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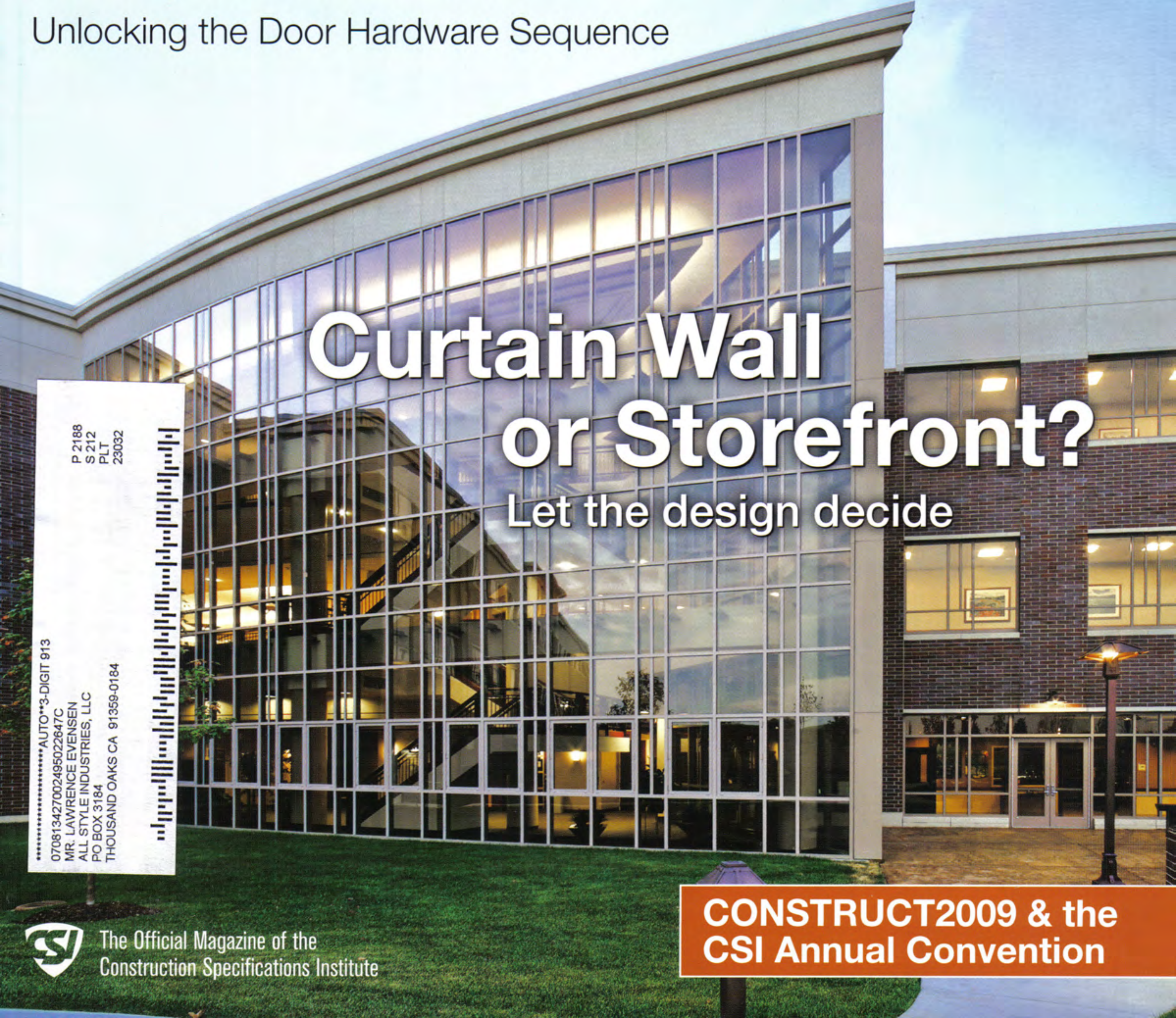

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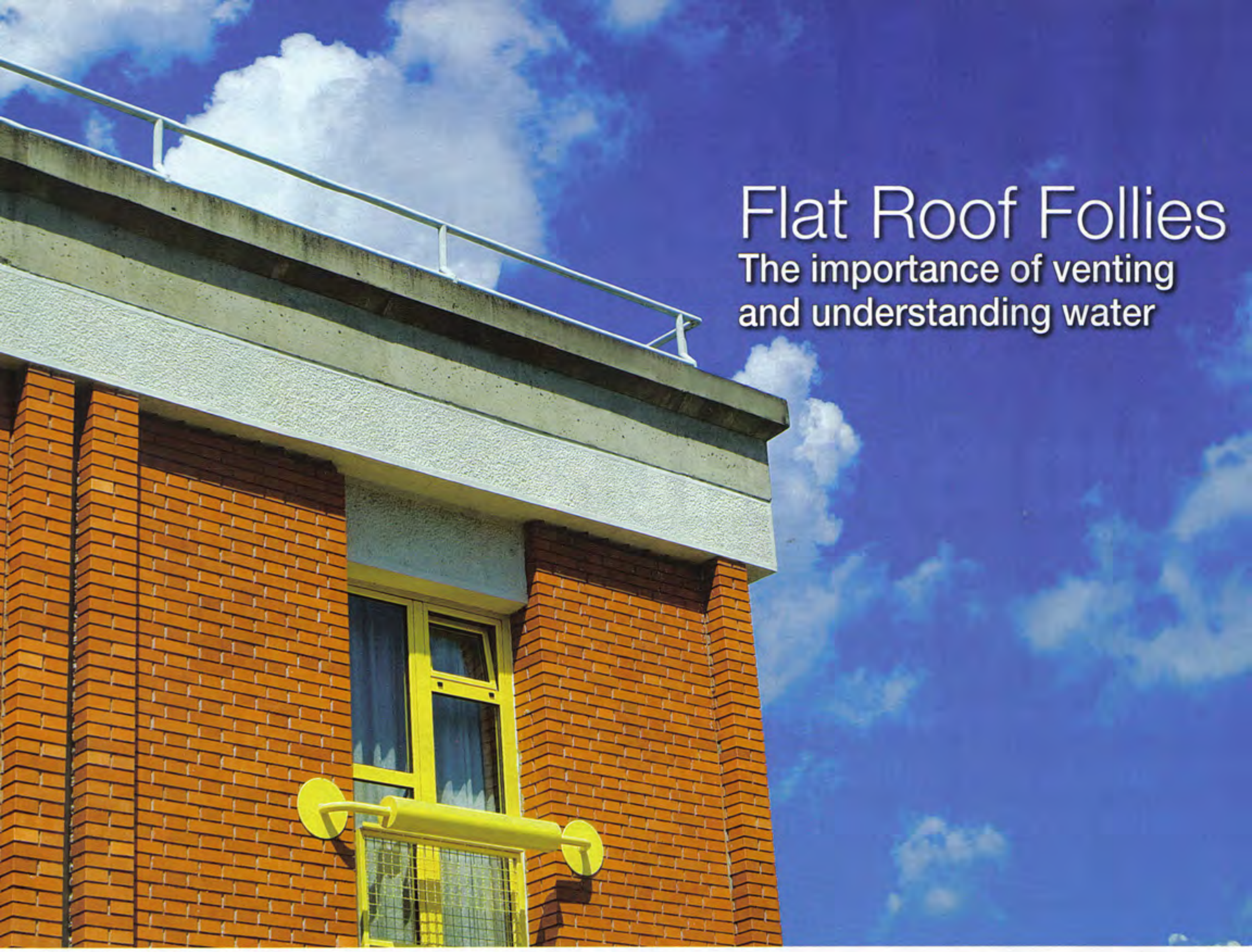


