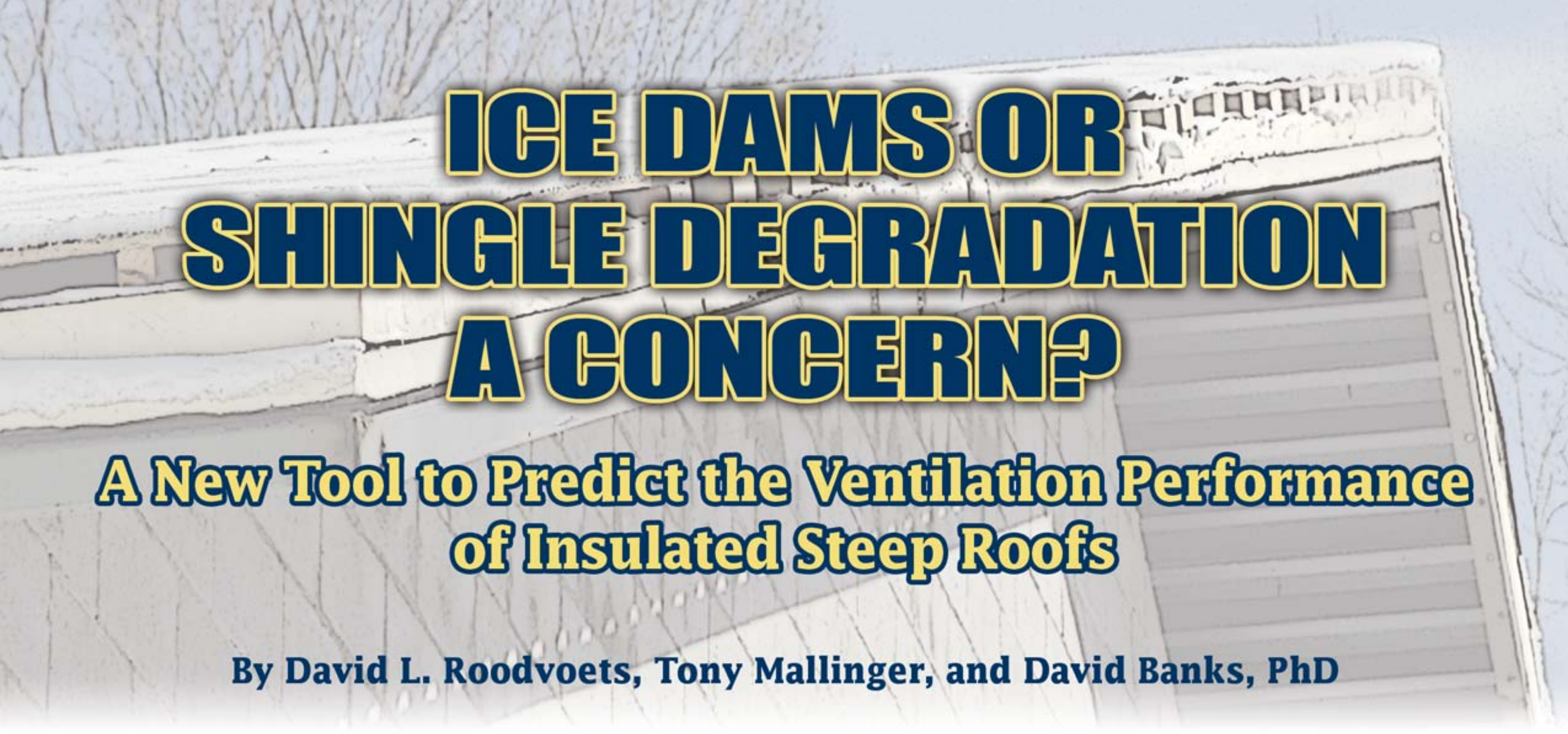

ICE DAMS OR SHINGLE DEGRADATION A CONCERN?

A New Tool to Predict the Ventilation Performance of Insulated Steep Roofs

By David L. Roodvoets, Tony Mallinger, and David Banks, PhD

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INTRODUCTION

This paper addresses two issues that are common to steep-sloped roofs: ice dams and excessive heat buildup that can lead to roof cover deterioration. Ice dams occur in U.S. climate zones 5-8 and are caused by melting snow or ice that refreezes at the lower edge or eave of steep roofs. Excessive heat buildup can occur when the cooling effects of a roof deck and building interior are blocked by an underlying insulation. Excessive roof heating can occur in most climates but is more of a problem in hot and hot/dry climates.

ICE DAMS

Ice dams occur when snow or ice melts at the top of a roof slope and refreezes at the bottom of the roof slope or eaves (*Figure 1*). Tobiasson et al.[1] gave detailed information as to why ice dams occur. To paraphrase Tobiasson's excellent research, ice dams occur because heat from the interior of the building accumulates at the top of the roof slope and raises the roof surface material to a temperature above freezing, thereby allowing melted water to flow downslope and refreeze. The cause is not primarily the heating by the sun, as that typically is uniform across the roof surface and therefore causes equal melting at the top and bottom of the slope. Random hot spots can also occur around chimneys, vent stacks, or directly above heating appliances. These hot spots may also be corrected with ventilation but usually need to be corrected by stopping air flow from the heated interior.

The primary cause of ice damming is that the heat coming from the interior is not removed quickly enough to prevent the temperature from rising above freezing. The quick response by some designers is that more insulation needs to be added. Although the additional insulation may be of value, it often is not the cure. The ice dams still occur because the roof surface remains above 32°F (0°C). Heat is entering the space beneath the roof deck because of heat transmission through insulation material and, in the case of attics, from air passing from the heated interior of the building directly though holes in the ceilings or walls adjacent to the attic space.

When the temperature is above 32°F (0°C), snow and ice melt; and the eave area will also be warm enough to prevent refreezing. Bright sunlight will help melt the dam, but it can also allow slippage of the entire semi-frozen mass, creating a significant hazard for anyone in the area. There are several designs of snow and ice guards that reduce the potential for large pieces of ice to slide from the roof. Basic roof design that eliminates steep slopes near pedestrian areas or ice guards should always be considered when there is a potential for icicles or ice dams.

Figure 1 – Typical ice dam.

SYSTEM DESIGN

Residential structures with attics or cathedral ceilings built to meet the requirements of the International Residential Code may not have adequate insulation to prevent ice damming if the attic space or cathedral ceiling system does not have ventilation. Currently, the International Residential and International Building Codes do not require attic ventilation. The International Residential Code requires R-49 attic insulation in climate zones 6, 7, and 8.

Commercial buildings designed using ASHRAE 90.1-2007 are required to have R-20 insulation. This is unlikely to be enough insulation to prevent ice damming in most areas where snow or ice storms are possible. Tobiasson's and the authors' research show that the most effective way to reduce the potential for ice damming is to add ventilation.

System design then calls for the code-required insulation to be installed and ventilation to be provided—either using the code-ventilation requirement of 1 sq ft of ventilation per 150 sq ft of floor space for attics—or by using the ventilation designs in Tobiasson's tables or the computer program discussed in this paper.

CORRECTING AND PREVENTING ICE DAM PROBLEMS

The first step when an attic space is involved in a structure with existing ice dam problems is to find the source of air entering the attic from within the heated building. It could be duct leakage or holes around vent stacks, lighting, or wiring fixtures. Don't overlook the possibility that the warm air could be coming from the basement or crawl space through the walls. All holes should be closed using an appropriate method, such as sealing large holes with an air-and-moisture barrier and using expanding foam for smaller cracks or penetrations. Stopping the air movement will also stop moisture coming from the interior. Moisture can be a significant problem in attics.

