CSi2eye: One-on-one Technical Education
March 16, 2017 – Chicago, Illinois

Long-term performance and aged R-value of polyisocyanurate insulation

presented by

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Polyisocyanurate insulation

U.S. product standard: ASTM C1289

Designation: C1289 – 16

Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board[1]

This standard is issued under the fixed designation C1289; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This specification covers the general requirements for faced thermal insulation boards composed of rigid cellular polyisocyanurate surfaced with other materials. The insulation boards are intended for use at temperatures between –40 and 200°F (–40 and 93°C). This specification does not cover cryogenic applications. Consult the manufacturer for specific recommendations and properties in cryogenic conditions. For specific applications, the actual temperature limits shall be agreed upon by the manufacturer and the purchaser.

1.2 This standard is intended to apply to rigid cellular polyurethane-modified polyisocyanurate thermal insulation board products that are commercially acceptable as non-structural panels useful in building construction. The term polyisocyanurate encompasses the term polyurethane. For engineering and design purposes, users should follow specific product information provided by board manufacturers regarding physical properties, system design considerations and installation recommendations.

NOTE 1—See Appendix X1 for guidance on determining wind pressure resistance of panels when required for wall sheathing applications.

1.3 The use of thermal insulation materials covered by this specification is typically regulated by building codes, or other agencies that address fire performance. Where required, the fire performance of the material shall be addressed through standard fire test methods established by the appropriate governing documents.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

NOTE 2—For conversion to metric units other than those contained in this standard, refer to IEEE/ASTM SI 10.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents, of the issue in effect on the date of material purchase, form a part of this specification to the extent specified herein:

2.2 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation
C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
C203 Test Methods for Breaking Load and Flexural Properties of Block-Type Thermal Insulation
C208 Specification for Cellulosic Fiber Insulating Board
C209 Test Methods for Cellulosic Fiber Insulating Board
C303 Test Method for Dimensions and Density of Preformed Block and Board–Type Thermal Insulation
C390 Practice for Sampling and Acceptance of Thermal Insulation Lots
C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C550 Test Method for Measuring Trueness and Squareness of Rigid Block and Board Thermal Insulation
C728 Specification for Perlite Thermal Insulation Board
C1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions
C1058/C1058M Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation
C1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus
C1177/C1177M Specification for Glass Mat Gypsum Substrate for Use as Sheathing

[1] This specification is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.22 on Organic and Nonhomogeneous Inorganic Thermal Insulations.
Current edition approved Jan. 15, 2016. Published January 2016. Originally approved in 1995. Last previous edition approved in 2015 as C1289 – 15. DOI: 10.1520/C1289-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Polyisocyanurate insulation

ASTM C1289:

- Type I (foil-faced wall sheathing)
- Type II (faced roof insulation)
- Type III (perlite board laminate)
- Type IV (wood-fiber board laminate)
- Type V (OSB/plywood laminate)
- Type VII (glass mat-faced gypsum board laminate)

<u>ASTM C1289, Type II:</u>

- Class 1 (reinforced cellulosic-mat facers)
  - Grade 1: 16 psi compressive strength
  - Grade 2: 20 psi compressive strength
  - Grade 3: 25 psi compressive strength
- Class 2 (coated glass facers)
- Class 3 (uncoated glass facers)
- Class 4 (½-inch-thick max., high density product)
  - Grade 1: 80 psi compressive strength
  - Grade 2: 110 psi compressive strength
  - Grade 3: 140 psi compressive strength

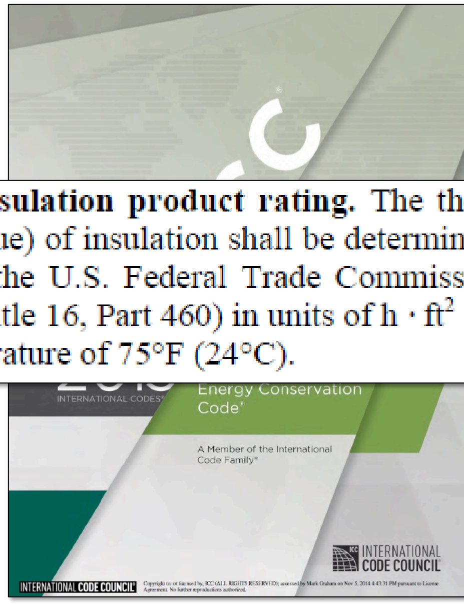
For roofing applications, polyisocyanurate insulation should be specified by using ASTM C1289 and the specific type, class and grade desired

For example: ASTM C1289, Type II, Class 1, Grade 2

Professional Roofing,
February 2016
www.ProfessionalRoofing.net

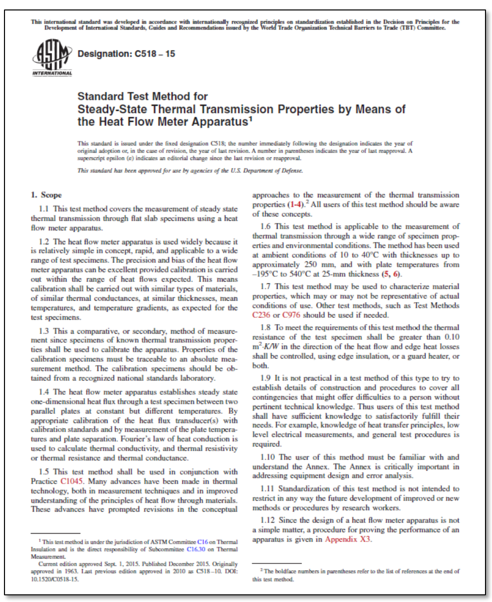
<u>NRCA's R-value testing</u>

International Energy Conservation Code



C303.1.4 Insulation product rating. The thermal resistance (*R*-value) of insulation shall be determined in accordance with the U.S. Federal Trade Commission *R*-value rule (CFR Title 16, Part 460) in units of h · ft² · °F/Btu at a mean temperature of 75°F (24°C).

ASTM C518



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: C518 – 15

Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[1]

This standard is issued under the fixed designation C518; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the measurement of steady state thermal transmission through flat slab specimens using a heat flow meter apparatus.

1.2 The heat flow meter apparatus is used widely because it is relatively simple in concept, rapid, and applicable to a wide range of test specimens. The precision and bias of the heat flow meter apparatus can be excellent provided calibration is carried out within the range of heat flows expected. This means calibration shall be carried out with similar types of materials, of similar thermal conductances, at similar thicknesses, mean temperatures, and temperature gradients, as expected for the test specimens.

1.3 This a comparative, or secondary, method of measurement since specimens of known thermal transmission properties shall be used to calibrate the apparatus. Properties of the calibration specimens must be traceable to an absolute measurement method. The calibration specimens should be obtained from a recognized national standards laboratory.

