Professional Roofing

March 2002

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What's the value of ventilation

A study of asphalt shingles demonstrates ventilation may not be as important as other variables

by Carl G. Cash, PE, and Edward G. Lyon, PE

The topic of asphalt shingles splitting and cracking has received much attention lately. Asphalt fiberglass shingles have been experiencing vertical splits, as well as horizontal splits in exposed tabs. These dislocations, called thermal splits, are the subject of a great deal of litigation, including class-action lawsuits. The splits are not associated with quality of installation. Rather, the splits occur in shingles where self-sealing adhesive firmly adheres the shingle tabs and a shingle's tear strength is low or inadequate to withstand a thermally or mechanically induced load.

Whenever asphalt fiberglass shingle manufacturers are faced with thermal-splitting one excuse they usually offer is that the area under a roof deck was not ventilated properly.

This excuse is offered not because there is any evidence of a cause-and-effect link between thermal splitting and ventilation but because shingle warranties (all the shingle warranties listed in NRCA's *2002-03 Steep-slope Roofing Materials Guide*) specifically exclude warranties in the case of "inadequate attic ventilation." This is based on the premise that shingles applied to decks over unventilated attics will be unacceptably hotter than shingles applied to decks over properly ventilated attics and have significantly shortened service lives as a result of the increased temperature.

Lawyers say impractical or unreasonable contract or warranty provisions may not be supported by court decisions. The following information reveals results from a study we conducted that investigated the reasonableness of the "inadequate attic ventilation" exclusion in warranties.

Some parameters that can influence roof temperature are geographic location, color, exposure orientation, slope and degree of attic ventilation. We report the means (averages) of the maximum and average annual temperatures of the roofing materials for each combination of these parameters.

Geographic location

The National Oceanic and Atmospheric Administration lists 264 locations in the United States that are representative of all U.S. climates. The locations range from Key West, Fla., with the warmest average annual temperature (79 F [26 C]), to Barrow, Alaska, with the coldest average annual temperature (9 F [-13 C]).

Previous research by Cash has shown temperatures plotted on a graph form a sinusoidal wave that is equally balanced (symmetrical) around the average temperature at each location. Therefore, mean temperature is an accurate index of a thermal environment.

For this study, we used the following seven locations (we excluded the West Coast because of its mild temperatures) to study the variation of roofing materials' temperatures with respect to geographic location (mean temperatures for each location are noted):

- Boston—51 F (11 C)
- Chicago—53 F (12 C)
- Green Bay, Wis.—44 F (6.5 C)
- Phoenix—70 F (21 C)
- Raleigh, N.C.—59 F (15 C)
- Miami—76 F (24 C)
- Washington, D.C.—57 F (14 C)

Study details

We used white and black shingles in our study. The materials' albedos (overall measure of a material's reflectivity to the full spectrum of the sun's energy) and emmissivities (percent of absorbed energy a material can radiate away from itself) used were obtained from measurements at the Lawrence Berkeley National Laboratories, Berkeley, Calif.

We limited our calculations to roof surfaces facing the following orientations: 90 degrees east, 135 degrees southeast, 180 degrees south, 225 degrees southwest and 270 degrees west.

In addition, we calculated the temperatures of roofs with slopes of 3-in-12 (14 degrees) to 12-in-12 (45 degrees) in 12.5 percent (1-inch-per-foot) increments. In this article, we only report the calculated results in 25 percent (3-inches-per-foot) increments because these calculated temperatures are close to each other.

Our calculated roof temperatures are reported without ventilation; with attic ventilation provided by 0.33 percent ventilated areas (1 square foot for each 300 square feet of attic plan area) and wind perpendicular to roof slope (no wind assistance to ventilation); and with 0.33 percent ventilated areas (1 square foot for each 300 square feet of attic plan area) and wind normal to the roof orientation (maximum ventilation assistance from wind).

Computer input

As the model for our calculations, we used the Hastings Ranch House referenced in "Analytical Study of Buildings with reflective roofs," published by the National Institute of Standards and Technology. We chose a cathedral ceiling rather than truss-attic space to maximize the difference between ventilated and unventilated roof temperatures. The ceiling-to-roof covering assembly construction we used was as follows:

- 1/2-inch- (13-mm-) thick gypsum drywall sheathing
- 10-inch- (254-mm-) thick fiberglass batt insulation between joists 16 inches (406 mm) on center
- 2-inch- (51-mm-) thick clear air space (to maximize the venting air effect, we did not use an air-friction value in any calculation)
- 5/8-inch- (16-mm-) thick plywood sheathing
- No. 15 asphalt felt and asphalt fiberglass shingles

The mathematical model calculates heat gain and loss for a width of roof extending from eave to ridge. The properties of each layer of the roof assembly are lumped together to create a calculation node.

