TEST METHODS FOR EVALUATING INSULATIONS FOR USE WITH SINGLE-PLY ROOFING SYSTEMS

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There are various insulation products available in the marketplace, most of which are used below single-ply roofing systems. The generic insulation types include cellular glass, expanded polystyrene, extruded polystyrene, fiberglass, perlite, phenolic foam, polyisocyanurate foam, urethane foam and wood fiberboard. The placement of these boards in a roofing system can vary depending upon the specific design. For example, certain products may not have a strong internal bond which eliminates their use directly below adhered systems. Other insulations may lack the compressive strength necessary to support the fasteners in mechanically-fastened designs. Still others may not be capable of structurally supporting the weight of a ballasted system and the traffic encountered during installation.

This paper outlines recommended physical property test methods for insulation products intended for use directly below various single-ply roofing systems. The properties discussed include core density, compressive strength, dimensional stability, perpendicular tensile strength, water absorption, thermal resistivity, peel strength, foot traffic and wind uplift performance. The testing methods, typical results, and industry recommended minimum values are also highlighted.

KEYWORDS

Cellular glass, expanded polystyrene, extruded polystyrene, fiberglass, insulation, perlite, phenolic foam, polyisocyanurate foam, urethane foam, wood fiberboard.

INTRODUCTION

There are numerous insulation products available in the marketplace today, most of which are used in commercial single-ply roofing applications. The required physical property values of the insulation will depend upon the particular job site conditions as well as the type of single-ply system chosen. These physical properties can be broken down into two categories; **thermal characteristics** and **system parameters.** Thermal characteristics include items such as thermal resistivity, that are not directly related to the waterproofing performance of the roofing system. These thermal characteristics are either quality control indicators or, in some cases, actually enhancements above what is needed for protection of the building from the outside elements. System parameters include items such as compressive and peel strength, that directly influence the roofing systems long-term waterproofing performance. These system parameters must be adequate to provide a stable foundation to support the single-ply system and ensure long-term field performance.

The physical demand placed on the insulation will vary depending upon the single-ply system selected. Adhered, ballasted, and mechanically-fastened designs all stress the underlying insulations in differing ways. All insulations must be able to resist the rooftop traffic associated with the installation of the specified system. In addition, the insulation must be capable of withstanding the wind loadings encountered in the field, as well as meet the thermal characteristics established by the specifier or building owner.

The physical property values, used to quantify the performance of insulations, include core density, compressive strength, dimensional stability, perpendicular tensile strength, water absorption, thermal resistivity, peel strength, foot traffic resistance and wind uplift performance. Core density, dimensional stability, water absorption and thermal resistivity are all included in the thermal characteristics category, while the remaining properties are included in the system parameters category.

The following discussion outlines the physical property values of insulation boards as they relate to single-ply roofing systems. The thermal characteristics are discussed for single-ply systems in general (because they do not directly influence field performance), while the system parameters are addressed in relation to specific single-ply designs. This paper addresses only the insulations used below the membrane.

THERMAL CHARACTERISTICS—SINGLE-PLY DESIGNS

Core density is somewhat linked to compressive strength insofar as a higher density generally results in a higher compressive strength. Also, it is theorized that core density has a direct effect on facer adhesion. However, core density is still considered a thermal characteristic in this paper because, by itself, it is not meaningful to system performance. The affect of core density on compression strength will be evaluated by the compressive strength test. The affect on facer adhesion will be evaluated by the peel strength test and the wind uplift performance. Therefore, as long as the industry recommended minimum density values are met (where established), and as long as the pertinent system parameters are adequate, the product density is considered unimportant.

Dimensional stability is an important laboratory quality control indicator and a benchmark for comparison to other materials. However, correlation to full-size boards in a field application is an uncertainty. Obviously, the least amount of growth possible is most desirable, but boards that have met the industry standard maximums have still experienced growth (or curling) in the field under certain conditions. Single-ply designs, being elastic in nature, can tolerate a moderate amount of insulation growth without being detrimentally affected. Therefore, the industry recommended maximums (where established) should be met for single-ply applications.

The water absorption capacity of an insulation could possibly be included under the system parameters. It has not been included there because measuring the amount of water that can be absorbed in a specified time period tells you nothing about the long-term effects of that moisture on the insulation or single-ply system. If water is allowed to enter into the roofing system (which is a very undesirable situation), the insulation will most likely tend to absorb some of that water. Once the source of water is eliminated, the insulation may dry out but its physical properties could have been affected (this is dependent upon the amount of water allowed to enter and the length of time before corrective action is taken). Unfortunately, the water absorption test does not evaluate the physical properties after being wet. Therefore, historical experience with insulation performance after becoming wet should be considered during the selection process.

