Guide to Effective Warehouse Design, Maintenance, and Modernization

Published by the Controlled Environment Building Association and the Global Cold Chain Alliance
2025

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A unique alliance

The **Global Cold Chain Alliance (GCCA)** exists to help its members build and strengthen the temperature-controlled supply chain worldwide. We do this by bringing third-party warehouse and transportation business leaders together in events and networking activities, providing advisory and educational services, and being a voice of cold chain to government regulators and other influencers around the world.

The **Global Cold Chain Foundation's (GCCF)** mission is to strengthen the global cold chain through education, research, and international development. Cold Chain Institute trains industry practitioners in the best practices of temperature-controlled product storage, handling, and transportation. Research manuals developed by the foundation serve as the definitive guide for the proper handling, storage, and freezing of perishable products as well as energy and facility management.

International development projects engage industry professionals in the development of cold chain infrastructure in emerging markets.

And a key partner to GCCA is the **Controlled Environment Building Association (CEBA)**. CEBA's mission is to represent expert builders who specialise in designing and constructing controlled environment buildings, including cold storage warehouses, food processing facilities, clean rooms, pharmaceutical facilities, food service, and retail distribution centres. With a strong value proposition and growth momentum, industry participation in CEBA programs has doubled since pre-pandemic levels.

Together we are the cold chain.

1500+ Member companies

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Acknowledgement

With appreciation to the Construction Codes Committee for its leadership, oversight, and valuable input in managing this publication update. Special thanks to committee members who volunteered to review selected chapters.

Executive Summary

This Design Manual establishes a unified set of standards and technical guidelines to support the planning, construction, operation, and maintenance of facilities, aligning with best practices in safety, efficiency, and performance. The manual is intended for engineers, facility managers, designers, and technical consultants who require clear, actionable direction across the full range of facility systems.

To improve accessibility and operational efficiency, this latest edition is being published in a modular format—organized into 15 focused chapters. Each chapter addresses a core system or component of facility design and management, enabling users to quickly reference specific content and apply standards directly to their area of responsibility.

1. Design – Foundational planning principles and performance objectives
2. Maintenance – Preventive strategies and operational reliability standards
3. Structural – Load-bearing frameworks and compliance specifications
4. Walls – Materials, insulation, and environmental controls
5. Floors – Surface treatments, drainage, and durability
6. Roofs – Construction systems, weatherproofing, and safety features
7. Refrigeration – Temperature control systems and efficiency metrics
8. Doors – Selection criteria, access control, and insulation
9. Lighting – Illumination standards, energy use, and fixture design
10. Material Handling – Flow optimization and equipment interfaces
11. Batteries – Storage, charging protocols, and hazard mitigation
12. Fire Protection – Risk reduction measures and system integration
13. Racking – Load standards, anchoring, and spatial planning
14. Dock Equipment – Levelers, seals, and operational safety
15. Automated Systems – Integration of robotics, controls, and data systems

This format enables continuous updates and targeted usage while reinforcing technical consistency across disciplines. The manual is designed to serve as both a foundational reference and an evolving toolset for ongoing facility innovation and compliance.

What follows is Chapter 6: Roofs

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Chapter 6: Roofs

6.1 Design

Historical Background of Contemporary Roof Systems

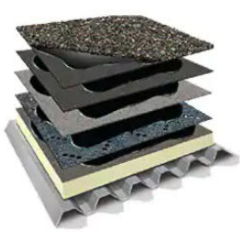
Built-up Bituminous Membranes. Today's built-up membranes are the descendants of the crude prototypical membranes invented in the 1840s, when square sheets of ship's sheathing paper, treated with a mixture of pine tar and pine pitch, served as the felts. The inter-ply bitumen of these early membranes was coal tar, a waste product readily available from the production of coal gas for illumination at plants near the nation's cities. As the next advance, coal tar was substituted for pine tar as a more fluid saturant for the sheathing paper, but square sheets were still dipped manually into the melted saturant and the excess pressed out. Then came the replacement of paper by felt rolls, running through continuously operating saturators. The use of felt rolls accelerated the application process and promoted more uniform membrane quality. Substitution of distilled coal tar pitch for the more expensive pine pitch-coal tar mixture followed.

Asphalt became a competitor of coal tar pitch before the end of the nineteenth century; both as mopping bitumen and as felt saturator. Asphalt was not only more economical than coal tar pitch but also a more versatile material. (Its wide range of viscosities adapts asphalt to much steeper slopes than coal tar pitch.) As a consequence of these advantages, asphalt ultimately replaced coal tar pitch as the most popular bitumen in built-up systems.

More recently, built-up membrane felts have undergone even greater changes. Organic felts containing cellulosic fibers monopolized the market for decades until the introduction of asbestos felts in the 1920s. Today, however, fiberglass felts, introduced soon after World War II, have virtually wiped out the competition. The cellulosic fibers in organic and, to a lesser extent, asbestos felts make them vulnerable to fungus rot, whereas fiberglass felts are virtually immune to this roofing disease. The moisture-absorptive propensity of both organic and asbestos felts makes them vulnerable to blistering. This formerly major problem is virtually eliminated with the porous fiberglass felts. They vent the entrapped air-water vapor mixture that, upon heating, can cause blister growth in poorly applied organic or asbestos-felted built-up membranes. Fiberglass felts also resist splitting better than organic and asbestos felts, which are drastically weakened by moisture absorption. Moreover, organic and asbestos felts are much weaker in the transverse direction than in the longitudinal direction. The greatly improved modern fiberglass felts have virtually isotropic (i.e., equal in both longitudinal and transverse directions) tensile strength.

As the name implies, built-up roofs are 'built-up' on the roof surface. The layers of insulation, typically four to six plies of reinforcement, and cap membrane are installed by hot mopping each layer onto the roof. Asphalt is melted in kettles, at temperatures of 500°F or more, and then using a mop to install the asphalt onto the roof surface, each layer is subsequently mopped into place. Asphalt is vulnerable to ultraviolet degradation, and so a cap sheet must be installed to protect the plies and the asphalt. Built-up roofs have two typical options for a cap sheet: a flood and gravel coat and a granule cap sheet. The first method consists of a layer of melted asphalt and gravel is broadcast into the asphalt. The gravel provides both a wearing surface and protection from ultraviolet rays. The granulated cap sheet is a modern version of the flood and gravel coat where the granules are embedded into the sheet in the factory and the sheet is installed in a layer of melted asphalt. The granules provide the same wearing and ultraviolet protection as a gravel surface, and can also be white or a highly reflective color to reflect ultraviolet rays to assist in decreasing hait gain from the sun into the building.

The contemporary built-up roofing assembly is a vast improvement over its predecessors, although strong fumes are still produced from the kettles as well as the potential for fire due to the kettle equipment. It still, also depends upon highly skilled application technique to realize this potential as each layer is installed laboriously onto the roof surface. However, due to the multiple layers, built-up roofs are robust in nature, have great resistance to wind uplift pressures produced by storms, and limit airflow through the roof assembly. All of which are advantageous to cold storage facilities.



Built-up roof, courtesy of GAF

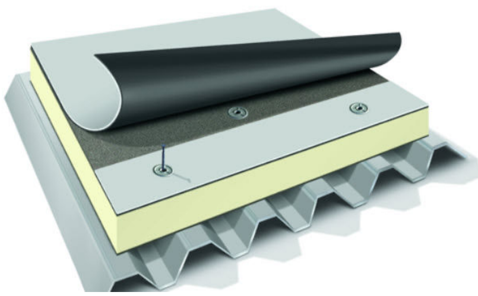
Single –Ply. By reducing the traditional four-ply built-up membrane to one single membrane layer (hence the name single ply membrane), the labor to install a roof assembly was significantly reduced. Both the ease of installation and the wide variety of installation methods quickly allowed for single-ply membranes to gain popularity and market share.

EPDM (Ethylene Propylene Diene Monomer). In the early 1960s the new synthetic single-ply material was introduced into low-slope commercial roofing and was far more expensive than conventional built-up roofing. EPDM was used in Italy before 1960, where Ziegler-Natta catalysis made its polymerization possible. After an incubation period of about ten years in the U.S., big improvements in material quality marked its exponential growth period. By 1975, its growth doubled every year until the mid-1980s. Behind the EPDM revolution is a combination of economic and technological factors:

- Skyrocketing petroleum prices during the energy crises of the 1970s closed the cost gap between more expensive synthetic materials and conventional built-up systems.
- Dissatisfaction with conventional built-up roofing provided a ready market of unhappy building owners and architects eager to try something new.
- The long-term trend toward greater reliance on prefabrication and lesser reliance on heavy field labor favored the generally less labor-intensive field installation of the newer, lighter materials.
- Environmental regulations increasingly limited the heavy polluting installation techniques of conventional built-up roofing, with its smoke-producing hot bitumen kettles.
- The new single-ply systems are generally cleaner and more aesthetically pleasing than built-up systems.
- They are also much better adapted to heat-reflective colors, an energy-conserving feature.

EPDM's excellent ozone and ultraviolet resistance, previously exploited by the automotive industry in tires, weather stripping, and trunk-lid gaskets, has now been exploited by roofing material manufacturers. EPDM's capacity for absorbing large quantities of cheaper reinforcing filler materials — notably carbon black, an UV inhibitor — lowers its cost while increasing its tensile strength. Due to the component of carbon black, EPDM membrane color is most often black, however, white EPDM is available, often at a higher cost.

EPDM, in typical thicknesses of 45 mil, 60 mil, or 90 mil, and is inherently flexible, which is advantageous for flashing of penetrations. The sheets can be installed in large sheets of 10 to 20' widths and the seams are taped or glued together. The sheets can be installed via mechanically attaching or adhering. Mechnically attaching uses fasteners that span from seams in the membrane sheets through the roof deck which allows for interior air loss through the roofing assembly as well as thermal bridges where each fastener is located. Adhering the membrane will limit some of the interior air loss and thermal bridging, which is ideal for cold storage facilities.



Mechanically attached single-ply system. Courtesy of GAF

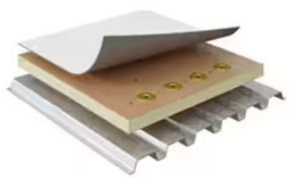
PVC & Blends. The use of PVC sheet material used in roofing in the United States began as a replacement of two-ply bituminous membrane vapor retarders after the famous General Motors fire in the late 1950s. The fire demonstrated that an internal fire could melt the bituminous material in built-up roofing, which could feed the fire by leaking down roof penetrations. Polyvinyl chloride (PVC) is an inherently fire retardant thermoplastic due to the presence of 57% chlorine in its molecular structure. Because of its fire resistance, it was used as a vapor barrier film layered in ribbons of cold adhesive. This fire-retardant film met the requirements of FM Class I, but did not play a significant part in the early use of single-ply roofing until much later. Its use as a fire-retardant vapor barrier on steel decks resulted in poor adhesion, splitting and lift-off.

In the early 1970s polymer-coated fabrics, originally used as trench tarpaulins, were adapted as roof membranes. Pond and ditch liners made of reinforced polymeric sheets were also elevated to the status of roof membranes. PVC had a major advantage over synthetic rubber material in its weldability, by either heat or solvent welding of field seams. After welding, the seams become fused together to form a monolithic sheet.

Early generations of PVC roof membrane had their problems. Some of the thin-mil, unreinforced membranes began to shrink and become brittle due to plasticizer loss from the membrane. In the early 1980s, PVC manufacturers began to introduce reinforcement to the membrane as well as increase the mil-thickness. Improved UV and plasticizer packages, such as the introduction to KEE, were introduced to make a much more durable membrane. PVC, and moreso, KEE membranes, have excellent resistance to animal fats and greases, which can be a consideration in meat processing facilities.

