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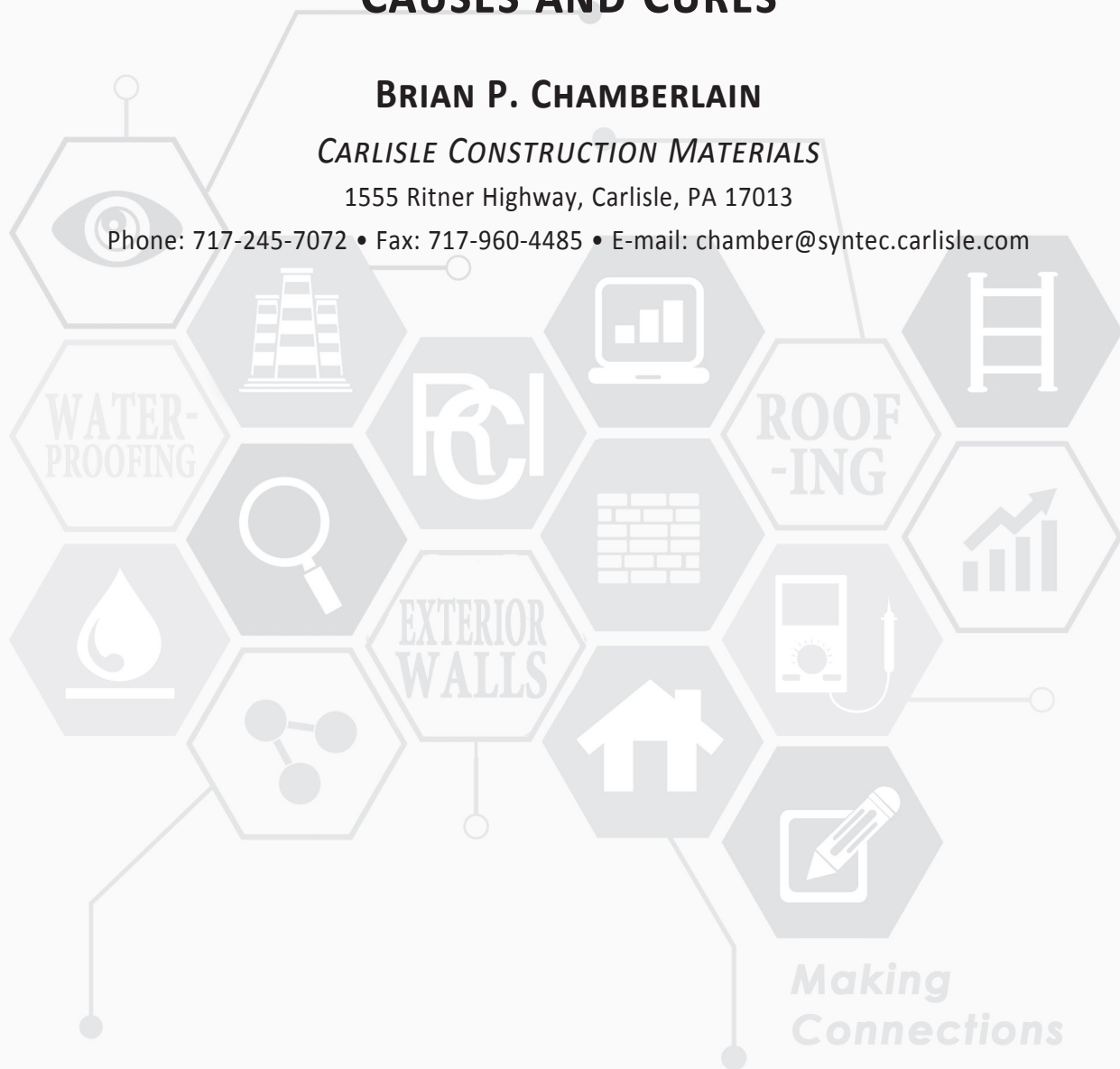
MOISTURE MIGRATION: CAUSES AND CURES

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ABSTRACT

As the roofing industry advances in product technology, building codes, and standards, the combination can create unforeseen consequences. One result has been moisture migration from different sources entering into the roof assembly, affecting long-term performance of the assembly and products. Since these conditions can be undetected for a time, it is important to review how the moisture moved into the roofing assembly, the unintentional results, and the details that were overlooked. Though it is important to understand the consequences, it is more important to make sure they are mitigated or corrected through the design process.

SPEAKER

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MOISTURE MIGRATION: CAUSES AND CURES

Advances in roofing material product technology and improvements within the building codes and standards have at times created unforeseen consequences. One of these consequences has been moisture migration from different sources entering the roof assembly, affecting its long-term performance and sometimes causing product deterioration or failure. These conditions can go undetected for a time, but eventually an exterior disturbance such as a wind event or an interior disturbance such as unexpected drips reveal the condition, and then it is an issue for all. This accumulation of unintentional moisture in the roofing assembly must be investigated to determine the source and path of entry and in order to be corrected.

The first point that must be clear is how moisture migrates into a roofing assembly, since if a roof is installed correctly, the products should not have any significant amount of moisture from the manufacturing process.

