Attic Ventilation Guidelines to Minimize Icings at Eaves

By Wayne Tobiasson, James Buska and Alan Greatorex

ABSTRACT

IN COLD REGIONS, ICICLES AND ICE DAMS may develop on roofs that slope to cold eaves. Ventilating the space below the snow-covered roof with outdoor air to create a "cold" ventilated roof is often an effective way to avoid such problems. Several buildings in northern New York were instrumented to determine how their attic temperature influenced icing. We observed that problematic icings developed very slowly, if at all, when the outside temperature was above 22°F. Such icings can be avoided by sizing natural, and if necessary, mechanical attic ventilation systems to maintain an attic temperature of 30°F when the outside temperature is 22°F.

Introduction

Icicles and ice dams form at the eaves of some roofs in cold regions. Water that ponds behind ice dams may leak into the building since most steep roofs are configured to shed water, not hold back standing water.

Figure 1 shows two roofs located near Watertown, NY. The two photos of identically constructed buildings were taken within minutes of each other. One roof contains large ice dams and icicles, but the other is ice free. Why? The snow on top of the chimney of one roof is the clue to the difference in behavior. That building was not being heated, while the other building was at room temperature.

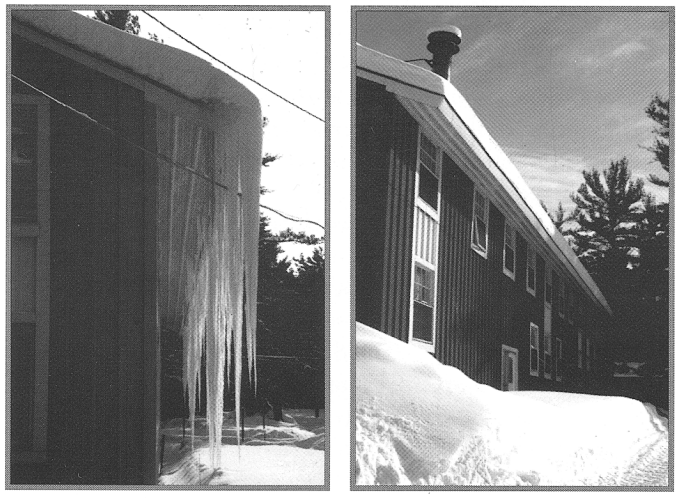

Figure 1: Two identically-constructed roofs photographed at the same time. The building on the right, with no icings, was unheated.

This example is used to illustrate that building heat, not the sun, is the primary cause of ice dams and icicles on roofs. When the sun melts snow on roofs, it also warms the eaves, and this tends to minimize the growth of icicles. Certainly, some icicles can form on unheated buildings and from solar heating, but they are usually small, infrequent, and do not cause chronic problems.

Pioneering work on ice dams[1], done in 1976, concluded that a combination of insulation, ventilation and correct house design is needed to reduce ice dam formation. More recent studies[2-4] also promote use of cold ventilated roofing systems to reduce icings at eaves. These studies also indicate that icings can be reduced by increasing the slope of the roof, by making the surface slippery so that snow slides off, by not installing gutters, and by reducing the overhang at the eaves. However, on roofs without gutters, too small an overhang can cause wetting of the walls below or formation of icings on them. A 12-in. overhang is often a good compromise in cold regions. Also, allowing snow to slide off roofs can create hazards.[2] Snow guards may be needed to hold snow on slippery roofs.[5]

Problems in Upstate New York

A few years ago, many buildings were built at Fort Drum near Watertown, NY. All these buildings have standing seam metal roofing systems above ventilated attics. Standing seam metal roofing systems have both strengths and weaknesses when used in cold regions[6]. Some of these roofs have remained clear of icicles and ice dams (*Figure 2*). Several have experienced some problematic icicles and ice dams (*Figure 3*)

and others have experienced severe icicles and ice damming (*Figure 4*). The range in performance is related to the ability of each building's attic ventilation system to remove heat that enters the attic from the warm building below and heat produced by HVAC equipment located in the attic.

Figure 2: Some creep of snow and cornicing is evident, but no icings occurred on this roof.

Figure 3: Minor icings occurred along the eaves of this roof and problematic icings developed at the base of valleys.

