STANDING SEAM METAL ROOFING SYSTEMS IN COLD REGIONS

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Standing seams that are out of the "flood plain" and sliding clips that allow metal panels to expand and contract thermally have significantly improved the performance of metal roofing systems. By fixing the metal panels to the frame only at the eaves, differential movements do not occur at that vulnerable location where all water drains, snow and ice may slide and ice dams may form. When water ponds on metal roofs behind icicles and ice dams, the risk of leaks increases greatly. Such risks can be reduced by using "waterproof" (not "water shedding") systems, by increasing the slope, by reducing the overhang at the eaves, by increasing the amount of roof or attic insulation, and by ventilating between that insulation and the metal to create a "cold" roof. Since it is difficult to properly ventilate a metal roof with a slope of 2 in./ft. or less, there is incentive to use greater slopes in cold regions.

Most metal roofing systems are not ventilated, but in cold regions, ventilation may be needed to reduce the risk of condensation problems and ice damming. Small, infrequent ice dams along the eaves of "cold" metal roofs seldom create problems. When large dams develop at the eaves, it maybe necessary to install electric heaters. The tendency for snow and ice to slide off slippery metal roofs complicates the installation of electric de-icing systems and may create hazards. Snow guards are needed on some metal roofs to prevent snow and ice from sliding.

Standing seam metal roofs are well suited to some applications in cold regions but not to others. When these roofs are used inappropriately, chronic problems that are very difficult and expensive to resolve are likely. When used appropriately, these roofs perform well.

KEYWORDS

Condensation, drainage, electric heaters, heating cables, ice dams, metal roofing, sliding snow, slope, snow guards, thermal expansion, vapor retarders, ventilation.

INTRODUCTION

In this paper, a "cold region" is a place where snow is present for some time, not just for a short period after an infrequent snow storm. By this definition, Atlanta, Ga., would not be a cold region but Boston, Mass., would be.

The coefficient of thermal expansion of steel, 0.0000067/F°, is a very small number. It represents the amount a unit length of steel will expand or contract as its temperature is increased or decreased by one Fahrenheit degree. A steel roofing system 100 feet long, subjected to a 140F° temperature change from 120°F to -20°F, will change 0.094 ft. in length (i.e., 1⅛ inches). The real-world implications of 0.0000067/F° are large movements, which are very important to consider when using metal roofing. Even greater movements occur with aluminum panels since the thermal coefficient of aluminum is 0.0000129/F°, about twice that of steel.

The philosophy of using metal in bituminous built-up roofing systems or as corrugated metal roof panels with lap seams has been to use short pieces and attach them securely to resist thermally induced movements. However, even a 10-foot-long piece of steel subjected to the above temperature variations tends to change dimension by ⅛ inch. This tendency can create large forces on the fasteners holding it in place. Back and forth, day and night, summer and winter, the metal tries to free itself from its bonds. It seldom gets free but it often breaks seals at gasketed fasteners, thereby violating the waterproofing integrity of the system.

A better way to use metal as a roofing material is provided by standing seam metal roofing systems. There are two types of standing seam systems. Terms such as architectural and structural; water shedding and waterproof; and hydrokinetic and hydrostatic are used to distinguish between them. As these names suggest, the former type is only capable of shedding water, while the latter type is designed to hold back standing water on occasion, in the same way that bituminous built-up and single-ply membrane roofing systems are designed to. None of these systems are designed to function under several inches of water for sustained periods.

Both types of standing seam metal roofing have most (but not all) of their fasteners concealed within the standing seam some distance above the metal surface on which water flows (i.e., the flood plain). These fasteners consist of clips that are attached to the building below, then hooked into the standing seams as the metal roofing panels are placed. Since the clips are attached some distance above the level at which water flows, any flaws in the seam sealing system are not likely to be a source of leaks. Sealants installed within the standing seams of "waterproof" systems, either in the factory or on the job site, allow seams to be closed tightly in the field. In the unlikely event that water ever reaches the elevated seam of a "waterproof" system, the sealant is intended to prevent water from entering the system.

In addition, each metal panel of most "waterproof" systems is firmly attached to the building only in one place, usually at the eaves in cold regions. Sliding clips secure it to the building frame at other locations, allowing it to expand and contract freely (i.e., to "float") up and down the slope. Figure 1 illustrates the sliding clip principle.

The panels of most "waterproof" systems are also configured so that thermal strains do not accumulate in the transverse direction (e.g., along the eaves). Figure 2 shows some typical configurations and how they accommodate transverse thermal movements.

Where the metal panels are firmly attached to the building, a few penetrations are made in the flood plain of the metal roof. Rubber gaskets are used on fasteners, and sealant tape (often butyl) is placed below the panels to seal those holes.

Advertisements show 5 ft. x 7 ft. flat test sections of standing seam metal roofs with 6 inches of water ponded on them. Such standing seam metal roofs are more like waterproof membrane roofing systems than a series of water shedding elements, such as shingles. As a result, "waterproof" (i.e., "structural" or "hydrostatic") standing seam metal roofs are being used on slopes as low as ¼ in./ft.

COMPLICATIONS

Stephenson (1984) provides an excellent overview of design considerations for standing seam metal roofs. His statement that such roofs "do some things very well and other things not well at all" is worth remembering, as is his statement that "installing standing seam roofs requires more skill than for other roofing types, despite claims to the contrary."

For simple shed or gable roofs in warm areas, few complications arise, and standing seam metal roofs have many advantages, aesthetics being an important one to many people.

However, penetrations in "floating" metal roofs are complicated by the presence of the standing seams, which may trap water when an obstruction is placed between them. Also, any curb attached to the metal moves with it; skylights move as do roof hatches. If the penetration contains heavy equipment that must be supported by the frame of the building, that equipment does not move, and special provisions such as counter-flashed inner and outer curbs may be needed to allow the metal roofing to expand and contract freely, perhaps as much as an inch or two, up and downslope.

Some standing seam systems do not use sliding clips. Instead, they are attached firmly along each standing seam by fixed clips and rely on panel buckling between fasteners to prevent large stresses from accumulating on fasteners. The authors view such systems with skepticism.

When the building plan jogs along the eaves, as does the building shown in Figure 3, attachment complications are introduced for "floating systems." If each long panel is attached along the eaves from A to B in that figure, differential movement will occur between adjacent panels from C to D. Either that junction must be designed to accommodate that movement or the long panels should be firmly attached to the building, not along line A-B, but along line C-E to eliminate differential movement along C-D. If the long panels are firmly attached somewhere other than at their eaves, movement will occur at the eaves. In cold regions this is not a good place to allow movement, since water may pond behind ice dams. The combination of movement and ponded water greatly increases the possibility of leaks.

There are other situations where accounting for movements is complicated. Attachment of metal panels to valley flashing is a primary example. Where roof areas are small and temperature extremes are not great, the compromises that are made may have no adverse effect. For some big roofs in cold regions, chronic problems have resulted.

