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A Guide to Vapor Retarder Design In Low-slope Roof Systems

Prepared by GAF Technical Services
June, 2020

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Introduction

Thank you for consulting “A Guide to Vapor Retarder Design In Low-slope Roof Systems.” You can find further information at www.gaf.com, or contact GAF Technical Support Services at 800-766-3411.

About GAF

Founded in 1886, GAF is the largest roofing manufacturer in North America.

As the industry leader, GAF proudly offers a comprehensive portfolio of award-winning, innovative roofing products for both steep-slope and commercial properties. Supported by an extensive national network of factory-certified contractors, GAF has built its reputation – and its success – on its steadfast commitment to Advanced Quality, Industry Expertise, and Solutions Made Simple.

GAF offers all major low-slope roofing technologies, including repair and maintenance products and roof restoration systems, as well as new roofing systems (BUR, modified bitumen, TPO, PVC, and liquid-applied roofing membranes). GAF has developed single-ply, asphaltic and liquid-applied membranes with excellent durability to meet the most rigorous industry standards.

For more information, visit www.gaf.com.

About Vapor Retarders

Vapor retarders are commonly used in low-slope roof assemblies to prevent moisture-laden air in a building’s interior from moving into the roof assembly where condensation may occur. Generally speaking, a vapor retarder is used where a building’s interior humidity conditions are expected to be relatively high, and/or the building is located in a cold climate. Additionally, vapor retarders can be used to help address moisture issues with structural concrete decks.

Important Considerations

The purpose of this Guide is to provide some fundamental information and important design considerations for roofing assemblies using vapor retarders.

GAF manufactures and sells roofing materials and does not practice architecture or engineering. GAF is not responsible for the performance of its products when damage to its products is caused by such things as improper building design, construction flaws, or defects in workmanship.

The design responsibility remains with the architect, engineer, roofing contractor, or owner. These guidelines should not be construed as being all-inclusive, nor should they be considered as a substitute for good application practices. Please consult your design professional for more information.

Fundamentals of Moisture Control

One of the primary purposes of a building envelope is to keep moisture out of a building. What makes this difficult is that moisture comes in many forms and can take many paths into a building. Building designers need to account for bulk water, capillary water, air-transported moisture, and water vapor, and defend against each of these in different ways.

Bulk water (i.e., rain and snow) is kept out of buildings with roof membranes and wall cladding systems. Capillary water is primarily a ground-based issue involving water moving into and through the building envelope via capillary action. Foundation waterproofing and water barrier layers or components are used to prevent this intrusion. Air-transported water, as the name implies, is carried into or out of a building by air that infiltrates or passes through the building envelope. Water vapor enters or exits a building by the process of diffusion through the building envelope materials or by air leakage (holes in or around the building envelope materials).

There is one simple rule that defines how heat, air, and moisture move—the second law of thermodynamics. In terms of building and roofing science, this means:

- Hot moves to cold
- Moist moves to dry
- High pressure moves to low pressure

Heat, moisture, and pressure always equalize when possible.

In order to understand some of the important design concerns for vapor retarders, it helps to be familiar with the following moisture control fundamentals:

- Relative humidity
- Vapor drive
- Condensation
- Moisture sources
- Air leakage vs. vapor diffusion
- Vapor retarder vs. air barrier

Relative Humidity

The amount of water vapor within a given volume of air is a function of temperature. This quantity is described by the term “relative humidity,” (a.k.a. RH) and is expressed as a percentage.

When air at a given temperature has a relative humidity of 100 percent, it is said to be saturated. Warm air can hold a larger quantity of water vapor than cold air.

Vapor drive

Water vapor exerts pressure. The amount of pressure is a function of temperature and relative humidity. The greater the temperature and higher the relative humidity, the greater the water vapor pressure.

When there are different temperature and relative humidity conditions on either side of a roof system, there is a corresponding vapor-pressure differential. Higher vapor pressure will move to reach equilibrium with the side of the roof system that has the lower vapor pressure. This drive from conditions of high pressure to low pressure is referred to as vapor drive.

For conventional buildings, warm, moist inside air moves outward during the colder winter months. Therefore, the direction of the vapor drive is from the interior to the exterior.

For cold storage buildings, the vapor drive direction is often times the opposite. The warm, moist outside air moves inward, because these types of buildings commonly are maintained at temperatures that are considerably lower than the exterior temperature. This is especially the case in southern climates, and is generally true for most geographic locations in the US for most months of the year. Therefore, the direction of the vapor drive is from the exterior to the interior.

Condensation

When moisture-saturated air is cooled, some of the moisture vapor contained in the air condenses. The temperature at which air becomes saturated with moisture vapor and condensation begins to form is referred to as the dew-point temperature.

When moisture vapor contacts a surface that has a temperature below the dew-point temperature, condensation will occur on that surface. If the surface temperature is below freezing (i.e., 32°F or 0°C), the condensation may freeze and appear as frost.

Moisture Sources

To prevent moisture accumulation in roof assemblies, the source and relative quantity of potentially damaging moisture must be known and the short- and long-term effects understood by the roof system designer and building owner. Sources of moisture within buildings can originate from construction operations and building occupancy.

Construction Generated Moisture: Significant amounts of water vapor may be generated by construction processes. Sources of construction-generated moisture include:

- The drying process of concrete floor slabs and the finishing of wall and ceiling systems.
- The combustion process of propane- or kerosene-fired heaters used for temporary heat during construction.
- The painting of interior surfaces.

Building Occupancy Generated Moisture: Significant amounts of water vapor can be generated by interior sources, such as swimming pools, laundry facilities and buildings that house manufacturing operations, such as food processing plants and textile and paper mills.

Air Leakage vs. Vapor Diffusion

Water vapor moves across or through a material or assembly by two different mechanisms: air leakage and diffusion. Air leakage generally allows much greater amounts of water vapor movement than diffusion.

The National Research Council Canada collected research data that illustrated how even small openings can affect overall air leakage performance. For example, only about 1/3 of a quart of water will diffuse through a continuous 4 ft. by 8 ft. sheet of gypsum during a one-month period even though gypsum board has a very high permeance.

However, if there is a 1-square-inch hole in this same sheet of gypsum, about 30 quarts of water can pass through the opening as a result of air leakage. This relationship is illustrated in Figure 1. This example illustrates that air leakage can cause more moisture-related problems than vapor diffusion.

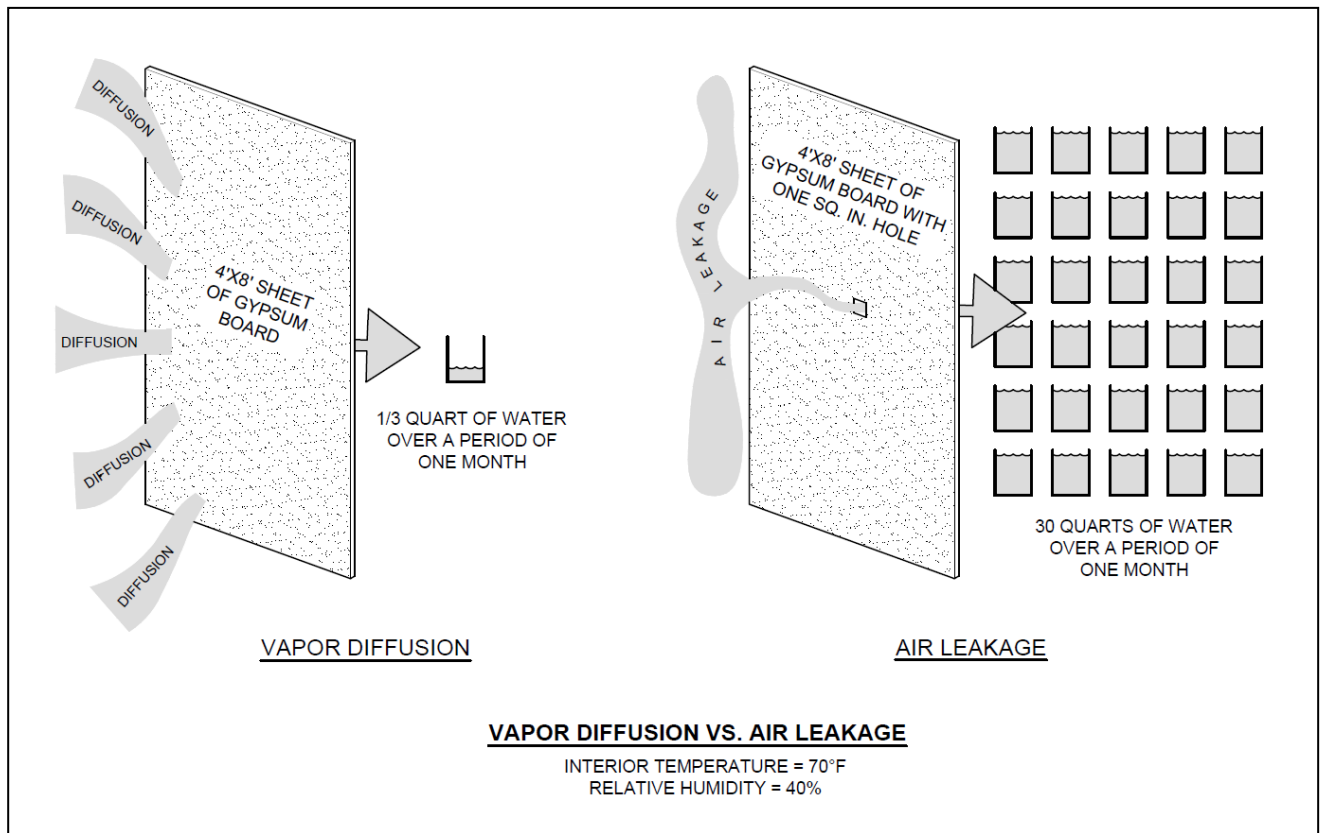


Figure 1: Air leakage vs. vapor diffusion
(Source: Building Science Corporation)

Vapor Retarder vs. Air Barrier

There is often confusion between vapors retarders and air barriers. The purpose of a vapor retarder is to minimize or reduce water vapor diffusion into a low-slope roof system or wall system. In other words, it is used to prevent the formation of condensation in a low-slope roof system or wall system.

The primary function of an air barrier is to prevent or restrict air leakage through a building's envelope. Air barriers are intended to control air flow from the exterior to the interior of a building, as well as from the interior to the exterior of a building.

