RIGID BOARD INSULATION

The purpose of roof insulation is to provide a substrate for the application of a roof membrane and thermal resistance. A roof can be one of the largest surface areas of a building envelope through which interior heat escapes. Insulation within a roof assembly may help to maintain the inside temperature of a building at a more constant, comfortable level.

Roof insulation that is properly manufactured, designed and installed serves several vital purposes:

- It can reduce the energy required to heat and cool buildings.
- It can reduce the potential for condensation occurring on interior surfaces.
- It can stabilize deck components by reducing their temperature variations and consequent thermal expansion and contraction.
- It can provide a relatively smooth substrate upon which roofing materials may be applied.
- It can provide fire resistance for certain low-slope roof assemblies.
- Tapered insulation can be used to provide slope for positive drainage where the deck does not.

Including rigid roof insulation in a roof assembly requires several design considerations. Depending on the type and thermal resistance of the insulation to be used, there may be a resultant need for changing or upgrading the design of the roof membrane. For example:

- Because insulation resists heat transfer, its use directly under a roof membrane does not allow solar heat to readily pass through to the interior of the building, as typically occurs if insulation is not present. Therefore, in compact roof assemblies, insulation contributes to an increase in roof membrane temperature during hot weather and a possible decrease during cold weather, thereby accelerating the aging process of roofing materials.
- In a roof system with insulation, a higher thermal resistance value may increase the magnitude of the thermal expansion and contraction of the roof membrane compared with a roof system without insulation.

- While reducing the potential for interior moisture condensation, rigid roof insulation sandwiched between a roof deck and roof membrane can increase the probability of condensation occurring within the roof system. For many projects in moderate and cold climates, the addition of insulation may add to the need for an effective air retarder and/or vapor retarder. Condensation control is an important consideration in the thermal design of most roof assemblies. Additional information regarding condensation control is provided in the Condensation and Air Leakage Control section of The NRCA Roofing Manual: Architectural Metal Flashing, Condensation and Air Leakage Control, and Reroofing.

Desirable Properties of Roof Insulation: An ideal roof insulation would have the following properties:

- Compatibility with bitumen and other adhesives—It would be able to withstand the effects of being in contact with adhesives, solvents and hot bitumen at the application temperatures required for installation of a roof membrane without degradation.
- Component compatibility—It would be formulated to be compatible with the other components of a roof assembly.
- Impact resistance—It would have strength, rigidity and a density high enough to resist impact damage during and after roof system installation.
- Fire resistance—It would be noncombustible and comply with the requirements of insurance underwriters and building codes.
- Moisture resistance—It would resist the effects of moisture vapor and water without degradation over the life of a roof system.
- Thermal resistance—It would have a low thermal conductivity (k-value) so the highest possible thermal resistance (R-value) can be achieved in the thinnest possible piece of material.
- Stable R-value—The R-value would remain constant and not drift or lose thermal resistance with age.
- Attachment capability—Its surfaces would accommodate secure attachment. Also, its resistance to moisture absorption would not impair its physical properties and attachment capabilities.
- Dimensional stability—It would be dimensionally stable under varying temperature and moisture conditions.
- Compressive strength—It would have sufficient strength to resist damage from roof system construction operations and normal rooftop traffic.

The 10 properties listed would be found in an ideal roof insulation. In reality, no single rigid board insulation product currently available has all these ideal properties. Therefore, designers need to choose rigid board insulation materials that have properties best suited to specific project conditions.

Types of Roof Insulation: Following are the generic types of rigid roof insulation that are referenced in this manual and are currently among those most commonly used or found in low-slope membrane roof systems in North America:

- Cellular glass
- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)
- Glass-faced gypsum
- Fiber-reinforced gypsum
- Stone wool
- Perlite
- Polyisocyanurate
- High-density polyisocyanurate
- Wood fiberboard
- Asphalt core board
- Cement board
- Composite board
- Tapered insulation

Guidelines that apply to all types of rigid board insulation are provided in Section 4.1—Guidelines Applicable to All

Insulation Types. Descriptions of each insulation type, its manufacturing process, application guidelines and precautions are provided in the sections that follow.

The following criteria should be considered by designers of roof assemblies containing rigid roof insulation board:

- On steel roof decks, the steel deck flutes' direction, rigid insulation board orientation and membrane layout should be designed to accommodate the satisfactory anchorage of roof system components and facilitate application of the membrane and installation of temporary tie-ins and water cutoff details.
- On steel roof decks, rigid insulation boards, if rectangular, should be placed with their longer dimension edges supported on the top flanges of the steel roof deck. The insulation boards placed directly over steel roof decks should not cantilever over the open steel deck flutes.
- In practice, steel decks are often installed incorrectly with minor curves or small incremental errors in overlaps. As successive insulation boards are installed on the deck, at some point the insulation edge may begin to cantilever off at the top flange of the steel deck panels. Unless corrected, some of the insulation panels may be misaligned, with the long dimension of the boards not directly supported by the top flange of the deck panels. When this condition is encountered, additional labor will be required to cut the rigid board insulation or align the board joints with the top flanges of the steel roof deck to correct the installation.
- In low-slope membrane roof system construction, use of two or more layers of rigid board insulation is preferred. The board joints in the second layer of rigid board insulation should be offset from the joints in the first layer to reduce thermal losses and membrane stress.
- NRCA recommends designers specify layers of rigid board insulation in specific thicknesses and type to comply with the design R-value and other project requirements.

Experience and research reported in "Thermal Evaluation of the Effects of Gaps Between Adjacent Roof Insulation Panels" from the *Proceedings of the DOE-ORNL Workshop on Mathematical Modeling of Roofs* have shown that a minimum of two layers of rigid insulation can provide the following benefits to low-slope roof systems:

- **Increased roof system thermal performance.** With double-layer insulation roof systems, it is preferable that only the bottom layer of insulation be mechanically fastened to roof decks that are appropriate for mechanical attachment. The second layer of insulation then can be adhered to the base layer or, if present, to the vapor retarder installed on top of the first layer with hot bitumen or approved adhesive. When a loose-laid, ballasted single-ply membrane system is used, both layers of insulation may be loose-laid. NRCA recommends the joints in the second layer be offset from the joints in the base layer to reduce thermal losses and membrane fatigue.
- **Reduced thermal loss.** A minimum of two layers reduces the thermal loss that occurs through the joints between single-layer insulation boards. Because gaps between single-layer insulation board joints can be paths for heat and moisture transport via air leaks, double-layer insulation systems help minimize "thermal shorts" at board joints and help control moisture vapor transport through the roof system.
- **Reduced thermal bridging.** Metallic mechanical insulation fasteners are thermal bridges; that is, they provide heat conduction paths through the insulation. NRCA suggests that mechanical fasteners not extend through both or all layers of insulation. With two or more layers of insulation, thermal bridging at fasteners can be confined to the first layer if additional layer(s) are adhered, except in mechanically attached single-ply membrane roof systems where the sheet side-lap fasteners penetrate through all insulation layers to the roof deck. For mechanically attached membrane roof systems, NRCA recommends thermal resistance design calculations account for thermal resistance losses due

to thermal bridges at metal fasteners where mechanical fasteners penetrate through all rigid board insulation layers to the roof deck.

- **Reduced potential for membrane buckling, ridging and splitting.** The continuous vertical-joint that is otherwise experienced with single-layer insulation boards is eliminated if board joints are offset.

When double-layer insulation is used, the joints of the insulation boards in the top layer should be vertically staggered and offset from the joints of the insulation boards in the layer below. Therefore, the as-manufactured edges of insulation boards should be straight, and corners should be square. During installation of insulation boards, adjacent boards should be applied so joints are in moderate contact. End joints of adjacent insulation boards should be staggered.

When specifying rigid plastic foam insulation, such as extruded polystyrene or expanded polystyrene, for use under hot-applied bituminous membrane roofing, NRCA recommends designers specify suitable cover boards over rigid plastic foam insulation. Examples of cover boards include fiber-reinforced gypsum board, glass-faced gypsum board, stone wool, perlite board, high-density polyisocyanurate board and wood fiberboard. When a cover board is used, the joints should be staggered from the joints in the rigid plastic foam insulation layer below.

NRCA also suggests designers consider the benefits of using an appropriate cover board with roof systems regardless of the roof membrane type. There are numerous combinations of insulations and membranes where the performance of the roof assembly can be enhanced with the use of an appropriate cover board. For example:

- Where increased impact or puncture resistance of the roof membrane is necessary
- When incompatibility of membrane and primary insulation is a possibility, such as polyvinyl chloride (PVC) membrane and polystyrene insulation
- When ballasting operations or construction traffic may damage low-density primary insulations

NRCA recommends designers not specify insulation according to the advertised thermal resistance (R-value).

Rather, designers are urged to calculate the desired thermal resistance using the in-service R-value for the specific insulation and specify by desired thickness.

NRCA recommends the following insulation criteria be clearly specified for any project:

- Insulation type, such as polyisocyanurate, perlite, etc.
- Thickness and board dimension
- C-value
- In-service R-value per inch of thickness
- Other physical properties, such as density and compressive strength, as appropriate

Information regarding fasteners used to attach rigid board insulation to roof decks is provided in Chapter 6—Fasteners.

Principles of Thermal Insulation: The primary function of insulation is to provide thermal resistance. Heat is a form of energy, and energy can be measured using a British thermal unit (Btu). A Btu is defined as the energy required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Because heat flows from warm to cooler areas, a significant amount of heat can leave a building through an inadequately insulated roof assembly in winter and enter a building through an inadequately insulated roof assembly in summer. A conditioned building with an inadequately insulated roof assembly, therefore, requires additional expenditure of energy to compensate for the inadequately controlled heat flow.

Terminology: The following terms are commonly used to characterize thermal performance of constructions—including roof assemblies—comprising the building envelope.

- **Thermal conductivity (k):** The time rate of steady-state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area. In English (inch·pound) units of measurement, it is the number of Btu that pass through a 1-inch thickness of a 1-square-foot sample of material in one hour with a temperature difference between the two surfaces of 1 degree Fahrenheit. In English (inch·pound) units, it is expressed as Btu·inch/h·ft^2·F.

Note 1: A thermal conductivity (k) value applies to 1-inch thickness of a specific material.

Note 2: It is mathematically incorrect to add, multiply or divide the thermal conductivity (k) value of a material to determine the thermal performance value of a different thickness of the same material. If it is necessary to determine the thermal performance of a specific thickness of a material, it is appropriate to convert the thermal conductivity (k) of the material to a thermal resistance (R) value (i.e., R = 1/k) and then perform the mathematical calculation.

- **Thermal conductance (C):** The time rate of steady-state heat flow through a unit area of a material or construction induced by a unit temperature difference between the body surfaces. In English (inch·pound) units of measurement, it is the number of Btu that pass through a specified thickness of a 1-square-foot sample of material in one hour with a temperature difference between the two surfaces of 1 degree Fahrenheit. In English (inch·pound) units, it is expressed as Btu/h·ft^2·F.

Note 1: A thermal conductance (C) value applies to a specific thickness of a specific material.

Note 2: It is mathematically incorrect to multiply or divide the thermal conductance (C) value for a specific thickness of a material to determine the thermal conductance value of a different thickness of the same material.

Note 3: It is mathematically incorrect to add thermal conductance (C) values to determine overall thermal performance. If it is necessary to determine the overall thermal performance of a construction, it is appropriate to convert the individual thermal conductance (C) values to thermal resistance (R) values (i.e., R = 1/C) and then add the thermal resistance values (i.e., $R_t = R_1 + R_2 + ...$).

- **Thermal resistance (R):** The quantity determined by the temperature difference at steady state between two defined surfaces of a material or construction that induces a unit heat flow rate through a unit area. In English (inch·pound) units, it is expressed as h·ft^2·F/Btu.

Note 1: A thermal resistance (R) value applies to a specific thickness of a material or construction.

Note 2: The thermal resistance (R) of a material is the reciprocal of the thermal conductance (C) of the same material (i.e., R = 1/C).

Note 3: Thermal resistance (R) values can be added, subtracted, multiplied and divided by mathematically appropriate methods.

- **Thermal transmittance (U or U-factor):** The heat transmission in unit time through unit area of a material or construction and the boundary air films induced by unit temperature difference between the environments on each side. In English (inch·pound) units, it is expressed as Btu/h·ft^2·F.

Note 1: A thermal transmittance (U) value applies to the overall thermal performance of a system (e.g., roof assembly).

Note 2: Thermal transmittance (U) is sometimes called the overall coefficient of heat transfer.

Note 3: Thermal transmittance (U) is the reciprocal of the overall thermal resistance (R_t) of a system (i.e., $U = 1/R_t$).

The following table provides a range of U-factor values and corresponding total assembly R-values.

U-factor	Assembly R-value
0.01	100
0.02	50
0.03	33.33
0.04	25
0.05	20
0.06	16.67
0.07	14.29
0.08	12
0.09	11.11
0.1	10
0.11	9.09
0.12	8.33
0.13	7.69
0.14	7.14
0.15	6.67
0.16	6.25
0.17	5.88
0.18	5.56
0.19	5.26
0.2	5
0.21	4.76
0.22	4.5
0.23	4.35
0.24	4.14

Some minimal thermal resistance is provided by thin air films that cling to the interior and exterior surfaces of building assemblies, including roof assemblies. Air movement—wind—reduces the thickness and effectiveness of the air film on a building's exterior and, therefore, reduces the exterior air film's thermal resistance (R-value) as wind speed increases.

The thermal resistance of indoor air films varies with the direction of heat flow. Air film on a ceiling has greater thermal resistance against downward heat flow because upward heat flow is accompanied by convective currents that disturb the air film and reduce its resistance to conductive heat flow. The result is that some convective heat transfer occurs through a ceiling air film when there is upward interior heat flow.

Figure 4-1 provides recognized thermal resistance values for air films for exterior and interior surfaces.

Thermal Resistance Values for Air Films[1]		
Surface[2]	**Condition**	**Thermal Resistance** h·ft^2·F/Btu
Inside air film (f_i)	Still air—horizontal surface[3]	
	Heat flow upward (winter)	0.61
	Heat flow downward (summer)	0.92
Outside air film (f_o)	Moving air (any position)	
	15 mph wind (winter)	0.17
	7.5 mph wind (summer)	0.25

1. Values derived from Table 1, *2009 ASHRAE Handbook—Fundamentals*, page 26.1.

2. Surface air films exist on every surface. They are layers of air that cling to the surface on a material and have some resistance to heat flow. Outside air films vary in thickness according to wind velocity; inside air films vary in effectiveness according to the direction of heat flow.

3. Inside air film values listed are for horizontal inside surfaces only. If the inside surface being evaluated is sloping or vertical, other thermal resistance values may apply; refer to Table 1, *2009 ASHRAE Handbook—Fundamentals*, page 26.1.

Figure 4-1: Thermal resistance values for air films

Enclosed airspaces, such as ceiling cavities, also provide some minimal thermal resistance provided the airspace is not vented or used as a return air plenum for the building's mechanical system. Figure 4-2 provides recognized thermal resistance values for enclosed airspaces.

Position of Airspace[3]	Condition[3]	Thickness of Airspace[4] in.	Thermal Resistance of Airspace[2, 5] h·ft²·F/Btu		
			Low-emittance (highly reflective) Surface[6]	Moderate-emittance Surface[7]	Emissive (non-reflective) Surface[8]
Horizontal	Heat flow upward (winter)	0.75	1.7	1.16	0.87
		1.5	1.81	1.21	0.89
		3.5	1.95	1.28	0.93
Horizontal	Heat flow downward (summer)	0.75	2.41	1.45	1.02
		1.5	3.27	1.73	1.15
		3.5	4.09	1.93	1.24

1. Values derived from Tables 2 and 3, *2009 ASHRAE Handbook—Fundamentals*, pages 26.2 and 26.3. The tables provide values for well-sealed cavities constructed with care.

2. Any airspace where the air is not ventilated or otherwise allowed to freely move has some thermal resistance to heat flow. If the airspace is ventilated or if the space is used as a plenum, the thermal resistance of the space and inside film must be considered zero.

3. The thermal resistance values listed are for horizontal airspaces with the direction of heat flow either in an upward (winter) or downward (summer) direction. If the airspace being evaluated is oriented in a sloping or vertical direction, other thermal resistance values may apply; refer to Tables 2 and 3, *2009 ASHRAE Handbook—Fundamentals*, pages 26.2 and 26.3.

4. Interpolation and moderate extrapolation for airspaces other than those listed is permissible.

5. Thermal resistance values based on 50 F mean temperature and 10 F temperature difference between a cavity's surfaces.

6. Values based on an Effective Emittance, ε_{EFF} = 0.20, where one surface ε_1 = 0.20 (e.g., aluminum coated paper, polished) and the other surface ε_2 = 0.90.

7. Values based on an Effective Emittance, ε_{EFF} = 0.50, where one surface ε_1 = 0.50 (e.g., aluminum paint) and the other surface ε_2 = 0.90.

8. Values based on an Effective Emittance, ε_{EFF} = 0.82, where both surfaces are emissive, i.e., ε_1 = ε_2 = 0.90 (e.g., wood, paper, masonry, nonmetallic paints).

Figure 4-2: Thermal resistance values for enclosed airspaces

Thermal resistance calculations: Thermal resistance calculations are accomplished by adding the thermal resistance (R) values of the individual components of a building assembly and then, if necessary, determining the assembly's overall coefficient of thermal transmission (U). The thermal resistance calculation procedure is illustrated by the following example.

A building's roof-ceiling assembly consists of an aggregate-surfaced built-up membrane roof system over two layers of insulation over a steel roof deck. The building's ceiling consists of a suspended ceiling system with an enclosed airspace. Figure 4-3 on page 162 is an illustration of this roof-ceiling assembly.