Along rakes and parapets that run parallel to standing seams, fixed flashings or terminations interact with the "floating" membrane whose movement increases as the distance increases from its point of fixity (usually the eaves). Whenever possible the moving joint at such locations should be between the cap flashing and the base flashing, several inches above the flood plain of the roof. This may make it difficult to secure the metal roofing system against wind uplift forces in such places. A number of metal roofing systems have suffered wind damage, so this is a real issue deserving attention and thoughtful detailing.

Where cumulative movement is handled at the ridge, a flexible ridge cap is rigidly attached to the metal panels on either side of it. The ridge cap flexes as the metal panels expand and contract. On a large roof the ridge cap may need to accommodate a few inches of panel movement. On such a roof, clips must also be able to handle large thermal movements. When such movements become too large for the clips to handle, it may be necessary to install a cross-slope expansion joint in the roof. However, since such joints are difficult to make watertight, they should usually be avoided in cold regions.

A "floating" metal roof cannot be relied on to provide diaphragm action thereby stiffening the building against lateral loads. For this reason we are reluctant to refer to the "waterproof" versions of these systems as "structural" systems.

Gutters placed along eaves are free to expand and contract thermally. Because of this they may need expansion joints. As shown in Figure 2, the metal roofing is designed so that each panel changes shape slightly to avoid accumulating thermal strains. As a result, the gutter moves relative to the metal roofing. Because it is difficult to create a waterproof seal where such movement occurs, often no attempt is made to seal between the gutter and the metal panels. Unfortunately all the water draining off the roof must pass over this difficult area. If that water is unimpeded, no leaks may develop, but if obstructions such as leaves, snow or ice exist there, problems may occur. For this reason, gutters are often avoided in cold regions.

DRAINAGE TO COLD EAVES

Most standing seam metal roofs drain to their eaves. Because of the difficulty of creating a watertight seal between the panels of a standing seam metal roof and gutters, such roofs seldom drain to internal gutters located over the building. Where internal drainage is used, a gutter within a gutter (each with its own system of leaders), may be needed to reduce risks of a leak into the building and to remove any moisture which condenses on the underside of the upper gutter. Our advice is to avoid internal gutters.

Bituminous built-up and "single-ply" membrane roofing systems are much easier to drain internally, since they do not contain ribs that channelize flow. In cold regions, internally drained roofing systems have a number of advantages over systems that drain to cold eaves, since they avoid sliding snow, icicles and ice dams at eaves, falling ice and snow, problems associated with excess ground water, and problems of below-grade dampness beneath the eaves. Mackinlay (1989) provides advice on roof design in snow country and concludes that "sloping roofs, snow arresters, and heated gutters represent an expensive alternative to flat roof design which can only be justified on aesthetic grounds." Any roof that drains to cold eaves, has some limitations in cold regions. Since most standing seam metal roofs drain to their eaves, it is quite important to understand these limitations for such roofs.

Roofs that drain to their eaves need an overhang to keep water off the walls below. In cold weather that overhang is cold, even when the roof is covered with snow. When building heat melts that snow at its base, the meltwater runs downslope. It may refreeze on the cold eaves, creating icicles and ice dams there. At times, large ice dams (Figure 4) may form that cause meltwater to pond on warm portions of the roof above.

Grange and Hendricks (1976) did pioneering work on the formation of ice dams. They also developed methods to reduce ice dam formation on residential roofs, concluding that a combination of insulation, ventilation and "correct house design" is needed.

Almost all "as-built" roofing systems are not 100 percent waterproof. The design intent for roofing systems should be to provide slope so that water drains away rather than ponds on a system that quite likely contains some imperfections. Ice dams overpower this design intent by promoting ponding. Many imperfect roofs cope with most situations, but leak like sieves when water ponds on them. Metal roofs are no exception.

As indicated earlier, it is unlikely that water would ever reach the sealant that weatherproofs the elevated seam of a metal roof. That is true until meltwater is produced in the snow on a roof or rain falls on a snow-covered roof. In valleys, behind ice dams and at other places where flow is concentrated, constricted or blocked, the water level in the snow rises and the standing seam can be subjected to several inches of hydrostatic pressure.

To minimize leaks at valleys, they should be wide to reduce the potential for ice clogging. Valley flashing should extend well upslope of the end of each standing seam on each side of the valley, and the underside of the valley and a portion of the adjacent roof should be lined with a self-adhering modified bitumen membrane or a sheet of rubber roofing.

The rate at which water in snow flows off a roof increases greatly as the slope increases. Also, the roof area on which ponding occurs behind an ice dam decreases significantly as the slope increases. For these reasons, there is extra incentive to use steeper slopes in cold regions. We advise against using "waterproof" standing seam metal roofs at a slope less than 1 in./ft., and usually recommend that more slope be provided.

In his overview of metal roofing, Haddock (1992) discusses improper matching of slope with climate. He suggests that "water shedding" systems may require more slope in cold regions than elsewhere, then acknowledges that in some places, some "water shedding" systems "just may not be suitable at all." He advises switching to "waterproof" systems in "northern climates."

Fortunately several things can be done to reduce ice damming. One is to provide the roof with an unobstructed slippery surface so that snow slides off. Metal roofs are at the top of the "slippery surface" list. National structural load design guidance (ASCE, 1990) and some building codes allow reductions in design snow loads for such roofs. As the slope increases, design loads decrease and the potential for ice damming is often reduced. However, a roof that produces big ice dams is not "unobstructed" and cannot take advantage of load reductions for having an "unobstructed slippery surface."

de Marne (1989) reviews problems with ice dams on residential roofs in northern New England and states that it is rare to find a metal roof that is slippery. He indicates that "the sticky deposits and the pitting caused by oxidation, dust, chemical pollution, acid rain, creosote deposits from wood burning and oil deposits from a poorly adjusted furnace offer enormous resistance to the timely discharge of the snow load." Snow has continued to slide off other metal roofs for decades, indicating that their surfaces have remained slippery.

Icings can be reduced by increasing the amount of thermal insulation in the attic or the roof, and by reducing the overhang at the eaves. The bottom of the fascia should have a drip edge and eaves should overhang at least 6 inches on roofs without gutters to avoid wetting the walls below or having icings form on them like those in Figure 4. A one foot overhang is often a good compromise in cold regions.

Even when the above guidelines are followed, icings still should be expected to form on occasions, such as when a warm day is followed by a very cold night. Normally these icings will be small enough and infrequent enough so that big problems do not develop.

VENTILATION

The most effective action that can be taken to reduce icings is to ventilate the roof to cool the underside of its top surface, thereby creating a "cold" roof (Tobiasson, 1989a). Periods during which meltwater is created by building heat are reduced when a cold, ventilated roofing system is used. Building heat, not the sun, is usually the primary cause of ice dams, since the sun also warms the eaves. However, on a cold but sunny day, bare portions of dark metal roofs can become quite warm and cause adjacent snow to melt.