1.4 The heat flow meter apparatus establishes steady state one-dimensional heat flux through a test specimen between two parallel plates at constant but different temperatures. By appropriate calibration of the heat flux transducer(s) with calibration standards and by measurement of the plate temperatures and plate separation. Fourier's law of heat conduction is used to calculate thermal conductivity, and thermal resistivity or thermal resistance and thermal conductance.

1.5 This test method shall be used in conjunction with Practice C1045. Many advances have been made in thermal technology, both in measurement techniques and in improved understanding of the principles of heat flow through materials. These advances have prompted revisions in the conceptual approaches to the measurement of the thermal transmission properties (1-4).[2] All users of this test method should be aware of these concepts.

1.6 This test method is applicable to the measurement of thermal transmission through a wide range of specimen properties and environmental conditions. The method has been used at ambient conditions of 10 to 40°C with thicknesses up to approximately 250 mm, and with plate temperatures from –195°C to 540°C at 25-mm thickness (5, 6).

1.7 This test method may be used to characterize material properties, which may or may not be representative of actual conditions of use. Other test methods, such as Test Methods C236 or C976 should be used if needed.

1.8 To meet the requirements of this test method the thermal resistance of the test specimen shall be greater than 0.10 $m^2 \cdot K/W$ in the direction of the heat flow and edge heat losses shall be controlled, using edge insulation, or a guard heater, or both.

1.9 It is not practical in a test method of this type to try to establish details of construction and procedures to cover all contingencies that might offer difficulties to a person without pertinent technical knowledge. Thus users of this test method shall have sufficient knowledge to satisfactorily fulfill their needs. For example, knowledge of heat transfer principles, low level electrical measurements, and general test procedures is required.

1.10 The user of this method must be familiar with and understand the Annex. The Annex is critically important in addressing equipment design and error analysis.

1.11 Standardization of this test method is not intended to restrict in any way the future development of improved or new methods or procedures by research workers.

1.12 Since the design of a heat flow meter apparatus is not a simple matter, a procedure for proving the performance of an apparatus is given in Appendix X3.

[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

Current edition approved Sept. 1, 2015. Published December 2015. Originally approved in 1963. Last previous edition approved in 2010 as C518 – 10. DOI: 10.1520/C0518-15.

[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

ASTM C1303

Designation: C1303/C1303M – 14

Standard Test Method for
Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation[1]

5. Significance and Use

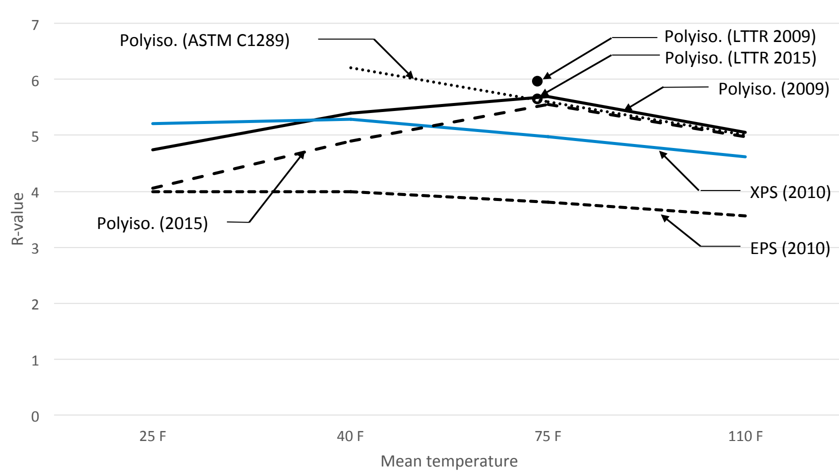
5.1 Rigid gas-filled closed-cell foam insulations include all cellular plastic insulations which rely on a blowing agent (or gas), other than air, for thermal resistance values. At the time of manufacture, the cells of the foam usually contain their highest percentage of blowing agent and the lowest percentage of atmospheric gases. As time passes, the relative concentrations of these gases change due primarily to diffusion. This results in a general reduction of the thermal resistance of the foam due to an increase in the thermal conductivity of the resultant cell gas mixture. These phenomena are typically referred to as foam aging.

LTTR is intended to represent the R-values of specimens tested after five years of aging when stored in a controlled laboratory environment. This five-year figure corresponds closely to a predicted 15-year, time weighted average of R-values.

NRCA's R-value testing

- Polyisocyanurate (2009 and previous)
- Expanded polystyrene (2010)
- Extruded polystyrene (2010)
- Polyisocyanurate (2015)

NRCA R-value testing



NRCA's design, in-service R-value recommendation

Polyisocyanurate insulation

1986-2011:

- R = 5.6 per inch thickness

2012-2015:

- R = 5.6 per inch thickness (cooling climates)
- R = 5.0 per inch thickness (heating climates)

Beginning in 2016:

- R = 5.0 per inch thickness

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

NRCA recommends polyisocyanurate insulation be specified by its thickness (and ASTM designation), not by its R-value or LTTR…

TECH TODAY

Polyiso recommendations

The NRCA Roofing Manual provides guidance for polyisocyanurate insulation

by Mark S. Graham

In the U.S., various types, classes and grades of rigid board, faced, polyisocyanurate insulation are used as components of low-slope roof systems. *The NRCA Roofing Manual: Membrane Roof Systems—2015* provides NRCA's best practice guidelines for using specific polyisocyanurate insulation products in membrane roof systems. Following is an overview of some of these guidelines.

> NRCA recommends designers specify a suitable cover board

ASTM C1289

The U.S. product standard for rigid board, faced, polyisocyanurate insulation is ASTM C1289-16a, "Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board." ASTM C1289 addresses 18 products. Within ASTM C1289, types, classes and grades differentiate various products.

NRCA recommends roof system designers use the complete ASTM C1289 designation (including type, class and grade) to clearly delineate the specific product intended.

R-value

ASTM C1289 requires polyisocyanurate insulation be tested and found to have the minimum thermal resistances (R-values) provided in ASTM C1289's Table 2—Thermal Resistance Properties. Also, product (board) or package marking must bear the product's tested R-value.

Instead of using R-value, U.S. polyisocyanurate insulation manufacturers are going to market using the long-term thermal resistance (LTTR) method for identifying polyisocyanurate insulation thermal resistance properties.

NRCA recommends designers specifying polyisocyanurate insulation determine roof system thermal resistance using an in-service R-value of 5.0 per inch. In NRCA's opinion, this design in-service R-value more closely represents conditions in the built environment than LTTR or tested R-value.

In addition to design in-service R-value, NRCA recommends designers specify polyisocyanurate insulation by its desired thickness and not LTTR or R-value to avoid possible confusion.