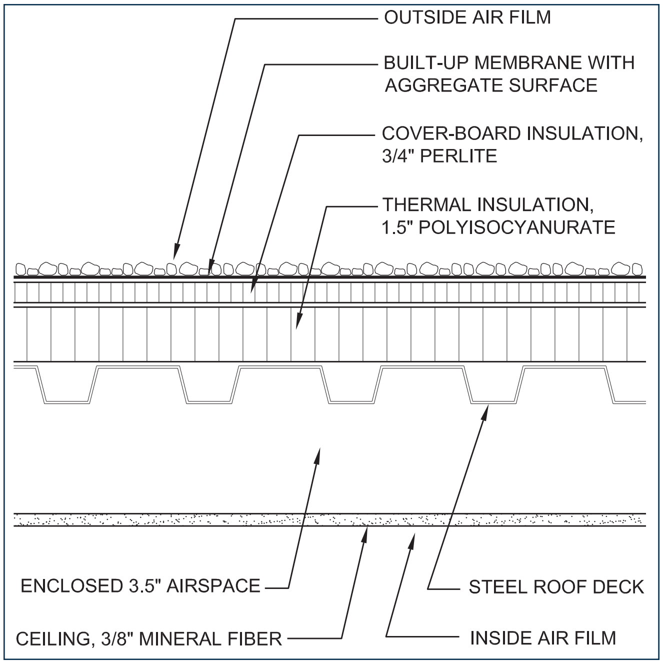

Figure 4-3: Roof-ceiling assembly illustration for example heat flow calculation

The assembly's overall R-value is determined as follows.

Component	**Heating Condition**	**Cooling Condition**
	R-value	**R-value**
Outside air film	0.17	0.25
Built-up membrane, aggregate surfaced	0.33	0.33
Insulation cover board, ¾-inch perlite board	2.08	2.08
Primary insulation, 1½-inch polyisocyanurate	7.50	8.40
Roof deck, steel	0.00	0.00
Enclosed airspace, 3½ inches	0.93	1.24
Ceiling, ⅜-inch mineral fiber	1.56	1.56
Inside air film	0.61	0.92
Total (R_t):	13.18	14.78

Note: R-values for components other than those described below are taken from Typical Thermal Properties of Building Materials in the Appendixes of the Condensation and Air Leakage Control Section of The NRCA Roofing Manual: Architectural Metal Flashing, Condensation and Air Leakage Control, and Reroofing. The R-values for the outside and inside air films are taken from the table in Figure 4-1. The R-value for the enclosed airspace is taken from the table in Figure 4-2. The R-value for the enclosed airspace is taken from the table in Figure 4-2. The R-values for the polyisocyanurate insulation are the NRCA recommended values found in Section 4.9—Polyisocyanurate.

Based upon the previous calculation of the assembly's R-values, the assembly's overall coefficient of thermal transmission (U) is determined as follows:

$$R = \frac{1}{R_t}$$

$$= \frac{1}{13.18}$$

$$= 0.759 \text{ Btu/ft}^2 \bullet \text{Hour} \bullet \text{F}$$

Note: In this example, R_t for heating conditions was used for determining the assembly's overall coefficient of thermal transmission (U) because it results in the most conservative value. It is a designer's prerogative to use the R_t for heating conditions or cooling conditions based on the predominant condition for the climate where the specific building being evaluated is located.

NRCA's EnergyWise Roof Calculator can also be used for thermal resistance calculations and comparing individual roof assemblies' thermal resistances.

Additional information regarding and examples of thermal resistance calculations are provided in the Condensation and Air Leakage Control Section of The NRCA Roofing Manual: Architectural Metal Flashing, Condensation and Air Leakage Control, and Reroofing.

4.1—Guidelines Applicable to All Insulation Types

The following guidelines apply to all types of rigid board insulation used as roof system components.

Joints: When double-layer insulation is used, all the joints of the insulation boards in the top layer should be offset from all the joints in the underlying layer a minimum of 6 inches. The edges of all abutting insulation boards should be in moderate contact. Insulation joints wider than ¼ of an inch should be properly filled with insulation to prevent thermal loss and provide a smooth substrate for the roof system.

Storage and Handling Protection: During storage and handling, rigid board roof insulation materials should be protected from weather. All roof system materials that are susceptible to retaining moisture or may be damaged by moisture should be stored in a dry location before application.

When moisture-sensitive materials are stored outside, they should be placed on pallets or platforms raised off the ground or roof deck. Materials sensitive to moisture should be covered with water-resistant coverings that have been secured. Coverings that are "breathable," such as water-resistant tarpaulins, are preferred. Some insulation materials are extremely light and must be weighted in storage to prevent displacement and possible damage from winds.

Protection With Temporary Tie-ins: At the end of each day's work, temporary tie-in ply or plies should be installed, adhered to the roof membrane, and adhered or sealed onto the top or bearing surface of the substrate to protect the exposed ends of insulation boards or blocks that have been applied that day. Unless water cutoffs have been specified and are to remain part of the finished roof assembly in the same location where temporary tie-ins are applied, the tie-ins should be cut and adhered or removed entirely before additional insulation is applied.

Cover With Roof Membrane: NRCA recommends installed rigid board insulation be covered with the roof membrane by the end of each day's work.

4.2—Cellular Glass

Cellular-glass roof insulation is manufactured as a rigid insulating material composed of heat-fused, closed-glass cells.

The following properties of cellular-glass roof insulation make it an effective insulating material:

- Bitumen and adhesive compatibility
- Component compatibility
- Fire resistance
- Durability
- Moisture resistance
- Thermal resistance
- Stable R-value
- Dimensional stability
- Compressive strength

Manufacturing Process: Cellular-glass insulation is produced by combining crushed glass, which has closely controlled physical properties, with a cellulating agent, such as carbon black. This mixture is placed in a mold and heated in a furnace to a temperature of about 950 F. At this temperature, the glass turns to a liquid, and the cellulating agent reacts with another constituent of the mixture, releasing gas that causes the mass of material to expand and fill a mold. This expanded insulating material is composed of millions of interconnecting closed cells, each of which contain an inert gas. After the cellular-glass material cures to a solid state, it is trimmed to obtain regular-shaped blocks. Then, the material is cut to size for roof insulation, kraft-paper facers may be applied and the finished product is packaged for shipment.

Product Standard: The U.S. product standard for cellular-glass roof insulation is ASTM C552, "Standard Specification for Cellular Glass Thermal Insulation." Within ASTM C552, Type I designates flat block manufactured product, Type II designates pipe and tubing insulation, Type III designates special shapes and Type IV designates boards. Products designated as Type II, Type III and Type IV are fabricated from Type I product. Cellular-glass roof insulation is typically designated as ASTM C552, Type IV.

R-value: Cellular-glass roof insulation has an R-value of 3.44 per inch thickness tested at a 75 F mean temperature. Cellular-glass roof insulation is recognized for having a stable R-value.

Board Sizes and Thicknesses: Cellular-glass roof insulation is typically available in flat blocks measuring 12 by 18 inches by 1½ inches thick, as well as 18 by 24 inches in thicknesses ranging from 2 inches to 6 inches in ½-inch increments.

Faced cellular-glass roof insulation is typically available in 2- by 4-foot board sizes.

Tapered cellular-glass roof insulation is typically available as blocks in 18- by 24-inch boards with tapers of ⅛, ¼ and ½ inch per foot tapered on the 24 inch side. The minimum thickness for tapered cellular-glass insulation is typically 1½ inches.

Usage Guidelines: The following guidelines apply to the usage of cellular-glass roof insulation.

Multilayer Insulation: Cellular-glass insulation can be used as a component of a properly designed multilayer insulation application. When the total required thickness of the cellular-glass insulation is 3 inches or greater, NRCA recommends designers specify cellular-glass insulation as multiple layers.

Combustibility: Cellular-glass roof insulation is noncombustible. It can be exposed directly to hot bitumen, torch flame or high temperatures, such as those produced by hot air welders.

Application and Securement: Application procedures for cellular-glass insulation may vary depending on the type of roof deck, roof membrane specified and configuration of cellular-glass insulation. The insulation and membrane manufacturers should be consulted for recommended application procedures.

- **Nailable Roof Decks:** NRCA recommends that a base sheet be mechanically fastened to nailable roof deck substrates. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners. Cellular-glass insulation then can be adhered to the base sheet using hot bitumen or cold adhesive.
- **Steel Roof Decks:** NRCA recommends a base layer of rigid board insulation such as glass-faced gypsum board, fiber-reinforced gypsum board, stone wool or wood fiberboard be mechanically fastened to steel roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners. Cellular-glass insulation then can be adhered to the base layer using hot bitumen or cold-applied adhesive.

  NRCA does not recommend the mechanical attachment of cellular-glass insulation. Cellular-glass insulation can spall and crumble when fasteners are overdriven and can also abrade fastener coatings. Cellular-glass insulation boards or blocks will not retain fasteners by themselves for such purposes as backnailing, etc.
- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends that cellular-glass roof insulation boards be applied using hot bitumen or a manufacturer-approved adhesive over the properly prepared deck. Priming of the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Information about roof membrane installation over cellular-glass insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.3—Expanded Polystyrene (EPS)

Expanded polystyrene is sometimes referred to as EPS. Expanded polystyrene insulation is formed with a polystyrene polymer. The polymer is impregnated with a foaming agent that, when exposed to heat, creates an expanded, relatively uniform, closed-cell material that is resistant to heat flow and moisture penetration.

The following recognized properties of expanded polystyrene insulation make it an effective insulating material:

- Compatibility with asphalt at low asphalt temperatures
- Component compatibility
- Impact resistance
- Durability
- Moisture resistance
- Thermal resistance
- Stable R-value

Typically, expanded polystyrene insulation is used in buildings with low-temperature interior spaces, such as refrigeration rooms, and in walls and roofs of other commercial, industrial and residential buildings.

Expanded polystyrene insulation should not be confused with extruded polystyrene insulation. Both products are based on a polystyrene polymer, but each has specific advantages and disadvantages. Typically, expanded polystyrene insulation is produced in a wider variety of densities, thicknesses and R-values but is more sensitive to ultraviolet degradation and moisture absorption under certain conditions. Extruded polystyrene insulation is more weather-resistant and is used in protected membrane roof systems and vegetative roof systems where the insulation is not covered by the roof membrane. Additional information regarding extruded polystyrene insulation is provided in Section 4.4—Extruded Polystyrene.

Manufacturing Process: The raw material, styrene, is made from derivatives of coke and crude oil. Styrene is polymerized to form polystyrene. A solution of blowing agent in molten polystyrene is formed into beads. These are later expanded up to 40 times by steam in a pre-expander, providing a density of 0.70 pounds to 2.4 pounds per cubic foot. The expanded beads then are stabilized in curing bins; fused into a billet in a block mold; and cut into boards of various sizes, thicknesses and tapers depending on job requirements.

Product Standard: The U.S. product standard for expanded polystyrene insulation is ASTM C578, "Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation." ASTM C578 applies to expanded and extruded polystyrene. Within ASTM C578 there are 14 type classifications; seven of these define expanded polystyrene. The types are characterized by distinctive physical properties, including density and compressive strength. The following table shows the common types, minimum densities and minimum compressive strengths for expanded polystyrene based upon ASTM C578.

Expanded Polystyrene (EPS)		
ASTM C578 Classification	**Density (minimum), pounds per cubic foot**	**Compressive Strength (minimum), psi**
Type I	0.90 (1.0 nominal)	10.0
Type II	1.35 (1.5 nominal)	15.0
Type VIII	1.15 (1.25 nominal)	13.0
Type IX	1.80 (2.0 nominal)	25.0
Type XI*	0.70 (0.75 nominal)	5.0
Type XIV	2.40 (2.5 nominal)	40.0
Type XV	2.85 (3.0 nominal)	60.0

* EPS complying with ASTM C578, Type XI (0.75 lb/ft^3 nominal density) is generally not intended for use in roofing applications.

NRCA does not recommend ASTM C578, Type I (1.0 lb/ft^3 nominal density) EPS insulation be used in roofing applications. Expanded polystyrene insulation complying with ASTM C578, Type XI (0.75 lb/ft^3 nominal density) classification generally is not intended to be used in roofing applications.

NRCA recommends expanded polystyrene insulation intended for use as rigid board roof insulation have a minimum density of a nominal 1.25 pounds per cubic foot, such as that complying with ASTM C578, Type VIII, having a minimum density of 1.15 pounds per cubic foot. Designers should specify expanded polystyrene insulation characterized by density and compressive strength values that meet specific project requirements.

R-value: The R-values for expanded polystyrene insulation vary based upon their type classifications; the R-values range from 3.1 to 4.3 per inch thickness tested at a 75 F mean temperature. For nominal 1.25 pounds per cubic foot density (Type VIII) expanded polystyrene, ASTM C578 provides for a minimum R-value of 3.8 for 1-inch-thick product.

Board Sizes and Thicknesses: Expanded polystyrene roof insulation is available in widths from 12 to 48 inches, lengths from 48 to 192 inches and thicknesses from ⅜ to 24 inches. 4- by 4-foot and 4- by 8-foot board sizes are used most frequently.

Tapered expanded polystyrene insulation is typically available as blocks in 4- by 4-foot and 4- by 8-foot boards with tapers of ⅛, ¼ and ½ inch per foot with a ⅜-inch minimum thickness.

Usage Guidelines: The following guidelines apply to usage of expanded polystyrene roof insulation.

Multilayer Insulation: Expanded polystyrene insulation can be used as a component of a properly designed multilayer insulation application.

Cover Board: NRCA recommends the use of a suitable cover board layer over expanded polystyrene insulation before roof membrane installation. Suitable cover boards include glass-faced gypsum board, fiber-reinforced gypsum board, stone wool, perlite board, high-density polyisocyanurate board, wood fiberboard or other compatible product intended for use as an insulation cover board. Cover boards are considered to be a component of a multilayer insulation application.

The following are additional notes for cover board installation:

- When adhering a cover board with hot asphalt, the cover board should be back-mopped.
- NRCA recommends using insulation joint tape at all cover board joints over expanded polystyrene insulation before applying bituminous roof membranes or adhered single-ply membranes. When taping insulation board joints, NRCA suggests an installation method, such as using mechanized taping equipment, that limits the migration of bitumen or adhesive into the joints.
- Cover boards may be applicable for certain loose-laid and ballasted roof systems, as well as certain mechanically attached systems.

Combustibility: Expanded polystyrene insulation is combustible. Therefore, it should not be exposed to direct flame or high temperatures, such as those produced by heat welders or torches. Expanded polystyrene insulation should be used only in roof assemblies as recommended by the manufacturer.

Compatibility: Expanded polystyrene insulation is affected by exposure to the sun, organic solvents and adhesives. Therefore, roof system specifications incorporating expanded polystyrene insulation and petroleum solvents, adhesives or hot bitumen should prevent or limit the contact between the expanded polystyrene insulation and potentially incompatible materials.

Expanded polystyrene insulation has a maximum recommended exposure temperature of 165 F. Expanded polystyrene insulation should not be used directly underneath exposed dark-colored roof membranes where reflected light or heat may cause excessive in-service membrane temperatures. In these situations, the installation of a suitable cover board may be adequate to provide a buffer between high membrane surface temperatures and expanded polystyrene insulation.

Expanded polystyrene insulation can melt and be damaged or destroyed by hot asphalt. Expanded polystyrene insulation can also be damaged or destroyed because of chemical incompatibilities with coal tar pitch, cold process membrane applications and certain solvents used in adhesives and cleaning agents for single-ply membranes.

Expanded polystyrene insulation may need to be isolated from certain thermoplastic membranes by using a separator sheet to prevent damage to the membrane as a result of plasticizer migration.

Application and Securement: Installation procedures for expanded polystyrene insulation can vary depending on the type and density of the insulation, type of roof deck, and type of roof membrane and securement method. Insulation and membrane manufacturers should be consulted for recommended application procedures.

- **Nailable Roof Decks:** Expanded polystyrene insulation can be mechanically attached in certain roof assembly configurations; however, expanded polystyrene roof insulation boards will not retain fasteners by themselves for purposes such as backnailing, etc. One method of mechanically attaching expanded polystyrene insulation is to attach both the expanded polystyrene insulation and a cover board with fasteners penetrating through the expanded polystyrene and the cover board layers.

  NRCA does not recommend direct mechanical fastening for the attachment of expanded polystyrene roof insulation without the use of a cover board. Failure to install a cover board may result in overcompression of the insulation at fastener plates, deformation of the expanded polystyrene adjacent to the fastener plate and a depression in the insulation's surface.

  Designers should consult the insulation and membrane manufacturers for their recommended mechanical attachment procedures. Information about fasteners used to attach the insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** When expanded polystyrene insulation is specified for use over a steel deck, a base layer of perlite insulation, gypsum board or other rigid, fire-rated material should be installed between the roof deck and expanded polystyrene insulation.

  Designers should consult membrane and insulation manufacturers for the minimum recommended thicknesses of base layer or deck overlayment board to be used over steel roof decks. Information about fasteners used to attach the insulation is provided in Section 6.2—Insulation Fasteners.

NRCA does not recommend direct mechanical fastening for the attachment of expanded polystyrene roof insulation without the use of a cover board. Failure to install a cover board may result in overcompression of the insulation at fastener plates, deformation of the expanded polystyrene adjacent to the fastener plate and a depression in the insulation's surface.

If low-rise foam adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturer of the adhesive, insulation and membrane regarding the appropriate type of adhesives and application rates.

- **Nonnailable Roof Decks:** Over dry, nonnailable roof decks, expanded polystyrene insulation may be adhered in adhesive approved by the insulation manufacturer. Priming the roof deck may be required to achieve adequate adhesion with this type of installation.