To create a cold roof, ventilation is needed between the metal roofing and the insulation below. This is easy to accomplish if the building has an attic with insulation at its base, since the attic itself can be ventilated. It is more difficult to provide ventilation when insulation is to be placed directly below the metal roofing. In this case, provisions must be added to raise the metal above the insulation to create continuous airways from intake openings at the eaves to exhaust openings at the ridge. Most standing seam metal roofing systems on the market are not ventilated, but a few ventilated systems are available.

ASHRAE (1989) presents information on how to determine the free area of inlets needed for natural convection within attics. We have had success sizing natural ventilation systems based on an outside temperature of 22°F and an attic temperature of 30°F. Our observations suggest that problematic icings develop very slowly, if at all, when the outside temperature is above 22°F. Using an attic temperature of 30°F instead of 32°F acknowledges that when most of the attic air is 30°F, it is likely that some areas will be somewhat warmer.

In residential buildings, the amount of ventilation provided to prevent condensation problems is usually enough to minimize icings at eaves in reasonably well-insulated buildings. Condensation will be discussed later in this paper.

Tobiasson (1986) summarizes ventilation requirements for moisture control for various roofing systems relative to slope and type of construction. Guidelines relative to the net area of openings for natural ventilation range from 1/300 (0.33 percent) of the area of the space to be ventilated to 1/150 (0.67 percent) of that area for many situations. At slopes below about 2 in./ft., there is little stack effect to cause a draft between intake and exhaust openings. For such roofs, natural ventilation is slight except during windy periods. Such low-slope roofs are prone to condensation problems because they are hard to ventilate. That same difficulty makes them prone to the problems brought on by ice damming. These are two good reasons for staying with slopes above 2 or 3 in./ft. for any roofing system that drains to cold eaves in cold regions.

HAZARDS

At some point, snow will slide off the roof or leave as meltwater. Icicles and ice dams will melt away or break free. Property has been damaged (Figure 5) and people have been injured and killed by ice and snow falling from roofs that slope to cold eaves. In cold regions, sliding snow and falling ice should be anticipated from slippery roofs that drain to cold eaves. Entrances, sidewalks and parking areas should be designed with this in mind.

At a ski resort in New England, an individual walking 40 feet from a four-story, metal-roofed building was injured by a softball-size chunk of ice that fell from the upper roof onto a sloped metal roof two stories below, which then shot sideways to hit him.

Falling ice and snow can damage lower roofs. Smith (1991a, 1991b) describes armor placed above metal roofs to protect them from falling ice. First, the ribs of the metal roof were reinforced. Then strips of neoprene about ⅜ in. thick were placed on the top of standing seams in the impact area and ⅝-in.-thick plywood was secured above, such that the neoprene strips acted as shock absorbers. The plywood was covered with metal roofing for aesthetics.

Tobiasson (1989a) describes icings, sliding snow and protected membrane roofing systems. With the membrane several inches *below* extruded polystyrene insulation and a ballast of stones or pavers, protected membrane roofs are well suited to resist impact loads from falling ice without incurring membrane damage. When concrete pavers are used for ballast, they should be strong (3,000 psi minimum compressive strength), and made with air-entrained Portland cement for freeze-thaw resistance.

Taylor (1985), and Paine and Bruch (1986) provide guidance on the trajectory of sliding snow.

In Anchorage, Alaska, meltwater from a "hot" metal roof (i.e., a roof with no ventilation between the metal and the insulation below) soaked piles of snow on the adjacent ground. That snow had slid off the roof earlier. The water in that snow rose above the level of the first floor of the building and entered the building at the base of the wall. Most floor-wall intersections are not able to hold back water under pressure. Carpets were damaged and office work was disrupted.

The water in the snow also flowed away from the building out over a sidewalk and a parking area, where it froze. Considerable effort had to be spent keeping the sidewalk clear of ice (Figure 6). Notwithstanding all this effort, an individual fell on the slippery surface and broke an arm.

The eaves of this building lacked a proper drip edge. In cold weather, meltwater from the hot roof froze on the walls, at one time encasing them in ice a foot thick.

Three ways of solving this problem were developed. One reconfigured the 1-on-12-slope, standing seam metal roof so it drained internally. Another added insulation by spraying 2-3 inches of polyurethane foam on the exterior of the metal roofing. The foam was to be protected with an elastomeric coating. The third suggestion was to create a cold ventilated roof by placing a second layer of metal roofing over the existing roof, and insulating and ventilating the space between.

All these suggestions were rather expensive. The building owner rejected them in favor of building a back-sloped shed in front of the building to catch snow, ice and meltwater (Figure 7). A heat-traced gutter between the shed and the existing eaves collects meltwater and drains it away. The shed is not attractive, but it has eliminated a serious safety hazard.

This example is a reminder of how difficult and expensive it is to correct such problems. It reinforces the point that it is far better to confront these problems when the building is being designed than to try to develop a solution after it has been built and starts causing problems.

ELECTRIC HEATERS

In cold regions it is common to zigzag electric heating cables along the eaves of residences that suffer from ice damming. The heaters do not prevent ice dams from forming on such roofs, but, by melting small tunnels through the ice, they prevent ponding behind the dams. This keeps the dams from growing very large, and it greatly reduces the risk of roof leaks.

Attaching heating cables to composition shingle roofs is relatively easy, but attaching them to standing seam metal roofs is much more difficult.

Tests are underway at Fort Drum near Watertown, N.Y., to develop ways to heat the valleys of numerous new standing seam metal roofs that are suffering ice dam problems. Figure 8 shows the nature of the problems.

Inadequate attic ventilation is the principal reason why these problems occurred. For some of these buildings, improving attic ventilation should eliminate ice damming. However, several of the buildings contain lots of heat-producing mechanical equipment in their attics that make it difficult to solve all icing problems by just improving attic ventilation. Electric heaters will be needed.

Placing mechanical equipment in attics may be appropriate, but the thermal consequences of doing that must be investigated carefully.

Figure 9 shows the heating cable layout used to protect one valley. This and all other heating cables under test are thermostatically controlled to energize only when the outside air temperature along the north side of the building falls below 40°F. Note how the parapet in Figure 8 chokes off a portion of the bottom of the valley. This constricts flow and makes this a very difficult place to waterproof. Figure 10 shows one of the heating cables that did not survive the winter. It was attached to plastic plates held on with an epoxy adhesive. Larger perforated stainless steel clips held on with neutral-curing silicone adhesive fared much better (Figure 11). This special silicone produces alcohol as a by-product of curing rather than acetic acid, which is corrosive.

One valley was protected with electric heating cables installed under the valley flashing. They kept a wide clear path down the valley, but the 1800 W dissipated in that valley was too much. It melted more snow than was necessary to clear the valley. That extra meltwater refroze on cold portions of the fascia, creating large, dangerous icicles.

