An Ice Dam Analyzed

An engineer's report shows that in snow country, soffit-to-ridge venting is typically the most practical way to prevent ice dams in cathedral ceiling assemblies

Figure 1. Ice dams on this new home in Michigan's Upper Peninsula formed above interior cathedral ceilings, which were insulated with low-density open-cell spray foam and were unvented. The roof sections with no ice are above unheated areas of the home.

by Jeffrey Hoffman, P.E.

I am a partner in a small mechanical engineering firm in Michigan's Upper Peninsula. We provide preconstruction design services and investigate design failures in existing buildings. In the case shown here, I was called in the fall of 2007 to investigate some large ice dams that had formed on the snow-covered roof of a new home in Toivola, Mich., the winter before (**see Figure 1**). Construction of the house was completed in the fall of 2005, and the owner moved in soon after. By January 2006, substantial ice buildups were occurring along most of the roof edges, causing severe leaks inside as water from melted snow backed up behind the ice and made its way under the asphalt roofing shingles. The flooding was so bad the local building official asked the owner's family to move out until repairs were completed or the leaks subsided. The homeowner, thinking he needed a new roof, sued the builder, who called me to get to the bottom of the problem.

I learned from the builder that the original plans for the house had called for a conventionally vented roof, with the usual ridge and soffit vents. According to the plans, there were to be insulation baffles between the 2x10 rafters to provide a vent space, with fiberglass insulation, a vapor retarder, and a cathedral ceiling below. However, during construction the plans changed: After talking with the insulation subcontractor, the homeowner decided to instead install a common low-density open-cell spray foam directly against the roof sheathing. The insulation contractor claimed that no vent space was necessary. The homeowner liked this option because, according to the insulation contractor, it would speed up the construction schedule.

I focused my investigation of the ice dams on three areas: the design of the roof, including the unvented cathedral ceiling; the performance of the spray-foam insulation; and the effect that a blanket of snow on top of the roof would have. What I discovered was that the unvented cathedral ceiling coupled with the heavy snowfall during the winter in question were the main factors causing the snow on the roof to melt and create ice dams.

Measuring Insulation Performance

I first visited the home in November 2007, ten months after the ice damming shown here. On the day I visited, there was no snow on the roof, which provided the ideal conditions for monitoring its thermal performance. Using a Flir Systems B400 infrared camera, I recorded thermal images of the pertinent roof surfaces. I also took ambient air temperature readings and measured surface temperatures at key locations inside and outside the house. Using this information, I was able to estimate the thermal conductivity of the foam insulation, as well as the overall effectiveness of the insulated roof.

Insulation R-value. To measure the insulation's R-value, I used an exterior garage wall. Like the roof, it was insulated with spray foam, and it provided easily accessible surfaces for taking temperature readings on both sides (**Figure 2**).

I then used heat transfer equations to calculate the R-value of the insulation in the garage wall, which I determined to be 3.2 per inch, with an uncertainty of ±0.45. My result was slightly less than the foam manufacturer's published value of 3.6 per inch, but given the uncertainty, I concluded that the insulation itself was not defective and was performing satisfactorily.

Assessing the Overall Roof

The homeowner reported that ice dams had formed along all the roof edges and had several photographs to prove it. The photographs, taken in January 2006, also showed sections of roof that had no icicles. The areas without ice were all above unheated sections of the home, which suggested that in this situation the icicles were caused not by solar heat or above-freezing outside air temperatures but by heat transfer from within the structure.

I made a number of thermal images of the roof sections that had experienced icing. The infrared photos showed that the roof surface temperatures were uniform within 3 or 4°F (**Figure 3, page 4**). This suggests that the roof was uniformly insulated, with no major voids, and that the melting was not the result of local hot spots but was a surface phenomenon.

Using the building geometry and the estimated R-value for the insulation as calculated based on the garage wall, I

Temperature Readings

Time	Location	Comments: Data
11:11 pm	North Lawn	Air temperature: 36°F, calm wind, clear skies
11:20 pm	Inside Garage	Air temperature: 52°F
	Inside Garage	West wall surface temperature: 53.9°F, roughly 5 feet above floor
	Inside Garage	South wall surface temperature: 55.2°F, roughly 5 feet above floor
	Inside Garage	South wall surface temperature: 54.5°F, roughly 5 feet above floor
	Inside Garage	South wall insulation thickness 2.75–3.5 inches
11:30 pm	Outside Garage	West wall surface temperature: 27°F, roughly 5 feet above floor
	Outside Garage	South wall surface temperature: 28°F, roughly 5 feet above floor
11:40 pm	Inside Main House	Main floor air temperature: 75.2°F
	Inside Main House	2nd floor air temperature: 75°F
	Inside Main House	Master bedroom air temperature: 74.2°F
12:00 pm	North Lawn	Air temperature: 35°F, calm wind, clear skies