For our model, we subdivided the insulation layer into thin sections and assumed a uniform 70 F (21 C) interior temperature. We then calculated the heat transfer between nodes in small-time increments because exterior temperature varies through a sinusoidal wave function based on average monthly conditions.

We used the average monthly cloud conditions to modify the solar equations in "Solar Engineering of Thermal Processes," by J.A. Duffie and W.A. Beckman, to reduce solar radiation gain by up to 60 percent and nighttime radiation cooling by 100 percent for full overcast cloud conditions. The potential for snow cover to reduce daily roof temperature cycles was not considered in this study.

We also calculated dew-point temperatures required for radiation gain and loss from a sinusoidal temperature and relative humidity function based on observed monthly average conditions. Average local wind speeds were adjusted from airport observation height and exposure conditions to an urban exposure at a 10-foot (3-m) eave height. Wind speed was used to calculate roof convective heat-flow coefficients, as well as its influence on roof ventilation.

In addition, we calculated ventilation airflow by applying the pressure developed by ventilated space and outdoor air temperature differences (stack effect), wind effects, and airflow resistance of screened openings at the eave and ridge. (We divided the ventilation area equally between the eave and ridge.)

During the study, wind blew either at an angle that maximized the pressure developed on the vents or at an angle that did not influence the stack-effect pressures. The ventilated space had no resistance in these calculations to maximize the effect of ventilation.

For unventilated roof systems, the calculated temperatures are representative of an entire roof system. For ventilated roof systems, the calculated temperatures are representative of a point halfway up a roof system.

Air movement would make eave and ridge areas slightly warmer or cooler than the temperature depending on airflow direction. The maximum roof temperature at any point for ventilated roof systems will not exceed the temperature of unventilated roofing materials.

Ventilated roofing calculations required a small time adjustment for calculations to remain stable. Because of calculation time constraints, we modeled one day in the middle of each month as representative of monthly average conditions. We started our calculation model at a uniform average layer temperature for a particular month and allowed a complete day calculation cycle for the assembly to normalize. We then calculated a second day cycle to generate peak and mean temperature values for the month. The yearly mean temperature was calculated by a weighted average of the monthly calculations.

Computer simulations often require correlation testing before being accepted as absolute predictors of real-world conditions. In our case, the goal was not to attempt to precisely predict a particular roof temperature but to study the "all other things being equal" thermal performances of different ventilation systems. Ventilation obviously will reduce roof temperature, and we have attempted to generously model the airflow potential of ventilated roof systems to define an outer boundary for cooling effects.

Previous work by Cash developed a thermal model and empirical relationship between a roof system's average service life and mean annual temperature to which roofing materials are exposed. In the case of asphalt shingles, a change of 1 degree Celsius is about equal to fourth of a year in average service life.

Data and results

Some data generated in the study are listed in Figures 1 to 4. The calculated temperatures are reported to two decimal places-not to imply an accuracy that does not exist but because some differences otherwise would be too small to distinguish.

The average roof temperature difference between roofing materials on unventilated decks and ventilated decks and difference between the temperature of roofing materials on unventilated decks and wind-assisted ventilated decks are listed in Figure 1.

Location	Unventilated vs. 1/300 plan ventilation		Unventilated vs. wind-assisted ventilation	
	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit
Boston	0.44	0.79	0.77	1.39
Chicago	0.54	0.96	0.84	1.50
Green Bay, Wis.	0.55	0.99	0.85	1.53
Miami	0.52	0.93	0.75	1.36
Phoenix	0.54	0.98	0.69	1.24
Raleigh, N.C.	0.61	1.10	0.82	1.48
Washington, D.C.	0.60	1.08	0.83	1.49

Figure 1: *The average roof temperature differences between unventilated and ventilated decks and unventilated decks and decks with wind-assisted ventilation*

Figure 2 lists the variations in average roof temperature caused by changing roof system color from black to white shingles.

