ROOF MEMBRANES

A majority of low-slope roof systems in North America use roof membranes to serve as the weatherproof coverings for roof assemblies. A roof membrane protects underlying roof assembly components, such as the insulation and roof deck, and the building from water entry. Most low-slope roof membranes have two principal components: weatherproofing layer or layers and reinforcement.

The weatherproofing component is the most important element within a roof membrane because it keeps water from entering a roof assembly. In built-up membranes, the weatherproofing component is the mop-applied bitumen or cold-applied bitumen-based adhesive. In polymer-modified bitumen membranes, the primary weatherproofing component is the polymer-modified bitumen. In single-ply roof membranes, the weatherproofing component is the thermoplastic or thermoset polymers. In fluid-applied systems, the waterproofing is the cured, fluid-applied membrane material.

The reinforcement adds strength, puncture resistance and dimensional stability to a membrane. In bituminous membranes, the reinforcement helps hold the weatherproofing bitumen in place and provides tensile strength to the membrane. In built-up membranes, the reinforcement may be a fiberglass ply sheet or polyester fabric embedded between the layers of weatherproofing bitumen or cold adhesive. In polymer-modified bitumen membranes, the reinforcement generally is fiberglass, polyester fabric or a composite of both that has been fabricated into the finished sheet in the manufacturing process. In single-ply roof membranes, fiberglass or polyester scrims, fabrics and mats are used for reinforcement. However, some types of single-ply membranes, such as unreinforced EPDM, do not use reinforcement.

This chapter describes four types of common roof membranes: built-up membranes, polymer-modified bitumen sheet membranes, single-ply membranes and liquid-applied membranes.

This chapter is further divided into sections. Section 5.1—Guidelines Applicable to All Membrane Types provides information that is applicable to all membrane types. Section 5.2—Built-up Roof Membranes provides information specific to cold-applied and hot-applied asphalt built-up membranes. Section 5.3—Polymer-modified Bitumen Roof Membranes provides information specific to cold-applied, hot-applied and self-adhering APP and SBS polymer-modified sheet membranes. Section 5.4—Single-ply Roof Membranes provides information specific to mechanically attached, adhered and self-adhering single-ply membranes. Section 5.5—Liquid-applied Roof Membranes provides information specific to liquid-applied membranes.

5.1—Guidelines Applicable to All Membrane Types

In addition to the guidelines in the following sections that are applicable to specific roof membrane types, the following guidelines apply to all roof membrane types.

Slope and Drainage: NRCA recommends membrane roof assemblies be designed to provide positive drainage. The criterion for judging proper slope for drainage is that there be no ponding water on the roof 48 hours after a rain during conditions conducive to drying. To satisfy this requirement, NRCA recommends designers make provisions in their roof assembly designs for positive slope. Slope generally is provided by:

- Sloping the structural framing or deck
- Designing a tapered insulation system
- Using an insulating fill that can be sloped to drain
- Proper location of roof drains, scuppers and gutters
- A combination of the above

Material Delivery and Storage: During storage and handling, all roof system materials should be protected from weather. Roof system materials that are susceptible to retaining moisture or may be damaged by moisture should be covered or stored in a dry location before application.

All materials delivered from manufacturers and suppliers should be carefully inspected at the time of delivery and examined during unloading. Manufacturers' product labels should be intact. Any damaged or unsuitable material should be rejected. Material that has been exposed to weather in transit or storage should be examined carefully for deterioration and damage.

When rolled materials are stored, the storage substrate should be swept to rid the surface of loose gravel, sharp objects and other debris that could damage the membrane material.

When roofing materials are stored on a roof deck, caution should be taken not to overload the roof deck or structural assembly.

Bitumen-based roll roofing materials should be stored on end to prevent crushing and be protected from moisture. Rolled single-ply membrane sheets may be stored as shipped, in original wrappings with rolls lying horizontally, or as required by the manufacturer.

Stored material should be raised up off the roof surface out of any standing water.

Lids should be secured on cans or buckets. Water-based adhesives and other water-based materials should be protected from freezing.

Moisture-sensitive materials should be covered with water-resistant coverings, some of which may be manufacturers' coverings that have been secured. Coverings that are "breathable," such as water-resistant tarpaulins, are preferred for covering moisture-sensitive materials.

Product manufacturers' safety guidelines for storage, handling, and using adhesives and solvents should be consulted and followed. Some materials are flammable and may contain hazardous materials.

Weather Conditions During Application: Membrane roof systems should be installed over clean, dry surfaces.

NRCA recommends that membrane roof systems not be installed if precipitation of any kind is occurring or is imminent. Roofing work can proceed when weather conditions are favorable for installation of the products in accordance with the manufacturer's recommendations. Cold-weather roofing precautions and guidelines as recommended by the membrane manufacturer should be observed when installing membrane roofing materials in temperatures below 40 F. Special attention should be given when adhesives are used during cold weather.

When membrane roofing materials are applied, entrapment of moisture should be prevented. Moisture in or on materials may cause membrane blistering. If precipitation occurs before completely installing the roof membrane, the membrane surface in the immediate work area and the substrate should be dried or allowed to dry before work resumes.

Construction Traffic: Construction site traffic from all trades should be limited to designated areas and walkways. Completed roof membranes are not suitable as work platforms or staging areas for other trades. If construction traffic is anticipated or inevitable, the use of temporary roofs can act as a sacrificial traffic surface, allowing for construction traffic and abuse until the primary weatherproofing membrane is installed.

Walkways: Repetitive rooftop traffic may damage the roof system, and such areas should receive additional protection. Permanent walkway paths may protect a finished membrane from rooftop traffic damage.

Roof-mounted Photovoltaic (PV) Applications: Membrane roof systems are sometimes used as substrates for roof-mounted PV installations.

Membrane roof systems acting as substrates for rooftop PV systems should incorporate design features and materials that enhance a membrane's resistance to mechanical damage, high surface temperature and ultraviolet (UV) radiation beyond the level of roof systems that do not function as substrates for roof-mounted PV systems.

NRCA recommends designers of membrane roof systems intended for use as substrates for roof-mounted PV systems specify the following enhancements:

- High-compressive-strength rigid board insulation
- Thermal barrier insulation located directly under the roof membrane
- For single-ply membrane roof systems, membranes of increased thickness
- Reflective roof surfaces or coatings that provide enhanced protection against the effects of UV radiation and high service temperatures

NRCA does not recommend the following practices for attachment of roof-mounted PV systems:

- Using ballast to provide uplift resistance for roof-mounted PV system components
- Installing adhered PV systems on the surface of mechanically attached roof membranes
- Combining a ballasted, loosely laid roof membrane system with a roof-mounted PV system

Guidelines for PV installations over low-slope membrane roof systems are provided in Appendix A2—Guidelines for Photovoltaic Installations Over Low-slope Membrane Roof Systems. Additional information about roof-mounted PV installations is provided in *NRCA Guidelines for Roof Systems with Rooftop Photovoltaic Components*.