Figure 2. By taking surface and air temperature readings on both sides of the foam-insulated garage walls, the author was able to estimate the R-value of the insulation in that location and — by extrapolation — in the cathedral ceiling.

estimated the overall effective R-value of the roof to be 30, ±4. While this is slightly lower than the Michigan code requirement of R-38, it's worth noting that lack of insulation did not alone account for the ice dams, as I'll show later.

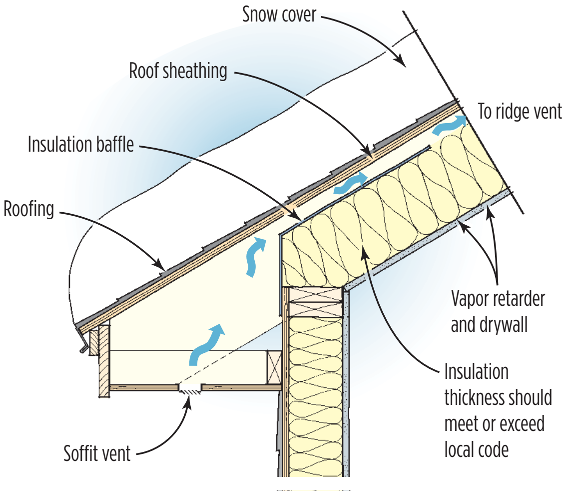
What Conditions Cause the Snow To Melt?

Next, I created a heat transfer model to predict the roof's tendency to melt snow. I had to consider not only the roof's thermal resistance but also the insulating effects of the blanket of snow on top. I wanted to figure out what outside air temperature and snow depth would cause sufficient snow to melt to create the ice dams.

I used a common winter scenario for the area, assuming light wind, cloud cover (no solar loading), an uncompressed snow layer, and an inside temperature of 74°F. Based on those assumptions, I modeled the roof's heat transfer behavior as a function of ambient outside temperature and the thickness of the snow cover. I was specifically interested in pinpointing the conditions in which the roof surface — the interface between the snow and the cathedral ceiling assembly — would have a temperature of 32°F. With an interface temperature equal to the melting temperature of snow, I could assume that melting would take place and that the liquid water would run down to the colder eaves, where freezing — and ice dams — would occur. (Note that for simplicity I ignored solar loading in this model: It's uncommon in the area during winter, and white snow reflects most of the solar radiation.)

The results of the model are summarized in (**Figure 4, page 4**). The graph shows that the existing roof assembly would in fact melt snow, given my assumed indoor and outdoor conditions, which are common in Toivola during the winter. For example, with 4 inches of snow