Location	Unventilated		1/300 plan ventilation		Wind-assisted ventilation	
	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit
Boston	1.22	2.20	1.11	2.00	1.07	1.92
Chicago	1.35	2.42	1.20	2.17	1.18	2.12
Green Bay, Wis.	1.32	2.39	1.20	2.15	1.16	2.09
Miami	1.50	2.70	1.36	2.45	1.33	2.39
Phoenix	1.67	3.01	1.51	2.72	1.49	2.69
Raleigh, N.C.	1.53	2.76	1.38	2.48	1.36	2.44
Washington, D.C.	1.53	2.76	1.38	2.48	1.35	2.44

Figure 2: *The variation in average roof temperature as a result of color change between black and white shingles*

Our data show roofs that face west have the lowest roof temperatures of those measured. We are quite sure roofs facing northwest, north or northeast would have lower temperatures, but western-facing roof temperatures are the lowest we calculated. We found the highest mean roof temperatures in south-facing roofs. The maximum difference between mean roof temperature of roofs facing south and west can be found in Figure 3.

Location	Unventilated		1/300 plan ventilation		Wind-assisted ventilation	
	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit
Boston	1.31	2.36	1.19	2.14	1.15	2.06
Chicago	1.46	2.58	1.31	2.37	1.29	2.32
Green Bay, Wis.	1.49	2.68	1.34	2.41	1.31	2.35
Miami	1.06	1.90	0.96	1.73	0.93	1.68
Phoenix	1.74	3.14	1.58	2.84	1.56	2.81
Raleigh, N.C.	1.52	2.74	1.37	2.47	1.35	2.43
Washington, D.C.	1.49	2.68	1.34	2.41	1.32	2.37

Figure 3: *The maximum difference in mean roof temperature of roofs facing south and west*

The slope with the maximum and minimum mean roof temperatures varied with location and slope. Figure 4 shows the maximum variation in mean roof temperature calculated for slopes of 3-in-12 (14 degrees) to 12-in-12 (45 degrees).

Location	Unventilated		1/300 plan ventilation		Wind-assisted ventilation	
	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit	Degrees Celsius	Degrees Fahrenheit
Boston	0.14	0.25	0.09	0.16	0.15	0.28
Chicago	0.19	0.35	0.17	0.31	0.26	0.46
Green Bay, Wis.	0.16	0.29	0.10	0.19	0.18	0.32
Miami	0.39	0.70	0.55	0.98	0.31	0.55
Phoenix	0.21	0.38	0.15	0.26	0.20	0.35
Raleigh, N.C.	0.18	0.32	0.26	0.46	0.18	0.33
Washington, D.C.	0.15	0.26	0.09	0.15	0.15	0.27

Figure 4: The maximum variation in mean roof temperature for slopes of 3-in-12 (14 degrees) to 12-in-12 (45 degrees).

We also wanted to determine the maximum monthly roof temperature (hottest roof system) and greatest temperature difference with 1/300 ventilation (best ventilation) for each location.

For the roof systems with black shingles, we studied maximum roof temperature; temperature differences for ventilated, ventilated with wind and change to unventilated white shingles; yearly mean temperature; and mean temperature differences for ventilated and change to unventilated white shingles.

We found roof temperature extremes do not relate directly to mean temperatures for service life. In all instances, changing roof color from black to white has more effect on yearly mean temperature than ventilation. Ventilation reduces the yearly mean temperature of a black roof system by an average 0.7 degrees Celsius, and changing to white shingles reduces the yearly mean temperature by an average 1.6 degrees Celsius.

Conclusions

The following conclusions are based on data from our numerical model:

- The greatest influence on roof temperature is geographic location. The mean roof temperatures for Miami and Green Bay, Wis., for example, differ by 18 degrees Celsius.
- The direction a roof faces has the second greatest influence on average roof temperature (in excess of 1.44 degrees Celsius in the east through south-to-west range studied, but the real difference is greater because other directions, such as north, will be cooler).
- The color of roofing materials influences the mean temperature of a roof system slightly less than direction (1.45 degrees Celsius average for these parameters).
- Ventilating the area under a roof deck reduces the average temperature 0.5 degrees Celsius (about one-third the influence of the direction or color and one-thirty-sixth the influence of geographic location). Even with wind assistance, ventilation reduces average roof temperature about half as much as using white rather than black shingles.
- Within the ranges studied, slope has the least influence on average shingle temperature.

Many shingle manufacturers provide warranted products that are widely distributed and are of many colors and exclude from warranties those shingles installed on unventilated decks. This exclusion has no justification; the variations in geography, direction and shingle color have greater influences on average temperature than the degree of ventilation.

However, ventilation should be recommended to remove the small quantity of moisture in a roof system; it can prolong the life of a wood deck even if it does not extend the life of shingles.

Carl G. Cash is a principal with Simpson, Gumpertz & Heger Inc., Arlington, Mass., and Edward G. Lyon is a senior staff engineer with Simpson, Gumpertz & Heger.