# Roof Slopes, Ice Dams and Cold Roofs

By Ian Mackinlay, FAIA and Richard S. Flood

IN SNOW COUNTRY IT IS TRADITIONAL TO design buildings with sloping roofs. Quintessential mountain architecture embodies various forms of the Swiss chalet, often without the user's understanding of its design principles. In New England, it is difficult to find a residential building without a steeply sloping roof. The conceptual underpinning of this almost universal design response to the snow and cold is that it is desirable to shed the snow off the roof onto the ground as quickly as possible, both to lower the load on the building and to reduce the chance of leaks. In the public's mind, good snow country design has become synonymous with the sloped roof. That sloping roof form has taken on a life of its own, which many designers and builders consider to be self-justifying. They believe that their duty to deal with the snow is satisfied by slope alone and no additional thought or investigation is required. Those who do choose to look further generally consider no more than the building official's mandated snow load and the character of the roof surface material. Perhaps the designer elects to apply a standing seam metal roof or a shingle roof with the eaves faced in stainless steel sheet metal, as is very common in New England. Unfortunately, these techniques do not always work. A prudent roof designer must look deeper into what actually happens when snow falls on a sloping roof.

Unless the fallen snow slips away quickly (and even on slippery roof surfaces it often does not), building heat causes melting at the junction of the roof material and the snow blanket. This moisture remains liquid, protected from the cold air by the insulating properties of the snow. The water runs down the roof slope to the eave edge where it refreezes into an ice dam. These ice dams are the single most serious problem with pitched roofs in snow country.

Snow-covered, sloping roofs with ice dam formations may be subject to loads greater than either ground or flat roof snow loads. These circumstances are created by a combination of site-specific environmental factors, the building's unique architecture, and its internal temperature. When these design ingredients are ignored or not fully understood, the result is a project where large, heavy ice dams are formed (*Figure One*).

In many instances, the mass of ice and the water reservoir backed up behind it exert a force on the structure that exceeds the loads mandated by the building code. Ice dams also create hydrostatic pressure at the roof surface which can force water through tiny cracks which otherwise would not leak. Impermeable underlayment is required from the eave to at least five feet above the line of the exterior heated wall. This is especially necessary where buildings have large unheated eaves and building heat melts snow at the roof surface. Snow meltwater, held on the roof by eave ice, adds to

*Sawtooth Wilderness Information Center near Sun Valley, Idaho, March 1989. © Ian Mackinlay*

*An interesting example of snow sticking to a metal roof. Carnellian Bay (Lake Tahoe), CA, February 1985. © Ian Mackinlay*

*Rick Flood had just come down from the roof of the Hewlett Cabin, in Sugar Bowl, CA (Donner Pass, at 2040′ elevation) on Nov. 13, 1998 and gotten out his camera to record a 15″ snow-load when the snow cascaded off the roof as he released the shutter. Cold roofs work! © Rick Flood*

both the weight of the snow and the hydrostatic pressure. The continuing melt/run down/freeze action can build ice dams to substantial height and mass. The deeper the snow on the roof, the larger the potential dam. Ice is heavier than snow and water is heavier than ice per unit volume. Thus, ice dams produce roof loads far greater than the same volume of drifted snow.

Other factors which can significantly increase loading or leakage problems on sloping roofs include rain-soaked snow pack, snow retentive roofing surface, snow drifting on roof slopes in the lee of storm winds, and projections through the roof surface such as dormers and plumbing vents. Roof geometry and orientation also play an important role in retaining snow on the roof. Ice dams can prevent snow shedding even from steeply sloped roofs with slippery surfaces. When these design ingredients are ignored or not fully understood, high roof snow loads and massive leakage can occur. The designer cannot change nature's environmental forces, but by understanding the snow's capricious characteristics, a satisfactory design solution can be achieved for most conditions.