One obvious way moisture can enter a roof assembly is through a hole in the membrane—by a splice being made incorrectly, damage caused by someone doing maintenance work on a unit, or simply from a child shooting an arrow into the air that ended up sticking into the membrane. Though these are obvious causes, each can be repaired to make sure the assembly continues to stay watertight and perform as intended.

It should be assumed for this discussion that the roof assembly was installed following the architectural specification with no insulation being specified under the deck, and that the applicator installed the roof following the manufacturer's instructions in a quality manner. In addition, moisture entry was not from physical damage to the roofing assembly, and all mechanical systems are working correctly.

Another source of moisture migration would be from the use of the building. Most standard interior uses of a building, such as office buildings or warehouses, do not generate a significant amount of humidity; however, buildings used for swimming pools and data centers generate a high

relative humidity (RH). This excess amount of humidity, if not controlled, moves from the interior of the building and into the roofing assembly.

The basic cause for this vapor migration or vapor drive is from hot, humid air attempting to create an equilibrium by combining with cold, dry air. At some point these two meet, which is referred to as a dew point. To avoid the moisture's finding the dew point, a barrier is incorporated towards the warm moist air of the dew point to control the vapor. This control will stop the movement of the humidity from going beyond the dew point and reaching a cool surface to condense. As long as the vapor moisture stays a vapor, no issue should occur.

This condition of vapor migration is nothing new. Wayne Tobiasson¹ wrote about this very subject back in 1989. He even offered methods for controlling the moisture drive by incorporating a vapor barrier and explained where to place it.

Based on this, it seems it should not be difficult to control the moisture drive. So why does it seem that some segments of our industry are not aware when a vapor barrier should be considered?

The National Roofing Contractors Association (NRCA)² offers an easy rule of thumb that can be used to determine if a vapor barrier should be used. The *NRCA Roofing and Waterproofing Manual – Fourth Edition* 1996, "Simple Guidelines," states that if the following two conditions are answered with a "yes," then a vapor barrier should be considered:

- The exterior average low temperature during January is 40°F or less.

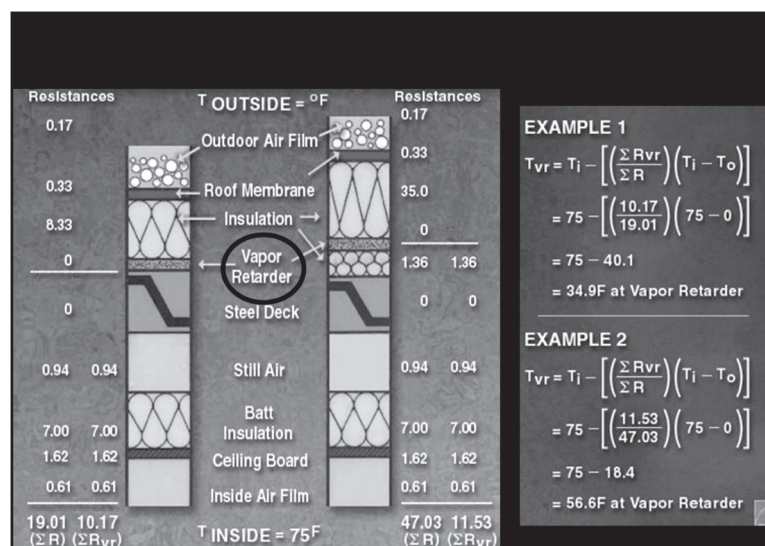


Figure 1 – ASHRAE dew point calculations.

- The interior RH is 45% or greater.

Here is an example of a prescriptive enhancement that has been used for years, but is often overlooked. It is interesting to note that this "rule of thumb" was determined based on the technology of that time, which included mostly dark-colored roof materials. With all the studies showing that when light-colored roofing materials are used, there is the potential of a greater accumulation of condensation, a review of these calculations should be completed to see if light-colored roofing materials have changed the parameters of those two conditions.

Determining if a vapor barrier is necessary can get complicated mathematically. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)³ (Figure 1) and Oak Ridge National Laboratory (ORNL)⁴ have methods explaining how this can be determined.

If a vapor barrier should be used, the placement should always be on the warm side of the insulation, typically towards the interior of the building. One should keep in mind that the above is a "rule of thumb" and does not fit all cases. An engineer should verify the need and placement of the vapor barrier, but as it has been reported in this fast-paced industry, where time is of the

Offices	30-50%
Hospitals	30-55%
Computer Rooms	40-50%
Department Stores	40-50%
Swimming Pools	50-60%
Textile Mills	50-85%

Figure 2 – Typical indoor RH in winter (by Wayne Tobiasson).

essence, this need has sometimes been overlooked.

After the decision to use a vapor barrier has been made, how do we determine the correct amount of insulation required to keep the vapor barrier warm so the dew point is not reached? The answer to the proper R-value of insulation can be calculated following the ASHRAE document or the ORNL method.