Application-specific guidance

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

Available thicknesses range from 1 to 4 inches thick. When using flatstock polyisocyanurate insulation, NRCA recommends designers specify polyisocyanurate insulation be installed in multiple layers with a 1½-inch minimum and 2½-inch maximum thickness per layer.

Furthermore, NRCA recommends designers specify polyisocyanurate insulation be manufactured to have a minimum 20-psi compressive strength (Grades 2 or 3) and have facers that are compatible with the assembly method and other roof assembly components.

ASTM C1289, Type I (foil facers) products generally are used in wall sheathing applications and, because of their facers and compressive strengths, they are not considered to be appropriate for roofing applications.

ASTM C1289, Type II generally designates products appropriate for roofing applications. Type II, Class 1 (reinforced cellulosic mat facer) products may be suitable with all roof system types. NRCA recommends Type II, Class 2 (coated glass facer) products be used with single-ply membrane roof systems using water-based bonding adhesives. Type II, Class 3 (uncoated glass facer) 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.

ASTM C1289 also includes four additional product types (Type III, Type IV, Type V and Type VII) to address polyisocyanurate insulation-based composite board products.

NRCA recommends designers specify the use of a suitable cover board layer over polyisocyanurate insulation before roof membrane installation.

Additional information regarding using polyisocyanurate insulation in membrane roof systems is provided in *The NRCA Roofing Manual: Membrane Roof Systems—2015's* Chapter 4—Rigid Board Insulation, Section 4.9—Polyisocyanurate.

MARK S. GRAHAM is NRCA's vice president of technical services.

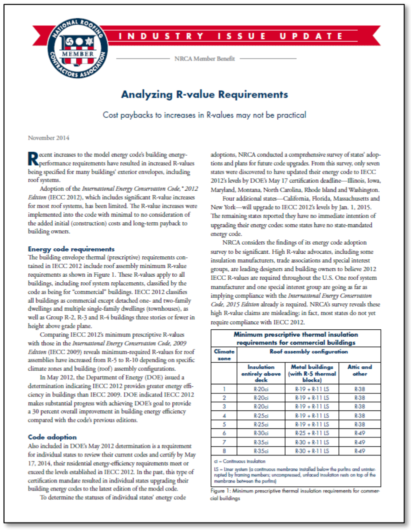
ON the WEB

Descriptions of ASTM C1289's type, class and grade designations and links to additional information regarding polyisocyanurate insulation are accessible at www.professionalroofing.net.

12 www.professionalroofing.net MARCH 2017

Professional Roofing,
February 2016
www.ProfessionalRoofing.net

Is there a realistic payback for high R-values?



INDUSTRY ISSUE UPDATE

NRCA Member Benefit

Analyzing R-value Requirements

Cost paybacks to increases in R-values may not be practical

November 2014

Recent increases to the model energy code's building energy-performance requirements have resulted in increased R-values being specified for many buildings' exterior envelopes, including roof systems.

Adoption of the *International Energy Conservation Code,® 2012 Edition* (IECC 2012), which includes significant R-value increases for most roof systems, has been limited. The R-value increases were implemented into the code with minimal to no consideration of the added initial (construction) costs and long-term payback to building owners.

Energy code requirements

The building envelope thermal (prescriptive) requirements contained in IECC 2012 include roof assembly minimum R-value requirements as shown in Figure 1. These R-values apply to all buildings, including roof system replacements, classified by the code as being for "commercial" buildings. IECC 2012 classifies all buildings as commercial except detached one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as Group R-2, R-3 and R-4 buildings three stories or fewer in height above grade plane.

Comparing IECC 2012's minimum prescriptive R-values with those in the *International Energy Conservation Code, 2009 Edition* (IECC 2009) reveals minimum-required R-values for roof assemblies have increased from R-5 to R-10 depending on specific climate zones and building (roof) assembly configurations.

In May 2012, the Department of Energy (DOE) issued a determination indicating IECC 2012 provides greater energy efficiency in buildings than IECC 2009. DOE indicated IECC 2012 makes substantial progress with achieving DOE's goal to provide a 30 percent overall improvement in building energy efficiency compared with the code's previous editions.

Code adoption

Also included in DOE's May 2012 determination is a requirement for individual states to review their current codes and certify by May 17, 2014, their residential energy-efficiency requirements meet or exceed the levels established in IECC 2012. In the past, this type of certification mandate resulted in individual states upgrading their building energy codes to the latest edition of the model code.

To determine the statuses of individual states' energy code adoptions, NRCA conducted a comprehensive survey of states' adoptions and plans for future code upgrades. From this survey, only seven states were discovered to have updated their energy code to IECC 2012's levels by DOE's May 17 certification deadline—Illinois, Iowa, Maryland, Montana, North Carolina, Rhode Island and Washington.

Four additional states—California, Florida, Massachusetts and New York—will upgrade to IECC 2012's levels by Jan. 1, 2015. The remaining states reported they have no immediate intention of upgrading their energy codes; some states have no state-mandated energy code.

NRCA considers the findings of its energy code adoption survey to be significant. High R-value advocates, including some insulation manufacturers, trade associations and special interest groups, are leading designers and building owners to believe 2012 IECC R-values are required throughout the U.S. One roof system manufacturer and one special interest group are going as far as implying compliance with the *International Energy Conservation Code, 2015 Edition* already is required. NRCA's survey reveals these high R-value claims are misleading; in fact, most states do not yet require compliance with IECC 2012.

Minimum prescriptive thermal insulation requirements for commercial buildings

Climate zone	Roof assembly configuration		
	Insulation entirely above deck	Metal buildings (with R-5 thermal blocks)	Attic and other
1	R-20ci	R-19 + R-11 LS	R-38
2	R-20ci	R-19 + R-11 LS	R-38
3	R-20ci	R-19 + R-11 LS	R-38
4	R-25ci	R-19 + R-11 LS	R-38
5	R-25ci	R-19 + R-11 LS	R-38
6	R-30ci	R-25 + R-11 LS	R-49
7	R-35ci	R-30 + R-11 LS	R-49
8	R-35ci	R-30 + R-11 LS	R-49

ci = Continuous insulation

LS = Liner system (a continuous membrane installed below the purlins and uninterrupted by framing members; uncompressed, unfaced insulation rests on top of the membrane between the purlins)

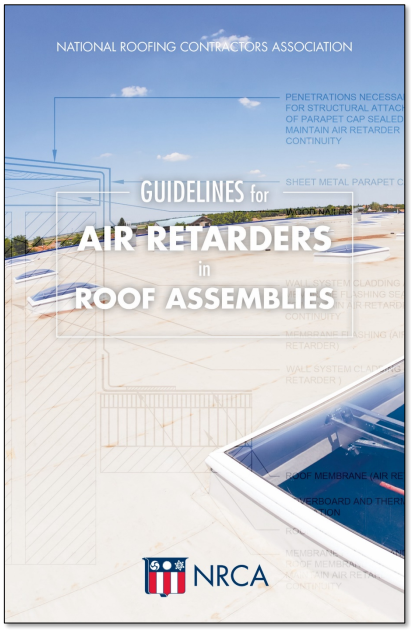
Figure 1: Minimum prescriptive thermal insulation requirements for commercial buildings

NRCA "Industry Issue Update," Nov. 2014:

- For Chicago:
  - R-10 to R-15: 7.5 yrs.
  - R-15 to R-20: 15.6 yrs.
  - R-20 to R-25: 25.2 yrs.
  - R-25 to R-30: 54.7 yrs.