Thermal resistivity is actually related to the energy costs associated with the interior building climate. Although R-value has limited impact on the waterproofing performance of the roofing system, it can be a very important consideration on any project.

SYSTEM PARAMETERS—SINGLE-PLY DESIGNS

Adhered Systems

On a fully-adhered roofing system, the membrane is glued to the insulation. Uplift forces with this system are transferred to the membrane which in turn are transferred to the insulation. As the membrane tries to flutter or inflate, it is restricted by the adhesive bond between the membrane and insulation. Consequently, the bond of the membrane to the board surface must be sufficient to resist field uplift conditions. If the insulation utilizes a facer, the interply facer strength, as well as the facer bond to the board and the cell structure of the board, must also be sufficient to resist the uplift forces. When the facer bonds and cell strengths are sufficient, the board itself must be structurally strong enough to support the installed fastener and plate, and resist breakage around or between the plates under uplift conditions. If an adhesive is used to attach the insulation to the deck, the board surface or facer bond strength again becomes critical, as does the internal structural board strength. Also, the adhesive used to bond the board to the deck or to bond the membrane to the board must be compatible with all products.

In order to select the proper insulation for use with an adhered system, the board's compressive strength, perpendicular tensile strength, peel strength, foot traffic resistance and wind uplift performance should be determined. Compressive strength identifies the boards capability of resisting compression or distortion when the fastener and plate is installed. To a lesser degree, it identifies the boards ability to resist fastener plate pull-through or board breakage during uplift situations. Perpendicular tensile strength measures the internal structural strength of the board which is also needed to resist wind uplift forces. Peel strength measures the bond strength of the membrane to the insulation, and indicates the potential field failure mode of delamination (membrane from the facer, within the facer, or facer from the foam). Foot traffic resistance and wind uplift are assembly-type tests which incorporate the substrate, insulation and membrane. Foot traffic resistance measures the ability of the system to resist rooftop traffic encountered during installation and during its service life. (High traffic areas may also need supplemental protection in the form of plywood protection during installation and a walkway after installation.) The wind uplift test measures the membrane bond strength to the insulation and also defines the structural board strength.

Assembly testing is necessary to ensure proper field performance. As an example, an insulation may have an adequate peel strength, but its cell structure may be brittle. The foot traffic test will subject the insulation to rooftop- type stresses and better identify potential deficiencies.

Ballasted Systems

Wind uplift forces encountered by a ballasted single-ply design try to displace the ballast and/or balloon the membrane. Since the membrane is not attached to the insulation, and the insulation is typically unattached, the insulation experiences no real stresses although stacking or shuffling can occur under a ballooned area. (If the insulation is attached to the deck through a loose-laid or mechanically-fastened vapor/air barrier, stresses similar to a fully-adhered system may be applied to the insulation.) The insulation must, however, be adequately designed to resist the concentrated rooftop traffic associated with the ballasting operation during construction as well as during normal service life traffic. Compression strength and traffic resistance testing should therefore be conducted. The compression strength test is a method of identifying a boards ability to resist compressing under a direct load. However, this procedure does not evaluate the condition of the sample after testing or its resistance to repeated loadings. The traffic resistance testing goes one step beyond merely measuring the compression strength of only the board. It incorporates the entire system into the test method and applies a cyclic loading. Not only are the boards compressive properties evaluated, but the physical condition of the test sample is also identified. This system testing is important because an insulation with a brittle cell structure may pass the compression test, but may not pass the traffic resistance test.

The type of stone or paver ballast used as well as the type of substrate below the insulation will influence the results of the traffic resistance test. Consequently, variations in substrate, ballast type and even membrane should be individually tested.

Mechanically-Fastened Systems

Wind uplift forces on insulations used with mechanically-fastened systems have virtually the same affect as was previously mentioned for ballasted systems. Since the membrane is fastened to the deck, independent from the insulation, uplift forces will flutter or inflate the membrane and directly stress the fastening device. The insulation experiences no direct uplift forces unless it is attached through a loose-laid or mechanically-fastened vapor/air barrier. The main function of the insulation with these systems is to provide support for the particular fastening system utilized. Therefore, compression strength and traffic resistance testing should be conducted. It is important that the board have a sufficient compressive strength to resist crushing or severe compression when the fastening device is installed. it is also important to support any side to side movement of the fastening device. Traffic resistance is important as well, since the board must be capable of resisting damage from rooftop traffic and maintain adequate support for the fastening system.