5.4—Single-ply Roof Membranes

Single-ply roof membranes are a category of roof membranes that are field-applied using just one layer of membrane material, either homogeneous or composite, rather than multiple layers.

There are two principal types of materials used in the construction of single-ply roof membranes: thermoset polymer sheets and thermoplastic polymer sheets. The terms describe the materials' different behaviors on heating that arise from their different molecular arrangements and chemical properties.

For thermoset roof membranes, the materials' principal polymers are chemically cross-linked. This chemical cross-linking of thermoset membranes means that once the sheet material is cured or vulcanized, it cannot be softened to bond with itself and cannot be reshaped.

Thermoset materials used in construction of single-ply membranes, such as ethylene propylene diene terpolymer (EPDM), are manufactured as cured or vulcanized sheets, or partially cured sheets intended to fully cure on the roof. Unlike thermoplastic materials, once fully cured, thermoset polymers can only be bonded to like material with a liquid-applied adhesive (glue) or adhesive seam tape because new molecular linkages may not be formed.

Currently, ethylene propylene diene terpolymer (or ethylene propylene diene M-class rubber) (EPDM) sheets are the only thermoset materials commonly used in construction of single-ply roof membranes in the North American market.

Other thermoset single-ply roof membrane materials that have been used historically include chlorosulfonated polyethylene (CSPE) and polyisobutylene (PIB). Refer to *The NRCA Roofing Manual: Membrane Roof Systems—2011* for additional information about CSPE and PIB single-ply roof membrane materials.

With thermoplastic single-ply membranes, the materials' chemical and physical characteristics allow them to repeatedly soften when heated and harden when cooled. Typically, there is no chemical cross-linking in the molecular composition of a thermoplastic membrane's compound. Because of the chemical nature of thermoplastic materials, thermoplastic sheets typically are seamed by heat-welding with hot air.

There are four common subcategories of thermoplastic membranes:

- Polyvinyl chloride (PVC)
- PVC alloys, including copolymer alloy (CPA), ethylene interpolymer (EIP) and nitrile alloy (NBP)
- Ketone ethylene ester (KEE)

Single-ply Membrane Components: The principal components used in constructing single-ply membranes are:

- Single-ply sheet material
- Sheet flashings
- Accessories

Descriptions of each of these components are provided in the following subsections that are divided by specific membrane type.

Polyvinyl Chloride (PVC): PVC polymers originally were produced in Germany during the 1950s. PVC polymers are versatile, and the materials produced with these polymers have wide ranges of use in residential, industrial and commercial applications. PVC is produced by the polymerization of vinyl chloride monomer, a gaseous substance resulting from the reaction of ethylene with oxygen and hydrochloric acid.

The basic chemical resin is a relatively hard material that requires the addition of plasticizers to make it supple and pliable for use as a flexible membrane roofing material. Chemical stabilizers and some proprietary ingredients are added to PVC membrane materials by manufacturers. As with other thermoplastic materials, accurate compounding of PVC is necessary so the PVC roof membranes have desired physical properties.

PVC membranes are resistant to bacterial growth, many industrial chemical atmospheres and plant-root penetration. Properly formulated, PVC membranes are fire-resistant and have hot-air welding seaming characteristics. PVC membranes are chemically incompatible with bituminous materials and, as such, should be separated from asphalt products.

Separator sheets, or felt-backed or specially formulated membranes, are required when incompatible products, including polystyrene insulations, are present in PVC roof systems.

PVC membranes used in roofing are typically white. However, PVC membranes can be formulated in a range of colors, including custom colors by special order.

PVC membranes are produced in a range of thicknesses, including 36 mils, 45 mils, 60 mils, 72 mils and 90 mils.

NRCA recommends designers specify PVC membranes with a minimum thickness of 45 mils for use in conventional single-ply roof systems.

PVC membranes are reinforced with fiberglass or polyester scrim, mat or fabric. Some PVC membranes are manufactured with nonwoven polyester fabric backing adhered to the underside of the sheet. Fabric-backed PVC membranes may facilitate adhesion to a substrate and/or serve as a separator from the substrate.

The U.S. product standard applicable to PVC membrane is ASTM D4434, "Standard Specification for Poly (Vinyl Chloride) Sheet Roofing." ASTM D4434 also provides classification for three material types. ASTM D4434, Type II designates reinforced PVC sheets in which fibers are incorporated into a production process, for example as a carrier, without appreciably affecting such physical property characteristics of the finished products as tensile strength or ultimate elongation but possibly providing other desirable characteristics, such as dimensional stability. ASTM D4434, Type III designates PVC sheets that are internally reinforced with fabric and may also have a fabric backing. ASTM D4434, Type IV designates PVC sheet that is internally reinforced with fabric and may also have a fabric backing with a minimum thickness of 0.036 inch. ASTM D4434 does not currently include Type I material classification.

NRCA recommends designers specify PVC membranes on the basis of their ASTM International designation, including the type classification desired and thickness.

PVC membrane laps are seamed by hot-air welding according to a specific manufacturer's recommendations.

PVC membrane systems may be specified as ballasted, adhered or mechanically attached to an approved substrate. Designers and contractors should consult the PVC membrane manufacturer regarding membrane securement configuration options.

NRCA recommends PVC membrane systems include separator sheets between the membrane and the substrate.

Membrane flashings typically used with PVC membrane systems consist of the same sheet material as the field sheet. Nonreinforced membrane flashing material also is available and is typically used for field-fabricated flashing configurations. NRCA recommends designers specify flashing membrane material according to the PVC membrane manufacturer's recommendations.

PVC membrane manufacturers make available a number of accessory products for use and compatible with their PVC sheet. Accessories include PVC-coated metal, preformed flashings, adhesives, water-block sealant and pourable sealant. Designers should consult PVC membrane manufacturers for additional information regarding their accessory products and specific requirements for their use.

PVC Alloys: PVC alloys compound various polymers with PVC. Membranes produced with PVC alloys are somewhat akin to PVC membranes in that they, too, are thermoplastic in nature; however, each has its own unique properties. PVC alloy materials manufactured for use as roof membranes typically are produced as reinforced sheets.

The following types of membranes may be classified as PVC alloys:

- Copolymer Alloy (CPA)
- Ethylene Interpolymer (EIP)
- Nitrile Alloys (NBP)

CPA membranes are produced by alloying polymeric plasticizers, stabilizers, biocides and antioxidants with PVC compounds. CPA membranes typically are produced in thicknesses ranging from 30 mils to 60 mils.