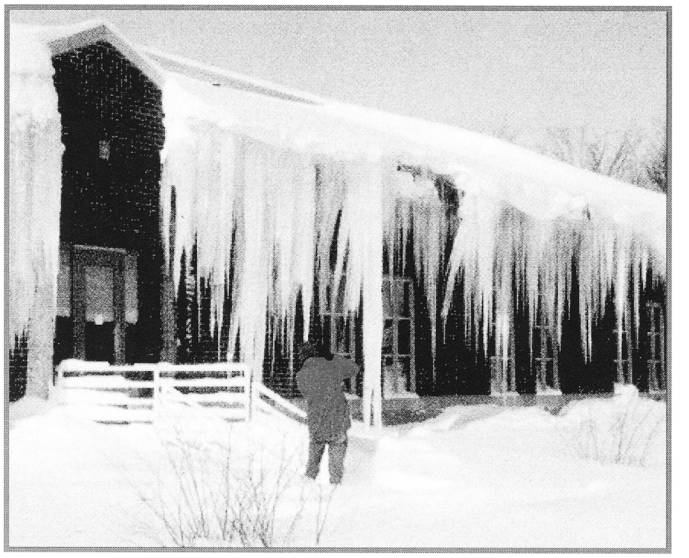

Figure 4: Severe, problematic icings developed all along the eaves of this dining facility.

We have developed recommendations for solving these specific problems and have attempted to better understand how and when icicles and ice dams form. During our first winter of study (1990-'91), four buildings were monitored to study a range of icing problems from "some" to severe. By "some," we mean that minor icings have occurred along the eaves and large, problematic icings have developed at some locations such as the base of valleys, as shown in *Figure 3*. A nearby building not experiencing icing problems was also monitored as a control. This paper describes those findings and uses them to develop ventilation guidelines to minimize icings at roof eaves. We also monitored these buildings after they received attic ventilation improvements. Those readings verified that our guidelines are effective.

Initial Measurements

Outside air temperature was measured in a small weather shelter in the vicinity of these buildings. Attic air temperature was measured near the middle of each attic. All temperatures were measured with thermistors. Temperature measurements were taken once an hour from Nov. 1, 1990 to April 10, 1991. Battery-operated data collection systems stored the data between our periodic visits to Fort Drum. An engineer at Fort Drum periodically photographed these buildings for us.

Findings

Observations of these buildings and others indicated that problematic icings seldom grew when the outside temperature was above 22°F.

Plots of attic air temperature vs. outside air temperature are presented in *Figures 5*, *6*, and *7* for buildings experiencing no icing problems, "some" icing problems and severe icing problems, respectively. *Figure 6* is representative of two other buildings that also experienced "some" icing problems. The least-squares equation of best fit and its correlation coefficient (r^2) are presented on each figure. Horizontal and vertical lines, representing, respectively, an attic air temperature of 30°F and an outside air temperature of 22°F are also presented on each figure. The portion of each graph to the right of the vertical 22°F line is warmer than conditions observed to create icings. The portion of each graph below the 30°F horizontal line is also not within the "icing envelope" because the attic is then so cold that snow on the roof is not melted by building heat.

We chose 30°F for the horizontal line instead of 32°F since we expect that there were places in the attics that were somewhat warmer than the places where our thermistors were located.

Of the four quadrants created in *Figures 5-7* by the 22°F vertical line and the 30°F horizontal line, the upper left quadrant defines the problem area (i.e., the "icing envelope").

For the roof with no icing problems (*Figure 5*), very few data points fall within the icing envelope, as expected. For the roof with "some" icing problems (*Figure 6*), about 6% of the observations fall within the "icing envelope." For the roof with

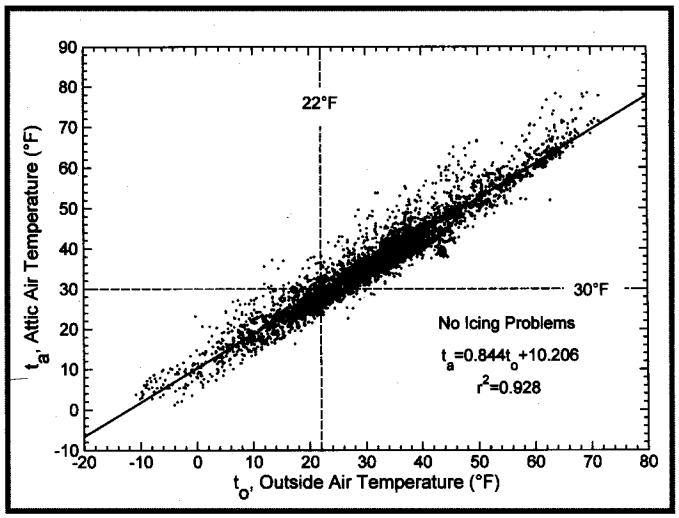

Figure 5: Attic temperature vs. outside air temperature for a roof experiencing no icing problems.