PHYSICAL PROPERTIES/TEST METHODS

In order to determine the thermal characteristics and system parameters of insulation products as previously described, established testing methods should be followed. Industry standard testing methods have been developed for core density, compressive strength, dimensional stability, perpendicular tensile strength, water absorption and thermal resistivity for various insulation products. In some cases, industry recommended minimum values have also been developed. Peel strength, foot traffic resistance and wind uplift testing procedures have been developed in an attempt to simulate conditions encountered in the field. The following section briefly describes these testing procedures and lists the industry minimum physical property values and typical values for generic insulations.

THERMAL CHARACTERISTICS

Core Density

Core density is a measure of the weight per volume of a material (without facings). It is reported in kilograms per cubic meter (pounds per cubic foot). The ASTM testing method used for cellular glass is C 303 and for rigid cellular plastics is D 1622. (No standard exists for other insulations but typical values can be obtained by following ASTM D 1622.) The core density is calculated by dividing the specimens weight by its measured volume. Figure 1 highlights the ASTM recommended minimum core density values as well as typical values for various insulation products.

Dimensional Stability

Dimensional stability is a measure of the amount of growth that an insulation board will experience under various temperature and relative humidity conditions. The ASTM test method for expanded and extruded polystyrene, phenolic, polyisocyanurate and polyurethane is D 2126, and for wood fiberboard is D 1037. (No standards exist for the other insulation types.) The methods consist of subjecting the test specimens to predetermined temperature and humidity conditions for a specific time period (typically 1, 7 or 14 days). The specimens are weighed and measured before and after testing, with the final results being reported as a percentage increase. Figure 2 highlights the ASTM and federal recommended maximum dimensional stability values for various insulation products.

Water Absorption

Water absorption is a measure of the amount of water that can be absorbed by the insulation in a specified time period. The ASTM test method for cellular glass is C 240, and for fiberglass, perlite, polyisocyanurate, polyurethane and wood fiberboard is C 209. For expanded and extruded polystyrene, the ASTM test method is C 272. The methods consist of submerging the specimen in water for two or 24 hours, then calculating the amount of water absorbed from the increase in sample weight. The results are reported as a percentage by volume. Figure 3 highlights the ASTM recommended minimum water absorption values for various insulation products.

Thermal Resistance

Thermal resistance, generally known as "R-value," is the measure of resistance to heat flow in any direction. The most widely used ASTM test method is C 518. (Other thermal conductivity measuring procedures include ASTM C 177 and C 236.) Prior to testing under the C 518, the insulation samples are typically aged for six months at 24°C (75°F) and 50 percent relative humidity. The test is conducted with a heat flow apparatus that applies a temperature differential across the insulation panel. The heat flow between the two surfaces is calculated and reported as thermal resistance (R) in units K m^2/W (°F ft^2h/BTU), or as thermal conductance (C) in units W/m^2K(BTU/h ft^2°F). Figure 4 highlights the ASTM recommended minimum R-value for various insulation products.

Refer to Table 1 for a summary of all the industry recommended minimum and typical physical property thermal characteristics.

SYSTEM PARAMETERS

Compressive Strength

Compressive strength is the measure of the amount of resistance encountered when a load is applied, and is reported in kilopascals (pounds per square inch). The ASTM testing methods used for cellular glass are C 165 and C 240, for rigid cellular plastics is D 1621, and for fiberglass and perlite is C 165. (ASTM C 209 does not reference compressive strength for wood fiberboard, but a typical value can be obtained by following ASTM C 165 or D 1621.) These methods consist of applying a uniform load to the top surface of the specimen until a 10 or 25 percent deformation, or yield occurs. The compressive strength is calculated by dividing the maximum load applied by the horizontal cross-sectional area of the specimen measured before the test. Figure 5 highlights the ASTM and federal recommended minimum compressive strength values as well as typical values for various insulation products.

Experience has shown that compressive strength values of at least 110 KPa (16 psi, measured at 10 percent deformation) for adhered systems, 69 KPa(10 psi, measured at 10 percent deformation or 83 KPa (12 psi) measured at 25 percent deformation) for ballasted systems, and 124 KPa (18 psi, measured at 10 percent deformation) for mechanically-fastened systems will give adequate performance in the field. That is, provided reasonable precautions are taken to protect the insulation from heavy traffic both during and after installation.

Perpendicular Tensile Strength

Perpendicular tensile strength is a measure of the load required to fail a sample in the direction perpendicular to the surface of the board. The ASTM test method for fiberglass, perlite, polyisocyanurate, polyurethane and wood fiberboard is C 209. (There are no ASTM test standards for cellular glass or polystyrene, but typical values can be obtained by following ASTM C 209.) The method consists of cementing the top and bottom surfaces of the specimen to 5cm by 5cm (2 inch by 2 inch) blocks which are mounted in a tensile testing machine. The load is increased until failure occurs. The results are reported in kilopascals (pounds per square foot). Figure 6 highlights the ASTM recommended minimum perpendicular tensile strength values as well as typical values for various insulation products.