All vapor retarders block air, but not all air barriers block vapor diffusion. Consequently, a vapor retarder in a roof assembly is also acting as an air barrier. The caveat is that the vapor retarder needs to be sealed at all perimeters and penetrations, and tied to the wall air barrier so air does not bypass the vapor retarder layer.

Fundamentals of Vapor Retarder Design

GAF does not practice architecture or engineering. This section is provided for guidance purposes only based on GAF's experience in the commercial roofing industry. However, there are many factors that may affect roof design, including specific job site conditions, local building codes, building use, etc., which must be taken into account. GAF recommends consultation with a design professional to determine specific roofing needs and requirements for each particular project.

Proper roofing system design and selection requires the consideration of many factors. Although GAF's expertise is in materials manufacturing, and not in engineering, architecture, or specialized roof consulting, GAF has decades of extensive experience in the practical aspects of roofing. Our experience suggests that careful consideration of the following will help provide a fundamentally sound basis for the design of vapor retarders used in roofing systems.

Basic Concepts of Vapor Retarder Design

For conventional buildings, a vapor retarder is typically installed under the roof insulation, i.e., on the warm (interior) side of a roof assembly. For a vapor retarder to be effective, the temperature at the bottom side of a vapor retarder must be warmer than the dew-point temperature. Sufficient insulation should be designed and installed over a vapor retarder to ensure the vapor retarder's temperature is higher than the dew-point temperature.

Determining the Need for a Vapor Retarder

To date, there are no consensus-based or widely-accepted guidelines for determining whether a vapor retarder is needed in a low-slope roof assembly. It is also important to note that a vapor retarder in a roof assembly is not required by building code.

However, The National Roofing Contractors Association (NRCA) provides some assistance. "The NRCA Roofing Manual: Architectural Metal Flashing and Condensation and Air Leakage Control" contains

guidance on vapor retarders. It also references guidelines from the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL).

Here is a brief summary of NRCA's guidelines:

- In new construction situations, the designer of the building's mechanical system is a knowledgeable party to help determine whether the use of a vapor retarder is necessary. The designer of the mechanical system typically needs to consider outside conditions and the desired design interior conditions in sizing the building's HVAC equipment.
- In reroofing situations, unless there is a specific roofing project designer as well as, plans and specifications, the need for including a vapor retarder in the replacement roof assembly may be less clear-cut. Generally, if the existing roof assembly includes a vapor retarder, consideration should be given to including a new vapor retarder in the design of the replacement roof system.
- Many low-slope roof assemblies are in effect self-drying roof assemblies; that is, they are designed and installed without an impermeable vapor retarder layer within the roof assembly. Years of experience have proved that low-slope, self-drying roof assemblies can perform successfully in buildings that don't have high interior humidity or moisture generating processes. This track record shows that many low-slope membrane roof assemblies in many parts of North America do not require vapor retarders.

However, in situations where a membrane roof system has a highly reflective roof surface, the membrane and the roof system's other layers will be cooler than a similar roof system without a highly reflective roof surface. As a result, roof systems with highly reflective roof surfaces will likely not dry down as quickly or to the same magnitude as roof systems without highly reflective roof surfaces.

To account for this phenomenon, NRCA recommends designers use a minimum of two layers of insulation in their membrane roof system designs and the two layers be installed with offset joints to minimize air leakage and movement and thermal shorts. NRCA also suggests the use of properly placed air barriers in roof systems with highly reflective roof surfaces.

- NRCA suggests that a vapor retarder be considered for low-slope roof assemblies:
 - located in Climate Zones 6A, 7 and 8.
 - where the interior humidity is expected to be high, such as swimming pools, museums and data centers.
 - where the outside average temperature during the coldest month is below 40°F (4°C) and expected interior winter relative humidity is 45 percent or greater.

Methods Used to Determine Vapor Retarder Effectiveness

Once it is determined a vapor retarder should be used, the amount of insulation necessary to ensure the effectiveness of the vapor retarder, and its location in a low-slope roof assembly should be verified.

There are a couple of methods that can be used:

- **Hygrothermal simulation software:** Computer-based modeling that provides simulations of heat and moisture transfer. The most commonly used software is WUFI®, which was developed by the Department of Hygrothermics at Fraunhofer IBP.
- **Temperature gradient analysis:** The calculation procedures can be found in the NRCA Roofing Manual: Architectural Metal Flashing and Condensation and Air Leakage Control or see Appendix B of this guide. It is important to note that this is a simplified procedure using theoretical constant values. Actual relative humidity and dew-point temperature values constantly change.
- **EnergyWise Roof Calculator:** NRCA offers this online tool that provides a graphical method of constructing roof assemblies and it will do the temperature gradient analysis. It can be accessed at: energywise.nrca.net.

Vapor Retarder Design Considerations

The design of vapor retarders requires special attention to the following design considerations:

- Building use and location
- Climate and building design values
- Air leakage and water vapor movement
- Vapor retarder material types
- Material selection criteria

Building Use and Location

A building's use and where it is located have a significant effect on the type, direction and degree of moisture movement that will occur into and out of the building.

The most familiar use of vapor retarders are in buildings located in colder climates and for buildings with high interior humidity levels, such as swimming pools, museums and data centers. For these scenarios, the most effective location for a vapor retarder is directly above the roof deck and below the roof insulation layer(s), or in some cases, directly above a rigid board (e.g., gypsum board) that is secured to the roof deck. In other words, the vapor retarder is installed on the warm side (in winter) of the insulation.

For cold storage buildings, the same principal applies; however, the vapor drive is from the exterior to the interior. Consequently, the vapor retarder is located on the outside of the insulation. Most

commonly, the roof membrane serves as the vapor retarder. This is certainly the case for cold storage buildings located in very warm climates, and is true for most geographic locations in the US for most months of the year.

Additional information on cold storage design can be found in “A Guide to Cold Storage Roof System Design” available at www.gaf.com.

Climate and Building Design Values

A designer may choose to perform a dew-point or hygrothermal analysis to confirm the design of a vapor retarder. Design values are needed for the following:

- Interior dry bulb temperature
- Interior relative humidity
- Exterior dry bulb temperature

Designers should keep in mind that the values used for design relative humidity and design interior temperature are theoretical constant values based upon design assumptions. These design values should be based upon conservative assumptions of probable conditions.

Air Leakage and Water Vapor Movement

Problems occur when there are paths for air and water vapor movement within the building envelope. It is imperative that the vapor retarder and roof system be continuous, tied to the wall air barrier, and completely sealed at:

- Laps and seams
- Roof penetrations, i.e., pipes, structural members, mechanical curbs, roof hatches, etc.
- Roof-to-wall interface/intersections

It is also advisable to limit the number of penetrations through the roof assembly. It is also required that the vapor retarder be completely sealed if any new penetrations are made through the roof assembly.

Vapor Retarders Material Types

There are generally two categories of vapor retarders, bituminous and non-bituminous. Bituminous-based vapor retarders are the most common and include self-adhering modified bitumen sheets, and adhered smooth-surfaced APP or SBS-modified bitumen sheets. Additionally, there are built-up bituminous vapor retarders which are generally composed of two layers of asphalt felts applied with two or three moppings of hot asphalt.

Non-bituminous-based vapor retarders include plastic sheets, kraft paper, kraft laminates and aluminum foil sheets. A very common non-bituminous type of vapor retarder is polyethylene sheets. These non-bituminous types of vapor retarders are installed loose-laid or adhered using a compatible adhesive to adhere the sheets to the roof deck or substrate.

Material Selection Criteria

When selecting a vapor retarder material, consider the following:

- Perm ratings
- Insulation type
- Roof deck type

Perm ratings: Vapor retarders are typically membranes with relatively low permeance values, but not all vapor retarders are equal. There are three classes of vapor retarder materials, as shown in Figure 2.

Class	Definition
I	0.1 perm or less
II	Greater than 0.1 perm to less than 1.0 perm
III	Greater than 1.0 perm to less than 10 perm

Figure 2: Three classes of vapor retarders

Most roof membranes are Class I vapor retarders. Perm ratings for single-ply membranes range from 0.03 to 0.06 perms. An example of a Class II vapor retarder is asphalt felts, which have perm ratings ranging from 0.3 to 0.8 perms. Examples of Class III vapor retarders are latex or acrylic paint.

It is important to note that these are material ratings only; the full system needs to be designed and installed correctly for proper functionality.

If a Class I vapor retarder is used, the concern is that any moisture (e.g., construction moisture due to installation methods, weather, etc.) that enters a roof system won't be able to dry out. It's often a good idea to select a vapor retarder that will allow some amount of drying from diffusion. Exceptions to this idea include roofs over indoor swimming pools and other high-humidity activities or processes. Another exception is that a Class I vapor retarder should be installed over a new concrete deck to help prevent the moisture in the concrete from drying into the roof system. See Appendix A—Vapor Retarders and Structural Concrete Decks for more information.

Roof Insulation: For conventional buildings in colder climates, the temperature at the vapor retarder level must be warmer than the dew-point temperature for the vapor retarder to perform its intended function. To ensure the temperature at the vapor retarder level remains higher than the dew-point temperature, sufficient insulation must be designed and installed above the vapor retarder to maintain the vapor retarder at a temperature warm enough to prevent condensation from occurring.

For cold storage buildings, refer to “A Guide to Cold Storage Roof System Design” which is available at www.gaf.com.