On other buildings it proved difficult to prevent ice from forming on either side of heating cables placed on the fascia. Additional tests are underway with emphasis on reducing power to each valley to reduce the amount of meltwater created and heating the fascia such that icicles do not form there.

Heating cables installed under the metal roofing are appealing, and attention is focusing on optimizing their placement. However, some valleys will be protected with heating cables installed on top of the metal roofing with the hope of developing easy-to-install systems that can survive up there.

Paine (1989) states that "roofs should not have to depend on an energy supply to work properly." We agree with that statement relative to the design of most new roofs. However, we feel that there are situations where electric heat can be used to solve chronic icing problems on existing buildings. Wherever possible, roof designs should be developed that do not rely on electric devices to solve problems associated with snow and ice loads and effects.

SLIDING SNOW

The benefits of having snow slide off a roof are associated with reductions in snow loads and ice damming. However, sliding snow can cause problems (Figure 12) and introduce hazards (Figure 5). It is necessary to design roof penetrations to resist heavy loads and, in some instances, to place devices (snow guards) on the roof to prevent snow from sliding. By placing roof penetrations near ridges, sliding snow loads on them can be reduced.

Taylor (1985), and Paine and Bruch (1986) provide guidance on the forces needed to prevent snow from sliding. Paine (1989) states that "on metal roofs, sliding is generally unlikely until the roof slope is 14° or more." From this observation he concludes that the effective coefficient of friction for standing seam metal roofs is about 0.25. He acknowledges that this is higher than either the static or dynamic coefficient of friction between painted metal and snow. He suggests that roof irregularities (e.g., the standing seams themselves) explain the high value.

While snow may not slide off low-slope metal roofs, it may creep slowly downslope even at a slope of ¼ in./ft.

An obstruction can hold back a wedge of snow, as shown in Figure 13. The authors' observations agree with Paine's that such wedges angle off at about 45°.

Snow splitters (i.e., snow diverters) are installed upslope of roof obstructions to reduce snow loads on those obstructions. Snow splitters are often configured as a wedge pointing up the roof. On metal roofs, it is usually necessary to anchor snow splitters into the building below. On "floating" metal systems, it is important to isolate fixed and floating portions. Solutions can become complex.

Snow guards (i.e., snow arresters) are objects placed on roofs to keep snow there (Figure 14). When snow guards are to be used, the forces expected on them should be determined. When calculating such forces, Paine (1989) recommends that a frictionless surface be assumed, since the snow may be "wet and lubricated."

The design of snow guards is usually based on holding snow in place, not resisting large dynamic forces caused by snow that has slid some distance and then confronts the snow guard. To reduce the risk of subjecting snow guards to dynamic forces on slippery roofs, it is beneficial to place several rows of moderately strong snow guards up the roof rather than rely on one very strong snow guard in the vicinity of the eaves. Snow guards should not be placed *at* cold eaves since they may facilitate the growth of ice dams there.

Except in areas experiencing very heavy snow loads, it is usually possible to secure snow guards to the floating metal roofing. Whenever possible, the guards should be attached to the standing seam itself, up out of the flood plain.

Plastic snow guards, a few inches long, are also available for metal roofs. Typically many are placed on a roof to hold back snow (Figure 15). They are fastened to the flood plain of the metal using either an adhesive or penetrating fasteners. We have heard mixed reviews of the adhesive system and have reservations about creating holes in the flood plain of the panel to attach them there. Those on the roof shown in Figure 15 were mechanically attached through the "floating" metal roofing and into the top flange of Z-purlins below. Large stresses build up on those fasteners as the metal changes temperature, and leaks have developed.

Snow guards should be used to prevent the downslope creep of snow into areas where electric heating cables are installed. The snow guards protect the cables from damage, and they forestall the formation of cornices on which secondary icings can form.

CONDENSATION

Tobiasson (1986) describes condensation problems in roofs, and places most of the blame on air leakage, not diffusion. The vinyl vapor retarders, used with batt insulation directly under many metal roofing systems, have a high resistance to vapor diffusion. So, for all but the most humid occupancies in very cold regions, they adequately resist diffusion. However, the methods of folding and stapling or taping the seams between adjacent sheets of this material do not always create a barrier that can adequately resist air leakage. Warm moist air within buildings tends to rise up into the roofing system, and wherever it can find its way around a seam it will.

Newer adhesive and release paper systems for making seals offer promise of improved air leakage resistance.

In buildings with attics and metal roofs, a polyethylene vapor retarder may be placed in the ceiling with batts of relatively inexpensive fibrous glass insulation placed over it. It has been found that such vapor retarders often contain no provisions to prevent air leakage around penetrations such as plumbing vent pipes. Figure 14 shows a typical example. It existed in the hospital in southeastern Alaska shown in Figure 15. In that hospital, enough moisture was being brought up into the cold, well-ventilated attic by air exfiltration from the humidified spaces below to coat the underside of the metal roofing in dew or frost much of the time. Some of that moisture dripped back down into the hospital and caused numerous problems. The humidification system had to be turned off, but even with a reduction in relative humidity from 50 to 30 percent, condensation occasionally occurred on the underside of the metal roof. Measures had to be taken to reduce air exfiltration into the attic.

The situations just discussed point out the importance of attacking air leakage as the primary culprit in condensation problems in metal roofing systems.

In cold regions, some metal roofing systems contain inadequate condensation control features. This is unfortunate since metal is a most unforgiving surface. It cools rapidly at night by radiation to the cold clear sky, often becoming much colder than the outside air. Thus, it is a surface "asking" for condensation. It cannot absorb moisture for short periods, then liberate it gracefully when the peak passes. Instead, the condensate runs downslope to a purlin or other object, where it drips.

The authors have even observed condensation on the underside of metal roofing in large attic spaces in the Midwest during a clear evening after a hot humid *summer* day.

The primary line of defense against condensation in cold weather must be control of air leakage up into the roof. Secondary lines of defense include provisions to reduce diffusion of moisture up into the roof and a provision of cold-side ventilation to remove any moisture that does enter.

In compact membrane roofing systems (picture a conventional bituminous built-up system in your mind's eye), the membrane and its flashings reduce air leakage to near zero, and ventilation is unnecessary. This approach is used for most metal roofing systems, and in many places, it works well. Small amounts of moisture that enter the roof in cold weather may condense on the metal, but are absorbed by the batt insulation pressed against it. In warmer weather that moisture is evaporated, and the vapor finds its way out of the system via the same paths that allowed it to enter. Up to a point, seasonal wetting and drying are not detrimental. However, for some combinations of building moisture and outdoor cold, too much moisture enters and degradation processes begin. If better ways of reducing air leakage and diffusion cannot be devised, it is necessary to aid the drying phase by ventilating the space between the metal roofing and the insulation.