Some CPA membranes are resistant to some chemicals and may be resistant to certain oils and greases. CPA membrane laps are seamed by heat-welding according to a specific manufacturer's recommendations.

EIP membranes are compounded with PVC and KEE polymers, certain pigments and antioxidants, and other proprietary modifiers specific to a manufacturer. EIP membranes generally are reinforced with polyester scrim or fabric. These membranes typically are 32 mils to 60 mils thick.

Laps typically are seamed by hot-air welding according to a manufacturer's recommendations.

NBP membranes are compounded with PVC; butadiene-acrylonitrile copolymers; plasticizers; and other additives, such as fungicides, algaecides, fire retardants and pigments. Nitrile copolymer, when blended with thermoplastic resins, is intended to impart flexibility and weathering characteristics. NBP membranes may be 30 mils to 40 mils thick, but they typically are produced as 40-mil sheets. These membranes are spread-coated using polyester scrim as reinforcement. NBP membrane laps typically are seamed by hot-air welding.

PVC alloy membrane systems may be used in the following configurations as recommended by the membrane manufacturer: ballasted, adhered or mechanically fastened to an approved substrate. Designers and contractors should consult the PVC alloy membrane manufacturer regarding membrane securement configuration options.

NRCA recommends PVC alloy membrane systems include separator sheets between the membrane and the substrate.

Ketone Ethylene Ester (KEE): DuPont introduced Elvaloy® KEE (ketone ethylene ester) in 1973 as a solid-phase plasticizer for single-ply PVC sheet membranes. KEE—sometimes also referred to as ethylene interpolymer (EIP)—is a thermoplastic copolymer of ethylene containing carbon monoxide and either vinyl acetate or acrylate monomer, which provides softness and flexibility. Carbon monoxide groups provide polarity which promotes compounding with PVC. Elvaloy® KEE does not leach out of the membrane over time, which enables the KEE sheets to remain flexible and workable.

KEE sheets are reported to be resistant to certain chemicals, air-conditioning coolants, jet fuels and restaurant grease, as well as UV radiation, airborne bacteria, acid rain and industrial pollutants.

KEE membranes are compatible with asphalt. KEE membranes generally are white or light gray but can also be produced in custom colors.

KEE membranes are available in a range of thicknesses, including 36 mils, 45 mils, 50 mils, 60 mils and 90 mils.

KEE membranes are reinforced with fabric. Some KEE membranes are manufactured with a polyester fabric backer adhered to the underside of the sheet. Fabric-backed KEE membranes may facilitate adhesion to asubstrate and/or serve as a separator from the substrate.

The U.S. product standard applicable to KEE membranes used as single-ply roof membranes is ASTM D6754, "Standard Specification for Ketone Ethylene Ester Based Sheet Roofing." This material specification requires KEE polymer make up a minimum 50 percent by weight of the polymer content of the sheet.

Some manufacturers market PVC alloy single-ply sheets with KEE additive that makes up less than the minimum 50 percent polymer content that distinguishes D6754-compliant sheets. The PVC alloy sheets may be referred to as EIP sheets.

NRCA recommends designers specify KEE membranes on the basis of their ASTM International designation and thickness.

KEE membrane laps are seamed by hot-air welding according to the specific manufacturer's recommendations.

KEE membrane systems may be specified as ballasted, adhered or mechanically attached to an approved substrate. Designers and contractors should consult the KEE membrane manufacturer regarding membrane securement configuration options.

NRCA recommends KEE membrane systems include separator sheets between the membrane and the substrate.

KEE membrane is used as membrane flashing for penetrations, corners and other flashing details. NRCA recommends designers specify flashing membrane material according to the KEE membrane manufacturer's recommendations.

Application of Single-ply Membranes:

Single-ply membrane roof systems are typically designed and installed in three configuration types: loose-laid ballasted, mechanically attached and adhered. Descriptions of each of these configuration types are provided in the following subsections.

Wood nailers, curbs, drains and other penetrations need to be in place and the membrane substrate prepared according to the manufacturer's guidelines before single-ply membrane application. Single-ply sheets should be unrolled and allowed time to relax and lie flat before application. Manufacturers commonly indicate a minimum period of 30 minutes for this. Adjoining sheets should be lapped so the flow of water runoff will not be against the laps.

Single-ply membranes typically are applied in a staggered end lap configuration. Joints that occur at laps where three sheets intersect (T-joints) should be detailed in accordance with manufacturers' instructions. Figure 5-5 shows typical T-joint details for thermoset and thermoplastic single-ply membranes.

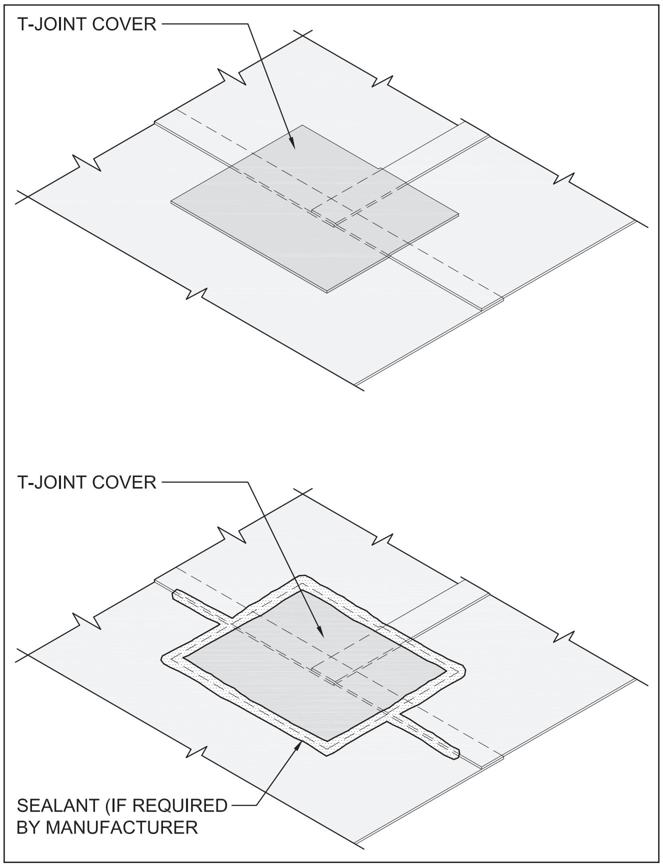

Figure 5-5: Examples of T-joints

Loose-laid, Ballasted: Loose-laid, ballasted systems seldom require field-membrane securement other than perimeter and base flashing attachment. As the system's name implies, the weight of the ballast and the force of gravity serve to secure the entire roof system. A design professional has the responsibility to determine the capability of a structure to carry the weight of a membrane roof system, including the ballast. As roof slope increases, consideration should be given to the type of ballast used. Ballast should be specified and installed in accordance with manufacturers' recommendations and local building code requirements for wind resistance. Additional information about wind loads and wind-resistant roof system design is provided in Appendix A1—Wind Uplift.

