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omy fell 17% from 1990 to 2000, added emissions resulting from US economic growth of 39% during the decade overwhelmed the improvements in carbon intensity.

LOVELAND, CO — North American sales of radiant tubing have doubled in the last four years, according to the Radiant Panel Association. Total tubing sales in 2001 were estimated at 193 million feet, compared to 96.9 million feet in 1997.

AUBURN HILLS, MI — A new plant for the manufacture of photovoltaic (PV) cells opened here in June. The plant, owned by Bekaert ECD Solar Systems, will produce three miles a day of thin-film PV cells by depositing solar material on a continuously moving roll of thin stainless steel. Bekaert expects PV cell production at the plant to reach 30,000 kW per year.

WAYNESBORO, VA — Sales of blower doors to Europe are booming, according to officials at Infiltec, an American blower-door manufacturer. "Right now, more blower doors are being shipped to Germany than any place in the world," says David Saum, Infiltec's president. In the case of exports to the UK, Infiltec reports high demand for their larger units. As of April 1, 2002, a new regulation requires all new buildings in England and Wales to include a "reasonably airtight" air barrier, and requires new buildings over 1,000 square meters to be blower-door tested. "We are now selling 60,000-cfm fans to the UK as fast as we ship them over there," says Baum.

RIVERSIDE, CT — Mold hysteria may be sweeping the country, but that hasn't stopped a British company from introducing edible mold to US supermarkets. *Fusarium venenatum*, a mold that grows naturally on dirt and grain, is being cultivated in vats by Marlow Foods and marketed as a meat substitute called Quorn. According to the *New York Times*, two Penn State mycologists, David Geiser and Gretchen Kuldau, accuse Marlow Foods of deceptive labeling. Quorn packages claim that the main ingredient "comes from a small, unassuming member of the mushroom family." The mycologists counter that *Fusarium venenatum* is not a mushroom but a fungus "more accurately described as a mold."

PARMA, OH — Ohio Governor Bob Taft has announced a \$100 million, three-year state initiative for fuel-cell research. The initiative, which will invest in fuel-cell technology research, hydrogen infrastructure research, and fuel-cell demonstration projects, is part of a state job-creation program called the Third Frontier Project. Taft announced the initiative during a tour of Graftech, Inc., a manufacturer of fuel-cell components.

DIAMOND BAR, CA — Ten homes in Southern California will each be equipped with a 5-kW fuel cell in a demonstration project funded by the South Coast Air Quality Management District (AQMD), a public agency in Orange County. Fuel Cell Technologies of Kingston, Ontario, will supply the fuel cells under a \$336,149 contract with AQMD. The solid-oxide fuel cells will be powered by natural gas, and will supply both electricity and domestic hot water to the 10 homes. Installation is expected to begin in the fall of 2002.

LATHAM, NY — Fuel cell manufacturer Plug Power Inc., has announced an agreement to collaborate with Honda R&D, a subsidiary of Honda Motor Co., to develop a stationary fuel cell that produces hydrogen gas for refueling vehicles. The companies envision a residential natural-gas-fired fuel cell that not only provides domestic electricity, heat, and hot water, but also is capable of refueling hydrogen-fueled cars.

SALT LAKE CITY, UT — Utah has passed legislation authorizing net metering for residential producers of electrical energy from renewable sources. The bill applies to photovoltaic, wind, micro-hydro, and fuel-cell installations of not more than 25 kW. Under the bill, customers will be able to sell excess power to the local electric utility at the retail rather than the wholesale rate.

HORSHAM, PA — Home Slicker, the three-dimensional nylon mat used in rainscreen applications (see *EDU*, April 2002), has received a Class A fire rating, according to Benjamin Obodyke Inc., the distributor of the product. Since Home Slicker has passed the ASTM E84 fire test, it can be used in any type of cladding system without degrading the fire resistance of the wall assembly.

RESEARCH AND IDEAS

Rethinking Attic Ventilation Requirements

Does roof ventilation significantly lower the temperature of asphalt shingles? Most US asphalt shingle manufacturers imply that unventilated sheathing can get hot enough to shorten shingle life, since they provide full warranty coverage only for shingles installed over ventilated sheathing.