Experience has shown that a perpendicular tensile value of at least 24 KPa (500 psf) for fully-adhered systems will give adequate performance in the field. The perpendicular tensile strength of an insulation has very little affect on the performance of ballasted and mechanically-fastened systems.

Peel Strength

Peel strength is the measure of the bond strength between the membrane and the insulation facer, and the facer to the insulation board. For insulations without facers, the peel strength measures the bond strength between the membrane and the top surface of the board, as well as the internal cohesive strength of the board. There is no standard for this test, but the method typically used consists of cutting a 10cm by 15cm (4 inch by 6 inch) insulation sample to which an 8cm by 30cm (3 inch by 12 inch) strip of cleaned membrane is bonded. The membrane is adhered for a length of 13cm (5 inches) leaving the remaining membrane loose. After a 7-day conditioning period at room temperature, the sample is inserted into a jig which holds the sides and top edges of the insulation without contacting the membrane. The loose membrane end is attached to the moving head of the tensile testing machine and the membrane is pulled at a 90 degree angle, perpendicular to the face of the board, at a speed of 5cm (2 inches) per minute. The test is conducted at room temperature and the mean load as well as the mode of failure is recorded. The results are reported in newtons per centimeter (pounds per inch) of width. Figure 7 highlights typical peel strength values for various insulation products.

Experience has shown that a peel strength value of at least 2.9 N/cm (1.7 lb/in) will give adequate field performance for fully-adhered systems.

Foot Traffic Resistance

Foot traffic resistance is the measure of the insulation boards ability to support concentrated and repeated traffic loads typically encountered during roof installation. The test consists of subjecting the roofing assembly (including substrate, insulation, membrane and top covering, if any) to cyclic loading. There is no standard for this test, but one such method utilizes a 15cm (6 inch) diameter plate attached to an air-actuated cylinder. The line pressure is set to simulate the weight applied by the foot of a 130 kilogram (285 pound) roofer. When the plate reaches full pressure, it is held for a two-second period before release. The test is conducted at room temperature and no conditioning period is necessary. The number of cycles performed as well as the condition of the insulation is reported. Figure 8 highlights typical foot traffic resistance results for various insulation products below a ballasted EPDM system.

Experience has shown that insulations, which exhibit only minor indentations and no cell damage after being subjected to 200 cycles on the foot traffic resistance test, will perform adequately in the field under all single-ply systems. That is, provided reasonable precautions are taken to protect the insulation from heavy traffic both during and after installation.

Wind Uplift Testing

Wind uplift testing measures the structural strength of the insulation board on a larger scale than the perpendicular tensile strength by incorporating the entire roofing system into the evaluation. The test method most widely used today was developed by Factory Mutual Research Corporation back in the 1950s. The procedure consists of attaching the insulation to a deck, then installing the membrane over the top. The assembly is sealed into a frame and pressurized with air from below. The pressure is incrementally increased by 700 pascals (15 pounds per square foot) until failure occurs. If 2.9 kilopascals (60 psf) is resisted for a one minute period, the first level of satisfactory performance is attained and an I-60 rating is given. If 4.3 KPa (90 psf) is resisted, the highest level is achieved and an I-90 rating is awarded. Figure 9 highlights typical wind uplift testing results utilizing a fully-adhered EPDM membrane with the insulation fastened once per every $0.2m^2$ (once per 2 ft^2).

Wind uplift failure modes for cellular glass, fiberglass, perlite and phenolic are typically delaminations. Polyisocyanurate, polyurethane and wood fiberboard (1.3cm, 0.5 inch thick fiberboard) typically fails by board breakage.

Refer to Table 2 for a summary of the industry recommended physical property system parameters, and to Table 3 for a summary of the typical physical property system parameters.

DISCUSSION

The minimum physical property values referenced in the text of this paper and contained in Tables 1 and 2 have been compiled from the individual ASTM Specifications referenced for each insulation type. The insulation system parameter values contained in Table 3 have been derived from laboratory testing in conjunction with practical field experience. Table 4 contains a list of references.

Insulations containing these physical properties have been used for many years with single-ply roofing systems producing acceptable results. Occasional problems have occurred however, including delaminations on adhered systems, crushed insulation on ballasted designs and damaged insulation (around the fastening device) on mechanically-fastened systems. These occurrences have generally been the result of a material quality control problem, physical abuse or an under-designed system installed in a demanding application. Specifying minimum system parameters will not eliminate all potential field problems, but it should help in minimizing them.