The next step is to make sure that ventilation is installed and that it is operating, not painted shut or plugged with insulation. Also determine that the code minimum ventilation of 1 sq ft of net-free ventilation for every 150 sq ft of ceiling area when the attic space is ventilated at both the eave and ridge is installed. Roofs that have the code-required minimum of 1 sq ft of eave ventilation for every 300 sq ft of ceiling area may not have adequate ventilation to prevent ice damming, as heat can be trapped at the ridge area.[2]

The third step is to add insulation to bring the attic up to current standards. The new International Energy Code and ASHRAE Standard 90.1 require more insulation in attic spaces than previous versions of the energy codes. The minimum insulation in attics of commercial buildings for climate zones 5, 6, and 7 is R-38. For residential buildings in climate zones 5 to 7, R-38 is required, R-49 is required for Climate zone 8. Having this much insulation will be most helpful if there are no direct air leaks into the attic space from within the building.

ASHRAE is a good source for information on controlling heat and moisture. Chapter 25 of *ASHRAE Fundamentals* provides the science and some design information that can be applied. Chapter 43 in the *ASHRAE Applications Handbook* provides examples of good design practice. Several tests, such as blower door tests, tracer gas tests, and infrared analysis can also be used to determine where the warm air is leaking into the attic space. Solving the air leakage problem is also likely to provide energy savings for the building owner.

ICE DAMMING AND CATHEDRAL CEILINGS

The cause of ice damming when cathedral ceilings are used differs from the attic system in that there is less likelihood that air is leaking from the interior into the space just below the deck. This includes heating ducts, which could leak but are not often found in the cathedral ceiling space.

Cathedral ceilings/roofs are primarily installed for aesthetic reasons, both for the outside and inside appearance. Historically, cathedral ceilings provided both the surface for the attachment of roofing materials and the interior finish. Many cathedrals used wood planking for the deck and provided a roof cover—typically lead, copper, tern, or slate—for water shedding. In the Middle Ages, cathedrals were unheated or had small stoves that provided a small amount of warmth. The relatively low R-values of the wood decks were not an issue, as there was little heat in the building. Prior to the energy crisis in the 1970s, cathedral ceiling roofs were still built primarily with wood planks with R-values of 3.5 to 7.

Because of energy costs and code-mandated higher energy efficiency, building owners have used many techniques to minimize the heat loss from the roof. Several have built structures inside the roof deck. This may be an insulated cathedral ceiling suspended from the roof or a flat or designer ceiling. Many have maintained the slope but not the aesthetics of the natural wood interior. Batt insulation with an air gap between the top of the insulation and the deck is often added in the space. Some have made the space an attic by putting a flat ceiling at a lower level and insulating above the ceiling. Other techniques include applying spray foam under the deck or to the top of new interior finished ceilings. All of these approaches save energy. Now almost all buildings with cathedral ceilings are heated and cooled.

Preserving aesthetics and providing more insulation can be done economically when the roof cover is replaced. This involves adding insulation on top of the structural deck. The system becomes the same as that used for compact roofs in low-slope construction. Although this adds R-value, insulation levels typically specified are not adequate to prevent ice dams. Tobiasson found that insulation R-values of R-45 or greater are required to prevent ice damming when there is one foot of snow on the roof.

Current building standards (ASHRAE 90.1, 2010) require R-20 insulation for low-slope roofs and R-38 insulation for steep-slop roofs on commercial buildings, churches, and other large auditoriums. It, therefore, is possible to meet the latest energy code and still have ice dams. Also, getting the insulation level to R-45 or greater is an expensive proposition. However, because there is a need to save energy and reduce carbon emissions, codes will be aiming at increased R-values in the future.

Techniques to alleviate ice damming have been covered quite thoroughly by Tobiasson. The basic solution for cathedral roof systems is to create an air space over the insulation under the deck that supports the roof cover. A key requirement of the air space is that the air must move freely from the eave to the ridge of the roof and not be heated to a temperature greater than 32°F (0°C). Systems should also provide for lateral movement of the air to avoid obstructions in the air space or limited ridge ventilation.

One choice for providing insulation and ventilation is to remove the existing roof cover, recover the deck with new roofing felt, and add 2-in x 4-in or 2-in x 6-in purlins and 1-in x 2-in cross purlins above the existing deck to provide ventilation and a cold roof deck. The cross purlins allow interconnected airflow in the system. The space between the main purlins is filled to within 1 in of the top of the main purlins with closed cell insulation to the designed predetermined depth. A new supporting roof deck and roof cover are installed over the new deck. This design does an excellent job and can be built by any competent contractor; however, it may not provide enough insulation/air gap for all buildings.

Several sources suggest the space between the main support purlins should be filled with closed-cell spray foam or a combination of rigid board foam and spray foam to provide a secondary moisture barrier.[3]

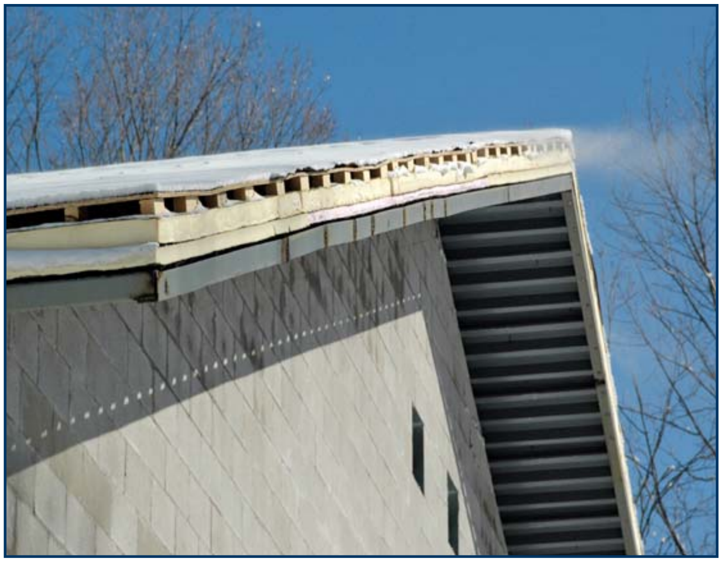


Figure 2 – Nailbase insulation.

For roofing contractors, products generically known as ventilated nailbase insulation sheathing (*Figure 2*) provide both insulation and ventilation. Ventilated nailbase insulations consist of closed-cell foam, spacers, and top surface. Typical products use either closed-cell polyisocyanurate foam or extruded polystyrene foam insulation. With shingled or metal roofs, oriented strand board (OSB) is typically used as the top surface of the ventilated nailbase. Other materials may be used for adhered single-ply or modified-bitumen roofs.