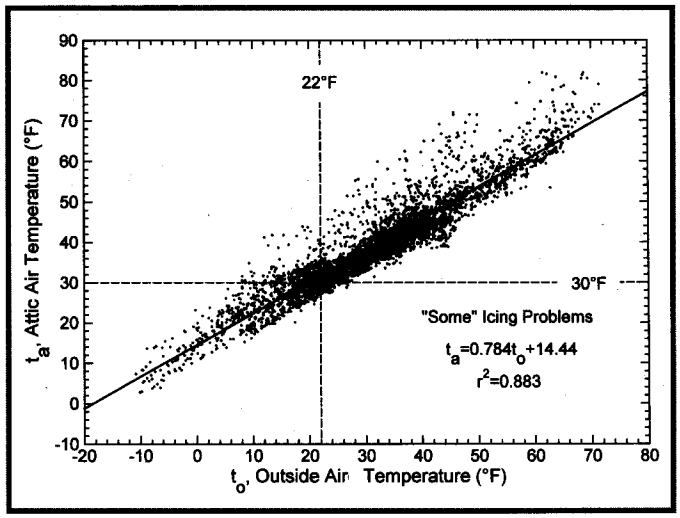

Figure 6: Attic temperature vs. outside air temperature for a roof experiencing "some" icing problems.

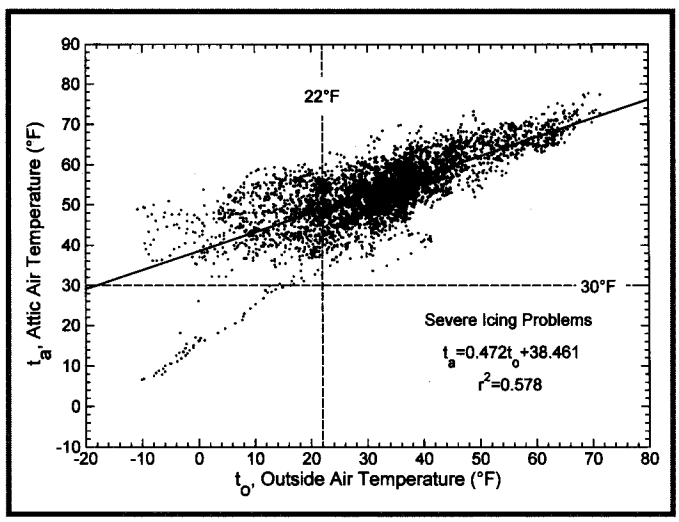

Figure 7: Attic temperature vs. outside air temperature for a roof experiencing severe icing problems.

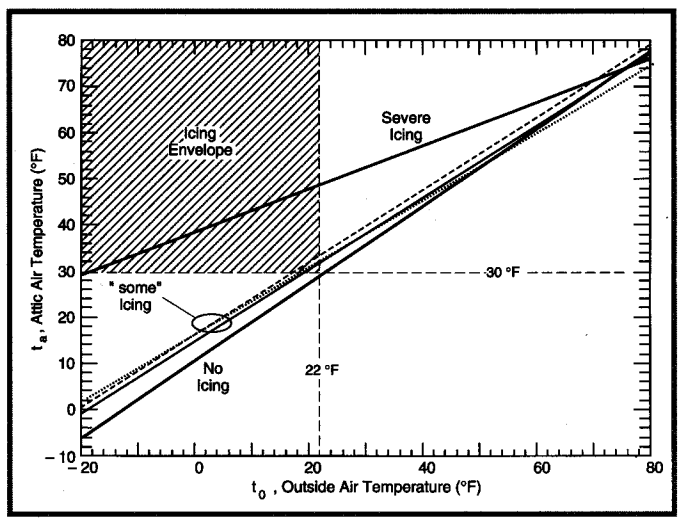

Figure 8: Lines of best fit for the three roofs shown in Figures 5-7, along with similar lines (dashed) for two other roofs also having "some" icing problems.

severe icing problems (*Figure 7*), 23% of the data (i.e., 23% of the time during the winter) falls within the "icing envelope."