It it very important to be aware that, because of the competitive nature of the roofing business, of environmental considerations, etc., products tend to change. Once an insulation material is tested and exhibits adequate physical property values for a particular single-ply system, the material should be periodically retested to ensure changes to the formulation, facer, or even manufacturing process have not negatively impacted its performance characteristics.

Insulation products which cannot be used directly under certain single-ply systems, can, in some instances, be installed below a board that has adequate physical properties. One such example of this would be EPS below fiberboard for an adhered system. The EPS alone would be unacceptable for use with a solvent-based adhered system, but the placement of fiberboard over the top makes the use of EPS feasible. Likewise, fiberboard can be used over crushable insulations with ballasted systems to improve traffic resistance.

DEVELOPMENT NEEDS

There exists a need for the development of at least two laboratory testing methods which currently do not exist. One test should simulate the long-term effects of moisture on insulations, and the other should measure the insulations ability to retard lateral fastener movement on mechanically-fastened systems.

A moisture study has already been started by Carlisle Syn-Tec Systems on wood fiberboard, but the evaluation has been continuing for over two years. A more time-effective moisture evaluation testing method for use with all insulations is desirable.

Compression strength testing is currently the only method of evaluating fastener support with mechanically-fastened systems. This is adequate for the vertical loadings encountered, but side to side movement caused by membrane flutter creates different stresses. With the increased use of mechanically-fastened systems, a small scale dynamic testing method is needed to ensure the insulation will properly support the fastening device and promote long-term performance.

CONCLUSION

Because there is such a wide range of insulation choices available, it is vitally important that the selected product be structurally designed to support the specified single-ply system and the associated rooftop traffic. Boards which have low facer bond strengths should not be used directly under an adhered membrane. Boards which cannot resist concentrated loads without being damaged should not be installed directly under a ballasted system. Insulations which cannot adequately support a particular fastening device should not be specified directly under a mechanically-fastened membrane. The test methods presented in this paper will aid in determining if a specific insulation is suitable for use with a specified single-ply roofing system.

Insulation	Core Density, Kg/m³ (pcf)
Cellular Glass (ASTM C 552)	112 (7.0) minimum 136 (8.5) typical
Expanded Polystyrene (ASTM C 578 Type I)	14 (0.9) minimum 16 (1.0) typical
Extruded Polystyrene (ASTM C 578 Type X)	22 (1.35) minimum 22 (1.4) typical
Fiberglass (ASTM C 726)	No minimum 112 to 160 (7 to 10) typical
Perlite (ASTM C 728)	No minimum 144 (9) typical
Phenolic (ASTM C 1126 Type 1, Grade 1)	No minimum 4.3 (2.7) typical
Polyisocyanurate (ASTM C 1013)	No minimum 27 (1.7) typical
Polyurethane (ASTM C1013)	No minimum 27 (1.7) typical
Wood Fiberboard (ASTM C 208 Regular Sheathing)	No minimum 240 (15.0) typical

Figure 1 *Minimum core density valves and typical valves for insulation products.*

Insulation	Max. Dim. Stability, % 70°C (158°F), 95% RH 7 Day Aging
Cellular Glass (ASTM C 552)	No maximum
Expanded Polystyrene (ASTM C 578 Type I)	2
Extruded Polystyrene (ASTM C 578 Type X)	2
Fiberglass (ASTM C 726)	No maximum
Perlite (ASTM C 728)	No maximum
Phenolic (ASTM C 1126 Type 1, Grade 1)	2
Polyiscyanurate (ASTM C 1013) (Fed. Spec. HH-1-1972/2)	4
Polyurethane (ASTM C 1013) (Fed. Spec. HH-1-1972/2)	4
Wood Fiberboard (ASTM C 208 Regular Sheathing)	0.5 20°C (68°F), 90% RH age until equilibrium

Figure 2 *Maximum dimensional stability values for insulation products.*

Insulation	Maximum Water Absorption, % Volume (2 Hour Immersion)
Cellular Glass (ASTM C 552)	0.5
Expanded Polystyrene (ASTM C 578 Type I)	4.0 (24 hour immersion)
Extruded Polystyrene (ASTM C 578 Type X)	0.3 (24 hour immersion)
Fiberglass (ASTM C 726)	10
Perlite (ASTM C 728)	1.5
Phenolic (ASTM C 1126 Type 1, Grade 1)	3.0
Polyisocyanurate (ASTM C 1013)	1.5
Polyurethane (ASTM C 1013)	1.5
Wood Fiberboard (ASTM C 208 Regular Sheathing)	7

