DO YOU *REALLY* KNOW WHEN TO USE A VAPOR RETARDER IN A CONVENTIONAL ROOF ASSEMBLY?

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ABSTRACT

In the design of a low-slope roofing system, the designer will make a decision as to whether a vapor retarder is required to guard against excessive condensation. Today's most commonly used guideline is taught in RCI, Inc. courses and within other segments of the roofing industry. However, this current guideline may no longer be universally applicable. The author will discuss the history of vapor retarder guidelines, the theory behind these guidelines, and changes in the roofing industry that may affect today's guidelines. Changes in the roofing industry that may affect the need for a vapor retarder will be discussed. Lastly, the author will suggest needed changes for current guidelines and other work that must be done in this field.

INTRODUCTION

This paper contains a summary of work that has been done to provide guidance in the decision-making process for determining whether a vapor retarder is needed for low-slope, over-deck roof systems, given building location, interior moisture conditions, temperature, and other variables. It is also a review of work being done in this field and outlines the need for further refinement and research. This paper does not provide the results of new research.

Let's start with a little history, because there is much to learn from our past experience.

There was a time when oil was cheap and roof insulation was not used. Roof decks consisted mainly of concrete and heavy timber. Bituminous BUR membranes were installed directly to concrete decks and to nailed felts or coated base sheets on heavy timber decks. Underlayment boards were installed on steel decks of sufficient thickness and strength to span the flutes. This situation existed until the 1973 energy crisis. Until that time, the price of oil had been steady at an inflation-adjusted price of about $20 per barrel for the prior 40 years. This oil embargo provided a wake-up call to conserve energy. As a result, the use and amount of insulation over decks increased dramatically.

It didn't take designers long to figure out that insulation under the membrane created greater roof membrane temperature swings. Also, calculations indicated that a colder membrane could cause condensation within the insulation and under the roof membrane. Although vapor retarders were used in northern climates under even minor amounts of insulation, the use of vapor retarders increased, with more common use of insulation and greater amounts of insulation.

But the widespread use of vapor retarders under insulation caused problems:

1. The most immediate problem was that vapor retarders installed direct-to-deck trapped water, making minor leaks near fatal for the roof system. At the same time, finding membrane leaks became nearly impossible, especially if leakage had occurred for some time prior to being telegraphed to the interior.
2. Since almost all roofs at that time were bituminous, the vapor retarders were also bituminous, which could lead to fire problems when installed directly to steel decks, as witnessed by the large GM plant fire in Livonia, Michigan, in 1953.
3. Also important in a competitive market—vapor retarders were not always necessary, and they cost money.

All of these difficulties gave rise to the initial consensus developed among many roofing experts for determining the need for a vapor retarder: When in doubt, leave it out. Later, this advice was modified slightly to: If in doubt, think it out (Griffin, NRCA). You can sense shifting thoughts concerning the use of vapor retarders. This guideline was obviously too vague, and further definition was necessary.

The next guide was reportedly developed by the National Roofing Contractors Association (NRCA). This was certainly a key step in developing assistance in the decision-making process. In this guideline, whenever the average or mean January temperature is 40°F or less and the interior relative humidity (RH) is 45% or higher, a vapor retarder should be used (see *Figure*