PVC membranes are often manufactured in thicknesses of 50 mil, 60 mil, and 80 mil, and can be mechanically attached, induction welded, and adhered. This wide range of application methods makes PVC membranes eligible for many building types, including cold storage. Seams are heat welded, which forms a monlothic membrane on the roof.

PVC is typically available in white or reflective colors, which are beneficial to reflect ultraviolet rays and decrease the heat gain from the roof.



Inducted welded PVC system. Courtesy of GAF.

TPO (Thermoplastic polyolefin). The development of a polyolefin thermoplastic material has its roots in the 1930s, when the first high-pressure process was developed for polypropylene. But progress was slow. In the 1960s, scientists succeeded at polypropylene copolymerization, creating EP (Ethylene propylene) polymers. But it wasn't until the 70s that today's TPO really began to take shape. In the 1970s, two significant advancements changed the face of TPO:

- The development of gas phase processes which allowed for more consistent and a greater variety of polyolefins and the successful compounding of polypropylene blends.
- The manufacturers driving these changes in TPO and the polymer technology were in the automotive industry.

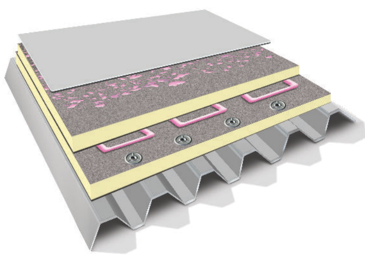
The first TPO automotive bumper was developed in Europe by Fiat in 1975. At this time, TPO was used only to replace the metal fascia on the bumper, not to manufacture the complete system itself. But as the decade progressed, auto manufacturers continued to expand their development of TPO components, in part because of its lighter weight and recycling potential.

The 1980s. Science continued to refine polypropylene composites and the production process. TPO use continued to grow in the automotive industry, especially for interior and exterior trim applications. By mid-decade, the technology had also been adopted by the household appliance industry, which used it for components in dishwashers, clothes washers and other water-based applications.

The technology grew quickly following the introduction of a catalyst system to polymerize the EP and polypropylene materials. In 1986, dynamic vulcanization helped introduce TPO to the roofing industry. However, the roofing membrane as we know it today — a mixture of EP and polypropylene — first came into regular production in 1989.

The 1990s. During this decade, the use of TPO in manufacturing has been rapidly growing globally. Inherent attributes – including chemical resistance — enhance the value of TPO in many demanding industrial environments. Advancements in manufacturing have revolutionized the TPO process.

TPO membranes are often manufactured in thicknesses of 545 mil, 60 mil, and 80 mil, and can be mechanically attached, induction welded, and adhered. This wide range of application methods makes TPO membranes eligible for many building types, including cold storage. Seams are heat welded, which forms a monlothic membrane on the roof. TPO is typically available in white or reflective colors, which are beneficial to reflect ultraviolet rays and decrease the heat gain from the roof.



TPO roofing assembly adhered. Courtesy of GAF.

Modified Bitumens. Concurrent with the single-ply elastomers came a more direct attack on conventional built-up membranes: the modified bitumens, pioneered in Italy and other European countries. By reducing the traditional four-ply built-up membrane to two (underlayment plus single-ply sheet), modified-bitumen sheets fulfill the perennial construction goal for reducing heavy field labor. And with their tremendous improvement in material quality (improved flexibility, elasticity, and ductility at subfreezing temperatures) modified-bitumen systems preserve most of the advantages of conventional built-up membranes, their superior puncture resistance and general toughness. In a sense, modified bitumens can be considered more an evolutionary improvement of conventional built-up membranes than a revolutionary alternative.

Like thermosetting and thermoplastic sheets, modified bitumens are a triumph of polymer chemistry. They evolved as an incidental technological by-product of more directly sought advances. One major ingredient in many modified bitumens, atactic polypropylene (APP), is a by-product of isotactic polypropylene (IPP), familiar in tool or hair dryer cases as the integrally molded hinge capable of flexing thousands of times without fatigue failure. The process producing IPP resin yielded a soft, non-crystalline by-product, APP. Seeking markets for this material, manufacturers found that it plasticizes asphalt, endowing it with greatly enhanced physical properties—the previously noted flexibility, elasticity, and ductility down into the subfreezing range (-15 F, -26 C). APP-modified sheets were first used in Italy, where APP polymer was readily available. They were soon imported into the United States.

Because APP-modified sheets have elevated softening points, they proved unsuitable for adhering with hot-mopped asphalt. They required heat fusion by propane torch, operating at temperatures approaching 3,000°F, not only to adhere the modified bitumen sheet to its substrate but also to seal field seams and form flashings.

Another plasticizer, styrene butadiene styrene (SBS) copolymer, produces a modified-bitumen membrane with greater elasticity and low-temperature flexibility than the thermoplastic APP-modified-bitumen membranes. Introduced in France in the 1960s, SBS-modified bitumens exploit the unique ability of SBS to form a polymer dispersion within a mass of asphalt. Even though the polymer represents only 12 percent or so of the mix, the SBS molecules form a net-work. The SBS-modified asphalt behaves something like a water-soaked sponge: despite the much greater weight of the water, the sponge nonetheless behaves like a solid, not a liquid. SBS-modified bitumen thus exhibits truly elastic behavior, recovering its original shape upon removal of deforming stress.

This unique polymer-dispersing property gives SBS a major advantage over APP as a bitumen modifier. Unlike APP-modified-bitumen sheets, SBS-modified-bitumen sheets can be field-adhered with conventional hot-mopped asphalt, because the greatly reduced quantity of SBS polymer elevates the melt point much less than APP does. SBS sheets can also be torch applied and installed with adhesives (known as cold applied, no heat is needed). Self-adhered SBS cap sheets are also available on the market.

The cap sheets of both APP and SBS sheets have factory applied granules that provide ultraviolet protection as well as increase robustness of the assembly. The granules come in a variety of colors, including white that is beneficial to reflect ultraviolet rays and decrease the heat gain from the roof.

Modified bitumen roofs are known to be durable and robust, as well as due to the nature of the multiple layers being installed without fasteners, they limit uncontrolled air movement within the roof assembly.

Roofing Trends

Conventional Low-Sloped Commercial Roofing Market: 2008 Compared to 2015		
Roof Membrane	**Market Share, in %**	
	2008	**2020**
Ethylene Propylene Diene Monomer (EPDM)	22	18
Thermoplastic Polyolefin (TPO)	28	46

Conventional Low-Sloped Commercial Roofing Market: 2008 Compared to 2015		
Roof Membrane	Market Share, in %	
	2008	2020
Polyvinyl Chloride (PVC)	10	13
Built Up Roofing (BUR Asphalt Roofing)	12	5
Single-Layer Asphalt (SBS/APP)	28	18
Single-Ply Market Share, 2020		
Roof Membrane	**Market Share, in %**	
Thermoplastic Polyolefin (TPO)	55	
Ethylene Propylene Diene Monomer (EPDM)	27	
Polyvinyl Chloride (PVC)	18	
Single-Ply Mil. Thickness, 2020		
Mil. Thickness	**Market Share, in %**	
.080	3	
.060	81	
.045	16	

Table 6.1

The trend appears to be toward TPO roofing. The reasons for this are improvements in the formulation of the membranes, hot-air welded seams and the reflectivity of the white membrane. The roofing system of choice has been mechanically fastened due to the ease and quickness of installation. Studies have shown that there is a reduction of R-value of up to 17% through the roofing fasteners in a mechanically attached system. A method to reduce the loss in insulating R-value brought by a mechanically attached system is by burying the fasteners in the roofing assembly. Mechanically attaching the first layer of insulation and then adhesion of subsequent layers of insulation and adhering the membrane to the insulation significantly reduces thermal losses due to fasteners.

In today's cold storage market the predominant roofing systems are TPO and PVC, due to the flexibility/elongation of the membranes, their white colors, resistance to chemicals, and ease of installation.

A roofing material's reflectivity and emissivity are important factors in thermal performance. In fact, the federal government, and many local and state utilities, will provide companies incentive/rebate money to install roof systems and membranes that have a high reflectivity and emissivity rating. These materials are typically relegated to PVC and TPO membranes. The value of these incentives can be up to 40% of the cost of the total project.

Table 1: Water Vapor Transmission

Commented [WK1]: Should this be table 6.2?

Tested per ASTM E-96 Standard Test Method for Water Vapor Transmission of Material (.045 to 048 mils) Water Method (Method B)

Membrane	W. V. T. (grains/hr ft²)	Permeance (perms)	Permeability (perm mils)
TPO	0.005	0.012	0.49
EPDM	0.014	0.035	1.62
PVC-I	0.115	0.277	13.30
PVC-II	0.158	0.253	
PVC-III	0.178	0.285	
PVC-IV	0.094	0.151	
PVC-V		0.220	

Table 6.2 Manufacturer membrane samples

WVT is tested ASTM E-96, A, B, BW, C, D and E. Generally, the preferred test for cold storage applications is method B or BW. Method B is the water method at 73.4 F and BW is the inverted water method at 73.4 F. The units for WVT are grains/SF x hr. The units for permeance are perms, permeability has units of perm x mil. The key listing here is permeance. The rating for vapor barriers is perms. The cold storage industry standard indicates that a perm rating of .10 or less is considered a good vapor barrier for cold storage.

Roofing Insulation. A vital component to any refrigerated building is the roof insulation. This is critical to the energy consumption of the facility and the longevity of the roof system. Careful consideration should be taken in the selection of roof insulation.

The majority of the roof insulation installed today is polyisocyanurate (polyiso, ISO). This is due to the thermal retention, higher published R-value per inch – which in turn reduces the insulation thickness and the length of fasteners needed in a mechanically fastened system and relatively low moisture absorption.

It is important to note that wet insulation is 1/65 of its R-value, frozen insulation is 1/100 of its R-value. (See Table 6.3).

Insulation	R-Value	Moisture Absorption
Polyisocyanurate	6.0 (LTTR-180 days) *5.6 (5 year)	1-1.5%
Extruded Polystyrene (XPS)	5.00	0.3%
Expanded Polystyrene (EPS)	3.85	4.0%
Perlite (used mostly in BUR)	2.70	1.5%
Wood Fiber Board	2.00	7.0%
FoamGlas®	3.03	0.2%
Fiberglass	3.60	5.0%
Gypsum Board	0.90	7.7%

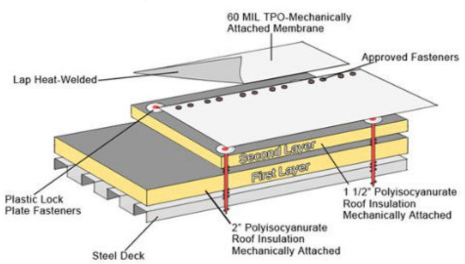
Table 6.3 R-Value Moisture Absorption (per inch) *NRCA/ASHRAE recommends 5 year aging

While the physical properties of insulations are important, the amount of insulation and the installation method are of equal importance. The 2018 edition of the American Society of Heating, Refrigeration and Air-Conditioning Engineers' Handbook – Refrigeration, offers suggestions for minimum R-values for roof insulation in cold storage buildings. Additionally, it is required by the International Building Code (IBC) to install a minium 2 layers of insulation, staggered and offset.