Figure 3 *Maximum water asorption values for insulation products.*

Insulation	Minimum R-Value per 2.5 cm (1 inch), Km²/W (F°ft² h/BTU)
Cellular Glass (ASTM C 552)	0.46 (2.6)
Expanded Polystyrene (ASTM C 578 Type I)	0.63 (3.6)
Extruded Polystyrene (ASTM C 578 Type X)	0.88 (5.0)
Fiberglass (ASTM C 726)	No minimum
Perlite (ASTM C 728)	0.50 (2.8)
Phenolic (ASTM C 1126 Type 1, Grade 1)	1.1 (6.3)
Polyisocyanurate (ASTM C 1013)	1.1 (6.2)
Polyurethane (ASTM C 1013)	1.1 (6.2)
Wood Fiberboard (ASTM C 208 Regular Sheathing)	0.44 (2.5)

Figure 4 *Minimum R-value for insulation products.*

Insulation	Comp Strength, KPa (psi) 10% Deformation
Cellular Glass (ASTM C 552)	517 (75) minimum 689 (100) typical
Expanded Polystyrene (ASTM C 578 Type I)	69 (10) minimum 69 (10) typical
Extruded Polystyrene (ASTM C 578 Type X)	104 (15) minimum 124 (18) typical
Fiberglass (ASTM C 726)	83 (12) min (25% def) 76 (11) typical (25% def)
Perlite (ASTM C 728)	138 (20) min (5% def) 241 (35) typical (10% def)
Phenolic (ASTM C 1126 Type 1, Grade 1)	110 (16) minimum 172 (25) typical
Polyisocyanurate (ASTM C 1013) (Fed. Spec. HH-I-1972/2)	110 (16) minimum 124 (18) typical
Polyurethane (ASTM C 1013) (Fed. Spec. HH-I-1972/2)	110 (16) minimum 124 (18) typical
Wood Fiberboard (ASTM C 208 Regular Sheathing)	No minimum 241 (35) typical

Figure 5 *Minimum compressive strength values and typical values for insulation products.*

Insulation	Perpendicular Tensile, KPa (psf)
Cellular Glass (ASTM C 552)	No minimum 57 (1200) typical
Expanded Polystyrene (ASTM C 578 Type I)	No minimum 62 (1300) typical
Extruded Polystyrene (ASTM C 578 Type X)	No minimum 57 (1200) typical
Fiberglass (ASTM C 726)	10 (200) minimum 14 (300) typical
Perlite (ASTM C 728)	28 (575) minimum 29 (600) typical
Phenolic (ASTM C 1126 Type 1, Grade 1)	7 (150) minimum 34 (700) typical
Polyisocyanurate (ASTM C 1013)	24 (500) minimum 53 (1100) typical
Polyurethane (ASTM C 1013)	24 (500) minimum 53 (1100) typical
Wood Fiberboard (ASTM C 208 Regular Sheathing)	29 (600) minimum 67 (1400) typical

Figure 6 *Minimum perpendicular tensile strength values and typical values for insulation products.*

Insulation	Peel strength, N/cm (lb/in)
Cellular Glass (ASTM C 552)	6.1 (3.5)
Expanded Polystyrene (ASTM C 578 Type I)	Not compatible w/solvent-based adhesives.
Extruded Polystyrene (ASTM C 578 Type X)	Not compatible w/solvent-based adhesives.
Fiberglass (ASTM C 726)	2.6 (1.5)
Perlite (ASTM C 728)	1.6 (0.9)
Phenolic (ASTM C 1126 Type 1, Grade 1)	3.5 (2.0)
Polyisocyanurate (ASTM C 1013)	3.5 (2.0)
Polyurethane (ASTM C 1013)	3.5 (2.0)
Wood Fiberboard (ASTM C 208 Regular Sheathing)	3.7 (2.1)

Figure 7 *Typical peel strength values for insulation products.*

Insulation	Foot Traffic-200 Cycles
Cellular Glass (ASTM C 552)	Minor indentations cells fractured
Expanded Polystyrene (ASTM C 578 Type I)	Minor indentations no damage
Extruded Polystyrene (ASTM C 578 Type X)	Minor indentations no damage
Fiberglass (ASTM C 726)	No damage
Perlite (ASTM C 728)	Minor indentations no damage
Phenolic (ASTM C 1126 Type 1, Grade 1)	Moderate indentations cells fractures
Polyisocyanurate (ASTM C 1013)	Minor indentations no damage
Polyurethane (ASTM C 1013)	Minor indentations no damage
Wood Fiberboard (ASTM C 208 Regular Sheathing)	No damage

Figure 8 *Typical foot traffic resistance results for insulation products below a ballasted EPDM system.*