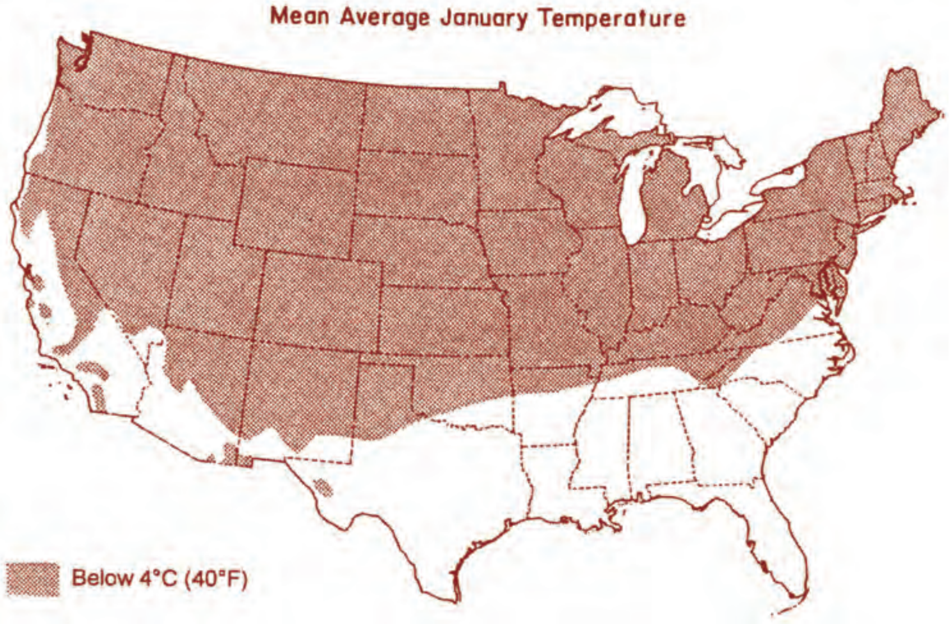

Figure 1 – Map of the continental United States with shaded area having a mean average January temperature below 40°F (Tobiasson).

1). This provided some definition but still left a lot of room for error. For example, a building located in a far-northern U.S. location could have a high interior temperature and 40% RH and not require a vapor retarder, according to this NRCA guideline. Obviously, this could lead to real problems.

In addition to these early NRCA guides, there was also the ASHRAE condensation accumulation calculation. Although widely used to evaluate the potential moisture accumulation in wall systems, the ASHRAE calculation was not applicable for roof system evaluation because of the vapor-impermeable roof membrane on the outside of the roof assembly.

Work was also under way to understand moisture movement and accumulation on at least two other fronts. In the early 1960s, Frank Powell and others at the National Bureau of Standards (now known as the National Institute of Standards and Technology, or NIST) were working on the concept of the self-drying roof. In this thought process, moisture could be allowed to condense within roofing systems during winter if the atmospheric conditions in summer would drive out all of this water in the drying cycle. For a self-drying roof to be effective, moisture cannot be allowed to accumulate from year to year. The concept of a self-drying roof was also documented by André Desjarlais *et al.* using a large-scale climate simulator and heat and moisture transport models (Desjarlais).

On the second front, Wayne Tobiasson and fellow researchers at the Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL) used this concept to generate a series of graphs to show where moisture accumulation could exceed drying (Tobiasson). In these graphs, roofs in Washington, DC, and Minneapolis, MN, are compared with interior wintertime humidities of 45% and 75% (see *Figure 2*). Due to the colder climate in Minneapolis, the roof would have much less drying time at that location and would require a vapor retarder. In Washington, DC, the self-drying action would work at 45% interior RH but not at 75% RH.

From these graphs, mathematical analysis, and input from roofing industry professionals, Tobiasson and his associates developed a map of the United States with isobars that show the maximum wintertime RH that is tolerable without a vapor retarder in order to rely on the self-drying action (*Figure 3*). Using this graphical technique,