  Expanded polystyrene insulation is sensitive to hot asphalt; however, it can be used adhered in hot asphalt if the asphalt has been allowed to cool below 250 F and the asphalt is of a consistency to adequately adhere the board to the substrate. This leaves only a narrow application temperature range for applying the insulation into the cooling bitumen. The bitumen must be sufficiently hot to successfully adhere to the substrate, but it also needs to be cool enough so it does not melt the expanded polystyrene insulation material. NRCA does not recommend using hot bitumen to adhere layers of expanded polystyrene insulation.

Roof Membrane Application: Expanded polystyrene insulation can be damaged by solvents and solvent-based adhesives. Also, expanded polystyrene insulation is not compatible with hot asphalt heated to more than 250 F. Therefore, built-up, polymer-modified bitumen and adhered single-ply membranes should not be installed directly to expanded polystyrene insulation boards.

NRCA suggests a suitable insulation cover board, such as a layer of glass-faced gypsum board, fiber-reinforced gypsum board, stone wool, perlite board, wood fiberboard insulation or other compatible product intended for use as an insulation cover board, be used to protect and prepare the expanded polystyrene insulation for roof membrane application. It is important to stagger the joints of the cover board from the joints in the insulation layer below. NRCA suggests taping or sealing the joints between cover boards to restrict hot bitumen migration onto the expanded polystyrene.

Additional information regarding roof membrane application is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.4—Extruded Polystyrene (XPS)

Extruded polystyrene is sometimes referred to as XPS. Extruded polystyrene insulation is formed with a polystyrene polymer. The blended polystyrene polymer compound is heated, put through an extrusion process and exposed to normal atmospheric conditions so the material will expand. Closed cells are formed within the material during the expansion phase. The extrusion process provides a smooth, skin-like surface on the material.

The following recognized properties of polystyrene board roof insulation make it an effective insulating material:

- Compatibility with asphalt at low asphalt temperatures
- Component compatibility
- Impact resistance
- Durability
- Moisture resistance
- Thermal resistance
- Stable R-value

Typically, expanded polystyrene insulation is used in buildings with low-temperature interior spaces, such as refrigeration rooms, and in walls and roofs of other commercial, industrial and residential buildings.

Extruded polystyrene insulation should not be confused with expanded polystyrene insulation. Both products are based on a polystyrene polymer, but each has specific advantages and disadvantages.

Extruded polystyrene insulation is more weather-resistant and, therefore, is appropriate to be used in protected membrane roof systems and vegetative roof systems where insulation is not covered by a roof membrane. Expanded polystyrene insulation is produced in a wider variety of densities, thicknesses and R-values but is more sensitive to ultraviolet degradation and moisture absorption under certain conditions. Additional information regarding expanded polystyrene insulation is provided in Section 4.3—Expanded Polystyrene.

Manufacturing Process: The raw material, styrene, is made from derivatives of coke and crude oil. Styrene is polymerized to form polystyrene. A solution of blowing agent in molten polystyrene is formed in an extruder under pressure. The extrusion process produces a continuous flow of material containing interconnecting closed cells, not unlike shaving cream passing through the nozzle of a pressurized canister. The extruded polystyrene solution is forced through an orifice into ambient temperature and pressure conditions. The blowing agent then vaporizes and causes the polymer to expand about 30 times its original size. The polymer develops enough strength to maintain dimensional stability at the time of maximum expansion. After expansion, extruded polystyrene that has been formulated for use as roof insulation then is cut to the desired size and shape.

Product Standard: The U.S. product standard for extruded polystyrene insulation is ASTM C578, "Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation." ASTM C578 applies to expanded polystyrene and extruded polystyrene.

Within ASTM C578, there are 14 type classifications; seven of these define extruded polystyrene. The types are characterized by distinctive physical properties, including density and compressive strength. The following table shows the common types, minimum densities and minimum compressive strengths for extruded polystyrene based upon ASTM C578.

Extruded Polystyrene (XPS)		
ASTM C578 Classification	**Density (minimum), pounds per cubic foot**	**Compressive Strength (minimum), psi**
Type IV	1.45	25.0
Type V	3.00	100.0
Type VI	1.80	40.0
Type VII	2.20	60.0
Type X	1.30	15.0
Type XII*	1.20	15.0
Type XIII*	1.60	20.0

* XPS complying with ASTM C578, Type XII and Type XIII classifications generally is not intended for use in roofing applications.

Extruded polystyrene insulations complying with Type XII and Type XIII classifications generally are not intended to be used in roofing applications.

Typically, extruded polystyrene insulation with a minimum compressive strength of 25 psi complying with ASTM C578, Type IV classification, is used in roofing applications where the insulation is placed below the roof membrane. In protected membrane roof (PMR) designs where insulation is placed above the roof membrane, ASTM C578, Type VI extruded polystyrene insulation with a minimum compressive strength of 40 psi typically is used.

NRCA does not recommend the use of ASTM C578, Type X (15 psi compressive strength) extruded polystyrene insulation or any polystyrene board insulation with compressive strength of less than 20 psi be used in roofing applications.

High-compressive strength products having compressive strengths of 40 psi (Type VI), 60 psi (Type VII) or 100 psi (Type V) may be used where higher compressive strength values are desirable, such as in plaza deck applications.

When extruded polystyrene insulation is used, NRCA recommends designers specify extruded polystyrene insulation with a compressive strength appropriate for specific project conditions.

R-value: The R-values for expanded polystyrene insulation vary based upon their type classifications; the R-values range from 3.9 to 5.0 per inch thickness tested at a 75 F mean temperature. Generally, an R-value of 5.0 per inch thickness is used for extruded polystyrene insulation in roof applications.

Board Sizes and Thicknesses: Extruded polystyrene roof insulation is typically available in 2- by 4-foot and 2- by 8-foot boards. Typical board thicknesses are 1, 1½, 2, 2½, 3 and 4 inches. Tapered extruded polystyrene insulation is typically available in tapers of ⅛, ¼ and ½ inch per foot with a ½-inch minimum thickness.

Usage Guidelines: The following guidelines apply to usage of extruded polystyrene roof insulation.

Multilayer Insulation: Extruded polystyrene insulation can be used as a component of a properly designed multilayer insulation application.

Cover Board: NRCA recommends the use of a suitable cover board over extruded polystyrene before the installation of a roof membrane. Suitable cover boards include glass-faced gypsum board, fiber-reinforced gypsum board, stone wool, perlite board, high-density polyisocyanurate board, wood fiberboard or other compatible product intended for use as an insulation cover board. Cover boards are considered to be a component of a multilayer insulation application.

The following are additional notes for cover board installation:

- When adhering a cover board with hot asphalt, the cover board should be back-mopped.
- NRCA recommends using insulation joint tape at all cover board joints over extruded polystyrene insulation before applying bituminous roof membranes and adhered single-ply membranes. When taping insulation board joints, NRCA suggests an installation method, such as using mechanized taping equipment that limits the migration of bitumen or adhesive into the joints.
- Cover boards may be applicable for certain loose-laid, ballasted roof systems, as well as certain mechanically attached systems.

Combustibility: Extruded polystyrene insulation is combustible. Therefore, it should not be exposed to direct flame or high temperatures, such as those produced by heat welders or torches. Extruded polystyrene insulation should be used only in roof assemblies as recommended by the manufacturer.

Compatibility: Extruded polystyrene insulation materials are affected by exposure to the sun, organic solvents and adhesives. Therefore, roof system specifications incorporating polystyrene insulation and petroleum solvents, adhesives or hot bitumen should prevent or limit the contact between the extruded polystyrene insulation and potentially incompatible materials.

Extruded polystyrene insulation has a maximum recommended exposure temperature of 165 F. Extruded polystyrene insulation should not be used directly underneath exposed dark-colored roof membranes where reflected light or heat may cause excessive in-service membrane temperatures. In these situations, the installation of a suitable cover board may be adequate to provide a buffer between high membrane surface temperatures and extruded polystyrene insulation.

Extruded polystyrene insulation can melt and be damaged or destroyed by hot asphalt. Extruded polystyrene insulation can also be damaged or destroyed because of chemical incompatibilities with coal tar pitch, cold-process membrane applications and certain solvents used in adhesives and cleaning agents for single-ply membranes.

Extruded polystyrene insulation may need to be isolated from certain thermoplastic membranes by using a separator sheet to prevent damage to the membrane as a result of plasticizer migration.

Application and Securement: Installation procedures for extruded polystyrene insulation can vary depending on the type and density of the insulation, type of roof deck, and type of roof membrane and securement method. Insulation and membrane manufacturers should be consulted for the recommended application procedures.

- **Nailable Roof Decks:** Extruded polystyrene insulation can be mechanically attached in certain roof assembly configurations; however, extruded polystyrene insulation boards will not retain fasteners by themselves for purposes such as backnailing, etc. One method of mechanically attaching extruded polystyrene insulation is to attach the extruded polystyrene insulation and a cover board with fasteners penetrating through the extruded polystyrene and the cover board layers. Designers should consult the insulation and membrane manufacturers for their recommended mechanical attachment procedures.

  NRCA does not recommend direct mechanical fastening for the attachment of extruded polystyrene insulation without the use of a cover board. Failure to install a cover board may result in overcompression of the insulation at fastener plates, deformation of the extruded polystyrene insulation adjacent to the fastener plate and a depression in the insulation's surface.

Information about fasteners used to attach insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** When extruded polystyrene insulation is specified for use over a steel deck, NRCA suggests a base layer of perlite insulation, gypsum board or other rigid, fire-rated material be installed between the roof deck and extruded polystyrene insulation. Information about fasteners used to attach the insulation is provided in Section 6.2—Insulation Fasteners.

  NRCA does not recommend direct mechanical fastening for the attachment of extruded polystyrene insulation without the use of a cover board. Failure to install a cover board may result in overcompression of the insulation at fastener plates, deformation of the extruded polystyrene insulation adjacent to the fastener plate and a depression in the insulation's surface.

  If low-rise foam adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturer of the adhesive, insulation and membrane as to the appropriate type of adhesives and application rates.

- **Nonnailable Roof Decks:** Over dry, nonnailable roof decks, extruded polystyrene insulation may be adhered in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Extruded polystyrene insulation can be damaged by solvents and solvent-based adhesives. Extruded polystyrene insulation is not compatible with hot asphalt heated to more than 250 F. Therefore, built-up, polymer-modified bitumen and adhered single-ply membranes should not be installed directly to the unprotected topsides of extruded polystyrene insulation boards.

NRCA suggests a suitable insulation cover board, such as a layer of glass-faced gypsum board, fiber-reinforced gypsum board, stone wool, perlite board, wood fiberboard insulation or other compatible product intended for use as an insulation cover board, be used to protect and prepare the extruded polystyrene insulation for roof membrane application. It is important to stagger the joints of the cover board from the joints in the insulation layer below. NRCA suggests taping or sealing the joints between cover boards to restrict hot bitumen migration onto the extruded polystyrene.

Additional information regarding roof membrane application is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.5—Glass-faced Gypsum

Glass-faced gypsum used in roofing consists of a gypsum-based core sandwiched between fiberglass-mat facings. Several products are available with surface coatings applied to one or both sides and are intended to aid with the installation process.

Although glass-faced gypsum is not typically classified as an insulating product, information about glass-faced gypsum is included here because glass-faced gypsum is used in roof assemblies as a thermal barrier to provide fire resistance, substrates for air and vapor retarders, and cover boards beneath roof membranes.

The following recognized properties of glass-faced gypsum make it well-suited for use in roof assemblies:

- Adhesive compatibility
- Component compatibility
- Fire resistance
- Moisture resistance
- Stable R-value
- Attachment capability
- Dimensional stability
- Compressive strength

Manufacturers' product literature should be consulted for specific information regarding their products.

Manufacturing Process: The gypsum board core is composed of gypsum, Portland cement and/or combinations of additives and modifiers, and allowed to cure. Products are manufactured with top and bottom nonwoven fiberglass-mat facers.

Several glass-faced gypsum products are available with surface coatings applied to one or both sides and are intended to aid with the installation process.

Product Standard: ASTM C1177, "Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing," is the U.S. material standard applicable to glass-faced gypsum board. Glass-mat gypsum substrate and glass-mat gypsum substrate, Type X (special fire-resistant) are both addressed by ASTM C1177. Both types of glass-faced gypsum board are used in roofing applications. The standard states glass-faced gypsum substrate, Type X (special fire-resistant) designates ASTM C1177-compliant glass-mat gypsum substrate that provides not less than 1-hour fire-resistance rating for substrate ⅝-inch thick or ¾-hour fire-resistance rating for substrate ½-inch thick when tested as part of an assembly as specified in the standard.

R-value: Glass-faced gypsum has R-values based upon thicknesses as follows.

Glass-faced Gypsum	
Thickness (inches)	**R-value**
¼	0.28
½	0.56
⅝	0.67

Board Sizes and Thicknesses: Glass-faced gypsum is available in 4- by 4-foot and 4- by 8-foot board sizes. Available thicknesses of glass-faced gypsum include ¼-, ½- and ⅝-inch thicknesses.

Usage Guidelines: The following guidelines apply to usage of glass-faced gypsum.

Multilayer Insulation: Glass-faced gypsum can be used as a component of a properly designed multilayer insulation application.

Glass-faced gypsum is used as a thermal barrier to provide fire resistance over steel roof decks and other combustible substrates, substrates for air and vapor retarders, and cover boards beneath roof membranes.

Cover Board: Glass-faced gypsum is suitable for use as a cover board layer. Cover boards are considered to be components of a multilayer insulation assembly.

Combustibility: Glass-faced gypsum boards are non-combustible. Gypsum boards are inherently fire-resistant because of gypsum calcination. Calcination in gypsum boards is the process whereby gypsum's crystalline structure breaks down and chemically bound water is driven out. This weakens the compressive and structural strengths of the boards. Calcination begins to occur when the gypsum board is exposed to temperatures higher than about 130 F.

Application and Securement: Application procedures for gypsum boards can vary depending on the roof deck type and membrane specified. Glass-faced gypsum boards can be covered by mopping, torching, and using cold-applied or solvent-based adhesives. Priming may be required. Manufacturers' instructions should be consulted for application and recommendations.

- **Nailable Roof Decks:** NRCA recommends that a base sheet be mechanically fastened to nailable roof deck substrates. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners. Glass-faced gypsum then can be adhered to the base sheet using hot bitumen or cold-applied adhesive.

  Mechanical fastening is a common method for attaching the base layer of faced gypsum boards to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** NRCA recommends mechanical fastening or adhesive attachment of glass-faced gypsum to steel roof decks under all membranes except loose-laid ballasted roof membranes. Glass-faced gypsum can be mechanically attached to steel roof decks with various types of fasteners. The glass-faced gypsum board manufacturer should be consulted for acceptable types of fasteners and plates. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

  If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturers of the adhesive, insulation and membrane regarding the appropriate type of adhesive and application rate.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying glass-faced gypsum in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming of the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: NRCA is concerned with the potential for blister formation when applying hot- and torch-applied roof membranes directly over gypsum board substrates, including glass-faced gypsum board. NRCA cautions designers about specifying roof membrane systems using adhered base sheets and built-up membranes applied using the hot asphalt mopping method to glass-faced gypsum board roof insulation.

Furthermore, NRCA cautions designers in other situations where relatively high in-service membrane surface temperatures may cause calcination and facer-sheet delamination in adhered faced gypsum board products used directly beneath roof membranes. Examples of situations where relatively high in-service membrane surface temperatures may be experienced include dark-colored membranes in southern climates, reflective roof surfaces that experience reflected sunlight and adhered photovoltaic installations.

Additional information about roof membrane installation over glass-faced gypsum insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.6—Fiber-reinforced Gypsum

Fiber-reinforced gypsum board used in roofing consists of cellulose fiber-reinforced gypsum that is factory-formed into a rigid board product.

Although fiber-reinforced gypsum is not typically classified as an insulating product, information about fiber-reinforced gypsum is included here because it is used in roof assemblies as a thermal barrier to provide fire resistance, substrate for air and vapor retarders, and cover board beneath roof membranes.

The following recognized properties of fiber-reinforced gypsum make it well-suited for use in roof assemblies:

- Bitumen and adhesive compatibility
- Component compatibility
- Fire resistance
- Moisture resistance
- Stable R-value
- Attachment capability
- Dimensional stability
- Compressive strength

Manufacturers' product literature should be consulted for specific information regarding their product.

Manufacturing Process: Fiber-reinforced gypsum is composed of gypsum, Portland cement and cellulose fibers and allowed to cure.

Product Standard: The U.S. product standard for fiber-reinforced gypsum is ASTM C1278, "Standard Specification for Fiber-Reinforced Gypsum Panel." Interior fiber-reinforced gypsum panels; water-resistant fiber-reinforced gypsum backing panels; exterior fiber-reinforced gypsum soffit panels; water-resistant exterior fiber-reinforced gypsum sheathing panels; interior fiber-reinforced gypsum underlayment panels and fiber-reinforced gypsum roof board panels are all addressed by ASTM C1278. For roofing applications, fiber-reinforced gypsum roof board panels, Type X (special fire-resistant) are generally used. The standard states fiber-reinforced gypsum panels, Type X (special fire-resistant) designates ASTM C1278-compliant fiber-reinforced gypsum panels that provide not less than 1-hour fire-resistance rating for panels ⅝-inch thick or ¾-hour fire-resistance rating for panels ½-inch thick when tested as part of an assembly as specified in the standard.

R-value: Fiber-reinforced gypsum has R-values based upon thicknesses as follows.

Fiber-reinforced Gypsum	
Thickness (inches)	**R-value**
¼	0.2
⅜	0.3
½	0.5
⅝	0.6

Board Sizes and Thicknesses: Fiber-reinforced gypsum is available in 4- by 4-foot and 4- by 8-foot board sizes. Available thicknesses of fiber-reinforced gypsum are ¼-, ⅜-, ½- and ⅝-inch thicknesses.

Usage Guidelines: The following guidelines apply to usage of gypsum board roof insulation.