Opening the roof at its eaves and ridge to provide ventilation is often appropriate, but it should be realized that doing this may promote air leakage up into the roof. Thus, there is a risk that ventilation can cause, as well as cure, condensation problems. One way to resolve this dilemma is to switch to a different roofing system for occupancies with a high potential for condensation problems. As an example, a vinyl vapor retarder/fibrous glass batt insulation/standing seam metal roofing system, ventilated or not, is probably not appropriate for a building housing an indoor pool in Minnesota.

For many metal roofing systems in cold regions, ventilation is an appropriate condensation control measure. Ventilation also creates a cold roof, thereby greatly reducing problems associated with ice damming, as previously discussed in the *Ventilation* section. Guidance on the amount of ventilation required for various situations is also mentioned in the *Ventilation* section. It is worth repeating here that it is very difficult to ventilate roofs that have a slope of 2 in./ft. or less.

Since ventilation has two important roles in cold regions (i.e., control of condensation and reduction of ice dams), it is important to configure roofs so that ventilation can be effective. In other words, provide the roofs with as much slope as possible.

SLOPE CONVERSIONS

Many internally drained, low-slope roofs with aged bituminous membranes are being roofed over with metal systems that drain to cold eaves. Some reasons for the popularity of such metal "slope conversions" are as follows:

- The cost and disruption of removing the existing system are avoided.
- The metal system is light, and few structural difficulties are usually encountered. *(Note: It is important to have qualified people assess the load-carrying ability of the existing system and the new system that transmits loads to it).*
- A sloped metal roof may be desired for aesthetic reasons.
- The conversion cost may be less than other alternatives.
- Inexpensive batt insulation can be used to improve the thermal resistance of the roof.

All of the issues discussed previously in this paper apply to metal slope conversions with the implications of changing from internal drainage to over-the-eaves drainage, a particularly important consideration. In addition, one rather important new issue is introduced.

Since the existing roofing system is being replaced, it is likely that the system is experiencing problems. The nature and extent of any problems in the existing system should be determined before any new system is placed on the existing roofing system, which is relied on for support.

A structural assessment should be made and a roof moisture survey, verified with some core cuts, should be conducted to determine if the existing roof contains wet insulation. If elements such as solid moppings of adhesives or a deliberate vapor retarder prevent any wet insulation from drying downward into the building, we expect that the wet insulation will remain in the roof for many years, even if the old membrane is slashed with an axe or breather vents are installed. To prevent premature deterioration, we feel that wet insulation should be removed from most roofs before any new system is placed on it (Tobiasson, 1989b).

However, many metal slope conversions are being placed over roofs that contain wet insulation.

SUMMARY

Standing seams that are out of the "flood plain" and sliding clips that allow metal panels to expand and contract thermally have significantly improved the performance of metal roofing systems. Sliding clips are particularly important in cold regions, where diurnal and seasonal temperature variations can be very large.

By fixing the metal panels to the frame only at the eaves, differential movements do not occur at that vulnerable location where all water drains, snow and ice may slide and ice dams may form. It is also difficult to seal the lower ends of the standing seams. Since metal roofs are sloped to drain, a few imperfections at joints usually do not cause problems, since they are subjected to hydrostatic pressure for short periods only. However, when water ponds on metal roofs behind icicles and ice dams, the risk of leaks increases greatly.

Such risks can be reduced by using "waterproof" (not "water shedding") systems, by minimizing the number of valleys, by increasing the slope, by reducing the overhang at the eaves, by increasing the amount of roof or attic insulation and by ventilating between that insulation and the metal to create a "cold" roof. It is difficult to properly ventilate a metal roof with a slope of 2 in./ft. or less. This is incentive to use greater slopes in cold regions.

Small, infrequent ice dams along the eaves of "cold" metal roofs seldom create problems. When large dams develop at the eaves, it may be necessary to install electric heaters. The tendency for snow and ice to slide off slippery metal roofs complicates the installation of electric heating cables and may create hazards. Snow guards are needed on some metal roofs to prevent snow and ice from sliding.

Most metal roofing systems are not ventilated, but, in cold regions, ventilation may be needed to reduce the risk of condensation problems and ice damming. Special precautions must be taken to control condensation if metal roofing systems are to be used above high-humidity spaces in cold regions. Other roofing systems may be more appropriate in such cases.

Standing seam metal roofs are well suited to some applications in cold regions but not to others. When they are used inappropriately, chronic problems are likely that are very difficult and expensive to resolve.

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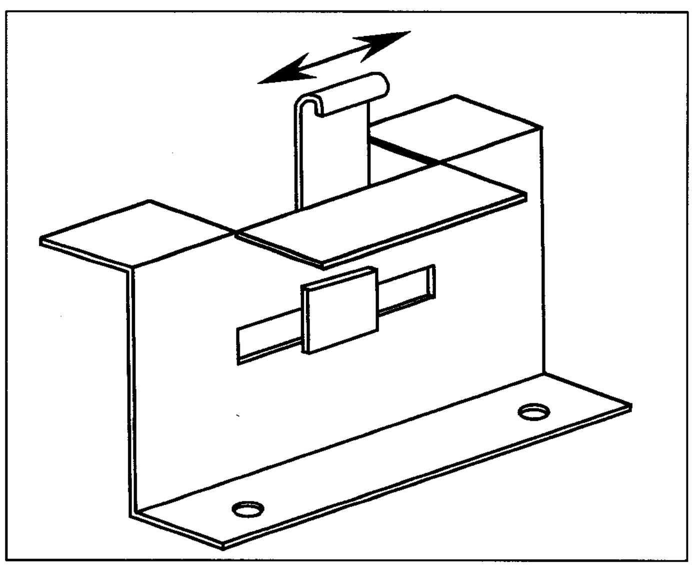