The separate line of points in *Figure 7* that runs down toward the lower left corner of the graph represents a 5-day period when the heating system of that building was off due to mechanical problems. Those points provide further evidence that building heat is the primary source of icing problems since, once cool, that building performed out of the "icing envelope."

The lines of best fit for these three roofs are shown together as solid lines on *Figure 8* along with similar lines, (shown dashed), for the other buildings we monitored that also had "some" icing problems. This information suggests that icings can be avoided by sizing attic ventilation systems to maintain an attic temperature of 30°F when the outside temperature is 22°F.

Calculations

With knowledge of the thermal resistance of the ceiling and the indoor and attic temperatures, the conductive heat losses from a heated building into its attic can be determined. To this can be added any heat introduced to the attic by HVAC equipment and any ducting located there. If the assumption is made that during the design condition, the roof is covered with an insulating blanket of snow that reduces conductive heat losses from the attic to near zero, then all the heat in the attic must be removed by ventilating air.

The following equation applies[7]:

$$Q = 51.4H/(t_a - t_o)$$

where Q = airflow rate required to remove heat (cfm), H = heat to be removed (BTU/min), t_a = attic temperature (°F)

and t_o = outside temperature (°F). This equation uses a specific heat of 0.24 BTU/lb °F and a density of 0.081 lb/ft^3 for 30°F air.

When attic air and outside air temperatures of 30°F and 22°F respectively are used, the above equation reduces to:

$$Q = 6.43H$$

If this airflow is to be provided by natural stack effect with cold air entering the attic all along its eaves and exhausting all along its ridge, the flow rate created when the attic has nearly equal intake and exhaust openings[7] is as follows:

$$Q = 221.3A[\Delta b(t_a - t_o)/(t_a + 460)]^{0.5}$$

where Q = stack-induced flow (cfm), A = free area of inlet openings (ft^2), Δb = height difference between inlet and exhaust openings (ft), t_a = attic temperature (°F) and t_o = outside temperature (°F). This equation uses a discharge coefficient for the openings of 0.65, and a gravitational constant of 32.2 ft/s^2. If the inlet and outlet areas are not about equal, a correction must be applied.[7]

When attic air and outside air temperatures of 30°F and 22°F respectively are used, the last equation reduces to:

$$Q = 28.3A\ \Delta b^{0.5}$$

To determine the free area of inlets needed to cool an attic enough by natural, stack-induced ventilation, the second and fourth equations are equated. Then,

$$A = 0.227H/\Delta b^{0.5}$$

The coefficients in the above equations changed slightly from those in previous versions of this paper.[8] The free area of inlet openings (A) is about 8 percent less since this report uses a density of 0.081 lb/ft^3 for 30°F air instead of the standard air density of 0.075 lb/ft^3 that we used in our previous reports. Note that the free area of inlet openings (A) is in square feet. Multiply by 144 to get it in square inches. If the required inlet and outlet areas can be provided so as to ventilate the entire attic, natural ventilation will suffice to keep the attic cool enough to prevent icings. If the required inlet and outlet areas cannot be provided, mechanical ventilation will also be needed.

A design firm used our calculations to develop recommendations for attic ventilation improvements for several buildings at Fort Drum. Those improvements were made in 1993 on four of the buildings we had been studying. We continued to monitor these buildings to determine the effect of the modifications.

The attic described by *Figure 7* had experienced severe icing problems. However, it needed help in the form of improved natural ventilation or mechanical ventilation for less than 23% of the winter. We were not able to provide enough inlet area to completely solve this attic's icing problems using only natural ventilation. Thus, several large fans were installed near the ridge as shown in *Figure 9*. The fans were not dampered. This allows the fan openings to serve as outlets for natural ventilation, thereby reducing the amount of time that mechanical ventilation is needed.

The fans are thermostatically controlled, since they are needed infrequently. They operate only when the attic temperature is above 30°F and the outside temperature is below 22°F. We installed instrumentation to monitor when the fans are used. During the winter of 1995-'96, these fans were used only 20% of the time.

Figure 10 compares the modified building to a similar unmodified building for the period Nov. 15, 1993 to Feb. 23, 1994. Both buildings were having similar severe icing problems before one was modified. The portion of each data set to the right of the 22°F outside air temperature line in *Figure 10* relates to natural ventilation since the fans cannot operate when it is warmer than 22°F outside. The dramatic difference in that portion of the two data sets indicates that natural ventilation has been improved significantly. We expect that much of this improvement would not have been achieved if the fans contained louvers that were opened only when the fans were on.