Flat Roof Follies

The importance of venting and understanding water

by Lawrence P. Evensen

Photo ©BigStockPhoto.com

THIS AUTHOR KNOWS OF A REPAIRMAN WHO WALKED ACROSS A COMMERCIAL FLAT ROOF IN VISALIA, CALIFORNIA, ONLY TO SUDDENLY BREAK THROUGH AND FALL 9 M (30 FT) TO THE CONCRETE FLOOR.

Despite being installed to modern codes and standards, the 10-year-old roof had dangerous defects that created an environment for the proliferation of fungi and mold. These agents of destruction not only discolored surfaces and led to odor problems, but also deteriorated the building materials to the point the roof became unsafe. (Fortunately, and miraculously, the repairman walked away, largely unscathed.)

A roof is designed to keep water out. However, just because rainwater cannot pass through a roof covering, that is no guarantee of dryness. Moisture problems are not caused by exterior leaks alone. Water vapor condensing inside a structure has to be considered. Indeed, today's structures are more insulated, airtight, and energy-efficient than ever before. This has its benefits, but is a double-edged sword—airtight structures have a higher concentration of moist air, which can now be trapped inside.

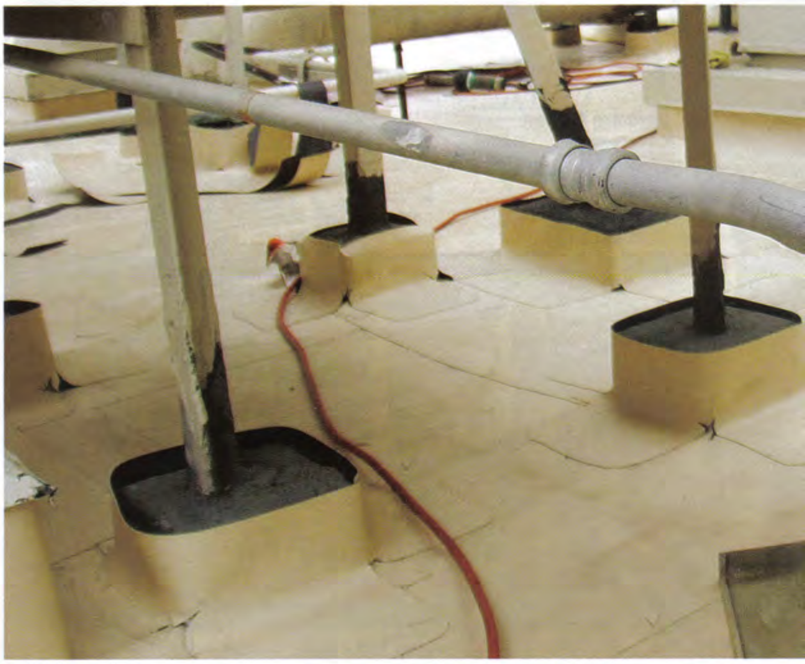
Consequently, it is critical to examine conditions that create water and water vapor within the building envelope. This article explores the physiology of water and the ability of venting to interrupt the water cycle. In so doing, it offers new methods for keeping low-sloped roofs dry, safe, and durable.

Moisture dangers

In the United States, the largest class of low-sloped roofing systems protecting commercial and industrial buildings is built-up roofing (BUR). Representing a third of the multi-billion dollar industry, BUR assemblies far outnumber the growing market share of single-ply or other roofing products installed each year. However, no matter what class of roofing system is installed, there must be considerations for allowing the escape of trapped water inside the structure. This is because many types of roofing membrane malfunctions are due to water's thermodynamic cycle. (For more on such changes of state, see "Riding the Water Cycle," page 72.)

The typical flat roof covering may consist of a structural roof deck, a near-impermeable vapor barrier, insulation, and an impermeable roof cover. Water can be introduced into this assembly via three common pathways:

- roofing materials with high moisture content due to relative humidity (RH) or from exposure to rain when the roof is assembled;
- leaks passing around the installed impermeable membrane due to damage, poor installation techniques, or faulty design; and/or
- moisture migrating up to the roof assembly from inside the structure.



Non-round roof penetrations are extremely difficult to flash. Pitch pockets are the lazy way to encase odd-shaped geometric shapes rather than creating a true roof flashing detail. These examples highlight issues presented by pocket filler products that shrink, crack, and funnel water into a structure.