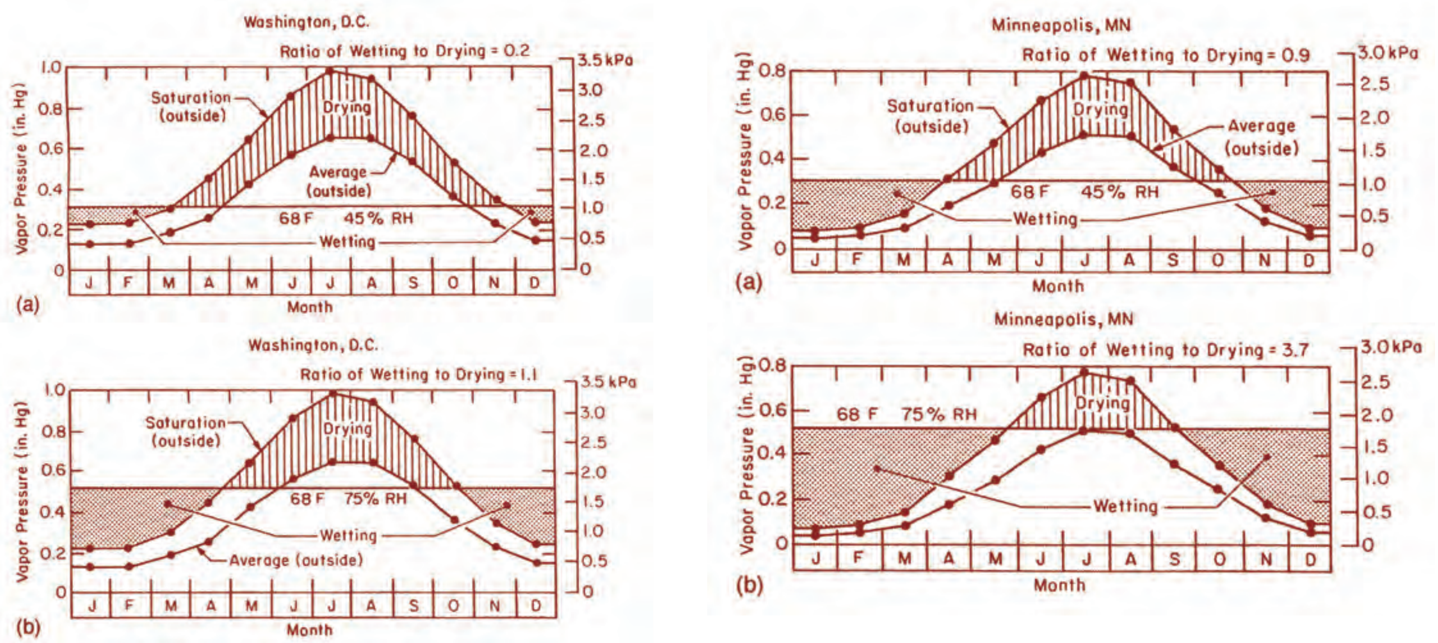

Figure 2 – Wetting and drying potentials for roofs in Washington, DC, (left) and in Minneapolis, MN, (right) with humidities of 45 and 75%. When ratio of wetting to drying is near or above 1.0, there is potential for long-term wetting (Tobiasson).

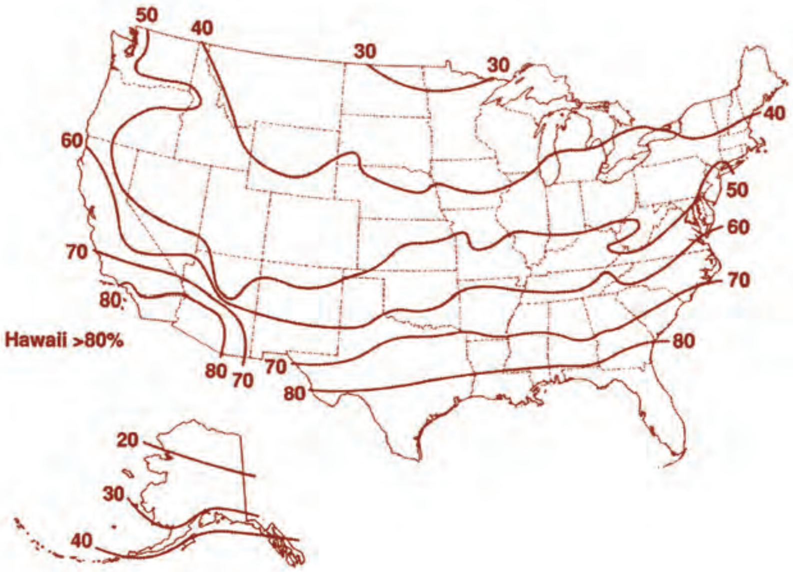

Figure 3 – Map showing maximum indoor humidities. If indoor wintertime humidity is greater than allowable humidity shown on map for the building location, a vapor retarder is needed. This map is based on an indoor temperature of 68°F (Tobiasson).

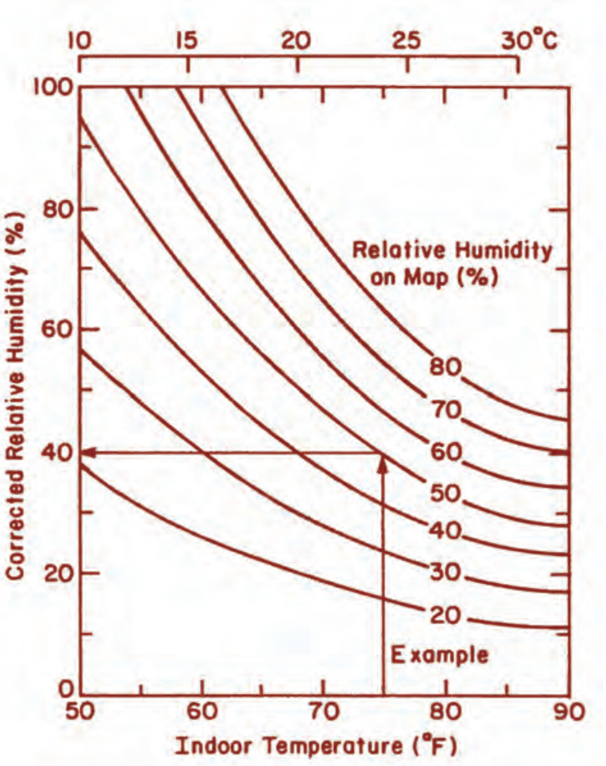

Figure 4 – Graph for correcting maximum humidities shown on Figure 3 for indoor temperatures other than 68°F (Tobiasson).