The "hunk" taken out of the data set for the building with improved attic ventilation reflects the contribution of the mechanical ventilation system. The mechanical system has been able to keep that attic out of the "icing envelope" most of the time. Without mechanical ventilation, it appears that the attic would have operated within the icing envelope for a significant amount of time with problematic icings expected. This verified our feeling that natural ventilation alone would not solve the icing problems being experienced by some of these buildings.

Figure 11 shows the two buildings just discussed on the same date (Jan. 12, 1994). The unmodified building is subjected to severe icings all along its eaves. There are only a few small icicles at the base of the valleys of the building with improved attic ventilation. All other irregularities along the eaves of that roof are snow cornices, not icicles.

Seven large fans were installed to mechanically ventilate this attic. Each one consumes about one kilowatt of power. Using the calculations discussed in this paper, four such fans would be enough to do the job but the designers used seven fans. To determine if only four fans would suffice, on Feb. 23, 1994, we had three of the fans turned off and blocked with sheet metal to preclude both mechanical and natural ventilation through them.

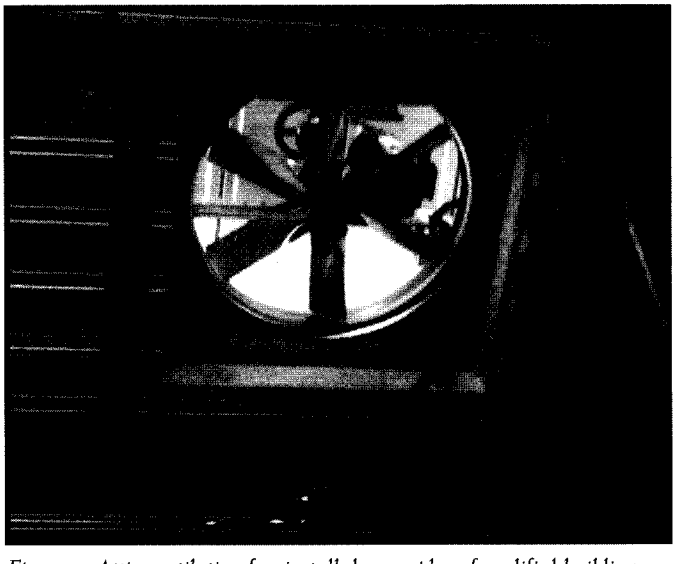

Figure 9: Attic ventilation fan installed near ridge of modified building.

The natural ventilation portion of the data for openings provided by four fans did not change noticeably from that when openings were provided by seven fans. When mechanical ventilation was needed, the four fans kept the attic out of the "icing envelope" almost as well as the seven fans did. No large icings formed on the modified building with only four of the seven fans working. These findings convinced us that the design approach presented in this paper can be used to size natural and mechanical ventilation systems for solving icing problems. We ultimately recommended using five fans on this facility in order to have some redundancy in case of operational problems with any of the fans.

Using the test results from the four buildings modified in 1993, we worked with the Fort Drum Directorate of Engineering and Housing to design attic ventilation improvements for the remaining 53 buildings. Attic ventilation modifications were completed on all those buildings during the summer of 1995. The winter of 1995-96 provided plenty of snow and cold weather to adequately test the modifications.

There were no reports of problematic ice dams or icings on any of the modified buildings. By changing these roofs from hot, poorly-ventilated systems to cold, well-ventilated systems, the meltwater that formed problematic icings at the eaves was not generated in cold weather.

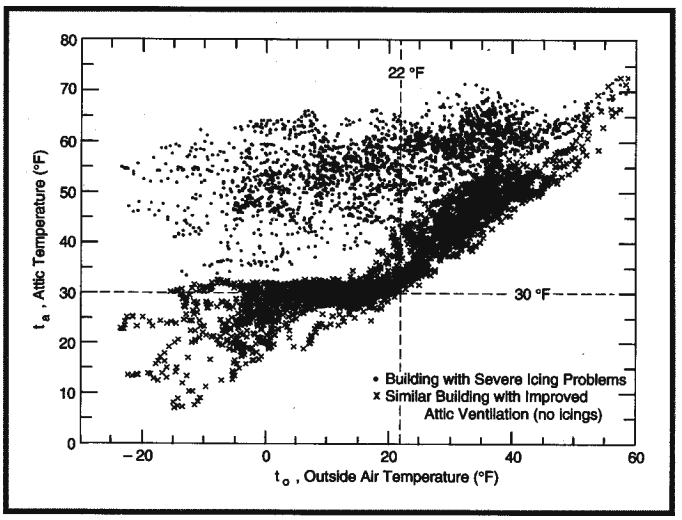

Figure 10: Attic temperature vs. outside air temperature for a building with severe icing problems and a similar building with improved attic ventilation experiencing no icing problems.

