Entrapped Moisture...
But This Is a LEED® Gold Building!

By Remo Capolino, RRC, PE

There has been much written recently about the presence of entrapped moisture within a roof assembly. No less than five informative and cautionary articles/bulletins have been written and published within the last four years about the moisture within newly placed concrete and its effect when a roof assembly is installed.[1,2,3,4,5] These articles and bulletins discuss the quantity of water a newly placed concrete slab can contribute to the roof assembly (between 1 and 2.6 quarts of water per square foot for each 6 inches of concrete slab[1]), as well as the equilibrium moisture contents of roof assembly components such as faced polyisocyanurate (iso) insulation and the potential for deterioration and even organic growth due to elevated moisture contents.

While all of these are very informative, they don't necessarily bring the concern of built-in moisture "home to roost." The intent of this project profile is to show how, despite the best efforts of several design professionals giving great care and attention to every single material that is installed in the entire building, the moisture from a newly placed 14-inch-thick concrete slab can be overlooked. This, then, contributed to the roof failure of a fully adhered, fleece-backed, white, single-ply roof membrane.

The building in question is a multistory LEED® Gold educational building on a university campus in the Northeastern United States. The structure was completed circa 2006, and the top floor is a very congested, warm, mechanical floor (*Figure 1*). The roof deck is a 14-in.-thick concrete slab covered with iso insulation that tapered from 1.5 to 9 inches, with all layers set in foam adhesive with a fully adhered, fleece-backed, reflective, white, single-ply roof membrane that, of course, utilized a water-based, low-VOC, LEED®-friendly bonding adhesive. The roof was relatively free from penetrations, with the exception of a few roof curbs, vent pipes, and, of course, roof drains (*Figure 2*).

In late 2012, it was noted that the single-ply membrane was "billowing up" when the wind blew more than a few miles per hour. Initial inspection openings concluded that the membrane was no longer bonded to the iso, and the assembly needed to be repaired or replaced for fear it would catastrophically fail and possibly blow off the building and into the city street below.

A slightly more thorough investigation was requested, which revealed a wealth of information about the site conditions and the cause of failure of the roof assembly.