The most common application rate for aggregate or stone ballast is 1,000 pounds to 1,200 pounds per 100 square feet for 1½-inch to ¾-inch round, river-washed gravel designated as Size Number 4 in ASTM D7655, "Standard Classification for Size of Aggregate Used as Ballast for Membrane Roof Systems." Ballast, aggregate size, application rates and ballast configurations also may change with the type of aggregate and ballast used. Ballast rates may need to be increased at perimeters and corners per local code requirements. NRCA recommends designers consult specific membrane manufacturers' recommendations for their acceptable aggregate types and ballast application rates.

Fasteners should not be used to attach rigid board insulation or field sheets of a roof membrane to a substrate in a ballasted single-ply roof system. NRCA suggests manufacturers' guidelines and recommendations be consulted.

Perimeter attachment of loose-laid ballasted single-ply membranes is accomplished in a variety of ways. There are proprietary fastener systems that include penetrating and nonpenetrating methods. Each method is unique in its design and installation. Specific membrane manufacturers should be consulted for perimeter securement recommendations and requirements.

Mechanically Attached: Mechanically attached systems use a variety of fasteners and fastening patterns to secure a membrane to a substrate. Among these methods are metal disks placed within a seam and attached through a membrane to a roof deck; metal or plastic bars placed within a seam and attached through a membrane to a roof deck; metal and plastic disks and/or bars placed over a membrane and covered with membrane stripping; polymer-coated metal disks used with fasteners to attach rigid board insulation to roof decks and heat welded to the underside of thermoplastic membranes using electromagnetic induction welding equipment; and other specialized proprietary securement systems. Mechanically attached systems apply significant dynamic loads to the substrate, which need to be accounted for.

Dynamic loads acting on roof assemblies primarily are produced by changes in outside and inside building air pressures that result from wind having to change direction as it clears the building in its path. As wind is redirected over a roof, roof areas adjacent to edges that define the roof shape—eaves, ridges and hips—tend to experience higher dynamic loads than areas away from roof perimeters. Depending on wind direction, roof shape and the size and height of the building, certain roof perimeter areas are expected to be exposed to highest loads. Corners at eaves when subjected to quartering winds (approaching diagonally) experience comparatively highest dynamic loads. Additional information about wind loads and wind-resistant roof design is provided in Appendix A1—Wind Uplift.

At roof perimeter and corner regions, membrane perimeter sheets (half sheets) that are about half the width of the membrane sheets used in the field are generally used. The use of these half sheets result in the installed membrane at the roof perimeter and corner regions having increased fastener densities to account for the greater wind loads expected in these areas of the roof. An illustration of this membrane layout configuration is shown in Figure 5-6.

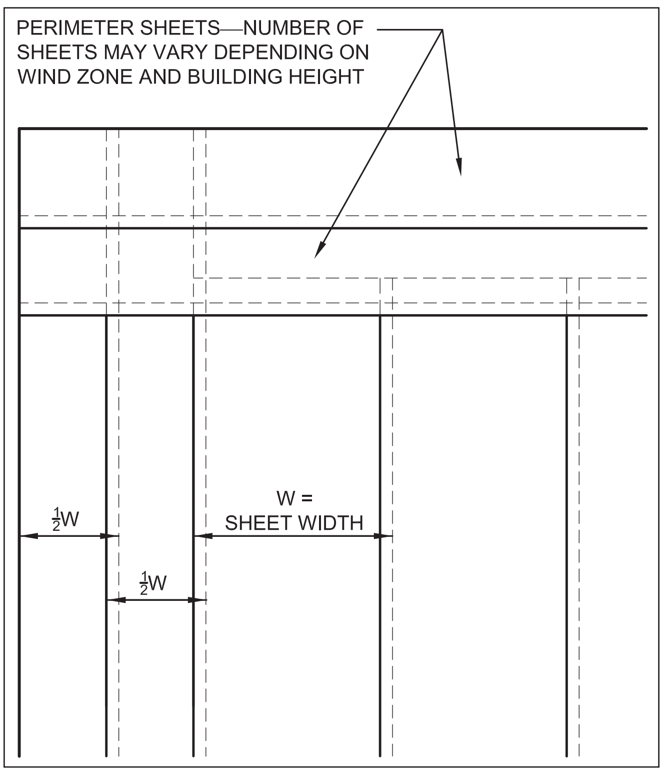

Figure 5-6: Half-sheet layout at perimeter and corner region of a mechanically attached single-ply membrane system

Perimeter mechanical attachment of single-ply membranes is accomplished in a variety of ways. There are proprietary fastener systems that include penetrating and nonpenetrating methods. Each method is unique in its design and installation. The specific membrane manufacturer should be consulted for its perimeter securement recommendations and requirements.

Fasteners for use with mechanically attached single-ply membrane system vary. Although some manufacturers will allow use of readily available screws and plates, other manufacturers require specialized, preassembled fastening components where specified. Specific deck types, warranty requirements and manufacturer's guidelines should be considered when selecting a proper fastener. The specific membrane manufacturer should be consulted for its perimeter securement recommendations and requirements.

Additional information regarding fasteners used in mechanically attached single-ply membrane roof systems is provided in Section 6.3—Membrane Fasteners.

Heat Induction Welding: An alternative method of mechanical attachment of single-ply roof membranes is heat welding a thermoplastic single-ply roof membrane to specially coated fastening plates using an electromagnetic heat-induction-welding tool. With this method, single-ply sheets are heat-welded at the seams, and, subsequently, the membrane is heat-welded to the fastener plates used to attach the roof insulation to the roof deck. See Figure 5-7. Because a thermoplastic weld is being created, TPO-coated plates must be used with a TPO membrane and PVC-coated plates must be used with a PVC or KEE membrane.