Two recently published papers discuss the effect of roof ventilation on asphalt shingle temperatures. One is a report by veteran shingle investigator William Rose, a

research architect at the University of Illinois in Champaign. The second is an article by Carl Cash and Edward Lyon, "What's the Value of Ventilation?", published in the March 2002 issue of *Professional Roofing* magazine.

Rose's Shingle Research

Rose's paper, "Measured Summer Values of Sheathing and Shingle Temperatures for Residential Attics and

Cathedral Ceilings," was presented at the Buildings VIII conference in Clearwater Beach, Florida, in early December 2001. The site of Rose's ongoing shingle research is a test building erected in Champaign, Illinois, in 1990 (see Figure 7). The building has a gable roof with a 5:12 pitch, with the peak running east-west. The building is divided into eight test bays, each with different experimental conditions (see Table 2). Each 8 ft by 20 ft bay is isolated from adjacent bays by an insulated wall. The roof is sheathed with $\frac{7}{16}$ -inch OSB covered with #15 asphalt felt. All of the bays have a minimum of R-30 roof insulation, located either in a cathedral ceiling or above a flat ceiling. During the summer months, indoor temperatures are maintained at 75°F.



Figure 7 — Bill Rose's shingle temperature data are collected at a test building in Champaign, Illinois. The research building has 10 bays, each 8 ft wide by 20 ft deep. On the roofs of the eight center bays are dozens of temperature probes wired to data loggers. The roofs over the two end bays are not part of the study.

Some of the roofs are vented and some are unvented. Vented roofs have ridge and soffit vents connected by continuous air passages. The nominal vent ratio (net free area of vent over the projected horizontal roof area) is 1/150.

For several years, temperature data have been collected at hourly intervals from various locations. Sheathing temperatures are measured by thermocouples located between the OSB sheathing and the asphalt felt, while shingle temperatures are measured by thermocouples sandwiched between two successive courses of shingles.

The study reports on how asphalt shingle and sheathing temperatures during the summers of 1994, 1995, and 1996 were affected by the following variables: ventilation, shingle color, orientation, framing type, number of shingle layers, and insulation placement. For the purposes of the study, the roof chosen as the "base case" roof was a vented roof with two layers of shingles (black shingles on top) above a truss-roofed attic with a flat ceiling. The temperatures of the other roofs were reported as either hotter or cooler than this "base case" roof.

Rose has developed his own statistical method for comparing temperatures from roof to roof. The data were represented in a form of correlational analysis. This was done using linear regression of individual cases against the base case. The slope of the regression line was used to permit the temperature of the comparison case to be expressed as "hotter than" or "colder than" the base case as a percent. The statistical method behind these comparisons is fairly complex. The method's most important feature is its usefulness in ranking factors in order of their effect on shingle temperature.

Table 2 — Roof Conditions at Champaign Research Facility

Bay number	Venting	Ceiling type	Roof framing	Shingle color	Number of shingle layers	Insulation type
1	Vented	Flat	Trusses	White	Two	R-30 fiberglass
2	Unvented	Flat	Trusses	Black	One	R-30 fiberglass
3	Vented	Flat	Trusses	Black	Two	R-30 fiberglass
4	Unvented	Flat	Trusses	Black	Two	R-30 fiberglass
5	Vented	Flat	Trusses	Black	One	R-30 fiberglass
6	Vented (no air chutes)	Cathedral	2x12 rafters	Black	One	R-30 fiberglass with gap above
7	Unvented	Cathedral	2x12 rafters	Black	One	R-30 fiberglass with gap above
8	Unvented	Cathedral	2x12 rafters	Black	One	R-30 fiberglass plus 1-in polyisocyanurate

Table 2 — At the Champaign Research Facility, each of the eight test bays has different conditions. Half of the bays have vented roofs and half unvented. For the purposes of the study, Bay 3 is considered the "base case" roof.