Multilayer Insulation: Fiber-reinforced gypsum can be used as a component of a properly designed multilayer insulation application.

Fiber-reinforced gypsum is used as a thermal barrier to provide fire resistance over steel roof decks and other combustible substrates, substrates for air and vapor retarders, and cover boards beneath roof membranes.

Cover Board: Fiber-reinforced gypsum board roof insulation is suitable for use as a cover board layer. Cover boards are considered to be a component of a multilayer insulation application.

Combustibility: Fiber-reinforced gypsum is noncombustible. They can be exposed directly to hot bitumen; torch flame; or high temperatures, such as those produced by heat welders. Gypsum boards are inherently fire-resistant because of gypsum calcination. Calcination, a process where the crystalline structure breaks down and bound water of hydration is driven out, occurs when the board is exposed to temperatures higher than about 130 F. This weakens the compressive and structural strengths of the boards.

Compatibility: Gypsum products are inherently temperature-sensitive to hot-applied asphalts and torch-applied membranes. Fiber-reinforced gypsum products should be protected from prolonged exposure to high temperatures during application of hot-applied roof systems.

Application and Securement: Application procedures for fiber-reinforced gypsum boards can vary depending on the roof deck type and membrane specified. Fiber-reinforced gypsum boards can be covered by mopping, torching, and using cold-applied or solvent-based adhesives. Priming may be required. Manufacturers' instructions for application and recommendations should be consulted.

- **Nailable Roof Decks:** NRCA recommends that a base sheet be mechanically fastened to nailable roof deck substrates. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners. Fiber-reinforced gypsum then can be adhered to the base sheet using hot bitumen or cold-applied adhesive.

  Mechanical fastening is a common method for attaching the base layer of fiber-reinforced gypsum boards to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** NRCA recommends mechanical fastening or adhesive attachment of fiber-reinforced gypsum to steel roof decks under all membranes except loose-laid ballasted roof membranes. Fiber-reinforced gypsum can be mechanically attached to steel roof decks with various types of fasteners. The fiber-reinforced gypsum board manufacturer should be consulted for acceptable types of fasteners and plates. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

  If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturers of the adhesive, insulation and membrane regarding the appropriate type of adhesive and application rate.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying fiber-reinforced gypsum in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming of the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Information about roof membrane installation over fiber-reinforced gypsum is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.7—Stone Wool

Stone wool insulation intended for roofing purposes is manufactured as a rigid insulating material. It is manufactured using rock, slag or glass, but rock is often the base ingredient. Natural and synthetic mineral materials may be combined, heated until molten and then spun into a fibrous material that is often referred to as stone wool. The stone wool fibers are bound together with a binding agent to form a rigid insulation board. Composite stone wool insulation constructed of a higher-density top layer and lower-density bottom layer is available. Stone wool boards top-coated with asphalt for use with bituminous roof membranes also are available.

The following recognized properties of stone wool insulation make it an effective insulating material:

- Bitumen and adhesive compatibility
- Component compatibility
- Fire resistance
- Durability
- Thermal resistance
- Stable R-value
- Dimensional stability

Manufacturing Process: The first step in the manufacturing process of stone wool insulation involves melting the mineral material. A blast furnace-type melting apparatus is used to heat the materials to a molten state, and the liquid is drawn off over cylindrical wheels that are spinning at high speed. While the liquid is moving over the rotating wheels, air is blown over it at high velocity. This cools the streams of spinning material into fine, solid fibers. Once the stone wool fibers are formed, they are bonded together with a formaldehyde-based solution.

Product Standard: The U.S. product standard for stone wool insulation used in roofing applications is ASTM C726, "Standard Specification for Mineral Fiber Roof Insulation Boards." Also, sometimes ASTM C612, "Standard Specification for Mineral Fiber Block and Board Thermal Insulation," is used to define stone wool insulation. ASTM C726 includes the following applicable classifications:

- Type I—Roof insulation board comprised of a monolithic fibrous material having a fibrous high-density upper surface layer and a lower-density fibrous bottom layer
  - Class I—Minimum upper surface layer actual density of 11.2 lb/ft^3 and a minimum lower layer actual density of 7.5 lb/ft^3
  - Class II—Upper surface layer and lower surface layer density less than Class I
- Type II—Roof insulation board of singular density
  - Class I—Minimum actual density of 9 lb/ft^3
  - Class II—Actual density less than Class I

R-value: Stone wool insulation has R-values based upon type as follows:

Stone Wool	
Type	**R-value (per inch thickness)**
Type I Top layer density = 13.75 lb/ft^3 Bottom layer density = 10.0 lb/ft^3	3.8
Type II Density = 12.5 lb/ft^3	4.0

Board Sizes and Thicknesses: Stone wool insulation is typically available in 4- by 4-foot board size and thicknesses ranging from 1 to 6 inches.

Usage Guidelines: The following guidelines apply to usage of stone wool insulation.

Multilayer Insulation: Stone wool insulation can be used as a component of a properly designed multilayer insulation application. When the total required thickness of the stone wool insulation is more than 1½ inches, NRCA recommends designers specify the stone wool insulation as multiple layers with offset and staggered board joints.

Cover Board: Stone wool roof insulation is suitable for use as a cover board layer. Cover boards are considered to be a component of a multilayer insulation application.

Combustibility: Stone wool roof insulation is noncombustible. It can be exposed directly to hot bitumen, torch flame or high temperatures, such as those produced by heat welders.

Application and Securement: Application procedures for stone wool insulation can vary depending on the roof deck type and roof membrane specified. The manufacturers of the insulation and the roof membrane should be consulted for the recommended application procedures.

- **Nailable Roof Decks:** NRCA recommends that a base sheet be mechanically fastened to nailable roof deck substrates. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners. Stone wool insulation then can be adhered to the base sheet using hot bitumen or cold-applied adhesive.

  Mechanical fastening is a common method for attaching the base layer of stone wool insulation to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** Stone wool insulation can be mechanically attached to a suitable roof deck with various types of fasteners. However, stone wool insulation can compress when fasteners are overdriven. Stone wool insulation will not retain fasteners by themselves for such purposes as backnailing, etc. NRCA recommends mechanical fastening of the base layer of stone wool insulation to steel roof decks under all membranes except loose-laid, ballasted membranes. The manufacturers of the insulation and roof membrane should be consulted for their requirements regarding minimum thicknesses of insulation when specifying stone wool insulation over steel roof decks.

  If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturers of the adhesive, insulation and membrane regarding the appropriate type of adhesive and application rate.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying stone wool insulation in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Information about roof membrane installation over stone wool insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.8—Perlite

Perlite board insulation intended for roofing purposes is a rigid insulating material manufactured from expanded volcanic minerals combined with organic fibers and binders. The top surface of perlite board roof insulation is generally treated with an asphalt emulsion to minimize bitumen absorption. The common R-value used to calculate the total thermal resistance of a perlite board insulation system is 2.78 per inch of thickness.

The following recognized properties of perlite board insulation make it an effective insulating material:

- Bitumen and adhesive compatibility
- Component compatibility
- Impact resistance
- Fire resistance
- Thermal resistance
- Stable R-value
- Attachment capability

Manufacturing Process: Perlite ore is a volcanic glass found in abundance in mountainous areas. The ore is extracted from the earth and then crushed, screened and graded for ultimate expansion into particle sizes suitable for a variety of end uses.

Perlite ore, in its natural state, ranges in color from a transparent light gray to glossy black and has a combined water content of 2 percent to 6 percent.

The water content characteristic of perlite ore allows the ore to expand from four to 20 times its initial volume when subjected to a temperature of about 1,700 F. At this temperature, the combined water vaporizes and the ore expands, or “pops,” into glass spheroids.

Expanded perlite ore is a principal ingredient in perlite roof insulation. During manufacture, a water slurry composed of expanded perlite, cellulose fiber, a small amount of asphalt and, in some cases, starch is formulated and deposited onto a moving screen. Excess process water is extracted through the carrier screen. The partially dried mass of slurry solids is pulled continuously through an oven or dryer to form the insulation board. As the insulation board exits the dryer, it is cut to size.

Product Standard: The U.S. product standard for perlite board insulation is ASTM C728, "Standard Specification for Perlite Thermal Insulation Board." The standard provides a classification for three types of perlite insulation board: Type 1, Roof Insulation Board; Type 2, Roof Cover or Re-cover Board; and Type 3, Roof Cover or Re-cover Board. Type 1 perlite board insulation typically is manufactured as ¾-inch- or 1-inch-thick layers, which are laminated to achieve boards with thicknesses greater than 1 inch. The ½-inch Type 1 perlite board insulation only is used in the manufacture of laminated composite board roof insulation products. Type 2 perlite board insulations are used primarily as cover boards over other roof insulation or in re-cover applications. Type 3 perlite board insulations are used primarily as cover boards in reroofing or re-cover applications. Perlite board insulation is available as flat stock and as tapered stock that may be used to provide slope for roof drainage.

R-value: Perlite board insulation has R-values based upon thicknesses as follows:

Perlite	
Thickness (inches)	**R-value**
½	1.39
¾	2.08
1	2.78
1½	4.17
2	5.56

Board Sizes and Thicknesses: Perlite is available in 2- by 4-foot and 4- by 4-foot board sizes and thicknesses of ¾, 1, 1½ and 2 inches.

Tapered perlite board insulation is also available.

Usage Guidelines: The following guidelines apply to usage of perlite insulation.

Multilayer Insulation: Perlite board insulation can be used as a component of a properly designed multilayer insulation application. When perlite insulation is used as the primary insulation layer, two-layer usage is recommended to allow for offsetting and staggering board joints.

Cover Board: Perlite board insulation is suitable for use as a cover board layer for built-up and polymer-modified bitumen membrane roof systems. Cover boards are considered to be a component of a multilayer insulation application.

Combustibility: Perlite board insulation is generally considered to be noncombustible. It can be exposed directly to hot bitumen. When a roof membrane is installed using torch flames or heat welders, precautions should be taken to prevent excessive heat buildup or combustion of perlite board insulation.

Application and Securement: Application procedures for perlite board insulation can vary depending on roof deck type and roof membrane specified. Insulation and membrane manufacturers should be consulted for the recommended application procedures.

- **Nailable Roof Decks:** Because of perlite board insulation's hygroscopic nature, NRCA recommends mechanically attaching a base sheet or vapor retarder to the nailable roof deck and adhering the perlite roof insulation in hot bitumen or cold-applied adhesive. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners.

  Mechanical fastening is a common method of attaching a base layer of perlite board insulation to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** Perlite board insulation can be mechanically attached to a suitable roof deck with various types of fasteners. NRCA recommends mechanical fastening of the base layer of perlite board insulation to steel roof decks under all membranes except loose-laid, ballasted membranes. Manufacturers of the insulation and roof membrane should be consulted for their requirements regarding minimum thicknesses of insulation when specifying perlite board insulation over steel roof decks.

If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturers of the adhesive, insulation and membrane regarding the appropriate type of adhesive and application rate.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying perlite board insulation in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Information about roof membrane installation over perlite insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.9—Polyisocyanurate

Polyisocyanurate insulation used in roofing is a rigid insulation material manufactured from closed-cell, polyisocyanurate rigid foam sandwiched between two facers. Facers include aluminum foils; fiberglass-reinforced cellulosic mats; coated or uncoated polymer-bonded fiberglass mats; or other rigid board materials, including perlite board insulation, wood fiberboard insulation and oriented strand board.

Where rigid board materials are used as a laminated facer, NRCA considers these products to be composite board insulation.

The following recognized properties of polyisocyanurate insulation make it an effective insulation material:

- Bitumen and adhesive compatibility
- Component compatibility
- Impact resistance
- Fire resistance
- Durability
- Moisture resistance
- Thermal resistance
- Attachment capability

Manufacturing Process: Polyisocyanurate insulation is manufactured through a controlled chemical reaction. Primary chemicals are metered and mixed at a specific temperature, and the mixture is applied to a moving base platen. Once the mixture is combined, the chemical blowing agent reacts with a catalyst to cause the liquid to quickly rise and form into cellular foam. In a matter of seconds, the liquid mixture becomes a solid, lightweight and thermally resistant material.

To create polyisocyanurate insulation, the closed-cell rigid foam stock is bonded to reinforcing facer material as the foam rises during the manufacturing process. Once the facers are bonded, the board stock is cut to size and should be allowed to cure before distribution.

Product Standard: The U.S. product standard for faced polyisocyanurate insulation is ASTM C1289, "Standard Specification for Faced Rigid Board Cellular Polyisocyanurate Thermal Insulation." This standard includes the following applicable classifications:

- Type I—Aluminum foil-faced on top and bottom sides:
  - Class 1—Nonreinforced polyisocyanurate foam core
  - Class 2—Fiberglass-reinforced polyisocyanurate foam core
- Type II—Mat-faced on top and bottom sides:
  - Class 1—Faced with fiberglass-reinforced cellulosic mat facers or coated or uncoated polymer-bonded fiberglass-mat facers on top and bottom sides
    - Grade 1—16 pounds per square inch (psi) minimum compressive strength polyisocyanurate foam core
    - Grade 2—20 psi minimum compressive strength polyisocyanurate foam core

  - Grade 3—25 psi minimum compressive strength polyisocyanurate foam core
- Class 2—Faced with coated polymer-bonded fiberglass-mat facers on top and bottom sides
- Class 3—Faced with uncoated polymer-bonded fiberglass-mat facers on top and bottom sides

Type I products are generally used in wall sheathing applications, and, because of their facers and the foam's compressive strength, they are generally considered not to be appropriate for roof applications. Type II generally designates products appropriate for roofing applications. Type II, Class 1 products may be suitable with all roof system types. NRCA recommends Type II, Class 2 products be used with single-ply membrane roof systems using water-based bonding adhesives. Type II, Class 3 products may be suitable with hot-applied built-up and polymer-modified bitumen roof systems.Type II also has a Class 4 that designates high-density polyisocyanurate panels intended for use as roof insulation cover boards at a maximum thickness of ½ of an inch. Section 4.10—High-density Polyisocyanurate addresses Type II, Class 4 materials.

ASTM C1289 also includes four additional product types, Type III, Type IV, Type V and Type VII, to address products that use polyisocyanurate insulation to fabricate various types of composite board insulation. See Section 4.14—Composite Board for information about these product types.

NRCA recommends polyisocyanurate insulation used in low-slope membrane roof assemblies be manufactured to have a minimum of 20 psi compressive strength (Grade 2 or Grade 3) and facer sheets that are compatible with the assembly method and other components of the roof assembly.

R-value: Effective Jan. 1, 2014, the Polyisocyanurate Insulation Manufacturers Association (PIMA) QualityMark^CM voluntary third-party certification program for the thermal value of polyisocyanurate insulation products began reporting polyisocyanurate LTTR values in accordance with ASTM C1289-11a.

In ASTM C1289-11a, the section addressing LTTR was revised to reference ULC-S770-09, "Standard Test Method for Determination of Long-Term Thermal Resistance of Thermal Insulating Foams" and ASTM C1303-11, "Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation" as two methods permitted for use for determining and reporting LTTR values. Earlier ASTM C1289 revisions referenced CAN/ULC-S770-03 in this section and the same test method also had been used to determine and report LTTR values through PIMA's QualityMark program since 2004.

The integration into QualityMark of the revised LTTR test methods resulted in polyisocyanurate LTTR values that are lower by approximately 7 percent than the LTTR values roofing professionals had previously been accustomed to using.

Individual polyisocyanurate insulation manufacturers may publish product- and thickness-specific LTTR values greater than those reported through the QualityMark program.

Definitions provided in CAN/ULC-S770 and ASTM C1303 state "long-term" in LTTR indicates a period of five years. The standards indicate the R-values produced by the LTTR method correspond to the thermal resistances measured for polyisocyanurate insulation materials stored in controlled laboratory conditions until they have aged five years. These values correspond closely to calculated 15-year time-weighted R-value averages for polyisocyanurate insulation. The five-year aged values of the LTTR method are developed from an R-value versus time relationship constructed from measurements of thin-sliced specimens obtained at a 75 F mean-temperature test condition at various defined intervals over a much shorter time period.

Although using thermal resistance values for laboratory-aged insulation at five years of age, as defined in the LTTR method, may be appropriate for laboratory analysis, research comparison and procurement purposes, NRCA does not consider five years a long-term period for determining roof insulation thermal resistance for design and in-service performance purposes.

NRCA recommends designers specifying polyisocyanurate insulation determine roof system thermal resistance using an in-service R-value of 5.0 per inch.

The following table provides QualityMark minimum LTTR values and NRCA-recommended design R-values for commonly available thicknesses of polyisocyanurate insulation board. The slightly increasing LTTR per inch thickness values indicate lower cell gas diffusion rates with thicker polyisocyanurate products.

Polyisocyanurate		
Board Thickness (inches)	QualityMark Minimum LTTR values	NRCA-recommended Design R-values
1.0	5.6	5.0
1.1	6.2	5.5
1.2	6.7	6.0
1.3	7.3	6.5
1.4	7.9	7.0
1.5	8.5	7.5
1.6	9.1	8.0
1.7	9.6	8.5
1.8	10.2	9.0
1.9	10.8	9.5
2.0	11.4	10.0
2.1	12.0	10.5
2.2	12.6	11.0
2.3	13.2	11.5
2.4	13.8	12.0
2.5	14.4	12.5
2.6	15.0	13.0
2.7	15.6	13.5
2.8	16.2	14.0
2.9	16.8	14.5
3.0	17.4	15.0
3.1	18.0	15.5
3.2	18.6	16.0
3.3	19.2	16.5
3.4	19.9	17.0
3.5	20.5	17.5
3.6	21.1	18.0
3.7	21.7	18.5
3.8	22.3	19.0
3.9	23.0	19.5
4.0	23.6	20.0

Furthermore, NRCA recommends designers specify polyisocyanurate insulation by its desired thickness and not LTTR or R-value to avoid possible confusion.