The interesting thing to note is that it doesn't take a high R-value in most cases to make a vapor retarder work, as long as the vapor barrier is not placed between high R-value materials. Using the NRCA's simple guidelines, in a building interior with a RH of 60%, interior temperature of 65°F, and an average January low of 15°F, the R-value required to make the vapor barrier work is only R-4. In fact, the minimum R-value required by ASHRAE to meet building code for energy efficiency (R-20 to R-35 in cooler regions), far exceeds the R-value necessary to make a vapor retarder work.

Though it seems responsible to incorporate a vapor barrier in many conditions, the NRCA also states that making a roof assembly "self-drying" is just as important. The concern is that if a vapor barrier were to be installed on a roof that did not need one, the trapped moisture within, between the vapor barrier and the membrane, would have no place to go. The thought is that this will be detrimental to the overall performance of the roofing assembly. Self-drying is a condition where a minor amount of vapor moisture does migrate into the roof during the winter, causing no real performance issue, and moves back out during the summer. Of course the operative phrase is "minor amount of vapor moisture."

So if we have known about moisture drive and when to consider incorporation of a vapor barrier for all these years, why are we experiencing all these issues with vapor moisture migrating into a roof assembly, creating condensation issues?

If we turn to the 2012 International Building Code (IBC) and review where it refers to vapor barriers, we discover that

the IBC refers us to ASHRAE. Within the ASHRAE document is an equation to determine if a vapor retarder is necessary and how much R-value is required to make it function. ASHRAE also offers an "Architectural Designers' Checklist," which asks, "Is the building humidified during winter, or is there a swimming pool or spa indoors, or is the winter design temperature below minus 15°F?" If yes, a vapor barrier should be specified "inside from the insulation." The problem is that most U.S. designers do not deal with -15°F or know what the RH inside the building will be at the design stage, unless it is obvious, such as in buildings occupied by swimming pools, indoor spas, or data centers.

In addition, the 2012 International Energy Conservation Code (IECC) requires a tighter building air envelope, which in turn may raise the RH by restricting the airflow. To illustrate this potential unexpected consequence, if a bathroom shower is being used but the bathroom door is left open with the bathroom fan off, most of the moisture vapor escapes from the shower area. But if the door is closed with the bathroom fan off, this vapor has no place to go and begins to accumulate on the walls of the bathroom as condensation. If this is the case, could Wayne Tobiasson's chart (Figure 2), showing that the office space has a RH of 30 to 50%, be too low? In addition, the energy code is expecting less air turnover in a building because of the trapped heat from the sealed building envelope. This lack of air movement could possibly allow the RH to increase even more.

It must be noted that Tobiasson's study did discuss that leakage of air movement from the interior or exterior through the details around the perimeter (roof to exterior wall) is a major cause of carrying moisture vapor into the roof assembly, increasing mois-

ture condensation. He points out that all locations that have air leakage should be sealed. Once completed, most condensation issues had been corrected.

The 2012 IECC (depending on the specific state) requires that a complete air barrier must be incorporated around the building envelope in new building construction. Currently, only a few new buildings have complete air envelopes (foundation, walls, and roofing). Though air movement is a concern and any open channel should be sealed, the question has been raised on how the air movement in a building with a complete air envelope might add vapor moisture to the roofing assembly. There are continuing studies on this issue, and until they are completed, the focus of this paper will be on the source of moisture and its movement through general vapor drives and how a vapor barrier (which can be used as an air barrier) would assist in controlling both issues.

UNFORESEEN CONSEQUENCES

What have been the unforeseen consequences of using or not using a vapor barrier, saving the cost by excluding the vapor barrier, and misunderstanding the complex building code?

Though one might site numerous consequences, for the purposes of this discussion, the three main consequences of moisture migration into the roofing assembly are:

1. Changing an existing interior building use to a different use
2. Industry construction practices
3. Increased popularity of lightweight structural concrete (LWSC)

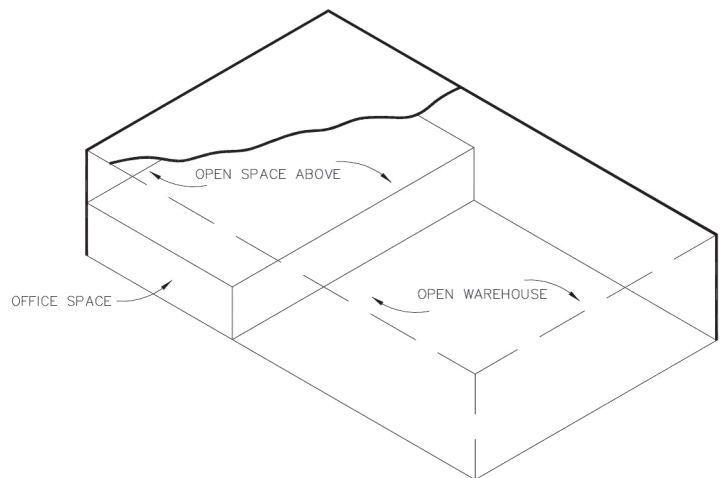


Figure 3 – New construction office/warehouse.