All commercial ventilated nailbase products use spacers to enable the airflow to rise up and/or across the slope when the vertical path is impeded. When the length of the run is less than 20 ft, the use of a 1-in

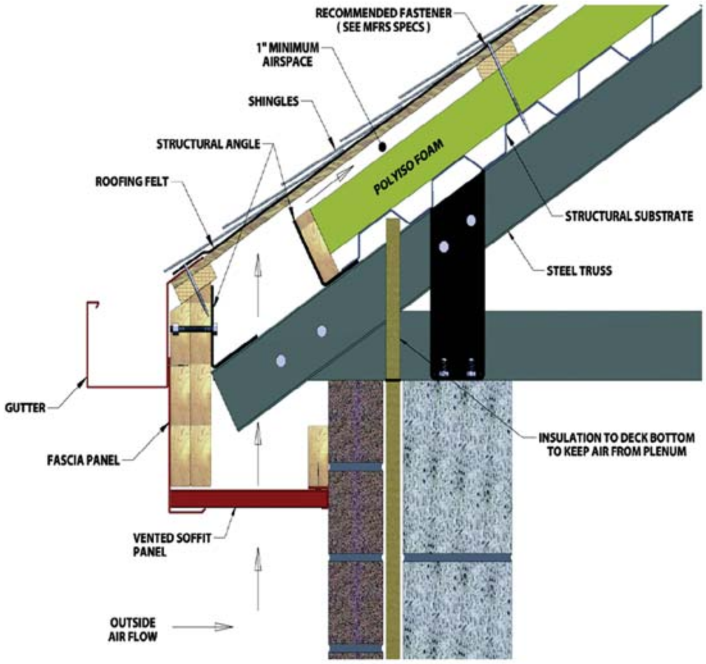


Figure 3 – Airflow is restricted through this complex site-built design.

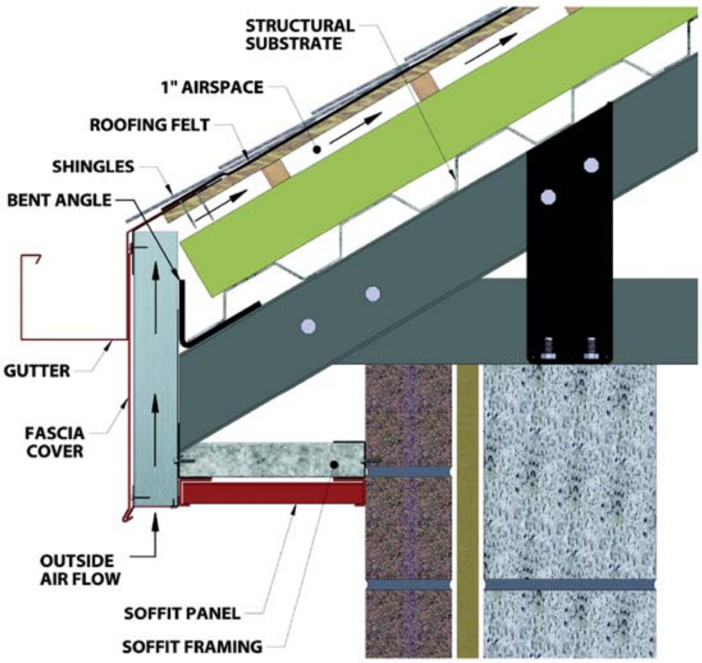


Figure 4 – Airflow is not restricted in this commercially available, premanufactured edge system.

air gap has proven adequate in most cases; however, when the distance from the eave to the ridge is greater than 20 ft, calculations using a program developed by CPP Wind Engineering and Air Quality Consultants show that a 1-in air gap height is insufficient. (See *Figures 3* and *4*.) Nailbase insulation with a 1-in air gap height that is traditionally used for residential applications provides a good solution where there are limited roof heights and eave-to-ridge runs. However, roofs of commercial buildings, churches, and other auditoriums feature much longer slopes that require different strategies for determining the needed air gap height and insulation.

CPP of Fort Collins, CO, conducted a study using known airflow and heat transfer relationships. The goal of this program was to provide guidance on the insulation R-value and air gap height required to prevent ice dams. As a result of the study, a program was developed to do the necessary calculations. This program is based on an assumed worst-case scenario of no wind. Research shows that wind will generally augment the airflow through the air gap and provide the required temperature reduction to keep the snow from melting; however, when there is no wind, the change in air density as it is heated becomes the primary driver for the airflow. In all cases, heat will be transferred from the interior of the building through the insulation to the air space. As the air space is heated, the air density will decrease, and the lower-density air will move upward (i.e., the buoyancy effect used in hot air balloons). This creates airflow that brings the cooler, heavier air into the air space at the bottom or eave; and the warmer, lighter air flows out at the ridge or top of the air space. The constriction for the airflow is the air gap between the insulation and the cover board. The more the space is restricted, the less airflow can occur, and the air temperature in the air gap will increase. Design requires that the height of the air gap does not impede the flow of the air, allowing the basic thermal driver to work.

The fundamental assumptions of the program are that heat is transferred from the interior of the building through interior surfaces and deck to the air space at a rate dependent upon the insulation level and the temperature difference between the building interior and the gap. The roof temperature is determined based on the reflectance and emittance of the roof covering. The insulating value of the nailbase material is also included. For winter conditions, it is assumed that the roof is covered with snow, providing high reflectance, and that the temperature at the roof surface is 32°F. Once the temperature increases beyond 32°F, the snow or ice will melt and flow toward the eaves. Another key assumption is that there is no wind. This is the worst-case situation, as in most cases when there is wind, it will create suction at the peak and some pressure at the eaves, driving more air through the air gap space and keeping the deck cool.

The program combines known relationships between air flow rates and viscosity, heat transfer and conductance, and radiation and emittance, to predict the airflow rate and air temperature rise in the ventilated nailbase airspace. The equations used in this analysis can be found in the complete report available online at **www.metalera.com**.[4]

By combining all factors that drive the airflow though the gap, the program iteratively solves the equations and plots the temperature in the air gap. The goal of the designer, then, is to achieve an air temperature in the air gap of less than 32°F at the top of the slope. Go to the Metal Era Web site to use the program. Several factors must be known for the roof being designed. These are roof slope, distance from eave to ridge, thickness of material used as an attachment base (the top plywood/OSB layer), ceiling insulation R-value, eave vent length, ridge vent length, the basic color and type of the preferred roof cover material, and outside temperature for summer conditions. (For winter, the program assumes a snow-covered roof at a temperature of 32°F.) An air gap is chosen and entered into the program. Clicking "calculate" results in a graph showing the temperature of the top surface material and the temperature of the air in the gap. It also provides a direct reading of the air temperature at the ridge vent.

Using the premise that air temperature

less than 32°F prevents the nailbase sheathing from exceeding the melt temperature of the snow, there should be no water to run down the roof slope and freeze. If the insulation/air gap chosen allows the temperature of the roof cover to heat up to greater than 32°F, a red line appears on the graph at a length down the slope where the temperature of 32°F is exceeded. The most effective way to decrease the temperature below 32°F is to increase the air gap height.

Tobiasson found 22°F to be a critical temperature for ice damming. His work shows that at temperatures above 22°F, ice damming rarely occurs, and there is less of a problem at colder temperatures. Therefore, 22°F is a good design outdoor temperature for ice dam prevention.[5] This is not to imply that the design temperature of the roof should be other than the code-required value for the building. But when considering all the factors, including the insulation and materials used, a calculation at 22°F is likely to provide data for the worst case for ice dams to occur, and the minimum insulation/air gap should be determined using 22°F.

The air gap height required is also a function of the slope of the roof and the distance between the eave and ridge or top of the roof section. Ice damming is a greater problem on roofs that have a 3/12 slope than those with greater slopes, and the air gap heights in the ventilated nailbase insulation need to be larger to adequately remove enough of the heat to prevent the ice damming.

Of course, the system needs free airflow through the roof vents greater than or equivalent to the airflow through the ventilated nailbase. Design of the eave and ridge vents is critical to getting the air through the system. Therefore, if the airspace requires a 2-in-high airspace, then the eave and ridge vents will need to have at least 2 inches per linear inch of net free area. It is also important that there is adequate air entering the eaves. There must be a clear air path from the eave vents to the base of the insulated nailbase air gap. Some soffit designs create complex paths that are ineffective in providing the air required to meet the airflow requirements of the system.