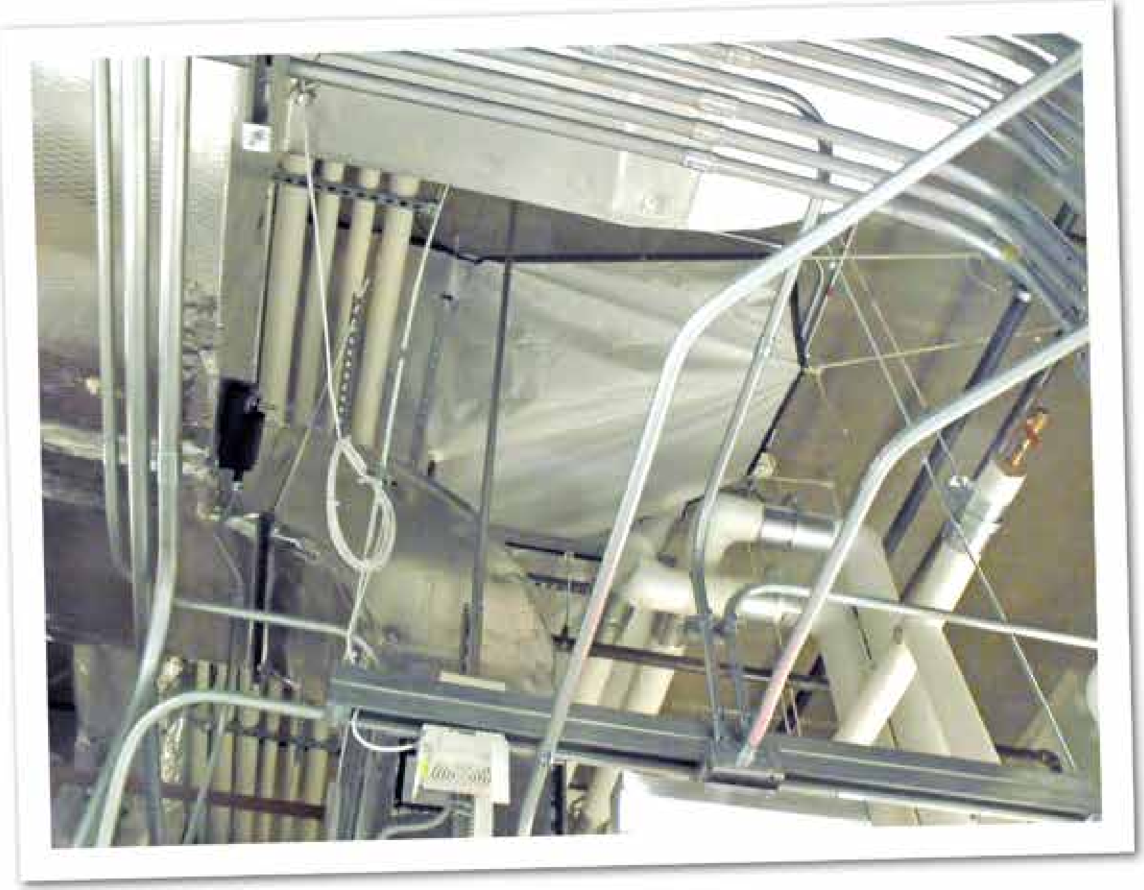

Figure 1 – Overview of congested mechanical room space directly below the roof deck.

The investigation consisted of roof cuts at areas observed to be debonded, areas that appeared well bonded, as well as areas near and far from drains (i.e., areas with thin and thick insulation). The effort was made to sample enough areas of the roof so as to be able to say whether it was adhered or debonded, and thick or thin insulation. A probe was made, and the condition of the assembly was observed and recorded at every possible combination of conditions noted above. Of particular interest were the location and mode of failure that caused the membrane to "billow up" when the wind blew.

At areas where the insulation was thin, the conditions of the insulation and membrane were similar: The single layer of insulation was debonded from both the concrete deck and the single-ply membrane. The mode of failure at both sides of the insulation board was a cohesive failure of the iso board fiberglass-reinforced paper facers (*Figures 3* and *4*). At locations where the insulation was a single layer, organic growth was observed at varying degrees (from moderate to complete) on the paper facer of the insulation board (*Figure 5*).

At areas where there were three layers of insulation, the conditions were noticeably different in that the insulation boards were well bonded to the concrete deck. The bond, however, between the single-ply membrane and insulation had failed, with the mechanism of failure being cohesive failure of the insulation paper facer (*Figure 6*). The interface between the top layer and underlying layer of insulation was inspected, and no adhesive was found; however, significant organic growth was noted on both paper facers at this level (*Figure 7*). To summarize, the failures observed at the areas with three layers of insulation were similar to the areas with one layer of insulation, in that cohesive insulation facer failures were noted in the top insulation layer and significant organic growth on the paper facers was also observed.

When areas with several (four) layers of insulation were probed, the single-ply membrane was generally well bonded to the insulation, and the insulation was well bonded to both the adjacent insulation and the deck. All layers of insulation and