Shingle Color Matters More Than Venting

Rose found that while ventilation does lower shingle temperatures, other factors, including shingle color and roof orientation, have a greater effect on shingle temperature. While ventilation was found to lower the temperature of shingles by 2.7% compared to a comparable unvented roof, white shingles were found to be 20% to 23% cooler than black shingles. Moreover, on the "base case" bay, the north roof slope was 8.7% cooler than the south roof slope.

Rose also found that shingles above a vented cathedral ceiling are cooler at the eaves and hotter at the ridge than shingles above a vented attic. This is due to the strong temperature gradient, especially on the south side of the roof, which exists in the ventilation channel above a cathedral ceiling. "It becomes apparent that venting can cool the lower section of a vented cathedral ceiling quite effectively, but the cooling effect is greatly reduced for the upper part of the cavity," writes Rose.

There are many good reasons to vent a roof — to maintain a shingle warranty, to remove moisture from the roof assembly, and to comply with code requirements. However, when it comes to lowering shingle temperatures, ventilation is far less important than roofing color. "The role of ventilation as a temperature modifier for shingles is perceived to be greater than it really is," concludes Rose.

Computer Modeling of Shingle Temperatures

While Rose's conclusions are based on rooftop temperature measurements, Cash and Lyon used computer modeling to compare asphalt shingle temperatures under a variety of scenarios. Cash and Lyon looked at several variables, including two different shingle colors (black and white), seven locations (ranging from Miami, Florida, to Green Bay, Wisconsin), a variety of roof orientations, and several different roof slopes. Under all of these scenarios, they compared the temperatures of shingles installed over cathedral ceilings with and without ventilation.

Cash and Lyon are aware of the limitations of computer modeling. "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 ventilations systems," they wrote.

Like Rose, Cash and Lyon found that shingle color trumps ventilation. "In all instances, changing roof color from black to white has more effect on yearly mean temperature than ventilation," wrote Cash and Lyon. "Ventilation reduces the yearly mean temperature of a black roof system by an average of 0.7 degrees Celsius, and changing to white shingles reduces the yearly mean temperature by an average 1.6 degrees Celsius."

Unlike Rose, however, Cash and Lyon were able to compare asphalt shingle temperatures in different climates. "The greatest influence on roof temperature is geographic location," wrote Cash and Lyon. "The mean roof temperatures for Miami and Green Bay, Wisconsin, for example, differ by 18 degrees Celsius." The second greatest factor after geographic location, Cash and Lyon concluded, was roof slope orientation.

To Remove Humidity?

Some manufacturer's representatives claim that one reason for ventilation requirements in shingle warranties is the removal of attic moisture. But most experts doubt that attic humidity shortens shingle life. "By and large, roofing materials, with few exceptions, are very resistant to water," says Cash. "They have to be." Rose notes that attic humidity levels are not the most important determinant of shingle humidity. "The wetness of shingles is entirely a function of rain and sun," says Rose.

Asphalt shingle warranties have not always required roof ventilation. "The earliest attachment of a venting condition to a shingle warranty dates from around 1988," says Rose. "For decades before that, we had a code requirement for attic ventilation, but the shingle manufacturers didn't piggyback their warranties on it. Then in the late 1980s they did, as soon as they started getting sued like crazy for cracking shingles."

Tom Bollnow, senior director for technical services at the National Roofing Contractors Association, often talks to roofers with warranty claims. "I feel that the manufacturers have been looking for reasons for shingle problems," says Bollnow. "Obviously heat buildup has been one of them." When cracked shingles show up on unventilated roofs, most manufacturers blame the installer. "Oftentimes, when a manufacturer's rep investigates a problem, the first two things they look for is ventilation and how the shingles are fastened," says Bollnow. "Those are the primary reasons that they say, 'There is a problem with the ventilation or the installation and it's not our problem.'"

Yet if high temperatures are enough to cause premature shingle failure, why do manufacturers guarantee black shingles on a ventilated Florida roof, but not white shingles on an unventilated Minnesota roof? This inconsistency leads Cash and Lyon to question the logic behind warranty ventilation clauses. "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," they write. "This exclusion has no justification; the variations in geography, direction and shingle color have greater influences on average temperature than the degree of ventilation."