Cold Storage Type	Interior Temperature Range °F (°C)	Minimum R-value for Roof Insulation
Coolers	40 to 50 (4.4 to 10)	30 to 35
Chill Coolers	25 to 35 (-3.8 to 1.6)	35 to 40
Holding Freezers	-10 to -20 (-23.3 to -28.9)	45 to 50
Blast Freezers	-40 to -50 (-40 to -45.5)	50 to 60

Table 6.4: ASHRAE Suggested Minimum R-values for Roof Insulation

Roofing Design Considerations Any roofing system has six design requirements that must be met. The design properties are regulated by criteria set by various testing bodies and associations and are subject to local building codes.

- **Weather Resistance** — The roof assembly must resist entry of water from environmental and other external sources. Other external sources may include condensation and leakage from roof-mounted equipment.
- **External and Internal Fire Resistance** — The roof must resist fire from both internal and external sources. External sources include sparks and fire brands. Local building codes and/or insurance carriers establish the degree of external fire resistance.
- **Wind Uplift Resistance** — The components of the roofing system must be attached to the building roof deck in such a manner as to resist uplift pressures caused by wind and/or internal building pressure. Refer to ASCE 7 Wind Uplift Guidelines or Factory Mutual Guidelines if FM Insured.
- **Thermal Performance** — The roofing assembly must have insulating characteristics to provide internal environmental control. The amount of thermal resistance required is usually established by ASHRAE "Recommended R Values for Refrigerated Facilities" (See Table 6.4). Note: Wet insulation is 1/65 of its original R-Value. Frozen insulation is 1/100 of its original R-Value.
    - Consideration of attachment method of the roofing assembly can have impact on thermal performance of the system. Mechanical fasteners act as thermal bridges when they extend through the all layers of the insulation. As metal is a great conductor of heat, they allow heat from the outside to flow through them, effectively reducing the R value of the insulation it is fastening through. A recommendation to reduce thermal bridging is to bury the mechanical fasteners into the roofing system. It is considered a best practice to mechanically attach the first layer of insulation to the deck and adhere subsequent layers of the roof assembly.
    - 

    - Figure XX, Mechanically attached single-ply system
- **Water Vapor Transmission** — A key element to the roofing system selection is the Water Vapor Transmission Rate of the membrane. The cold storage industry

standard is that a perm rating of 0.1 or less is usually considered a good vapor barrier for cold storage construction. (See Table I for typical perm ratings on different types of roof systems.)

- **Control of Air Movement through the Roofing Assembly** — The roof assembly must prevent uncontrolled air movement through the roof assembly. It is critical to install roof termination and penetration details to include closed cell spray foam or other methods to prevent warm, moist air from meeting with the cold air at the interior of the cold storage facility.

These criteria must be met by any roofing system considered as a reroofing or recovering option. However, the standards that apply and the exact significance of each vary with the roofing system involved. Checking with individual testing bodies is required to assure which standards are applicable and the requirements for each.

These general specifications may be easier to meet in a situation where the roof is completely stripped to the deck and reroofed. The existence of underlying roof materials may compromise the performance of the new roofing materials applied in a recover situation.

In addition to a loss of performance, a recovered roof may not be insurable. If the plant's insurance carrier requires an Underwriters Laboratory (UL) or Factory Mutual (FM) rated roof (if FM Insured), the recovery may not qualify. FM and UL are based on specific roof assemblies. In order to qualify for the listings, the roof must contain only the materials specified. No listings exist for some recover assemblies. Code violations may result in certain areas from this inability of recovered roofs to be rated.

FM roof ratings may be affected by recovering. Recovering an FM Class II roof does not change its rating. However, using unapproved materials to recover a Class I roof may change its rating to Class II. The Factory Mutual Approval Guide should be consulted, for those insured by FM, for approved materials.

The site-specific information that plays a critical part in the selection process, whether the existing roof is replaced or recovered, must be obtained from many sources. Plant structural drawings, maintenance records, thorough knowledge of plant operations, and local climatic conditions provide the bulk of the information needed.

Building Structure – Reroofing. An analysis of the structural characteristics of the building to be reroofed is required. The roof deck must be able to support the weight of the new roof. The original plant structural framing plan contains the live and dead load information from which this determination is made.

Maximum allowable roof loading limits the weight per square foot of the roofing material considered. Any additional weight added to the deck decreases the amount of snow or ponding loads that the deck can support. Ballasted systems and four ply asphalt and gravel roofs are the heaviest roofing option. Adhered single ply systems are generally the lightest.

The amount of lateral, differential, roof-to-wall building movement and structure-borne vibration from equipment must be investigated to determine the amount of elasticity and resistance to flexural failure required of the proposed roof material. The service of an architectural firm is helpful in determining the effect of the parameters of roofing choices.

Existing roof slope determines the type of system that is applicable as a reroof choice. Very low slope and dead level roofs can benefit from a retrofit that increases drainage. Lightweight concretes, lightweight insulationg concrete, and tapered insulation can be applied to the deck and sloped to provide drainage in a reroof situation. Tapered insulation systems of various materials are also available for providing an increase in roof slope. Insulation systems also have the advantage of increasing thermal performance of the new roof assembly.

Interior conditions of the building have an effect on roof choice. The existence of high internal humidity, hot deck conditions due to interior processes, and pressurized interiors require decisions regarding the use of vapor retarders installed on the deck level.

Chemical Considerations. Exhausted materials from interior processes are part of the exterior environment roof systems must handle. Direct contact with these materials is much more acute than with general atmospheric pollutants. Certain chemicals, oils, and fats degrade the performance of some single ply products and asphalt roofs. Hot air above 160°F (57°C) in direct contact on thermoplastics can accelerate failure. Steam contact and debris should be avoided on most roofing materials. Chemical compatibility should be confirmed prior to any roof assembly selection.

Climatic Considerations. Ultraviolet radiation (UV) is the most important factor in degradation of most roof systems. The addition of chemical additives to single-ply membranes offer resistance, as well as granulated cap sheets on asphaltic systems.

Another climatic factor that affects the choice of a roof system is the presence of ozone, a strong oxidizer. Ozone's effect on single ply systems varies.

Heat load from sunlight varies greatly depending on building location. In areas where sun exposure is high, the use of light colors for the roof surface is effective in reducing roof temperatures. On a 95°F day roof temperatures can reach 180°F on a black surface, a white surface may be 110°F making a significant difference on heat gain into the interior. However, in cold storage, it is beneficial to reduce the heat gain from the exterior as the added heat gain will increase the run times on interior cooling equipment.

Frequency and severity of freeze-thaw cycles have an effect on system choice. The roofing membrane must accommodate the change in roof deck dimension from quickly fluctuating temperatures. Most membranes have the ability to meet these changes but material characteristics vary in their ability to withstand the cyclic nature of these tensile forces. Design of the membrane/insulation structure also affects the roof system's ability to handle the effects of any relative motion that may occur between them. The addition of roof expansion joints is required at locations where the anticipated movement is more than expected of roof materials.

Construction Considerations. According to the Roofing Industry Educational Institute's (RIEI) outline on considerations for selection and use included in their "Reroofing Options" course notes, all reroofing systems are competitive. The tradeoff is lower cost insulations or reduced labor sometimes can compensate for more expensive membrane materials. Based on this assumption, other construction factors gain more importance in the selection process.

Application of all roof systems requires special training and equipment. This factor alone can have a significant impact on selection because the existence of a competent local contractor may limit the type of system available. Proper installation is the most important factor for a satisfactory roofing operation.

The type of system chosen may limit the weather window of opportunity during application. Adhesive bonded systems are best installed when surfaces are dry and at least 5°F above the dew point of the ambient air. Torch and hot air welded systems are capable of vaporizing slightly damp surfaces. Adhered systems should be 40° and above for installation, although lower temperatures may be possible with special adhesives. Wind can make installation of a loose laid and adhered system difficult. Consult roofing manufacturers guidelines.

Onsite conditions and owner requirements such as explosive atmospheres, fire hazards, and special fume contamination requirements, may restrict the use of open flames or torches required to install hot bituminous roofing systems.

The amount and type of roof penetrations have an effect on the labor intensity of the system chosen. The flashing requires skill; time attention and sheets in the field of the roof may have to be narrower.

Overburden Consideration – Solar Readiness.
Roofing System as a Substrate for Solar Photovoltaic (PV) Array Evaluation:

1. For existing roofing systems covered under an active roof system guarantee the following should be considered:
    a. Before installing a PV system over an existing roof, consider whether the remaining guaranteeable life of the roof is equivalent to the expected life of the PV system (typically >20 years). If it is expected that the PV installation will function longer than the remaining guarantee able life on the roofing system, re-covering or roof replacement before PV installation should be considered.
    b. If equipment mounts are installed on an existing roofing system covered under an active roof system guarantee, the new flashing are generally included per the terms of the existing guarantee, when installed by a manufacturer Certified

Contractor, provided all applications and solar notification/ installation procedures are followed.

On TPO and PVC single ply systems, rooftop equipment (ie; Solar Panels, Conduit and HVAC) units are attached by the use of fastened Equipment mounts. The mounts are fastened through the roofing assembly into the structural decking with 2-8 approved fasteners. The membrane cover is then hot air welded around the perimeter to the roof membrane. Fastener selection is dictated by the system assembly, deck type, and the project engineer. Refer to installation instructions and the specified roofing material manufacturer requirements before installing.

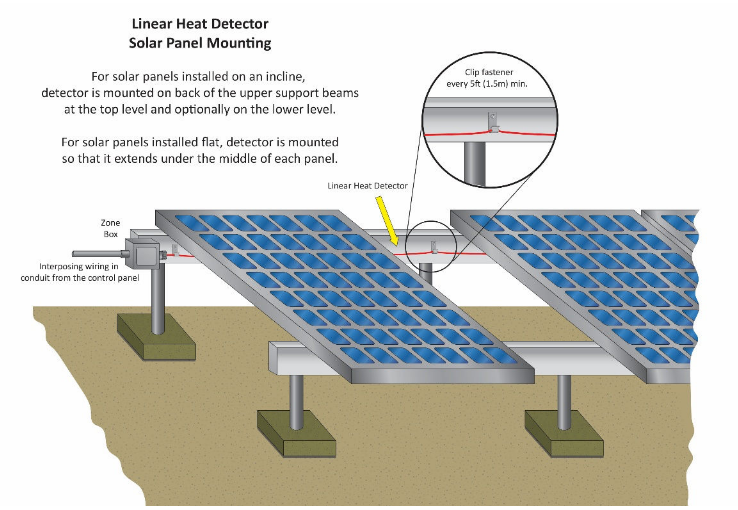
2. For new roofing systems the following should be considered:
    a. Consider designing the roofing system in which the guaranteeable life of the roofing system and the service life of the PV are the same. It is recommended that the design professional choose a roofing system with a longer guarantee term of 25, 30, or 35 years such as one with a 60- to 80-mil membrane PVC / TPO.
    b. Other factors to consider include additional roof system penetrations, increased rooftop traffic, increased surface temperatures, as a result of the PV installation, etc.
    c. General recommendations for all new roofs that will be receiving PV include:
    d. High compressive strength rigid-board insulation.
    e. Cover board located directly under the roof membrane.
    f. Use of thicker roof membranes In addition to these general recommendations, use of slip sheets in between the contact areas of the ballasted PV and the roof. The slip sheet can be loosely laid or adhered (heat-welded or cold-applied with adhesive) to the roof membrane. c. For ballasted PV systems, slope of the roof should not exceed 2:12.