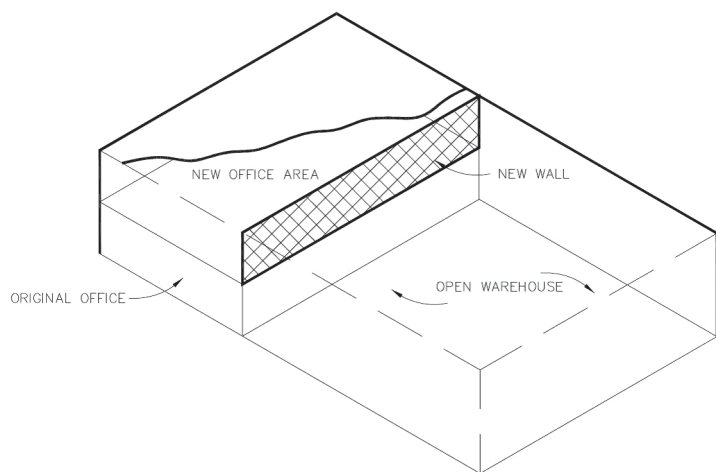


Figure 4 – Addition of new office space.

Change the Use of an Existing Building

A developer saw the opportunity to build an office/warehouse in a northern climate. He has no idea who the end-user will be. The designer of record specified an office inside one area of the open warehouse. The designer knows that the inside warehouse area will have the same RH as the exterior RH, so he determines there will be no vapor drive, so a vapor barrier is necessary. The office space might need to be addressed with a vapor barrier at the walls and ceiling, but not the warehouse. The building is built, and the developer finds a buyer (Figure 3).

Once the building is purchased, the new owner sees the open space above the office as a place to add more office area. He has it renovated so the upper area is enclosed, using the original interior wall and extending it up to the structural deck. The owner decides to heat the new office space with gas heat, which is hot and humid pumped air, for the comfort of the employees (Figure 4).

Unfortunately, the roof deck flutes that run from the new upper office area to the warehouse were not enclosed. In addition, the original roof assembly above the roof deck never incorporated a vapor retarder.

The result was that the hot humid air from the new office space migrated not only into the roofing assembly, causing condensation, but also migrated down the flutes and entered into a portion of the warehouse (Figure 5).

The correction of this issue with the roofing system and the interior was filling the flutes from underneath the deck and the top. This involved removing a section of the roofing membrane to expose the deck

and then seal any possible airways into the warehouse (Figure 6). Due to cost, the roof over the office space was switched to a black membrane to assist in mitigating the condensation under the membrane to avoid complete removal of the existing roofing assembly.

To avoid an unpleasant situation with a customer and a potential problem that could cause other issues, when a building has a new addition or the building is changing its interior use, the designer of record needs to assess the building based on how the building will be used. We can no longer assume that a warehouse will simply be used as a warehouse for dry goods. Once we have ascertained what the building owner wants, we can address the situation.

Industry Construction Practices

Industry construction practices have resulted in two major problems. The first problem is construction-generated moisture. This moisture source needs to be addressed, especially during the cooler months of the year.

A scenario has been reported and documented as follows. After the exterior walls and roof deck of a warehouse were put up, the contractor was asked to install the roof system. Since this was a warehouse, the designer of record decided a vapor barrier was not necessary, so none was included. The contractor saw no reason to wait, so he completed the roof assembly quickly (Figure 7). Soon after, the schedule for the pouring of the concrete floor on the interior started (Figure 8).

Because of schedule needs, the amount of moisture in the concrete, and the need to cure it quickly, bullet heaters were installed, which created a condition very similar to an interior swimming pool's RH. During specific times of the year and depending on geographic location, this might not be an issue. But in the northern climates, during the cooler period of the year, this moisture is looking for a cold surface to collect upon.

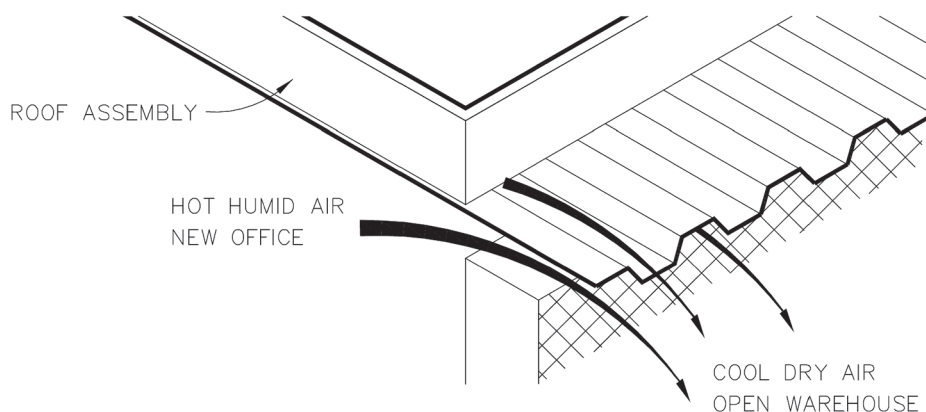


Figure 5 – Moisture migration from office to warehouse.

