Metal Roofing Underlayment -Tips on Choosing the Best System

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1. INTRODUCTION

Underlayment products for use beneath metal panel roof systems should be carefully selected to provide a roofing system that performs satisfactorily for its intended service life. Several considerations must be addressed in the roofing system design, including ensuring that the four barriers needed in any building enclosure (Le., water barrier, thermal insulation barrier, vapor retarder, and air barrier) are provided and are in the correct location for a given climate.

Long term, in-service roof performance can be affected by several important factors including: the metal roofing system and its expected service life, the climate at the building location, roof slope and geometry, and ambient conditions (temperature/relative humidity) within the building. Improper selection of the roof underlayment may allow roof leakage or entrap moisture due to vapor diffusion or air exfiltration, which may accelerate deterioration of concealed components, shortening their service life and necessitating repairs. Further, to provide longevity the underlayment should match the intended service life of the metal roofing system.

Although there is no universal design that applies to all buildings, this paper attempts to clarify many of the issues involved in selecting appropriate metal roof underlayment materials, and provides guidelines to builders who are responsible for constructing metal roofing systems. In general, contractors should be wary of changing the system design or recommending an underlayment product without considering all of the parameters that may affect performance. The system designer should be responsible for determining an appropriate design for any given project.

2. TYPES OF METAL ROOF SYSTEMS

The origins of metal roofing date back several centuries in Europe. In the United States, metal roof construction began in 1802 with Paul Revere's copper roof installation on the Massachusetts State House in Boston, Massachusetts. Following the development of rolling mills in the United States and the introduction of steel in the early 1900s, metal roofing emerged as a popular roof covering with designers due to its architectural appeal, light weight, long service life, and relatively low maintenance. Since that time, metal roofs with standing or flat seams have been widely used on religious buildings, university institutions, and cupolas and domes on a variety of buildings (Photo 1).

Metal roof panel systems are typically classified as either Architectural or Structural. Architectural metal panel roof systems are considered "water-shedding" assemblies, intended to shed water rapidly down the roof slope. The Architectural Sheet Metal Manual (ASMM) by the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) provides recommended practices for proper design and installation of architectural sheet metal roofs for commercial, industrial, and residential buildings. These assemblies require adequate slope, a continuous deck, and a roofing underlayment. The minimum slopes of architectural metal panel types are listed in Chapter 6 of ASMM. For some types of metal (e.g., zinc), and for specialty high-humidity buildings, ventilation beneath the architectural metal panel may be necessary. However, the design of vented metal roof systems is not the focus of this paper.

Structural metal panel roof systems are considered "barrier" systems designed to resist water infiltration at joints, terminations, and transitions on low-slope applications using sealants and gaskets. Structural roof panel systems are designed to span structural supports without requiring a structural deck; therefore, these systems do not typically include roof underlayment since the installation lacks a continuous substrate to support the underlayment material. As such, structural metal roof systems are not included within the scope of this paper.

3. MOISTURE MIGRATION THROUGH BUILDING ENCLOSURES

In addition to water leakage paths, moisture can migrate through a roofing assembly by either diffusion of vapor through the building materials, or by air movement through gaps or holes in the assembly.

3.1 Moisture Migration via Vapor Diffusion

Vapor diffusion is driven by vapor pressure differentials. To maintain equilibrium, the high vapor pressure of warm, humid air creates a drive for the moisture to migrate to cooler, dryer conditions (low vapor pressure). Vapor migration occurs at a microscopic level, through the pores of the materials. This migration through the roofing system is controlled by a vapor retarder, usually a sheet membrane such as polyethylene or aluminum foil. Current building codes define a vapor retarder as a material with a permeance of 1 perm or less (e.g., sheet polyethylene, non-perforated aluminum foil, or kraft paper). The vapor retarder is traditionally placed on the warm side of the insulation to prevent vapor from migrating through the system to cold surfaces, and condensing. The appropriate location of a vapor retarder within the roof assembly depends on the climate type and building occupancy. The tendency has been to place a vapor retarder in relation to the primary insulation layer based upon the type of climate. Regions within the United States (U.S.) are categorized into different climate zones based on thermal criteria (Le., heating/cooling degree days and marine, dry or humid seasons) as illustrated by the ASHRAE 90.1 climate zone map (Figure 1) and described in Table 1. As this map shows, the U.S. has many different climate zones and special areas of consideration. Discussion of all of these climate zones is not necessary, but the major considerations can be described in more generic terms, as follows:

- **Heating Climate:** In areas in the northern U.S. primarily requiring heating of occupied spaces (Le., Zones 5 through 7), the vapor drive is typically from the interior to the exterior in the winter. A vapor retarder is placed on the interior side of the insulation.

- **Mixed Climate:** In areas in the middle to southern U.S. requiring both heating in the winter and cooling in summer (Le., Zones 3 and 4), the vapor drive is in both directions. A vapor retarder is placed on either the interior or exterior side of the insulation.

- **Warm/Humid Climate:** In areas in the southeastern U.S. primarily requiring cooling of occupied spaces (Le., Zones 1 through 3), the vapor drive is typically from the exterior to the interior during summer. A vapor retarder is placed on the exterior side of the insulation.

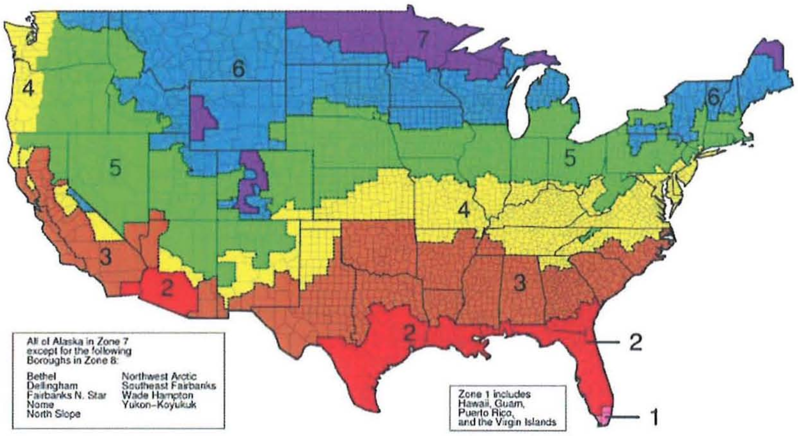

Figure 1

ASHRAE 90.1 Climate Zone Map

Table 1 – International Climate Zone Definitions[1]

Zone Number	Name	Thermal Criteria[1]
1A and 1B	Very Hot-humid (1A), Dry (1B)	9000 < CDD50°F
2A and 2B	Hot-Humid (2A), Dry (2B)	6300 < CDD50°F ≤ 9000
3A and 3B	Warm-Humid (3A), Dry (3B)	4500 < CDD50°F ≤ 6300
3C	Warm-Marine	CDD50°F ≤ 4500 and HDD65°F ≤ 3600
4A and 4B	Mixed-Humid (4A), Dry (4B)	CDD50°F ≤ 4500 and 3600 < HDD65°F ≤ 5400
4C	Mixed-Marine	3600 < HDD65°F ≤ 5400
5A, 5B, and 5C	Cool-Humid (5A), Dry (5B), Marine (5C)	5400 < HDD65°F ≤ 7200
6A and 6B	Cold-Humid (6A), Dry (6B)	7200 < HDD65°F ≤ 9000
7	Very Cold	9000 < HDD65°F ≤ 12600
8	Subarctic	12600 < HDD65°F

Note: CDD = Cooling Degree Day; HDD = Heating Degree Day

This general practice for typical climate zones is adequate for many commercial or residential buildings, but it does not always perform well for specialized buildings such as low-temperature freezer facilities, high-temperature and high-humidity spaces such as indoor pools, or constant temperature/humidity spaces such as museums or computer data centers. Additionally, governing building codes may include prescriptive requirements for vapor retarder placement. For some project conditions, the best type or placement of the vapor retarder for performance reasons may be in conflict with the building code requirements. The designer must not only recognize the code requirements, but also understand how the overall system will perform in a given climate.