Images courtesy All Style Industries

Figure 1

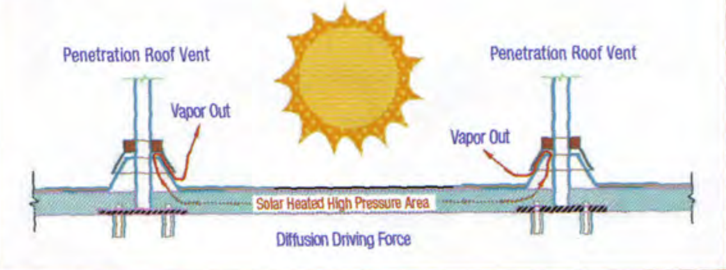


Figure 2

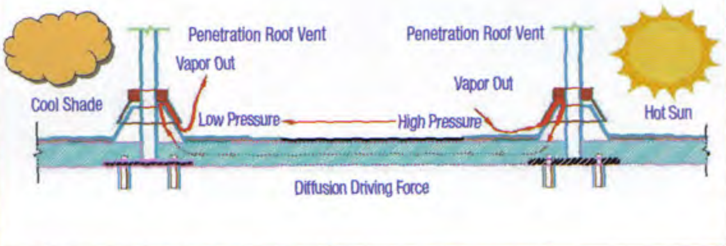
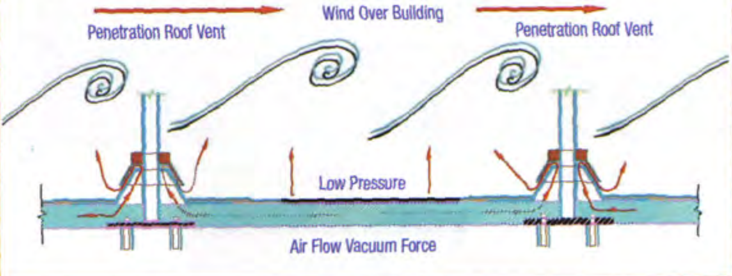


Figure 3



To design a successful roof, one must include considerations for water vapor within the assembly and provide escape routes for that moisture. The figures above illustrate the three dynamic forces that can help facilitate this. Figure 1 shows how convection's pumping action (caused by pressure changes) can promote 'breathing' within the assembly, pushing vapor out the roof. Figure 2 provides an example of diffusion flow—water phase change pushing vapor from areas of high pressure to sections with lower pressure. Figure 3 demonstrates how wind passing over a building creates a low pressure across its surface that can draw air out of openings.

No matter how water enters a roof system, it will change phase between solid, liquid, and gaseous states and cause problems.

When vapor barriers are installed, they can promote a cycle where vapor rising to a cool, impermeable roof cover reaches the dewpoint and changes back into a liquid. Now heavier, the liquid water then cascades down to the near-impermeable vapor barrier, where the heat-cool process begins again.

These cycles waste enormous quantities of energy that negate the value of the insulation and create conditions that promote fungi, mold, and mildew. Structural components can rot to the point of failure, and the building's integrity and useful life may be jeopardized.

Venting strategies

A sound and robust roof design must include provisions for water vapor within the assembly and provide escape routes for that moisture. The designer can count on three dynamic forces to facilitate a workable vapor-venting strategy.

To start, air can move laterally through roof assemblies by convection. A roof subject to heating and cooling cycles will experience a water phase change at different locations across its surface. The resulting pumping action caused by pressure changes can promote 'breathing' within the assembly, pushing vapor out of the roof (Figure 1).

Next, water vapor can move through a roof system by way of diffusion flow or differences in vapor pressure. Water vapor held within a roof assembly will not heat uniformly over the entire roof surface. Unevenly heating a roof area creates different levels of vapor pressure between locations due to irregular solar heat gain or shading across its surface. This patchy warming causes unstable levels of water phase change that push vapor from areas of high pressure to sections with lower pressure (Figure 2).

Lastly, water vapor can be extracted by positive airflow from outside the structure. Wind passing over a building creates a low pressure across its surface that can draw air out of the openings. The amount of pressure is related to the structure's design, height, and shape, along with how hard the wind is blowing (Figure 3).

The fluid dynamic phenomenon explaining this vacuum is the 'Bernoulli principle,' named after the man who discovered an increase in the speed of a fluid (*i.e.* air, in this case) occurs simultaneously with a decrease in pressure. A shower curtain demonstrates this principle by moving inward when the water spray is turned on. The water/air velocity moving along the inside of the curtain (relative to the still air on the other side) causes a pressure drop (or vacuum), pulling it inward.

Further, the Bernoulli principle has an impact on vapor movement out of openings on a roof as wind passes across the openings. Lower pressures within the opening draw air up and out of the building. This phenomenon, the 'Venturi effect,' is the same dynamic principle demonstrated when air blows across the open top of a straw and pulls liquid up the straw.

Running back to Saskatoon

In reality, a roof is not 'blown' off a building by wind. What actually happens is that when the air pressure on the roof's top side is sufficiently lower than the air pressure inside, the higher pressure literally pushes the roof off the building.

Testing has been done to offer clues on the effectiveness of venting on dry flat roof assemblies. Published by the National Research Council of Canada Institute for Research in Construction (NRC-IRC) in the May 1976 *Canadian Building Digest*, M.C. Baker's small-scale long duration effectiveness tests show dynamic roof drying is possible (Figure 4, page 74).[1]

The test location was the Canadian city of Saskatoon, Saskatchewan, for a duration of six years. A dozen test panels using four types of rigid insulation (including fiberglass, perlite, and bead polystyrene materials) were employed—each measured 600 mm (24 in.) wide by 1200 mm (48 in.) long by 50 mm (2 in.) thick. These test panels included three different vent placement configurations over the insulation panels:

- vent placed directly on the center of the insulation surface;
- vent placed at the point of intersection of butt joints formed by cutting the insulation into four equal pieces; and
- vent placed directly on the center of the insulation surface over a 25-mm (1-in.) hole cut into the insulation material.

(The single vent allows for only diffusion breathing.) The test groups were wetted with a measured amount of water and each panel was sealed in

RIDING THE WATER CYCLE

The Visalia, California, incident discussed on page 68 exposes the illusion of a building's watertight integrity. It illustrates the powerful forces that can overwhelm and destroy even the best roof design. Only by understanding these forces can a designer overcome the dynamic cycle created when water exists as a solid, liquid, and gas within a building envelope.

As we learned in high school science class, all matter exists in one of three states, depending on pressure and temperature subjected to its mass of atoms. As something switches from a solid, liquid, or gas, the conversion of its physical state (*i.e.* phase transition) is accompanied with changes in heat-holding capacity and temperature.

Roofers are familiar with materials that change phase when asphalt is melted. Asphalt is hard and brittle when cold; it must be put into a roofer's kettle and heated before use. As the asphalt is heated, it changes from a solid into a liquid. If the roofer were to continue adding heat, the asphalt would again change phase into vapor. (Asphalt vapor is an explosive gas and kettle fires are extremely dangerous.)

The culprit behind the Visalia building's roof failure, water, is another 'phase change' material.* The chemical formula 'H_2O' describes one molecule of water as having two hydrogen atoms bonded to a single oxygen atom. The strong hydrogen bond between H_2O molecules provides a sticky structure (*i.e.* surface tension cohesion) that attracts water molecules so firmly they stay together as droplets even as they fall thousands of feet through the sky as rain.