if the anticipated wintertime interior RH is greater than that shown on the map for the location of the building, a vapor retarder is required. This map is based on an interior temperature of 68°F. For interior temperatures higher or lower, the critical interior maximum RH is adjusted using a provided correction graph (see *Figure 4*).

This CRREL guideline has been the accepted guide for determining the need for a vapor retarder for the last 20 years or so. It is based on sound technology, provides the necessary parameters, and is widely used. This guide has been referenced by NRCA and is taught in our RCI, Inc. courses as the reference to use. However, there are difficulties with this guide:

1. The CRREL guide was developed at a time when the dominant roof system was aggregate-surfaced BUR. With the widespread use of white or reflective roof membranes, the CRREL guide may not be applicable.
2. The CRREL guide (as well as the older NRCA guides) is based on a compact roof system in which moisture accumulation is primarily due to diffusion. As stated by Wayne Tobiasson, "It is very important to realize that all of the above guidelines apply only to compact roofing systems where air leakage is well controlled." (Tobiasson) It is widely recognized that air movement into a noncompact roof assembly is the cause of most roof moisture accumulation rather than diffusion (Dregger).

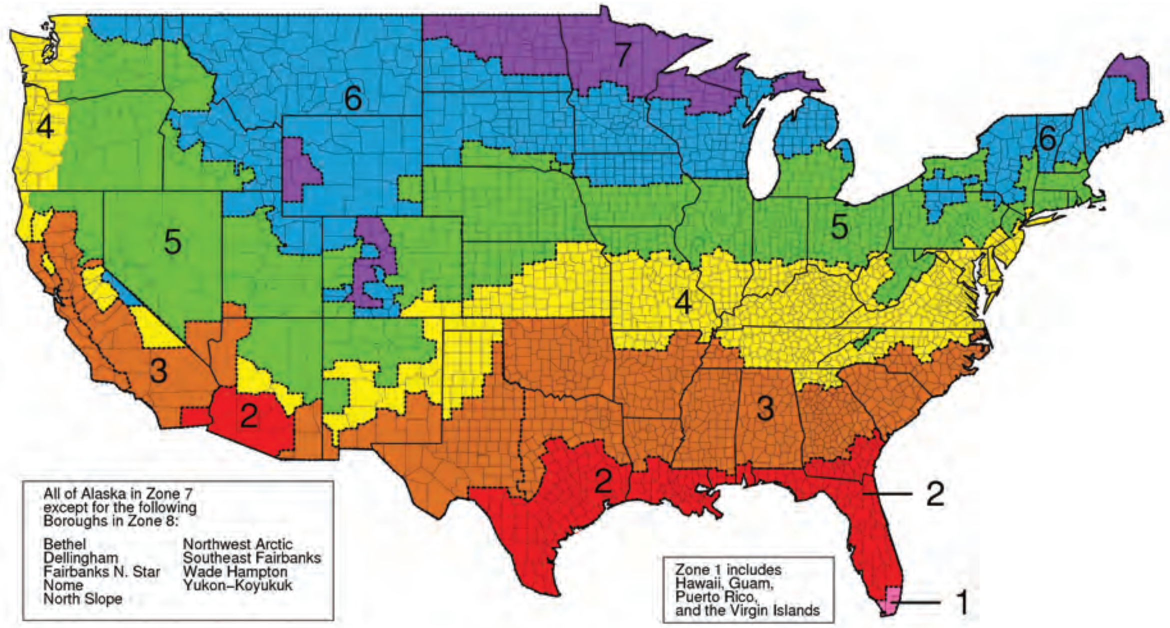

Figure 5 – Climate zones for United States (ASHRAE Standard 62.2).