Figure 1 *The sliding clip principle.*

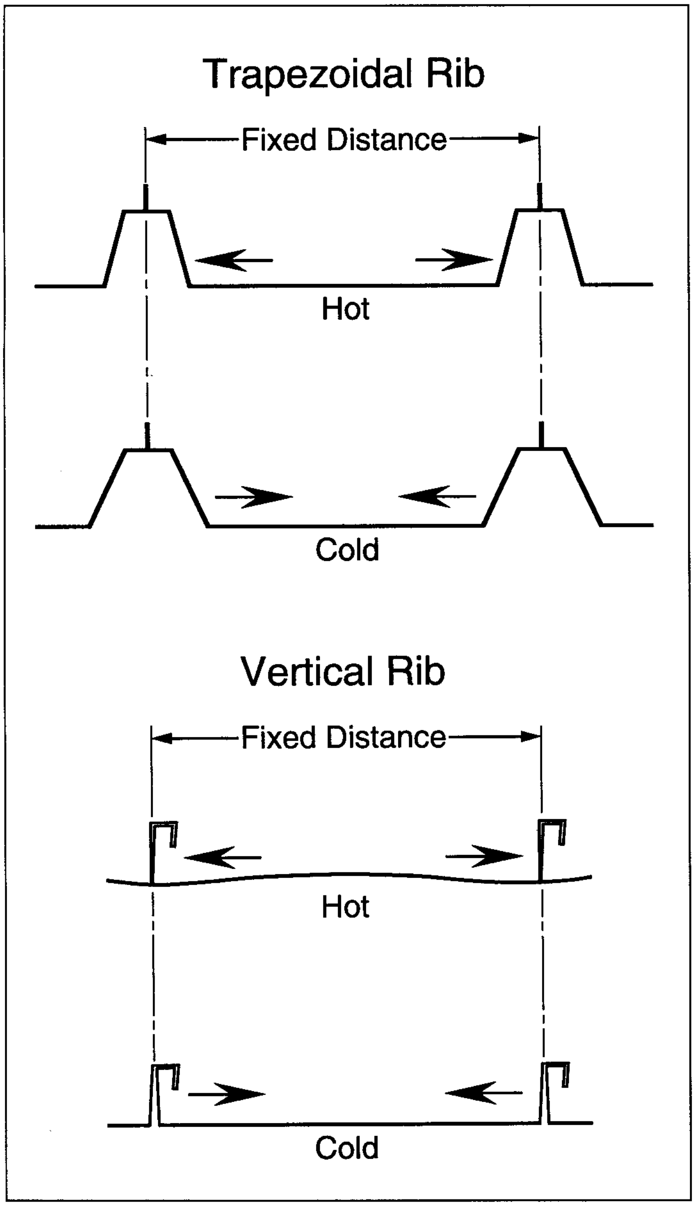


Figure 2 *Typical panel cross sections showing how transverse movements are accommodated not accumulated.*

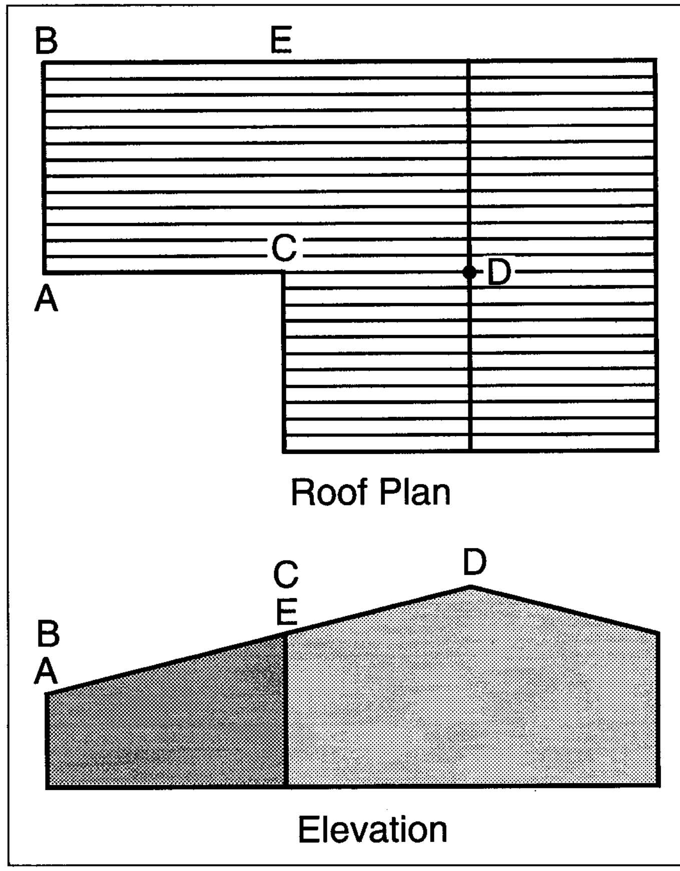


Figure 3 *A jog in the eaves complicates things.*

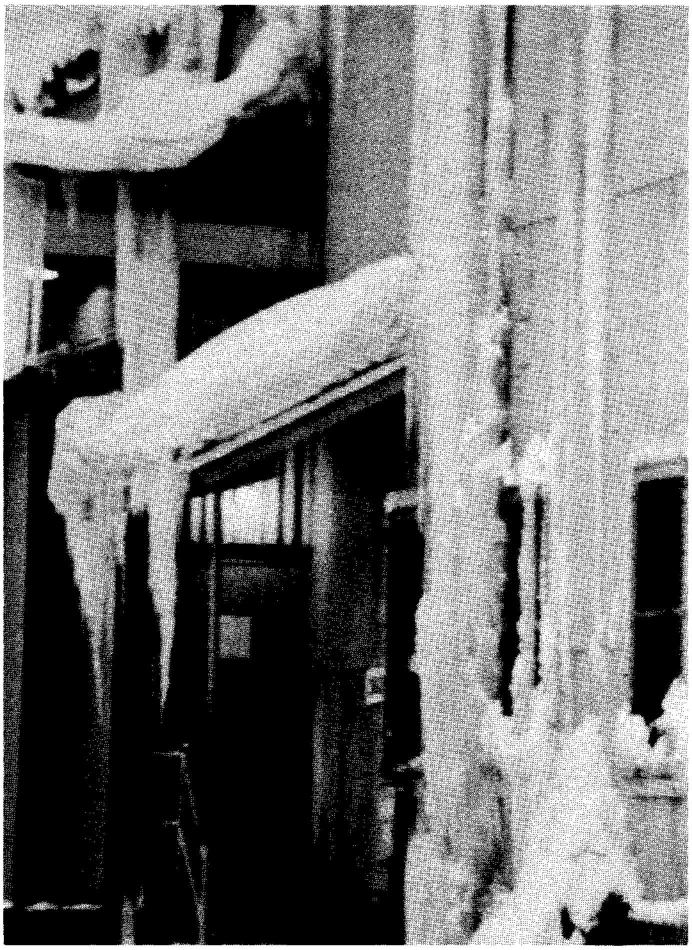


Figure 4 Ice dams and wall icings on a poorly insulated building in Fairbanks, Alaska, with a hot metal roof.

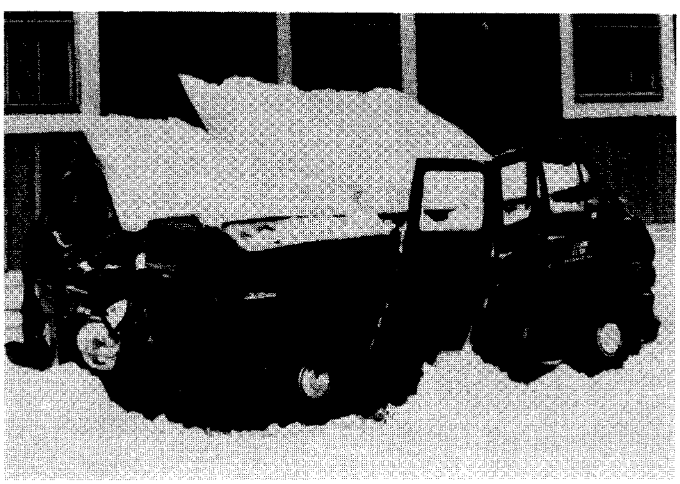


Figure 5 Van crushed by ice from a roof.