Water becomes less dense as a solid, expanding in volume by about nine percent. (This is the reason ice floats when most other solids, such as asphalt, sink.) As water vapor expands in volume, it fills a space up to 1700 times larger than its liquid phase.

Building envelope failures are often the result of water's strong hydrogen bond, which provides for the second highest ability of all chemical compounds to hold and release energy. During phase transitions, the amount of heat energy released or absorbed (*i.e.* latent heat) is very large, compared to other substances. (Ammonia is the only substance with a greater heat-holding capacity.) The energy requirements to evaporate and condense water is the reason it takes so much time to boil, and why ice cubes cool a drink so quickly.

Changes of state

At sea level, water changes from a solid into a liquid or from a liquid into a gas at two critical temperatures.

Liquid/solid

At 1 C (33 F), water is a liquid, but when it releases enough heat energy to reach 0 C (32 F), there is a phase change into solid ice. The energy required to alter water through this transition without changing its temperature is the 'heat of fusion.'

This point (or inversely, 'specific melting heat') equals the amount of thermal energy absorbed or extracted from a substance to change it from a solid into a liquid (or vice versa). For water, the heat of fusion energy released or gained at the critical temperature of 0 C is 79.7 cal/gram.

continued on page 74

continued from page 72

Liquid/gas

At 99 C (211 F), water is a liquid, but when it gains enough heat energy to reach 100 C (212 F), there is a phase change into steam vapor. The energy required to change water through this transition without affecting its temperature is referred to as 'heat of vaporization.'

The heat of vaporization (or inversely, 'heat of condensation') equals the thermal energy absorbed or extracted from a substance to change it from a liquid into a gas (or vice versa). For water, the heat of vaporization energy released or gained at the critical temperature of 100 C is 539 cal/gram.

When water has a phase transition from a gas into a liquid, it is called 'condensation.' This normally occurs when water vapor is cooled to its dewpoint at constant barometric pressure. The 'heat of condensation' is equal to that of vaporization, but has the opposite effect of releasing energy.

Water molecules generally stay bonded until enough energy exists to break them away from the liquid state and allow them to float away as a vapor. Heat can also affect the surface of liquid water through ambient heating (*e.g.* sunshine) creating movement of surface molecules. As the molecules collide, they transfer energy to each other; sometimes, enough energy is absorbed to cause the water molecule to vibrate, break the hydrogen bond, and allow escape into the atmosphere.

The transformation where molecules in a liquid state spontaneously become gaseous vapor is called 'evaporation.' As hydrogen bonds are excited, and molecules break from the surface, the remaining liquid water loses 539 cal/gram of latent heat energy due to the effects of the heat of vaporization. This lowers the temperature of the remaining volume of liquid water, and is the process behind evaporative cooling.**

Under pressure

Vapor can also be phase-changed through variations in pressure. A good example is exhibited by a gas cylinder that holds condensed liquid propane (C_3H_8) gas. When the tank valve is opened, the expanding C_3H_8 liquid rapidly transitions into the vapor gas. As the gas transitions, there is a huge heat of evaporation effect that cools the valve and metal exterior of the tank.

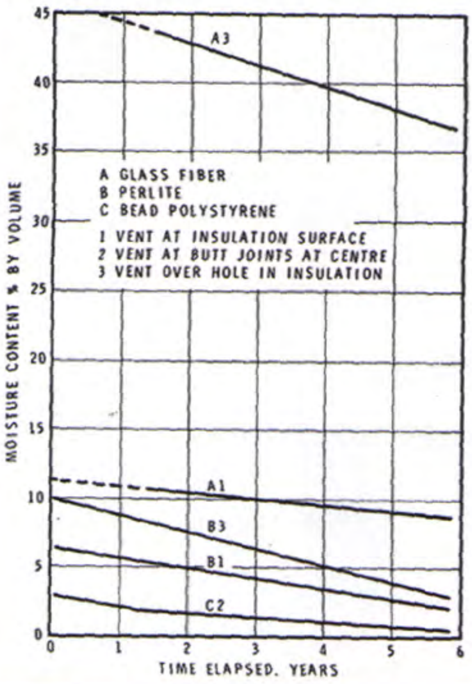
As ice forms on the outside of the C_3H_8 cylinder, it represents the cycle of evaporation and condensation in a classic setting. Atmospheric water vapor surrounding the tank is cooled to the dewpoint by the cylinder's cold exterior because of the heat-of-evaporation phenomenon. The condensing liquid water freezes onto the side of the tank.

As the liquid water cools, it loses 79.7 cal/gram of energy (heat of fusion point), and changes into ice at the exact time enough energy is lost for its temperature to reach 0 C. This example of the thermodynamic cycle, repeated on a huge scale, causes massive fluctuations in the earth's climate and provides major challenges for building envelope designers.

* Water is the only innate inorganic liquid and the only chemical compound occurring naturally in all three physical states.

** Swamp coolers use this principle to cool living spaces such as homes and offices. Since the process depends on evaporation, swamp coolers are usually found in relatively dry climates such as desert regions. **CS**

Figure 4



The work of the National Research Council of Canada Institute for Research in Construction (NRC-IRC) proved that dynamic roof drying is possible.

polyethylene (except for the hole under the vent). The panels were placed on the roof of an experimental building; they were weighed at intervals to determine changes in moisture content.

The results of the tests showed moisture escaped from each test panel at differing slow drying rates. Consistent venting and slow gradual diffusion drying is evident for well-designed waterproof roof systems. The data also indicates drying roofs with vapor barriers, insulation, and impermeable roof covers is possible. A conclusion is roof vents can accomplish improvements in drying effectiveness, and reductions of moisture introduced to a roof during the construction process and/or after installation.

Vents can provide an escape route for the water vapor when the roof design is watertight and a lot more ventilating area is provided. The National Roofing Contractors Association (NRCA) has been recommending designers of steep-slope roof assemblies to provide attic ventilation by using static, balanced ventilation systems with a minimum amount of 0.09 m^2 (1 sf) of net free ventilating area for every 28 m^2 (150 sf) of attic space measured at the attic floor level (*i.e.* 1:150 ventilation ratio). It only makes sense to provide an equal standard for flat roof venting.