Average roof life is 17.4 yrs.

Air retarders



Guidelines for Air Retarders in Roof Assemblies

- Ch. 1: IECC and ASHRAE
- Ch. 2: Industry research
- Ch. 3: Recommendations

Some key points…

- Building and roof system designers are responsible for proper design….
- Construction Documents should clearly denote locations, materials, application methods and details
- NRCA considers a continuous, air-impermeable roof membrane to function as an air retarder
  - Built-up roof system
  - Polymer-modified bitumen roof system
  - Single-ply membrane roof system

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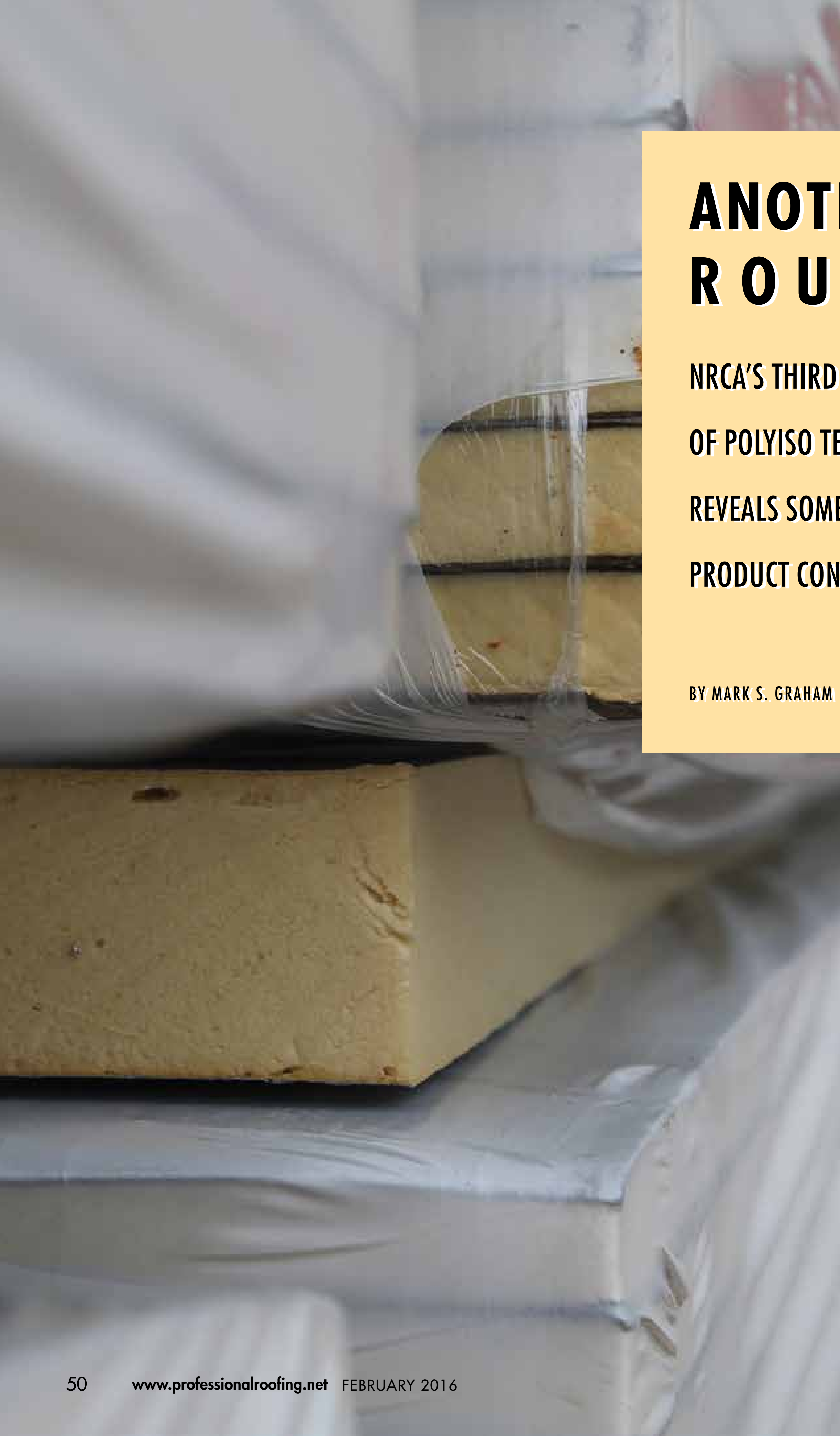

ANOTHER ROUND

NRCA'S THIRD ROUND OF POLYISO TESTS REVEALS SOME PRODUCT CONCERNS

BY MARK S. GRAHAM

In late 2015, NRCA conducted physical property testing on a limited number of samples of new (uninstalled) faced, rigid board polyisocyanurate insulation used as components of low-slope roof systems.

The purpose was to determine the samples' compliances with the U.S. product standard for polyisocyanurate insulation, ASTM C1289, "Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation." The results also provide a basis for comparison with previous testing conducted by NRCA in 2002 and 2009.

ASTM C1289

ASTM C1289 describes methods for testing faced polyisocyanurate insulation's physical properties and R-values and provides consensus–based minimum or maximum values for the properties tested. For example, ASTM C1289's Section 11—Test Methods indicates dimensional stability testing shall be conducted using ASTM D2126, "Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging," except each test specimen shall be 12 inches by 12 inches by the full-faced board thickness. ASTM C1289's Table 1-Physical Properties prescribes maximum dimensional stability values of 2 percent linear change in a board's length and width and 4 percent linear change in a board's thickness.

ASTM C1289 also provides prescriptive requirements addressing polyisocyanurate insulation's dimensional tolerances, face trueness and package marking.

PREVIOUS NRCA TESTING

NRCA previously conducted similar physical property test programs on faced, rigid board polyisocyanurate insulation in 2002 and 2009. Data from these test programs provide a basis for comparing results from NRCA's current test program with its previous test programs.