Board Sizes and Thicknesses: Polyisocyanurate insulation is commonly available in 4- by 4-foot and 4- by 8-foot board sizes. Available thicknesses range from 1 to 4 inches thick.

When flatstock, rigid board polyisocyanurate insulation is considered in a roof system design, NRCA recommends the designer specify the polyisocyanurate insulation be installed in multiple layers with a 1½-inch minimum and 2½-inch maximum board thickness. For example, when a designer is considering a 5-inch thickness of polyisocyanurate insulation, NRCA suggests two layers of 2½-inch-thick polyisocyanurate insulation be specified. When tapered-board polyisocyanurate insulation is considered in a roof design, NRCA recommends a maximum 2½-inch thickness for tapered boards and a maximum 4-inch thickness for flat fill boards.

NRCA also recommends designers specify a maximum 4- by 4-foot board size for polyisocyanurate insulation adhered to a substrate. The 4- by 8-foot board size is appropriate for loosely laid and mechanically attached applications.

Usage Guidelines: The following guidelines apply to usage of polyisocyanurate insulation.

Multilayer Insulation: The NRCA recommended specification for polyisocyanurate insulation is for multilayer application, especially when the total required insulation thickness is more than 2½ inches. NRCA also recommends designers specify a suitable cover board over polyisocyanurate insulation in all low-slope membrane roof systems. Cover boards are considered to be components of a multilayer insulation assembly.

Cover Boards: NRCA recommends the use of a suitable cover board layer over polyisocyanurate insulation before the installation of roof membrane.

Combustibility: Polyisocyanurate insulation is combustible. It should not be subjected to long-term exposure of high temperatures or sustained high temperatures, or exposed to direct flame.

Application and Securement: Application procedures for polyisocyanurate insulations can vary depending on the roof deck type and roof membrane specified. Insulation and membrane manufacturers should be consulted for recommended application procedures.

- **Nailable Roof Decks:** NRCA recommends that a base sheet be mechanically fastened to nailable roof deck substrates. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners. Polyisocyanurate insulation then can be adhered to the base sheet using hot bitumen or manufacturer-approved adhesive.

Mechanical fastening is a common method for attaching the base layer of polyisocyanurate insulation to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** Polyisocyanurate insulation can be mechanically attached to a suitable roof deck with various types of fasteners. NRCA recommends mechanical fastening of the base layer of polyisocyanurate insulation to steel roof decks under all membranes except loose-laid ballasted membranes. Manufacturers of the insulation and roof membrane should be consulted for their requirements regarding minimum thicknesses of insulation when specifying polyisocyanurate insulation over steel roof decks.

  If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturers of the adhesive, insulation and membrane regarding the appropriate type of adhesive and application rate.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying polyisocyanurate insulation in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Because the potential for blister formation exists when hot bitumen is applied directly to polyisocyanurate insulation, hot-applied bituminous roof membranes should not be adhered directly to the polyisocyanurate insulation. If polyisocyanurate insulation is specified for use in hot-applied bituminous systems and the polyisocyanurate insulation will have hot bitumen applied onto or over it, NRCA recommends using a suitable insulation cover board, such as a layer of stone wool, perlite board, asphalt-impregnated wood fiberboard or other compatible product intended for that use. Typically, the cover board is adhered to the polyisocyanurate insulation facer with hot bitumen to prepare the foam insulation for hot bituminous membrane application. When a cover board is used, it is important to stagger the joints of the cover board from the joints in the insulation layer below.

4.10—High-density Polyisocyanurate

High-density polyisocyanurate insulation is a rigid insulation material manufactured from closed-cell, polyisocyanurate rigid foam sandwiched between two coated or uncoated polymer-bonded fiberglass mats.

High-density polyisocyanurate insulation differs from conventional polyisocyanurate roof insulation, such as that described in Section 4.9—Polyisocyanurate, primarily by its compressive strength. Depending on its grade, high-density polyisocyanurate insulation has minimum compressive strength values of 80 pounds per square inch (psi), 100 psi and 140 psi, and conventional polyisocyanurate insulation has minimum compressive strength values of 16 psi, 20 psi and 25 psi depending upon its grade.

The following recognized properties of high-density polyisocyanurate make it well-suited for use in roof assemblies:

- Adhesive compatibility
- Component compatibility
- Impact resistance
- Fire resistance
- Durability
- Moisture resistance
- Attachment capability

Manufacturing Process: High-density polyisocyanurate insulation is manufactured through a controlled-chemical reaction. Primary chemicals are metered and mixed at a specific temperature, and the mixture is applied to a moving base platen. Once the mixture is combined, the chemical blowing agent reacts with a catalyst to cause the liquid to quickly rise and form into cellular foam. In a matter of seconds, the liquid mixture becomes a solid, lightweight and thermally resistant material.

To create high-density polyisocyanurate insulation, the closed-cell rigid foam stock is bonded to reinforcing facer material as the foam rises during the manufacturing process. Once the facers are bonded, the board stock is cut to size and should be allowed to cure before distribution.

Product Standard: Beginning with its 2012 revision, ASTM C1289, "Standard Specification for Faced Rigid Board Cellular Polyisocyanurate Thermal Insulation," which is the standard applicable to conventional faced polyisocyanurate insulation, also provides material specification requirements for high-density polyisocyanurate board insulation, which it classifies as Type II, Class 4 material in three grades:

- Grade 1—80 psi minimum compressive strength polyisocyanurate foam core
- Grade 2—110 psi minimum compressive strength polyisocyanurate foam core
- Grade 3—140 psi minimum compressive strength polyisocyanurate foam core

Manufacturers should be consulted for specific physical property information.

R-value: Beginning with its 2012 revision, ASTM C1289 provides minimum R-value requirements for ¼-inch- and ½-inch-thick high-density polyisocyanurate boards. The standard requires application of the long-term thermal resistance (LTTR) method for determining and reporting R-value for high-density polyisocyanurate insulation; however, high-density polyisocyanurate boards primarily are used as cover boards because of their high compressive strength and not for their R-value.

High-density polyisocyanurate insulation manufacturers currently report R-values obtained using a test method that is not included in the LTTR method. The R-values currently reported are 1.0 for ¼-inch-thick boards and 2.5 for ½-inch-thick boards.

Board Sizes and Thicknesses: High-density polyisocyanurate roof insulation is typically available in 4- by 4-foot and 4- by 8-foot board sizes. Available thicknesses include ¼-, ⅜-, and ½-inch products and may vary by manufacturer.

Usage Guidelines: The following guidelines apply to the use of high-density polyisocyanurate insulation.

Cover Boards: High-density polyisocyanurate insulation is suitable for use as a cover board.

Combustibility: High-density polyisocyanurate roof insulation is combustible. It should not be exposed to direct flame or high temperatures.

Application and Securement: Application procedures for polyisocyanurate insulation can vary depending on the roof deck type and roof membrane specified. Insulation and membrane manufacturers should be consulted for recommended application procedures.

- **Nailable Roof Decks:** Mechanical fastening is a common method for attaching high-density polyisocyanurate insulation to certain types of nailable roof decks. If a base sheet first is mechanically fastened to the deck, manufacturer-approved adhesive may be used to adhere the insulation.

  Additional information about fasteners for use with high-density polyisocyanurate insulation over nailable roof decks is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** High-density polyisocyanurate insulation can be mechanically attached to a suitable roof deck with various types of fasteners. High-density polyisocyanurate insulation boards will not retain fasteners by themselves for such purposes as backnailing, etc. NRCA recommends mechanical fastening for attaching high-density polyisocyanurate insulation to steel roof decks under all membranes except loose-laid, ballasted systems.

  Additional information about fasteners for use with high-density polyisocyanurate insulation over steel roof decks is provided in Section 6.2—Insulation Fasteners.

  If foam or liquid-applied adhesive will be used to adhere insulation to steel decks, NRCA recommends obtaining agreement from the manufacturer of the adhesive, insulation and membrane as to the appropriate type of adhesive and its application rate.

- **Nonnailable Roof Decks:** Over dry, nonnailable roof decks, NRCA recommends applying high-density polyisocyanurate insulation in manufacturer-approved adhesive over the properly prepared deck.

Roof Membrane Application: Because the potential for blister formation exists when hot bitumen is applied directly to high-density polyisocyanurate insulation, hot-applied bituminous roof membranes should not be adhered directly to the high-density polyisocyanurate insulation. Additional information regarding roof membrane application over high-density polyisocyanurate foam board roof insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.11—Wood Fiberboard

Wood fiberboard insulation intended for roofing purposes is a rigid insulating material manufactured from wood or cane fibers and various binders. The common R-value used to calculate the total thermal resistance of a wood or cane fiberboard insulation system is about 2.78 per inch of thickness.

The following recognized properties of wood fiberboard roof insulation make it an effective insulating material:

- Bitumen and adhesive compatibility
- Component compatibility
- Impact resistance
- Durability
- Thermal resistance
- Stable R-value
- Attachment capability
- Dimensional stability

Wood-fiber "sheathing" boards generally do not possess sufficient physical properties to be suitable for use as roof insulation. Designers should be aware of differences between wood fiberboard roof insulation and wood-fiber sheathing and specify them only for their intended use.

Manufacturing Process: A water slurry composed of cellulose fibers, binders and, in some types of wood fiberboard material, a small percentage of asphalt is formulated and deposited onto a moving screen. A wet mass of slurry solids is left as the water drains through the moving screen. The wet mass is heated in an oven or dryer to form the rigid insulation board.

Product Standard: The U.S. product standard for wood fiberboard roof insulation is ASTM C208, "Standard Specification for Cellulosic Fiber Insulating Board." There are six types of cellulosic-fiber insulating board covered by ASTM C208. Type II is roof insulation board. Grade 1 is primed and designed primarily for use under built-up and polymer-modified bitumen roof membranes. Grade 2 is unprimed and designed primarily for use under single-ply roof, built-up and polymer-modified bitumen roof membranes and generally has higher density and higher-quality physical properties. The finished product is produced in different forms:

- Plain
- Coated with asphalt (on all six sides)
- Impregnated with asphalt

R-value: The common R-value used to calculate the total thermal resistance of a wood or cane fiberboard insulation system is about 2.78 per inch of thickness.

Board Sizes and Thicknesses: Wood fiberboard roof insulation is available in 2- by 4-foot, 4- by 4-foot and 4- by 8-foot board sizes. Available thicknesses include ½-, 1- and 2-inch thicknesses.

Tapered wood fiberboard insulation is also available.

Usage Guidelines: The following guidelines apply to usage of wood fiberboard insulation.

Multilayer Insulation: The recommended specification is for multilayer insulation, especially when the total required thickness of the insulation is more than 1½ inches.

When wood fiberboard roof insulation is used as the primary insulation layer, two-layer usage is recommended to allow for offsetting and staggering board joints.

Cover Board: Wood fiberboard roof insulation is suitable for use as a cover board layer for built-up and polymer-modified bitumen membrane roof systems. Cover boards are considered to be components of a multilayer insulation assembly.

Combustibility: Wood fiberboard roof insulation is combustible. Therefore, it should not be directly exposed to flame or high temperatures, such as those produced by heat welders or torches. Wood fiberboard insulation should be used only in configurations recommended by the manufacturer. When installing membranes fabricated with hot-air-welded seams, precautions should be taken to prohibit excess temperature buildup or combustion on wood fiberboard substrates.

Application and Securement: Application procedures for wood fiberboard insulation can vary depending on the roof deck type and roof membrane specified. Insulation and membrane manufacturers should be consulted for the recommended application procedures.

- **Nailable Roof Decks:** Because of wood fiberboard roof insulation's hygroscopic nature, NRCA recommends mechanically attaching a base sheet or vapor retarder to the nailable roof deck and adhering the wood fiberboard insulation in hot bitumen or manufacturer-approved adhesive. Information about base sheet fasteners is provided in Section 6.1—Base Sheet Fasteners.

  Mechanical fastening is a common method of attaching a base layer of wood fiberboard insulation to certain types of nailable roof decks. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Steel Roof Decks:** Wood fiberboard insulation can be mechanically attached to a suitable roof deck with various types of fasteners. The insulation manufacturer's recommendations should be consulted for mechanical attachment information. Information about fasteners used to attach the base layer of rigid board insulation is provided in Section 6.2—Insulation Fasteners.

- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying wood fiberboard insulation in hot bitumen or manufacturer-approved adhesive over the properly prepared deck. Priming the deck may be required with this type of installation.

Generally, low-rise foam and liquid-applied adhesive can be used to attach wood fiberboard insulation that is coated with asphalt or impregnated with asphalt and does not present a dusty surface. If low-rise foam or liquid-applied adhesive will be used to adhere insulation to roof decks, NRCA recommends obtaining agreement from the manufacturer of the adhesive, wood fiberboard insulation and roof membrane as to the appropriate type of adhesive and its application rate. Wood fiberboard insulation and membrane manufacturers should be consulted for their requirements regarding minimum thicknesses of insulation when specifying wood fiberboard insulation over roof decks.

Roof Membrane Application: Information about roof membrane installation over wood fiberboard insulation is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.12—Asphalt Core Board

Asphalt core boards used in roofing are semi-rigid, multiply panels constructed of a core of water-insoluble mineral filler with bituminous binder sandwiched between two reinforcing facings. The panel core commonly is composed of crushed limestone and air-blown asphalt binder or modified asphalt binder. The reinforcing facings typically are fiberglass mats.

Although asphalt core board typically is not classified as an insulating product, information about asphalt core board is included here because it is used in roofing applications as a cover board over primary insulation and separation board in re-cover applications.

Currently, there are no recognized standard material specifications for asphalt core board materials for roofing applications.

The following recognized properties of asphalt core board make it well-suited for use in membrane roof assemblies:

- Asphalt compatibility
- Component compatibility
- Impact resistance
- Fire resistance
- Moisture resistance

- Attachment capability
- Dimensional stability
- Compressive strength

Manufacturers' product literature should be consulted for product-specific information.

Manufacturing Process: Crushed mineral filler is heated and mixed with hot asphaltic binder to yield a uniform paste that is delivered between two continuously fed webs of fiberglass mat. The webs align and converge to pass inside a pair of parallel steel rollers. The paste fills the gap and adheres to the facings. The roller spacing controls the finished product thickness. The combined sheet is redirected over support rollers. It is cooled, trimmed on the sides and cut into panels that are stacked and packaged for shipment.

R-value: Asphalt core board is used as a cover board and not for its R-value. Asphalt core board manufacturers typically do not publish asphalt core board R-values. Designers should contact the asphalt core board manufacturer for specific product R-values.

Board Sizes and Thicknesses: Asphalt core board for roofing applications typically is available as 4- by 4-foot, 4- by 5-foot and 4- by 8-foot panels that are ⅛-inch, 3⁄16-inch or ¼-inch in thickness. Other panel sizes and thicknesses may be available, depending on manufacturer.

Usage Guidelines: The following guidelines apply to usage of asphalt core board in roofing applications.

Multilayer Insulation: Asphalt core board may be used as a component of a properly designed multilayer insulation application.

Cover Board: Asphalt core board is suitable for use as a cover board layer beneath compatible roof membranes. Roof membranes compatible with asphalt core board include built-up roof membranes and polymer-modified bitumen roof membranes. Cover boards are considered to be components of a multilayer insulation assembly.

Combustibility: Asphalt core board for roofing applications generally is considered fire-resistant. It can be exposed directly to hot bitumen and roofing torch flame.

Securement: Securement methods for asphalt core board vary depending on substrate and roof membrane specified. Roof system manufacturers should be consulted for the recommended securement procedures.

Roof Membrane Application: Information about roof membrane installation over asphalt core board is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.13—Cement Board

Cement board used in roofing consists of a core of Portland cement, pozzolans, water and aggregates that may include sand, expanded clay, expanded shale or expanded polystyrene beads and fiberglass-scrim facings. Some products include nonwoven polyester fabric reinforcement applied to machine-direction edges.

Cement board does not contribute significant thermal resistance when used as part of roof assemblies. Information about cement board is included here because cement board is used in roof assemblies as a thermal barrier to provide fire resistance, substrates for air and vapor retarders, and cover boards beneath roof membranes.

The following properties of cement board make it well-suited for use in roof assemblies:

- Adhesive compatibility
- Component compatibility
- Fire resistance
- Moisture resistance
- Attachment capability
- Compressive strength
- Impact resistance

Manufacturers' literature should be consulted for specific information regarding their products.

Manufacturing Process: Cement board core is formed from a mixture of water, Portland cement, pozzolans, sand and lightweight aggregates or expanded polystyrene beads. The core is encased between fiberglass-scrim facings and passed through a curing oven where the material develops initial strength necessary for handling. Reinforcement of nonwoven polyester fabric may be applied to machine-direction edges. The material is cut to length, stacked and allowed additional cure time before it is shipped.

Product Standard: Cement board marketed for roofing use in the U.S. is manufactured to comply with ASTM C1325, "Standard Specification for Non-Asbestos Fiber-Mat Reinforced Cementitious Backer Units." ASTM C1325 addresses backer units suitable for use as substrates on walls, floors and decks in wet and dry areas. The standard provides a classification for two types of materials: Type A—sheets intended for exterior applications and Type B—sheets intended for covered exterior applications or for interior dry or wet area applications. Type A materials are used for roofing applications.

Board Sizes and Thicknesses: Cement roof board is available as 4- by 4-foot and 4- by 8-foot panels that are 7⁄16-inch-thick or ½-inch-thick.

R-value: R-values reported for cement roof board are product-specific. Manufacturers should be consulted for R-value information.

Usage Guidelines: Cement board is used as a thermal barrier to provide fire resistance over steel roof decks and other combustible substrates, substrates for air and vapor retarders, and cover boards beneath roof membranes.

The following guidelines apply to usage of cement roof board:

Multilayer Insulation: Cement board can be used as a component of a properly designed multilayer insulation application.