On a typical building in North America where the ridge runs east and west, the north-facing sloping roof faces away from the sun, and often is in the lee of the storm winds. Building heat produces snowmelt. With a typical shingle roof surface, there is a great tendency for retention of the snowpack on the roof. The south facing roof slope often faces into the storm winds. The north facing roof slope, with a typical slope of 5:12, receives the least solar exposure (almost none at mid-winter). Any gap in the roof insulation will lead to excessive melting of the snow blanket on the roof. Meltwater freezes at the eaves which are unheated. These conditions can lead to ice dams several feet high at the roof edge, massive roof loads and impressive icicle formation.

Such conditions can lead to much more roof load than that calculated by applying the factors given in the building codes. Due to drifts and ice damming, the lee-side, north-facing roof could readily be subjected to 1-1/2 to 3 times the ground snow load. This can be 200% to 500% greater than the original sloped roof design load as required by current regulations. At the same time, due to wind stripping and solar radiation, the portion of the roof that is south-facing (on the windward side of the ridge) could have very little snow cover. This uneven roof loading is often overlooked by roof designers.

Projects with these characteristics suffer from significant north roof ice damming and unbalanced loading conditions, even in light snow years. North side dormers, down slope chimney projections and vent pipes in the roof field contribute to the north side snow/ice buildup. Some relief through snow shedding might be obtained if the roof is designed with standing seam metal roof rather than shingles. Ice dam build-up is magnified by roof surfaces that retain the snow blanket on the roof. Unfortunately, even standing seam metal roofs can retain ice dams at sloping roof eaves, as the ribs freeze into the snow pack and prevent the snow from sliding. When the snow pack does cascade from such metal roofs, it comes without warning and with great force (see photo this page). Without manual roof snow/ice dam removal several times per winter season, the north side roof would be overstressed structurally most of the time, even in moderate snow years. Hand snow removal can cause great damage to the roof. If the cold weather strate-

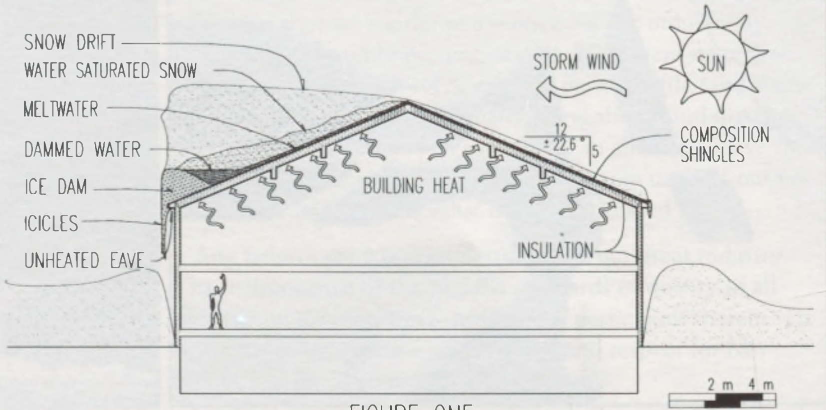

FIGURE ONE

INCREASE IN SNOW LOAD DUE TO DRIFTING AND ICE DAM FORMATION
36° N. LATITUDE ; 2499m ( 8200 FT. ) 250 PSF GROUND SNOW LOAD

gy is to periodically remove the snow, then suitably durable roof surface materials must be selected.

One strategy for ice dam mitigation is through the use of a snow arrester/heated gutter combination. The snow arresters are placed at the edge of the eave and the heated gutter is placed immediately upslope of the arrester. The arresters retain the snow blanket on the roof. The snow blanket insulates the meltwater, keeping it from freezing. The heated gutter intercepts the meltwater prior to its exiting the snow blanket and keeps the intercepted water from freezing as it is drained away, thus reducing ice damming and roof loading. This technique is especially effective where outdoor pedestrian-/vehicular circulation space occurs below the eave. Proper design will often result in snow loads not exceeding ground snow load on roofs where no load reductions due to slope are taken. It is important to design the snow arrester for the full weight of the snow blanket all the way from roof edge to ridge. This must be done regardless of the frictional resistance of the roofing material.

