

Plain Talk About Condensation
and Radiation Below Metal Roof Assemblies

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ABSTRACT

During recent decades an increasing number of users have chosen metal roofing for various commercial, industrial and institutional buildings. Because of several advantages, construction of new pre-engineered and "hybrid" buildings has outpaced low-rise, nonresidential conventional construction since 1984. Unfortunately, some of these advantages may give rise to certain disadvantages in comfort, durability and operating costs (7).

This paper provides a brief historical overview of common metal roof insulation methods as well as recent innovations for low cost/no cost performance enhancements. Following is a discussion of current industry trends and design considerations for those seeking to control the combined effects of conduction, convection, radiation and moisture migration in individual roof assemblies.

INTRODUCTION

A primary objective of this paper is to try and simplify the complex subject of condensation in metal roof assemblies. A secondary objective is to focus on condensation considerations with reflective insulation systems (as commonly confused with radiant barrier systems) (12).

It is important to understand initially that, unlike many common building materials (10), metal roof and/or wall panels have perm ratings (WVTR; Water Vapor Transmission Rate) of 0.00. Therefore, metal panel assemblies, especially in

climates that include both hot and cold extremes, may be substantially less "forgiving" than other types of exterior building materials that "breathe".

In general, nonventilated metal roofs in climates with potential for winter temperatures below 40 degrees F and interior relative humidity above 40% often become candidates for interior vapor retarders. On the opposite extreme, in hot and humid only climates, some designers may opt to utilize metal roof panels and closure accessories as an exterior vapor retarder. This type of roof assembly may subsequently integrate a perforated (approximately 30 perm) radiant barrier system as the primary insulation strategy in air conditioned structures.

METAL BUILDING CONDENSATION 101

As colder weather sets in, some metal roofing contractors experience a surge of phone calls regarding "roof leaks", even though it has not rained for several days. Water indeed may be dripping from the roof to the floor or ceiling tiles. The source, however, is often internal, not external. The phenomenon of condensation in structures occurs much more frequently than many realize. Condensation, both exposed and concealed, often goes unnoticed - until it reaches a magnitude sufficient to attract the attention of building owners, designers or contractors.

Simply stated, condensation occurs when warm, moist air comes into contact with a cold surface - a surface at or below the "dew point". Table 1 (2) shows dew points for various temperatures and relative humidities.

DRY BULB TEMP. DEGREES F	PERCENT RELATIVE HUMIDITY								
	10	20	30	40	50	60	70	80	90
	DEW POINT TEMPERATURE DEGREES F								
-20							-27	-24	-22
-10				-28	-23	-20	-17	-14	-12
0		-30	-23	-18	-13	-10	-7	-5	-2
+10	-30	-21	-13	-8	-4	0	+3	+5	+8
20	-23	-12	-5	+1	5	10	13	15	18
30	-15	-3	+5	11	15	19	22	25	28
40	-8	+5	13	19	24	28	31	34	37
50	0	13	21	27	32	37	40	44	47
60	7	20	29	35	41	46	50	54	57
70	14	28	37	45	50	55	59	63	67
80	20	36	46	54	60	65	69	73	77
90	27	44	54	63	69	74	79	83	87
100	34	52	63	71	78	84	88		
110	41	60	71	80	87				

Table 1. Dew Point Chart For Temperatures and Humidities

Figure 1 is an example of exposed, external condensation during mild, humid weather. The photo depicts where the vinyl faced blanket insulation below the deck is and is not performing. The darker (wet) portions of the roof fell below the ambient air dew point temperature, causing condensation. The lighter areas of the roof are above stapled insulation seams. The convective heat loss at these seams raised the surface temperature above the dew point of outside air, thus, these areas remained dry.



Figure 1. Exterior condensation on school roof assembly.

The photo in Figure 2 depicts the same roof after a light snowfall. Again, note the weakness in the insulation and vapor retarder at the seams. It is at these locations when internal temperature and relative humidity conditions become just right (or wrong!) that concealed condensation may first occur. The dark horizontal lines are steel purlins where a severe "thermal short circuit" is common in structures that include no thermal spacer blocks (6,7,8). "Sweating purlins" on the inside (not illustrated here) are one example of exposed condensation - and an indication that even more severe problems may be lurking elsewhere.