Special Note for Mechanically Attached Systems. Mechanically attached and induction-weld attached roofing systems have the possibility of billowing due to high wind or building pressure differences. Billowing could cause ballasted PV systems to shift, and can also lead to localized abrasion of a roof membrane, as it rubs the edges and corners of a PV mounting system (at ballast trays, for example).

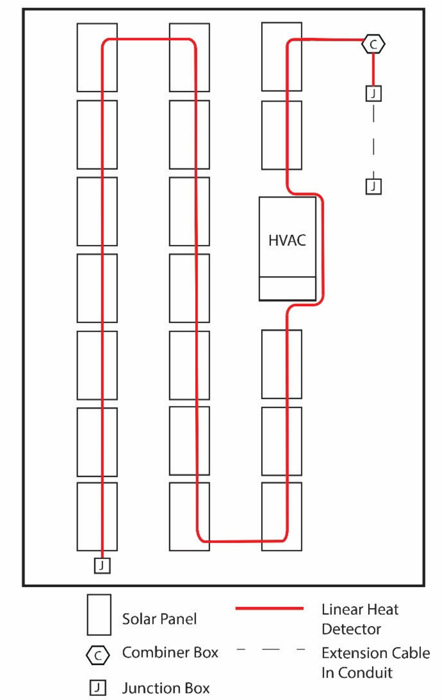
Solar – Fire Detection. Fire detection systems for rooftop solar installations shall be connected to a fire alarm control panel that will initiate an appropriate alarm when the detection system activates.

Installing solar panels on the roof of a building introduces new fire risks. Solar panel installations have been shown to increase the chances for ignition due to the failure of electrical components of the system, and they can increase the severity of a fire by enabling a fire on the roof to spread faster and over a larger area.

Linear Heat Detection. Linear heat detectors include metallic wire, fiber optic sensor cables, and other types. The metallic wire provides a fixed-temperature fire alarm signal along its entire length, and the fiber optic cable provides continuous temperature monitoring. See Chapter 12 – Fire Detection for additional information on linear heat detection. Below is a typical linear heat detection installation for rooftop solar protection.



Flame Detectors. A flame detector will sense the radiant-emission wavelengths associated with a rooftop solar panel system fire. An example is the triple IR (infrared) flame detector. There are no prescriptive installation guidelines for flame detectors. The designer will determine the number and placement of the flame detectors based on the layout and size of the rooftop solar installation and on the characteristics of the selected flame detector.



Aesthetic Consideration. Roofs are not usually visible to observers at street level, however, they may be visible from adjacent buildings. In the case of sloped roofs, however, a system that provides protection as well as eye appeal is an architectural requirement. Single ply roofs are often chosen originally for these applications because of their inherent aesthetic appeal. Replacement of roofs in these areas is often in kind to preserve the architectural integrity of the building.

Maintenance

Inspection and Maintenance Consideration. The choice of a replacement roofing system brings with it inspection pros and cons. Visual inspection, an integral part of roof management, can be complicated by system choice. Heavily ballasted and graveled asphalt roofs make visual inspection difficult. It is critical that seam inspections are made prior to these areas being covered by ballast or gravel. Adhered and mechanically attached membranes are much easier to inspect. Ballasted and graveled roof systems can be very difficult for leak detection.

The Single Ply Roofing Institute publishes an excellent booklet called "Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single Ply Roofing Systems". Some roofing manufacturers also provide similar booklets.

Extending the Life of Existing Membranes. Another aspect of roof maintenance or modernization a warehouse company should consider is the reconditioning of existing roof membranes. Roof coatings are available in a variety of formulations, such as acrylic or silicone, that can be installed on the existing roof after it has been cleaned. This can extend both the useful life and warranty of roof membrane at a fraction of the cost of replacing the roof prior to the roof reaching the end of its useful life.

Warranties. Roofing warranties require specific criteria be met before they can be issued. Warranties are available for all systems, although their length and scope vary. Most warranties require that the approved materials be applied by approved methods by an approved contractor. In most cases, passing carefully planned inspections by the manufacturer or an outside party representing the manufacturer during and after installation is a requirement.

Modernization

Roofing Basis-Modernization. The majority of existing flat or low slope roofing is synthetic membrane single-ply. The justification required to implement the reroofing decision is similar for all roof types. The specifics of individual roofing systems alter the importance of some factors in the decision-making process. Age of the roofing unit; general condition of the membrane, insulation and flashings; existence of obvious defects; amount of maintenance time spent fixing leaks; and amount of interior damage caused by these leaks may provide the building engineer with enough evidence that a reroofing operation is on the horizon.

Excessive interior damage, roof conditions that pose safety hazards to building personnel, and catastrophic losses (such as fire, wind blow off, localized failures from excessive ponding of snow loading) typically provided the immediate basis for a roof project.

Reroofing decisions should be based on economic justification. The decision to continue to repair or reroof can depend on the answer to the question: is the total cost of additional roof service life achieved by repair lower than the total annual cost of a new roof system?

An economic comparison based on equivalent annual cost (EAC) is required to fairly compare the two alternatives. For example, a repair program costing $2.00/square foot (psf) is estimated to extend roofing life three years. A tear-off replacement costing $ 5.00 psf is estimated to provide 18 years' service life. Comparing these alternatives to a life cycle (long-term) cost basis requires that each capital cost be reduced to EAC. Assuming an interest rate of 12% compounded annually, the annual cost for repairs is calculated as follows:

EAC = Cost psf debt service constant

= Project Cost psf x [i(1+i) n] / [(1+i) n- 1]

Where i = interest rate, %

n = service life, yr

Thus, the cost for repair is: EAC = $ 2.00 x [0.12 $(1+0.12)^3$] / [$(1+0.12)^3$–1]

= $ 0.83 psf

The cost of tear off replacement is: EAC = $ 5.00 x [0.12 (1+0.1218th power] / [(1+0.12)18th power –1]

= $ 0.69 psf

Based on the EAC, the reroofing cost is $ 0.14 psf less expensive that the repair alternative, and is the obvious choice if the monies for this expenditure are available. Although based on estimated values, the EAC method of comparing expenditure alternatives offers hard figures for action justification. Determining the breakeven point for economic partial replacement versus total tear off and replacement is a unique, complex and job-dependent question. A rule-of-thumb guideline states that a job requiring the removal of 25% or more of the roof is a candidate for total tear off.

However, this method alone should not be used to determine a roofs candidacy for replacement. Other factors, such as energy improvements by increasing the amount of insulation on the roof, can have a larger upfront cost, but can significantly decrease energy and cooling bills over the life of a cold storage facility.

Options for Modernization. Before the designer begins the task of specifying the new roof, an investigation into the present type, general failure mode of the roof, and the condition and type of deck is required.

There are three options available for providing a new roof: recovering, retrofitting, and reroofing. The method of replacement cost may rule out some options for certain roof types.

Recovering refers to placing new roofing material over the existing roof. Major factors to consider are:

- Compatibility of the existing roofing material with the retrofit material.
- Ability of the deck to safely carry the load of the extra roofing material.
- Condition of the insulation and deck below the existing roof.
- Ability of the roof to be recovered.

The International Building Code (IBC) limites the number of roofs on a building to two. This limits the times a roof can be recovered or will limit the number of roofing systems or materials that can be applied over an existing roof before both systems have to be removed.

Retrofit refers to placing a new system over the existing roof, but includes the additional steps of upgrading thermal insulation and in most cases, improving drainage through slight modification of the roof slope.

Reroofing refers to the operation in which the existing roof system is stripped to the deck and new materials (insulation, vapor barriers, and membrane) are installed.

The reroofing option is considerably more expensive than simple recovering. The cost to reroof is always greater than to recover. In many cases, the actual figure is twice that of a recovering operation. Removal of existing roofing materials is labor intensive and controlled by weather conditions. A bare roof deck (especially fabricated types such as wood, metal or precast concrete) affords little protection from water intrusion into the building interior in the event of an unforecasted rainstorm.

With recent bans on landfilling certain types of solid wastes, the disposal cost of removed materials is a factor in the overall expense of a reroofing operation. Worker and environmental safety is also an issue and cost-escalator in the removal of older roofing systems that may contain asbestos. Dirt and dust generated by reroofing can be a problem.

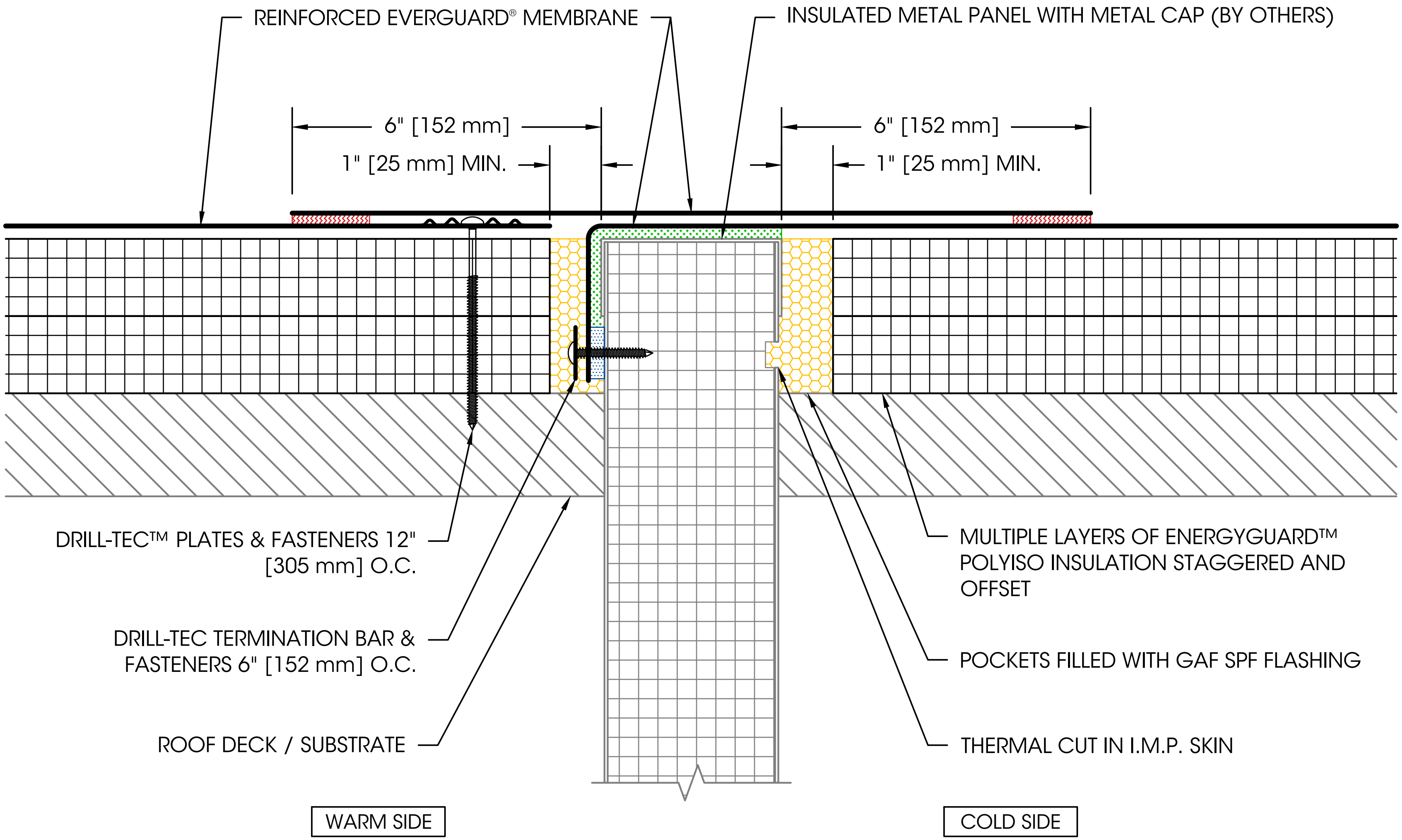
Despite the risks and costs associated with removal of the roof, there are advantages that make this operation attractive:

- Thorough roof inspection of the entire roof deck can be conducted only in a reroof situation
- Deck repairs, when necessary, can easily be accomplished.
- Integrity of the new roof is not compromised by substandard conditions remaining from the old roof.
- Additional upgrades, such as additional insulation, can be included for building energy savings. The color of the roof may also be upgraded to white or a highly reflective color that will limit heat gain into the building interior.