Summary

We determined appropriate design temperatures of attic ventilation systems to minimize icing problems by monitoring several buildings in northern New York, all but one of which were experiencing icing problems.

Problematic icings appear to develop very slowly, if at all, when the outside temperature is above 22°F. We feel that, owing to variations in temperature within an attic, design should be based on an attic temperature of 30°F.

Thus we recommend that, to eliminate icing problems, attic ventilation systems be sized to maintain an attic temperature of 30°F when the outside temperature is 22°F.

Fifty-seven buildings experiencing icings were modified using these guidelines to improve attic ventilation. Severe icings did not form on them after they were modified. Instrumentation installed to monitor their performance has validated our design approach.

Properly designed attic ventilation systems that create cold ventilated roofs avoid the many problems associated with ice dams and icicles along roof eaves.

Our research was conducted on relatively large buildings. Other work we have done using the same design approach indicates that icing problems on most smaller residential buildings can be solved by providing or improving on natural ventilation (mechanical ventilation is usually not needed). In homes it is important to ensure that the natural ventilation provided to cool the roof is not somehow blocked. Also, heating and ventilating ducts that pass through the attic should be well sealed and insulated and the heat they add to the attic should be considered when sizing the ventilation system. Finally, good insulation and continuous air barriers between the living space and the attic are essential so as to minimize the passage of heat and warm air into the attic. In cold regions, vapor retarders are often necessary to reduce moisture migration. The ventilation provided to minimize icings also serves as a second line of defense against accumulation of moisture in attics.

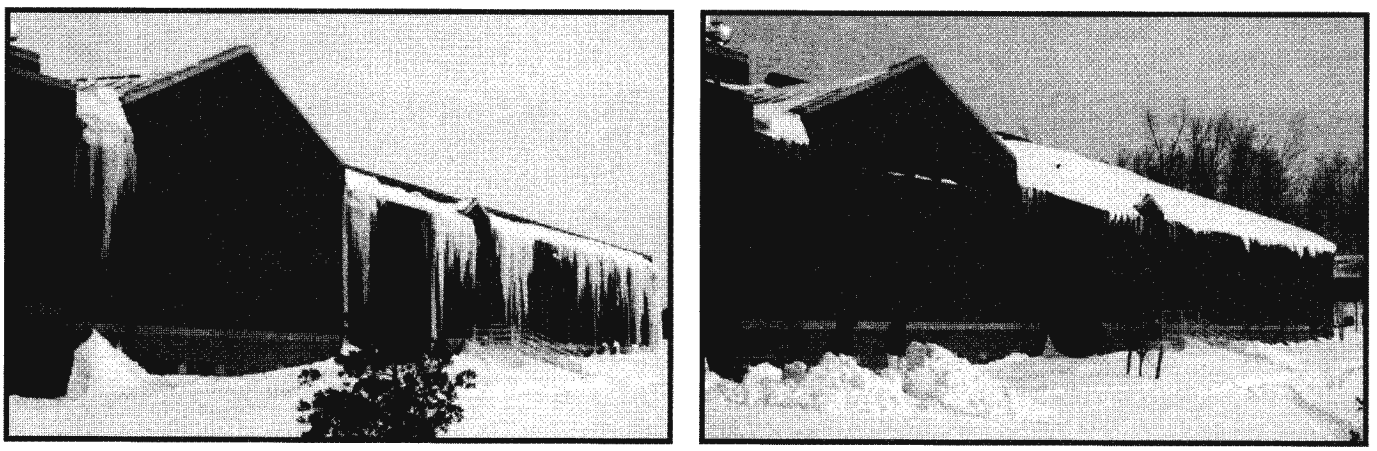

Figure 11: Both buildings from Figure 10 photographed at the same time. The unmodified building shown at the left was experiencing severe icings. The other building with improved attic ventilation had no icing problems.

Acknowledgements

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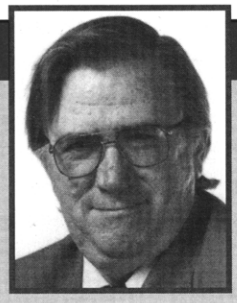

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