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[1] Table B-4 Internal Climate Zone Definitions – 2007 ASHRAE 90.1, pg 114

For building envelope assemblies, computer modeling of the assembly is the best current practice used to design and select an appropriate vapor retarder material and determine its correct position in the assembly based on the building location and climate conditions. State-of-the-art models include local weather data (rain, solar gain, temperature, relative humidity), allow input of interior conditions, and perform multi-year simulations to establish trends for moisture content of components and moisture accumulation within the assembly.

Although the volume of water vapor transported by vapor diffusion is typically much less than the volume transported by air leakage, condensation from vapor diffusion can cause concealed damage in metal roof assemblies over time.

3.2 Moisture Migration via Air Movement

Air that is allowed to migrate through the building envelope, either from inside to outside (exfiltration) or outside to inside (infiltration), will carry water vapor within it. The amount of water vapor depends on the relative humidity of the air. As air flows through an envelope assembly, condensation will occur if the air cools below its dewpoint temperature. Air barriers are intended to prevent the movement of air through the envelope in both directions (i.e., exfiltration or infiltration). Unlike vapor diffusion, air flow occurs primarily at a macroscopic level, through gaps, holes, joints, or other openings that create a path from one side of an enclosure to the other side. To this end, an air barrier must be a complete and continuous layer to control air flow.

The location of the air barrier within the envelope assembly is generally not critical, and is not governed by climate like vapor retarders. The more important considerations in the location of air barriers is the method of attachment, the ability to resist air pressure caused by wind, stack effect, or mechanical pressurization of a building without tearing or displacing, and the convenience for achieving continuity and sealing penetrations. An effective air barrier must be continuous at all intersections and interfaces between the roofing and exterior wall systems. All joints and seams between building materials making up the air barrier must be sealed.

In many circumstances, the air barrier can be the same layer as the vapor retarder (discussed further in Section 3.3 below). For instance, in warm climates where the vapor retarder should be installed on the exterior side of the insulation, a vapor impermeable underlayment can serve as the vapor retarder, air barrier, and water-resistive barrier beneath the metal roofing.

Several commercial building codes, including the Massachusetts State Building Code (Eighth Edition CMR), require air barriers for building enclosures and this appears to be a continuing trend in the industry. These building codes as well as the Air Barrier Association of America (ABAA) and American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) typically specify materials that are part of an air barrier assembly must have an air permeance of less than 0.004 cfm/ft^2 under a pressure differential of 0.3 in. water (1.57 psf) when tested in accordance with ASTM E2178.

3.3 Underlayment Materials

For architectural metal roofing assemblies, roof underlayment is necessary as a secondary barrier to control water leakage through the roofing system during heavy rain storms or under snow melting conditions. Upgraded roof underlayment is often specified in cold climates for additional protection against ice dam leakage. Most architectural systems will leak under ponded water conditions created by ice dams, which requires heavy reliance on underlayment for successful in-service performance. Proper roof system design dictates that leakage water be directed to the exterior at the roof eaves. Typical underlayment materials include:

- Asphalt-saturated felt underlayment (felt underlayment)
- Synthetic sheet underlayment
- Rubberized asphalt or butyl-based sheet, with polyethylene facer, adhered to the deck (self-adhering membrane underlayment)

Felt Underlayment

The traditional and most common material used for roof underlayment on steep-slope applications is non-perforated, asphalt-impregnated felt underlayment. At present, many types of felt underlayment are available on the market including both organic reinforced (ASTM D4869) or inorganic reinforced (ASTM D6757). Compared with organic reinforced felt underlayment, glass-fiber- reinforced felt underlayment typically lays flatter and is subject to less deterioration over time.

Depending on the requirements of the project designer, governing building code, or metal panel manufacturer, one or two layers of non-perforated asphalt felt are mechanically-fastened to the roof deck before the metal panels are installed. End and side laps in successive underlayment courses are overlapped to minimize the risk of leakage. Felt underlayment relies on adequate roof slope to shed water.