Beyond the question of ventilation's role in modifying shingle temperatures is the question of whether shingle temperature matters. Although many people assume that high temperatures shorten shingle life, there is not much data to back up the theory. "We have a pretty good history on our products, and there is no indication at all that black shingle roofs fail in a shorter time than white shingle roofs," notes Husnu Kalkanoglu, director of technology for the roofing division at CertainTeed, a shingle manufacturer.

Like Cash and Lyon, Rose feels that recent research findings require a response from the manufacturers. "I'm throwing the ball back in the court of industry," says Rose. "If they are saying that ventilation is important, then the public is left with the impression that

ventilation is important because it modifies temperature. Since I'm showing that ventilation has a small ability to modify temperature compared to other factors, they have more explaining to do. I'm waiting for that explanation."

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The Point Five Rule

In a house with 50 cfm of natural infiltration, how much additional airflow will result from the installation of an exhaust fan that moves 75 cfm? The surprising answer: 37.5 cfm. The rule behind this phenomenon can be simply stated: The installation of an exhaust or supply fan that moves less than twice the airflow of the natural infiltration rate will cause additional airflow in the house equal to half the airflow moved by the fan. Or, again assuming that the fan moves less than twice the natural infiltration rate, total flow equals natural infiltration plus 0.5 times fan flow.

The Point Five Rule was first noted in a paper by Larry Palmiter and Tami Bond, *Impact of Mechanical Systems on Ventilation and Infiltration in Homes*, published in 1992 as part of the ACEEE Summer Study. Paul Francisco, a research scientist who works closely with Palmiter at Ecotope in Seattle, Washington, explained the Point Five Rule to an interested audience at this year's Affordable Comfort conference in Cincinnati, Ohio.

Francisco noted that during the heating season, the stack effect in a house causes outdoor air to enter low and indoor air to exit high. The height at which the airflow direction changes (where the pressure difference between the inside and the outside is zero) is the neutral level. A house with more holes near the floor will have a lower neutral level than a house with more holes near the ceiling. Pressurization of a house by a supply fan lowers the neutral level, while depressurization by an exhaust fan raises the neutral level.

The installation of a balanced ventilation system with a 75-cfm exhaust fan and a 75-cfm supply fan will result, unsurprisingly, in 75 cfm of added airflow entering and leaving the house. But, in a house with 50 cfm of infiltration and 50 cfm of exfiltration, the installation of a 75-cfm exhaust fan will result in added airflow of not 75 cfm but 37.5 cfm, raising the infiltration level to 87.5 cfm. Although the 75-cfm fan moves 75 cfm of air, the house gets only 37.5 cfm of additional airflow.

This occurs because the operation of the exhaust fan raises the house's neutral level, causing some of the wall leaks that were outlets to become inlets. The flow through the ceiling and upper walls decreases by 37.5 cfm, while the flow through the floor and lower walls increases by 37.5 cfm. The total infiltration rate is thus increased by 37.5 cfm.

What happens to the same house when a larger exhaust fan is installed? Assuming (as most models do) that 50% of the leaks in the house are in the walls, 25% in the floor, and 25% in the ceiling, operation of a 100-cfm exhaust fan will stop any air from exiting

Table 3 — Modeled and Measured Airflows, Tracer Gas Study

Modeled Measured Fan Airflow (cfm)	Added Airflow Using the Point Five Rule (cfm)	Ratio of Measured Added Airflow (cfm)	Modeled Airflow to Measured Airflow (cfm)
75	37.5	36.5	1.03
27	13.5	13.5	1.00
50	25.0	26.2	0.95
67	33.5	30.4	1.10
205	102.5	85.0	1.21
94	47	61.0	0.77
198	101.0	124.8	0.81
227	158.0	137.3	1.15

Table 3 — The Point Five Rule posited by Palmiter and Bond suggests that the added airflow resulting from the installation of an exhaust fan will be equal to 0.5 times the fan's airflow. Using the MultiTracer Measurement System developed at Lawrence Berkeley Laboratory, Palmiter and Bond found that actual airflow measurements made at eight sites in seven houses correlated closely with the predicted airflows calculated according to the Point Five Rule.