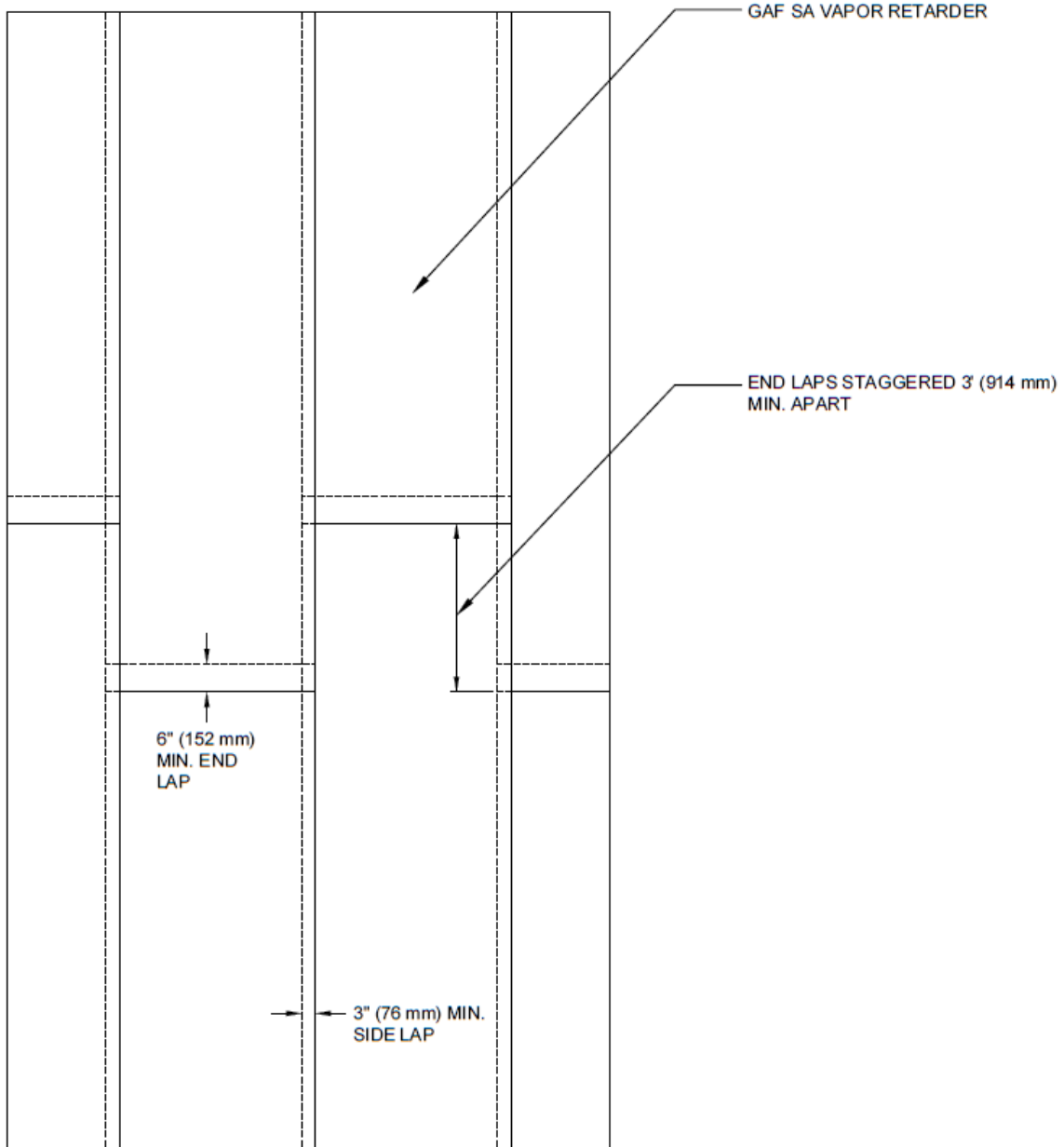
Chemical and physical compatibility are key considerations when selecting the type of vapor retarder and adhesive to be used with the different types of insulation.

Roof deck type: In colder climates, a vapor retarder is best placed directly on top of the roof deck. The roof deck should be a solid, continuous substrate in order to minimize damage to the vapor retarder. Examples include cementitious wood fiber panels, lightweight insulating concrete, structural concrete, and plywood/OSB panels.

A steel roof deck generally is not a suitable substrate for direct vapor retarder attachment. Most vapor retarder materials are extremely vulnerable to puncture damage. Therefore, placing a vapor retarder directly on a steel roof deck should be avoided unless the vapor retarder is designed for this application and care is taken to prevent puncture damage.

For roofing assemblies that have a steel deck, installing a layer of low-R-value, fire-resistant insulation, or glass-mat-faced/fiber-reinforced gypsum board products, directly to the steel roof deck with mechanical fasteners will provide a solid, continuous substrate. The vapor retarder is then applied to this layer and subsequent layers of insulation are installed on top of the vapor retarder.

Important note: A vapor retarder may be used to help address moisture issues with structural concrete. See Appendix A—Vapor Retarders and Structural Concrete for additional information regarding this type of application.