Cover Board: Cement roof board is suitable for use as a cover board layer. Cover boards are considered to be a component of a multilayer insulation application.

Combustibility: Cement roof board is noncombustible. It can be exposed directly to hot bitumen, torch flame or high temperatures, such as those produced by heat welders.

Securement: Application procedures for cement roof board can vary depending on the roof deck type and roof membrane specified. The cement roof board manufacturer and the roof membrane manufacturer should be consulted for the recommended application procedures.

Roof Membrane Application: Information about roof membrane installation over cement board is provided in Chapter 5—Roof Membranes and Chapter 1—Roof System Configurations.

4.14—Composite Board

Composite board roof insulation typically consists of two layers of different types of insulation that are laminated together in a factory. Typically, the primary insulation is polyisocyanurate or expanded polystyrene (EPS), which is laminated to a perlite board or wood fiberboard, serving as secondary insulation. There also are composite insulation products available that are composed of one layer of insulation (typically polyisocyanurate) that is laminated to a nailable roof substrate (typically oriented strand board [OSB], plywood, a gypsum panel or a combination of these laminations).These composite boards form a unified, multilayer component. The top or bottom surfaces of some types of composite insulations may be coated or impregnated with asphalt or other binders. Some are covered with facer materials, such as foils, organic and fiberglass felts, or kraft paper.

Product Standard: The ASTM standard for composite boards using polyisocyanurate insulation is ASTM C1289,"Standard Specification for Faced Cellular Polyisocyanurate Thermal Insulation Board." The chart on page 184 lists the various polyisocyanurate composite roof board types.

Composite boards with EPS as the primary insulation may have a top layer of OSB, plywood, wood fiberboard or polyisocyanurate insulation. Currently, there are no recognized standard material specifications for composite board insulation using EPS as the primary insulation.

The following recognized properties of composite board roof insulation make it an effective insulating material:

- Most are generally compatible with bitumen and adhesive
- Impact resistance
- Some are fire-resistant
- Durability
- Thermal resistance
- Various securement capabilities

Composite Board Types (Polyisocyanurate as primary insulation)				
Product Type	**Type III**	**Type IV**	**Type V**	**Type VII**
Facer Covering One Surface	Perlite insulation board	Cellulosic insulation board	Oriented strand board or wafer board	Glass-mat-faced gypsum board
Facer Covering Opposite Surface	Fiberglass-reinforced cellulosic felt or uncoated or coated polymer-bonded fiberglass mat facer	Fiberglass-reinforced cellulosic felt or uncoated or coated polymer-bonded fiberglass mat facer	Fiberglass-reinforced cellulosic felt or uncoated or coated polymer-bonded fiberglass mat facer	Fiberglass-reinforced cellulosic felt or uncoated or coated polymer-bonded fiberglass mat facer
Compressive Strength, psi	16	16	16	16

Manufacturing Process: Composite board roof insulation materials typically are produced by laminating a relatively thin base layer of roof insulation or substrate material to a plastic foam insulation. The top surface of most composite board insulation contains an asphalt-saturated felt or fiberglass facer. The base layer, foam and facer are laminated on a continuous production line. The blowing process for polyisocyanurate is controlled, and the foam is allowed to expand between the base layer and facer. This process produces a composite insulation product in which all components are bonded together.

Usage Guidelines: The following guidelines apply to usage of composite board insulation.

Multiple-layer Insulation: Although composite insulation boards typically are designed by manufacturers for single-layer installation, NRCA suggests that when composite insulations are specified for low-slope roof membrane systems, the designer consider double-layer design. For example, if a composite polyisocyanurate/perlite insulation is intended to be installed with perlite set against a roof deck, the designer should consider specifying a cover board for application over the polyisocyanurate. Cover boards are considered to be components of a multiple-layer insulation assembly.

Cover Board: NRCA recommends the use of a suitable cover board layer over composite insulation board before installating the roof membrane to allow for off-setting and staggering board joints. Suitable cover boards include glass-faced gypsum board, fiber-reinforced gypsum board, stone wool, perlite board, high-density polyisocyanurate board, wood fiberboard or other compatible product intended for use as an insulation cover board.

Combustibility: Because unprotected polyisocyanurate and polystyrene can burn, appropriate fire safety precautions should be followed when handling, installing and roofing over composite board insulation materials. Composite roof insulation boards containing plastic foam insulation should be used only in roof assemblies as recommended by the manufacturer.

Application and Securement: Application of composite insulation boards varies depending on the type of membrane and roof deck specified, as well as the type of composite insulation to be used. Consult with the insulation and membrane manufacturers for recommended application procedures.

Generally, low-rise foam and liquid-applied adhesive can be used to attach composite board insulation that is firmly bonded and does not present a dusty surface. If low-rise foam or liquid-applied adhesive will be used to adhere insulation to roof decks, NRCA recommends obtaining agreement from the manufacturer of the adhesive, composite board insulation and roof membrane as to the appropriate type of adhesive and its application rate. Consult with the composite board insulation and membrane manufacturers for their requirements regarding minimum thicknesses of insulation when specifying composite board insulation over roof decks.

- **Nailable Roof Decks:** Composite roof insulation boards consisting of plastic foam insulation laminated to a layer of perlite or wood fiberboard are not intended to retain fasteners. Composite insulation boards composed of plastic foam and about a ½-inch layer of plywood or OSB are sometimes referred to as "nailbase" insulation. In certain compact roof assemblies, these boards are suitable for retaining appropriate fasteners. However, both of these composite insulation board types may be attached to suitable roof decks with various types of mechanical fasteners. Mechanical fastening is a common method for attaching certain composite board roof insulation to certain types of nailable decks. Hot bitumen or adhesives may be used to attach some types of composite roof insulations if a base sheet or vapor retarder first is mechanically fastened to the deck. Consult the manufacturers for specific attachment recommendations.

- **Steel Roof Decks:** NRCA recommends mechanical fastening for attaching composite board insulation to steel roof decks under all membranes except loose-laid ballasted roof systems. Consult with the insulation and membrane manufacturers regarding minimum thicknesses of insulation when specifying composite board insulation over steel roof decks.
- **Nonnailable Roof Decks:** On nonnailable roof decks, NRCA recommends applying composite insulation boards in hot bitumen or adhesive over the properly prepared decks. Priming of the deck may be required to achieve adequate adhesion with this type of installation.

Roof Membrane Application: Because the potential for blister formation exists when hot bitumen is applied directly to polyisocyanurate foam materials, hot-applied bituminous roof membranes should not be fully adhered directly to the plastic foam or facer of composite insulation. If composite insulation is specified for use with the foam side up in hot-applied bituminous systems that will have hot bitumen applied onto or over the insulation, NRCA recommends installation of a suitable insulation cover board. Suitable cover boards include stone wool board, perlite board, asphalt-impregnated wood fiberboard or other compatible product intended for that use. Typically, the cover board is adhered to the foam insulation facer with hot bitumen to prepare the foam insulation for hot bituminous membrane application. When a cover board is used, it is important to stagger the joints of the cover board from the joints in the insulation layer below.

Hot-applied bituminous roof membranes may be installed directly over composite board roof insulation if the wood fiber or perlite side is up because this layer will cover the polyisocyanurate foam core of the finished product. However, if the composite insulation contains polystyrene, NRCA recommends taping the board joints when a hot-applied bituminous membrane system is to be installed.

4.15—Tapered Insulation

Tapered insulation can be used to meet the requirements for slope in new construction and reroofing projects, as well as in cases where a roof deck will not provide adequate slope to drain water off a roof surface.

The roofing industry recognizes there is a need to drain water off a roof surface in a timely manner. For new construction, most model building codes and most local building codes require a minimum ¼:12 roof slope for all low-slope roof assemblies except coal tar, which requires a minimum ⅛:12 roof slope.

When a building is designed, decisions must be made as to how to achieve sufficient slope for adequate roof system drainage. The model building codes require a minimum roof slope for new roofing projects. The basic consideration is a choice between a structural means of achieving roof slope, such as sloping the structural roof deck or its supporting structural framing, or using a tapered material over the structural roof deck to achieve the slope. A combination of structural slope and tapered material can be used to enhance drainage. In some cases, the choice is greatly affected by economics depending on the building and construction circumstances. However, designers and owners are urged to select the method that is most appropriate for roof assemblies' long-term performance.

Although the primary reason for using tapered roof insulation is to improve slope and promote drainage, there are other advantages:

- Tapered insulation can provide additional thermal resistance thus increasing the energy efficiency of a roof system.

- Certain tapered insulations, such as perlite, can serve as cover boards over primary thermal insulations to provide mopping surfaces before applying some hot-applied roof membranes.

Design Criteria: When deciding whether a tapered insulation system should be used and how it should be designed, there are numerous criteria that must be considered. Each project is different, and individual project conditions affect how the tapered system should be designed.

Following are some of the criteria that should be considered:

- Substrate conditions
- Drainage systems
- Perimeter conditions and roof penetrations
- Component compatibility
- Thermal insulation value
- Building code requirements
- Moisture control

Substrate Conditions: When deciding the degree of slope necessary for a tapered insulation system, a designer should determine the net slope desired. The designer must consider substrate conditions that may affect the draining surface of the roof system and specify a tapered insulation system with sufficient slope to accommodate the following:

- Potential and existing deck deflections and deck irregularities
- Actual slope of the roof deck

Drainage Systems: Typically, removing water from a low-slope membrane roof system is accomplished by installing interior roof drains, perimeter scuppers or gutters. Quantity, size and location of these drainage components are essential to the successful drainage of any roof surface and are critical when designing a tapered insulation system. The roof drainage system should be designed by a professional with knowledge about drainage-component sizing, volume capacities, requirements of local codes and other related requirements. Drainage-component locations and the ability to add to the design additional drainage devices will directly affect the efficiency of the layout of a tapered roof insulation system.

Perimeter Conditions and Roof Penetrations: Because a tapered insulation system will provide the substrate over which a roof membrane is installed, the tapered system must be designed to allow proper clearance for the installation of appropriate membrane flashing and any counterflashing at roof perimeters, penetrations, etc. Raised curbs must be designed for sufficient height above the tapered insulation to allow for minimum flashing heights of 8 inches. The height of adjacent walls and openings in those walls, such as window sills, door sills, through-wall flashing or weep holes, also must be high enough to allow for minimum flashing requirements. Insulation thickness at intersections between individually drained roof areas should match to allow for smooth transition of the roof membrane. Area dividers sometimes can be used to facilitate transitions. Refer to Chapter 2—Roof Decks of this manual. If a constant fascia profile is desired along a low roof edge, the tapered insulation system should be designed with a uniform thickness along that edge. Parapet walls may accommodate and allow for greater and varying thickness of tapered insulation when they are constructed to ample height.

Component Compatibility: A tapered roof insulation system must be compatible with the roof membrane specified for the project. The type of material, as well as its slope and thickness limitations, should be acceptable for use with the roof membrane specified. Designers should consult manufacturers' instructions for specific compatibility criteria and any slope and thickness limitations.

Thermal Insulation Value: Because a tapered insulation system does not have a constant thickness, a roof system will not have a consistent thermal resistance (R-value) over the entire roof area. Determining a tapered insulation system's thermal resistance is an important consideration when it is necessary to meet energy conservation code requirements or when evaluating proposed dew-point location and use of a vapor retarder.

There are two common industry approaches that may be used for determining the thermal resistance of a tapered insulation system:

- Minimum R-value
- Average R-value

These are explained in greater detail as follows.

Minimum R-value/Minimum Thickness: The minimum R-value approach establishes thermal resistance (R-value) for a tapered roof insulation system by determining the R-value of the tapered material at the thinnest point in the tapered system layout. Therefore, the R-value is not expected to be less than this minimum value anywhere throughout the entire tapered insulation system.

It is appropriate to use the minimum R-value approach for determining the R-value of a tapered insulation system when a conservative thermal-efficiency design is desired; when performing dew-point analyses; or when determining the necessary minimum thickness of thermal insulation above a vapor retarder membrane to prevent condensation. The minimum R-value/minimum thickness is determined at the low point of the roof insulation assembly (i.e., gutter edge, outer edge of roof drain assembly or scupper).

Average R-value: The average R-value approach establishes the thermal resistance (R-value) for a tapered roof insulation system by determining the R-value of the tapered material at the representative average thickness in the tapered system layout. There are a number of mathematical methods for calculating the representative average thickness of a tapered system layout. The specific method used depends on the configuration, shape or drainage pattern of the tapered system layout.

- Arithmetic Average Thickness Method: Arithmetic average thickness is the thickness of tapered and flat stock insulation at the midpoint between the minimum thickness (i.e., low point) and the maximum thickness (i.e., high point) in a tapered insulation system. See Figure 4-4.

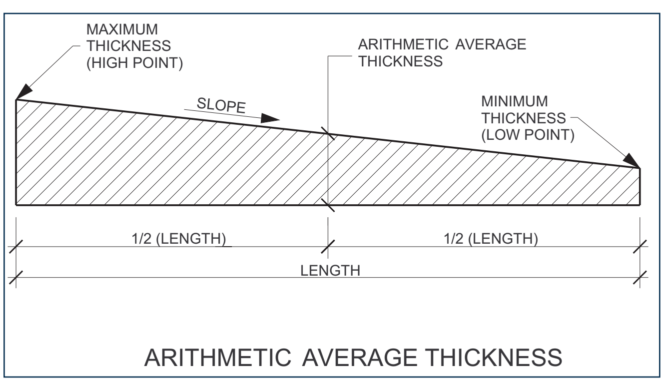

Figure 4-4: Arithmetic average thickness

The formula for calculating arithmetic average thickness for simple-slope tapered insulation system is:

Arithmetic average thickness = LP + [½ (HP - LP)]

Where:

LP = Low point, or the tapered insulation system's minimum thickness, inches

HP = High point, or the tapered insulation system's maximum thickness, inches

Use of the arithmetic average thickness method for determining the average R-value of a tapered roof insulation is appropriate for simple-slope (e.g., one- and two-way slope) tapered insulation systems or for more complex tapered configurations when the tapered layout can be broken down into one- and two-way slope regions.

- Volumetric Average Thickness Method: Volumetric average thickness is the thickness of tapered and flat-stock insulation where one-half of the tapered insulation's total volume occurs downslope of the volumetric average tapered insulation thickness location; the remaining one-half volume occurs upslope. See Figure 4-5.

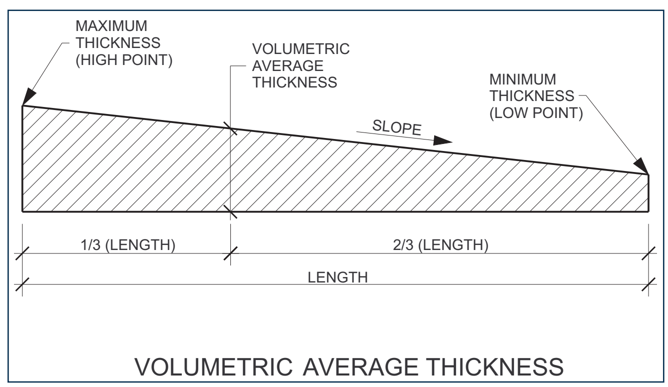

Figure 4-5: Volumetric average thickness

For symmetrical four-way slope tapered insulation systems, the formula for calculating volumetric average thickness for the tapered insulation is:

Volumetric average thickness = LP +[⅔ (HP - LP)]

Where:

LP = Low point, or the tapered insulation system's minimum thickness, inches

HP = High point, or the tapered insulation system's maximum thickness, inches

Use of the volumetric average thickness method for determining average insulation thickness is only appropriate for symmetrical four-way slope tapered insulation layouts where the roof area of each region being considered is square and the valleys are perpendicular (i.e., 90 degrees) to each other. See Figure 4-6.

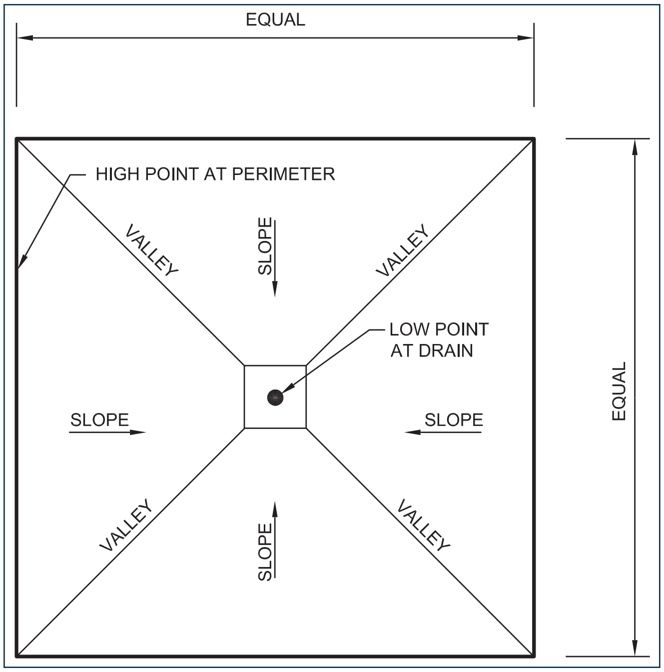

Figure 4-6: Symmetrical four-way slope

Use of this formula for tapered insulation layouts other than those shown above may result in inaccurate results.

An alternative method for determining the volumetric average thickness for tapered insulation systems is to determine the total volume of tapered material, deducting for any anticipated waste and then dividing by the roof surface area. The formula for calculating volumetric average thickness by this method is:

Volumetric average thickness =

$$\frac{\text{Total board footage - Anticipated waste}}{\text{Roof surface area}}$$

Use of this formula is appropriate for determining the volumetric average thickness for any tapered insulation configuration.

Volumetric average thickness can also be determined by finding the volume of solid insulation if there was no slope and then deducting the pyramid-shaped volume of empty space. See Figure 4-7.