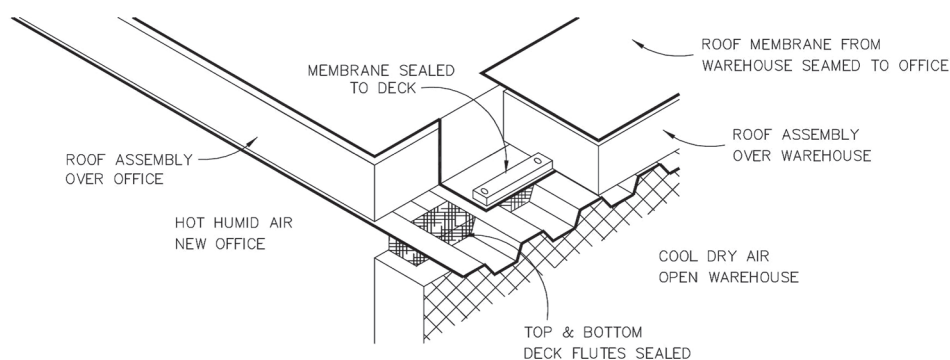


Figure 6 – Detail correction.

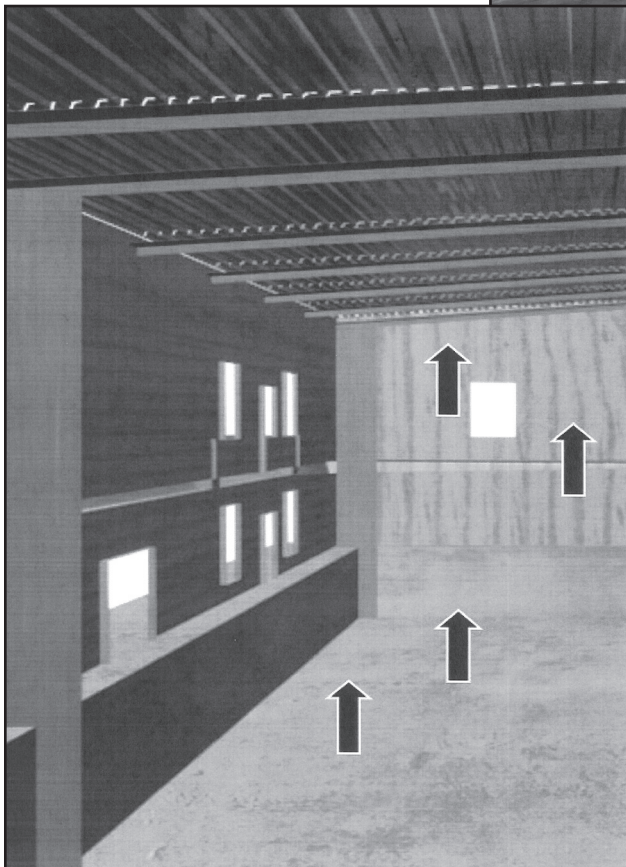


Figure 7 – New roofing assembly being installed.

Figure 8 – Line of cement mixers for the concrete floor.



Figure 9 – Moisture migration from new concrete into roof assembly.



Since the roof assembly has insulation installed directly on the deck, the deck is kept warm from the interior, so the vapor moisture bypasses this location through joints and openings and continues up into the roof assembly, looking for a point to condense. This location ends up being the underside surface of the exterior membrane (Figure 9).

Because of the time of year (cooler part of the year), installation of the roof assembly, followed by pouring of the concrete floor, initiated this problem. Controlling the installation is necessary, but if we do not have control, what can we do? I would recommend specifying a vapor barrier to protect the roofing assembly and the building owner. Though it may not be necessary during certain times of the year and for the eventual operation of the building, the removal of this moisture, once trapped in the roof assembly, becomes very difficult.

Some have tried to remove the trapped moisture within a roof by using mechanical ideas, such as one-way vents, air equalization systems, and desiccant drying systems, but none have been proven to work efficiently or inexpensively.

Another option would be to dehumidify the building as the concrete was



Figure 10 – Pouring of concrete deck.

Figure 11 – Roof damaged from condensation.



being poured, with positive airflow under the roof deck through industrial fans, which has been used successfully.

The second industry construction practice we will review is the request for installing a new roofing assembly directly over newly poured concrete deck or “green” concrete (Figure 10) that hasn’t cured for 28 days. This usually comes as a request to the membrane manufacturer regarding their requirements for concrete curing time before installation of the roofing material can start.

Twenty-eight days is a concrete industry standard curing period and is generally sufficient to achieve a structurally sound substrate and a dry surface for the roof assembly. But while the exterior surface of the concrete deck may be “dry to the touch” for proper adhesion, there is a possibility of moisture being trapped within the concrete either from the original pouring process or from a weather event. The trapped moisture through natural vapor drive conditions (depending on the time of year) could be driven upward as a vapor and condense directly under the primary membrane. If excessive moisture condenses within the roof assembly, this moisture might harm the insulation (Figure 11) and possibly affect the long-term wind uplift resistance of the system.

So if 28 days is not enough, what is? The problem becomes compounded with other factors, such as concrete thickness and compressive strength, geographic temperature, exterior and interior RH, water-to-cement ratio, and precipitation.