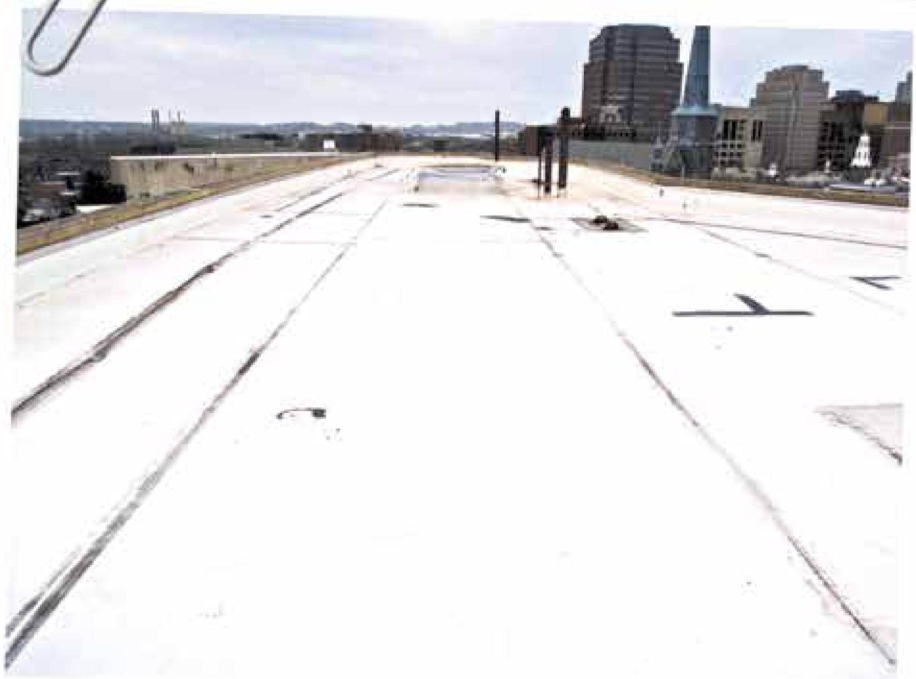

Figure 2 – Overview of roof.

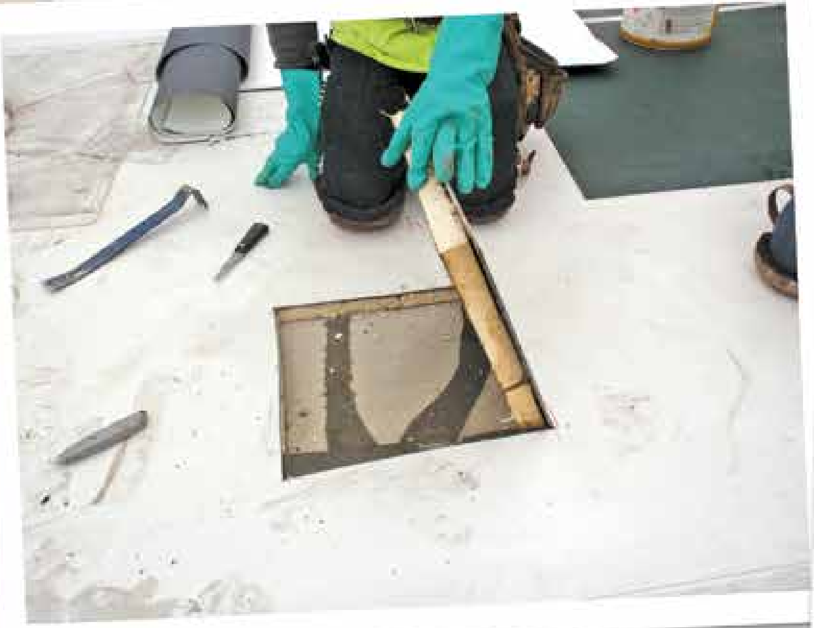

Figure 3 – Cohesive facer failure. Note facer material on adhesive ribbons on deck but no foam core visible.

Figure 4 – Mostly (80%+) cohesive failure of facer with remnants of facer on iso board and bottom side of fleece-backed membrane.