Insulation	Wind Uplift, KPa (psf)
Cellular Glass (ASTM C 552)	5.0 to 6.5 (105 to 135)
Expanded Polystyrene (ASTM C 578 Type I)	Not compatible w/solvent-based adhesives
Extruded Polystyrene (ASTM C 578 Type X)	Not compatible w/solvent-based adhesives
Fiberglass (ASTM C 726)	2.9 to 4.3 (60 to 90)
Perlite (ASTM C 728)	2.2 to 2.9 (45 to 60)
Phenolic (ASTM C 1126 Type 1, Grade 1)	4.3 to 5.0 (90 to 105)
Polyisocyanurate (ASTM C 1013)	5.0 to 5.7 (105 to 120)
Polyurethane (ASTM C 1013)	5.0 to 5.7 (105 to 120)
Wood Fiberboard (ASTM C 208 Regular Sheathing)	3.6 to 5.0 (75 to 105)

Figure 9 *Typical wind uplift testing results using fully-adhered EPDM membrane.*

Insulation	Core Density, Kg/m³ (pcf)	Maximum Water Absorption, % Volume (2 Hour Immersion)	Minimum R-Value per 2.5 cm (1 inch), Km²/W (F°ft²h/BTU)	Max. Dim. Stability, % 70°C (158°F), 95% RH 7 Day Aging
Cellular Glass (ASTM C 552)	112 (7.0) minimum 136 (8.5) typical	0.5	0.46 (2.6)	No maximum
Expanded Polystyrene (ASTM C 578 Type I)	14 (0.9) minimum 16 (1.0) typical	4.0 (24 hour immersion)	0.63 (3.6)	2
Extruded Polystyrene (ASTM C 578 Type X)	22 (1.35) minimum 22 (1.4) typical	0.3 (24 hour immersion)	0.88 (5.0)	2
Fiberglass (ASTM C 726)	No minimum 112 to 160 (7 to 10) typical	10	No minimum	No maximum
Perlite (ASTM C 728)	No minimum 144 (9) typical	1.5	0.50 (2.8)	No maximum
Phenolic (ASTM C 1126 Type 1, Grade 1)	No minimum 43 (2.7) typical	3.0	1.1 (6.3)	2
Polyisocyanurate (ASTM C 1013)	No minimum 27 (1.7) typical	1.5	1.1 (6.2)	4
Polyurethane (ASTM C 1013)	No minimum 27 (1.7) typical	1.5	1.1 (6.2)	4
Wood Fiberboard (ASTM C 208 Regular Sheathing)	No minimum 240 (15) typical	7	0.44 (2.5)	0.5 20°C (68°F), 90% RH Age until equilibrium

Note: All minimum and maximum values are extracted from the ASTM Specification referenced for each insulation type. All typical values are derived from laboratory testing based on the ASTM Specification referenced for each insulation type.

Table 1 *Industry recommended/typical insulation physical property values (thermal characteristics).*

Insulation	Comp Strength, KPa (psi) 10% Deformation	Perpendicular Tensile, KPa (psf)	Peel Strength, N/cm (lb/in)	Foot Traffic Resistance	Wind Uplift, KPa (psf)
Cellular Glass (ASTM C 552)	517 (75) minimum	None to date	None to date	None to date	None to date
Expanded Polystyrene (ASTM C 578 Type I)	69 (10) minimum	None to date	None to date	None to date	None to date
Extruded Polystyrene (ASTM C 578 Type X)	104 (15) minimum	None to date	None to date	None to date	None to date
Fiberglass (ASTM C 726)	83 (12) min 25% deformation	9.6 (200) minimum	None to date	None to date	Noné to date
Perlite (ASTM C 728)	138 (20) min 5% deformation	27.5 (575) minimum	None to date	None to date	None to date
Phenolic (ASTM C 1126 Type 1, Grade 1)	110 (16) minimum	7.2 (150) minimum	None to date	None to date	None to date
Polyisocyanurate (ASTM C 1013) (Fed. Spec. HH-I-1972/2)	110 (16) minimum	24 (500) minimum	None to date	None to date	None to date
Polyurethane (ASTM C 1013) (Fed. Spec. HH-I-1972/2)	110 (16) minimum	24 (500) minimum	None to date	None to date	None to date
Wood Fiberboard (ASTM C 208 Regular Sheathing)	None to date	28.7 (600) minimum	None to date	None to date	None to date

Note:[1] All minimum values are extracted from the individual ASTM Specifications referenced for each insulation type.