Condensation in metal roof assemblies can however, be eliminated or minimized by proper design, planning and assembly. Once the roof assembly is completed and the insulation becomes saturated or metal components corrode, corrective measures may become quite difficult - and expensive.

Condensation control measures generally fall into three categories:

- (1) The use of sufficient insulation to keep surface temperatures above the dew point;
- (2) The installation (on the warm side) of a vapor retarder and seal to handle the most severe temperature, humidity, and wind pressure (9) conditions to be encountered; and/or
- (3) Natural or mechanical ventilation (balanced with the above) to prevent a buildup of excessive relative humidity in the building or attic cavity.



Figure 2. Melting snow indicates major points of winter heat loss and initial locations of concealed condensation in metal roof assembly with stapled insulation seams.

Numerous papers, books and articles have been written on variations of the three basic condensation control measures mentioned above, so the balance of this paper focuses on two current, significant trends in the metal roofing/insulation industry. The first involves insulation options with substructural systems commonly used to provide much needed roof slope to existing structures. The second topic is the growing use of thin "reflective insulation systems" and "radiant barrier" membranes.

IMPACTS OF NIGHTTIME RADIATION

Before discussing emerging technologies in the construction industry, it is appropriate to make an analogy to modern automobile windows: Have you ever wondered why we must often scrape frost off car windshields, even with air temperatures of 40 degrees, but may have little trouble with (vertical) side windows? The reason for this is simple: on cold, clear nights, a sloping or horizontal surface facing the sky radiates much greater quantities of heat than calculations based upon ambient air temperatures alone would indicate (11). Even though ambient air temperatures may be well above 32 degrees, sloping windshields are prone to lose so much heat by radiation to the cold, clear sky that the surface temperature of glass often falls below the dew point, forming condensation that subsequently freezes.

SUBFRAMING WITH INSULATION AT OLD ROOF LINE

With windshields in mind, refer to Figure 3, a cross section representative of one popular method with standing seam reroofing. Many are surprised to learn that, even with ambient air temperatures in the high 20's, exterior panel surfaces (and subsequently interior panel surfaces) may drop to single digit temperatures due to thermal radiation to cold, clear night skies. This can become extremely confusing to owners, engineers, and reroofing contractors who are unfamiliar with this phenomenon and who rely only on natural ventilation to control condensation in the cavity. Psychrometric tables, for example, may indicate that with a 20 degrees dry bulb temperature, the dew point should be near 13 degrees or 18 degrees respectively with relative humidities as high as 70 percent or 90 percent. In reality however, there is often insufficient wind or air movement just before dawn and the relative humidity in the cavity needs to reach only 40 percent or 60 percent respectively for condensation to form on the bottom of all panel surfaces that drop (by radiation) to 1 degree or 10 degrees.

Unless the cavity is adequately vented, other possible locations for condensation:

- (1) the new fasteners/substructure;
- (2) around joints in the (wet) insulation;
- (3) on or around penetrations where warm, moist air escapes from the old roof.