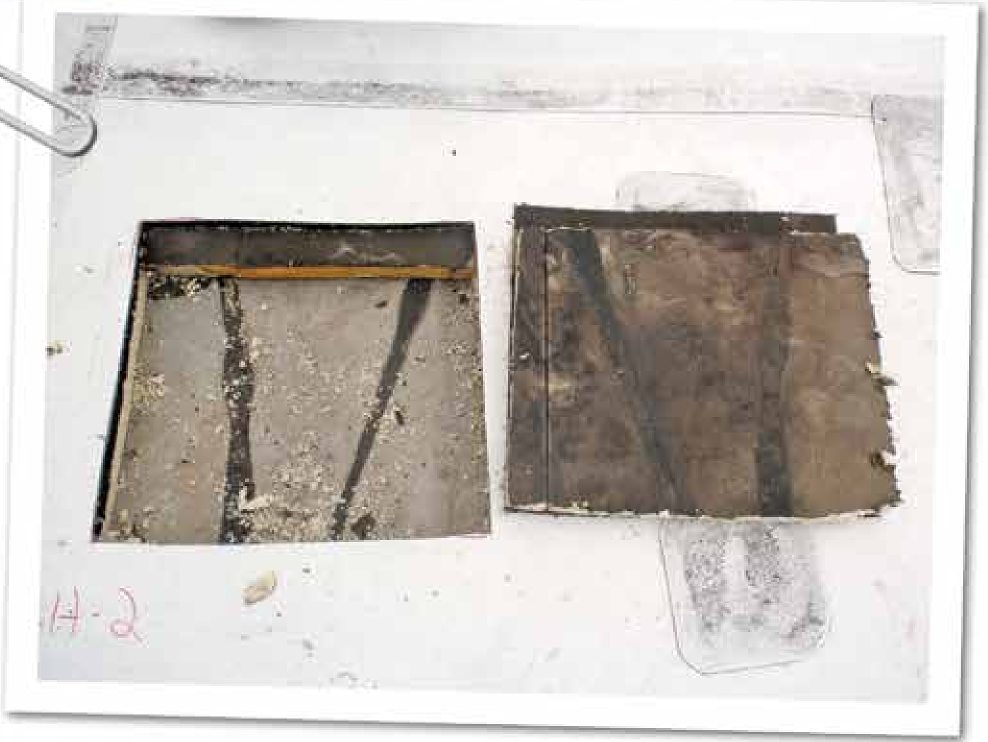

Figure 5 – Organic growth on bottom facer

concrete deck surfaces were clean and dry, both visibly and by touch.

A condition of interest after laboratory testing was the mode of failure of the insulation boards during removal from the roof. The boards were adhered; however, forced removal resulted in cohesive failure of the iso facers and did not cause the facer to peel off of the foam core (*Figure 8*).

Samples of the insulation from the probed areas were laboratory-dried to determine moisture content. The facer and foam were dried together, and as such, the moisture information obtained is for the insulation board in its entirety. Moisture information for the facer and the foam core individually would be interesting; however, it was not obtained on this project. A tabulation of overall insulation thickness and its related moisture contents is provided in *Table 1*.

While on site, the single-ply roof was visually inspected and did not show any signs of physical abuse. Any telltale signs of a new building with a single-ply roof that had been brutalized by the carpenters, pipefitters, sheet metal workers, and electricians were not readily visible on this roof. In a perfect world, electronic leak detection would have been done to find the breaches that are all too often missed by a visual inspection; however, due to time and budget constraints, this type of testing was not done. Based upon visual observations of the membrane while on site, it was concluded that breaches through the single-ply membrane were not likely a significant source of water within the roof insulation cavity.

Observations of the probes would lead one to say that when fewer/single layers of insulation are present, the impact of moisture upon the insulation is more obvious. The writings referenced above and the laboratory testing of the insulation can be used to assist in the explanation of the conditions observed at this building.

The approximately 2.1 quarts per sq. ft. of unhydrated concrete mix water contained within the 14-in.-thick concrete slab (0.9 qt./sq. ft. per 6 in. of thickness x 14 in. = 0.9/6 x 14 = 2.1) is directed due to vapor drive from areas of high vapor pressure to low. This translates to a vapor drive from warm to cold. In the Northeast, this direction is from the warm mechanical room to the cold exterior during the fall, winter, and spring months (October through May). Even in the summer, when the exterior temperatures are warm, the mechanical room is relatively warm/hot; the vapor drive is toward the exterior, due to the “cool roof,” heat, and humidity of the mechanical room space, with the gradient of the vapor pressure being somewhat reduced when compared to the fall/winter/summer months. As a result, little to no drying of the concrete slab will occur toward the interior, and the vast majority of the unhydrated mix water will migrate toward the exterior.

This unhydrated concrete mix water travels toward the building exterior and is prevented from escaping by the vapor-im-

Sample #	Insulation thickness/# layers	Moisture Content
1	9 in./4 layers	4.5%
2	1.5 in./1 layer	14.5%
3	5 in./3 layers	2.1%
4	1.5 in./1 layer	17.7%
5	6 in./3 layers	7.2%