Felt underlayment is a loose-laid, relatively breathable, water-shedding material that provides little resistance to air and moisture vapor migration. The vapor permeance of felt underlayment is greater than 1 perm and increases with exposure to higher relative humidity; therefore, it is an ineffective vapor retarder by most standards.

The air permeance of asphalt saturated No. 30 roofing felt is 0.0369 cfm/ft^2, which is nearly 10 times the ABAA or ASHRAE performance limit for air barrier materials (Source: Canada Mortgage Housing Corporation). No. 15 non-perforated felt is even leakier with an air permeance of 0.078 cfm/ft^2. As such, felt underlayment is an ineffective air barrier.

Architectural metal roof assemblies utilizing felt underlayment are best suited for buildings with proper slope (typically 4:12 minimum), low interior moisture loads (i.e., most office buildings), and buildings in dry or arid climates. In cold climates, felt underlayment is appropriate in conjunction with ice dam protection at eaves and other critical transitions. A separate air barrier and vapor retarder is needed within the assembly.

Synthetic Sheet Underlayment

In recent years, the use of synthetic sheet underlayment beneath metal roofing has increased substantially. These plastic sheet products are commonly made of polyethylene, polyolefin, or polypropylene; vary between 8-30 mils thick; and are typically reinforced for greater strength. Many contractors prefer these products instead of felt underlayment because they tend to be less subject to wind damage, and lay flatter when subjected to wetting after installation. Also, they are less sensitive to cold weather installation and are less expensive than self-adhering membrane underlayment. Some products have textured surfaces to improve slip resistance. The sheets are fastened to the deck with fasteners and washers, and end and side laps are overlapped; the sheets are not adhered to the deck and the laps are not typically sealed.

Although products vary, manufacturers report the vapor resistance of many of these sheets to be 0.04 to 0.06 perms, which makes many of these products an effective vapor retarder. Some products are promoted as breathable, with vapor resistance of up to 16 perms; these products are therefore not considered vapor retarders. Air permeance data for these products is not typically tested or published by manufacturers; however, the unsealed lap joints typically used mean that the sheet does not qualify as an air barrier. A separate air barrier is needed within the assembly.

Self-adhering membrane underlayment

Sheet membrane roof underlayment, consisting of either a rubberized-asphalt or butyl-based adhesive with a polyethylene carrier sheet, is intended to adhere to the roof deck. Self-adhering sheet membrane products are typically used in architectural metal roofs for ice dam protection (at roof eaves) or areas of high water/snow concentration such as valleys, dormers, or rising walls. Compared to asphalt-based membranes, butyl-based self-adhering sheet membranes provide superior stability at high temperatures. This is of particular importance for architectural metal roof assemblies because elevated roof surface temperatures, especially in desert climates and at high elevations, can exceed the melting point of some asphalt-based sheet membranes and damage the membrane.

These membranes are typically vapor impermeable (less than 0.10 perms) and therefore provide a vapor retarder within the system. Some self-adhering sheet membrane products are becoming available in vapor permeable versions; it is important to distinguish that vapor permeable sheets are in their infancy and do not have an established track record of successful in-service performance.

Rubberized-asphalt or butyl based products such as these typically meet the ABAA guidelines for air barrier products. Further, since the self-adhering membranes are fully-bonded to the substrate and to adjacent sheets at side and end laps, they sufficiently resist air pressure differentials, are continuous, and therefore function as an effective air barrier material.

4. EXAMPLES OF PROBLEMS/FAILURES

Concealed deterioration of building materials within architectural metal roof panel systems can be caused by water infiltration or moisture migration via vapor diffusion or air leakage.

Vapor Diffusion

Improper location of the vapor retarder in the metal roofing system design (i.e., on the cold side of the insulation) can cause concealed deterioration of roofing materials.