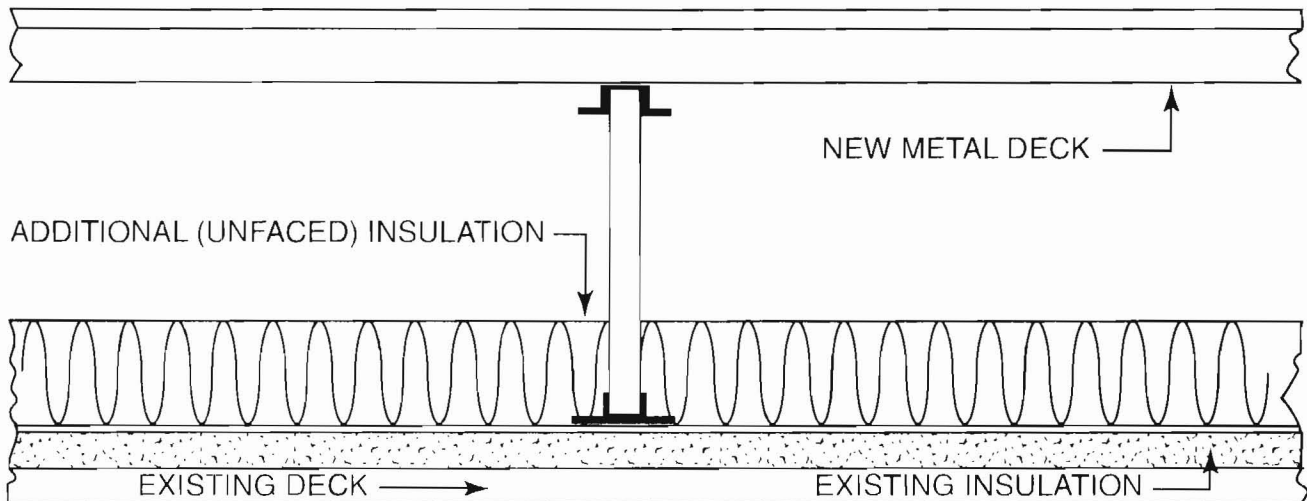


Figure 3. Subframing with insulation at old roof line.

SUBFRAMING WITH INSULATION AT NEW ROOF LINE

Figure 4 is representative of another alternative favored by some standing seam panel manufacturers. With insulation below the roof panel, the inward facing surface of the new roof assembly has some level of "resistance" (R) separating the extremely cold panel and the vapor retarder. Using the same ambient air and humidity figures in the scenario stated above, it is interesting to ponder the probability of the surface temperature of the insulation vapor retarder dropping to 18 degrees, 13 degrees, 10 degrees or 1 degree.

While adding insulation at this location may not be as inexpensive (or efficient in the winter) as (unfaced) insulation per Figure 3 (assuming both are dry), this location may reduce not only "wind chatter" associated with certain standing seam profiles, but also the amount of ventilation required. Beware, however, even with insulation and a quality vapor retarder (not white vinyl), some level of ventilation may still be necessary to minimize or eliminate condensation at three typical "thermal short circuits" locations mentioned in discussions of Figure 3.

In installations similar to both Figures 3 and 4, heavy ventilation is often critical during the first few months after enclosure if the existing roof insulation has a high moisture content. (Removal of old decking/insulation is not always necessary, yet perforation of membrane may be.)

REFLECTIVE INSULATION SYSTEMS

Figures 5 and 6 describe other trends and options in both new and retrofit metal roofing. Doublesided foil products, ranging in thickness from about .03" to .33" are being used more and more in lieu of or to supplement "bulk" insulation (18). These systems may indeed provide R-values (by enclosing air space) (3), and are defined technically as a "reflective insulation system" (RIS). They are discussed here to illustrate that, if used alone in cold climates, a "single layer" RIS, much like thin or severely compressed blanket insulation, may sometimes provide inadequate "resistance" to prevent condensation from forming on the bottom side of the material.

Under summer conditions, a 3½ inch reflective air space (Figure 6) may provide an R-8.17 (1,3). In winter conditions this same air space has an R value of only 2.01. As the depth of the cavity decreases to 1½ inches, ¾ inch, and ½ inch, the respective (wintertime) values are R-1.81, R-1.66, and R-1.57. Depending upon a number of variables - primarily climate, ventilation and end use of building - these single layer "wintertime Rs" (plus air films) may or may not be sufficient to keep interior surface temperatures above the dew point in some enclosures. Figures 5 and 6 compare calculated resistance values for two typical "single layer" RIS's in new metal roof assemblies - and identify the "weakest link" in each.