Table 1

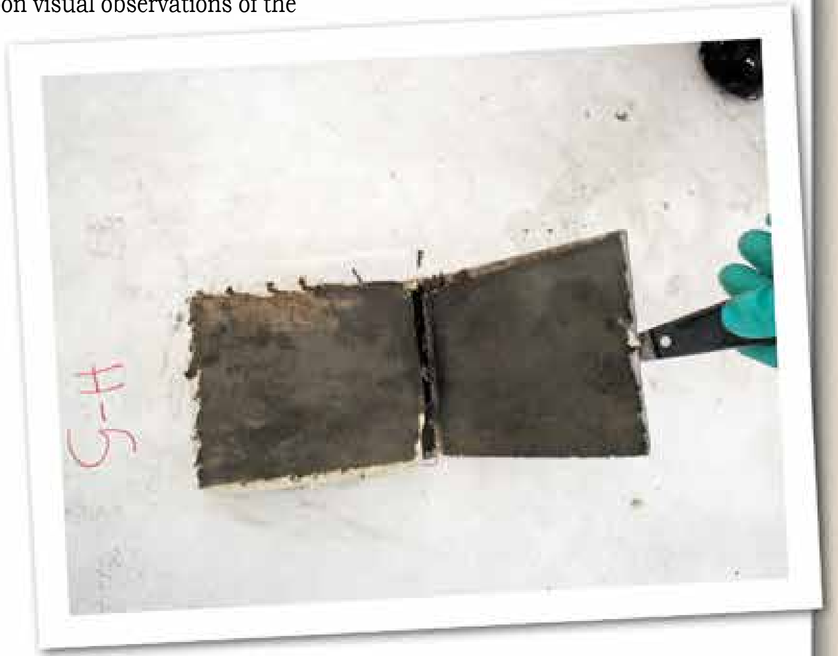

Figure 6 – Cohesive failure of iso board top facer, leaving facer remnants on iso board and fleece-backed membrane.

permeable single-ply membrane. Prior to getting to the single-ply membrane, it encounters the paper facers of the insulation board(s). If there is only one insulation board with two facers (top and bottom), then all the water that travels to the exterior is absorbed by these two facers. This accumulation of moisture causes deterioration of the facer and results in a cohesive failure of the facer as well as organic growth. At locations with a single insulation board, these exact conditions were observed.

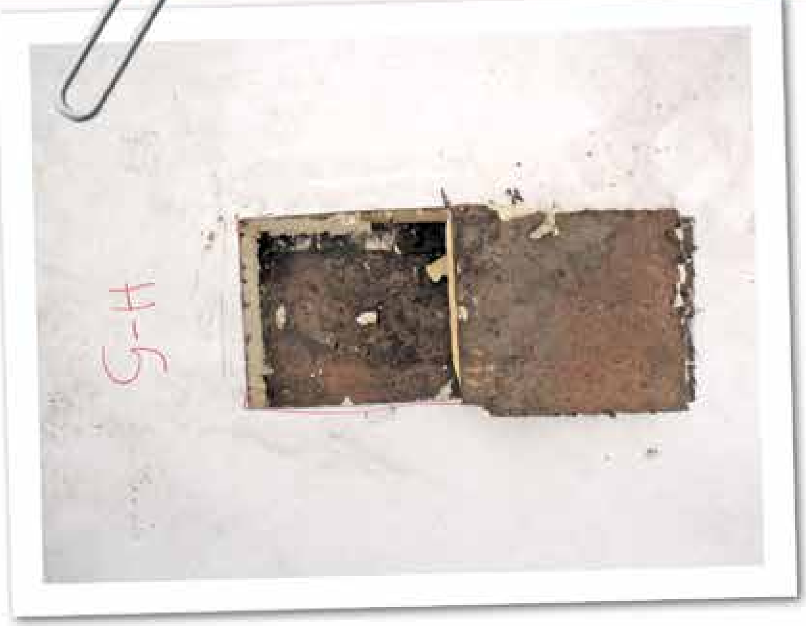

Figure 7 – Organic growth on iso facers.

Because of the light color of the single-ply membrane on this roof, it did not heat up above ambient temperatures as it would have if the membrane were dark/black. As a result, solar heat gain does not have a sufficient impact upon the vapor pressure to either wholly change its direction inward to counteract the in-to-out vapor drive, or at the very least, lessen the gradient of the vapor drive. If there were greater solar heat gain, water directly under the single-ply membrane would be heated, resulting in a higher vapor pressure that would distribute water throughout a deeper depth of the roof insulation cavity. By distributing the water throughout a deeper depth, more layers of iso facer would be present to absorb the water and would result in lower moisture contents for each layer. In short, the vapor drive and accumulation of unhydrated mix water under the roof membrane is a problem, but the white color of the roof membrane allowed the water to be concentrated to a very limited depth below the membrane and caused the moisture content of the top layers of iso to be elevated to a point where their physical properties were deteriorated.