For non-vented compact systems in cold climates, a vapor retarder is normally included on the interior side of the system; therefore, using a second vapor retarder on the exterior side can create a vapor trap or a “dual vapor retarder” situation. Low-vapor permeance roof underlayments (i.e., self-adhering sheet underlayment or some synthetic sheet underlayment products), or the metal roofing itself, can inadvertently act as a vapor retarder in the incorrect position for cold climates, and can cause moisture accumulation. Water that is built-into, or migrates, into the roof assembly initially (either due to wet materials or exposure to precipitation) is unable to dry out readily. This moisture can remain in the roof for prolonged periods, and cause premature degradation of wood components and insulation, or corrosion of steel fasteners and clips.

Photos 2 and 3 show the deterioration of oriented strand board (OSB) sheathing beneath self-adhering sheet membrane underlayment, but not below the felt underlayment installed upslope. The roof was left with temporary protection over the winter prior to installing the metal roofing panels. Moisture models show that high initial moisture in the OSB sheathing was able to dry out of areas with felt underlayment and damage was prevented, but moisture did not dry out in areas of self-adhering sheet membrane underlayment and the sheathing deteriorated.

Air Exfiltration

Breaches or discontinuities in the air barrier system provide opportunities for interior conditioned air, laden with water vapor, to flow into the roofing system and condense on cooler surfaces. This is of particular importance for specialty high humidity buildings, such as indoor swimming pools, museums, or computer data facilities. Airflow through the roof system can create condensation on the underside of metal roof panels in cold climates, exposing the roofing system to prolonged moisture and resulting in the deterioration of the roof sheathing, insulation, and corrosion of the fasteners. Breaches can stem from workmanship issues (e.g., holes or unsealed laps) or from discontinuities due to design detailing (e.g., at wall to roof transitions).

Additionally, air leakage through the building enclosure can exacerbate ice dams in cold climates, increase energy consumption, cause drafts, or create difficulties in maintaining the prescribed interior conditions with the HVAC equipment.

Photo 4 shows deterioration of plywood sheathing on an indoor pool due to air exfiltration out of the gable end; the air barrier was not integrated at the roof/wall transition. Photo 5 shows overall deterioration of plywood sheathing on another indoor pool. The roofing system included felt underlayment and a polyethylene vapor retarder, neither of which provides an air barrier. The building was positively pressurized, and exfiltrating humid air caused extensive condensation and related rotting of the plywood and corrosion of the metal roofing.

Ice Dams

Ice dams occur when building heat melts the snow pack, then re-freezes when the melt water reaches the cold eave. The buildup of ice obstructs the flow of melt water from the roof, causing water to pond on the metal roof panels and leak through unsealed seams, joints, or transitions (Photo 6). Two separate design features are needed to control leakage associated with ice dams:

- Self-adhering membrane installed at the locations of potential ice dams, to prevent leakage through the metal roof panels from reaching the interior.
- Sufficient ventilation beneath the roof deck to keep the roof surface near outdoor temperatures, such that melting of snow does not occur.

Inclusion of an interior air barrier in the design is also critical to the effectiveness of the ventilation, so that conditioned interior air does not exfiltrate into the vent space and melt the snow pack.

Super-insulated roof assemblies, typically using closed-cell spray-applied urethane foam insulation, help to reduce the frequency and magnitude of ice dam formation without the use of ventilation, but the low-vapor permeable closed-cell spray-applied urethane foam insulation does not allow moisture to dry to the interior. Therefore, if roof leaks develop the polyurethane foam will not allow leakage water to dry, promoting deterioration of the roof structure and deck with no visible indication to the occupants of a roof leak.