Results from NRCA's 2002 test program are characterized by relatively high compressive strength and dimensional stability values in a board's thickness though only one sample exceeded ASTM C1289's 4 percent allowable linear change limit in a board's thickness.

Some products included in NRCA's 2002 test program are now known to have been manufactured using the then-common HCFC-141b blowing agent while other products were manufactured using the next generation hydrocarbon- (pentane-) based blowing agents. Because Dec. 31, 2002, marked a federally mandated deadline for ceasing production of HCFC-141b, polyisocyanurate insulation manufacturers were in a period of transitioning blowing agents during the time NRCA collected polyisocyanurate insulation board samples for its 2002 test program.

All the products included in NRCA's 2009 test program are believed to have been manufactured using hydrocarbon-based blowing agents, the same general class of blowing agent currently used for products.

Results from NRCA's 2009 test program are characterized by relatively high compressive strength values and a range of dimensional stability values. One sample tested exceeded ASTM C1289's 2 percent allowable linear change limit in the cross-machine direction, and two samples exhibited shrinkage in board thickness.

2015 TESTING AND RESULTS

NRCA obtained seven multiple-board samples of newly manufactured (uninstalled) 2-inch-thick, permeable facer-sheet-faced polyisocyanurate insulation made by six U.S. manufacturers. The samples were obtained from NRCA contractor members throughout the U.S. from their stored stocks.

Samples 1-A and 1-B were manufactured by the same manufacturer. Sample 1-A is faced with Class 1 fiberglass-reinforced cellulosic felt facers, and Sample 1-B is faced with Class 2 coated polymer-bonded fiberglass mat facers. Samples 2, 3, 4 and 6 were manufactured from four manufacturers using Class 1 facers. Sample 5 was manufactured by a different manufacturer using Class 2 facers. All U.S. manufacturers of rigid board polyisocyanurate insulation are represented in the sampling.

The samples were provided to a nationally recognized testing laboratory, Structural Research Inc. (SRI), Middleton, Wis., for testing and analysis. A minimum of five specimens per sample were subjected to testing for the samples' compressive strength, dimensional stability, flexural strength and tensile strength properties using the methods defined in ASTM C1289.

The samples' densities also were determined; density measurement is not part of ASTM C1289.

Measured apparent overall density (including the facer sheets) and apparent foam core density values for each of the samples are shown in Figure 1. The values reported in the figures are the per sample averages for the multiple specimens tested.

Sample	Facer type	Density (lb/ft³)	
		Apparent overall density	Apparent foam core density
1-A	Cellulosic (Class 1)	2.16	1.57
1-B	Coated fiberglass (Class 2)	3.80	1.68
2	Cellulosic (Class 1)	2.25	1.56
3	Cellulosic (Class 1)	2.26	1.65
4	Cellulosic (Class 1)	2.25	1.64
5	Coated fiberglass (Class 2)	3.16	1.79
6	Cellulosic (Class 1)	2.39	1.68

Figure 1: Density

The difference between a sample's apparent overall density and apparent foam core density is an indication of the relative mass of the foam's facers (top and bottom facers). Although Samples 1B and 5 (the samples with coated fiberglass facers) have notably higher apparent densities than other samples, their apparent foam core densities are similar to the cellulosic felt-faced samples.

Apparent foam core density values in NRCA's 2015 test program are similar to those from its 2009 testing and slightly lower than those in the 2002 testing.

Tested compressive strength values for each of the samples are shown in Figure 2. All the samples tested comply with ASTM C1289's Grade 2 designation, meaning they have a 20-psi minimum compressive strength. Sample 1-B also complies with ASTM C1289's Grade 3 designation (25-psi minimum compressive strength).

Compressive strength values with facers in the 2015 test program are notably lower than those from NRCA's 2002 and 2009 testing.

Tested dimensional stability values for each of the samples are shown in Figure 3. Only Samples 1-A and 5 comply with the maximum percent linear change allowable limit in ASTM C1289. Samples 2, 3, 4 and 6 exceed the allowable limit in the machine direction (MD); Samples 2 and 4 also exceed the allowable limit in the cross-machine direction (XMD). Sample 1-B exceeds the allowable limit in the sample's thickness.

Sample	Compressive strength (psi)		
	With facers	Machine direction	Cross-machine direction
1-A	22.3	16.1	26.5
1-B	28.4	21.2	29.8
2	24.4	16.7	22.0
3	24.5	17.5	19.4
4	23.5	18.5	21.0
5	24.4	20.6	19.8
6	24.5	18.9	21.1
ASTM C1289, Type II requirement	Grade 1: 16 (minimum) Grade 2: 20 (minimum) Grade 3: 25 (minimum)	No requirement	

Figure 2: Compressive strength

Dimensional stability values in the 2015 test program are notably higher than those in NRCA's 2002 and 2009 testing. From NRCA's 2002 and 2009 testing, only one sample failed to comply with ASTM C1289's dimensional stability limits. In the 2015 test program, five of the seven did not comply.

Tested flexural strength, modulus of rupture, break load and tensile strength perpendicular to the surface for each of the samples are shown in Figure 4. All the samples have tested values well in excess of ASTM C1289's minimum requirements. Samples 1B and 5 (the samples with coated fiberglass facers) have somewhat higher modulus of rupture and break strength values than the samples with cellulosic felt facers.

Modulus of rupture and break strength values in NRCA's 2015 test program are slightly lower than those from the 2002 and 2009 testing. Tensile strength values are similar in all three test programs.

KNIT LINE ASSESSMENT

Linear surface depressions, or rutting, sometimes is associated with smooth-surfaced membrane roof systems, particularly single-ply membrane roof systems applied directly over faced, rigid board polyisocyanurate insulation. An example of this condition is shown in the photo.

Field investigations and test cuts reveal such rutting typically correlates to linear depressions occurring on the flat surfaces of polyisocyanurate insulation. These depressions align with knit lines that occur through the foam's cross-sectional thickness. Multiple knit lines occur in the foam's machine direction as a result of streams of liquid foam spreading and rising between mix heads during

Sample	Dimensional stability (Percent linear change after seven days at 158 F and 97 percent relative humidity)		
	Machine direction	Cross-machine direction	Thickness
1-A	1.22	1.27	1.77
1-B	0.54	1.31	5.88
2	3.35	2.91	-1.11
3	2.42	1.53	3.19
4	2.14	2.24	1.21
5	0.56	0.75	3.74
6	2.52	1.96	1.68
ASTM C1289, Type II requirement	2.0 (maximum)		4.0 (maximum)

Figure 3: Dimensional stability (The shaded values denote those values exceeding ASTM C1289's maximum allowable requirement.)

manufacturing. The number and spacing of knit lines per polyisocyanurate insulation board may vary by manufacturer and plants based on the number of mix heads and liquid streams used in a particular manufacturing line.