One could liken the paper-faced insulation boards to a hamburger. The insulation board paper facers are analogous to the buns of the burger, and the iso foam core is the meat patty. Dip a burger in water, and the buns will absorb the lion's share of the water absorbed by the burger/bun combo. So, too, will the paper facers rapidly absorb most of the available water when in the presence of elevated relative humidity. The buns (facers) will accumulate water in the form of increased relative humidity, and when the temperature falls due to radiant heat loss of the single-ply "cool roof membrane," this water in the form of humidity condenses and is retained/absorbed by the paper facer. In this analogy, a wet bun changes properties drastically with slight changes in moisture content, while the burger remains relatively unchanged after being dipped in water. The cellulosic and fiberglass facers of the iso similarly are drastically impacted by slight changes in water content. We have all seen the impact of removing the white plastic wrapping from a bundle of iso, only to see the top few boards cup within an hour due to the black facers being exposed to the sun and rapidly shedding their moisture due to evaporation. There does not even need to be liquid water on the top board when the wrapping is removed for this to happen. The mere reduction in moisture content will cause the cupping.

Now, some may say the hamburger analogy is simplistic, and it is. There are many factors at play in this scenario, all of them boiling down to the fact that they are having an impact upon the weakest link in the chain. Based upon personal experience

Figure 8 – Removal of insulation at area with several layers. This appeared dry when compared to areas with a single layer. Note removal of top insulation board resulted in cohesive failure of facers.

and from discussions with others in the industry, paper facers of insulation boards experience problems when placed into roof assemblies that subject them to warm, humid conditions.

The equilibrium moisture content (EMC) of iso was the topic of articles by Carl Cash in 1985 and 2003,[6,7] in which he concluded that the EMC of faced iso boards is 1.1% at 45% relative humidity or 2.9% at 90% relative humidity at 20°C. As can be seen by the laboratory testing of insulation boards from this roof, the moisture content of the iso would indicate that the relative humidity of the insulation cavity is near or in excess of 90%, and as such, would categorize the iso board as being wet. I would agree with this categorization of the iso, because when dry, the mode of failure of iso boards is typically facer delamination from the foam core, not cohesive failure within the facer material.

This issue is still evolving, and hopefully those who have already investigated, researched, and written about the phenomenon will continue and focus not only on the peripheral circumstances and theory, but also drill down to the nitty-gritty of what needs to be changed in order to prevent future occurrences. Of particular interest to the author would be not only additional information when cellulosic paper facers are used, but also moisture impacts upon the coated fiberglass facers that most insulation manufacturers offer.

REFERENCES

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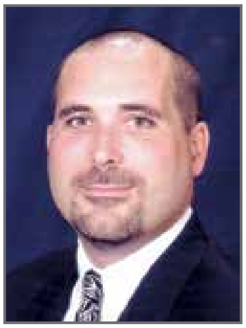

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Remo R. Capolino, a principal with Wiss, Janney, Elstner & Associates, grew up in a family-owned specialty roofing contracting business and graduated from the University of Connecticut with a BS in civil engineering. After more than 15 years in contracting and leadership roles with the Association of General Contractors (AGC), the Northeast Roofing Contractors Association (NERCA), and the National Roofing Contractors Association (NRCA), he turned to consulting. Capolino has lent his expertise in copper, zinc, slate, and other specialty roofing assemblies on a number of internationally recognized projects.

SPRI Releases Bulletin on Recommended Rooftop Supports

SPRI has released a technical bulletin covering potential performance issues related to surface-mounted, non-structurally integrated rooftop support systems. SPRI represents sheet membrane and component suppliers to the commercial roofing industry.

Industry Information Bulletin 1-14 (April 25, 2014) emphasizes that extra care should be taken by roofing professionals when specifying and installing rooftop supports for piping, equipment, solar panels, and other items. The document includes factors to consider when choosing rooftop supports and also addresses material compatibility. To help in this area, the bulletin includes an extensive chart on dissimilar metal compatibility and potential galvanic reactions between different metals.

SPRI also examines load distribution, thermal movement, weathering, and durability issues. A second chart, "Rooftop Support Material Durability and Weathering Performance Guide," lists the effects of humidity on ten common rooftop support materials and finishes.

The bulletin can be viewed and downloaded free of charge at http://www.spri.org/pdf/1-14-SPRI-Bulletin_Recommendations-for-Rooftop-Supports.pdf.