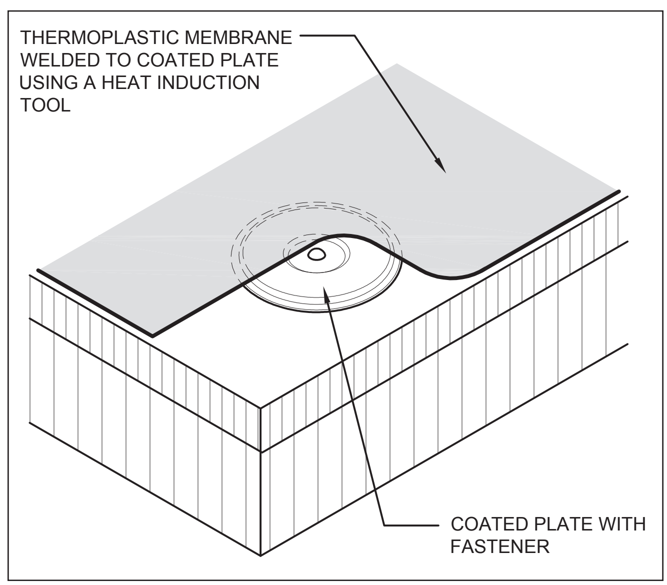

Figure 5-7: Heat-induction welding method of mechanical attachment of a single-ply membrane

The fastening plates are positioned on a grid that provides attachment for the insulation boards and membrane attachment locations independent of sheet seam locations. Fastening patterns are designated by number of fasteners per 4- by 8-foot insulation boards. Typically, a heat-induction-welded roof system's fastening patterns are categorized to address wind-uplift requirements, and, accordingly, the number of fasteners for insulation boards are designated for field, perimeter and corner zones. For instance, an FM 1-90-rated roof assembly may have six fasteners per 4- by 8-foot insulation board in the field zones, 10 fasteners in the perimeter zones and 16 fasteners in the corner zones. Manufacturers vary on fastening patterns required for wind-uplift requirements and, therefore, should be consulted for selecting appropriate fastening patterns. Examples are provided in Figure 5-8 (on page 233 and page 234).

Manufacturers vary on insulation board layout; however, NRCA recommends roof insulation be installed in multiple layers and the top layer should be laid out where board joints are in a continuous straight line in both directions, not in a staggered pattern. See Figure 5-9 (on page 235). If an insulation board extends into a perimeter or corner zone, it should be fastened at the higher rate.

Heat-induction-welded roof systems may be installed directly over insulation boards that will not melt by the welding process, such as fiber-reinforced gypsum board, glass-faced gypsum board, stone wool and polyisocyanurate. If a heat-induction-welded roof system is applied directly to polyisocyanurate insulation, a compressive strength of 20 or 25 pounds per square inch is recommended. Application directly over expanded polystyrene (EPS), extruded polystyrene (XPS) or foil-faced insulation board is not recommended. A cover board should be used, and the recommended minimum thickness of cover board insulation over EPS and XPS is ½ of an inch and 1½ inches over foil-faced insulation board.

Designers should keep in mind a heat-induction-welded roof system is not appropriate when energy concerns warrant eliminating thermal bridging or when a roof assembly is required to have an air barrier.

NRCA recommends designers specify PVC, KEE and TPO membranes with a minimum thickness of 60 mils for use in heat-induction-welded roof systems.

Designers should consult manufacturers of the single-ply membrane and mechanical fasteners for additional information.

Air Intrusion: A characteristic of mechanically attached roof membranes is that they are subject to vertical displacement between attachment points. The descriptions commonly used when this movement is observed in service or during system testing include flutter, bellowing and ballooning, and may give indication of dynamic, static or some combination of both types of behavior, depending on conditions. Where this type of displacement is present, it indicates air exchange occurs between the building interior and roof assembly.

Mechanically attached roof membrane flutter or billowing is driven by pressure changes above the roof membrane. Pressure drops (negative pressure because of wind, for instance) cause unrestrained membrane to rise; pressure increases cause it to fall down again. As the membrane rises, negative pressure develops on its underside. To equalize the low pressure within the roof assembly, indoor air enters from below but the roof membrane prevents it from escaping to the exterior environment. The mechanism of this behavior is termed "air intrusion."

Air intrusion has significance for roof assembly performance for two primary reasons. It contributes to mechanical fatigue of roof assembly components, including field membrane, flashings, mechanical attachment components and roof deck. It also provides a mechanism for depositing excess moisture inside a roof assembly.

When specifying mechanically attached single-ply membranes, designers should follow manufacturers' recommendations for mechanical securement of field membrane around penetrations. Because billowing of field membrane can concentrate stress at penetration locations, membrane flashings at penetrations can be subject to increased fatigue. Single-ply roof membrane manufacturers should be consulted for product-specific recommendations for membrane securement around penetrations.

Designers also may consider including an air retarder below the roof deck level as another option for addressing air intrusion effects in roof assemblies. Additional information about air retarders, as well as NRCA guidelines for roof assembly air retarders, is provided in Chapter 4—