To assess the surface depressions associated with faced, rigid board polyisocyanurate insulation's knit lines, NRCA asked SRI to record the number of knit lines and measure knit line depths on each of the samples included in NRCA's 2015 test program (see Figure 5).

Example of rutting in polyisocyanurate insulation in an adhered EPDM membrane roof system

ASTM C1289 neither specifically addresses knit line depressions in polyisocyanurate insulation nor provides allowable maximum knit line depression tolerances. Relating to surface variability, ASTM C1289's Section 8.1—Dimensional Tolerances indicates "… the thickness tolerance shall not exceed ⅛ in. (3.2 mm), and the thickness of any two boards shall not differ more than ⅛ in. (3.2 mm). …" Section 8.5—Face Thickness indicates "… boards shall not depart from absolute flatness more than ⅛ in./ft. (10 mm/m) of length and width." Section 8.7—Crushings and Depressions indicates "… boards shall have no crushed or depressed areas on any surface exceeding ⅛ in (3.2 mm) in depth on more than 10% of the total surface area."

Sample	Flexural strength		Tensile strength perpendicular to surface (lbf/ft^3)
	Modulus of rupture (psi)	Break strength (lbf)	
1-A	MD: 79.6 XMD: 61.2	MD: 64.8 XMD: 49.3	3259
1-B	MD: 127.9 XMD: 135.5	MD: 102.4 XMD: 108.2	2590
2	MD: 93.0 XMD: 64.1	MD: 75.4 XMD: 51.1	3080
3	MD: 98.4 XMD: 59.5	MD: 75.8 XMD: 47.2	3083
4	MD: 73.0 XMD: 52.6	MD: 58.1 XMD: 42.2	2904
5	MD: 121.1 XMD: 93.6	MD: 92.9 XMD: 76.9	3668
6	MD: 96.3 XMD: 55.8	MD: 71.3 XMD: 41.7	2657
ASTM C1289, Type II requirement	40	17	500

Figure 4: Flexural strength and tensile strength

Sample	Board side indication	Knit line depth (inch)							
		Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8
1-A	None	-0.084	-0.078	-0.068	—	—	—	—	—
	"This side down"	-0.061	-0.137	-0.110					
1-B	None	-0.038	-0.030	-0.048	—	—	—	—	—
	None	-0.049	-0.085	-0.041					
2	None	-0.015	-0.059	-0.060	-0.028	-0.020	-0.028	-0.010	-0.005
	"This side down"	-0.130	-0.167	-0.161	-0.193	-0.210	-0.166	-0.171	-0.143
3	None	-0.023	-0.049	-0.046	-0.051	-0.047	—	—	—
	None	-0.015	-0.031	-0.045	-0.036	-0.021			
4	None	-0.035	-0.038	-0.068	-0.055	-0.062	—	—	—
	"This side down"	-0.091	-0.112	-0.122	-0.114	-0.072			
5	None	-0.023	-0.036	-0.045	-0.040	-0.025	—	—	—
	None	-0.013	-0.016	-0.013	-0.013	-0.012			
6	None	-0.136	-0.169	-0.189	-0.170	-0.171	-0.173	-0.165	-0.146
	None	-0.035	-0.015	-0.017	-0.007	-0.005	-0.018	-0.036	-0.037

Figure 5: Knit line depth assessment (The shaded values denote those exceeding ⅛-inch in depth.)

In Figure 5, measured values in excess of ⅛ of an inch (0.125 in.) are highlighted. NRCA considers this value to be excessive, particularly for adhered, single-ply membrane roof systems. Possible pooling of adhesives in these depressions during application, bridging of the membrane over the depressions and the rutted finished membrane surface appearance are among NRCA's concerns.

CLOSING THOUGHTS

NRCA's Technical Operations Committee has overseen and reviewed the results of NRCA's 2015 testing of faced, rigid board polyisocyanurate insulation.

The results show some variability in faced, rigid board polyisocyanurate insulation products; instances where specific physical property values do not fall within ASTM C1289's allowable limits; and instances where values have noticeably changed from NRCA's previous testing in 2002 and 2009. NRCA acknowledges the sampling used in this program may not be statistically representative of all polyisocyanurate insulation currently being manufactured.

The test program's findings regarding dimensional stability are of specific concern. NRCA first raised this issue specific to faced, rigid board polyisocyanurate insulation during the mid-1990s. The 2002 and 2009 testing showed some improvements in polyisocyanurate insulation's dimensional stabilities, but NRCA's 2015 testing shows dimensional stability issues are recurring with newly manufactured products and the magnitude of the issues is equal to or greater than in the 1990s. This finding also is consistent with field reports NRCA's Technical Services Section is receiving.

In addition, the issue of surface depressions associated with knit lines in faced, rigid board polyisocyanurate insulation is of particular concern. Although this problem was previously seen only in isolated instances, it now appears to be more pronounced and widespread with the current generation of polyisocyanurate insulation blowing agents and manufacturing processes. Polyisocyanurate insulation manufacturers need to improve the flatness of their roofing-specific products, and appropriate evaluation criteria need to be developed and included in ASTM C1289.

Until these issues are adequately addressed, NRCA maintains its longstanding recommendation to roof system designers for use of a suitable cover board over faced, rigid board polyisocyanurate insulation. Additional information regarding polyisocyanurate insulation and NRCA's cover board recommendations are provided in *The NRCA Roofing Manual: Membrane Roof Systems—2015.*

NRCA looks forward to working constructively with polyisocyanurate insulation manufacturers at ASTM International and elsewhere in the roofing industry to address these issues.

MARK S. GRAHAM is NRCA's vice president of technical services.

Polyiso recommendations

The NRCA Roofing Manual provides guidance for polyisocyanurate insulation

by Mark S. Graham

In the U.S., various types, classes and grades of rigid board, faced, polyisocyanurate insulation are used as components of low-slope roof systems. *The NRCA Roofing Manual: Membrane Roof Systems—2015* provides NRCA's best practice guidelines for using specific polyisocyanurate insulation products in membrane roof systems. Following is an overview of some of these guidelines.

NRCA recommends designers specify a suitable cover board

ASTM C1289

The U.S. product standard for rigid board, faced, polyisocyanurate insulation is ASTM C1289-16a, "Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board." ASTM C1289 addresses 18 products. Within ASTM C1289, types, classes and grades differentiate various products.

NRCA recommends roof system designers use the complete ASTM C1289 designation (including type, class and grade) to clearly delineate the specific product intended.

R-value

ASTM C1289 requires polyisocyanurate insulation be tested and found to have the minimum thermal resistances (R-values) provided in ASTM C1289's Table 2—Thermal Resistance Properties. Also, product (board) or package marking must bear the product's tested R-value.