Vented vs. Unvented Roofs

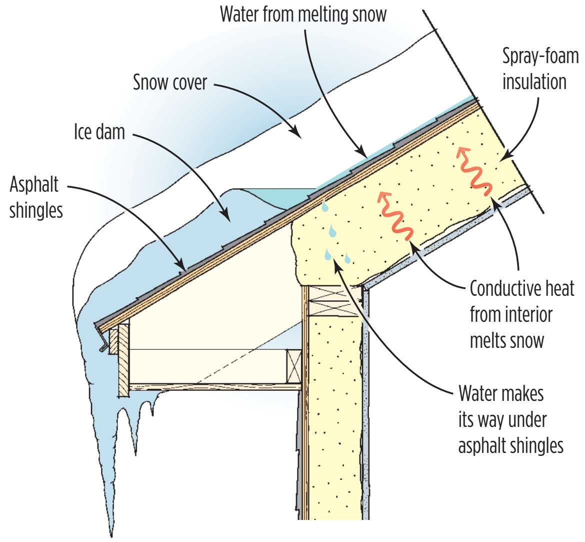


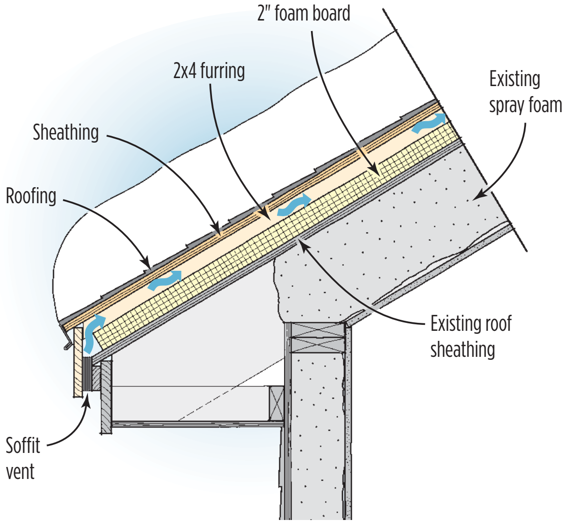
Conventional Vented Roof

A conventional vented roof slows the melting of the winter snow cover by keeping the sheathing at the outside temperature.

Unvented Roof

An unvented cathedral ceiling, like the one shown in this article, may cause ice dams as heat from inside the house warms the roof surface.





Proposed Solution

One fix for an unvented cathedral roof with icing problems is to retrofit a built-up vented assembly. Adding rigid foam insulation increases R-value and slows conductive heat loss through framing members.

Building		Location Description	Front - Loft	Survey Date	11/13/2007	Report Date	12/1/2007

FLIR SYSTEMS	Camera	ThermaCAM B400	Lens	FOL18

General Information	
Thermographer	Douglas Fox
Image Date	11/13/2007
Image Name	IR_002 Loft.jpg
Emissivity	0.096
Image Time	12:39AM

Label	#	Temp	Comment
Cross Hair	1	20.1	Middle
Cross Hair	2	22.2	Middle
Cross Hair	3	24.3	Middle

Building		Location Description	Back - Bedroom	Survey Date	11/13/2007	Report Date	12/1/2007

Comments

FLIR SYSTEMS	Camera	ThermaCAM B400	Lens	FOL18

General Information	
Thermographer	Douglas Fox
Image Date	11/13/2007
Image Name	IR_007 Bed Room.jpg
Emissivity	0.096
Image Time	12:29AM

Label	#	Temp	Comment
Cross Hair	1	17.5	Top 1/3 of Roof
Cross Hair	2	19.7	Top 1/3 of Roof
Cross Hair	3	20.4	Top 1/3 of Roof

Page 7 of 8 Garage & Back Bedroom Images

Figure 3. Infrared images of the areas that had experienced severe icing the previous winter showed that temperature variations across the surface were within a few degrees of each other, indicating that the roof assembly was uniformly insulated and not subject to "hot spots" that could have caused localized melting.

on the roof, melting would occur when the outside temperature climbed above 10°F. The eaves would of course be at the outside ambient temperature, and the liquid water running down the roof surface would refreeze before dripping from the edge, generating ice dams.

By contrast, if the roof had been properly vented so that the underside of the sheathing remained at the outside temperature, the roof would theoretically generate ice dams only when it was exactly 32°F outside. When it was warmer outside, the snow would still melt, but the water would drip from the roof edge because the eaves would also be above freezing.

Comparing With Actual Weather Data

Now that I had the model, the final step was to compare its predictions with the actual weather data from the period when the ice dams occurred. From Weather Underground (wunderground.com), I collected weather observations for the week before January 7, 2006, when the photographs of the ice dams were taken. There was no data posted for Toivola, so I used the data for Houghton, Mich., the nearest town with data available (**Figure 5, page 5**).

I then created a bar representing a range of snow depths from

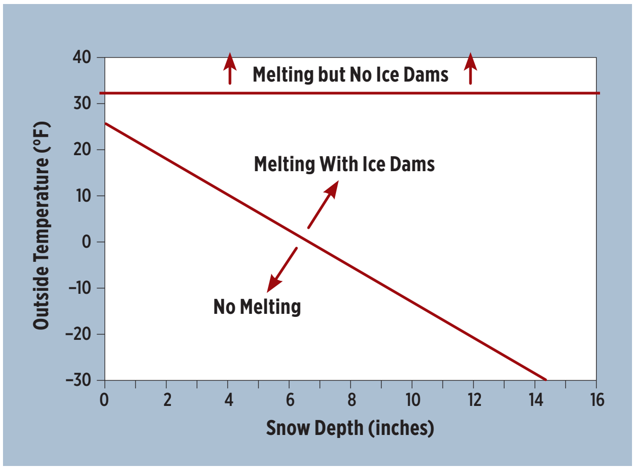


Figure 4. Given the calculated R-value of the roof and an assumed interior temperature of 74°F, this graph plots melting on the roof surface as a function of snow cover and outside temperature. Below the sloped line, no melting occurs; above it, but below 32°F, melting will occur and ice dams will form at the eaves. Above 32°F (the horizontal line across the top), melting would take place without freezing.