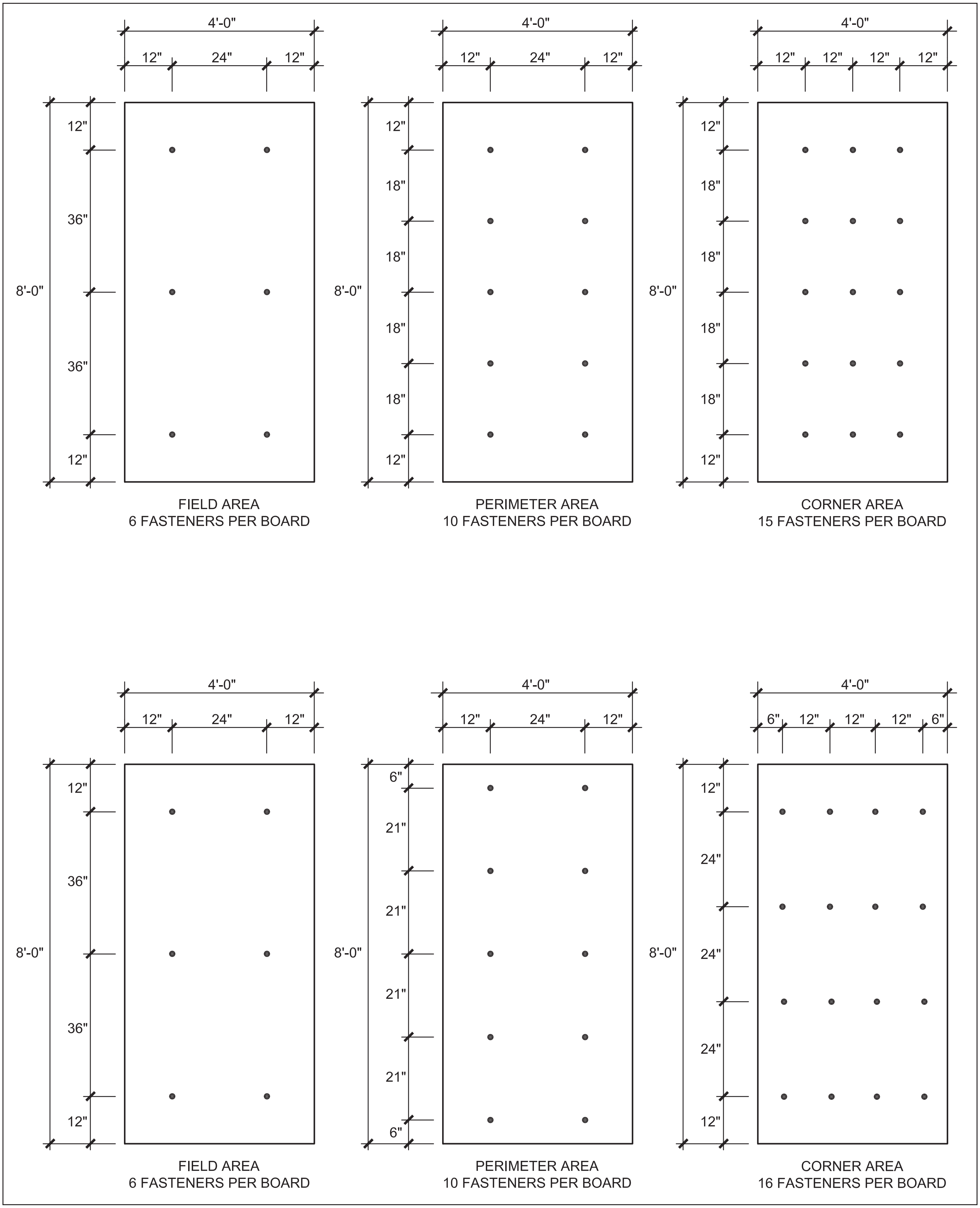

Figure 5-8: Fastener layout examples for heat-induction welding method of mechanically attached single-ply membrane roof systems

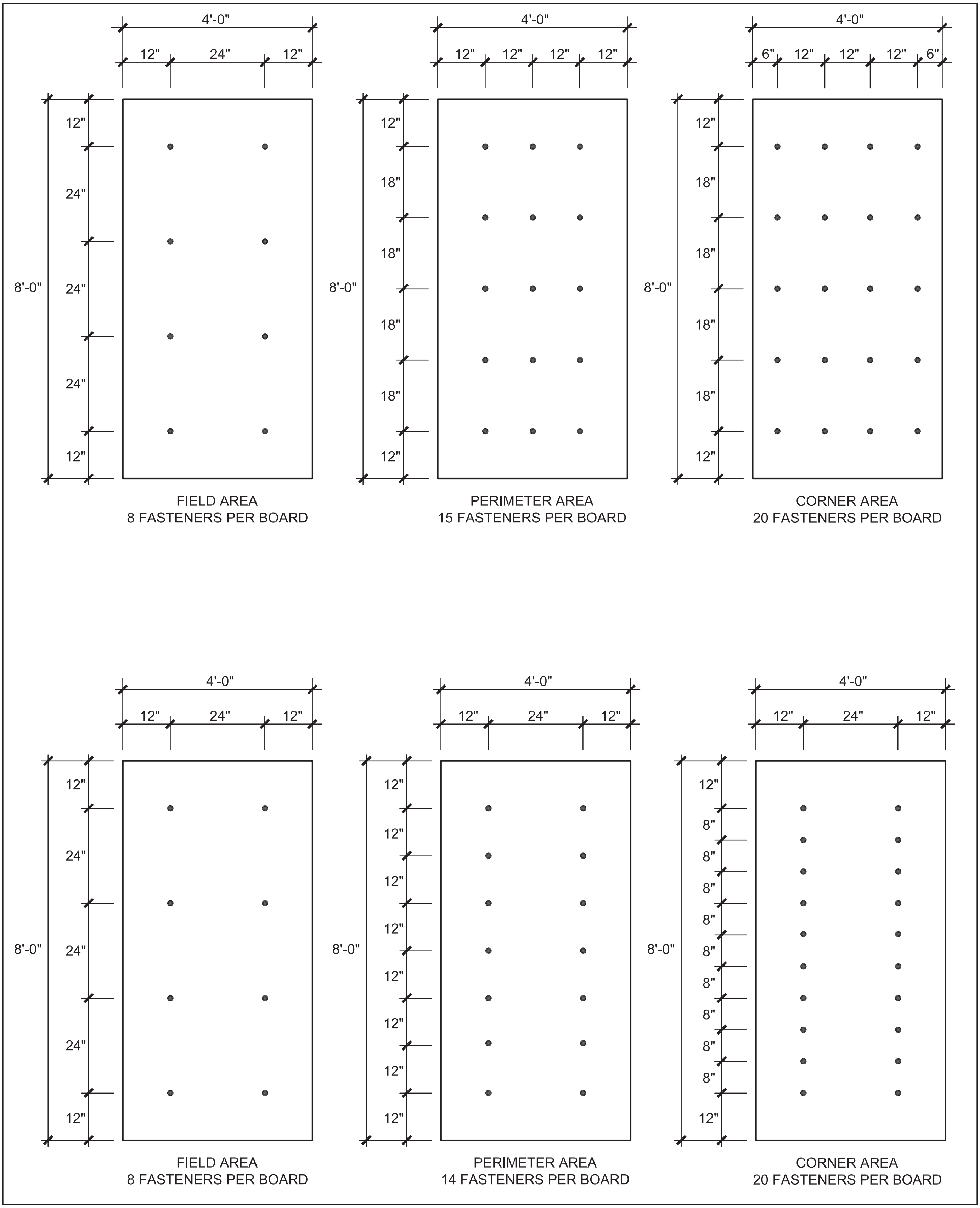

Figure 5-8: Fastener layout examples for heat-induction welding method of mechanically attached single-ply membrane roof systems (continued)