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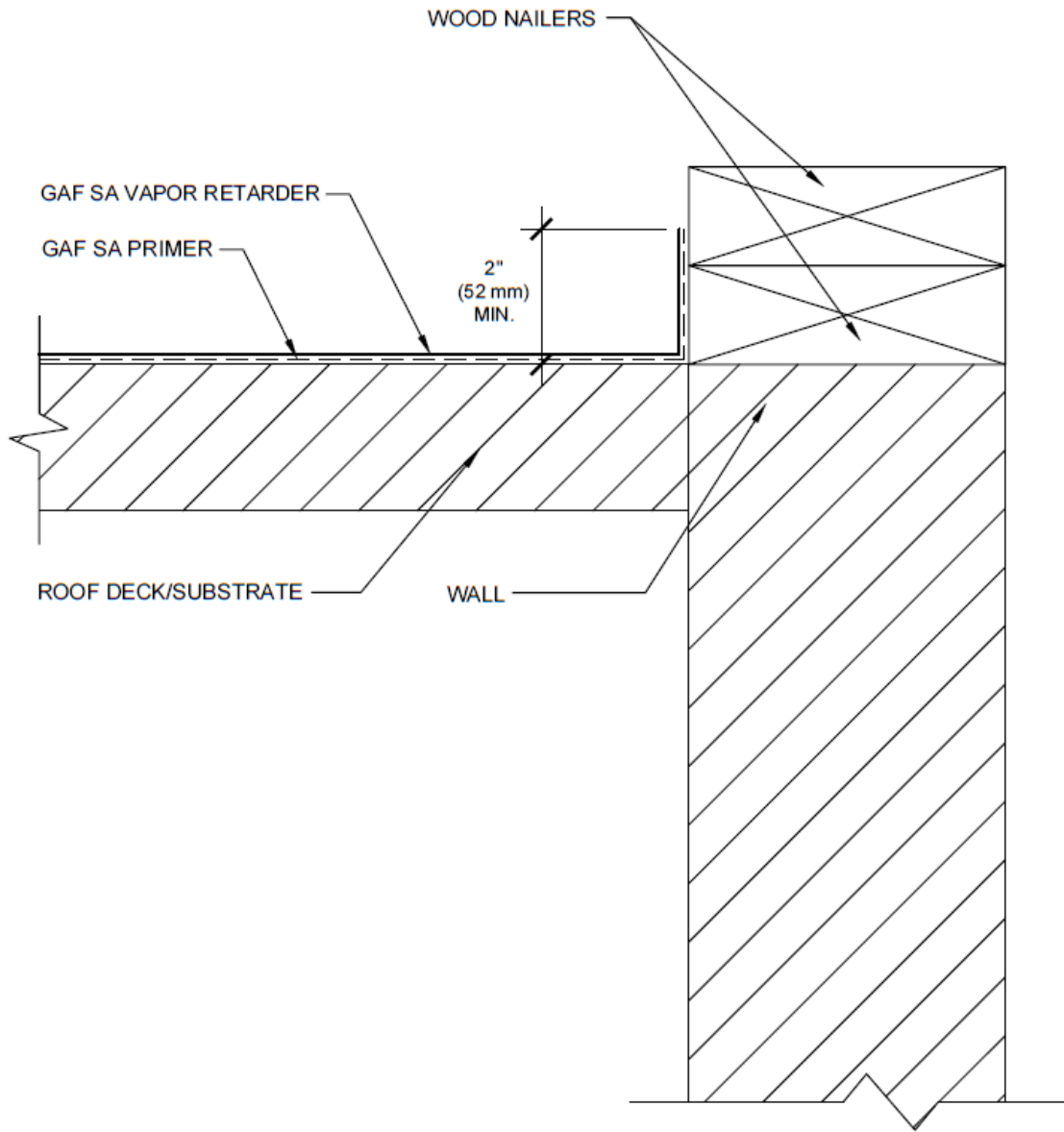
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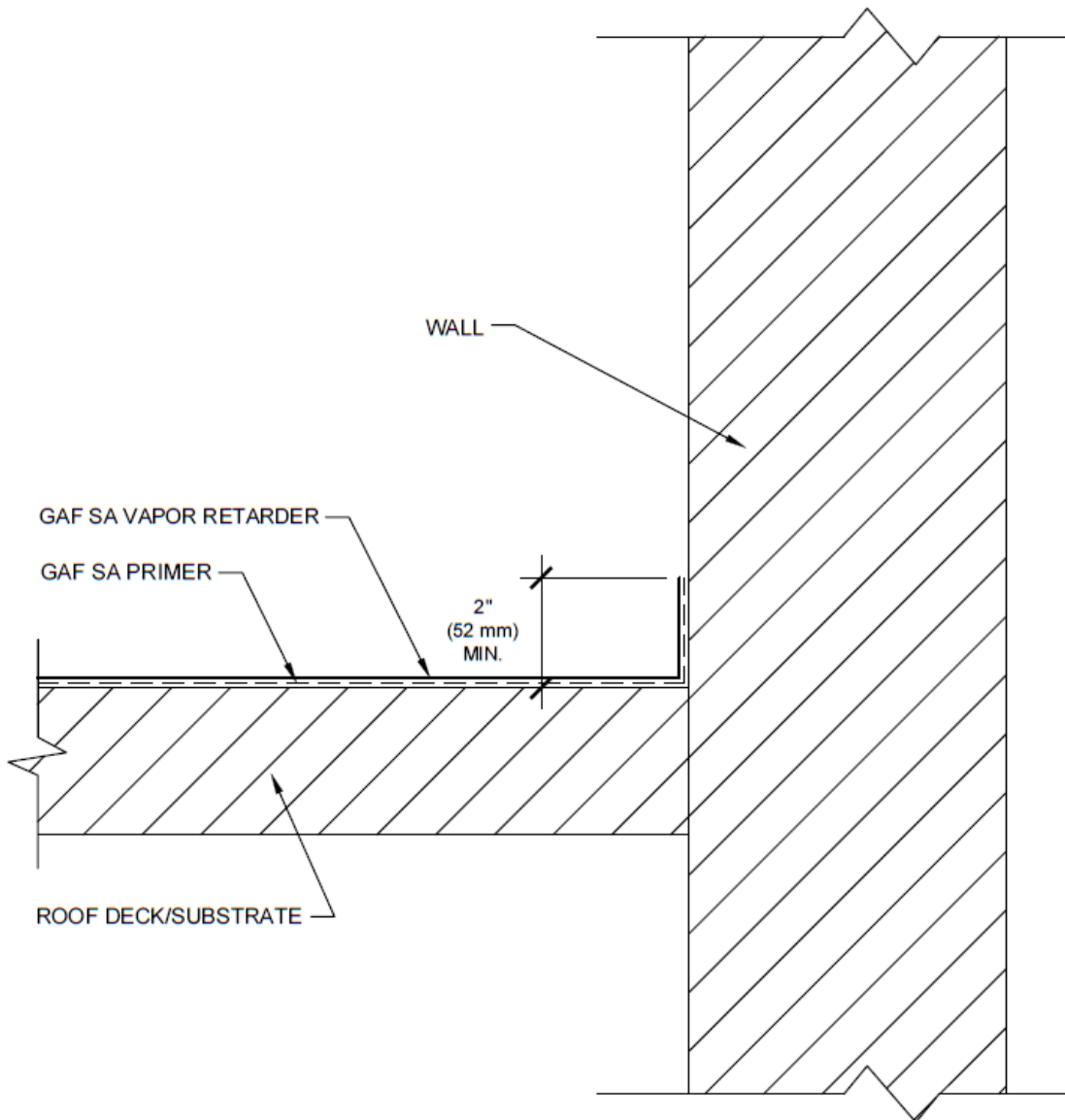
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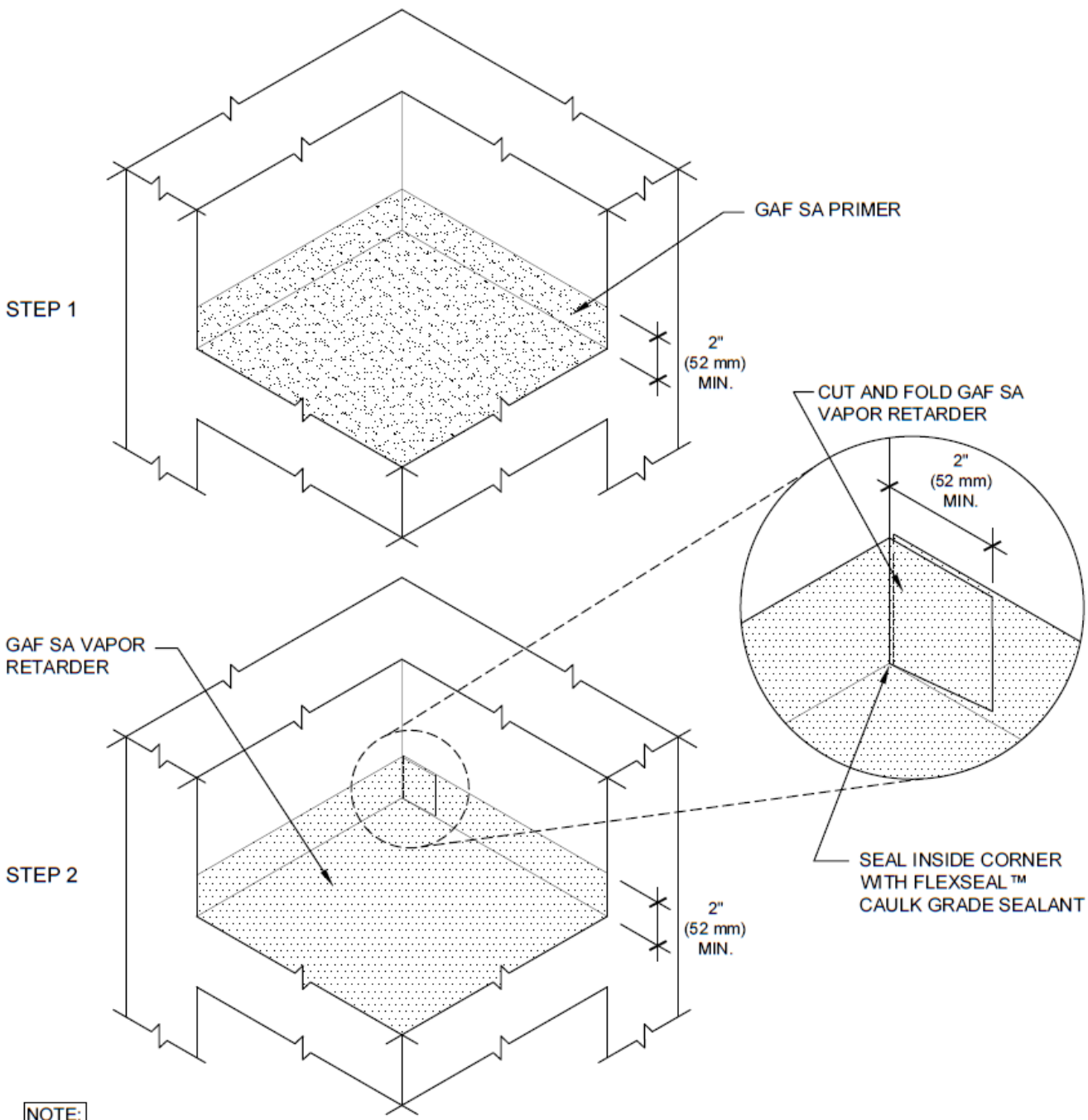
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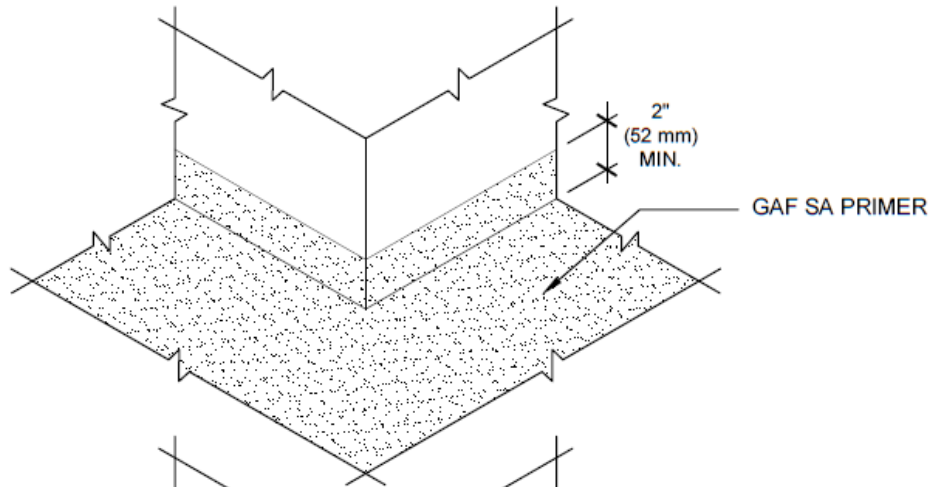


