beginning to take very seriously.

Roof condensation also damages most types of roof insulation. Fiberglass batt insulation is commonly used in residential building construction. When wetted, the fiberglass insulation compresses, reducing the amount of air spaces that give the product its insulating value. Consequently, the product's thermal resistance is reduced. Many times, this increases the condensing rate, increasing the damage to building components.

Condensation due to vapor drive also leads to interior water damage that is often misidentified as a "roof leak." A contractor may try many repairs that are ineffective at stopping these mysterious "roof leaks." The result is wasted time, money, and opportunity for additional damages before the root cause is properly identified.

Possible Solutions

All components within the roof assembly must be carefully evaluated to prevent vapor drive problems. The vapor retarder/air barrier must be properly specified and installed. The vapor retarder should be installed on the warm side of the roof insulation. Proper detailing and installation of these systems are also required around penetrations and tie-ins to wall vapor retarders/air barriers.

Adequate and controlled roof ventilation is very effective at preventing condensation within the roof assembly. Cold roof systems, as described above, provide good ventilation that minimizes the risk for vapor drive problems.

The use of breathable roof underlayments should be considered. Newer underlayments are available on the market that have excellent resistance to hydrostatic pressure yet are very vapor permeable. Their use on the field of the roof will greatly reduce the potential for vapor drive problems.

SNOW RETENTION

Snow falls in a variety of densities and moisture contents. Melting and refreezing "ripens" the snow, creating different layers. These different layers create shear planes that permit movement of upper snow layers under the right circumstances.

Contributing Factors

Roof pitch has the greatest effect on snow retention. Roof pitches of 4:12 to 9:12 typically require retention devices to keep the snow in place. Roof pitches in excess of 9:12 make snow retention difficult or impossible.

Different roofing systems have varying kinds of surfacing that affect snow retention. Metal roof systems have a low coefficient of surface friction that permit snow movement at lower roof pitches. Asphalt shingle roofs are fairly coarse and resist snow movement on steeper roof pitches.

Inadequate retention devices promote snow movement. Snow brackets (snow guards) are sometimes ineffective at roof slopes 7:12 and greater. The spacing of snow brackets is sometimes inadequate. Snow fences may be required to resist snow movement on steeper pitches.

Snow accumulation depth also affects its movement. Snow brackets have limited heights and will not prevent movement when accumulation significantly exceeds the height of the device. Snow fences increase the accumulation depth that can be retained on the roof.

Resultant Problems

Uncontrolled snow movement can damage the roofing, flashings, and roof drainage systems. Clay and concrete tile can break, and metal roofing can be damaged when snow falls onto the surface. There is a risk of injury to people and damage to lower building components and structures when snow slide is not controlled.

Possible Solutions

Snow movement should be minimized to prevent injury to people or damage to buildings. Snow slide can be controlled with roof pitch and roof surfacing, but consideration should also be made for proper roof drainage and roof ventilation when choosing a particular roof slope. Roof slopes between 4:12 and 7:12 typically meet all of these requirements.

Snow bracket size and spacing should be carefully examined to see if they will be sufficient to prevent most snow movement. The structural attachment and penetration detailing through the roof system need to be thoroughly reviewed. Snow fences retain more snow than snow brackets, so attachment to the building requires structural engineering. An example of a snow fence is shown in *Figure 5*. Retention of snow increases the live load on the roof structure. When retaining snow on the roof, it is imperative to verify that the entire structure is designed to accommodate the load.

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Figure 5: Snow fence and reinforcing cable system to retain snow on a 14:12 pitch roof.

ROOF ICE MELT SYSTEMS

Types of Roof Ice Melt Systems

Stringing runs of heat tracing on the roof surface is the most prevalent type of roof ice melt system, and it is the least expensive to install. Heat cable degrades with exposure to the elements and may not alleviate all ice dam problems. Heat tracing also can be easily torn off the roof. Heat cable must have sufficient wattage (10 watts per lineal foot minimum) to help prevent ice dam formation.

