

COOL ROOFS IN THE NORTH:

Some Studies Suggest Condensation Under White Membranes in the North Is Rare

By Thomas J. Taylor, PhD

White TPO installed on a roof.

EDITOR'S NOTE: RCI is opposed to the requirement of cool roofs in Climate Zones 4 and up.

For the past 40 years, there has been continued growth of single-ply roofing. More recently, “cool” single-ply membranes with highly reflective surfaces have come to represent over 50% of the commercial roofing market. In fact, each year, well over 1.5 billion square feet of these white membranes are installed. However, with the advent of membranes such as thermoplastic polyolefin (TPO) and

polyvinyl chloride (PVC) have come concerns that they contribute to moisture condensation buildup within the roofing system. There have been presentations and evidence discussed within the industry showing damage allegedly due to the use of white roofing membranes.

This article examines whether or not cool roofs do cause condensation issues. It appears that both theoretical “on-paper” studies, as well as detailed field surveys,

point to moisture condensation in single-ply roofing as being a rare occurrence. In fact, condensation under membranes appears to have several possible causes.

Condensation has historically been seen with multi-ply systems and later with nonreflective single-ply membranes. Roof systems are fairly complex parts of often-sophisticated building envelopes and, depending on the building use, condensation has been known to occur regardless of

the membrane. This article discusses condensation under reflective membranes and concludes that condensation is rare. In fact, good roofing practices and building design can largely prevent such issues from occurring. Some guidelines and best practices are discussed in this article.

FIELD EXPERIENCE WITH SINGLE-PLY ROOFING

Before single-ply roofing became popular, condensation had been observed in built-up roofing systems as noted by Walters.¹ The issue was seen as being related to external temperatures, indoor humidity, moisture diffusion rates within the roofing system, and the position of the dew point. Before highly reflective roofing became popular, EPDM was the dominant single-ply membrane. DuPuis² noted that preliminary reports found small amounts of moisture under single-ply membranes initially, but that the moisture was gone during follow-up investigations. The DuPuis survey found some circumstantial evidence pointing to small amounts of moisture under ethylene propylene diene monomer (EPDM) membranes. However, there was direct evidence of moisture in the insulation layers.

During the 1960s, a concept known as the self-drying roof was promoted.³ The premise was that condensation of interior humidity on the underside of membranes would occur almost inevitably during the winter months. Then, during warmer months, the moisture would be driven downward back into the building. It seems, as evidenced by the work of Walters and DuPuis, that the new single-ply membranes caused a reexamination of condensation, even though the problem was not new.

Since highly reflective membranes have become dominant, the issues of condensation and moisture buildup have been examined again. However, a difference might be that high reflectivity could negate the self-drying mechanism thought to exist with lower reflectivity membranes such as EPDM as described by Powell and Robinson.³ Ennis and Kehrner undertook a field survey of ten white roofs that was designed to maximize the likelihood of observing moisture under such membranes.⁴ The buildings were all located in ASHRAE Climate Zone 5. The roofs were surveyed during the colder months and in the morning to minimize any inadvertent drying out due to heating. In seven cases, there was no evidence of moisture anywhere in the system. In three cases,

moisture was found on the underside of the membrane and/or the top face of the insulation. No evidence was found of detrimental effects of moisture in any of the systems. After also modeling the roof systems, taking into account insulation levels, reflectivity, and humidity levels, they concluded that the roofs dried out completely during summer months. The absence of damage and the supporting modeling data suggest that moisture buildup was not occurring in any of the roofs surveyed.

Target Corporation has almost exclusively installed white mechanically attached PVC roofing membranes on its big-box buildings for approximately 20 years. In 2013, 26 such roofs located in Connecticut, Illinois, Massachusetts, Michigan, Minnesota, New York, Washington, and Wisconsin were examined for any evidence of moisture.⁵ The survey was conducted during August and September to assess whether or not summer moisture drive was occurring within reflective roof assemblies.

The Target stores surveyed had a range of insulation thicknesses, some installed as single layers, and some double with staggered joints. No evidence was found of any condensation; in fact, the absence of staining suggested that condensation had not occurred during winter months in ASHRAE Climate Zones 4, 5, and 6.

Importantly, the roofs ranged in age between 10 and 14 years, during which time condensation would have caused visible damage had it been occurring. In a single case where evidence of moisture was found, it was clearly attributable to a roof leak.

Although the surveys described so far suggest that moisture buildup is not an issue for cool roofing, it should be noted that all the roofs were over metal decks. Metal decks have significant porosity, which is a basic requirement of the self-drying roof concept.