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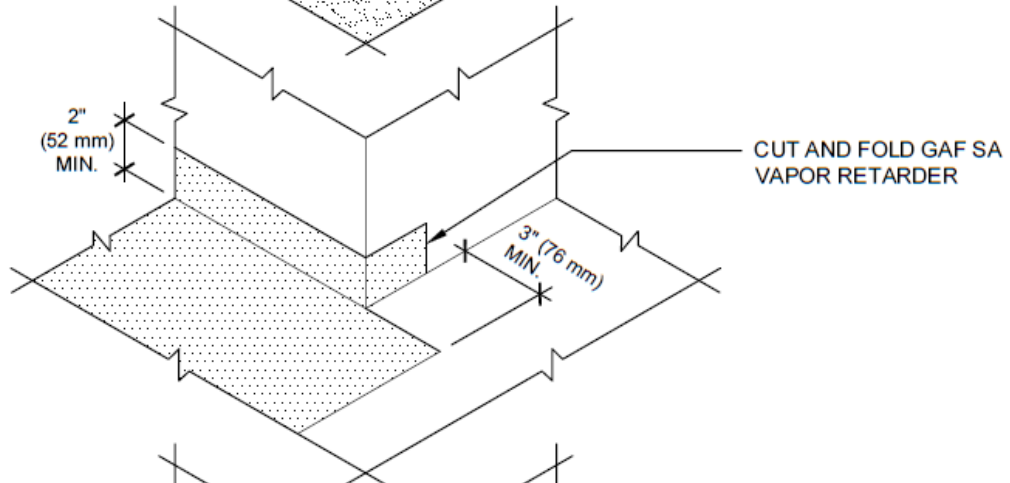
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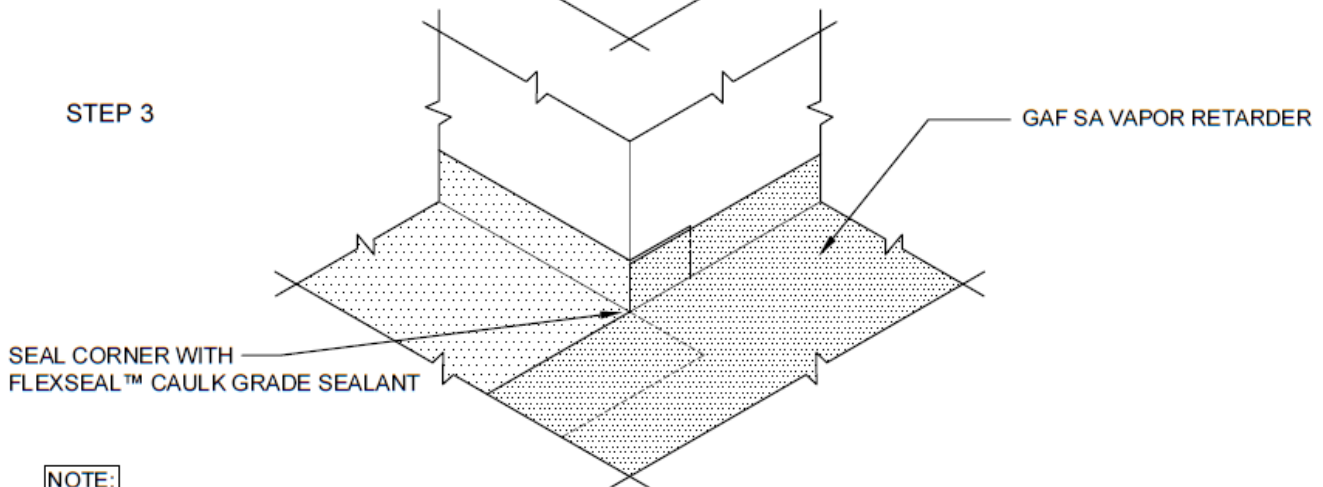
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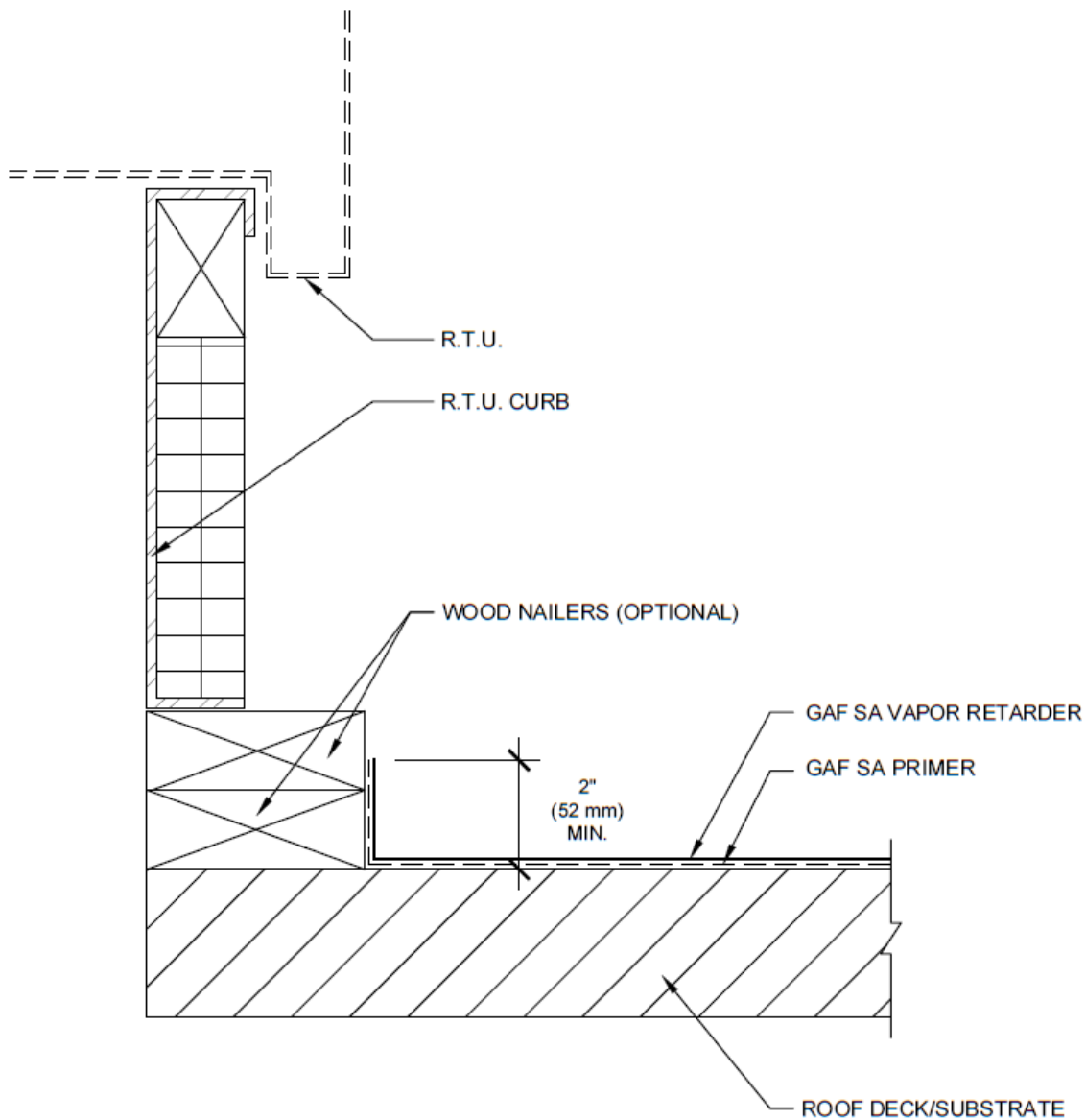
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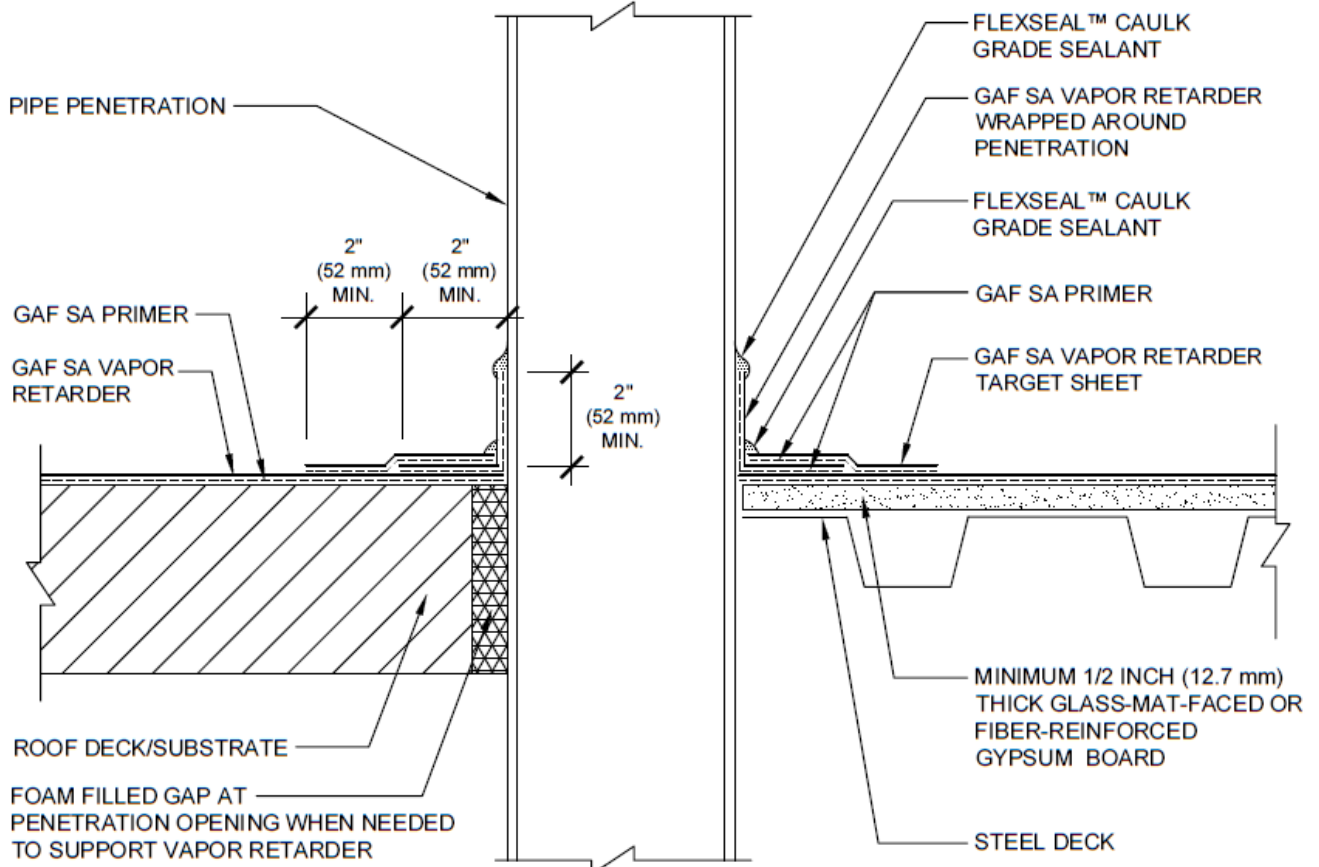
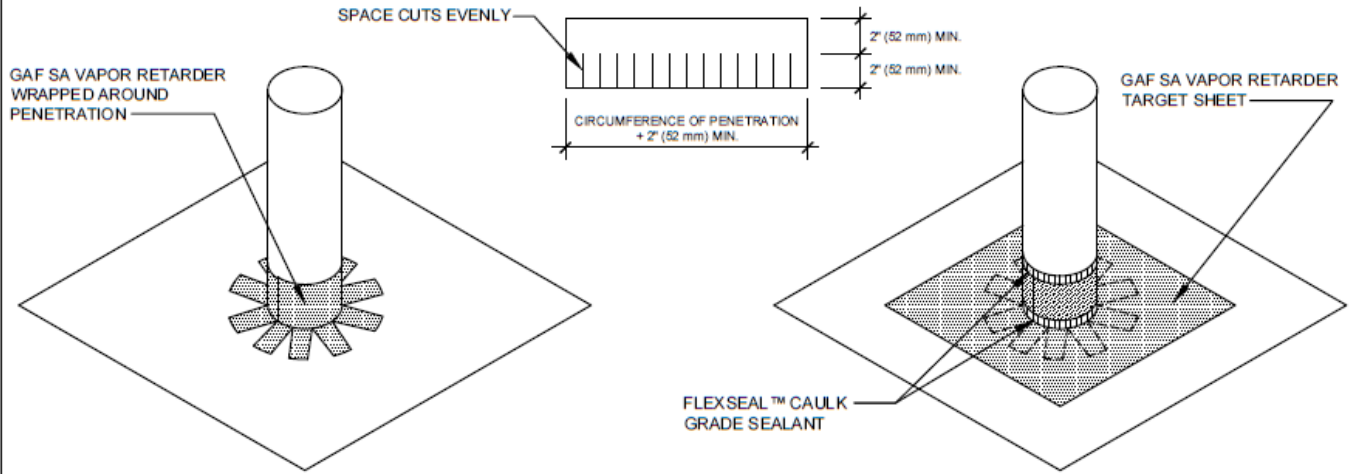
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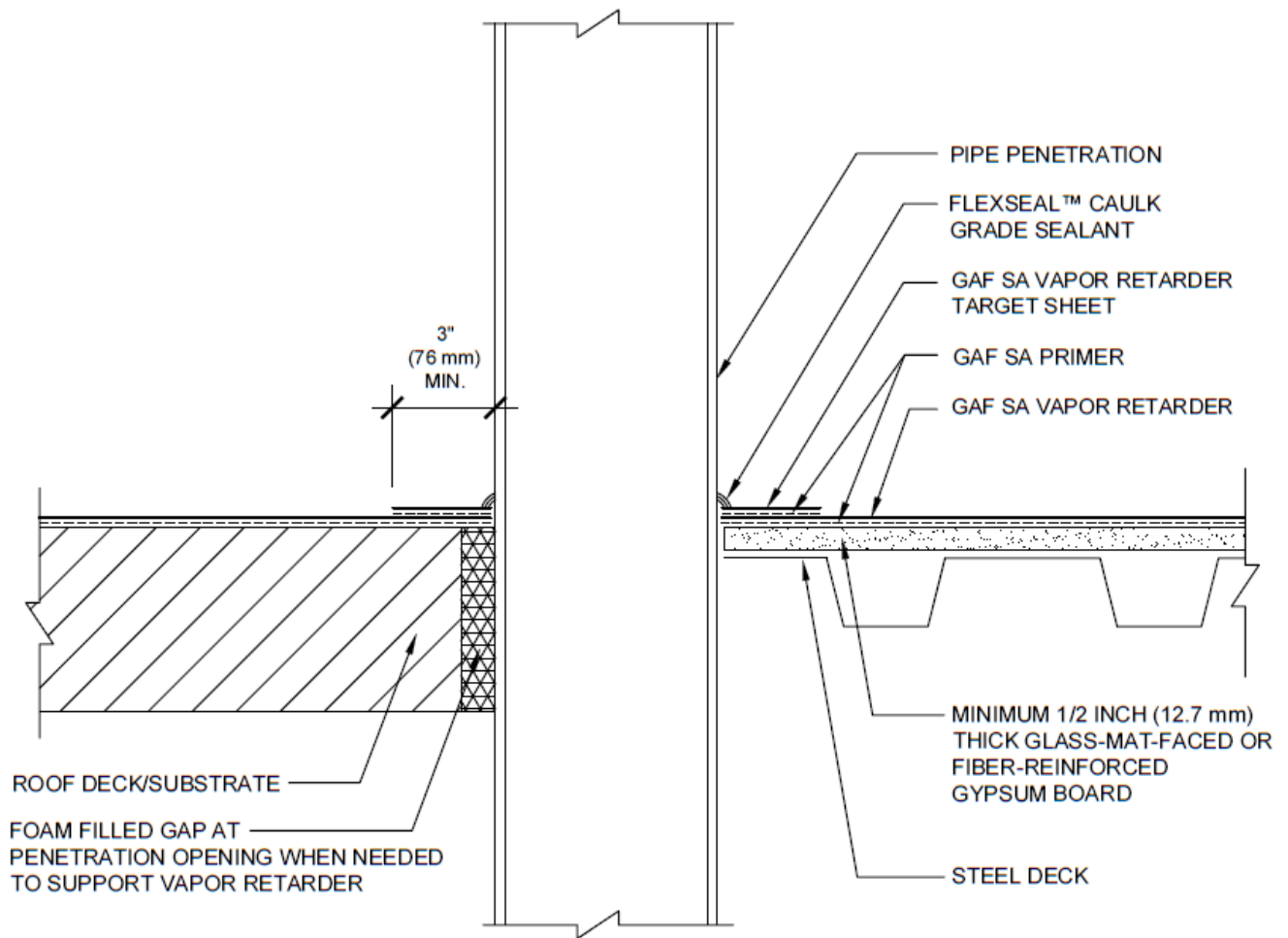