Water's great escape

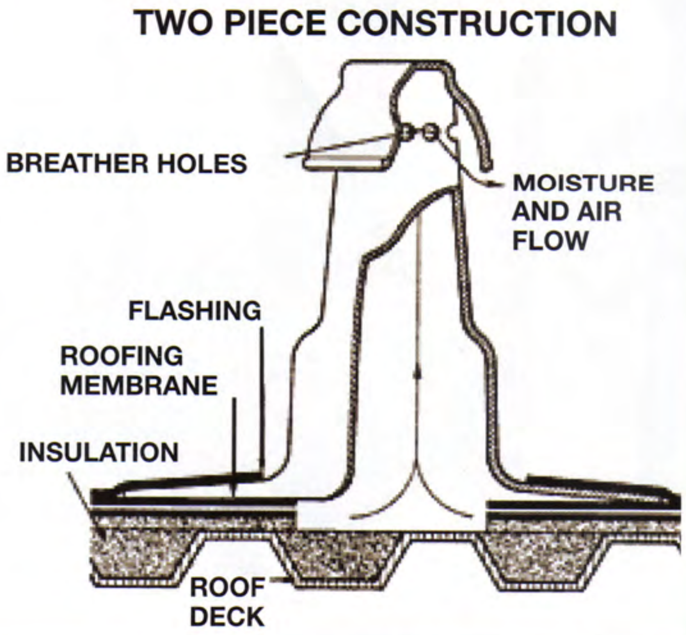
A completely closed roof system is a myth—even under perfect conditions, flat roof seals are unpredictable. The opaque cloud of water condensation exhibited inside sealed double-pane windows is proof the water cycle can negatively affect even the tightest 'sealed' systems. It is folly to expect sealed roof assemblies to remain perfectly dry when factory-made double-pane windows regularly fail.

Provisions for venting a roof enhance the possibility of long life and a healthy building envelope by using one or all of the following venting methods.

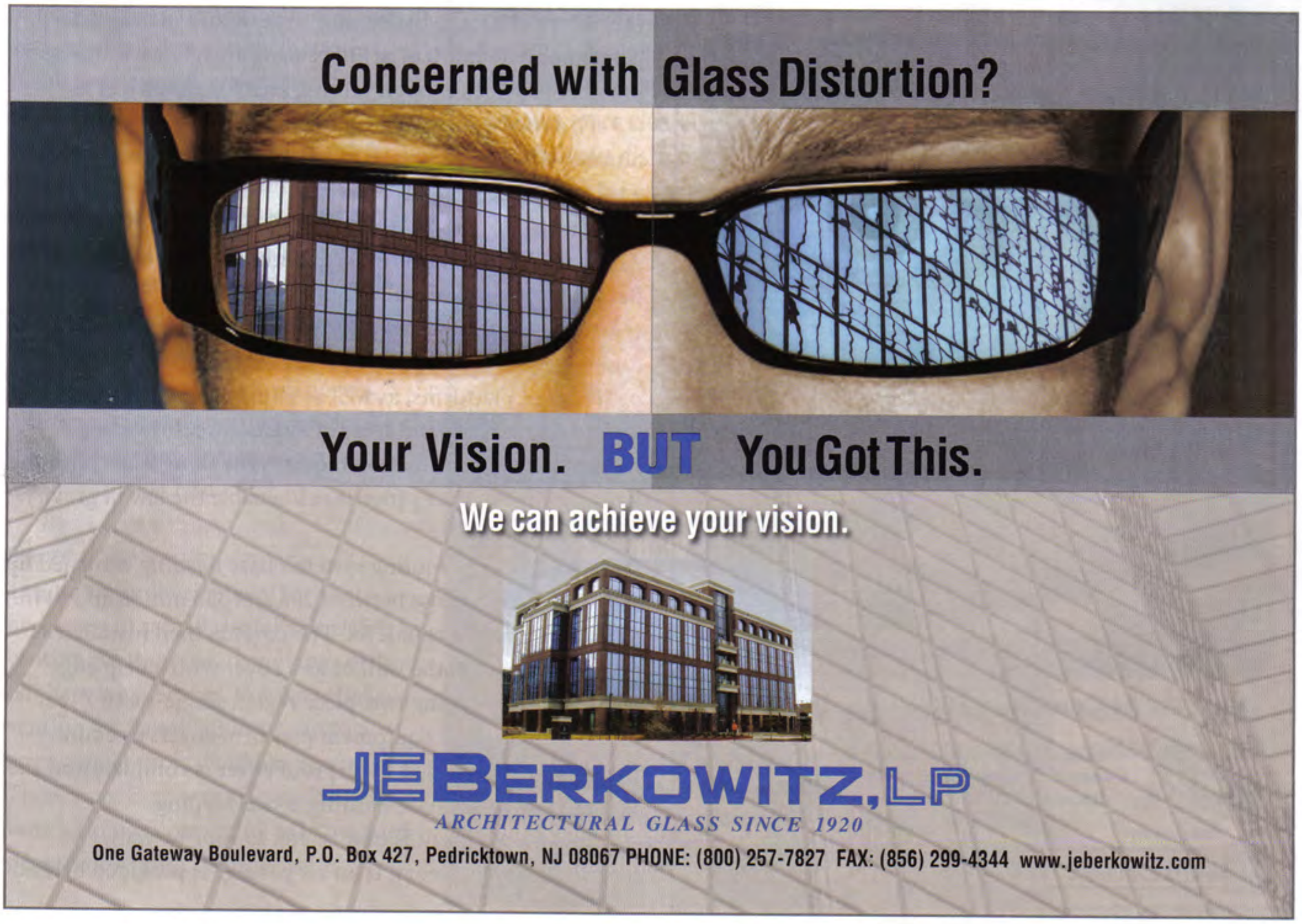
Breather vents

A breather vent can be fabricated in many cone diameters and lengths with cap designs that provide a one-way exit of wet, vaporous air from within a roof assembly (Figure 5). Pre-made vents provide one option, but the oft-cited manufacturer's recommendation of a 102-mm (4-in.) breather for each 93 m^2 (1000 sf) of roof area causes concern. With a cone diameter of 102 mm, each breather's overall venting area is 810 mm^2 (12.56 si).

Figure 5



Breather vents come in many cone diameters and lengths with cap designs, offering a one-way exit of wet, vaporous air from within a roof assembly.



This photo shows an onsite fabricated penetration flashing created from single-ply roofing materials. The mechanically attached flashing creates a rise in roof levels that are typically caulked and band clamped tightly onto the penetration, allowing no avenue for building movement or vapor escape.