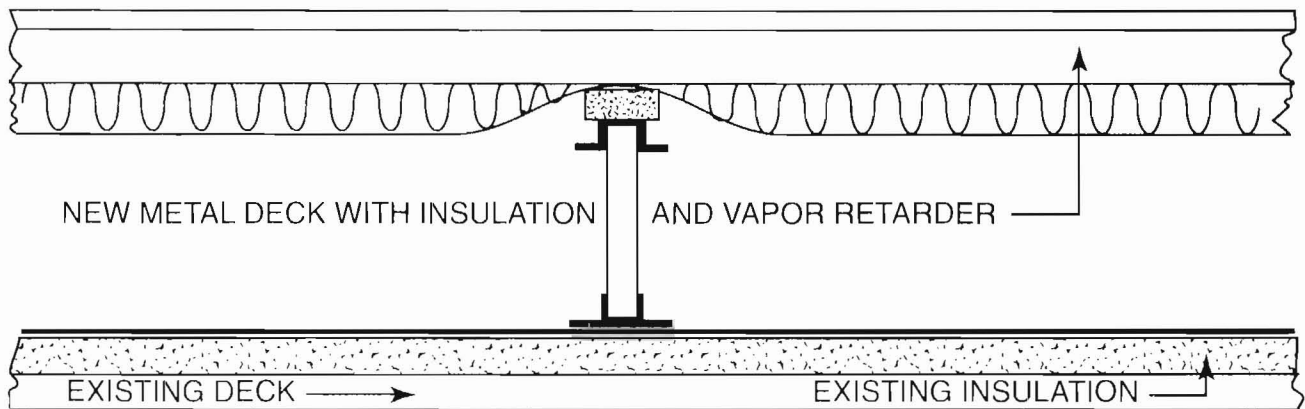


Figure 4. Subframing with insulation at new roof line.

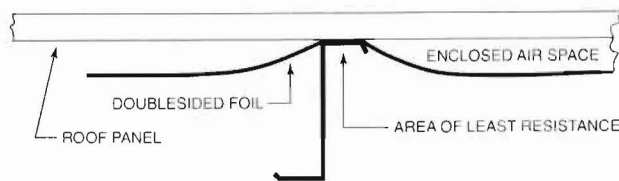


Figure 5. Single layer RIS, no thermal block. With Heat Flow Up: R-3.14. Heat Flow Down: R-9.45.

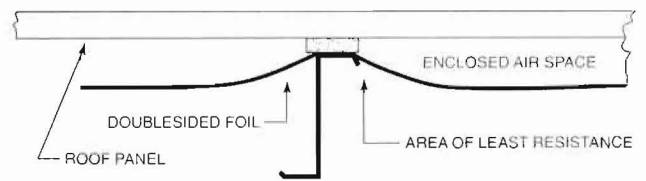


Figure 6. Single layer RIS with thermal block. With Heat Flow Up: R-3.52. Heat Flow Down: R-12.07.

RADIANT BARRIER SYSTEMS

Reinforced aluminum foil products are also being used to create "radiant barrier systems" (RBS). An RBS is defined technically as "a low emittance (high reflectance) surface facing an open air space - with air moving freely". Therefore, by definition, RBS's may not necessarily be intended to control conduction, convection or moisture migration. It should be understood that the sole function of some radiant barrier systems is to block radiant heat transfer between two surfaces (17). Simply stated, RBS's dramatically reduce far-infrared heat transfer (between a hot roof deck and cooler floor - or vice-versa) by changing the emittance/reflectance values of inward surfaces from roughly 90 percent/10 percent to 5 percent/95 percent.

RBS's are most effective in hot climates (5), especially in "open bay" warehousing and manufacturing facilities (16). In fact, Low E surfaces facing down may actually be providing better thermal performance enhancements than more easily quantified mass insulations or reflective

cavities commonly present on the opposite side (4, 13). It is very possible, however, for RBS's to result in negative benefits on cold but sunny days - while helping retain building heat on cloudy days and during non-sunshine hours. (See Figure 7 for a better general understanding of this complex subject.)

With sealed joints, some (unperforated) RBS's (and/or RIS's) may also serve as an excellent "vapor retarder assembly" (14). If a reinforced foil membrane is selected with "low perm vapor retarder" characteristics as the primary function, and if a foil side is installed adjacent to an open air space (even facing down to an open attic or building below), then RBS benefits may become a "no cost" secondary function in all four seasons (5).