In some regions, cool roofs have been installed over systems containing plywood decks.⁶ In these situations (quite common on the U.S. West Coast), thermal insulation is installed below the deck. This, in effect, puts a large moisture sink immediately under the membrane, possibly at the dew line, depending on the course of a yearly weather cycle. While this could provide satisfactory performance with a dark membrane, a reflective membrane might not allow the plywood to dry out during warmer time periods.

MODELING OF MOISTURE MOVEMENT WITHIN SINGLE-PLY ROOF SYSTEMS

The large-scale adoption of single-ply roofing membranes began in the 1960s. As noted by DuPuis, preliminary reports from the field indicated that these membranes might cause moisture buildup.² In 1985, Walters carried out modeling of water vapor diffusion and its condensation through EPDM roofing systems. Later, Tobiasson developed simple rules based on location, indoor air temperatures, and humidity to determine if vapor barriers were needed.⁷ The use of vapor barriers was intended to limit interior humid air from reaching the roofing system. However, Tobiasson did note that such vapor barriers had the potential for trapping moisture within the system. Both Walters and Tobiasson noted that there were conditions that could lead to moisture buildup. However, these were unusual and associated with very northern locations.

With the advent of sophisticated modeling tools in the 1990s, more detailed studies became possible. Desjarlais tested the conditions required to create a self-drying roof assembly.⁸ For the locations studied, including Bismarck, ND, no circumstances were found under which reflective roofing would lead to moisture buildup.

Similar work by Bludau et al. used the hygrothermal WUFI⁹ validated software to compare white and dark roofs in Phoenix, AZ; Chicago, IL; and Anchorage, AK.¹⁰ They concluded, "Only in those regions with very cold ambient temperatures is there a risk of moisture accumulation, especially if using a bright surface." For West Coast wood deck systems, WUFI modeling has enabled calculation of the amount of above-deck insulation required to prevent moisture buildup in the deck for coastal locations ranging from Portland, OR, to San Diego, CA.¹¹

However, as noted by Hoff, more accurate and sophisticated modeling is still dependent on the chosen inputs.¹² For low-slope roof systems, air flows in the building—and particularly through the roof system—are not well characterized and may, in fact, be highly variable. Hoff's review of current research concluded, "Moisture condensation in all roofs is a relatively rare phenomenon that tends to occur in the presence of one or more severe design conditions." These included:

1. Extremely cold external temperatures
2. Extremely high internal temperatures

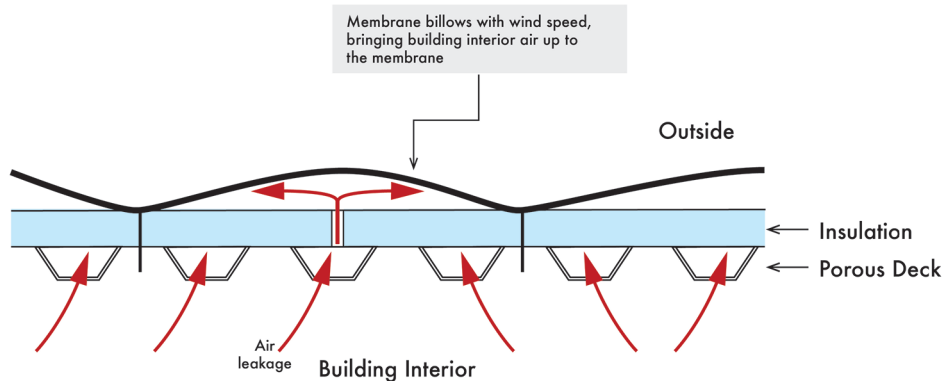


Figure 1 – Schematic showing the effect of wind uplift forces on a mechanically attached membrane.

- tures and humidity
- 3. Unusually low amounts of over-deck roof insulation
- 4. Unusually high levels of air movement within the roofing system

- Airflow to the underside of the membrane should be limited but not eliminated. The specification of that airflow is still not known; however, certain guidelines can be given based

DISCUSSION AND CONCLUSIONS

Clearly, moisture buildup beneath roofing membranes has been a problem since well before the advent of reflective membranes. As recently pointed out by DuPuis¹³ and Hoff, roof systems that are designed to be self-drying generally do not accumulate moisture from year to year and may, in fact, not exhibit any evidence of condensation. Certainly the roof surveys described here did not find evidence of moisture buildup, but it must be noted that all the roofs examined fit the definition of self-drying roofs.