In cold regions, sloped roofs should have overhangs. Tobiasson recommends at least one foot of overhang.[6] This overhang can include a soffit, or the underside of the deck may be exposed if there is sufficient closure at the wall. Ventilated edge systems that incorporate the details required by adequate airflow design can now be purchased as premanufactured products specifically designed for the building. The key requirements of eave vents are that they provide an unobstructed air gap at least as large as the ventilated nailbase air gap, and that the airflow is not restricted.

BUILDING CODE INSULATION REQUIREMENTS

Residential buildings up to three stories typically are built to the International Residential Code (IRC), which includes energy design requirements and also references the International Energy Code. The IRC code requires R-30 or greater insulation levels for most areas of the U.S.; and for the heaviest snow areas (Climate Zones 6, 7, and 8), R-49 is required. For typical residential applications, the 1-in gap height, with adequate eave and ridge ventilation, works (typical 6/12 slope and 1-story height increase). This additional insulation provides a greater margin of safety before ice damming occurs on residential roofs. However, the additional insulation is not as effective in preventing ice dams as is additional ventilation.

Most U.S. commercial buildings,

churches, and schools are designed using the International Building Code (IBC). The IBC code references ASHRAE Standard 90.1 for energy design requirements. ASHRAE Standard 90.1 now requires an R-20 roof for most of the U.S. commercial buildings, churches, and schools, with cathedral ceilings that may have lower slopes and almost always have much longer distances between the eave and ridge. Thus, using less insulation and longer slopes can lead to ice damming issues in the northern, heavy snow areas. The solution is a combination of more insulation and a greater air-gap height so that the nailbase insulation remains cool.


Figure 5 – Potential solution for hip roof ventilation.

CHANGING CATHEDRAL CONSTRUCTION

Most cathedral ceilings for large buildings are now constructed with the same steel decks used in low-slope roofs. They have an interior finish, generally constructed of gypsum board; are insulated on the exterior with foam board insulation; and have a wide variety of roof coverings. In most cases, the heavy planking is gone, the supports are steel construction, and the interior finishes vary and may be directly attached to the bottom of the deck or attached with an attic space between the ceiling and the structural deck. All designs should have the dewpoint fall within the insulation; if possible, there should be no condensing surfaces. A vapor barrier may be required to accomplish this in some situations.

Designs incorporating ventilated nailbase insulation are a way to capture the needed R-value and ventilation for steel-deck-based construction, and they minimize ice damming. Decks constructed with wood planking may provide the aesthetics and strength required, but they do not meet the code-mandated R-values; therefore, these roofs also need extra insulation, and the most effective system is a ventilated cathedral design. The ventilation also serves to keep the base of the roof covering cooler when it is exposed to direct sun in cooling mode.

Hip roofs, where the ridge vent is less than 20% of the length of the eave vent, present a special challenge, as the ridges adjoining the other sections of the roof are somewhat difficult to ventilate with adequate waterproofing and there is resistance to blowing or drifting snow. One of the more practical solutions is to extend the main ridgeline of the roof a few feet over the hipped section and to then install a gable-type vent in the triangle section created between the roof slopes (*Figure 5*). To be most effective, the air must be able to move laterally to the primary ridge, the ventilation from the opposing slopes should be interconnected, and the exhaust ventilation should exceed that required for a gable-end roof.

The Dutch hip roof is one way to obtain additional ventilation in a hip roof design. Vents are added in the A section. These can be powered, if required, to achieve the amount of ventilation desired. When hip roofs converge at a single point, a cupola or modified cupola may provide the required ventilation.

VENTING TO MINIMIZE COOLING COSTS

Researchers at Oak Ridge National Laboratory have been evaluating tile and metal shingle roofs, which have a natural airflow. They have found that the ventilation from tile and other roofs where there is an air gap between the covering and the deck provides additional cooling to the building. Tile and similar products have air flow up the slope and into the systems at many points. The moving air dissipates heat from the surface and results in less cooling load for the building. If there is adequate air flowing up the surface with ventilated cathedral ceilings, there should also be measurable building cooling effects.[7]

The computer program developed by CPP provides a recommended air gap height for roofs in cooling-dominated climates. The same parameters are used as those when designing for heating climates. In cooling climates, air is warmed by sunlight that falls on the roof surface, and the maximum temperature of the roof surface is driven by the reflectivity or albedo of the roof surface material. The interior of the air gap is cooled by the roof deck, but in this case, cooling is reduced by the insulation between the air gap and building. The same phenomenon of air heating and rising due to buoyancy creates the driving force to remove the hot air from the building. The program ignores the effects of wind, as the wind is likely to improve the airflow through the system.

In all cases, the program includes the fundamentals of heat transfer, conduction, convection, and radiation, along with effects of air films and fluid dynamics. To calculate the airflow rate through the space, the amount of temperature increase is needed. This is found by taking into consideration such variables as airflow rate, temperature increase, and heat transfer coefficients. These calculations occur in the background, so the user of the program deals only with the final answer. Constrictions created by eave and ridge ventilation, as well as the air gap height between the insulation and the deck, will affect the performance of the system. The program shows that less air gap height is needed to cool the deck in the summertime than is needed to prevent ice dams in the winter. Therefore, a design that avoids ice dams will also avoid excessive heating of shingles and other roof coverings.

PROGRAM USE AND RESULTS

The program developed in this study can easily be accessed and is available for no charge at **www.metalera.com.** The Web site provides a list of inputs that can be changed by the user. To use the program, the user should know the following information about the roof being designed:

ROOF SHAPE DETAILS

- Pitch on 12
- Length of passage from eave vent to ridge vent (ft)
- Thickness of OSB/plywood (in)
- Height of gap (in)
- Ridge length (ft)
- Eave length (ft)

THERMAL INFORMATION

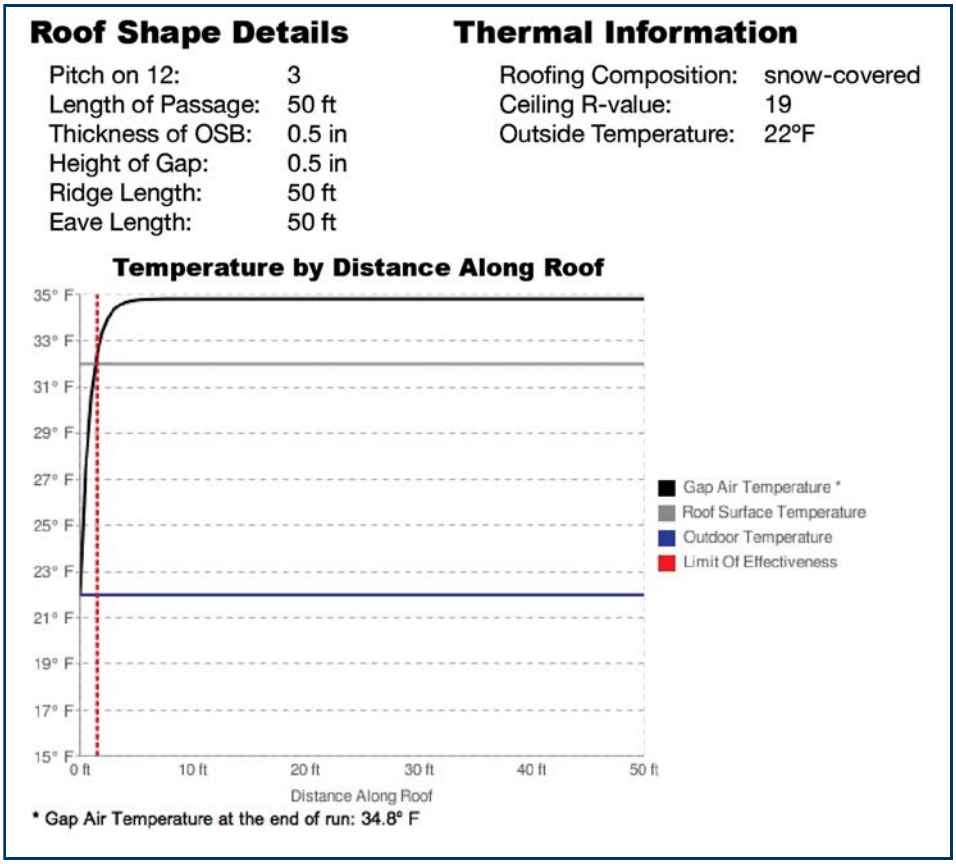
- Roofing composition
  - Full sun – roofing material (This is a drop-down menu.)
    - * Cement - Dark
    - * Cement - Medium
    - * Cement - Light
    - * Ceramic - Red
    - * Ceramic - White
    - * Shingle - Dark
    - * Shingle - Medium
    - * Shingle - Light
    - * Wood - Dark
    - * Wood - Medium
  - Snow-covered (When the roof is snow-covered, the expected rooftop temperature is 32°F.)
- Ceiling/wall insulation R-value
- Outside temperature in degrees Fahrenheit (From Tobiasson's research, an outside temperature of 22°F creates the worst case, so that is a good temperature to use.)