Where unprotected parking or decks are below sloping roofs, no cascading of snow and ice is permissible. (*Figure Two*). A steel tube arrester bar is often required, due to high structural load. The snow arrester tube must be firmly tied to the basic structure and allowance must be made for uneven loading. When support metal tubes are carried into warm, heated, interior space, they must be insulated within the soffit and rafter space to prevent condensation.

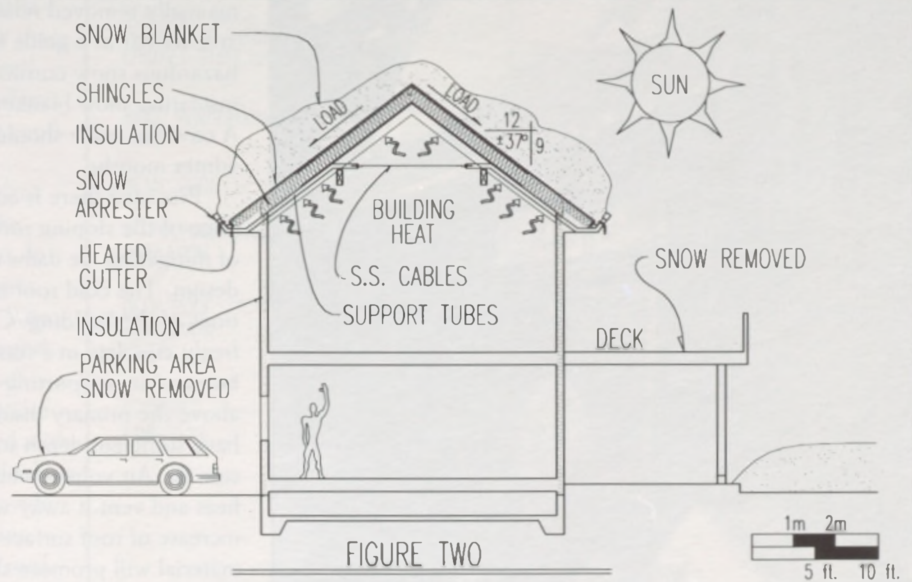

FIGURE TWO

SNOW ARRESTORS PROTECT PEOPLE ON DECKS AND IN PARKING AREAS
38 30' N. LATITUDE; 1400m (6300 FT.) 150 PSF GROUND SNOW LOAD