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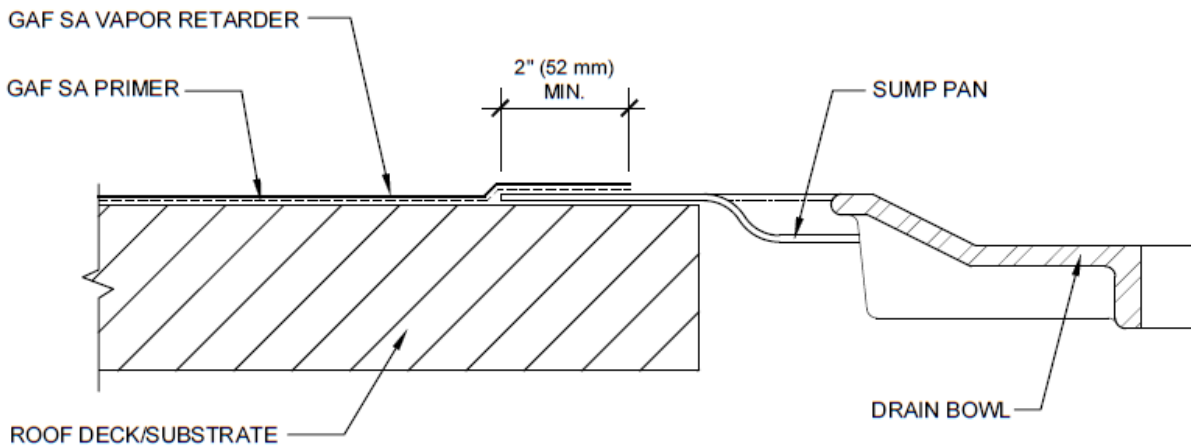
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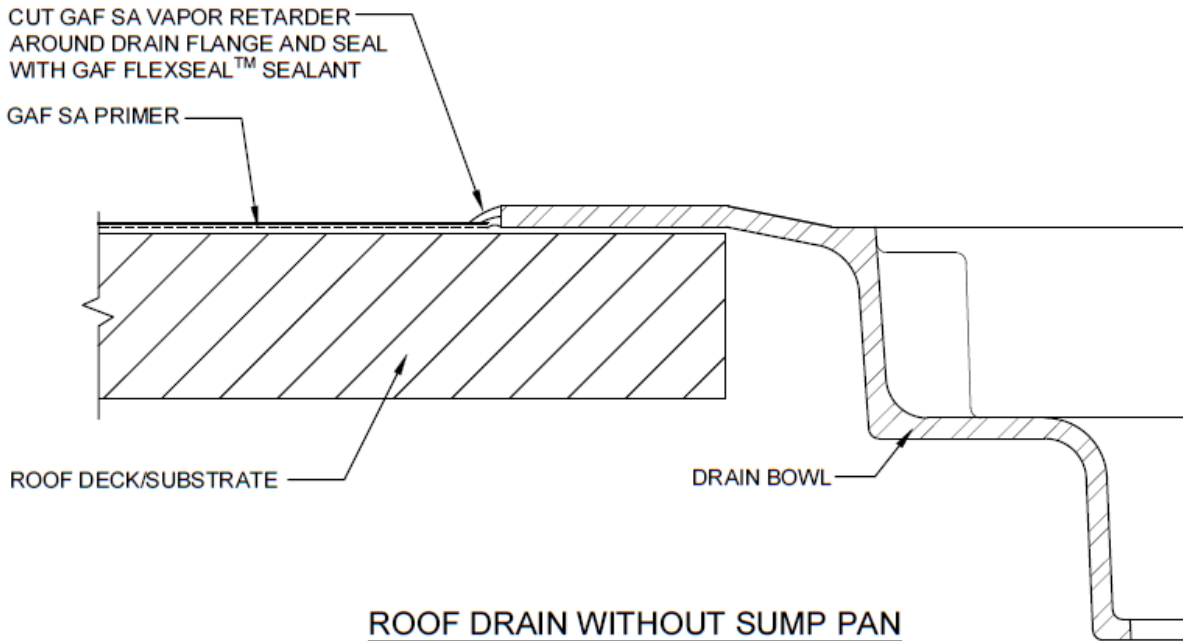
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1. USE DETAIL IN CONJUNCTION WITH THE STANDARD ROOF PENETRATION DETAIL FOR APPROVED ROOF SYSTEM.
2. REFER TO GAF SA PRIMER INSTALLATION INSTRUCTIONS FOR GENERAL GUIDELINES.

 www.gaf.com 1 Campus Drive, Parsippany, NJ 07054	 ROOF PENETRATION SERIES	DRAWING # 506A	SA VAPOR RETARDER DETAIL AT PIPE PENETRATION	THIS DETAIL APPLIES TO: ALL SYSTEMS
	VAPOR RETARDER DETAILS	SCALE N.T.S.		REVISION DATE 6-19-20





ROOF DRAIN WITH SUMP PAN



ROOF DRAIN WITHOUT SUMP PAN

NOTE:

1. USE DETAIL IN CONJUNCTION WITH THE STANDARD DRAIN DETAIL FOR APPROVED ROOF SYSTEM.
2. REFER TO GAF SA PRIMER INSTALLATION INSTRUCTIONS FOR GENERAL GUIDELINES.
3. A MINIMUM 1/2 INCH (12.7 mm) THICK GLASS-MAT-FACED OR FIBER-REINFORCED GYPSUM BOARD IS REQUIRED OVER STEEL DECKS.
4. MAINTAIN SEPARATION BETWEEN VAPOR RETARDER AND MEMBRANE/ADHESIVE TO AVOID POTENTIAL INCOMPATIBILITY ISSUES.

 www.gaf.com 1 Campus Drive, Parsippany, NJ 07054	 SINGLE-PLY ROOFING SYSTEMS ROOF PENETRATION SERIES	DRAWING # 513	SA VAPOR RETARDER DETAIL AT DRAIN	THIS DETAIL APPLIES TO: ALL SYSTEMS
	VAPOR RETARDER DETAILS	SCALE N.T.S.		REVISION DATE 6-19-20

Appendix A—Vapor Retarders and Structural Concrete Decks

A commonly used method to help address moisture issues in structural concrete decks is the use of a vapor retarder. This appendix discusses this type of application.

Background

Concrete roof decks that retain moisture continues to be a concern in the roofing industry. Initial reports were limited to lightweight structural concrete decks, but the industry has also been seeing problems with normal weight structural concrete.

There are three types of concrete used in roofing assemblies:

1. Normal weight structural concrete – with a density ~150 lbs/ft³
2. Lightweight structural concrete – with a density ~85-120 lbs/ft³
3. Lightweight insulating concrete – with a density ~20-40 lbs/ft³

Normal weight structural concrete uses normal weight aggregate that is generally dense and tends to hold the least amount of water of the three concrete types (typically called “hard rock”).

Lightweight structural concrete uses lightweight, porous aggregate, such as shale, which can absorb up to 25% water by weight. As noted above, there are density differences between both types of structural concrete.

Lightweight insulating concrete uses lightweight insulating aggregates composed of perlite or vermiculite. It may also be produced by mixing Portland cement and water with pre-generated foam; this is referred to as lightweight cellular insulating concrete.

There are two types of applications where structural concrete is poured for roof decks:

1. Cast-in-place over removable forms
2. Cast-in-place over a metal form deck that is not removed

Lightweight insulating concrete is typically used as a topping material over substrates, such as metal form decks, structural concrete or precast concrete planks or tees.