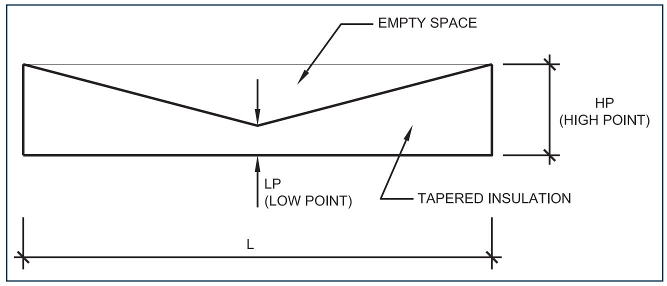

Figure 4-7: Volumetric average thickness, second method

Volume of solid insulation = HP x L x L

Volume of empty space = ⅓ x L x (HP - LP)

Volume of insulation = (HP x L2) - ⅓ L (HP-LP)

Volumetric average thickness =

$$\frac{\text{Volume of insulation}}{\text{Roof surface area}}$$

This method can only be used accurately for symmetrical four-way slope tapered insulation systems.

Using an average R-value method for determining the thermal resistance of a tapered roof insulation system is preferred by some because it reports a higher thermal resistance than the minimum R-value approach. However, it is important to realize that when using an average R-value method, large portions of the roof area will have an R-value less than the average R-value. Depending on the method used to calculate average R-value, up to two-thirds of the total roof area can have an actual R-value less than the calculated average R-value. This can be an important design consideration, especially if the tapered insulation system is relied on as a large contributor to the overall thermal efficiency of the roof assembly or when considering moisture-control analysis.

Therefore, when an average R-value method is used, NRCA recommends designers accurately determine and properly represent the thermal efficiency of the tapered roof insulation system. When the thermal efficiency of a tapered insulation system is a consideration, NRCA suggests designers of tapered insulation systems report the minimum R-value, average R-value and specific method of average R-value determination.

Energy Code Requirements: The 2006, 2009 and 2012 editions of the International Energy Conservation Code (IECC), the applicable energy code for most of the U.S., include a prescriptive minimum thermal resistance requirement for roof insulation.

In IECC 2006 and 2009, Section 502.2.1 Roof assembly (and in IECC 2012, Section 402.2.1 Roof assembly) states the minimum R-value of the insulation installed continuously as part of a roof assembly shall be as specified in Table 502.2(1) (Table C402.2). The language specifically applicable to tapered insulation systems is provided in an exception to said section(s). Except for an updated table reference, IECC 2006 through 2012 provide the same language for the exception. It states:

> "Continuously insulated roof assemblies where the thickness of insulation varies 1 inch (25 mm) or less and where the area-weighed U-factor is equivalent to the same assembly with the R-value specified in Table C402.2."

IECC 2012 Table C402.2 provides minimum R-value requirements for building envelope systems, including roof assemblies.

The code's intent is to permit the use of a roof area-weighted average R-value for compliance with the requirement only for tapered insulation systems where the insulation thickness varies by no more than 1 inch.

The Commentary to IECC 2012 indicates the 1-inch limitation is not intended to prevent tapered insulation systems from having larger variations in thickness; the limitation simply does not allow the insulation thickness beyond the 1-inch variation to be included in the calculation of the roof area-weighted average R-value used for energy code compliance purposes.

When the tapered insulation's thickness variation exceeds 1 inch, the Commentary indicates it is permissible to use an R-value based on the thickness of the insulation where the insulation is 1 inch thicker than the tapered system's low point. Portions of the roof area with insulation thicknesses greater than that 1-inch variation are assumed to have the same R-value for energy code compliance purposes.

For example, for a ¼-inch-per-foot tapered insulation system, the 1-inch thickness variation will occur 4 feet from the tapered system's low point. In this case, the R-value for the insulation at that 4-foot point in the tapered system is intended to be used to comply with the energy code. See Figure 4-8.

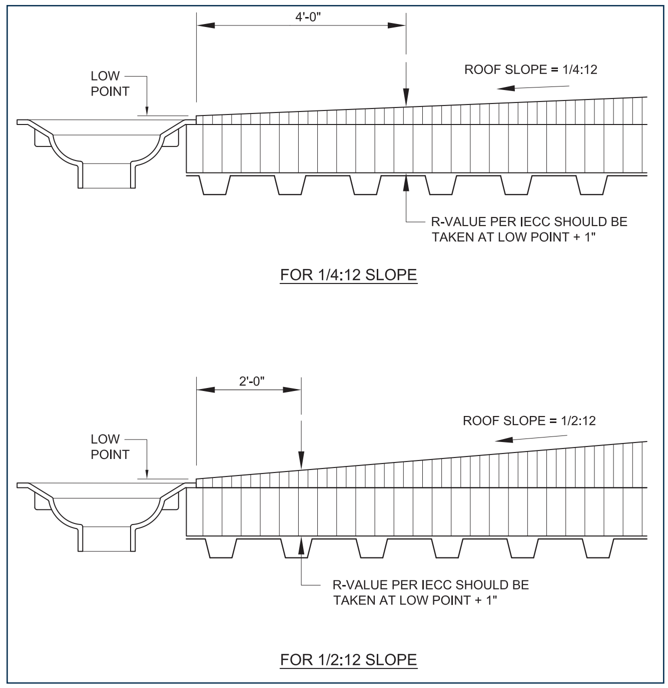

Figure 4-8: Tapered roof insulation system R-value to be used for compliance with IECC requirements.

Locally adopted energy conservation code provisions may provide different minimum requirements for building envelope thermal resistance, including roof assembly thermal resistance. For roof assemblies with above-deck insulation, local code provisions may require a specific minimum insulation thickness is provided at the low point (e.g. roof drains, scupper edges or gutter edges) in a tapered roof insulation system.

In IECC 2015, the corresponding section C402.2.2—Roof assembly, references Table C402.1.3 for the minimum R-value of the insulation installed continuously as part of a roof assembly. Also, an exception has been added in this section to clarify the code's application to tapered above-deck roof insulation. The exception states:

> "2. Where tapered insulation is used with insulation entirely above deck, the R-value where the insulation thickness varies 1 inch (25 mm) or less from the minimum thickness of tapered insulation shall comply with the R-value specified in Table C402.1.3."

Moisture Control: Analyzing a roof system using a tapered roof insulation system for moisture-control considerations, such as location of dew point and need for a vapor retarder, is not unlike the moisture-control analysis necessary for a conventional low-slope roof system using a constant thickness of roof insulation. For specific information about moisture control, refer to the Condensation and Air Leakage Control Section of The NRCA Roofing Manual: Architectural Metal Flashing, Condensation and Air Leakage Control, and Reroofing.

Calculations to determine dew-point temperature and need for a vapor retarder are typically governed by the minimum thermal insulation within a roof assembly. When analyzing a roof system using a tapered insulation system, it is critical that the calculations be based on the minimum thermal resistance of the tapered insulation system; that is, the minimum R-value approach for determining the thermal resistance for the tapered insulation system should be used.

Types of Tapered Roof Insulation: Factory-tapered board roof insulation systems are composed of multiple layers of insulation boards that are tapered at a factory to provide slope. The preformed tapered insulation boards are available in several dimensions, typically 2 by 4 feet, 3 by 4 feet, 4 by 4 feet, or 4 by 8 feet. Other dimensions may be available. Board sizes vary from manufacturer to manufacturer and product to product. The most common taper slopes available are ⅛ inch per foot, ¼ inch per foot and ½ inch per foot. Other taper slopes, such as ⅜ inch per foot, are available with certain products. Some manufacturers have the capability to cut custom slope pieces to meet specific project needs.

Following are types of tapered rigid roof insulations:

- Cellular glass
- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)
- Stone wool
- Perlite
- Polyisocyanurate
- Wood fiber

For more information about specific insulation descriptions, manufacturing processes, requirements and precautions, refer to the specific insulation material listings in the previous subsections of this section.

Design: Preformed tapered board insulation involves the use of factory-sloped rigid boards and flat boards for fill to construct a sloped insulation system. A designer should plan the layout (i.e., how these pieces are to be assembled where valleys, crickets, etc., will occur) to achieve the desired drainage scheme.

Tapered insulation layouts should be designed to form a sump that measures the size of the drain bowl's diameter plus approximately 24 inches at roof drains, and crickets should be installed on the high sides of all roof curbs. Over nailable and steel roof decks, NRCA recommends a 1½-inch minimum thickness of insulation at roof drain sumps.

Slope Pattern: There are a number of factors that affect the design and layout of tapered insulation. A roof system designer should be aware that, depending on the configuration of the roof, several different patterns may need to be used in combination to achieve thorough drainage for an entire roof system. Therefore, selection of the specific layout or drainage pattern will not only depend on the high and low points but also the geometry of the area, need for slope within a specific area and relationship of the pattern to other adjoining areas.

For example, for a square or rectangular roof area with perimeter drainage, such as gutters, a simple one- or two-way slope pattern may work well. Figure 4-9 illustrates a one-way slope layout.

Figure 4-10 illustrates a two-way slope layout.

For a square roof area with an interior drain, a four-way slope pattern directed toward the center can provide uniform perimeter thickness and simplify edge detailing. With a four-way slope pattern, uniform slope is provided

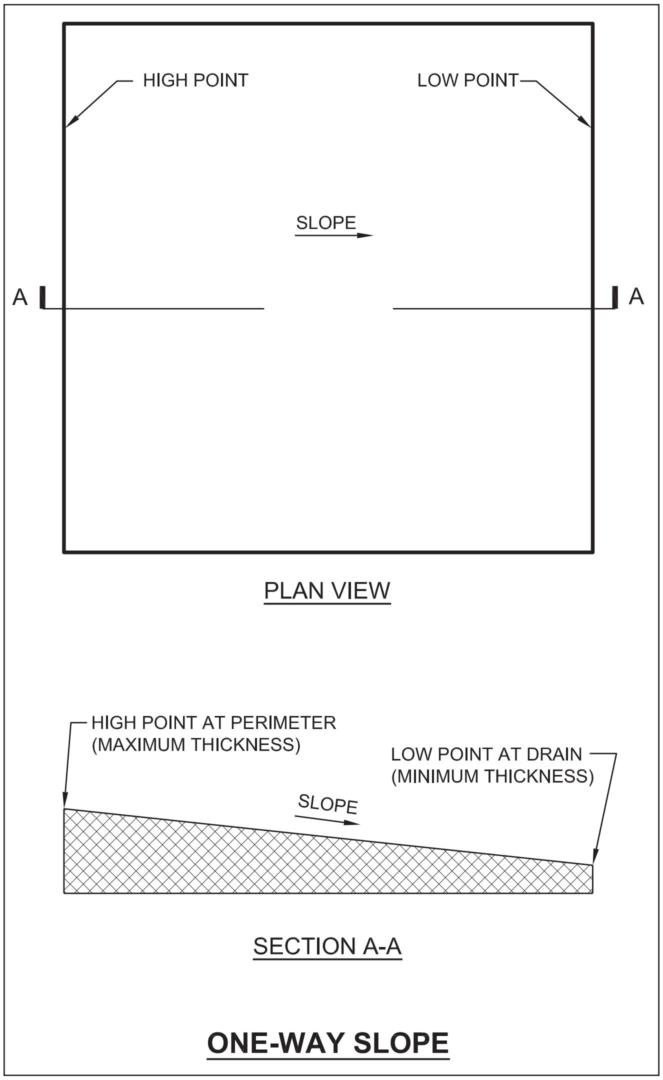

Figure 4-9: One-way slope layout

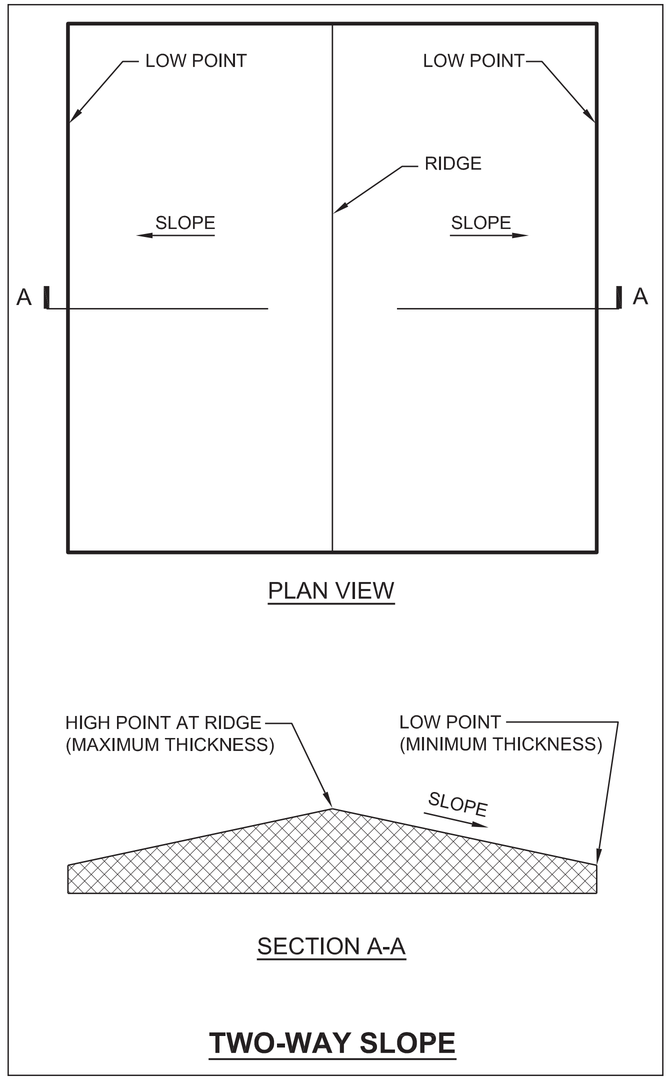

Figure 4-10: Two-way slope layout

over all four intersecting insulation areas. See Figure 4-11 (on page 194).

Additionally, a two-way slope pattern can be designed to provide results similar to a four-way slope pattern. Crickets should be used in the intersecting valley formed by a two-way slope to divert runoff toward interior roof drains.

For a rectangular roof area with a single interior drain, a simple two-way slope pattern incorporating tapered insulation crickets to divert water to the drains can be used. A general rule of thumb for designing sufficiently sloping saddles and crickets is that they be twice the slope of the adjacent field of the roof. See Figure 4-12 (on page 194).

This generally will keep water from remaining on the roof surface at the cricket or saddle. However, for the cricket or saddle to drain, NRCA recommends designers recognize the importance of cricket and saddle geometry and valley slope. NRCA's guidelines for length-to-width (L:W) ratios for saddles and crickets are provided in Figure 4-13 (on page 195).

For a roof area with two interior drains, a simple two-way slope pattern incorporating a saddle and crickets formed of tapered insulation can be used even if the deck has been designed to provide slope. See Figure 4-14 on page 195.

The use of tapered insulation for slope-to-drain may not necessarily result in complete, immediate drainage of roof membrane surfaces. Some residual surface water may remain on roof membrane surfaces at junctures, transitions and immediate drain areas following periods of precipitation.

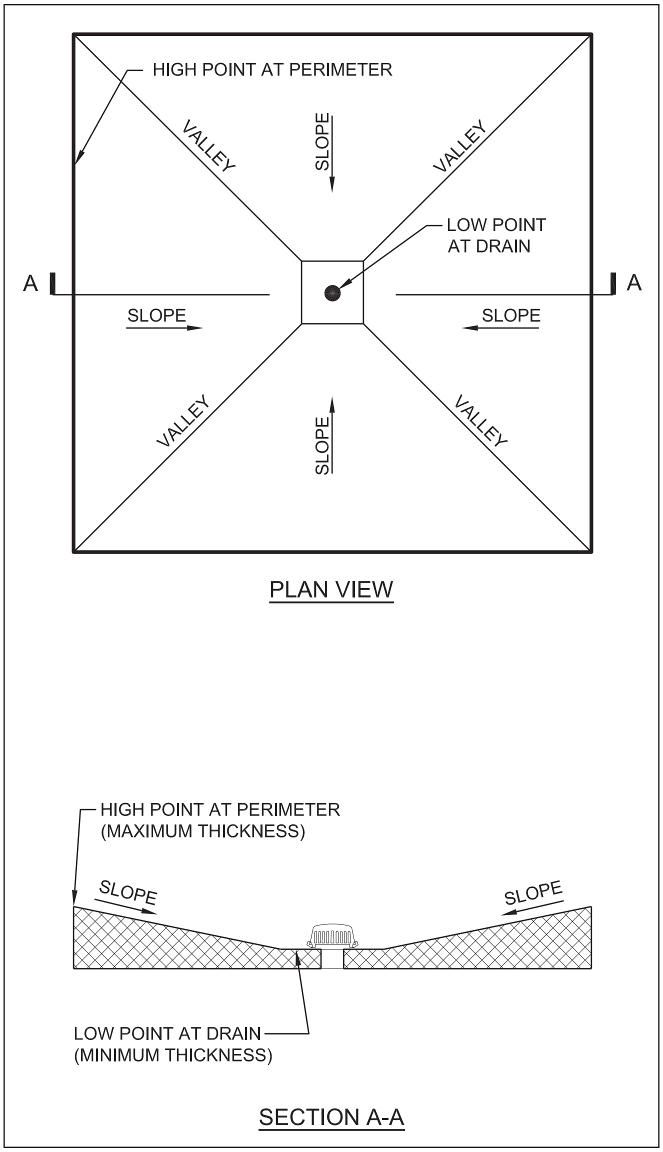

Figure 4-11: Four-way slope to interior drain

Hips and Valleys: When using preformed tapered insulation boards of one consistent slope, all valley centerlines should be 45 degrees from the direction of slope; that is, the valley centerlines are 90 degrees apart. Designing layout patterns with 45-degree valley lines makes it easier to cut the board stock during field layout (the boards easily can be cut at 45 degrees from one edge or corner to the opposing corner) and provides the maximum slope in the valley. Any departure from the simple 45-degree miter cut concept can create difficulties during layout and increase on-site assembly time. See Figures 4-15 and 4-16 (on page 196).