Let’s look more closely at the effect of reflective roof surfaces, assuming that the roof system is compact and does not allow air movement in the assembly. On a sunny and warm summer day, an aggregate-surfaced BUR can be about 160°F. Under similar weather conditions, the surface temperature of a white single-ply may be closer to 110°F. With both of these roof systems having diffused water under the membrane, there will be different drying rates. Water at 160°F has a vapor pressure of about 4.83 psi; at 110°F, water has a vapor pressure of about 1.35 psi. Water vapor moves from regions of high pressure towards areas of lower pressure. The rate of this movement is determined by the difference in vapor pressure. Obviously, the drying rate will be different with the greater vapor pressure associated with the higher temperature. Also, the seasonal wetting rate may be different.

This is not news, however. In August 2009, Christian Bludau, Daniel Zirkelbach, and Hartwig Kunzel of the Fraunhofer Institute for Building Physics of Bavaria published a paper in *Interface* titled “Condensate Problems in Cool Roofs.”[1] This paper discussed the self-drying roof concept and applied the concept to roofs in Phoenix, Chicago, and Anchorage. They stated that in most locations, the self-drying roof works independently of the applied surface color where the only source of moisture is vapor diffusion from the interior. They did not discuss the potential of air movement in the system so were limited to compact roofs.

Only in locations with low average temperatures can moisture accumulation not be ruled out due to a reflective roof surface. The authors used WUFI (WUFI is a computer simulation program that allows realistic calculation of the transient coupled one-dimensional heat and moisture transport in multilayer building components exposed to natural weather) simulations to predict moisture accumulation over years in roofs in Phoenix, Chicago, and Anchorage. No vapor retarder was used in the roof system studied. Their study concluded that any color roof system would perform well in Phoenix. However, in Chicago, roof systems should be constructed with dark-surfaced roofs. As would be expected, in Anchorage, the reflective roof system would lead to rapid moisture accumulation. A dark roof would be just below the critical limit. However, this paper did not disclose the interior moisture used in the simulation. It can only be assumed to be an average or “normal” humidity level. This article raises concerns but does not provide a guide as to when a vapor retarder would be required based on interior RH.

More recently, the subject of condensation caused by reflective roof surfaces was addressed in a paper by Mike Ennis, technical director of SPRI, and Manfred Kehrer, senior researcher at ORNL.[4] This paper was presented at the 2011 NRCA International Roofing Symposium by Ennis. The paper is titled “The Effects of Roof Membrane Color on Moisture Accumulation in Low-Slope Commercial Roof Systems.” This study involved two field investigations and one WUFI modeling study. In the beginning of the study, it is acknowledged that black membranes are generally 50°F warmer than white membranes on a typical sunny day. These authors looked at the impact of color and the associated temperature differences on the location and occurrence of the dew point, and the impact of color on the ability of a roof system to dry out.

The first field study involved cutting into ten roof systems to observe any indication of moisture. All roofs were five years old or older, were located in ASHRAE climate zone 5, were climate-controlled, and consisted of one layer of insulation and no vapor retarder.

The result of this field study was that seven of the ten roofs showed no indication of moisture under the roof membrane. The remaining three roofs showed indications of moisture ranging from damp to wet. The indications of moisture were stains and wrinkled facings but nothing that affected the integrity of the polyisocyanurate core. The foam was observed to be dry, and there was no corrosion on the deck. The conclusions listed from the investigation of these roofs were:

1. The investigation showed that there was minimal effect to the roof assembly integrity, insulating value, or roof performance caused by damp or wet facings. (The roofs investigated were all mechanically attached single-ply systems. Had the membranes been attached to the foam rather than to the deck, the damp or wet facing could affect the cohesive strength of the facer, making the membrane more susceptible to wind uplift.)
2. In combination with indoor air infiltration, moisture accumulation and damage are more likely.
3. Further investigation is recommended for climate zones 6, 7, and 8.
4. Further work is recommended to quantify the effect of indoor air infiltration into the roof assembly.