As always, it is interesting to change the inputs to determine the effects of changes in the basic parameters. The results from several iterations follow.

Starting with a minimum air gap height, it is easy to see that with an R-19 roof, there will be ice dams formed as the temperature in the gap (and hence, the bottom of the nailbase) will reach 32°F just about 3 ft from the eave, creating an ideal condition for ice damming.

What is the effect of insulation R-value? Can increasing insulation R-value avoid ice damming? *Figure 6* shows the outlet temperature when a high-slope roof is insulated. It can be seen that doubling the R-value of the insulation does not provide an outlet temperature that prevents ice damming, as the air temperature is still above freezing (*Figure 7*). The R-50 roof does not bring the outlet temperature below freezing and would not prevent ice damming on this roof with a 50-ft air passage length. The air passage length is the distance from the inlet or eave vent to the outlet or ridge vent. It is assumed to be a straight line for this program.

Increasing the air gap height to 1 in for



Roof Shape Details

Pitch on 12: 3
Length of Passage: 50 ft
Thickness of OSB: 0.5 in
Height of Gap: 0.5 in
Ridge Length: 50 ft
Eave Length: 50 ft

Thermal Information

Roofing Composition: snow-covered
Ceiling R-value: 19
Outside Temperature: 22°F

Temperature by Distance Along Roof

* Gap Air Temperature at the end of run: 34.8° F

Figure 6 – Air gap height = 0.5 in.

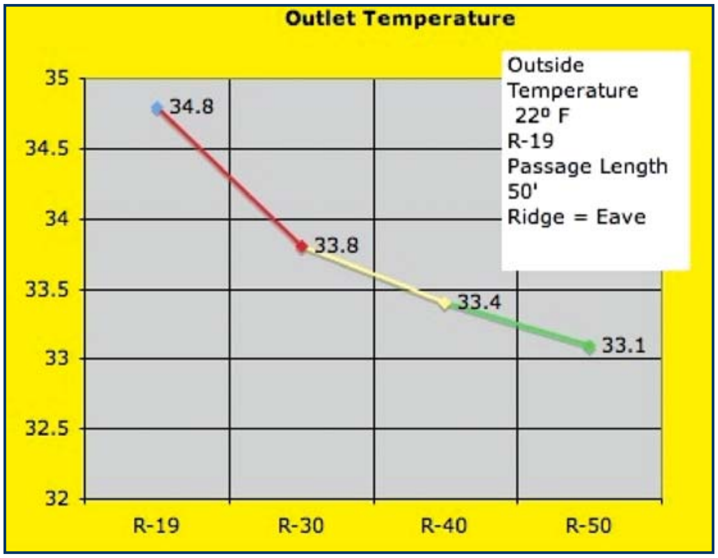


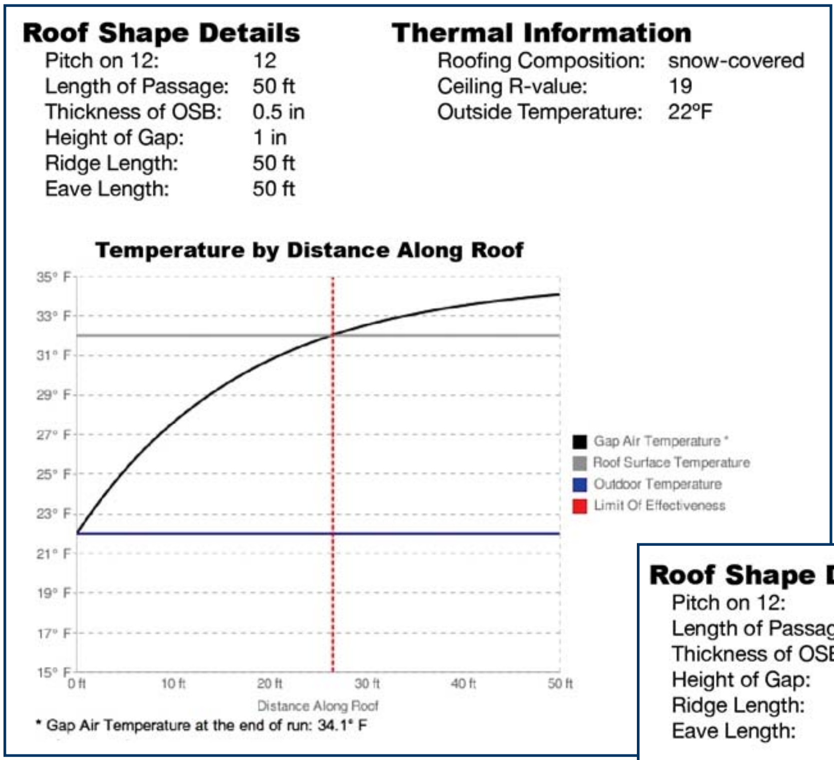
Figure 7 – Slope, 12 in x 12 in; air gap, 0.5 in.

Roof Shape Details

Pitch on 12: 12
Length of Passage: 50 ft
Thickness of OSB: 0.5 in
Height of Gap: 1 in
Ridge Length: 50 ft
Eave Length: 50 ft

Thermal Information

Roofing Composition: snow-covered
Ceiling R-value: 19
Outside Temperature: 22°F



* Gap Air Temperature at the end of run: 34.1° F

Figure 8 – Air gap height, 1 in; slope, 12 in x 12 in; R-19.

the R-19, 12-in x 12-in sloped roof does not adequately supply cool air to avoid ice damming, because the airflow is restricted. However, as seen in *Figure 8*, the point where the air gap temperature exceeds 32°F is at about 25 ft. This justifies the use of this standard 1-in air gap height for most residential buildings, since the passage length of most of the cathedral ceilings is less than 25 ft.