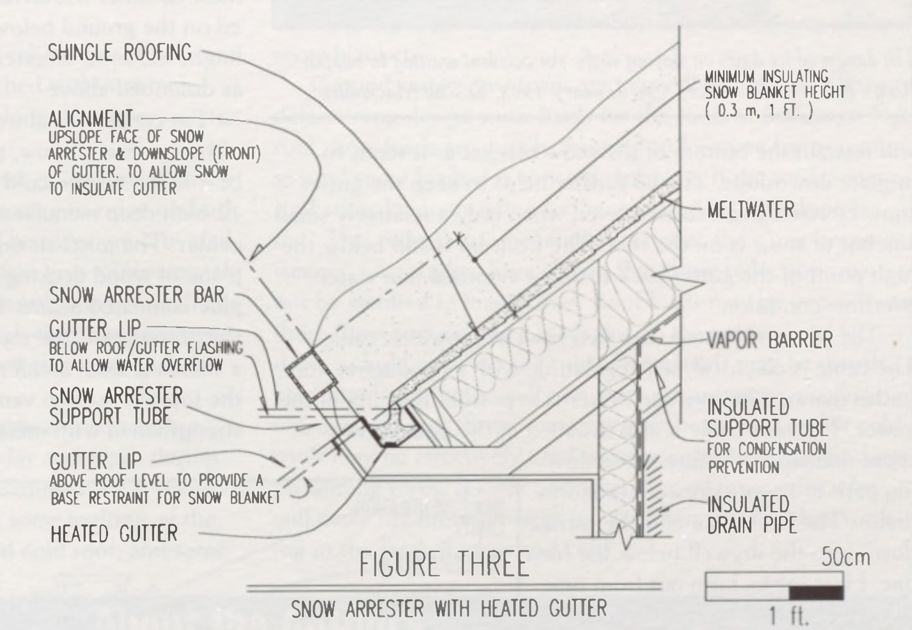

FIGURE THREE

SNOW ARRESTER WITH HEATED GUTTER

The upslope face of the arrester bar must be positioned to restrain a minimum 12-inch thick snow blanket. This thickness of snow blanket is usually sufficient to insulate and protect the roof meltwater from freezing. The heated gutter is positioned to align the front (downslope) face nominally in the same plane as the upslope face of the arrester bar. This is done to allow the snow blanket to completely cover the gutter and leave only a minimal roof surface downslope (*Figure Three*).

The front lip of the gutter deviates from standard rain gutters in that it extends above the plane of the roofing approximately two inches. This high front lip will stop small amounts of snow that slide under the arrester bar and

*A heated gutter up-roof of a snow arrester. Incline, NV. © Ian Mackinlay*

*The danger of ice dams on sloping roofs. An accident waiting to happen. King's Beach (Lake Tahoe), CA, January 1993.* © *Rob Mackinlay*

will restrain the bottom of the snow blanket as it tends to migrate downslope. The lip further helps to keep the gutter snow covered and insulated, even when only a relatively small amount of snow is on the roof. The front lip is still below the high point of the gutter back to allow a normal rain water overflow condition.

The gutter is heated with two rows of snowmelt cable. The cable is electrical, self-regulating, with a conductive core. In this manner the roof meltwater is kept from freezing in the gutter. The heat cable is also installed in the piped/downspout drainage to ensure a free-flowing path to on-site drywells or storm drains. The heat trace must be carried down into the drywell below the frost line. Heat cables burn out from time to time and must be replaced. The design should allow for this contingency.

With snow arresters and heated gutters, ice dam formation is greatly reduced as the gutter intercepts almost all of the roof meltwater without permitting it to refreeze while the arrester retains the snowpack. This limits ice dam/icicle formation and protects people and property below.

In heavy snow years, or under certain drifting conditions, the snow blanket may be of such depth that snow cornices will occur over the top of the arrester bar. If the snow cornice becomes a hazard, it can be manually removed relatively easily and safely by using the arrester bar as a guide for the removal tool. Removal of the hazardous snow cornice does not jeopardize retention of the insulating snow blanket, nor does it damage the roof surface. A cover of snow should be left on the roof at all times during winter months.

Provided there is an unoccupied area below the lower edge of the sloping roof for snow slippage, the best method of mitigating ice dams is to incorporate a "cold roof" into the design. The cold roof is an "umbrella" over the heated portions of the building. Cold, outside ambient air is allowed to freely circulate in a roof cavity directly below the roofing surface and its supporting substrate. This ventilation cavity is above the primary insulated roof. The ventilation cavity must have sufficient depth to promote an unrestricted flow of outside air. Air volume must be great enough to absorb building heat and vent it away without contributing significantly to an increase of roof surface temperature. Use of a slippery roofing material will promote shedding of the snow blanket. As a word of caution, the falling roof snow needs a dump area that will not fall back against the wall of the building. The design must consider the effects of the snow berm that will be created on the ground below the roof slope. An alternate design might use snow arresters to hold the snow blanket on the roof as described above.