For example, the effect of trapped moisture in non-removed materials may inhibit thermal performance of the new roof and lead to long-term degradation of both new roofing and existing deck materials. Resistance to wind lift may also be affected. Areas of degraded attachment of the original roof system caused by moisture degradation of membrane bonding planes or fastener corrosion may compromise the wind lift resistance of the new roof.

Cold Storage Roof Vapor Details

As an additional resource to the Guide to Effective Warehouse Design, Maintenance, and Modernization, CEBA Committee roofing experts developed sample roof edge details that address a number of scenarios. These construction details are meant as a guide only. Each project is different. Be sure to consult with a specialist during your design process. It should be noted, however, that termination and penetration details should be air tight. The exact methods for achieving air tightness will vary by construction method and building type, but air tightness is often achieved by installing closed cell spray foam. Closed cell spray foam should be installed in metal deck flutes at roof deck to wall intersections and around penetrations, a minimum of 12” measured out from the wall/ penetration. Additionally, rigid insulation should be held back a minimum of 1” from the wall/ penetration and closed cell spray foam should be installed to fill the gap from the roof deck to the top of the insulation. Additional considerations for air sealaing roof terminations should be met based on the construction type for each project.



NOTES:

1. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE.

Cold to Warm Transition - IMP Above Deck

Legend:

Heat Weld

Sealant

Adhesive

Foam

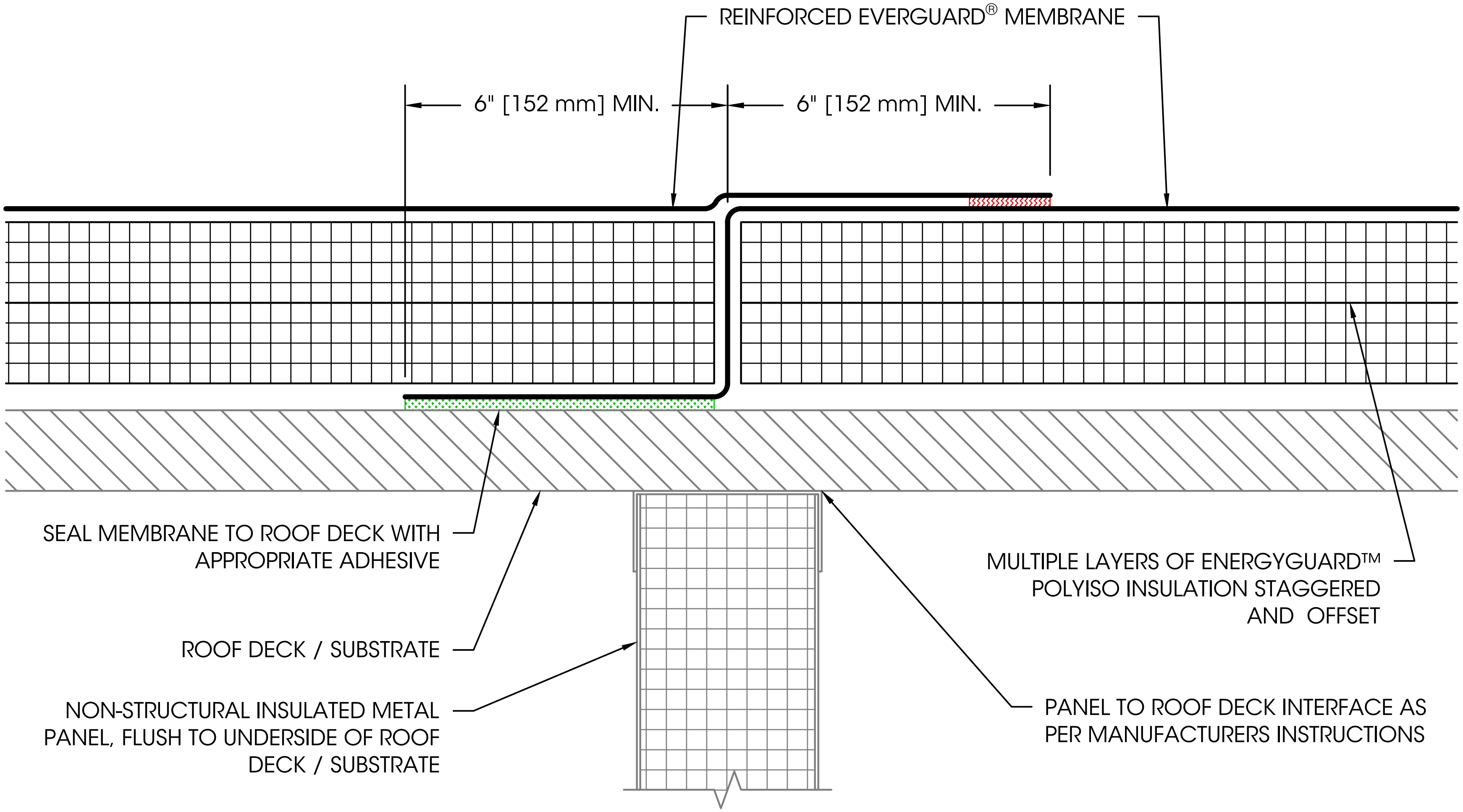
Product: EverGuard TPO

Installation: Cold Storage Systems

Maximum Warranty: —

Date: 2/13/2025

Scale: Not To Scale



NOTES:

1. FOR STEEL ROOF DECKS: FILL TOPSIDE OF STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE, BOTH SIDES OF WALL.
2. AIR SEAL WALL-TO-UNDERSIDE OF ROOF DECK INTERFACE AS PER ARCHITECTURAL DRAWINGS.

Cold to Warm Transition - IMP Below Deck

Legend:
Heat Weld
Adhesive

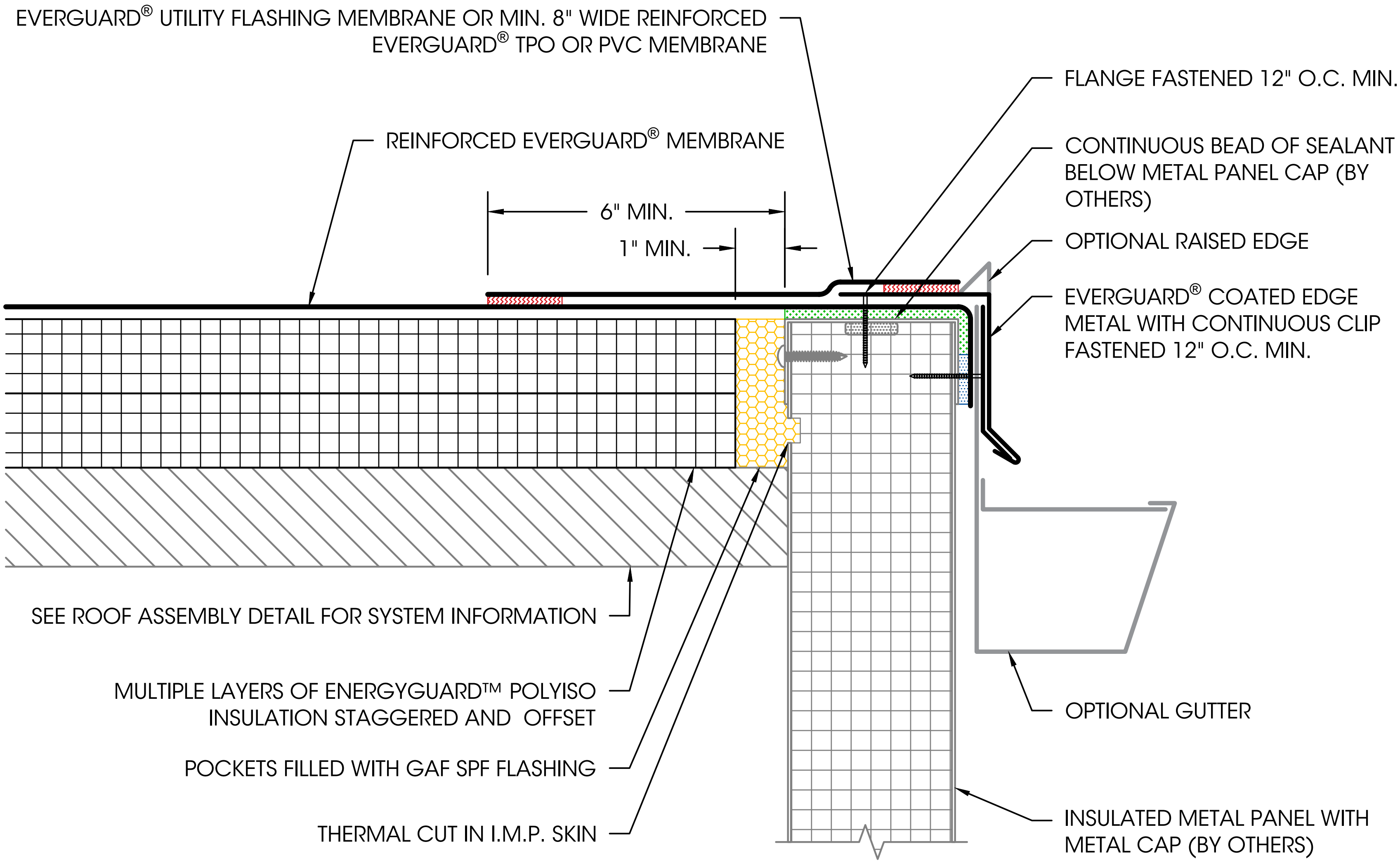
Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/13/2025

Scale:
Not To Scale



NOTES:

1. EDGE METAL SHOULD DESIGNED FOR WIND RESISTANCE IN ACCORDANCE WITH THE APPLICABLE EDITION OF ASCE 7. ADDITIONAL REQUIREMENTS APPLY FOR GUARANTEE COVERAGE OF ATTACHMENT TO INSULATED METAL WALL PANELS. CONTACT coldstorage.assistance@gaf.com FOR DETAILS.
2. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" FROM FACE OF WALL ON EACH SIDE.