Increasing the air gap height to 2 in for the R-19, 12-in x 12-in sloped roof provides adequate airflow to avoid ice damming. The airflow is not restricted, and it continues to remove the heat from the interior of the building, avoiding the melting at the top of the slope. *Figure 9* is the desirable shape of a chart from the computer program. When the temperature in the air gap is less than 32°F at the end of the air passage, ice dams are not likely to occur, as the building is not heating the underside of the wood-sheathing surface of the nailbase.

Air gap height has a major influence on the outlet air temperature, and in most cases, it is likely to be the simplest and least expensive to change (*Figure 10*). Although steeper slopes reduce the outlet temperature (*Figure 11*), increasing the slope is not likely to avoid ice dams unless the outlet temperature is already very close to 32°F.

What happens when we are attempting to keep the roof surface cool to avoid premature damage to the roof covering in a cooling climate? In this case, a vertical line occurs when the air gap air temperature reaches 150°F. This an arbitrary default number in the program. The critical factor is that the air gap continues to cool the underside of the roof deck. *Figure 12* shows that the air exiting the roof is at 134°F and the roof deck surface is 151°F, so air in the gap continues to cool the underside of the deck.

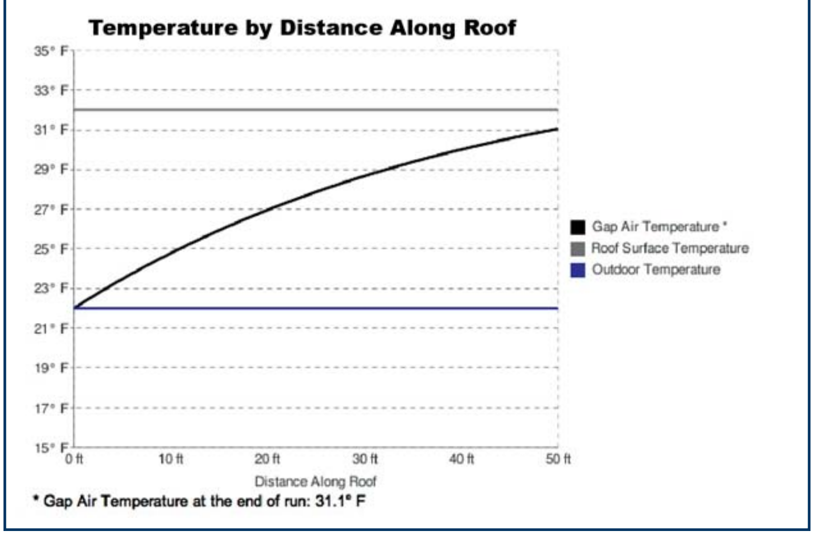
When the roof cover is changed to a darker-colored asphalt shingle, the starting temperature of the roofing material in bright sunlight exceeds 150°F, so the arbitrary limit of effectiveness is not meaningful. The criti-

Roof Shape Details

Pitch on 12: 12
Length of Passage: 50 ft
Thickness of OSB: 0.5 in
Height of Gap: 2 in
Ridge Length: 50 ft
Eave Length: 50 ft

Thermal Information

Roofing Composition: snow-covered
Ceiling R-value: 19
Outside Temperature: 22°F



* Gap Air Temperature at the end of run: 31.1° F

Figure 9 – Air gap height, 2 in; slope, 12 in x 12 in; R-19.

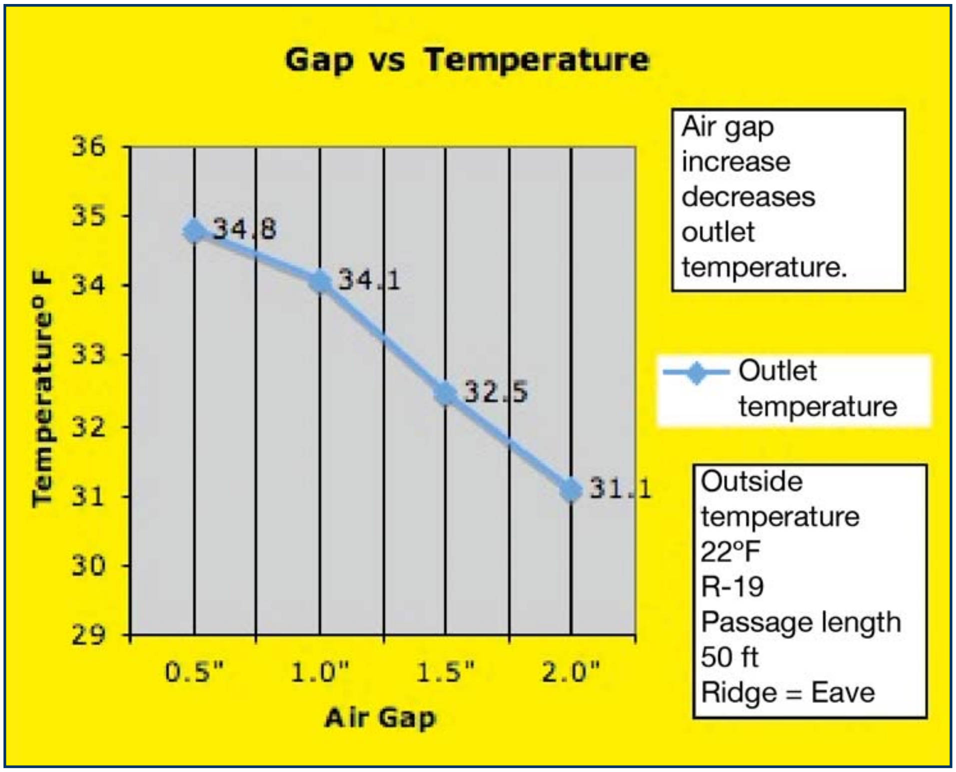


Figure 10 – Air gap increase decreases outlet temperature.

cal factor shown in *Figure 13* is that the air temperature at the outlet is 22°F less than the temperature of the roof covering; so the air gap continues to provide cooling to the roof deck and roof covering materials.

In cooling climates, the air gap is very effective in cooling the underside of the roof deck as shown in *Figure 14*. When there is little gap (0.5 in), the temperature is 166°F, and with the 3-in gap, the temperature at the outlet is 116°F. This lower outlet temperature is expected to have a major positive effect in reducing cooling load.

Increasing slope also reduces the outlet temperature and increases the cooling effect (*Figure 15*).