Reasons for Moisture Issues with Structural Concrete Decks

There have been changes in the materials and methods used in the construction of structural concrete decks over the past 30 years. Two significant changes to note are the use of lightweight aggregate in structural concrete and the use of non-removable forms. The use of lightweight aggregate that can hold more initial water than traditional “hard rock” aggregate, combined with the use of metal forms that are left in place, can increase the likelihood of the presence of moisture in the deck. And recent work

indicates that even normal weight structural concrete poured over non-removable forms retains a significant amount of water within the concrete.

Problems and issues with structural concrete that pose significant risks to the roofing system and its installation include:

- Determining when a deck is ready for roofing
- Measuring concrete moisture content
- Loss of adhesion
- Blistering
- Insulation facer delamination
- Loss of R-value
- Microbial growth potential
- Water-based adhesive curing and re-wetting
- Corrosion of roof fasteners and other ferrous-containing roof components

Where We Are Today

To date, there hasn't been a general consensus on the best method to determine the moisture content in a structural concrete deck, as well as, criteria for accepting a substrate for roofing application.

Furthermore, proposed solutions—such as using admixtures in the concrete or roof top vents to remove the water—have been met with skepticism and concerns that they will not perform their intended purpose.

Given those circumstances, the use of a vapor retarder to restrain moisture from the deck into the roofing system continues to be a commonly used method. However, roof system designers should take into account the following:

- The vapor retarder is restricting the movement of moisture into the roofing system, in the case of a system (insulation included) that is adhered to the vapor retarder, it is also critical to the attachment of the roofing system.
- If attachment is “through” the vapor retarder, consider how much moisture is going to be restricted when fastening through the component that depends on low permeability for its performance. This may be less of a concern where the vapor drive is less, e.g., Atlanta as opposed to Minneapolis.

Vapor Retarder Design Options

The following are available options (in no particular order of preference) that may help meet the particular needs for a roofing system.

Option	Vapor Retarder/Roofing System Construction	Critical Considerations
A	<ul style="list-style-type: none"> <input type="checkbox"/> Mechanically fastened venting base sheet, attached using pre-drilled stainless steel fasteners. <input type="checkbox"/> Over this base sheet, install an adhered vapor retarder, e.g., heat welded SBS membrane or a two ply hot mopped vapor retarder. <input type="checkbox"/> Insulation and roofing membrane adhered over the vapor retarder. 	<ul style="list-style-type: none"> ▪ The long term durability of the fasteners into a wet deck. ▪ The maximum uplift resistance of the roofing system is limited by the use of a base sheet.
B	<ul style="list-style-type: none"> <input type="checkbox"/> 6 mil polyethylene sheet vapor retarder <input type="checkbox"/> Mechanically fastened venting base sheet, attached using pre-drilled stainless steel fasteners. <input type="checkbox"/> Insulation and roofing membrane adhered over the base sheet 	<ul style="list-style-type: none"> ▪ The long term durability of the fasteners into a wet deck. ▪ The maximum uplift resistance of the roofing system is limited by the use of a base sheet. ▪ This configuration results in approximately one fastener through the vapor retarder every square foot
C	<ul style="list-style-type: none"> <input type="checkbox"/> 6 mil polyethylene sheet vapor retarder <input type="checkbox"/> Insulation attached through the vapor retarder into the concrete deck using stainless steel fasteners or spikes. <input type="checkbox"/> Over the 1st layer of insulation, adhere additional insulation (if/as required) and then the roofing membrane 	<ul style="list-style-type: none"> ▪ The long term durability of the fasteners into a wet deck. ▪ The uplift resistance of the roofing system is dependent on the attachment of the first layer of insulation. ▪ The attachment of the insulation is through the vapor retarder.
D	<ul style="list-style-type: none"> <input type="checkbox"/> Adhered vapor retarder, e.g. heat welded SBS membrane or a two ply hot mopped vapor retarder <input type="checkbox"/> Insulation attached through the vapor retarder into the concrete deck using stainless steel fasteners or spikes. <input type="checkbox"/> Over the 1st layer of insulation, adhere additional insulation (if/as required) and then the roofing membrane 	<ul style="list-style-type: none"> ▪ The long term durability of the fasteners into a wet deck. ▪ This configuration adds attachment confidence for the roofing system while fastening through the vapor retarder

E	<ul style="list-style-type: none"> <input type="checkbox"/> Adhered vapor retarder, e.g., heat welded SBS membrane or a two ply hot mopped vapor retarder. <input type="checkbox"/> Supplemental attachment through the vapor retarder in the perimeters and corners using stainless steel fasteners or spikes. <input type="checkbox"/> Insulation and roofing membrane adhered over the vapor retarder. 	<ul style="list-style-type: none"> ▪ The long term durability of the fasteners into a wet deck. ▪ This configuration adds attachment confidence for the roofing system while fastening through the vapor retarder in a limited area
F	<ul style="list-style-type: none"> <input type="checkbox"/> Use of a protected roof membrane assembly 	<ul style="list-style-type: none"> ▪ Attachment is provided/supplemented by the overburden ▪ With the membrane at the deck level, it serves as the vapor retarder

Who is Responsible?

The roof system designer is responsible for considering the building envelope’s performance and the potential for moisture when specifying a roofing system installed over a concrete deck, particularly when the concrete is installed over a non-venting substrate.

For new construction, roofing contractors should not accept responsibility for determining when a newly placed concrete substrate is ready for roofing. That decision should be made by the building’s structural engineer, general contractor, concrete contractor and/or the roof system designer.

Where concrete decks are encountered in re-roofing, GAF recommends that roofing contractors consult a design professional for the appropriate roofing system design to address high moisture content.

Appendix B—Procedure for Determining Temperature Gradient

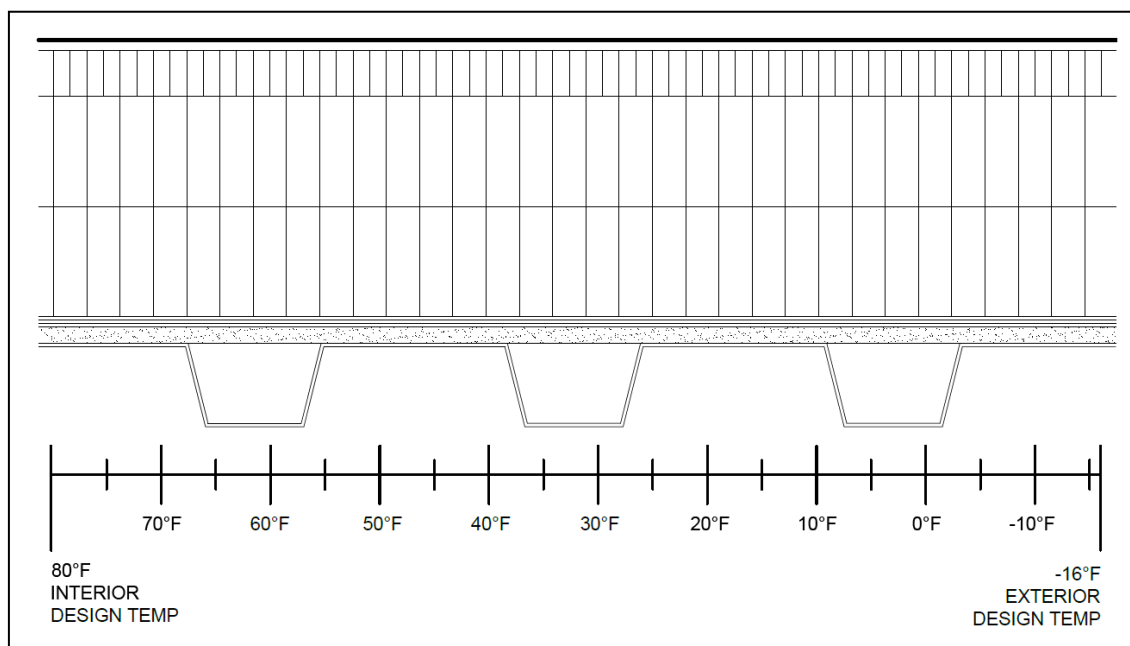
The following is a step-by-step example of how to calculate the temperature gradient through a roof assembly.

Building type: Natatorium (a.k.a. a building with a swimming pool inside)
Building location: Minneapolis, MN
Roof assembly: TPO roof membrane
½" thick high-density polyisocyanurate insulation cover board
Two layers of 2½" thick polyisocyanurate insulation
Two-ply felt and asphalt membrane vapor retarder
½" thick gypsum board
Steel deck

Step 1: Determine the winter interior design dry bulb temperature. This design value is essentially the temperature that the building's interior will be set at during the winter months. This information typically can be obtained from the HVAC system designer. However, for existing buildings, the building maintenance engineer is a possible resource. For this example, let's use 80°F for the winter interior design dry bulb temperature.

Step 2: Obtain the winter exterior design dry bulb temperature. Design values can be found in Chapter 14—Climatic Design Information of the 2017 ASHRAE Handbook—Fundamentals; or in the Appendix of The NRCA Roofing Manual: Architectural Metal Flashing and Condensation and Air Leakage Control—2018. For Minneapolis, the winter exterior design dry bulb temperature is -16°F.

Step 3: Draw the roof assembly to a practical scale. A scale of 3 inches=1 foot works well and typically fits on a standard 8.5x11 size sheet. Underneath the roof assembly, draw a temperature scale below the roof assembly. The starting temperature, i.e., the left side of the scale, will be the winter interior dry bulb design temperature. The scale will end with the winter exterior design dry bulb temperature. Then, place evenly spaced vertical lines between these two lines to represent 5- and/or 10-degree increments. See below.



Step 4: Determine the roof assembly's overall R-value. Thermal properties of roofing materials can be obtained from manufacturers' product literature. Other possible sources include: Chapter 26—Thermal Transmission Data of the ASHRAE Handbook—Fundamentals; or the Appendix of The NRCA Roofing Manual: Architectural Metal Flashing and Condensation and Air Leakage Control.

Below are the R-values for the proposed roof assembly.