Coated Drip Edge with Flashing Strip at IMP

075423

Legend:
Heat Weld
Sealant
Adhesive
Foam

Product:
EverGuard TPO

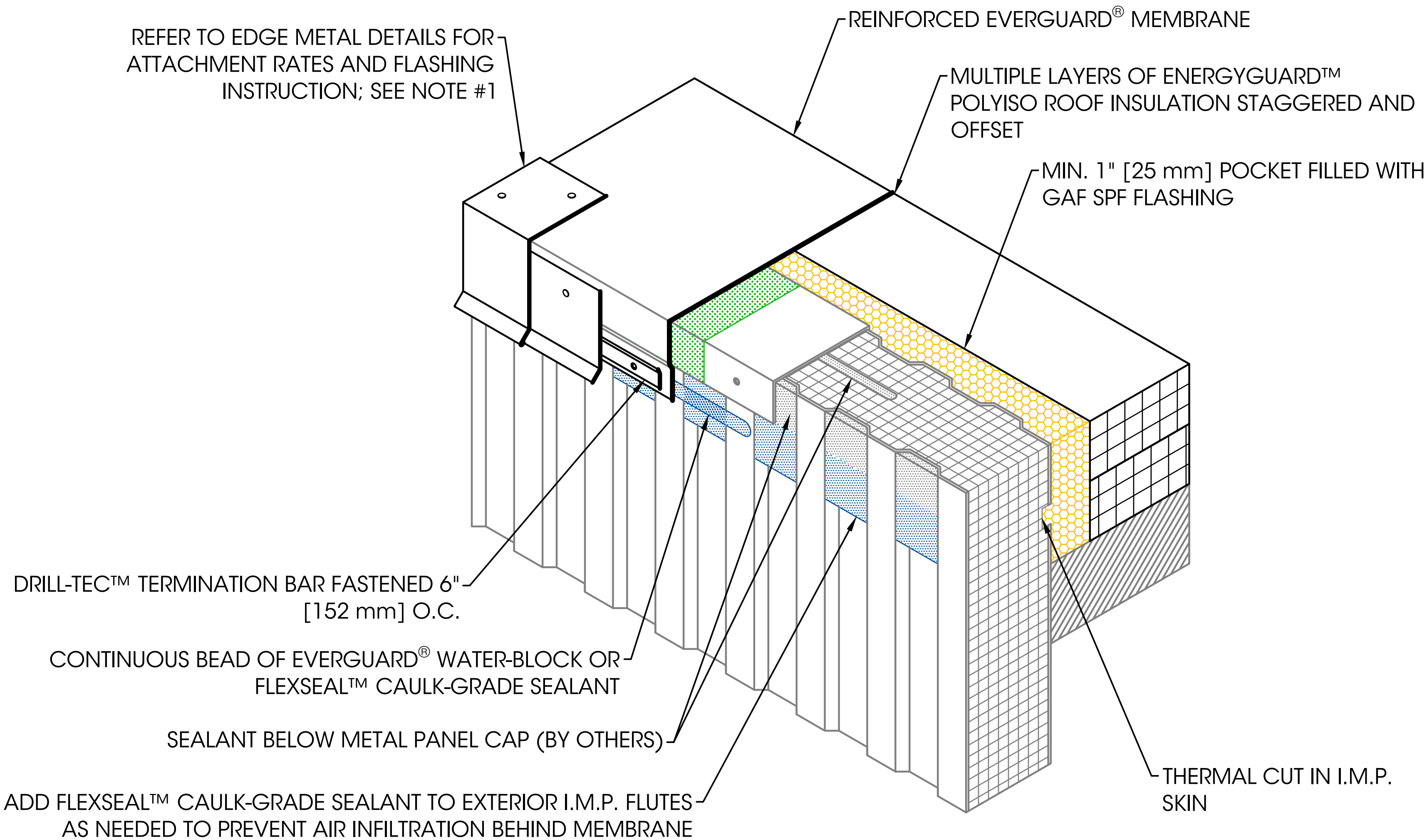
Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/14/2025

Scale:
Not To Scale

.



NOTES:

1. EDGE METAL SHOULD DESIGNED FOR WIND RESISTANCE IN ACCORDANCE WITH THE APPLICABLE EDITION OF ASCE 7. ADDITIONAL REQUIREMENTS APPLY FOR GUARANTEE COVERAGE OF ATTACHMENT TO INSULATED METAL WALL PANELS. CONTACT coldstorage.assistance@gaf.com FOR DETAILS.
2. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL.

Preparation of IMP Walls for Edge Termination

Legend:
Sealant
Adhesive
Foam

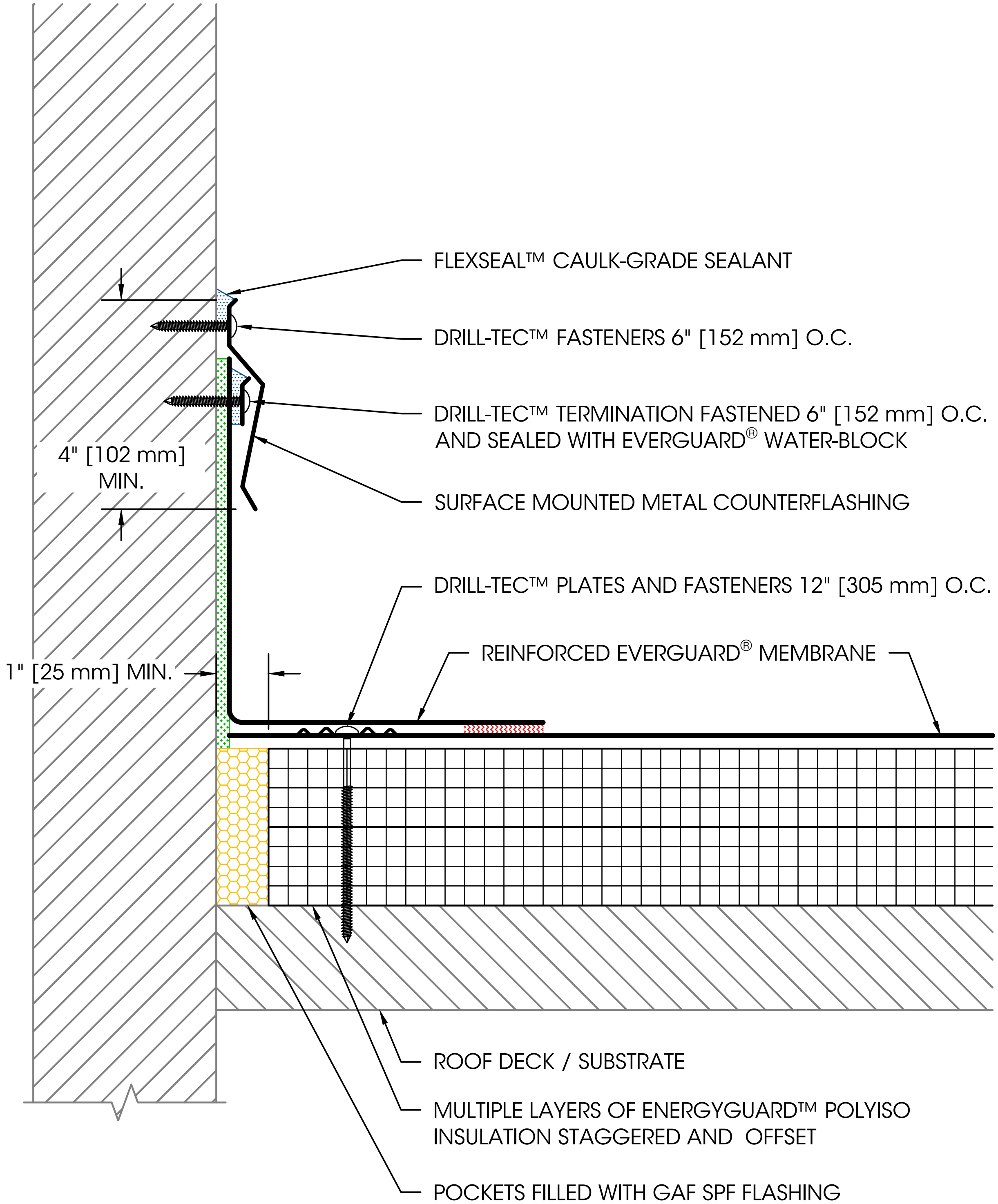
Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
9/12/2025

Scale:
Not To Scale



Legend:
Heat Weld

Sealant

Adhesive

Foam

NOTES:

1. EXPOSED WALLS AND CURBS MUST BE WATERPROOFED AND MAINTAINED ABOVE THE BASE FLASHING IN ORDER FOR ANY SURFACE MOUNTED TERMINATION TO BE EFFECTIVE.
2. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE.

Product: EverGuard TPO

Installation: Cold Storage Systems

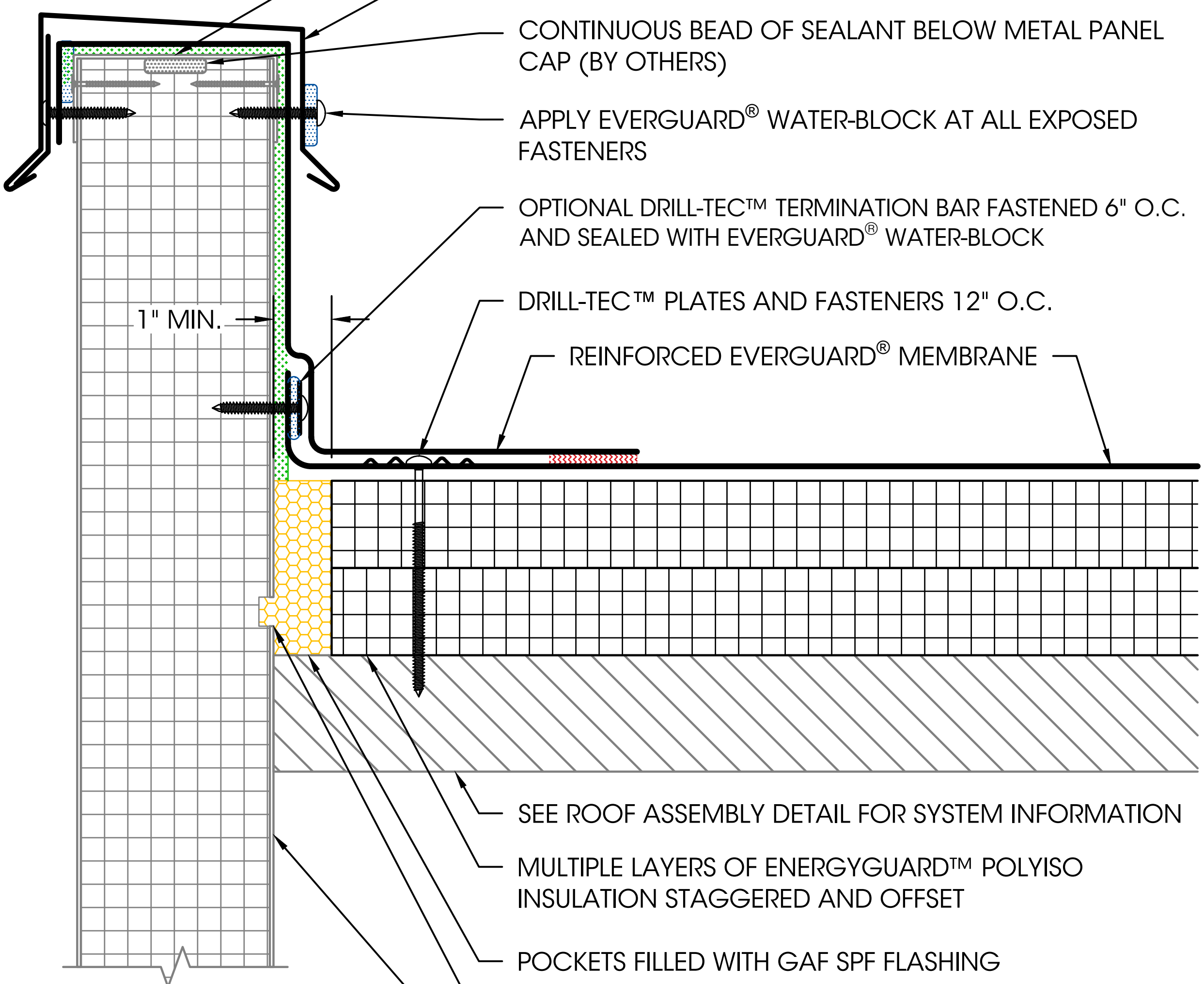
Maximum Warranty:

Date: 2/14/2025

Scale: Not To Scale

Wall Flashing with Surface Mounted Counterflashing

075423



Legend:
Heat Weld

Sealant

Adhesive

Foam

Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:

Date:
2/14/2025

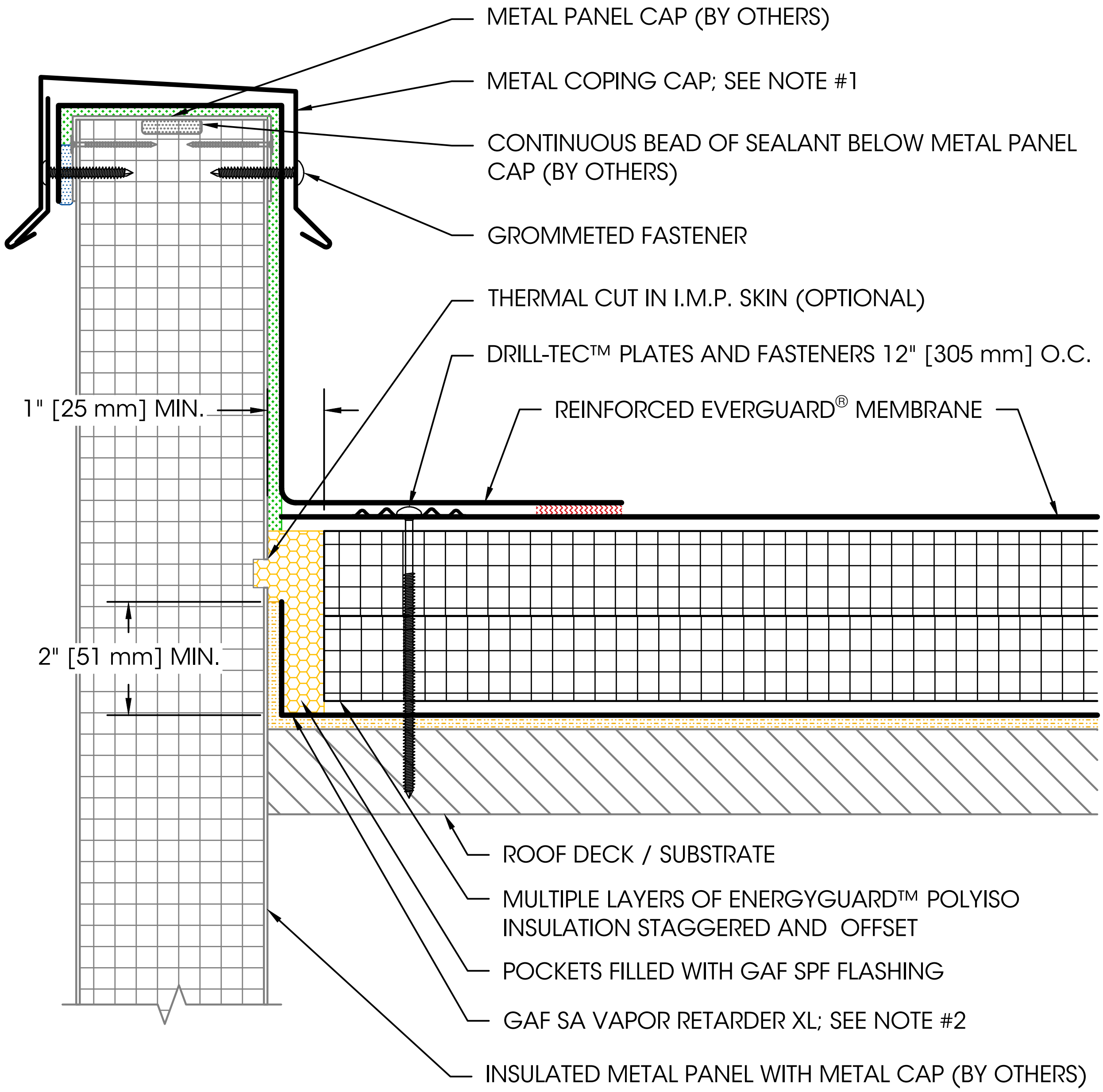
Scale:
Not To Scale

—

NOTES:

1. EDGE METAL SHOULD DESIGNED FOR WIND RESISTANCE IN ACCORDANCE WITH THE APPLICABLE EDITION OF ASCE 7. ADDITIONAL REQUIREMENTS APPLY FOR GUARANTEE COVERAGE OF ATTACHMENT TO INSULATED METAL WALL PANELS. CONTACT coldstorage.assistance@gaf.com FOR DETAILS.
2. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" FROM FACE OF WALL ON EACH SIDE.

IMP Wall Flashing with Coping Cap



NOTES:

1. EDGE METAL SHOULD DESIGNED FOR WIND RESISTANCE IN ACCORDANCE WITH THE APPLICABLE EDITION OF ASCE 7. ADDITIONAL REQUIREMENTS APPLY FOR GUARANTEE COVERAGE OF ATTACHMENT TO INSULATED METAL WALL PANELS. CONTACT coldstorage.assistance@gaf.com FOR DETAILS.
2. A VAPOR RETARDER MAY BE USED AT THE DECK LEVEL IF THERE ARE CONCERNS WITH POTENTIAL MOISTURE ISSUES DUE TO CERTAIN CONSTRUCTION PROCESSES OR OTHER SOURCES DURING BUILDING USE.
3. REFER TO GAF SA PRIMER INSTALLATION INSTRUCTIONS FOR GENERAL GUIDELINES.
4. MAINTAIN SEPARATION BETWEEN VAPOR RETARDER AND MEMBRANE / ADHESIVE TO AVOID POTENTIAL INCOMPATIBILITY ISSUES.
5. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE.

IMP Wall with Coping Cap and Vapor Retarder

Legend:

Heat Weld

Sealant

Adhesive

Foam

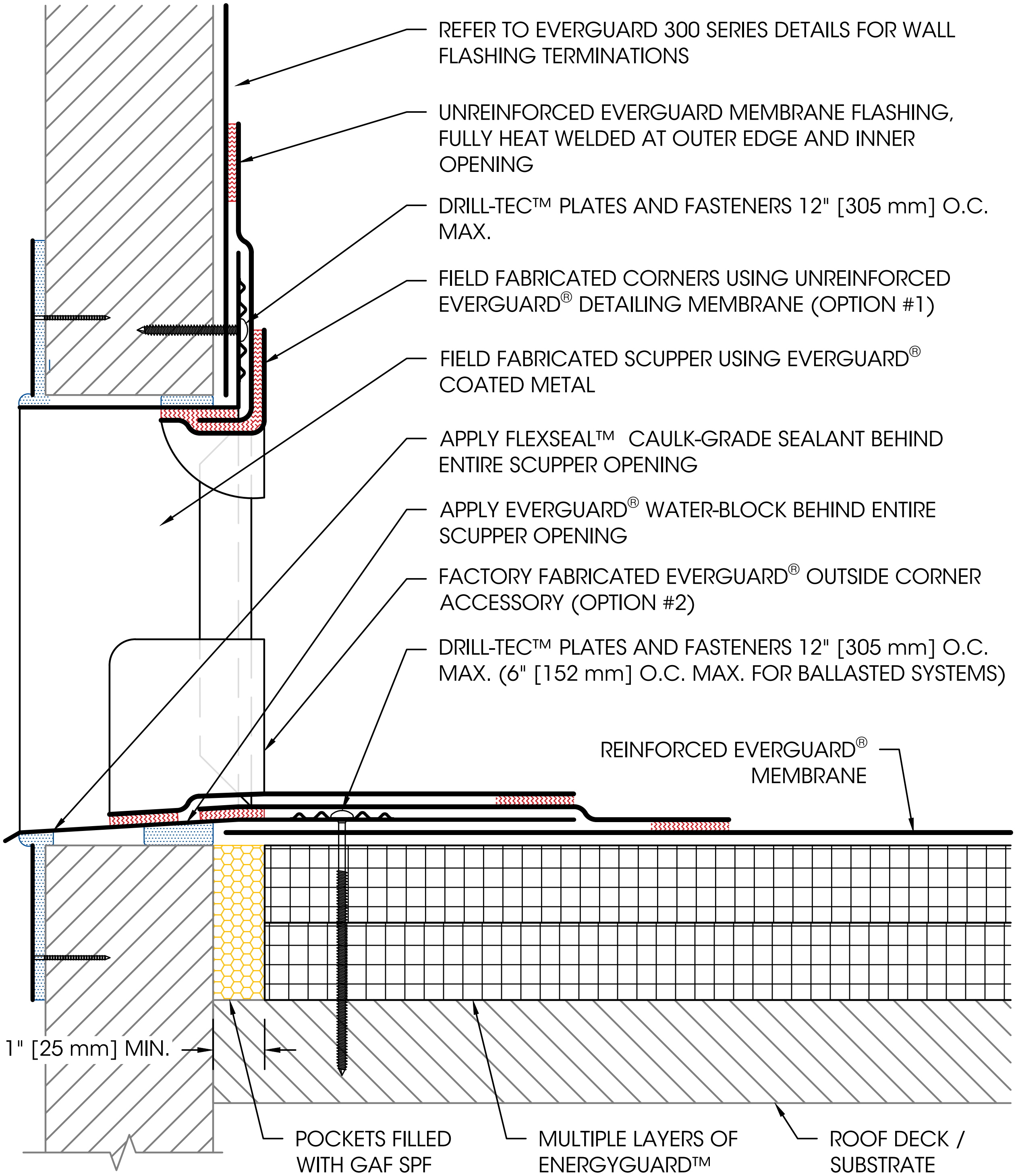
Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/14/2025

Scale:
Not To Scale



Legend:
Heat Weld
Sealant
Foam

NOTES:

1. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE.
2. ALL (4) ROOF-SIDE CORNERS OF SCUPPER MUST BE COMPLETELY SEALED USING EVERGUARD® UNREINFORCED DETAILING MEMBRANE OR EVERGUARD® PREFORMED CORNER ACCESSORIES.
3. SCUPPER MUST BE SEALED OFF ON EXTERIOR FACE OF BUILDING.