Whether faced foam boards, faced blanket insulations or thin reinforced foil membranes, when "vapor retarders" are installed as in Figure 7, careful attention must be given to proper joint treatment and/or ventilation/dehumidification to prevent warm, moist air from reaching and then condensing on cold panel surfaces.

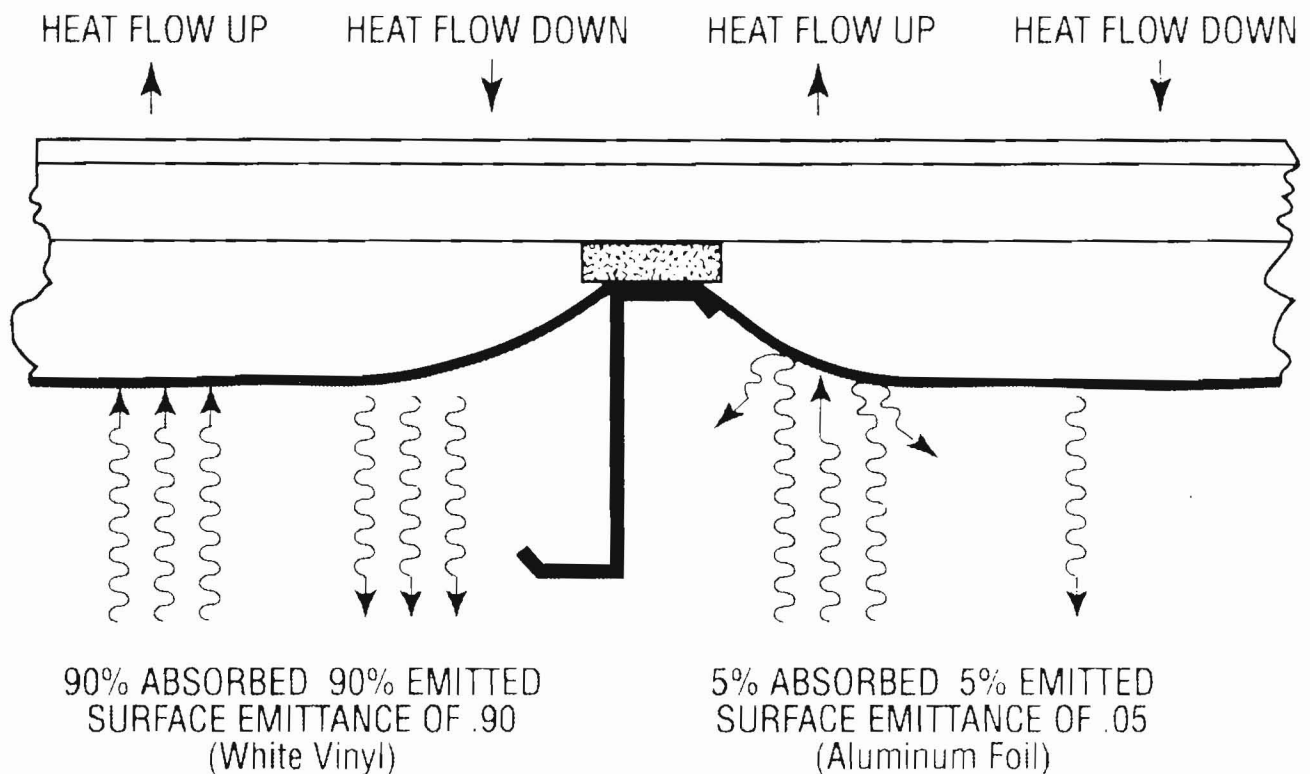


Figure 7. Impacts of inward-facing vapor retarder surface emittance values on radiant heat transfer.

ALTERNATIVES

Figures 8 and 9 depict a roof insulation system where the primary function is to minimize or eliminate moisture migration via both adhesive and mechanically sealed overlapping seams (15). In these applications, the vapor retarders also serve as the support system for unfaced blanket insulation. In Figure 8 the system provides a "no cost" RBS (Per Figure 7; emittance: 0.03). In Figure 9, the contractor selected a "low perm" vapor retarder with a bright white polypropylene finish (emittance: 0.68), thus considerably compromising human comfort for aesthetics in the manufacturing facility (13).