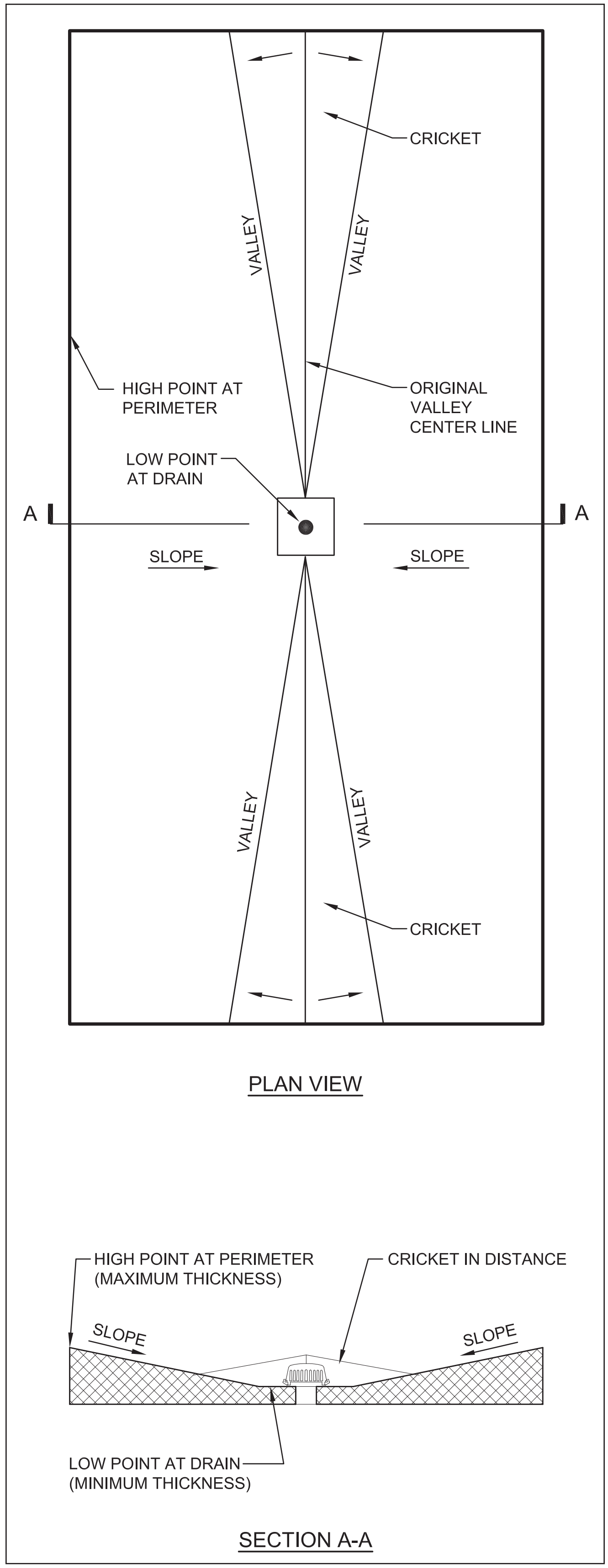

Figure 4-12: Two-way slope to interior drain with crickets

Recommended Maximum L:W Ratios for Saddles and Crickets		
Roof Slope	**Saddle Material Slope**	**L:W Ratio**
⅛	¼	3:1
¼	½	3:1
½	½	4:1

Figure 4-13: Guidelines for maximum L:W ratios for saddles and crickets

When a valley cannot be placed at a 45-degree angle to the slope, it becomes critical to calculate the tapered insulation heights at both sides of the valley and adjust the slope so the heights of the tapered insulation at each side of the valley match.

Ridges: When a ridge occurs, especially between adjoining tapered patterns, thought must be given to the resulting thicknesses of the two adjoining patterns so a common, uniform thickness occurs at the ridge line. To achieve simple, consistent ridge thicknesses, the ridge line should be spaced equidistant between drainage points. The ridge line will be perpendicular to a line that connects the two drainage points. See Figure 4-17 (on page 197).

If the patterns do not permit a common, uniform thickness at the ridge, an area divider may be required to provide an adequate transition. It is important to note area dividers should not block the flow of drainage runoff. See Figure 4-18 (on page 197).

Thickness: Because the thickness of a tapered roof insulation system varies, conditions related to height or clearances must be considered.

- **Flashing Heights:** Designers must plan for the varying flashing heights that occur with tapered roof insulation systems. Rooftop equipment may need to be raised to maintain adequate flashing height clearances. The insulation thickness may interfere with penthouse access doors, windows, and through-wall flashings or weep holes. These need to be appropriately addressed to provide adequate flashing clearances.
- **Constant Perimeter Edge Thicknesses:** If there is a need for constant perimeter edge thickness, the slope pattern should be laid out accordingly. For interior drains, it is easiest if the drainage points are equidistant from perimeter edges.

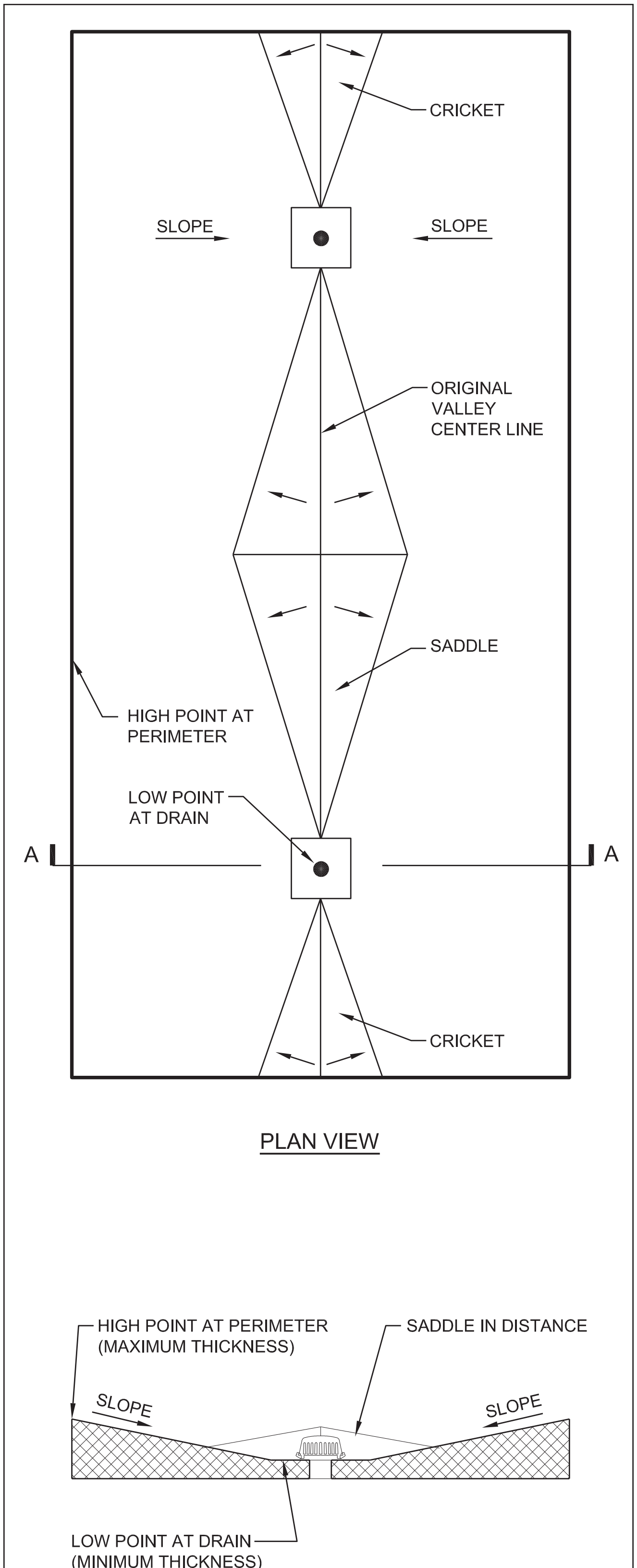

Figure 4-14: Two-way slope to interior drain with saddle and crickets

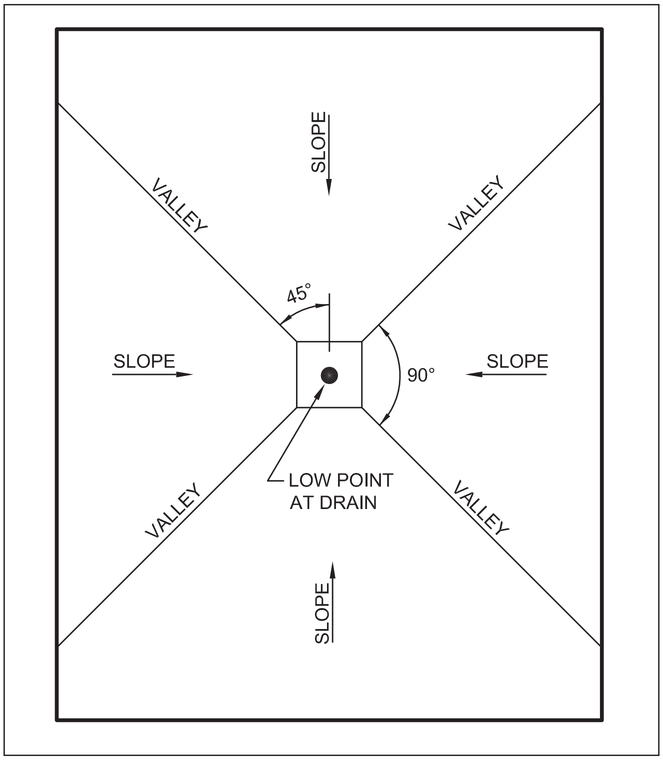

Figure 4-15: Layout of valley lines for four-way slope to one interior drain

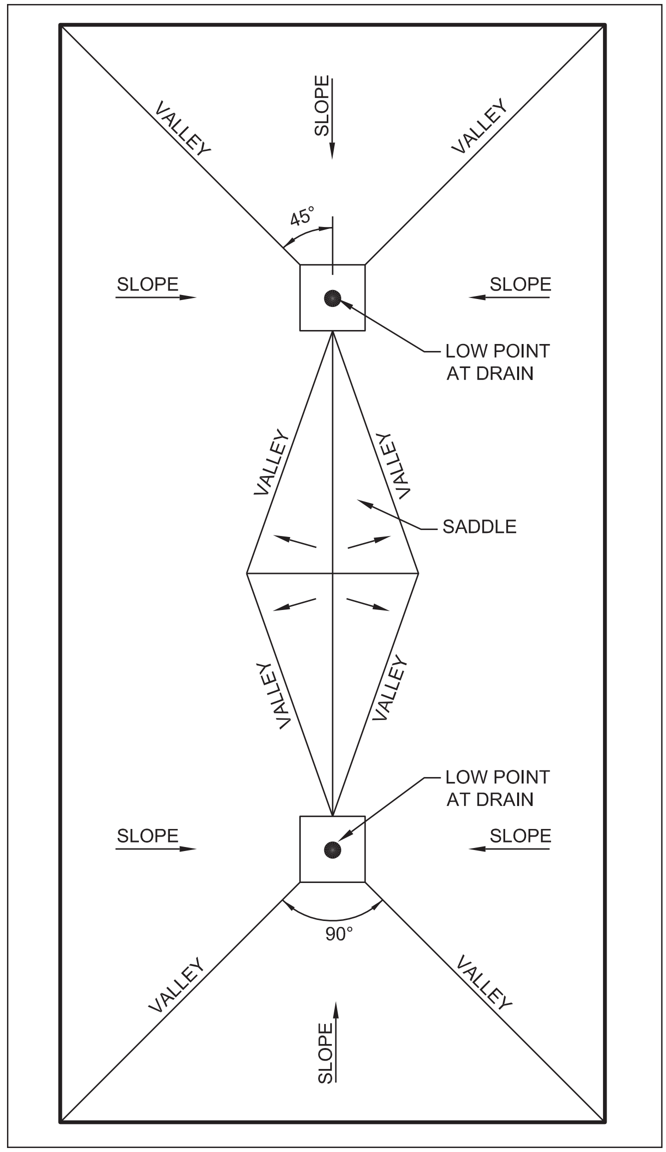

Figure 4-16: Layout of valley lines for four-way slope to two interior drains

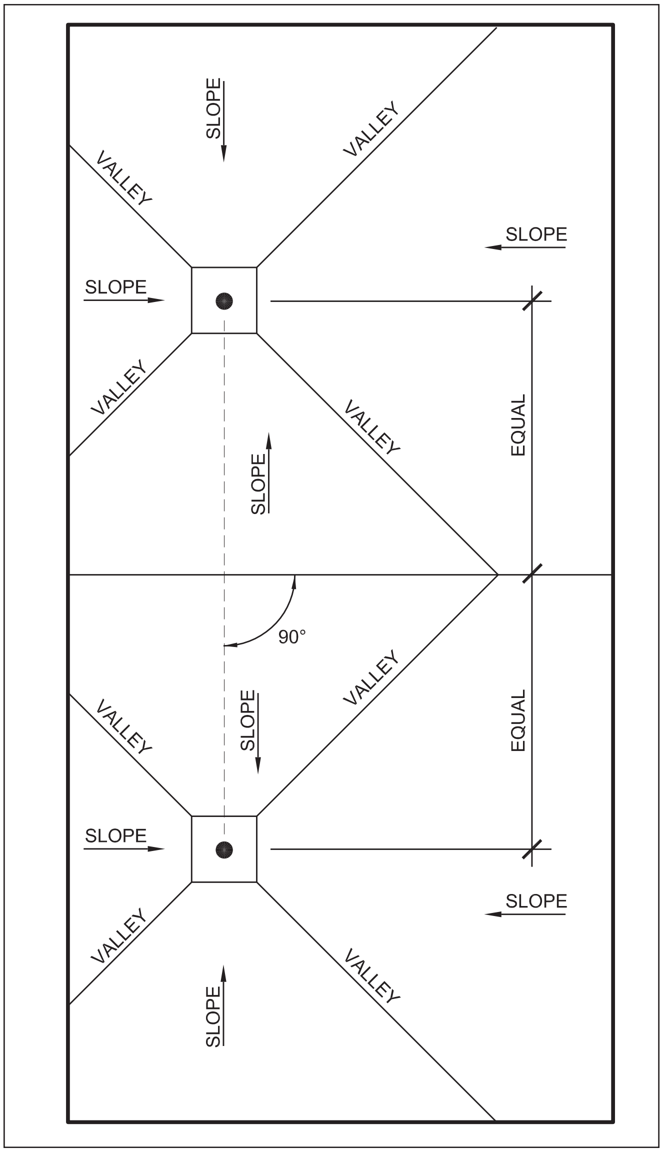

Figure 4-17: Layout of common ridge lines for adjacent slope patterns

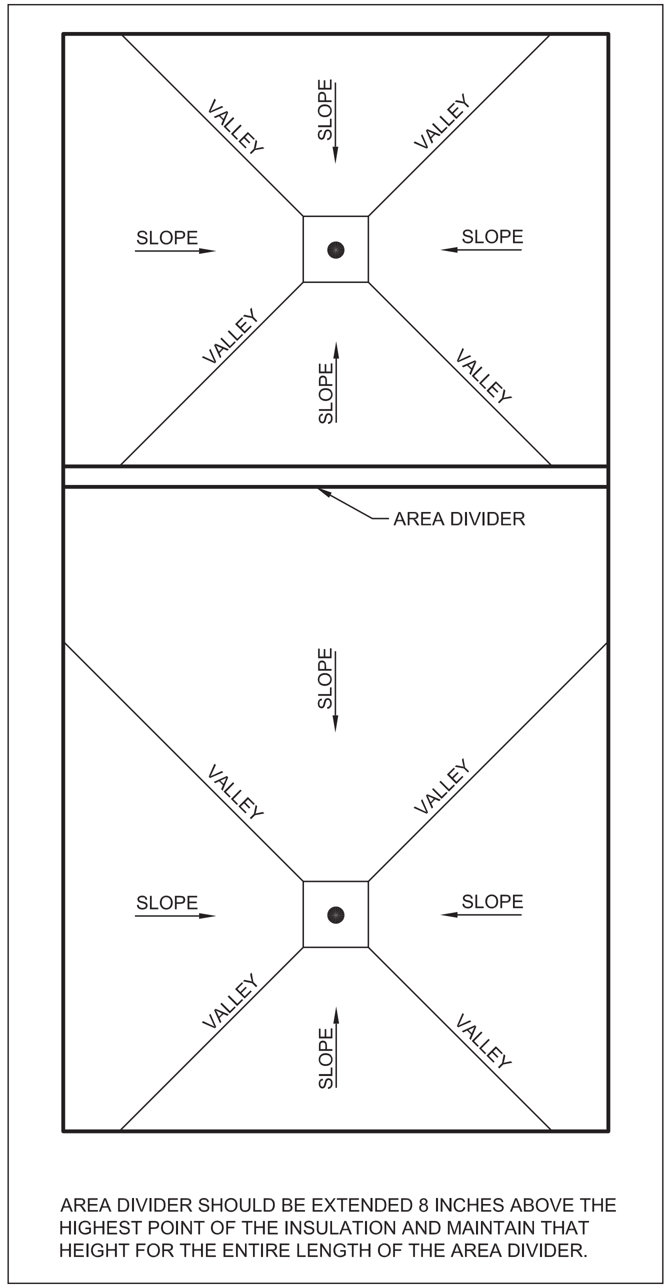

Figure 4-18: Layout of a ridge for adjacent slope patterns where an area divider may be used to provide a transition