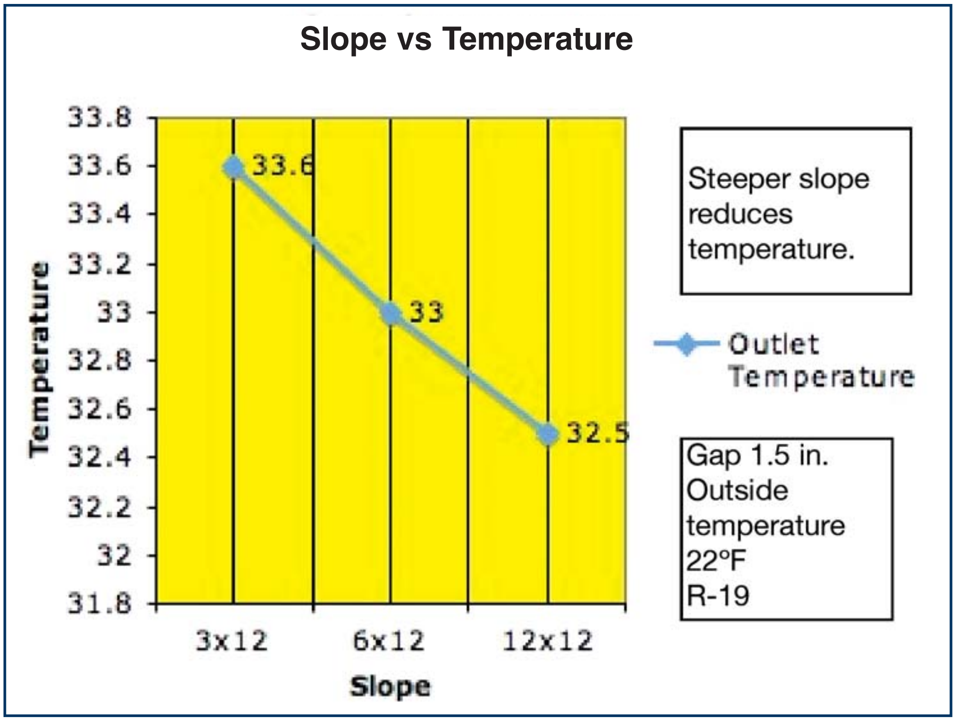
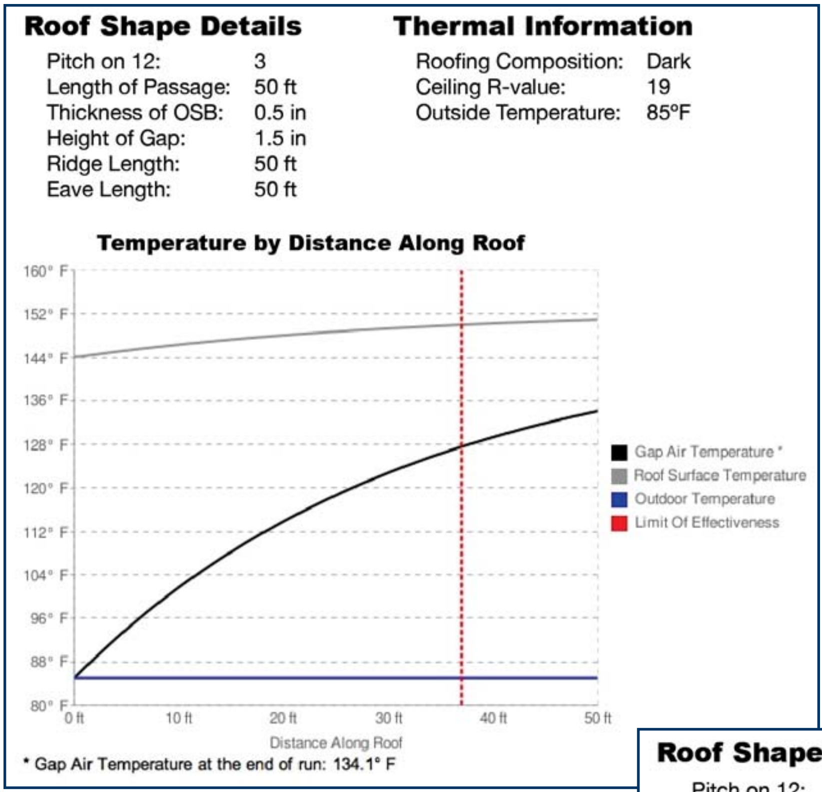


Figure 11 – Steeper slope reduces temperature.



Roof Shape Details

Pitch on 12: 3
Length of Passage: 50 ft
Thickness of OSB: 0.5 in
Height of Gap: 1.5 in
Ridge Length: 50 ft
Eave Length: 50 ft

Thermal Information

Roofing Composition: Dark
Ceiling R-value: 19
Outside Temperature: 85ºF

Temperature by Distance Along Roof

* Gap Air Temperature at the end of run: 134.1° F

Figure 12 – Outside temperature, 85ºF; dark concrete tile roof; air gap height, 1.5 in.

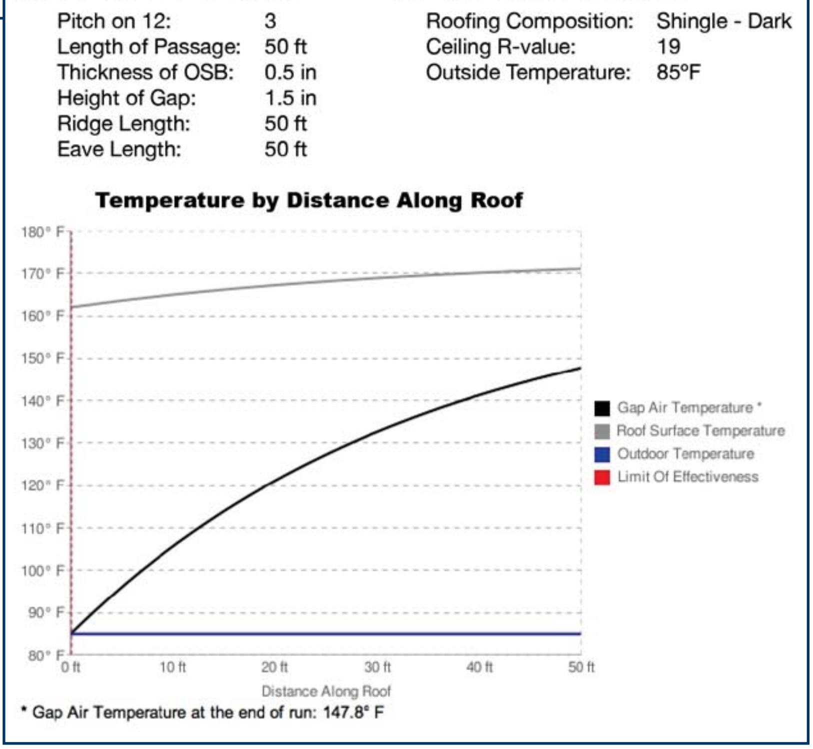
Figure 13 – Outside temperature, 85ºF; dark shingle roof; air gap height, 1.5 in.

Roof Shape Details

Pitch on 12: 3
Length of Passage: 50 ft
Thickness of OSB: 0.5 in
Height of Gap: 1.5 in
Ridge Length: 50 ft
Eave Length: 50 ft

Thermal Information

Roofing Composition: Shingle - Dark
Ceiling R-value: 19
Outside Temperature: 85ºF



Temperature by Distance Along Roof

* Gap Air Temperature at the end of run: 147.8° F

Insulation has little effect on the air gap temperature in cooling climates. Major drivers of the roof temperature are the color and reflectivity of the roof. Highly reflective roofs have much lower surface temperatures than darker, nonreflective roofs. The program has predetermined set points for reflectivity based on the material chosen. This consists of a drop-down menu that offers many of the options that may be considered.

CONCLUSIONS

Adding an air gap to a steep-sloped roof may have some significant benefits in avoiding ice dams and keeping the roof cover cooler. There also may be energy-saving benefits in cooling-dominated climates.