Heated metal systems best address most of the issues associated with ice dam prevention. They are typically the most effective and aesthetic means of controlling ice dams; however, their initial installation costs are significantly higher.

Heated asphalt roof shingles are relatively new on the market and may become an effective method for prevention of ice damming.

Design Considerations

The orientation of the building and shaded areas need to be reviewed. Ice melt systems should be installed in areas prone to ice dam formation due to solar radiation.

Even cold roof systems may not provide sufficient roof ventilation within valleys to prevent ice dam formation due to building heat loss. Running an ice melt system two-third the length of the valley is typically sufficient to prevent the formation of ice dams.

Heat tracing is typically installed in a zig-zag pattern on the surface of the roof along eaves and valleys. This can be aesthetically unappealing when snow is not on the roof. It also causes snow on the roof to melt in an irregular pattern. Heated metal systems are typically the most aesthetically appealing, but heated roof shingles may also be an option.

ROOF DRAINAGE SYSTEMS

Low-slope Roofing

Generally, internal drains that benefit from heating by the interior spaces do not require ice melt systems or special consideration. External drains and scuppers are prone to ice formation, which can prevent proper roof drainage. Heating or heat tracing may be required.

Steep-slope Roofing

Exposed gutters are typically at ambient air temperature and are very prone to icing. Ice weighs approximately 57 pounds per cubic foot and can easily accumulate to the point that gutters and downspouts are ripped from the roof. Heat tracing and adequate attachment to the structure are required for external gutters on steep-sloped roofs.

Concealed gutters suffer less potential for structural failure due to ice dam formation; however, use of heat tracing or underpan heating is highly recommended.

CLOSING

Super-insulated roofs are not recommended for addressing ice dam formation due to building heat loss, and conventionally vented roofs may also be inadequate. The cold roof system provides the greatest amount of ventilation to help prevent ice dam formation due to building heat loss.

Roof ice melt systems are required at high altitudes to address ice dam formation due to solar radiation. Roof orientation and configuration can also help reduce the potential for ice dams.

Proper selection of a vapor retarder considers all components within the roof assembly. The vapor retarder requires careful installation and tie-in to adjacent penetrations and the wall vapor/air barrier. Proper roof ventilation will also help alleviate problems associated with vapor drive.

Roof pitch and roofing types are key factors that affect the requirements for snow retention devices. Snow brackets or snow fences should be installed when required to keep snow from sliding. The attachment and flashing details are important, as well as ensuring the entire building structure is designed to retain anticipated snow loads.

In cold and high altitude regions, some form of roof ice melt system is almost always required. Heat tracing has the lowest initial cost but may not have the performance, reliability, and aesthetics required for the project. Heated metal systems have many benefits but are significantly more expensive to install.

Most roof drainage systems, with the exception of internal drains, require heat tracing to prevent ice formation that inhibits proper drainage or that results in damage to the roof drainage system.

Roofs in cold and high altitude climates have design considerations not common in most areas. In addition to the many concerns always associated with roof construction, the prudent designer will address ice dam formation due to building heat loss and solar radiation, vapor drive, snow retention, roof ice melt systems, and roof drainage systems. A proper roof design will balance all of these design constraints, resulting in a roof system that will provide long term performance. ■

About the Author



Steve Bunn is the head of Architectural Engineering at Gillans, Incorporated in Westminster, Colorado. He obtained a Bachelor's Degree in Aeronautical Engineering from the University of Washington in 1994. Bunn has eight years experience as an exterior envelope consultant. He began his career working with Colin Murphy at Exterior Research & Design, where he ultimately headed the design division. Steve joined Gillans in February 2000, and became head of the exterior building systems department. He has worked many fields within roof consulting, including forensic investigation, laboratory analysis, code approvals, design, and contract administration.