Figure 6 Sidewalk in Anchorage, Alaska, that had to be cleared of ice frequently. The source of that ice was meltwater from the unventilated, hot roof of the adjacent building.

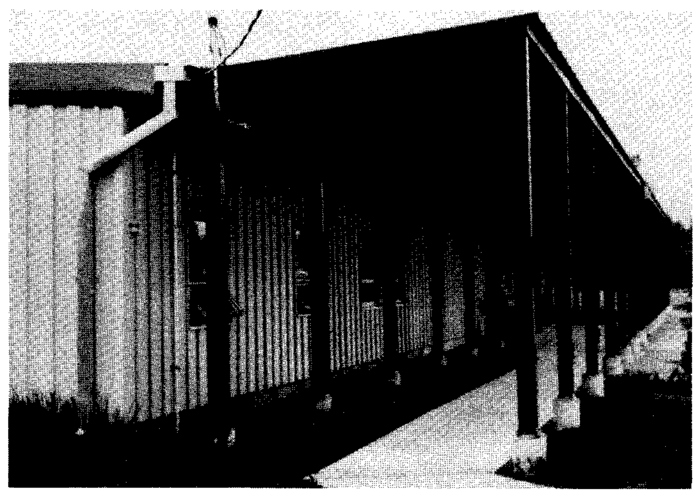


Figure 7 Shed installed to eliminate the icing problem shown in Figure 6.

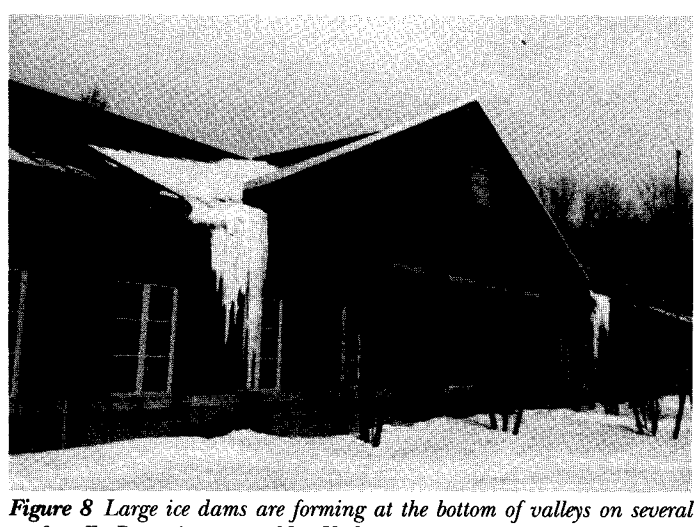


Figure 8 Large ice dams are forming at the bottom of valleys on several roofs at Ft. Drum in upstate New York.

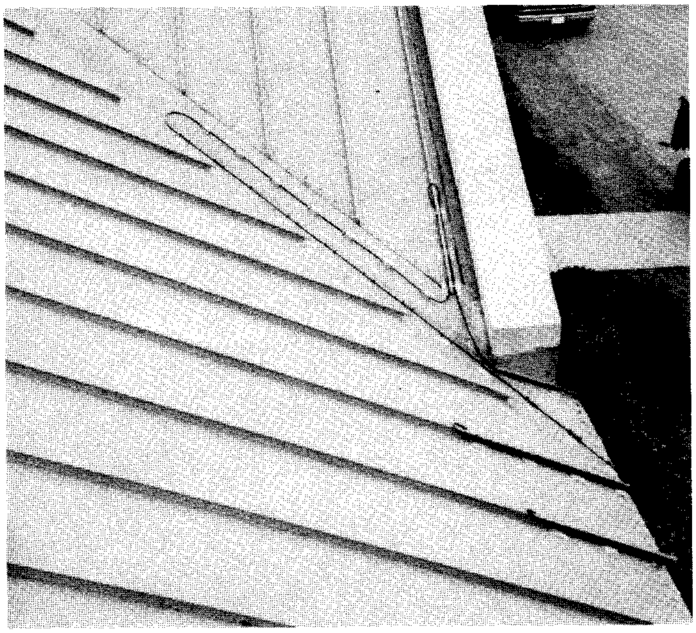


Figure 9 *One of several heating cable systems being evaluated at Ft. Drum.*

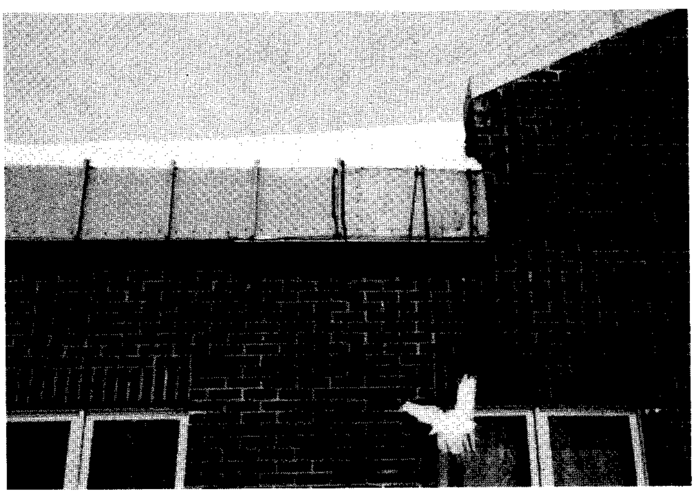


Figure 10 *Some of the heating cable systems installed at Ft. Drum were damaged by moving ice and snow.*