FUTURE RESEARCH

Several questions and opportunities still need to be explored. Does the program adequately address the systems that are not constructed with commercial nailbase insulation? Because of the surface roughness of field-constructed systems, increasing the air gap height from that recommended by the computer program will be the

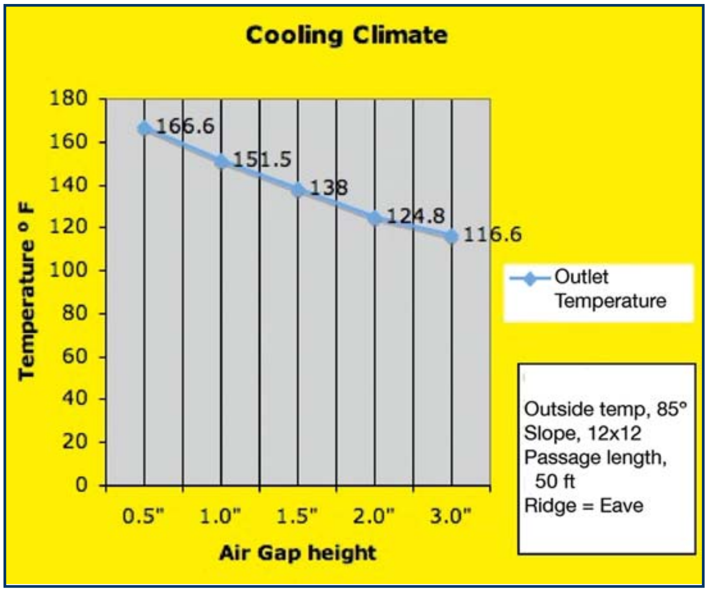


Figure 14 – Outside temperature, 85ºF; slope, 12 in x 12 in; passage length, 50 ft.

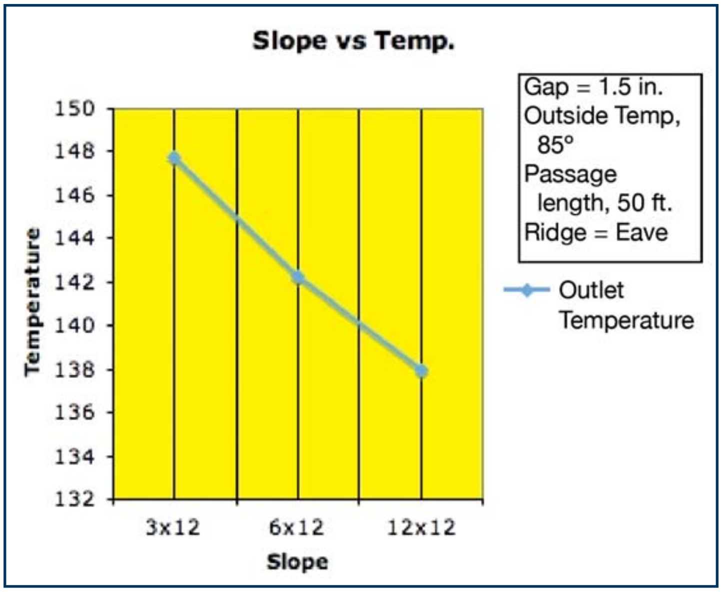


Figure 15 – R-19 insulation.

more conservative solution. Another subject for further exploration is the effect on building cooling by the air gap. Is this effect equal to that achieved with tile and other systems that are installed on spacers above the primary roof deck? Are there benefits from an air gap on a reflective roof? All of the roof designs derive some cooling benefit from the air gap, but the value of that cooling in relation to energy savings may be the focus of a future paper.

FOOTNOTES

1. W. Tobiasson, J. Bruska, and A. Greatorex, "Roof Ventilation to Prevent Problematic Icings at Eaves," Transactions v. 104, American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), 1998.
2. The 2006 International Building Code (IBC), Section 1203.2.
3. "Unvented Roof Assemblies for All Climates," Building Science Corporation BSD-149, Westford, MA, 2007.
4. The research serving as the basis for this program is available from the coauthor, Tony Malinger.
5. W. Tobiasson, J. Bruska, and A. Greatorex, "Guidelines for Ventilating Attics and Cathedral Ceilings to Avoid Icings at Their Eaves," *Proceedings of Thermal Performance of the Exterior Envelopes of Buildings VIII*, ASHRAE, Clearwater Beach, FL, Dec. 6-10, 2001.
6. Tobiasson *et al.*, 1998.
7. W.A. Miller *et al.*, "Natural Convection Heat Transfer in Roofs with Above-Sheathing Ventilation," *Proceedings of Thermal Performance of the Exterior Envelopes of Buildings X*, ORNL, Clearwater Beach, FL, Dec. 2-7, 2007,

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W. Elenbaas, “Heat Dissipation of Parallel Plates by Free Convection,” *Physica 9* (1): 2-28, 1942.

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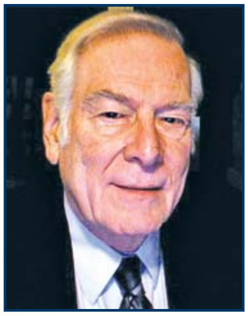
W.A. Miller, J. Wilson, and A. Karagiozis, “The Impact of Above-Sheathing Ventilation on the Thermal and Moisture Performance of Steep-Slope Residential Roofs and Attics,” *Proceedings of the 15th Symposium on Improving Building Systems in Hot and Humid Climates*, Orlando, FL, July 24 - 26, 2006.

A.F. Rudd and J.W. Lstiburek, “Vented and Sealed Attics in Hot Climates,” *Proceedings of the ASHRAE Symposium on Attics and Cathedral Ceilings*, Toronto, ON, June 1997. The seminar is available on ASHRAE Transactions TO-98-20-3.

David L. Roodvoets



David L. Roodvoets is an independent consultant. He consults with ARMA and several manufacturers of roofing products. He served as technical director for SPRI, is past chairman of the Roof Industry Committee on Weather Issues (RICOWI), and is a board member of the Cool Roof Rating Council (CRRC). Previously, he was employed as an associate development scientist for the Dow Chemical Company and was technical director for the T. Clear Corporation. Roodvoets has been involved with research on all facets of roofing systems. He has worked with major research institutions conducting extensive wind tunnel testing of roofing systems. Dave has published articles in several journals and is active in International Building Code development.

Tony Mallinger

Tony Mallinger, chief operating officer and VP of sales for Metal-Era, Inc., has been with the company since 2001. He is closely involved with Metal-Era’s sales staff, regularly working with inside sales managers as well as Metal-Era’s network of over 350 independent reps. He also plays a crucial role in the overall direction of the company by heading the research and development committee and coordinating projects between the customer service, sales, and marketing departments. Tony is actively involved with RCI and SPRI (sheet membrane and component suppliers to the commercial roofing industry) and serves on SPRI’s ES-1 task force.

Dr. David Banks

Dr. David Banks has completed research related to trace gas analysis for his master’s degree in aerospace engineering from the University of Toronto and award-winning published research relating to wind suction forces induced on roofs by conical vortices for his PhD from Colorado State University. He has ten years of experience in consulting engineering related to wind and airflow around and through buildings, including extensive use of both computational fluid dynamics (CFD) and physical modeling. His current focus is the combination of CFD and wind tunnel modeling to improve natural ventilation design. He is the subcommittee chairman for chapter 34 of the ASHRAE fundamentals handbook, *Indoor Environmental Modeling*.

CONESTOGA OIRCA ROOFING TRAINING CENTRE OPENS

The Centre for Roofing Training & Technology has recently opened in Waterloo, ON. A joint project between Conestoga College and the Ontario Industrial Roofing Contractors Association (OIRCA), the 12,000-sq-ft facility is the only school in the province dedicated to roofing-specific education. The center will deliver courses on roofing fundamentals, in-school apprenticeship, skills upgrading, occupational health and safety, and professional development, including roofing estimating and contract management. Approximately half of the $2 million price tag was paid by federal and provincial government funds, and the other half came from cash and in-kind donations from OIRCA members. The building has roughly 8,000 sq ft of shop space, a hands-on training hall, two classrooms, and an indoor elevated training mezzanine. At the exterior is a 30-ft x 30-ft canopy-covered outdoor training area.