When designing and building structures' low-sloped roofs, it is important to examine the various conditions creating water and vapor within the building envelope.

Image © BigStockPhoto.com

NRCA's 1/150 guideline provides that for every square (*i.e.* 9.3 m^2 [100 sf]), the venting area should include 0.66 percent or 0.06 m^2 (0.67 sf) of venting area. Since a 102-mm breather provides enough venting area for about 1.12 m^2 (13 sf), a roof would need eight breather vents—a substantial number—for every square to satisfy the 1:150 venting rule.

Wall vents

Another additional overlooked method of venting for a flat roof is the use of wall vents (Figure 6, page 78). Rarely are buildings without roof-to-wall details. A roof wall can be found as part of parapets, equipment platforms, and roof penetration platforms, as well as at the intersection between lower and higher plane areas of a structure. Providing a successful wall termination requires the same waterproofing flashing with a cover procedure to enable the law of gravity to work.

In this case, the roofing system's base flashing is turned up the wall to create a rise between 203 and 356 mm (8 and 14 in.) above the finished roof level. The cover is then installed as an integral part of the wall or as a cover with a drip edge termination. By using two-piece reglet, single-piece Z-bar, parapet copings, or equipment platform covers as counter-flashings, the provided waterproof cover is complete and the upward end of the base flashing is overlapping.

A roof-to-wall vent is easy to add to roof-to-wall terminations. In theory, if an air passage is provided behind

the base flashing extending under the impermeable cover, then water vapor accumulating within the insulation layers has a means to escape. A vent behind the base flashing allows the dynamic forces to drive water vapor out from within the roof. The challenge is providing a practical and reliable air escape channel scheme.

One solution is an off-the-shelf venting mat designed to provide vapor venting for steep-slope hip and ridge roof designs. A ridge vent mat is a randomly aligned natural fiber product made by heat-curing a latex-bonded polyester mesh. The natural fiber vent provides airflow, along with a barrier to most ambient water, dust, and pests. Vent mats are made with a cross-sectional dimension of 18.75 mm (3/4 in.) and, if used for wall vent applications, potentially create net free venting area along the entire edge.

Each 262.5-mm (10.5-in.) wide roll of fiber mat can be laid against a wall and extended down to the bottom insulation layer of a roof assembly, providing 5806 mm^2 (90 si) of net ventilating area for each 3.1 m (10 ft) length of wall. Ideally, wall vents would follow behind the base flashing and terminate at the open end of the mat safely under any wall's metal counter-flashing or cap. With hundreds of lineal feet of walls, parapets, and equipment platforms, wall termination venting provides a lot more net venting area at an extremely low installation cost.

Penetration vents

The total number of breather vents necessary to satisfy the NRCA 1/150 venting solution means relying solely on them is expensive. To have sufficient venting for 93 m^2 (1000 sf), up to 80 commercial vents would be required. There is an easy way to get additional ventilation by converting existing roof penetrations into breather vents.

Over the centuries, roof construction evolved to include two waterproofing techniques—flashings and counter-flashings. They both create a rise in the roof's membrane high enough to keep the elements from entering the waterproofing membrane. Pipes, conduits, vents, and support legs use a sleeve or 'jack' flashing to create a rise in the roof's level.

As a general rule, roof product manufacturers recommend using a flashing or inserting jacks for projections through a roof's membrane between 203 and 356 mm (8 and 14 in.) above the