Instead of using R-value, U.S. polyisocyanurate insulation manufacturers are going to market using the long-term thermal resistance (LTTR) method for identifying polyisocyanurate insulation thermal resistance properties.

NRCA recommends designers specifying polyisocyanurate insulation determine roof system thermal resistance using an in-service R-value of 5.0 per inch. In NRCA's opinion, this design in-service R-value more closely represents conditions in the built environment than LTTR or tested R-value.

In addition to design in-service R-value, NRCA recommends designers specify polyisocyanurate insulation by its desired thickness and not LTTR or R-value to avoid possible confusion.

ON *the* WEB

Descriptions of ASTM C1289's type, class and grade designations and links to additional information regarding polyisocyanurate insulation are accessible at www.professionalroofing.net.

Application-specific guidance

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

Available thicknesses range from 1 to 4 inches thick. When using flatstock polyisocyanurate insulation, NRCA recommends designers specify polyisocyanurate insulation be installed in multiple layers with a 1½-inch minimum and 2½-inch maximum thickness per layer.

Furthermore, NRCA recommends designers specify polyisocyanurate insulation be manufactured to have a minimum 20-psi compressive strength (Grades 2 or 3) and have facers that are compatible with the assembly method and other roof assembly components.

ASTM C1289, Type I (foil facers) products generally are used in wall sheathing applications and, because of their facers and compressive strengths, they are not considered to be appropriate for roofing applications.

ASTM C1289, Type II generally designates products appropriate for roofing applications. Type II, Class 1 (reinforced cellulosic mat facer) products may be suitable with all roof system types. NRCA recommends Type II, Class 2 (coated glass facer) products be used with single-ply membrane roof systems using water-based bonding adhesives. Type II, Class 3 (uncoated glass facer) 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.

ASTM C1289 also includes four additional product types (Type III, Type IV, Type V and Type VII) to address polyisocyanurate insulation-based composite board products.

NRCA recommends designers specify the use of a suitable cover board layer over polyisocyanurate insulation before roof membrane installation.

Additional information regarding using polyisocyanurate insulation in membrane roof systems is provided in *The NRCA Roofing Manual: Membrane Roof Systems—2015*'s Chapter 4—Rigid Board Insulation, Section 4.9—Polyisocyanurate.

MARK S. GRAHAM is NRCA's vice president of technical services.

Analyzing R-value Requirements

Cost paybacks to increases in R-values may not be practical

November 2014

Recent increases to the model energy code's building energy-performance requirements have resulted in increased R-values being specified for many buildings' exterior envelopes, including roof systems.

Adoption of the *International Energy Conservation Code,® 2012 Edition* (IECC 2012), which includes significant R-value increases for most roof systems, has been limited. The R-value increases were implemented into the code with minimal to no consideration of the added initial (construction) costs and long-term payback to building owners.

Energy code requirements

The building envelope thermal (prescriptive) requirements contained in IECC 2012 include roof assembly minimum R-value requirements as shown in Figure 1. These R-values apply to all buildings, including roof system replacements, classified by the code as being for "commercial" buildings. IECC 2012 classifies all buildings as commercial except detached one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as Group R-2, R-3 and R-4 buildings three stories or fewer in height above grade plane.

Comparing IECC 2012's minimum prescriptive R-values with those in the *International Energy Conservation Code, 2009 Edition* (IECC 2009) reveals minimum-required R-values for roof assemblies have increased from R-5 to R-10 depending on specific climate zones and building (roof) assembly configurations.

In May 2012, the Department of Energy (DOE) issued a determination indicating IECC 2012 provides greater energy efficiency in buildings than IECC 2009. DOE indicated IECC 2012 makes substantial progress with achieving DOE's goal to provide a 30 percent overall improvement in building energy efficiency compared with the code's previous editions.

Code adoption

Also included in DOE's May 2012 determination is a requirement for individual states to review their current codes and certify by May 17, 2014, their residential energy-efficiency requirements meet or exceed the levels established in IECC 2012. In the past, this type of certification mandate resulted in individual states upgrading their building energy codes to the latest edition of the model code.

To determine the statuses of individual states' energy code adoptions, NRCA conducted a comprehensive survey of states' adoptions and plans for future code upgrades. From this survey, only seven states were discovered to have updated their energy code to IECC 2012's levels by DOE's May 17 certification deadline—Illinois, Iowa, Maryland, Montana, North Carolina, Rhode Island and Washington.

Four additional states—California, Florida, Massachusetts and New York—will upgrade to IECC 2012's levels by Jan. 1, 2015. The remaining states reported they have no immediate intention of upgrading their energy codes; some states have no state-mandated energy code.

NRCA considers the findings of its energy code adoption survey to be significant. High R-value advocates, including some insulation manufacturers, trade associations and special interest groups, are leading designers and building owners to believe 2012 IECC R-values are required throughout the U.S. One roof system manufacturer and one special interest group are going as far as implying compliance with the *International Energy Conservation Code, 2015 Edition* already is required. NRCA's survey reveals these high R-value claims are misleading; in fact, most states do not yet require compliance with IECC 2012.

Minimum prescriptive thermal insulation requirements for commercial buildings

Climate zone	Roof assembly configuration		
	Insulation entirely above deck	Metal buildings (with R-5 thermal blocks)	Attic and other
1	R-20ci	R-19 + R-11 LS	R-38
2	R-20ci	R-19 + R-11 LS	R-38
3	R-20ci	R-19 + R-11 LS	R-38
4	R-25ci	R-19 + R-11 LS	R-38
5	R-25ci	R-19 + R-11 LS	R-38
6	R-30ci	R-25 + R-11 LS	R-49
7	R-35ci	R-30 + R-11 LS	R-49
8	R-35ci	R-30 + R-11 LS	R-49

ci = Continuous insulation

LS = Liner system (a continuous membrane installed below the purlins and uninterrupted by framing members; uncompressed, unfaced insulation rests on top of the membrane between the purlins)

Figure 1: Minimum prescriptive thermal insulation requirements for commercial buildings