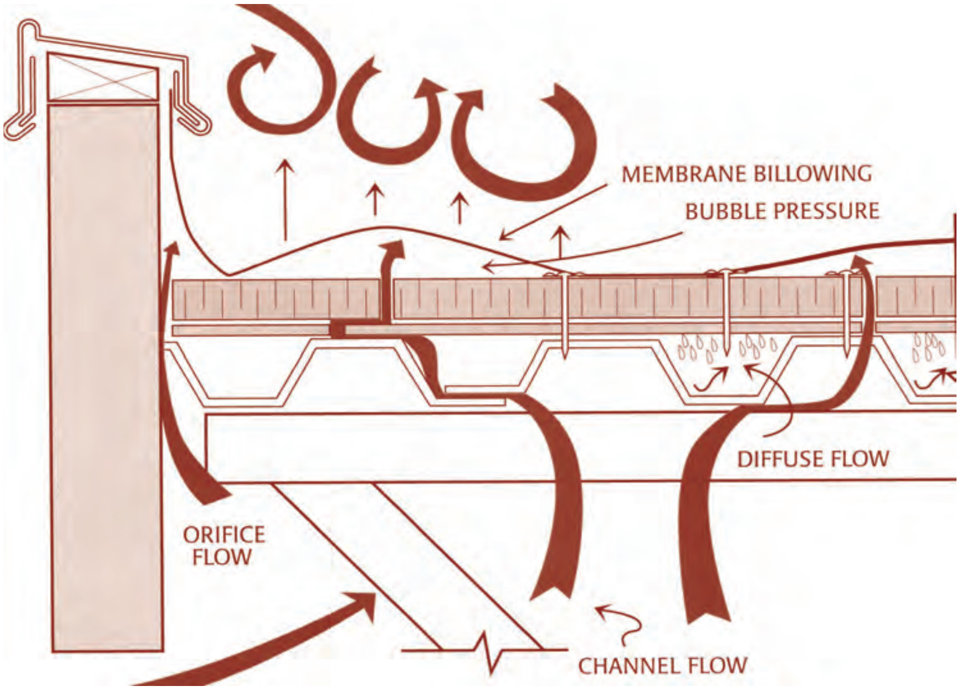

Figure 6 – Typical paths of moisture intrusion under mechanically attached roof membranes caused by moist air movement due to pressure differentials and vapor migration. (B. Baskaran, M. Sudhakar, and P. Beaulieu, National Research Council of Canada SIGDERS study.)

Interior wintertime RH was not recorded, and buildings were used for "normal" purposes such as office, retail, school, and grocery. As a result, this investigation provided good data but did not add guidance to the decision of when to use a vapor retarder or an air barrier.

The second part of the work reported on by Ennis was a WUFI study. This study mimicked the on-site investigation of the ten roofs, so weather and insulation thicknesses were based on the field-sample sites. The modeling was conducted using white roofs (solar absorption of 30%) and black-surfaced roofs (solar absorption of 90%). The author did not list the interior RH used in the WUFI study. The conclusions based on this WUFI study were as follows:

1. All physical and WUFI locations were in climate zone 5 (*Figure 5*). However, the exact locations within that zone and insulation thicknesses had only a minor influence on condensation risk.
2. With this modeling technique, the amount of condensation for white roofs is more than twice the condensation amount for black-surfaced roofs.
3. Both black and white simulations showed a return to a dry condition during the course of the year.

The third part of the work reported on by Ennis included work conducted jointly by SPRI and ORNL. In this field study, a failed wet roof was covered by a white membrane and a black membrane—roughly half of each. The purpose of this investigation was to observe the rate of drying of the wet roof system as affected by the color of the roof cover. The roof system was instrumented to observe temperature and RH within the roof system. There was a recorded difference in rate of drying as affected by color of roof covering, but after two years, the underlying roof system dried, and there was no effect of membrane color on performance of fasteners or insulation. Again, good data were provided, but there was no guidance on use of a vapor retarder.

So far in this discussion, the emphasis has been on diffusion of moisture as the determination of moisture accumulation and the available guides for determining the need for a vapor retarder. In the author's opinion, existing research has verified that the color of the roof does affect moisture accumulation and rate of drying, but none of the reported work has provided the data necessary to modify our currently most-used guide. It should be noted that WUFI can be used to determine if a vapor retarder is needed, assuming that the roof is compact and does not allow air movement in the system. WUFI will account for the effect of reflective surfaces and is an excellent guide for compact systems.

At the same time, numerous papers and articles[3,8,11] have been pointing toward the importance of air movement within the roof assembly as a major cause of condensation and moisture damage. In fact, Tobiasson has always emphasized that air movement is the greater cause of condensation for moisture accumulation in roof assemblies as compared to just diffusion.