For conventional wood frame buildings located in an area of heavy winter snow, the regulatory ground snow load might be 400 lbs/sf. The cold roof structure is comprised of nominal 12-inch deep manufactured wood truss joists at two feet on center. The joists sit on a vapor retarder covered continuous plane of wood decking which is structurally supported by glue-laminated beams 4-1/2 feet on center. Plywood roof sheathing spans the top of the joists and provides support for a standing seam metal roofing system. The plywood forms the top of the deep ventilation cavity. The joists are laterally strengthened with metal "X" bracing in lieu of solid blocking

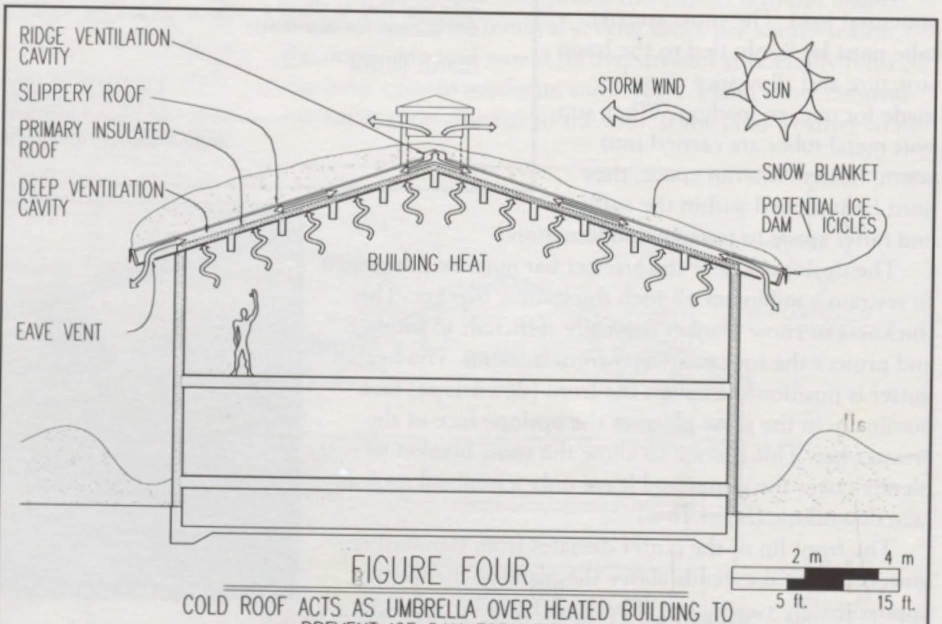

FIGURE FOUR

COLD ROOF ACTS AS UMBRELLA OVER HEATED BUILDING TO PREVENT ICE DAM FORMATION

38° 30' N. LATITUDE ; 2146m ( 7040 FT. ) 400 PSF GROUND SNOW LOAD

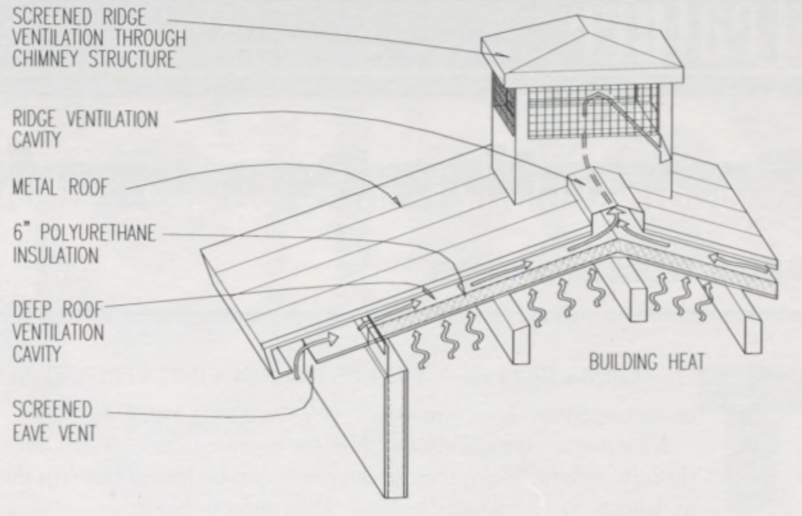

FIGURE FIVE

COLD ROOF – VENTILATION PATH DIAGRAM

at the beam lines to ensure an open ventilation cavity. The bottom half of the joist space is filled with R-38, 6-inch thick closed cell polyurethane insulation sealed on its surface. The upper half is left open, providing a ventilation cavity (*Figure Four*).