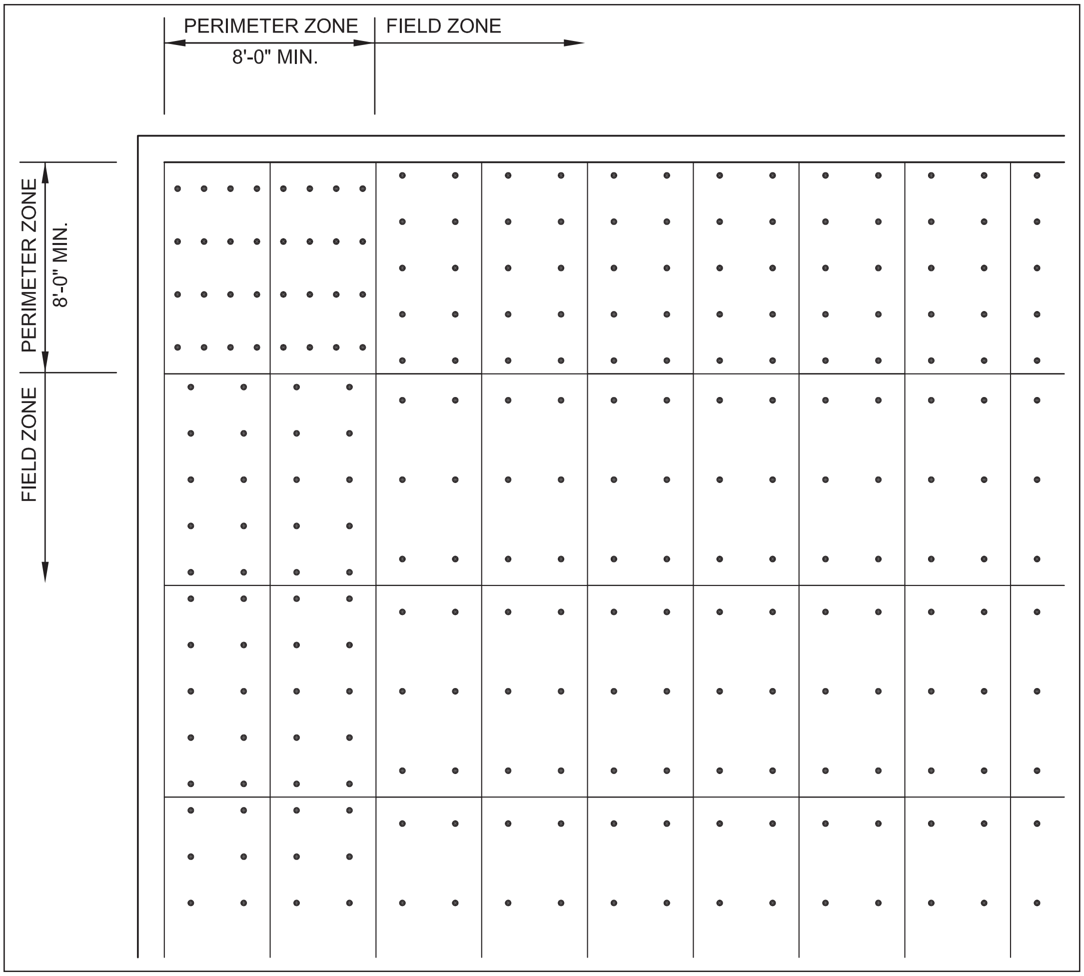

Figure 5-9: Example of roof plan illustrating nonstaggered board joints

recommendations for a specific system and compliance with local code requirements.

Adhered single-ply roof membranes constructed with smooth-backed sheets use cold-applied bonding adhesives to bond the membranes to their substrates. Depending on application, the bonding adhesive may be applied to the sheet underside and substrate or the substrate only. Bonding adhesive application typically is accomplished with a roller; a brush, squeegee or spraying equipment also may be used, depending on manufacturer recommendations. Seam areas should not receive any bonding adhesive.

Air Retarders for Roof Assemblies in the Condensation and Air Leakage Control section of The NRCA Roofing Manual: Architectural Metal Flashing, Condensation and Air Leakage Control, and Reroofing.

Adhered: Adhered membrane systems are generally applied using a liquid-applied contact adhesive. Some membranes are made with a factory-laminated fleece backing that allows adhesion with alternative types of adhesives, such as hot asphalt and low-rise polyurethane foam. Self-adhering membrane systems also are available. Membrane sheets should be set in continuous applications of adhesives or as recommended by the membrane manufacturer.

The method of attachment of the insulation or base sheet underlying an adhered membrane provides wind-uplift securement for a roof system. Securement can be affected by roof slope, and the number of fasteners to be installed may vary based on the requirements of a membrane manufacturer or the building code of jurisdiction. NRCA recommends designers consult the manufacturer's

Adhesive application rates vary depending on adhesive material and substrate texture or porosity. The bonding adhesive is allowed a flash-off time, which varies in length depending on adhesive, ambient and substrate temperatures and relative humidity, before the sheet is mated to the substrate. The mated sheet is broomed or rolled to promote adhesive bond creation.

Single-ply membranes constructed with fleece-backed sheets may be adhered in cold-applied adhesives, low-rise foam adhesives or hot asphalt. When using cold-applied adhesives, the adhesive typically only is applied to the substrate. Cold-applied adhesives may be applied with a roller or a squeegee, or spray equipment. Low-rise foam adhesives are applied to the substrate in a spaced ribbon pattern or using spray equipment, as required for the application. Hot asphalt adhesive may be applied to the substrate in a spaced ribbon pattern or mopped. Depending on adhesive and application type, the sheet may be rolled into the adhesive immediately or following an application-specific interval. The mated sheet is then broomed or rolled to promote adhesive bond creation.

Manufacturers should be consulted regarding guidelines and requirements for substrate preparation, site conditions appropriate for application, adhesive application procedures and rates, adhesive open times and adhesive flash-off times, sheet positioning and setting into adhesive, and hot-air welding procedures.

Depending on the liquid carrier(s) used, cold-applied single-ply roof membrane adhesives currently available can be placed into one of three categories:

- Volatile organic compound (VOC) solvent-based adhesives
- Low-VOC (also known as VOC-exempt solvent-based) adhesives
- Water-based adhesives

VOC Solvent-based Adhesives: VOC solvent-based single-ply adhesives typically include xylene or toluene as the main carrier(s). Manufacturers provide specific recommendations for storage, handling and application of VOC solvent-based adhesives.

VOC solvent-based adhesives typically are applied to both mating surfaces half a sheet width at a time with the sheet folded back on itself. The adhesive is then allowed a flash-off time that varies depending on ambient conditions. Typically, manufacturer guidelines for determining when it is acceptable to roll the sheet into the substrate involve a finger touch test to establish whether enough adhesive solvent has flashed off to develop a sufficient-strength contact bond when the sheet is mated to the substrate.

VOC solvent-based adhesive, primer, membrane cleaner and sealant use increasingly is being restricted by regional regulations intended to limit VOC emissions. Sustainable construction rating systems such as LEED provide incentives for eliminating VOC-containing materials in construction. Also, some building codes contain provisions restricting the use of VOC-containing materials.

Low-VOC Adhesives: Low-VOC single-ply adhesives contain compounds exempt from VOC emissions regulations.

California was first in mandating limits on VOCs , where VOC emissions regulations were adopted in 1989. Other states followed, predominantly in the New England and Middle Atlantic regions, and developed their own rules for low-VOC adhesives, primers, membrane cleaners and sealants. Beginning in 2009, jurisdictions in those regions started enforcing regulations restricting the use of VOC solvent-based materials.

Low-VOC adhesives are not formulated by simply replacing the VOC solvent content with other solvents exempt from VOC emissions regulations, and they perform unlike the materials they are replacing. Also, low-VOC material formulations in California are different from those used in the Northeast and Mid-Atlantic regions.