Some have advocated the use of two layers of insulation with staggered joints to reduce moisture gain within sheet membrane systems.[7] However, more recent laboratory work[9] by Baskaran and associates has shown that staggered joints will contribute to the rate of air flow under conditions of wind or mechanical pressurization but will not affect volume of air intrusion. Others have indicated that fully adhered membranes with current spray-applied adhesives would eliminate air intrusion. But, is this really the case? I do not know of any tests that have proven this concept.

In Canada, there has been a longer and greater emphasis on the use of vapor retarders and air barriers in roofing assemblies. The current Ontario Building Code states, "Where a component or assembly will be subject to a temperature differential and a differential in water vapor pressure, the component or assembly shall include a vapor retarder." Canadian counterparts state that this vapor retarder is viewed as important as much for its function as an effective air barrier as a vapor retarder. In the U.S., the roof membrane may be tied into the wall air barrier to function as a continuous whole-building air barrier. This roof membrane *does* reduce transfer of air into and out of the building, but *does not* reduce moisture-laden air from moving into or out of the roof assembly, especially if the membrane is a mechanically attached single-ply.

Compounding the problem of determining when to use a vapor retarder in the U.S. are changes in materials and installation techniques. One of the biggest changes is the move away from using asphalt for adhering insulation to the deck and to laminate layers. For example, the old norm was to mechanically fasten one layer of insulation to a steel deck, mop in a cover board, and then mop in a base sheet and membrane. The asphalt would substantially seal the components together, resulting in a compact roof, reducing the movement of moisture vapor and interior airflow.

Today, the system may rely more on ribbon-applied foamed adhesives and mechanical fasteners, making the roof system more vulnerable to air movement. With these open construction techniques, moisture-laden air can be pumped into the roof system under dynamic wind conditions, due to mechanical system-induced pressures or due to stack effect in high-rise construction (see *Figure 6*). Even without this pumping action, moisture is freer to move through joints in the roof system than diffuse through roofing materials.[9]

For example, a prominent consultant in Texas recently investigated a roof failure in South Texas where condensation in the roof assembly caused massive polyisocyanurate board curling and delamination between the deck and the insulation and between the roof membrane and the cover board. Granted, this installation included structural lightweight concrete (LWC) over a steel deck; a single-layer of polyisocyanurate adhered to the LWC with ribbons of low-rise, water-based (as possibly mandated by today's green building code), gypsum-based cover board adhered to the iso board with the same adhesive; and a fully adhered reflective single-ply. In retrospect, this problem should have been foreseen. However, blindly using the CRREL guide for the use of vapor retarders, a vapor retarder on the concrete deck would not have even been considered—unless the roof designer correctly assumed that the source of potential moisture diffusion was not from the building interior but from the moisture within the LWC. Using old practices for roof construction, the deck would have been allowed to dry until it passed the "hot asphalt pour test" prior to attaching the foam in a full flood coat of hot asphalt, adhering the cover board with hot asphalt, and then adhering the membrane with adhesive to the cover board. Even then, it would have been prudent to install a vapor retarder on the LWC prior to installing the insulation and roof system.

From the previous discussions on the effect of reflective surfaces and on air movement in modern roof systems, it is clear that the existing CRREL guide for the determination of the need for a vapor retarder is not appropriate to predict the need for a vapor retarder in many of today's roofs.

So, where do we go from here?

Need for further research:

1. As a starting point, WUFI simulations should be used to develop a new diffusion-based maximum-allowable interior RH map for reflective roof surfaces similar to the existing CRREL map as a starting point for those used to the current CRREL maps. Rather than using a new modified CRREL map, the roof designer could just run a WUFI simulation. However, unless the WUFI simulation incorporated air movement, the result of the simulation would only apply to roofs that do not allow air movement.
2. Field studies are needed to determine condensation levels in reflective roof systems over high-humidity enclosures to verify WUFI studies.
3. Study the potential for roof air barriers that readily pass liquid moisture, which would allow easier leak location detection and reduce large-scale water entrapment. These studies should include prior work on hydrodiode membranes leading to practical commercial systems.
4. Study the effectiveness of continuously applied low-rise foam adhesive as an effective air barrier.