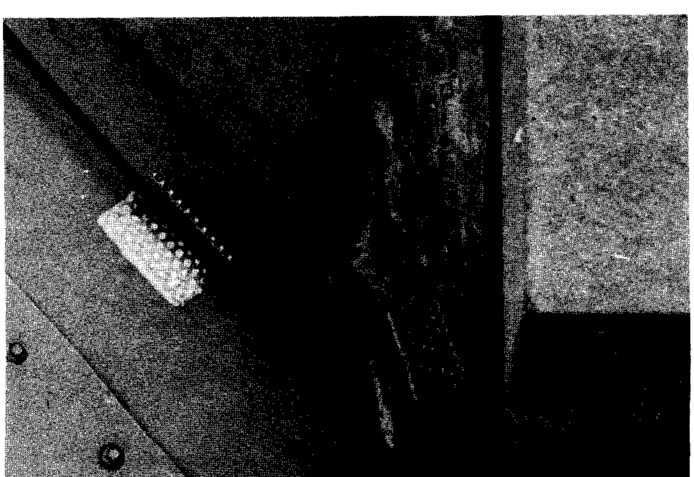
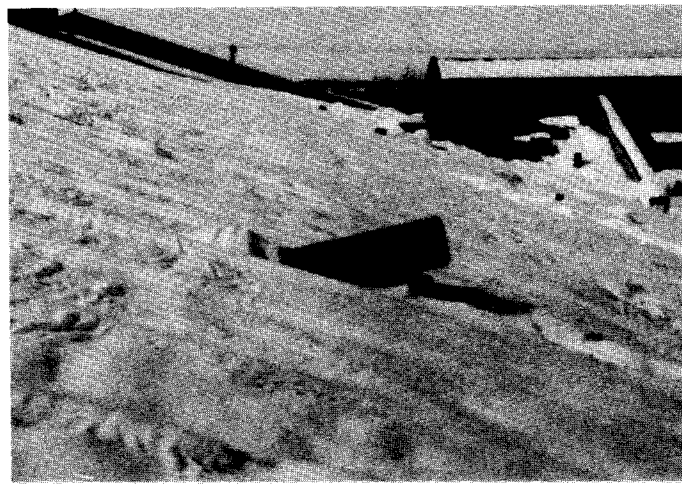
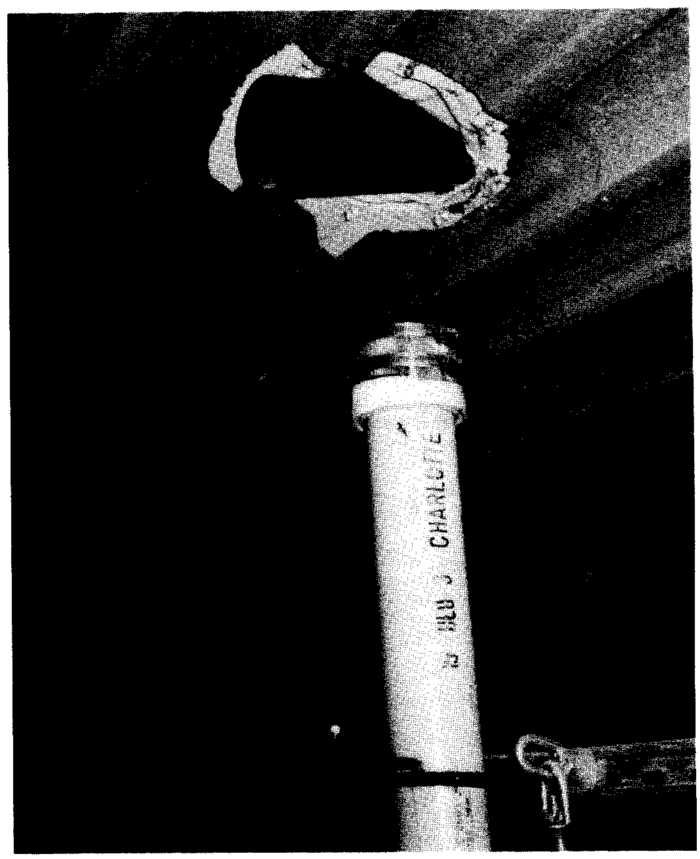


Figure 11 *Perforated stainless steel clips attached with special non-acid-catalyzed silicone sealant survived the winter.*



Exterior View



Interior View

Figure 12 *Plumbing vent sheared off by sliding snow.*

Figure 13 A small obstruction on a roof can hold back a wedge of snow.

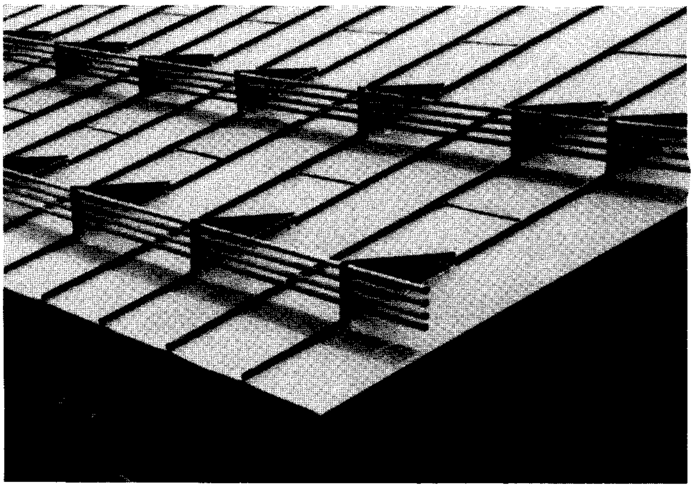


Figure 14 Snow guards on metal roofs in Stowe, Vt.

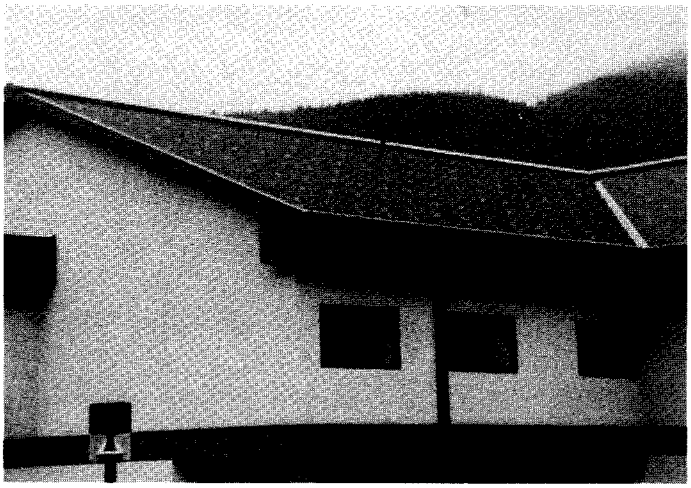


Figure 15 Plastic snow guards on a roof in southeastern Alaska.

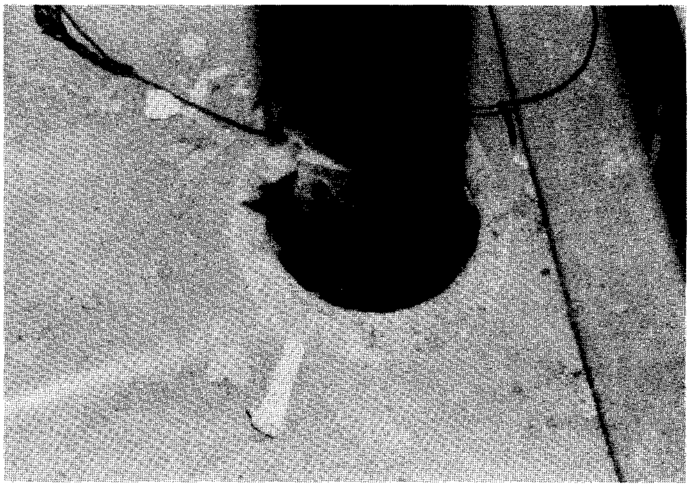


Figure 16 Unsealed polyethylene vapor retarder in a ceiling at a pipe penetration.