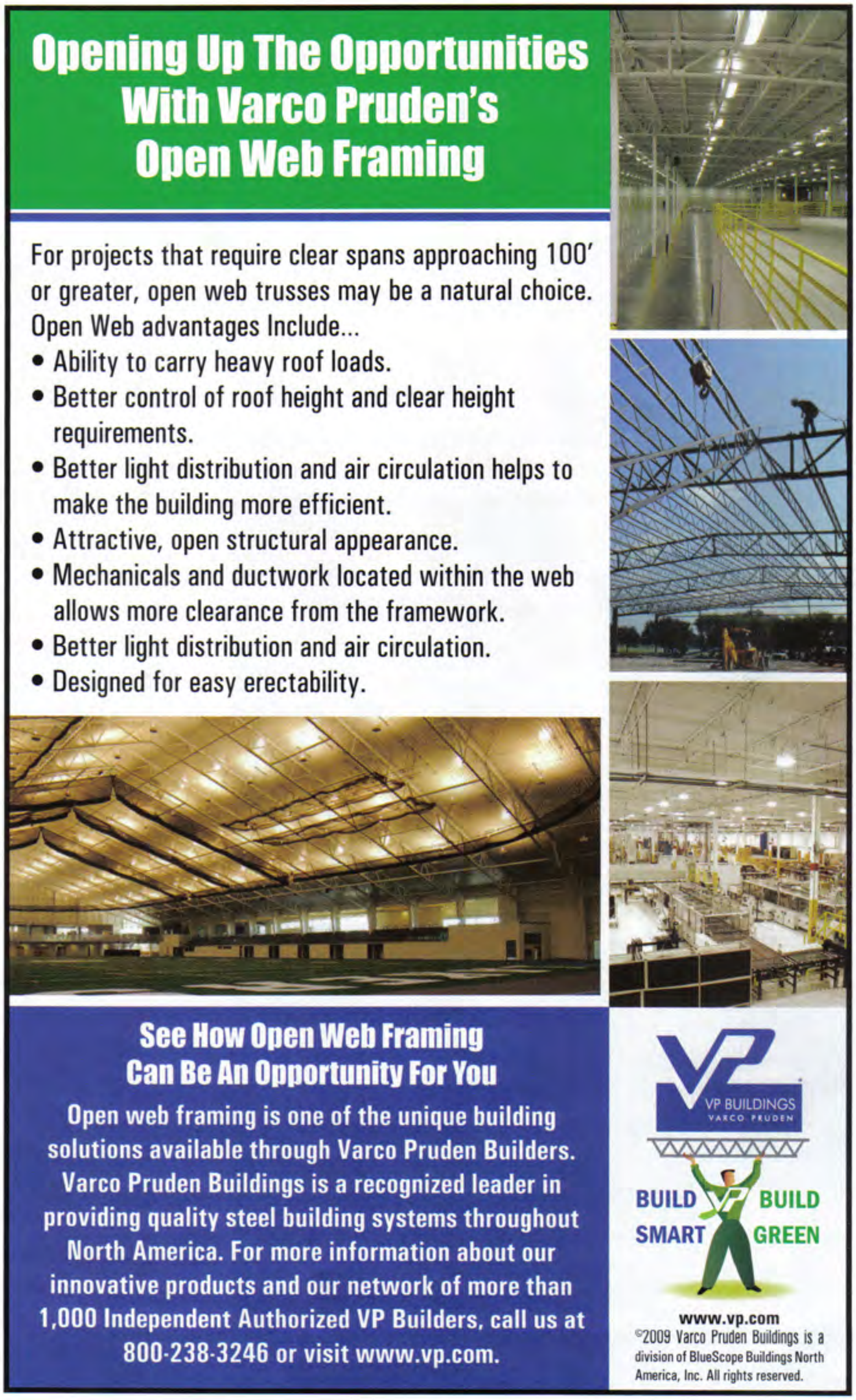
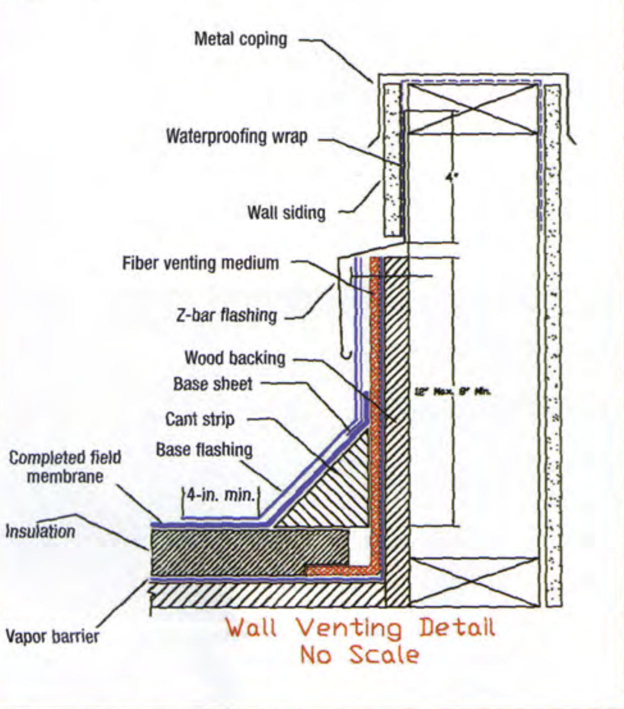
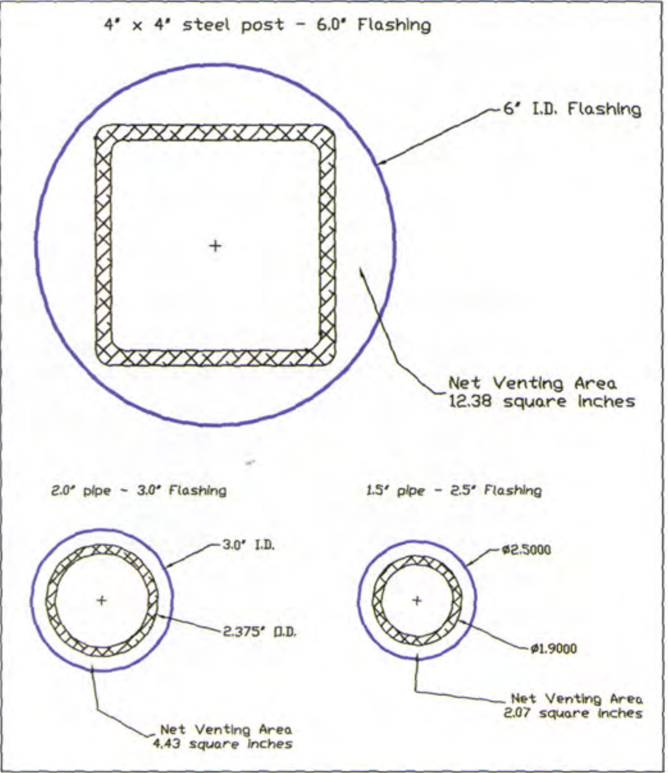


Figure 6



Wall vents are an oft-overlooked method of venting for a flat roof.



These details show cross sections of loose 'extra-space' roof penetration flashing assemblies. The space between tubular flashing risers that surround any geometric-shaped post, support, or pipe is area that can vent gases out of roof assemblies.

finished roof level on low-slope roof applications. The roof rise feature (or flashing) facilitates water runoff as long as weather conditions are not extreme enough to overflow.

Each respective manufacturer's standard roof specifications include penetration details for plumbing vents, electrical conduits, HVAC line sets, domestic water lines, natural gas, and all sorts of other roof penetrations. Each penetration can be matched to a pipe flashing jack with a proper outside diameter.

The cover or counter-flashing is designed to allow water to shed over or around the flashing opening. For each class of flashing, physics and the law of gravity for water flow are the same. The roof flashing is constructed to rise above the highest expected water level from a weather event, and is counter-flashed to cap its opening, allowing gravity to divert water.

Most penetration details are not designed using the flashing/counter-flashing method, but are mechanically attached to the roof penetration. A typical installation includes caulk at the union of the flashing opening and compression using a stainless steel band clamp. No allowance is made for thermal, seismic movement, or trapped water vapor.

If the tops of the flashings are not mechanically clamped, but remain open, then the roof design would allow for thermal and seismic movement, and offer vapor-escape avenues with free venting areas. This concept can be taken further when each flashing jack is sized larger than the roof penetration. An oversized flashing could provide greater amounts of free ventilation areas. Further, since a building can include hundreds (if not thousands) of roof penetrations, this venting technique can be exploited at little cost to the owner.

Storm collars

Using roof flashing covers called 'storm collars' or 'rain hoods' is an accepted technique.[2] Extra venting area can be gained by employing larger, loosely installed flashing jacks with a storm collar counter-flashing cover that protects the open rise end of a flashing.