Weather Data

	Temperature (°F)		
Date	**Min.**	**Max.**	**Weather Observations**
Jan. 1, 2006	21	30	Snow/Overcast
Jan. 2	24	33	Snow/Overcast (approx. 3 hours above 32°F)
Jan. 3	30	32	Fog/Rain/Overcast
Jan. 4	28	34	Fog/Rain/Overcast (approx. 6 hours above 32°F)
Jan. 5	19	28	Rain/Snow
Jan. 6	19	25	Snow
Jan. 7	24	28	Snow

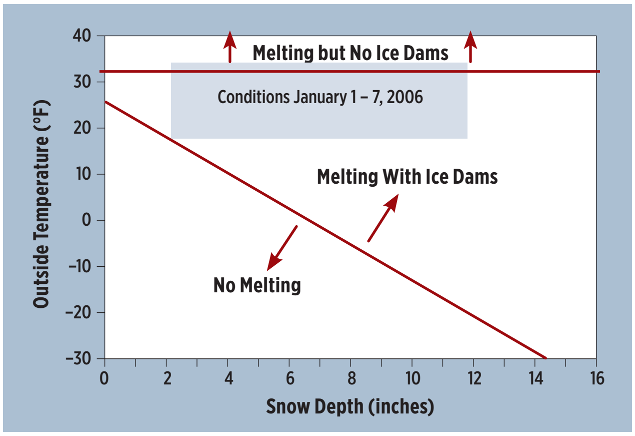


Figure 5. The author collected historical weather data for the week before the ice dams were photographed (left), averaged it, and superimposed it on the graph to make the point visually that conditions were ripe for icing at the eaves.

2 to 12 inches, based on an average of the recorded temperatures during the week before the photographs were taken. I superimposed this on the modeled conditions in Figure 4, demonstrating that weather conditions during that week were conducive to ice damming on this roof, as predicted by the heat transfer model.

Industry Recommendations

In addition to this evidence, I provided the builder with information from the low-density insulation manufacturer recommending that fully vented sheathing be used for climates like Toivola's (Zone 7 as defined by the International Energy Conservation Code). The manufacturer's recommendation specifically includes soffit and ridge vents, as well as installation of polystyrene vent chutes under the sheathing before the foam is sprayed.

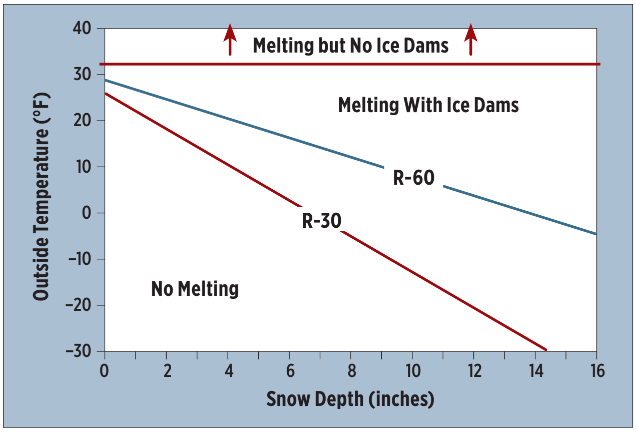


Figure 6. Even with ceiling R-values up to 60, the normal range of winter temperatures would still lead to ice dams, given a blanket of snow on the roof.

Last, I pointed out section R806.1 of the 2003 Michigan Residential Code — currently enforced in Toivola — which dictates that "enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof rafters shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain or snow." Installing the foam directly against the roof sheathing without venting was in fact a code violation.

In my report, I concluded that had the builder stuck to the original plans for the house, which showed a fully vented cathedral ceiling, severe ice dams would have been unlikely. In fact, in our region, where it is not uncommon to get 200 inches of snow in the course of a winter, a vented roof assembly is always the safest precaution. As the graph in **Figure 6** shows, even if the levels of insulation in the ceiling assembly were increased, normal weather conditions for the region would likely lead to ice dams on an unvented roof.

As it turned out, my client — the builder — settled out of court, and the owner and insulation subcontractor agreed to split the cost of a new roof. They planned to strip the shingles and then install 2x4 sleepers to create a vent channel, followed by new sheathing, new shingles, and soffit and ridge vents.

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