Low Slope

In some designs, architectural metal roofing systems are used on roof slopes that are below industry standard or the manufacturer's recommended slope. In these circumstances, designers sometimes require self-adhering membrane underlayment to act as the primary roof beneath the metal roofing. This is a risky design for numerous reasons:

- The self-adhering membrane underlayment may function as a vapor retarder on the cold side of the insulation, creating a risk of condensation in cold climates.
- The membrane underlayment is designed as the primary defense against leakage, but is not intended by manufacturers to be a primary roof, and is not warranted as such. Manufacturers intend these products to provide underlayment only. The use of a metal roof below the manufacturer's recommended minimum slope, and the improper use of underlayment material in situations other than its intended purpose, create a design that does not meet industry standards.
- To be effective at controlling water leakage, installation of the membrane underlayment requires much higher installation standards (more like a waterproofing system) than are typically used for roof underlayment, which must be clearly expressed in the bid documents. Photo 7 shows a common membrane underlayment installation, with lap joints that are unsealed and may be reverse-lapped due to installation sequencing. These defects may be tolerable on steep slopes, but will leak at lower slopes.

Fastener penetrations also become a greater concern at low slopes. The membrane must have free drainage to prevent the buildup of hydrostatic pressure.

- If water leakage occurs, repairs to the concealed primary roof require removing the roof covering to first locate and then repair defects in the membrane underlayment. For metal roofs, this typically requires replacement of the roof panels and patching of all holes in the roof underlayment, at significant expense. No warranty coverage will likely be available from either the metal panel or underlayment manufacturers.

5. GENERAL GUIDELINES FOR UNDERLAYMENT SELECTION

Based on lessons learned during building investigations, field mockup tests, and subsequent reconstruction projects, we have developed some general guidelines for choosing underlayment materials that are appropriate under certain conditions (Table 2):

Table 2 – General Guidelines for Roof Underlayment Selection[1]

Application Guideline	Waterproofing Membrane	Water-Shedding Underlayment	
	Self-Adhering Membrane	Felt Underlayment	Synthetic Sheet Underlayment
Cold climates	x[2]	●	?[2]
Ice dam protection in cold climates	●	x	x
Warm climates	●	○	○
High interior relative humidity	x	●	?
As an air barrier	●	x	x
As a vapor retarder	●	x	?
Vented roof assemblies (beneath sheathing)	●	○	○

Note: ● Best ○ May be Suitable x Not Recommended ? Depends on vapor permeance of product

1. The designer is responsible for meeting or exceeding industry standards for proper roof design.
2. See discussion below

The guidelines shown above are generic, and depend highly on the roofing assembly as a whole and the building occupancy and use. For example, some metal roofing systems include a passive ventilation space beneath the roof deck (above the insulation) to help control moisture accumulation and formation of ice dams. For these assemblies, self-adhering membrane can safely be used beneath the metal in cold climates without causing concern about vapor diffusion; the vapor retarder and air barrier for the system should be included below the ventilation space.

Conversely, compact systems with felt or synthetic underlayment that lack another layer to serve as the air barrier may be prone to air leakage problems. Interior vapor retarders commonly consist of loose-laid polyethylene without taped joints or continuous support; these materials do not create an adequate air barrier. The metal roofing panels themselves can create a sufficient air barrier, but only if all seams and laps are completely sealed which is not common practice.

Moisture/thermal modeling of the assembly is recommended to verify that the design is suitable for the climate and interior building conditions.

The following design guidelines can be used to help provide the four barriers necessary within any metal roofing assembly:

- Proper slope to drain for the metal roofing system, meeting industry standards and manufacturer's recommendations.
- Underlayment material that will remain in service for the expected life of the roof covering, with detailing that allows drainage of water that reaches the underlayment. In cold climates, the underlayment should generally be breathable (vapor permeable) unless moisture migration analysis shows that the intended system will perform satisfactorily. Ice dam protection should be provided at roof eaves in cold climates.
- Continuous, nailable sheathing or decking, consisting of a durable material that can resist occasional leaks without deterioration.
- Thermal insulation meeting the building code (as a minimum), either beneath the sheathing or the structural deck.
- An air barrier that is continuous and integrated with the exterior wall assembly. This may or may not be the same layer as the underlayment.
- A vapor retarder that is on the correct side of the insulation for the climate at the site. This may be the same layer as the underlayment in southern climates.
- The air barrier and vapor retarder may be the same layer if it is positioned correctly, continuous, and meets the criteria for both.