Structurally, the lateral force transfer of the snow loaded roof diaphragm into the shear walls below must be accomplished. In this example, lateral design snow load uses one third of the roof design snow load. The slippery nature of the metal roof predicated the use of this value. One half of the roof design would probably be more appropriate for a nonslippery roof or a roof designed with snow arresters. Normally, solid wood blocking would be used between the joists to provide the force path. In this case, solid blocking would negate any airflow into the cold roof cavity. To solve this problem, a series of steel plates with a hole cut out will be used to transmit the horizontal forces to the peripheral shear walls and still permit air circulation.

Pressure equalization between adjacent cavities is achieved by having the wood joists factory-punched with one inch diameter holes at 12 inches on center along the upper quarter point of their plywood web.

The gable roof thus comprises a series of 24-inch-wide by 6-inch ventilation cavities running from eave to ridge on both the north and south sides of the roof. The eaves are provided with continuous screened vents with a free area approximately 75% of the cross sectional area of the ventilation cavity. The ventilation cavities are vented up through the chimney structures at the ridge, utilizing the metal roof ridge cap as an airflow duct (*Figure Five*).

Cold roofs work best when the outside ambient air temperature remains cold, below freezing, day and night during the snow season. Where the winter air temperature is often above freezing at midday, there will be some melting of the snow blanket, even with a well designed cold roof, and some ice damming may occur at the eaves and some icicles may form. This ice damming will be far less than it is where the building heat significantly contributed to the melting of the snow blanket.

Ground snow snow loads are generally used as the basis of determining design snow loads for the roofs of buildings. Flat roof snow loads are usually assumed to be some fraction of ground snow loads due to wind stripping. If the roof slopes, roof snow loads are often further reduced by the "slope factor." This reduction is generally greater as the slope becomes steeper. Our studies have shown that these reductions may not be justified in many cases. Roof loads may be two or even three times ground snow loads due to the tendency of ice dams to hold snow on the roof. These loads may be distributed highly asymmetrically on the roof structures, producing unbalanced loads. Snow arresters with heated gutters or cold roofs may be effectively used to reduce the effect of ice dams on sloping roofs. A clear understanding of these principles will make life more pleasant for designers and builders working in the land of snow and cold.

## About the Authors

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***Ian Mackinlay*** *is president of Ian Mackinlay Architecture Inc., San Francisco, CA. He is a licensed architect in 14 states and Guam, was named a Fellow of the American Institute of Architects (AIA) and has been on its Committee on Design. Mackinlay has earned over 50 awards for Architectural Design Excellence and is a three-time winner of America's highest award for constructed architecture, the AIA National Award. He has published widely on snow country design and spent six years in Europe as Chief Engineer with European Exchange System. Mackinlay's interest in architectural problems of the snow and cold has led him to publish and lecture on the subject and to be appointed to the Loads Subcommittee of the American Society of Civil Engineers (ASCE).*

***Richard S. Flood*** *has been a licensed architect for 21 years. He has been associated with Ian Mackinlay for the last 28 years and has been involved with the technical design and failure analysis of more than 25 major projects in the snow and cold. Currently he is consulting with major ski resort developments in Colorado and Idaho. In 1996, he co-authored a paper, "The Impact of Ice Dams on Buildings in Snow Country," which he co-presented with Ian Mackinlay at the Third International Conference of Snow Engineering in Sendai, Japan.*