Field Fabricated Coated Metal Scupper Flashing

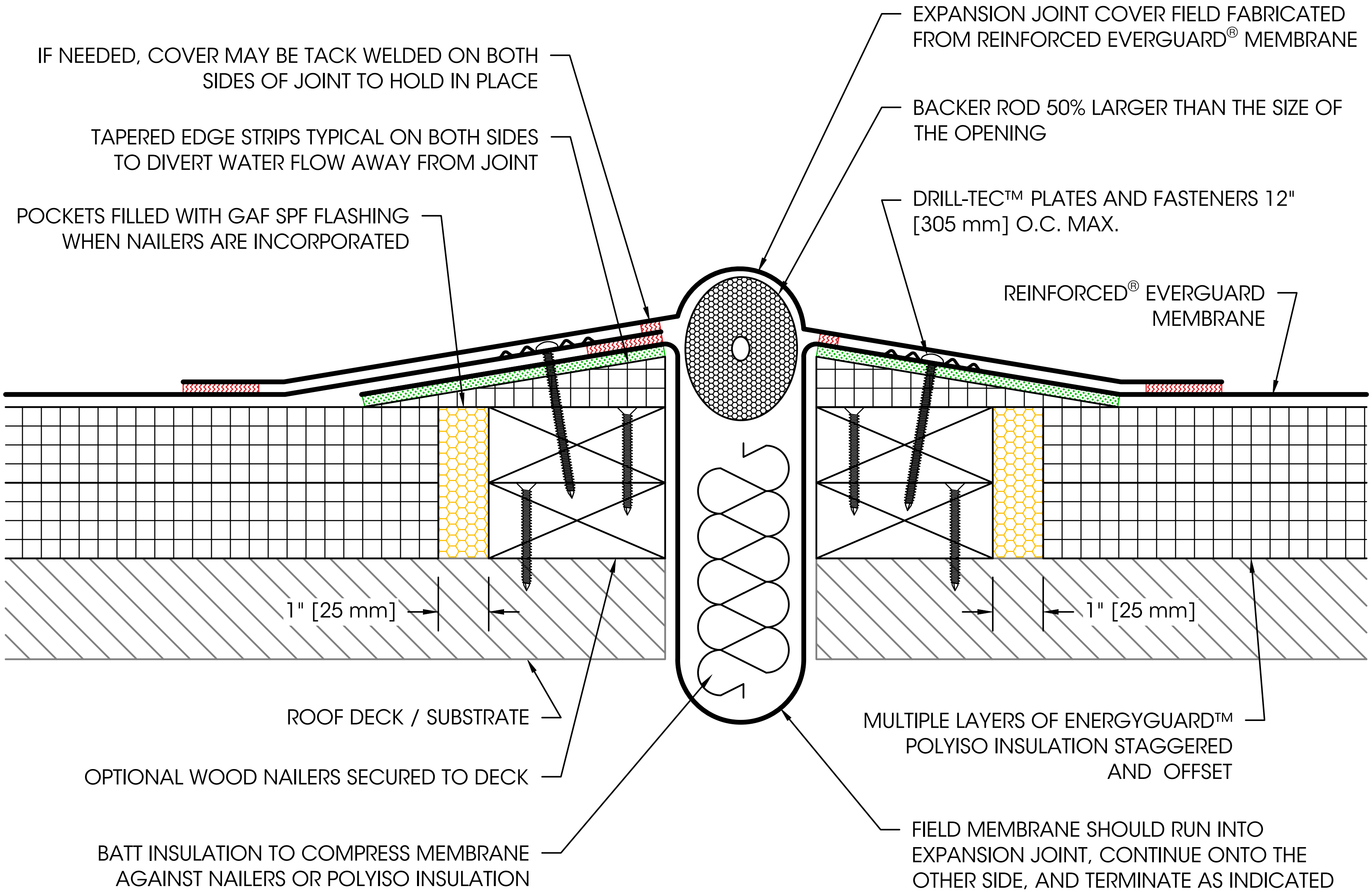
Product: EverGuard TPO

Installation: Cold Storage Systems

Maximum Warranty: —

Date: 2/14/2025

Scale: Not To Scale



NOTES:

1. FOR STEEL ROOF DECKS: FILL STEEL DECK FLUTES WITH CLOSED CELL SPRAY FOAM INSULATION PRIOR TO THE INSTALLATION OF ABOVE DECK INSULATION A MINIMUM OF 12" [305 mm] FROM FACE OF WALL ON EACH SIDE.

Field Fabricated Expansion Joint - Flat Type

Legend:
Heat Weld
Adhesive
Foam

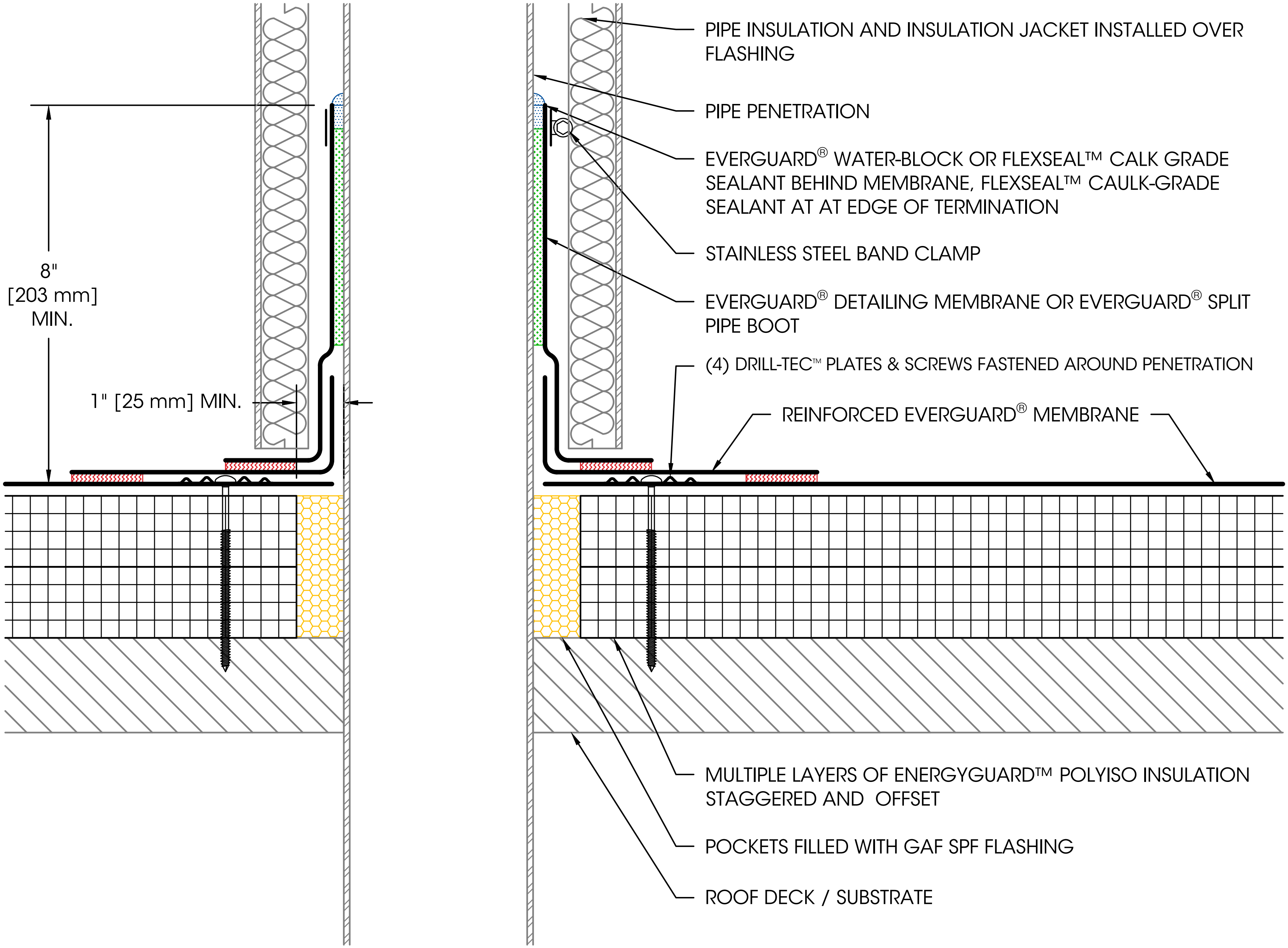
Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/14/2025

Scale:
Not To Scale



Insulated Pipe Penetration with Insulation Over Flashing

Legend:
Heat Weld
Sealant
Adhesive
Foam

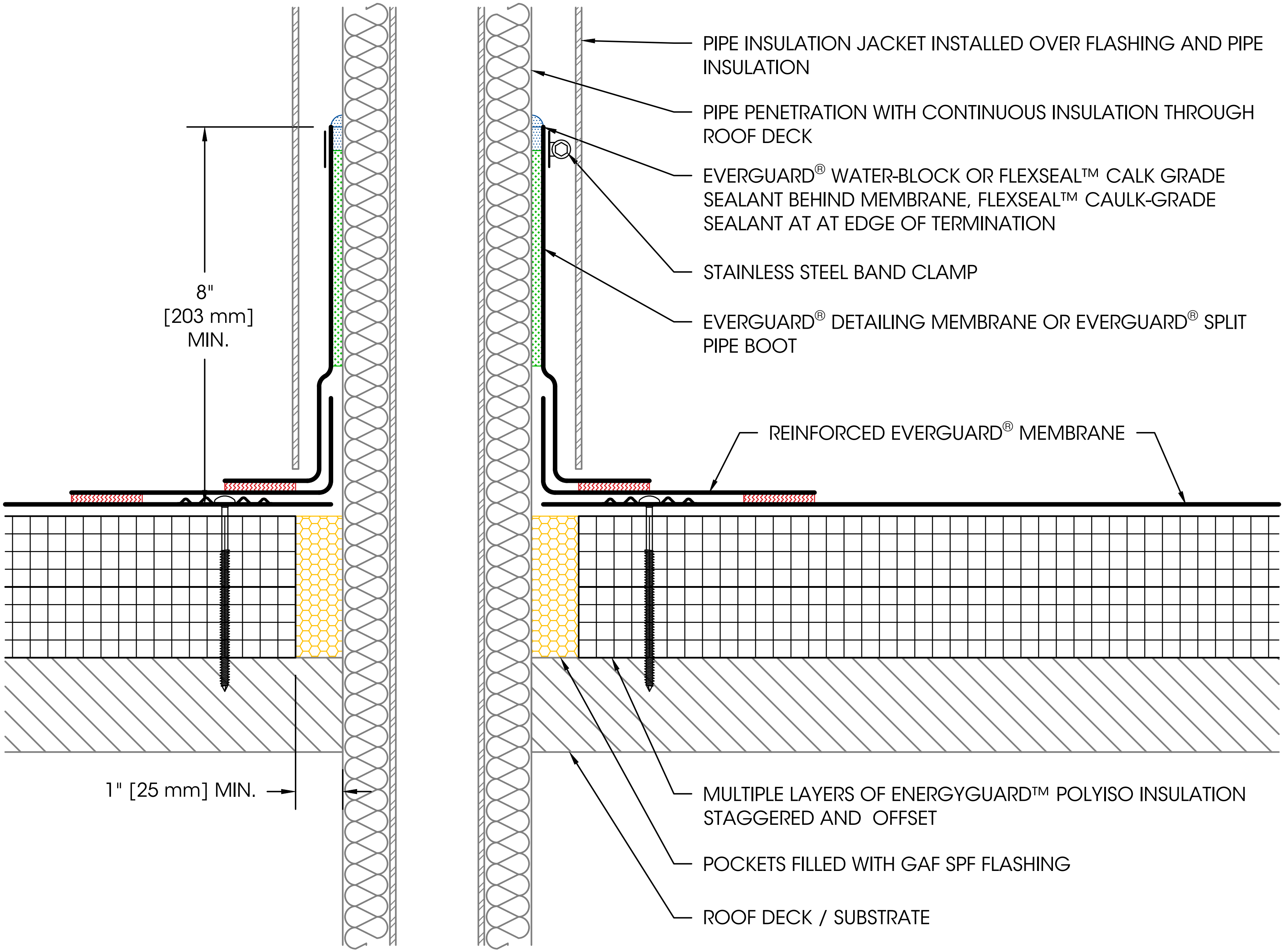
Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/14/2025

Scale:
Not To Scale



Insulated Pipe Penetration with Flashing Over Insulation

Legend:
Heat Weld
Sealant
Adhesive
Foam

Product:
EverGuard TPO

Installation:
Cold Storage Systems

Maximum Warranty:
—

Date:
2/14/2025

Scale:
Not To Scale