The chart in Figure 12, from Karnare’s “Concrete Floors and Moisture,”⁵ shows how many days it would take to reach the acceptable level of 3 lbs./1,000 sq. ft./hour based on different water-to-cement ratios. The study shows the best case ratio is over 150 days. Most are over a year in duration.

Another study, by Bruce A. Suprenant,⁶ shows again (depending on the water-to-cement ratios) that it could be 52 days to over a year (Figure 13). You will notice between

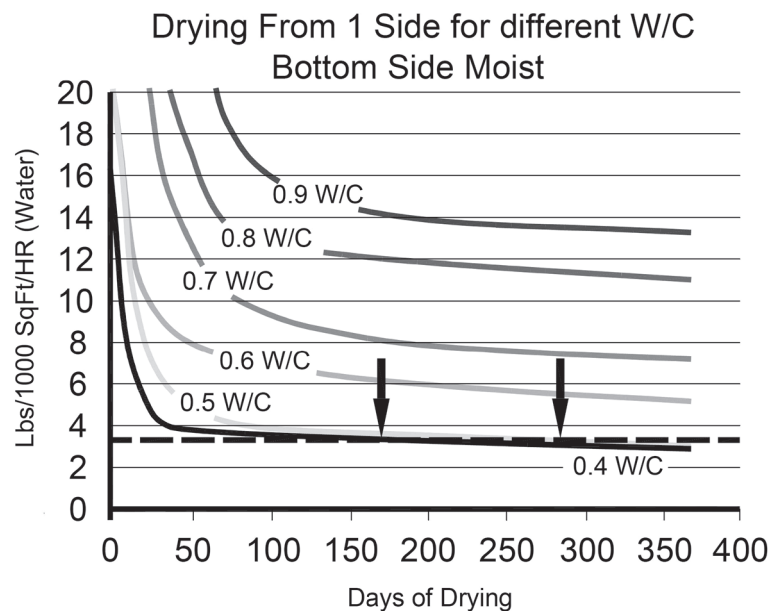


Figure 12 – Four-inch-thick concrete at constant room temperature and RH of 60%.

4-inch thick Slab at 73 degree F and 50% Relative Humidity			
Water to Cement Ratio	Bottom Sealed	Bottom Surface Exposed to Water Vapor	Bottom Surface Exposed to Water
	(Over Steel Deck)	(Self-Supporting Slab)	(Slab on Grade)
0.4	46	52	54
0.5	82	144	199
0.6	117	365	>365
0.7	130	>365	>365
0.8	148	>365	>365
0.9	166	>365	>365
1	190	>365	>365

Figure 13 – “Moisture Movement Through Concrete Slabs.”
By Bruce Suprenant.

the two charts that a difference in RH can greatly affect the result. Keep in mind that both studies were done in a controlled indoor environment, while the concerns that are being reported are exposed environment concrete decks. Since the exterior concrete roof deck experiences weather events, both studies’ results need to be considered.

As a result, the question of how long it will take a concrete roof deck to be ready for the roof system should not be asked of the membrane manufacturer, but rather the building industry. The problem is the building industry does not know, since no code standard exists. Studies are still ongoing to determine when a concrete deck would be ready for the roof assembly to be installed based on testing of the RH within the concrete. The proposed testing method is similar to the test method that is performed on interior poured concrete. The test method under consideration is the in-situ test following ASTM F2170.

Growing Popularity of Lightweight Structural Concrete

Going hand in hand with “green” concrete is the lightweight structural concrete (LWSC) that was introduced in the 1920s⁷ as a way to limit the weight on a building but still offer the strength of concrete.

Though it has been used for more than 90 years, LWSC is more expensive than standard concrete, so its use has been limited until now. With the industry focused on ways to lighten up concrete roof decks so that less-robust structural components are needed to hold the decking up, LWSC has become more popular.

In the process of mixing lightweight concrete, a significant amount of water must be used to make it a workable product that can be transported to the roof and spread evenly. The curing time for strength of the product is similar to standard concrete, but the time required for trapped latent moisture within the concrete to migrate out is much longer. Standard concrete, depending on many factors, could dry out within three to six months. Studies have documented cases where LWSC has taken over a year to dry out.

Back in the 1980s, this did not seem to be a public issue, since most adhered

systems either were installed with fasteners to hold the insulation in place (including the plastic that was used as a vapor barrier), or they had been adhered with a flood coat of asphalt. Asphalt installed in this fashion can be used as a vapor barrier. It was not until the industry started to use two-part urethane adhesive applied in ribbons as an option to adhere insulation to concrete decks without a vapor barrier that the issue emerged. As the moisture from the concrete migrated into the roof assembly between the ribbons, the moisture condensed. Sometimes the moisture would flow back to the deck surface during the spring and summer, where it would saturate the paper facer of the polyisocyanurate. The roof assembly would delaminate from the bottom, causing the roof assembly to float (Figure 14).

Field studies are underway to see how long a deck will take to dry out. Some studies have shown it may take over a year before the deck could be considered dry. Matt Dupuis reports,⁸ “I have measured moisture in LWSC roof decks that were five years old and still returning 99% RH by ASTM F2170 probes.”