NRCA's theoretical energy savings and cost payback analysis				
Climate zone	**City**	**R-value increase**	**Btu savings (heating and cooling)**	**Payback**
1	Miami	R-10 to R-15	14,094,020 Btu	10.8 years
		R-15 to R-20	7,870,571 Btu	22.1 years
		R-20 to R-25	4,561,644 Btu	35.4 years
		R-25 to R-30	3,232,756 Btu	76.7 years
2	Phoenix	R-10 to R-15	17,587,010 Btu	18.5 years
		R-15 to R-20	9,743,286 Btu	38.1 years
		R-20 to R-25	5,620,822 Btu	61.3 years
		R-25 to R-30	3,969,578 Btu	133.0 years
	New Orleans	R-10 to R-15	21,213,494 Btu	15.0 years
		R-15 to R-20	11,760,541 Btu	30.9 years
		R-20 to R-25	6,787,331 Btu	49.7 years
		R-25 to R-30	4,794,863 Btu	107.8 years
3	Atlanta	R-10 to R-15	32,188,755 Btu	7.8 years
		R-15 to R-20	17,795,916 Btu	16.2 years
		R-20 to R-25	10,253,829 Btu	26.1 years
		R-25 to R-30	7,234,929 Btu	56.7 years
	Los Angeles	R-10 to R-15	16,585,533 Btu	11.6 years
		R-15 to R-20	9,175,377 Btu	23.8 years
		R-20 to R-25	5,288,761 Btu	38.2 years
		R-25 to R-30	3,732,720 Btu	83.0 years
	Dallas	R-10 to R-15	27,291,307 Btu	15.2 years
		R-15 to R-20	15,107,897 Btu	31.4 years
		R-20 to R-25	8,711,683 Btu	50.5 years
		R-25 to R-30	6,150,345 Btu	109.6 years
4	Seattle	R-10 to R-15	41,511,732 Btu	10.0 years
		R-15 to R-20	22,875,846 Btu	20.9 years
		R-20 to R-25	13,155,552 Btu	33.7 years
		R-25 to R-30	9,268,949 Btu	73.5 years
	Philadelphia	R-10 to R-15	45,256,460 Btu	7.5 years
		R-15 to R-20	24,967,532 Btu	15.5 years
		R-20 to R-25	14,368,027 Btu	24.9 years
		R-25 to R-30	10,128,298 Btu	54.3 years
4	Kansas City, Mo.	R-10 to R-15	51,295,159 Btu	9.4 years
		R-15 to R-20	28,314,737 Btu	19.4 years
		R-20 to R-25	16,299,591 Btu	31.3 years
		R-25 to R-30	11,492,733 Btu	68.0 years
5	Boston	R-10 to R-15	49,647,013 Btu	6.7 years
		R-15 to R-20	27,375,148 Btu	13.8 years
		R-20 to R-25	15,748,557 Btu	22.3 years
		R-25 to R-30	11,098,822 Btu	48.5 years
	Denver	R-10 to R-15	52,120,379 Btu	12.1 years
		R-15 to R-20	28,732,017 Btu	25.1 years
		R-20 to R-25	16,526,782 Btu	40.4 years
		R-25 to R-30	11,646,024 Btu	88.2 years
	Chicago	R-10 to R-15	58,340,933 Btu	7.5 years
		R-15 to R-20	32,175,508 Btu	15.6 years
		R-20 to R-25	18,512,379 Btu	25.2 years
		R-25 to R-30	13,047,818 Btu	54.7 years
6	Milwaukee	R-10 to R-15	63,370,658 Btu	9.4 years
		R-15 to R-20	34,933,522 Btu	19.4 years
		R-20 to R-25	20,093,821 Btu	31.4 years
		R-25 to R-30	14,159,572 Btu	68.3 years
	Minneapolis	R-10 to R-15	68,995,466 Btu	9.1 years
		R-15 to R-20	38,033,780 Btu	18.8 years
		R-20 to R-25	21,876,909 Btu	30.4 years
		R-25 to R-30	15,415,978 Btu	66.1 years
7	Sault St. Marie, Mich.	R-10 to R-15	78,807,463 Btu	8.5 years
		R-15 to R-20	43,428,492 Btu	17.6 years
		R-20 to R-25	24,975,104 Btu	28.4 years
		R-25 to R-30	17,596,619 Btu	61.8 years
8	Nome, Alaska	R-10 to R-15	119,135,728 Btu	3.7 years
		R-15 to R-20	65,648,986 Btu	7.7 years
		R-20 to R-25	37,752,688 Btu	12.4 years
		R-25 to R-30	26,598,690 Btu	27.0 years

Figure 2: Results of NRCA's theoretical energy savings and cost payback analysis

NRCA is committed to providing accurate and up-to-date information addressing energy code adoption. You can check the status of your state's energy code adoption by accessing the Energy Codes page of the Technical section of NRCA's website at www.nrca.net/technical/energycodes.

Energy savings and payback

NRCA has conducted an energy-savings and payback analysis for roof assembly R-value increases in 16 cities representative of the energy code's eight U.S. climate zones.

A hypothetical project that consisted of insulation above a roof deck assembly on a 10,000-square-foot single-story building was considered. Construction cost increases and corresponding theoretical energy-savings information were developed for changing the hypothetical roof assembly in each city from R-10 to R-15, R-15 to R-20, R-20 to R-25 and R-25 to R-30. City-specific current energy costs (natural gas for heating and electricity for cooling) were used in the analysis. Payback length is determined by dividing the incremental increased cost for adding R-value by the calculated theoretical energy cost savings. The results of NRCA's analysis are shown in Figure 2.

NRCA's 16-city analysis reveals insulation increases from R-10 to R-15 have the relatively shortest paybacks ranging from 3.7 years to 12.1 years. Conversely, increases from R-20 to R-25 and R-25 to R-30 have paybacks ranging from 12.4 years to 133 years. Payback lengths vary by a city's climatic conditions and heating and cooling energy costs. For example, energy costs significantly vary between Boston and Denver, resulting in wide variances in paybacks even when comparing cities in the same climate zone.

Considering current heating and cooling energy costs, NRCA's analysis concludes R-value increases resulting in payback lengths approaching or beyond a roof assembly's anticipated life span are not financially justifiable for building owners. A 2004 study conducted by The Roofing Industry Alliance for Progress revealed the average life span for a commercial low-slope roof system in the U.S. is about 17.4 years.

As heating and cooling energy costs increase, shorter payback lengths will occur and may better justify the current model energy code's high minimum-required R-values.

You can determine theoretical heating and cooling costs (and savings) for roof assembly configurations in specific cities using NRCA's EnergyWise Roof Calculator accessible at http://energywise.nrca.net.

NRCA recommendations

NRCA considers a roof assembly's thermal performance to be an important attribute to overall roof system performance.

NRCA recommends roof assembly designers provide designs that comply with the minimum requirements of the specific energy code applicable to the jurisdiction where a building is located.

Additional information about complying with the roofing-related requirements of IECC 2009 and IECC 2012 is provided in NRCA's *Guidelines for Complying With Energy Code Requirements for Roof Assemblies: International Energy Conservation Code, 2009 and 2012 Editions,* available by accessing shop.nrca.net or contacting NRCA's Customer Service Department at (866) ASK-NRCA (275-6722) or info@nrca.net.

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