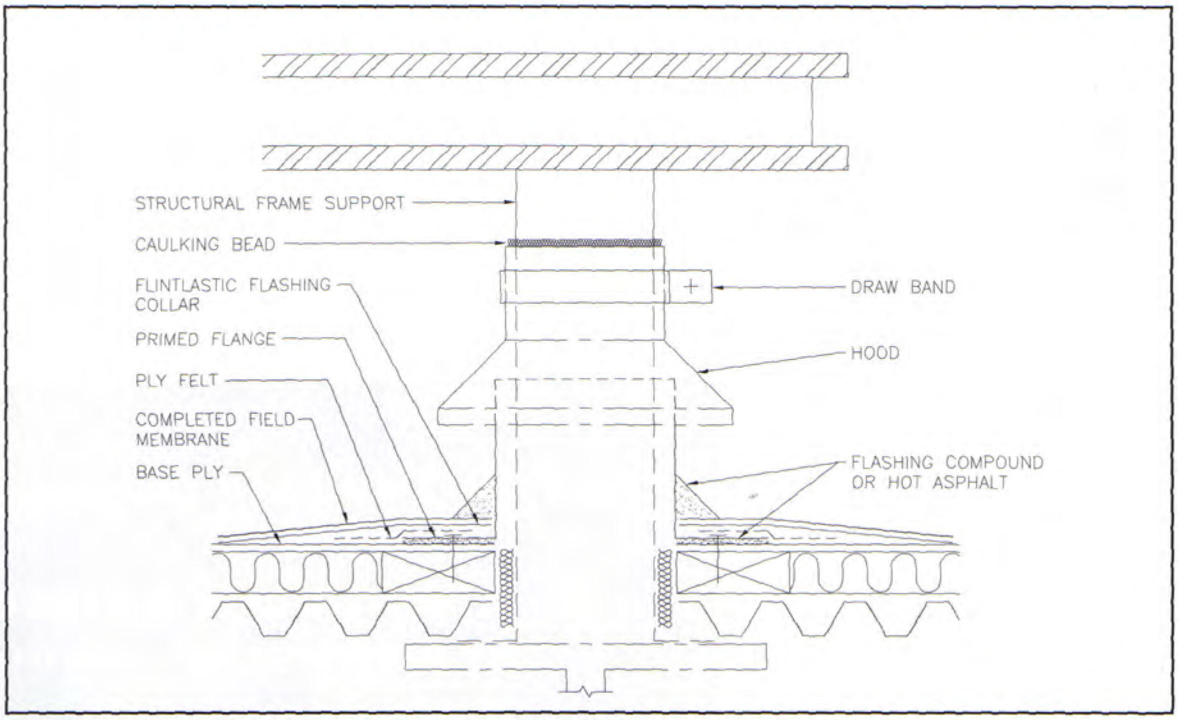
For example, installing oversized 62.5-mm (2.5-in.) flashings around a 51-mm (2-in.) vent pipe provides a venting area of about 290 mm^2 (4.5 si) per penetration. Similarly, using 51-mm flashing around a 38-mm (1.5-in.) vent pipe yields 129 mm^2 (2 si) of extra venting area per penetration. For a 102 x 102-mm (4 x 4-in.) square steel equipment screen post, an extra 798.7 mm^2 (12.38 si) of venting area is available for each post location.

A storm collar as a cover over the top of a properly installed roof flashing is part of almost every manufacturer's installation specifications. Creating details using this technology is an economical, supplemental venting solution.

Visalia revisited

The repairman that fell through the commercial flat roof in Visalia in the example cited at the beginning of this article took the building owner to court. The facility in question is a tilt-up manufacturing warehouse; the building's diaphragm roof deck included large steel and wood beams that allowed the deck to span its great width and length.

Between the structural beams hung 3.1-m (10-ft) long 2x4 fir rafters spaced on 1.22 m (4 ft) centers and situated into metal hangers. The building was then covered with 15.6-mm (5/8-in.) plywood sheathing. The roof that covered the building was installed over double-cross-lapped layers of 25-mm (1-in.) fiberboard insulation. A BUR covering was installed over the fiberboard as the impermeable roof cover.



This detail from a manufacturer's specification manual is a clear example of an odd-shaped geometric square post flashing detail. Using a storm collar or counter-flashing over the top of a roof penetration flashing is normal practice.

Image courtesy CertainTeed Corp.

The rafters began to sag as the building aged, creating cupping areas across the deck. As is inevitable with any flat roof, water was able to enter the roof assembly by:

- being built into the roof system when it was installed via wet or humid construction materials;
- skirting the impermeable roof cover due to damage and/or faulty design (*i.e.* swamp cooler leaks); and
- being vapor that rose into the roof assembly from inside the building.

Vapor ascended to the bottom of the impermeable roof cover during cool nights; the condensed liquid was absorbed into the fiberboard insulation. As the insulation became saturated, the heavy water accumulated across the surface of the sagging asphalt-coated plywood sheathing. Mildew, mold,

ADDITIONAL **INFORMATION**

Author

Lawrence Evensen is the president of All Style Industries, a manufacturer of storm collars and flashings. He holds various U.S. patents in roof sealing and waterproof roof decks post-construction. A member of RCI–The Institute of Roofing, Waterproofing & Building Envelope Professionals, Evensen was a roofing contractor in California for more than 20 years. He can be contacted via e-mail at larry@spinflashing.com.

Abstract

Moisture problems are not caused by exterior leaks alone, but are also the result of water vapor inside a structure. Today's structures are more insulated, airtight, and energy-efficient, but this also means a higher concentration of moister vapor-laden air trapped inside. It is imperative to examine conditions that create water and water vapor within the building envelope and provide proper ventilation.

MasterFormat No.

07 12 00–Built-up Bituminous Waterproofing
07 72 00–Roof Accessories

UniFormat No.

B1020–Roof Decks, Slabs, and Sheathing
B1020–Roof Construction Vapor Retarders, Air Barriers, and Insulation

Key Words

Division 07
Bernoulli principle
Built-up roofing
Low-sloped roofs
Ventilation
Thermodynamic cycles
Water vapor

and fungi had an ideal environment to feast on wet wood, destroying the structure. However, all this occurred under what appeared to be a perfectly sound BUR cover.

Historically, designing for moisture protection by principally considering rainwater from above has been the waterproofing criterion for flat roofs. The thermodynamic cycles affecting them have been set aside or ignored in favor of this narrow approach. By including breather, wall, and storm collar penetration venting in their arsenal, designers have the opportunity to make building envelopes more energy-efficient and safer. **CS**

Notes

[1] For more information visit irc.nrc-cnrc.gc.ca/pubs/cbd/cbd176_e.html.

[2] For more on storm collars, see this author's article, "The Case of the Roof Penetration: New Waterproofing Solutions for Old Mysteries," in the August 2008 issue of *The Construction Specifier*.

When design professionals think about water penetration considerations for their roofing assemblies, the threat of rainfall comes immediately to mind. However, vapor is also critical. By including breather, wall, and storm collar penetration venting, building envelopes can be made more energy-efficient and safer.

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