What this creates is a concern over the impact of moisture on the long-term performance of the roofing assembly. As an example, 28 days after a concrete deck was poured in February, the roofing contractor was asked to install a membrane directly to the concrete deck.

In a very short period of time, it was found that this roof was not adhering, and many areas had become loose (Figure 15). When the contractor cut open the loose areas, condensation was found under the membrane (Figure 16).

In other cases, condensation damage was not discovered until much later, when the moisture had migrated into the adhered roof membrane assembly during the winter and condensed under the membrane, saturating the top paper facer of the polyisocyanurate, weakening the facer’s physical structure. Later a wind event occurred, and because of the weakened nature of the paper facer, delamination of the membrane was discovered. Upon investigation, it was recorded that paper facer was found on the membrane and on the insulation. This is what is referred to as an “inter-ply failure of the facer,” which has always been a strong indication of moisture infiltration (Figure 17).

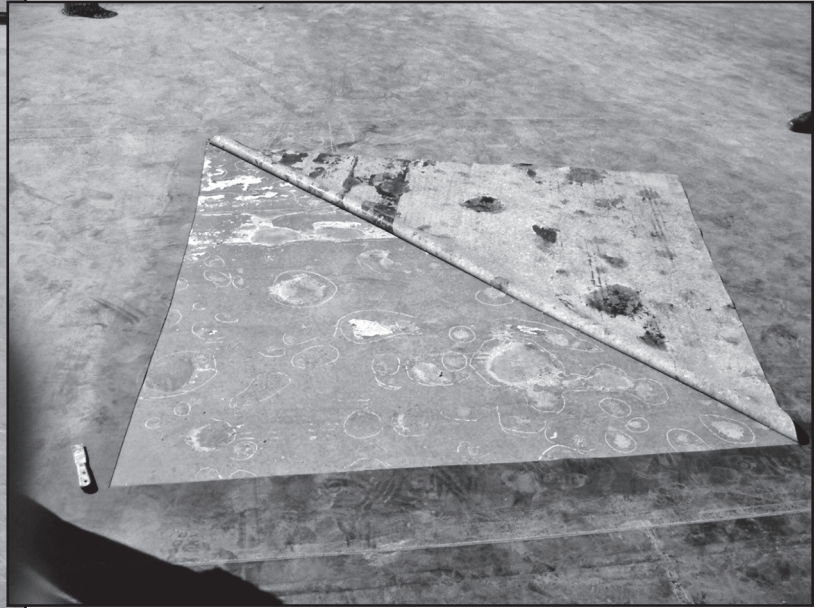


Figure 14 – Floating adhered membrane assembly.



Figure 15 – Membrane coming loose.

Figure 16 – Membrane losing adhesion because of moisture.



The insulation R-value is what is necessary to keep the vapor moisture in the concrete as vapor so it does not cause any problems with the new system.

ed membrane with moisture-tolerant insulation. Please note that the IBC has limitations on ballasted membrane, so this option should be reviewed carefully.

In my opinion, until technology or an industry standard is developed, we should consider that the interior of the concrete or lightweight concrete deck will have a high RH and moisture content that could infiltrate the roof system. A vapor barrier should always be incorporated to safeguard the assembly and the owner.

There are many ideas on how to correct this issue, such as fastening a vented base sheet to the concrete (similar to what was done for new gypsum decks) to using a curing catalyst that would use up the excess moisture, to putting a coating over the deck as a barrier to the interior moisture. The problem with the vented base sheet idea is all the fastening, labor, and noise. Most curing catalysts and coatings have been found to make the surface of the concrete too smooth for any adhesives to grip.

It is interesting to note that some built-up roofing manufacturers allowed the concept of a temporary roof, but their specifications required the temporary roof to be removed prior to installation of the new built-up roofing materials. With the introduction of “peel-and-stick” products, specifiers are trying to leave them in place and install the new system on top. Perhaps the old method of removing the temporary roof prior to installation of the new roofing assembly might be a better option.

Another option is not to use the vapor barrier as a temporary roof, but as the vapor barrier that it needs to be. Once the peel-and-stick is installed, there should be no waiting time for the new roof—including the insulation and membrane—to be installed.

If the schedule of the project makes it necessary for a peel-and-stick to be used as a temporary roof, and it is during the cooler months of the year, a solution has been to temporarily insulate and ballast the temporary roof and then, in the spring, completely remove the ballast and insulation, repair any delaminated areas of the temporary roof, and install the final roofing assembly.

If adhesion is still an issue or delamination of the temporary roof material is found, one could simply secure, at a minimum, the first layer of insulation to bypass the adhesion concern.