With this research as a starting point, specifiers should consider:

1. Construction schedules that require closing in a project early when high moisture-producing activities remain.[6] If such conditions are anticipated, a vapor retarder should be incorporated in the roof design.
2. Impact of roof surface reflectivity in the decision-making process for ASHRAE climate zones 4-8, including possibility of increasing insulation thickness as an offset for reflective surface. Again, WUFI could be a good starting point.
3. Impact of roof systems that allow free movement of moisture-laden air within the roof system. Although some[7,8] have advocated the use of offset joint insulation or cover boards, other lab experiments show that these approaches only reduce the speed of air infiltration, not quantity.[9]
4. Consider using polymer-bonded glass facers on polyisocyanurate where short-term moisture situations may be present due to construction schedule. It may be advisable to use these glass facers on all installations involving reflective roofing in zones 4-8.
5. Consider installation of a continuous vapor retarder directly over the substrate when installing roofing over concrete decks or interior spaces with elevated RH levels.[10]

Is it time for a paradigm shift in the way that low-slope roofs are built? We have inherited the gradual changes of a deck with more and more insulation on the deck, usually without a vapor retarder or effective roof system air barrier for northern applications. Today's construction techniques have only exacerbated the potential for moisture accumulation. Although it is possible to return to a more frequent use of the old vapor/moisture barrier approach, is it possible to reduce moisture transport and accumulation through new construction techniques? Following are some ideas for system developers:

1. Broader use of air barriers in all systems open to air movement
2. Broader use of protected membrane roof (PMR) systems, perhaps with primary insulation beneath the

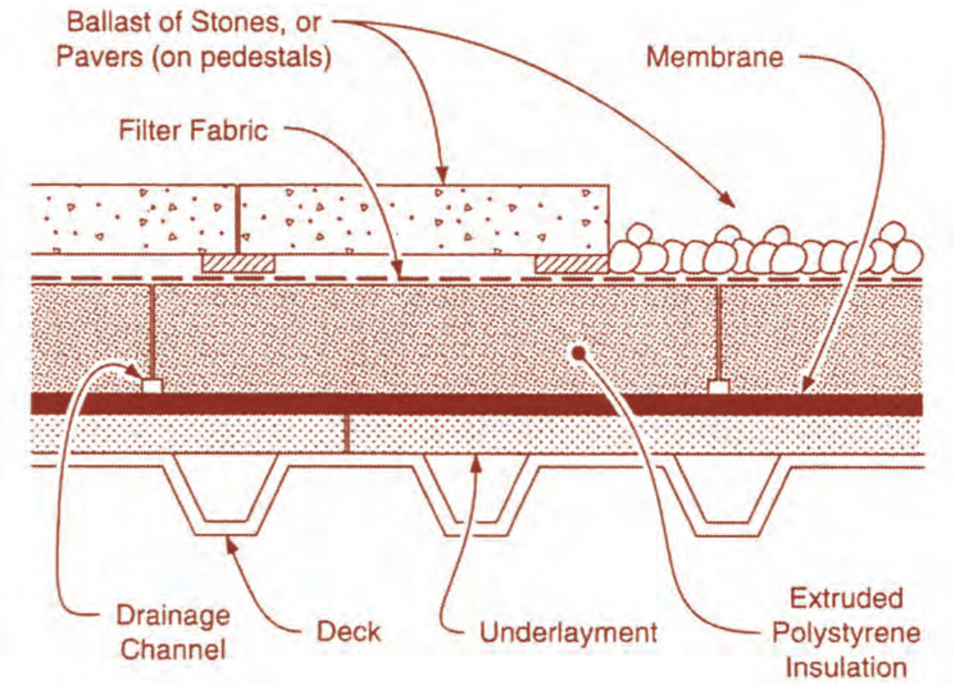

Figure 7 – Typical PMR roof assembly (W. Tobiasson, ASTM Manual 18, Chapter 16, "General Considerations for Roofs," 2nd Edition, October 2009).

membranes and insulation above the membrane as necessary (*Figure 7*)

3. Broader use of PMR vegetative roofing assemblies
4. Creating air barriers out of steel deck using spray foam or other techniques
5. Use of some sort of sealed roof underlayment board as an air barrier
6. Taped joints in base layer of insulation with a seal at perimeters and penetrations
7. Commercialization of sheet air barriers that transmit liquid water

It is obvious that roof design decisions have become more complicated with changes in construction techniques and in materials being used. The roof system designer must evaluate roof system design to determine the need for moisture retarders or air barriers.[8] We clearly need more data and better guides to aid in making decisions. The existing guides to the use of vapor retarders are based on systems that are not being widely used today. Some of the needed guidance may come from additional WUFI studies; however, WUFI may need additional product information and air movement data to be widely used. And, as always, there is room for innovation in our ever-changing roofing market.

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