If the architect involved with the building in Figure 8 had elected to use a doublesided foil and an enclosed air space in lieu of singlesided product and blanket insulation, he would have an RIS with performance characteristics per Figure 5 or 6 (and 7). Note the average R-value of the air space in Figure 6 is considerably less in the winter than similar thickness 0.6 lb. density blanket, but about the same at summer temperatures. While a doublesided foil installation alone may sometimes be much less expensive - and quite appropriate in some climates - the additional "wintertime R-2 to R-5" provided by blanket insulation and/or thermal blocks can often mean the difference between a dry "metal building" interior and one that "rains".

Figure 10 describes two alternatives in a typical "conventional building" roof assembly. Good joint treatment, at least in retrofit, is very challenging (14), if not impossible to achieve at this particular RBS location (16) between bar joists. However, numerous installations of this type in Texas climates indicate there is far less concern (than in pre-engineered metal buildings) for concealed condensation on the bottom of the deck with normal occupancies. (This is often attributable to the substantially continuous thermal break provided by rigid board insulation.)

CONCLUSION

Unfortunately, there is no "universal" answer to condensation control in metal roof assemblies. We're often dancing with Mother Nature. And, as seasoned building professionals know, Mother Nature, in concert with Father Time, can create real nightmares when basic principles are violated.

In summation, optimum insulation and/or ventilation strategies must still be determined after careful consideration of specific climates, individual building needs and budgets. When in doubt, think it out. But don't disregard those emittance values, interior surface temperatures or dew points!



Figure 8. Foil-Elastomeric-Scrim-Kraft Vapor Retarder/Radiant Barrier; Emittance of 0.03.

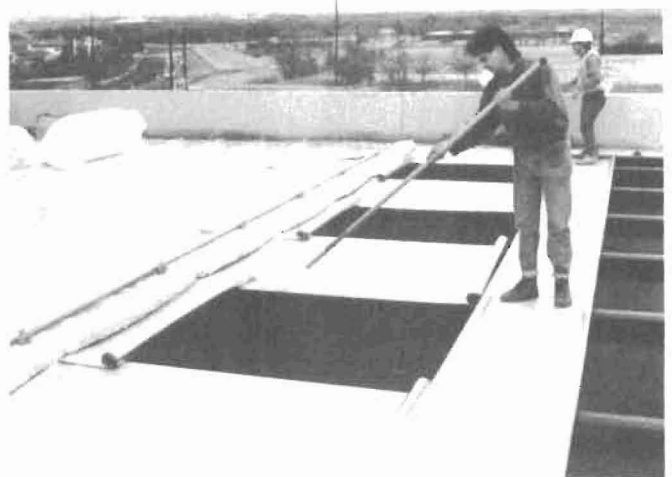


Figure 9. White Polypropylene-Scrim-Kraft Vapor Retarder; Surface Emittance of 0.68.

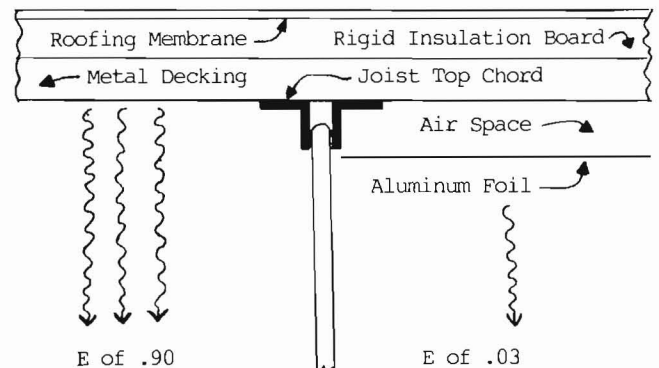


Figure 10. Conventional Roof Surface Emittance Alternatives. (Review Figure 7 for Similarities.)

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