Of course, this option leads to an obvious conclusion to specify a ballast-

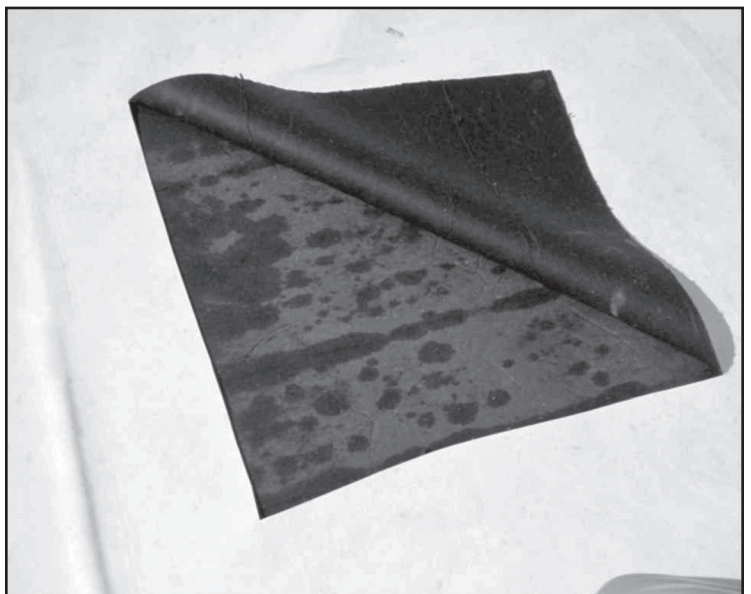


Figure 17 – Inter-ply failure of insulation facer from condensation.

TRUE CONSEQUENCES

The three major causes listed in this paper may seem basic to some, but for the industry, they have become the cause of many discussions, meetings, and possibly lawsuits. Even after it has been proven to the building owner that the moisture was caused by natural moisture migration, the owner might still believe the cause is a leak. At some point, the frustration level might increase until the owner then looks to drag everyone into the discussion.

On one project, after an investigation of a membrane delamination from a concrete deck that was caused by trapped moisture within the concrete and not by faulty products or poor workmanship, the manufacturer continued to be involved for over six months, continually making the point that it was not the membrane or adhesives. Since this specified roof area was small compared to the rest of the complex, this area was eventually taken out of the warranty coverage until the issue could be resolved. Instead of continuing the discussion, the designer of record went to other manufacturers for guidance. At this point, the designer was confronted with the exact same concerns. Everyone said the problem was moisture entrapment, and no one wanted to get involved. The result was that this roof area was never warranted.

So the key to controlling this moisture drive is to understand first how moisture moves; second, where it is coming from; and finally, how to control it so that it will not be an issue to the roofing design or structure. In construction, numerous questions need to be asked of the building owner.

For instance, if the building owner wants to add a room to store bananas next to his cooler, the designer needs to make sure that both are completely isolated and a vapor retarder is installed on the warm side (the interior of the banana storage area). If the building owner wants to add an area within his structure that will be storing


tropical fish for distribution, this area again should be a structure within the structure, not an open-wall addition. Special environments not previously planned for need to be planned for now.

I have worked with many data center designers who wanted to make sure the roof system was enhanced to withstand a tornado, but no thought was given to incorporate a vapor barrier because of the high humidity that is necessary to keep the communication equipment working properly. Moisture then migrated into the roof assembly, condensed, and dripped on the equipment. It's nice to know that we will not lose our cellular service during a tornado, but it's too bad that a drip will break the whole system down.

IN CONCLUSION

To assist in avoiding potential problems, I recommend the following questions be asked whenever there might be a concern about vapor drive:

1. Is a vapor barrier necessary, based on the use of the building?
2. What is the RH of the building?
3. Is the outside January temperature average low 40°F or below?
4. Where is the building located geographically?
5. What is the use of the building?
6. Is a new addition or interior of the existing building planned?
7. Has a complete assessment of the existing building and material been completed?
8. Is the deck concrete or LWSC?
9. When was the concrete poured?
10. Based on the parameters of the roof installation, is a temporary roof necessary? specifier can no longer put out specifications and expect the building code to address all conditions. Since roofing material manufacturers get inquiries on this issue nearly daily, they are not only

attempting to develop products that will help mitigate these issues, such as promoting the use of coated fiberglass facers on polyisocyanurate (which is moisture-resistant), they are also assisting in educational courses and seminars. Just as we currently do not have a standard for determining if a concrete deck is dry, communication has become as important as using common sense, but neither is required by the building code. 

REFERENCES

1. Wayne Tobiasson, "Vapor Retarders for Membrane Roofing Systems," North Conference on Roofing Technology, 1989.
2. *The NRCA Roofing and Waterproofing Manual*, Fourth Edition, 1996.
3. *ASHRAE Handbook of Fundamentals*, 1993.
4. A.O. Desjarlais and A.N. Kragiozis, "Review of Existing Criteria and Proposed Calculations for Determine the Need for Vapor Retarders," North American Conference on Roofing Technology.
5. H. Karnare, "Concrete Floors and Moisture," Eng. Bulletin, #119, 2005.
6. Bruce A. Suprenant, *Moisture Movement Through Concrete Slabs*, 1997.
7. ACI Committee 213, "Guide for Structural Lightweight Aggregate Concrete," 1999.
8. Matt Dupuis, "Light Weight Structural Concrete Roof Decks, What to Do", T&R Update, *Midwest Roofer*, August 2014.