There are several characteristics of a self-drying roof that are worth emphasizing here. The following are core guidelines summarized from the work of Hoff, DuPuis, Dregger, Desjarlais, and others.^{14,15,16,17}

- The deck must be permeable. This is certainly the case for steel decks, such as those used in big-box designs as described earlier in this article. For decks with limited permeability, the design professional needs to consider moisture transport within the roof system very carefully. Minor water leaks or even membranes with some degree of permeability will result in moisture within the system that might have nowhere to escape. Many nonpermeable decks can also contain water left from construction, such as is the case with concrete decks of various subtypes. Drying out of such decks and/or controlling moisture flow upward into the roof system needs to be carefully planned.

on field observations. Large-scale airflow that would occur with a fibrous insulation is to be avoided. Foam insulation, such as polyisocyanurate (polyiso), generally has low moisture permeance, but the effect of the joints between boards needs to be considered. Double layers of such insulation with staggered joints have been used with apparent success.

- Fully adhered membrane systems based on polyiso insulation significantly reduce airflow to the underside of the membrane. In addition, fully adhered systems do not billow upwards due to wind loads, again reducing airflow. Billowing of a mechanically attached membrane is shown schematically in Figure 1. The differences between mechani-

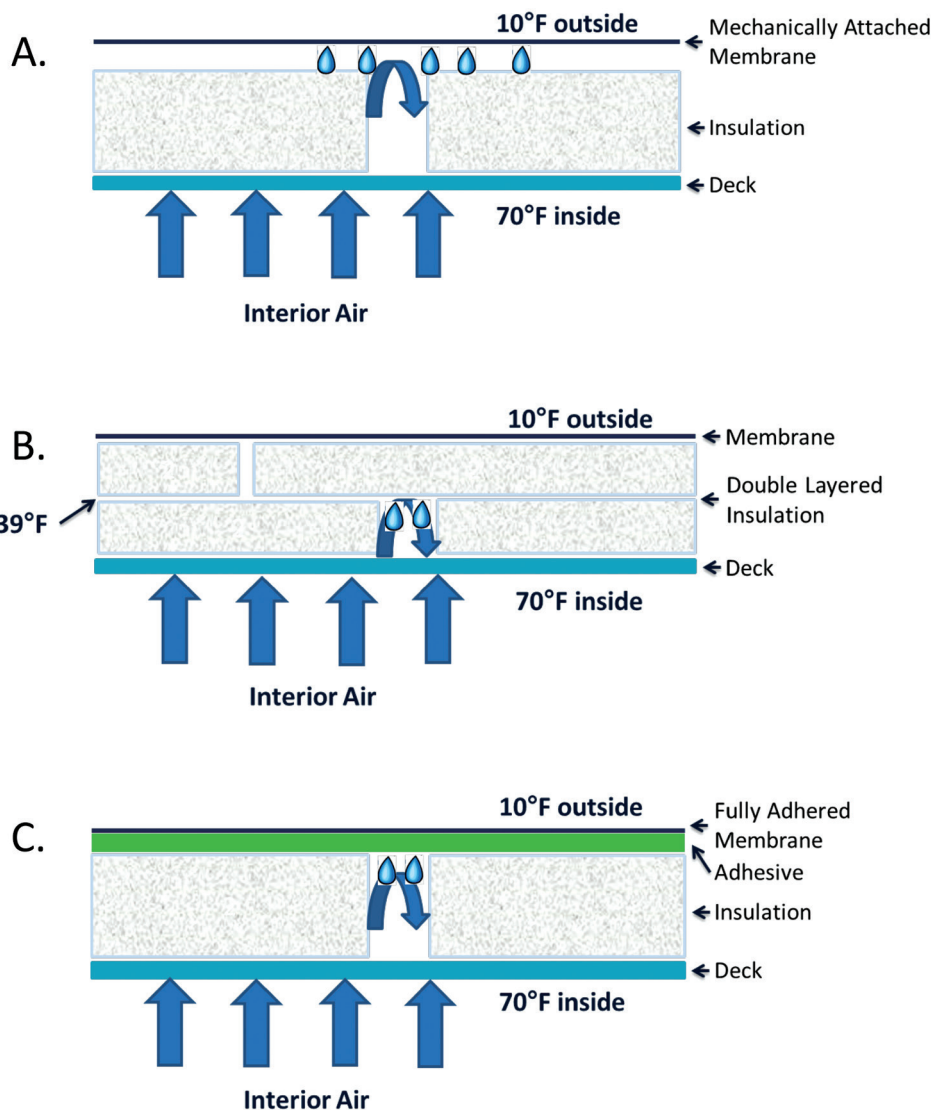



Figure 2 – Schematic of the differences between: A) mechanical attachment, plus the effect of B) a double layer of insulation with staggered joints, and C) a fully adhered system on the condensation of building moisture.

cally attached, fully adhered, and staggered double layered insulation systems are shown in *Figure 2*.