Material	R-value
Exterior air film* (winter)	0.17
TPO	0.24
½" HD polyisocyanurate insulation cover board	2.50
2.5" polyisocyanurate insulation	14.40
2.5" polyisocyanurate insulation	14.40
Two-ply felt and asphalt membrane vapor retarder	0.12
½" gypsum board	0.56
Steel deck	0.00
Interior air film* (winter)	0.61
Total R-value	33.00

**Note that an "air film" exists on both the inside and outside of a roof assembly. Air films actually have an R-value and they contribute to a roof assembly's overall R-value. Also, there are different R-values for interior and exterior air films for winter and summer.*

Step 5: Calculate the amount of heat loss occurring at the top surface of each material/layer. The temperature at the top of each material is lower as we move from interior to exterior. The heat loss formula for temperature drop (T_d) is:

$$T_d = T_i - [(R/R_T) \times \Delta T]$$

where:

T_d = temperature drop (temperature at top surface of material), degrees Fahrenheit

T_i = design inside (interior side) temperature, degrees Fahrenheit

ΔT = (winter interior design dry bulb temperature) - (exterior design dry bulb temperature)

$\Delta T = 80 \text{ degrees} - (-16 \text{ degrees}) = 96 \text{ degrees}$

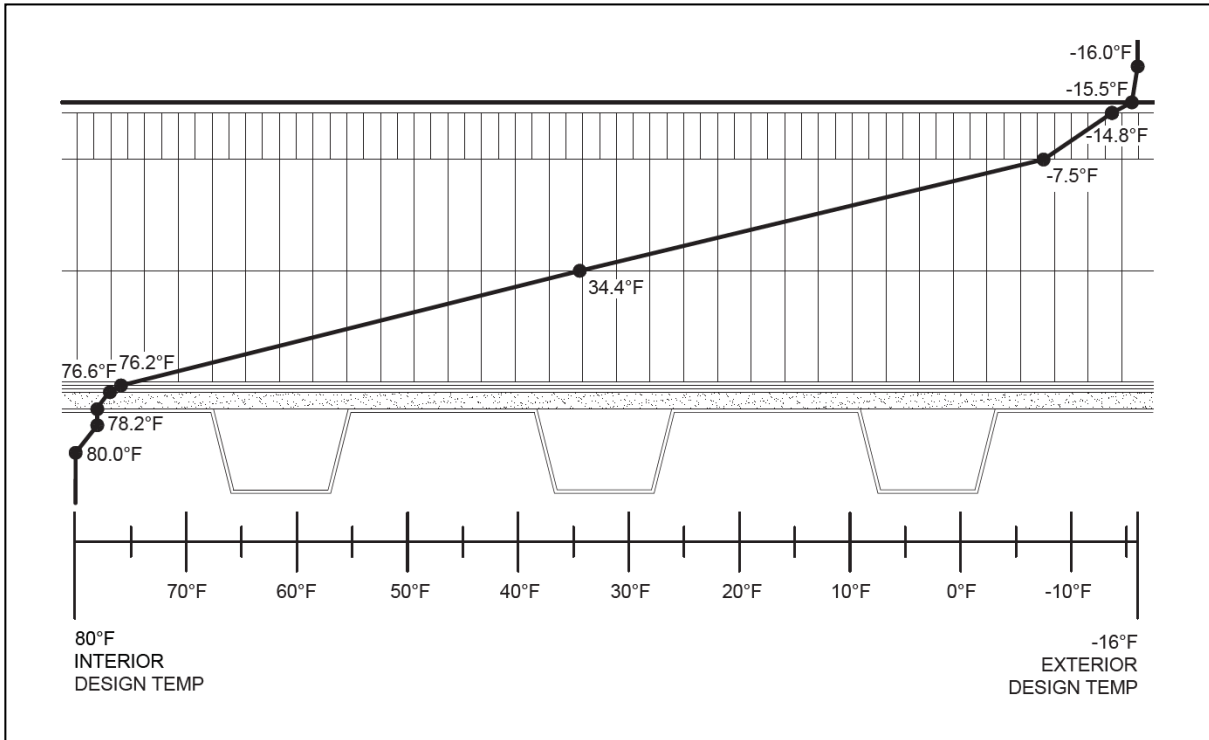
R = cumulative R-values of materials starting from the interior

R_T = R-value of the total assembly

The table below displays the calculations for each roofing material in the roof assembly example.

Material	Temperature at top face of material (degrees Fahrenheit)
Interior air film (winter) $80 - \left[\left(\frac{0.61}{33.00} \right) \times 96 \right]$	78.2
Steel deck $80 - \left[\left(\frac{0.61 + 0.00}{33.00} \right) \times 96 \right]$	78.2
½" gypsum board $80 - \left[\left(\frac{0.61 + 0.00 + 0.56}{33.00} \right) \times 96 \right]$	76.6
Two-ply felt and asphalt membrane vapor retarder $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12}{33.00} \right) \times 96 \right]$	76.2
2½" polyisocyanurate insulation $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12 + 14.40}{33.00} \right) \times 96 \right]$	34.4
2½" polyisocyanurate insulation $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12 + 14.40 + 14.40}{33.00} \right) \times 96 \right]$	-7.5
½" HD polyisocyanurate insulation cover board $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12 + 14.40 + 14.40 + 2.50}{33.00} \right) \times 96 \right]$	-14.8
TPO roof membrane $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12 + 14.40 + 14.40 + 2.50 + 0.24}{33.00} \right) \times 96 \right]$	-15.5
Exterior air film (winter) $80 - \left[\left(\frac{0.61 + 0.00 + 0.56 + 0.12 + 14.40 + 14.40 + 2.50 + 0.24 + 0.17}{33.00} \right) \times 96 \right]$	-16.0

Step 6: Plot the calculated temperature gradient values for top surface of each material on the roof assembly drawing. Draw a line from the winter interior dry bulb design temperature to the next value and continue to “connect the dots” until you reach the winter exterior design dry bulb temperature.



Step 7: Determine the dew-point temperature. Dew-point temperature can be determined by using a simplified version of the ASHRAE psychrometric chart, shown below.

Dew-Point Temperature (°F)															
Relative Humidity	Design Dry Bulb (Interior) Temperature (°F)														
	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83
50%	16	20	24	28	33	36	41	46	50	55	60	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	16	21	25	29	33	37	42	46	50	54	59	62
20%	6	7	8	9	13	16	20	24	28	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34

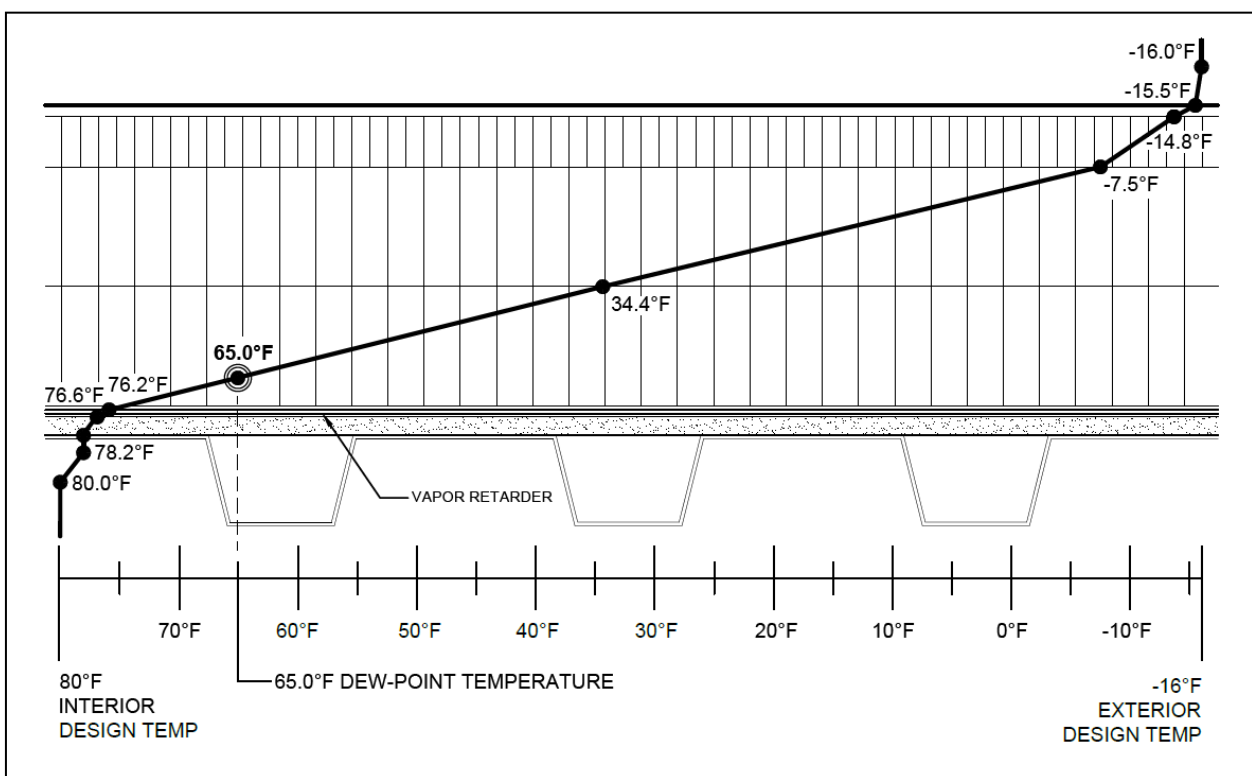
Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Handbook—Fundamentals.

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For this example, look at the top row of the chart and locate the design dry bulb (interior) temperature column, which, in this case, is 80°F. Next, locate 60 percent relative humidity on the left side of the chart. The dew-point temperature is at the intersection of the design dry bulb temperature column and relative humidity row. For this example, the dew point temperature is 65°F.

Note: If the design values don't exactly match the values in the chart, you can use linear interpolation to determine the dew point temperature. Another option is to use a dew-point calculator app, such as www.dpcalc.org.

Step 8: Locate the dew-point temperature value on the temperature gradient line on the roof assembly drawing. If the dew-point temperature falls within the insulation that is above the vapor retarder, there is sufficient roof insulation above the vapor retarder. Therefore, the vapor retarder should be effective in preventing or minimizing condensation from occurring within the roof assembly.



If the dew-point temperature falls below the vapor retarder, additional insulation is needed. After selecting a new amount of roof insulation, confirm the new amount is sufficient by doing the graphic analysis again. Conversely, if the dew-point temperature falls within the upper layer of insulation—say in the upper one-third of the total insulation layer—the amount of roof insulation might be able to be reduced to prevent condensation, as long as the dew-point temperature stays within the insulation and, importantly, the revised insulation amount still meets energy code requirements. Perform another graphic analysis to verify the reduced insulation amount is adequate.