Manufacturers indicate low-VOC adhesive is more sensitive to certain conditions, including substrate type, air and substrate temperatures, relative humidity and sun exposure. Flash-off times are longer and less predictable with low-VOC adhesives as compared with VOC solvent-based adhesives.

Low-VOC adhesives typically are applied to both mating surfaces half a sheet width at a time with the sheet folded back on itself. The adhesive is then allowed a flash-off time that varies depending on ambient conditions. Typically, manufacturer guidelines for determining when it is acceptable to roll the sheet into the substrate involve a finger touch test to establish if enough adhesive solvent has flashed off to develop a sufficient-strength contact bond when the sheet is mated to the substrate.

Manufacturers' guidelines for low-VOC materials impose restrictions on storage, transport and application conditions that may be difficult to meet or impractical during fall, winter and spring in the Northeast and Mid-Atlantic states. Manufacturers generally recommend low-VOC materials be transported and stored at temperatures between 60 F and 90 F. Most manufacturers' application instructions state low-VOC adhesive use is limited to periods when rooftop temperatures are 40 F and rising.

Water-based Adhesives: Water-based single-ply adhesives typically are acrylic latex emulsions. These materials comply with regulations intended to limit VOC emissions. Also, water-based single-ply adhesives have reduced odors during application and curing.

Designers, general contractors, construction managers, building owners and roof construction observers need to be aware of water-based single-ply adhesives' limitations. Designers specifying water-based adhesives for single-ply roof membrane applications need to be aware of manufacturers' restrictions on the use of these materials. It should be recognized that under some site conditions, water-based adhesive application will need to be delayed or suspended until favorable conditions exist.

In situations where roofing work must take place during conditions unfavorable for water-based adhesive use—such as when construction project sequencing requires roofing work be conducted in fall or winter in a cold climate, in cold and damp conditions, or in hot and humid conditions—NRCA recommends building owners and designers specify alternative roof system types that are not as sensitive to site conditions. Roofing product manufacturers and roofing contractors should be consulted for specific recommendations.

NRCA recommends single-ply applicators pay close attention to manufacturers' recommendations and work closely with manufacturers' technical and field staff, starting with the planning stages of projects involving water-based single-ply adhesives, primers and sealants.

Water-based adhesives may be applied to the substrate only or both mating surfaces, depending on adhesive and application. With one-sided application, the sheet typically is rolled into wet adhesive.

With two-sided applications, half a sheet is adhered at a time. A flash-off time is necessary. Because water-based adhesive flash-off times are affected by ambient conditions to a greater extent as compared with solvent-based adhesives, they are less predictable. Determining when it is appropriate to roll the sheet into the substrate typically involves a touch test as with solvent-based adhesive applications. Some water-based adhesives are formulated to undergo a color change around the time they reach the end of their flash-off time.

Manufacturers' guidelines for water-based adhesives impose storage, handling and application condition limitations that may be difficult to meet or impractical depending on-site conditions.

Manufacturers generally recommend water-based adhesives be transported and stored at temperatures between 60 F and 90 F. Most manufacturers' application instructions state water-based adhesive use is limited to periods when rooftop temperatures are 40 F and rising. Also, prior to application, water-based adhesives should never be exposed to temperatures below 40 F or allowed to freeze. If allowed to freeze, water-based adhesives no longer are suitable for use.

Manufacturers' instructions warn against using water-based adhesives when there is a possibility of freezing temperatures within 48 hours after application. Because nighttime radiative cooling may lower roof surface temperature below air temperature during curing, NRCA suggests water-based single-ply adhesive use be limited to periods when ambient temperatures are expected to remain at a minimum of 50 F and rising during application and the next 48 hours.

Manufacturers indicate water-based adhesive is sensitive to conditions, including air and substrate temperatures, relative humidity, sun exposure and substrate porosity. Because high relative humidity extends drying time for water-based adhesives, the dry down time on a warm, very humid day can be expected to be similar to dry down time on a cold, damp day. Also, single-ply applications using water-based adhesives should be protected from upward moisture vapor drive, such as moisture release from the substrate or vapor drive from a building's interior.

Porous substrates increase water-based adhesive drying rates; however, cellulose fiber-based substrates may absorb excess adhesive. NRCA recommends water-resistant substrates be used for water-based single-ply adhesives.

Single-ply applications using water-based adhesives commonly are slower to develop adequate green strength as compared to VOC solvent-based adhesive applications. Also, full adhesive bond strength typically requires a long curing time to develop as compared with VOC solvent-based adhesives.

<u>Self-adhering Sheets:</u> Self-adhering single-ply sheets incorporate factory-applied elastomeric pressure-sensitive adhesive on the bottom side. Self-adhering single-ply sheets are available in sizes similar to conventional single-ply sheets. These materials ship with split release film protecting the adhesive.

After the sheet is unrolled, it is positioned for application and half the width is folded back. The release film is removed from the folded-back half and the sheet is mated to the substrate by rolling back in the width direction. A weighted roller is used to apply pressure to the mated half by rolling in the width direction. These steps are repeated to adhere the other half of the sheet.

Side laps typically are heat-welded. Also available are self-adhering single-ply sheets provided with factory-applied side-lap contact adhesive designed to seal the sheets at side laps. Sheet ends are butted together and stripping plies are heat welded at end laps.

Substrate type, surface preparation and temperatures at the job site are critical for self-adhering single-ply membrane roof system performance. Manufacturers' requirements call for continuous dimensionally stable substrates. Priming of substrate surfaces may be required. Some manufacturers require the installation of a mechanically attached base sheet over specific substrates. The base sheet is intended to bridge joints and improve adhesion. Self-adhering single-ply sheet manufacturers should be consulted for product-specific substrate preparation requirements and application temperature limitations.

Membrane Flashing Application: Membrane flashing configurations for common construction detail conditions are depicted in Chapter 10—Construction Details. Construction details specific to EPDM roof membranes are denoted as "EPDM-" followed by a number and possibly a letter (e.g., EPDM-1, EPDM-2, EPDM-3). Construction details specific to thermoplastic single-ply membranes (PVC, PVC alloys, TPO, KEE) are denoted as "TP-" followed by a number and possibly a letter (e.g., TP-1, TP2, TP-3).

The manufacturer of the specific single-ply membrane roof system being installed should be consulted for its specific recommendations for membrane flashing materials and application.

Additional information: NRCA suggests consulting the membrane manufacturer's literature for additional application guidelines and recommendations.

Guidelines for quality control and quality assurance during the application of single-ply membrane roof systems are provided in a separate NRCA publication, *Quality Control Guidelines for the Application of Thermoset Single-ply Roof Membranes.*

Chapter 1—Roof System Configurations in this manual contains additional information about installing single-ply membrane roof systems.