- Roof system components that can absorb significant amounts of moisture should be used very cautiously. It is advisable to use foam insulations, as these are recognized as having limited moisture absorption.
- Use sufficient insulation such that the dew point for cold periods is not at the underside of the membrane. This is relatively easy to accomplish if the ASHRAE prescriptive insulation requirements are followed for the climate zone. Moving the dew point to within the insulation reduces the risk of condensation. However, care must still be taken to minimize airflow up into the roof system. 

REFERENCES

1. R. B. Walters. "Condensation Modeling of EPDM Single-Membrane Roof Systems." *Proceedings of the Second International Symposium on Roofing Technology*. NRCA. 1985. pp. 391-395.
2. R. M. DuPuis. "Field Survey of Moisture Gain Behavior Within Single-Ply Roof Systems." *Proceedings of the Second International Symposium on Roofing Technology*. NRCA. 1985. pp. 261-264.
3. Frank J. Powell and Henry E. Robinson. *The Effect of Moisture on the Heat Transfer Performance of Insulated Flat-Roof Constructions*. U.S. National Bureau of Standards. 1971.
4. M. Ennis and M. Kehrer. "The Effects of Roof Membrane Color on Moisture Accumulation in Low-slope Commercial Roof Systems." *Proceedings of the International Roofing Symposium*. NRCA. 2011.
5. M. Fenner, M. DiPietro, and S. P. Graveline. "Cool Roofs in Northern Climates." *Architectural Roofing and Waterproofing*. October 2014.
6. Phil Dregger. "'Cool' Roofs Cause Condensation - Fact or Fiction?" *Interface*. RCI, Inc. March 2013. pp. 19-26.
7. W. Tobiasson. "Vapor Retarders for Membrane Roofing Systems." *Proceedings of the 9th Conference on Roofing Technology*. NRCA. 1988. pp. 31-37.
8. A. O. Desjarlais. "Self-Drying Roofs: What! No Dripping!" *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings*. 6th Conference, Clearwater, FL. 1995. pp. 763-773.
9. WUFI is free software from Oak Ridge National Laboratories.
10. C. Bludau, D. Zirkelbach, and H. M. Kunzel. "Condensation Problems in Cool Roofs." *Interface*. RCI, Inc. August 2009. pp. 11-16.
11. A. O. Desjarlais, H. Hardy Pierce, W. Woodring, and S. Pallin. "Practical Application of Hygrothermal Modeling of West Coast Wood Deck Systems." *Interface*. RCI, Inc. March 2014. pp. 9-16.
12. J. Hoff. "Roofs and Condensation." *Building Envelope Magazine*. May 2015.
13. M. DuPuis. "Roofing Folklore. Physics Can Disprove an Urban Legend about Moisture Accumulation in Highly Reflective Roof Membranes." *Professional Roofing*. NRCA. March 2015. pp. 30-35.
14. B. A. Baskaran and S. Molleti. "Air Intrusion Versus Air Leakage: The Dilemma for Low-Sloped

Mechanically Attached Membrane Roofs." *Interface*. RCI, Inc. November 2009. pp. 4-10.

15. M. Jablonka. "Managing Moisture and Condensation in Metal Roofing Systems with Vapor-Permeable Underlayments and Drainage Layers." *Interface*. RCI, Inc. November 2009. pp. 19-24.
16. J. F. Straube. "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance." *Proceedings of Thermal Performance of Building Envelopes VII: Clearwater Beach, Florida*. 2001.
17. A. O. Desjarlais, T. W. Petrie, P. W. Childs, and J. A. Atchley. "Moisture Studies of a Self-Drying Roof: Tests in the Large-Scale Climate Simulator and Results from Thermal and Hygric Models." *Proceedings of Thermal Performance of Building Envelopes VII: Clearwater Beach, Florida*. 2001.



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Steel Industry Releases EPD on Steel Joists and Steel Deck

The Steel Joist Institute (SJI) and Steel Deck Institute (SDI) have jointly released the first industry environmental product declarations (EPDs) for steel joists and steel deck manufactured in the U.S. and Canada. The products are used to construct roofs and floors for single-story, low-rise, and high-rise buildings. The associations' member companies produce the majority of these products used in the U.S. The Open Web Steel Joists EPD can be downloaded free of charge at steeljoist.org, and the Steel Roof Deck and Steel Floor Deck EPDs can be downloaded free at sdi.org.

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