Table 2[1] *Industry recommended insulation physical property values (system parameters).*

Insulation	Comp Strength KPa (psi) 10% Deformation	Perpendicular Tensile, KPa (psf)	Peel Strength, N/cm (lb/in)	Foot Traffic[2] 200 Cycles	Wind Uplift,[3] KPa (psf)
Cellular Glass (ASTM C 552)	689 (100)	57 (1200)	6.1 (3.5)	Minor indentations cells fractured	5.0 to 6.5 (105 to 135)
Expanded Polystyrene (ASTM C 578 Type 1)	69 (10)	62 (1300)	Not compatible w/solvent-based adhesives	Minor indentations no damage	Not compatible w/solvent-based adhesives
Extruded Polystyrene (ASTM C 578 Type X)	124 (18)	57 (1200)	Not compatible w/solvent-based adhesives	Minor indentations no damage	Not compatible w/solvent-based adhesives
Fiberglass (ASTM C 726)	76 (11) 25% deformation	14 (300)	2.6 (1.5)	No damage	2.9 to 4.3 (60 to 90)
Perlite (ASTM C 728)	241 (35)	29 (600)	1.6 (0.9)	Minor indentations no damage	2.2 to 2.9 (45 to 60)
Phenolic (ASTM C 1126 Type 1, Grade 1)	172 (25)	34 (700)	3.5 (2.0)	Moderate indentations cells fractured	4.3 to 5.0 (90 to 105)
Polyisocyanurate (ASTM C 1013)	124 (18)	53 (1100)	3.5 (2.0)	Minor indentations no damage	5.0 to 5.7 (105 to 120)
Polyurethane (ASTM C 1013)	124 (18)	53 (1100)	3.5 (2.0)	Minor indentations no damage	5.0 to 5.7 (105 to 120)
Wood Fiberboard (ASTM C 208 Regular Sheathing)	241 (35)	67 (1400)	3.7 (2.1)	No damage	3.6 to 5.0 (75 to 105)

Notes:
1. All typical values are derived from laboratory testing based on the ASTM Specification referenced for each insulation type, or based on the non-standard test method described in the text of this paper.
2. Foot traffic test construction consisted of insulation, 1.1mm (.045 in) EPDM membrane and river worn gravel.
3. Wind uplift values based on actual test results or past experience by Factory Mutual. The construction utilized was fully adhered EPDM membrane with the insulation fastened once per every 0.2m² (1 per 2 ft²). All insulations were 3.8 cm (1.5 in) thick except fiberglass and perlite which were 2.5 cm (1 in) thick, and wood fiberboard which was 1.3 cm (½ in) thick.

Table 3[1] *Typical insulation physical property values (system parameters).*

ASTM C 165	Standard Method For Measuring Compressive Properties Of Thermal Insulations.
ASTM C 177	Standard Method For Steady-State Heat Flux Measurements And Thermal Transmission Properties By Means Of The Guarded Hot-Plate Apparatus.
ASTM C 208	Standard Specification For Insulating Board (Cellulosic Fiber), Structural and Decorative.
ASTM C 209	Standard Methods Of Testing Insulating Board (Cellulosic Fiber), Structural and Decorative.
ASTM C 236	Standard Test Method For Study-State Thermal Performance Of Building Assemblies By Means Of A Guarded Hot Box.
ASTM C 240	Standard Methods Of Testing Cellular Glass Insulation Block.
ASTM C 272	Standard Test Method For Water Absorption Of Core Materials For Structural Sandwich Constructions.
ASTM C 303	Standard Test Method For Density Of Preformed Block-Type Thermal Insulation.
ASTM C 518	Standard Test Method For Steady-State Heat Flux Measurements And Thermal Transmission Properties By Means Of The Heat Flow Meter Apparatus.
ASTM C 552	Standard Specification For Cellular Glass Thermal Insulation.
ASTM C 578	Standard Specification For Preformed, Cellular Polystyrene Thermal Insulation.
ASTM C 726	Standard Specification For Mineral Fiber And Mineral Fiber, Rigid Cellular Polyurethane Composite Roof Insulation Board.
ASTM C 728	Standard Specification For Perlite Thermal Insulation Board.
ASTM C 1013	Standard Specification For Membrane-Faced Rigid Cellular Polyurethane Roof Insulation.
ASTM C 1126	Standard Specification For Faced Or Unfaced Rigid Cellular Phenolic Thermal Insulation.
ASTM D 1621	Standard Test Method For Compressive Properties Of Rigid Cellular Plastics.
ASTM D 1622	Standard Test Method For Apparent Density Of Rigid Cellular Plastics.
Factory Mutual Approval Standard 4470.	
Federal Specification HH-I-1972/2 Insulation Board, Thermal, Polyurethane or Polyisocyanurate Faced With Asphalt/Organic Felt, Polymer/Organic Mat, Asphalt/Glass Mat or Polymer Glass/Mat On Both Sides Of Foam.	

Table 4