Roofing No. 3001

Subject: **NRCA Polyiso R-value recommendation**

Date: **January 2008 (Revised January 2019)**

NRCA has updated their R-value recommendation for polyisocyanurate roof insulation with the publication of updates to the 2015 The NRCA Roofing Manual: Membrane Roof Systems.

The new recommendation for R-value is based upon testing by NRCA on current generation polyisocyanurate roof insulations. The new NRCA R-value recommendation is as follows:

Polyiso R-value = 5.0 per inch thickness in all climate conditions.

Attached to this bulletin is a “Staying up to date” article published in Professional Roofing by Mark Graham, NRCA’s Vice President of Technical Services.

To read other Professional Roofing articles about polyisocyanurate insulation’s R-value and for links to the research referenced in this article, please visit www.professionalroofing.net.

Revised R-values

NRCA has revised its longstanding design R-value recommendation for polyisocyanurate insulation

by Mark S. Graham

SINCE 1987, NRCA has recommended designers use an in-service R-value of 5.6 per inch thickness for polyurethane and polyisocyanurate roof insulation used in roof systems. With the January 2011 publication of *The NRCA Roofing Manual: Membrane Roof Systems—2011*, NRCA is updating its design R-value recommendation for polyisocyanurate roof insulation.

Background

Most roofing professionals recognize polyisocyanurate roof insulation loses some of its R-value over time. At the time polyisocyanurate insulation is manufactured, it has a relatively high R-value. As the insulation ages and is exposed to varying temperatures and field conditions, the gas producing the high R-value in the insulation's cells slowly diffuses and is replaced with air.

Considering an insulation's actual in-service R-value—instead of its as-manufactured R-value or long-term thermal resistance (LTTR) value—is important for designers because the in-service R-value more closely represents conditions in the built environment.

Since NRCA's 1987 R-value recommendation of 5.6 per inch thickness was announced, the insulation industry and ASTM International have developed a number of conditioning (aging) procedures to more accurately report R-values.

The 1995 publication of ASTM C1303, "Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Unfaced Rigid Closed-Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions," introduced the LTTR method of reporting R-values that most polyisocyanurate insulation manufacturers currently use. LTTR is a 15-year time-weighted average of tested values, and it closely approximates R-value after five years of aging in controlled laboratory conditions.

In 2005, NRCA participated in a limited testing program that showed a majority of polyisocyanurate insulation samples tested one to four years after being manufactured had actual R-values less than their LTTR values.

In 2009, NRCA conducted R-value testing at various temperatures. R-value typically is tested in controlled laboratory conditions where the temperature is 75 F. NRCA's testing of polyisocyanurate insulation at 25 F, 40 F, 75 F and 110 F showed actual R-values less than LTTR values.

Revised recommendations

Although the LTTR method of R-value determination and reporting may be appropriate for laboratory analysis, research comparison and procurement purposes, NRCA does not consider LTTR use to be appropriate for roof system design purposes when actual in-service R-value can be an important aspect of roof system performance.

In *The NRCA Roofing Manual: Membrane Roof Systems—2011*, NRCA recommends designers using polyisocyanurate insulation determine thermal insulation requirements using an in-service R-value of 5.0 per inch thickness in heating conditions and 5.6 per inch thickness in cooling conditions. Designers should use the recommended in-service R-value for heating or cooling conditions based on the predominant conditions for building use and climate where the specific building being considered is located.

One way to evaluate whether the heating or cooling condition is predominant is by comparing the heating degree day (HDD) with cooling degree day (CDD) values for a specific climatic location. HDD and CDD values are provided in the *ASHRAE Fundamentals Handbook* and other authoritative references for thermal envelope design and evaluation.

NRCA also recommends designers specify polyisocyanurate insulation by its desired thickness—not its R-value—to avoid possible confusion during procurement.

To read other *Professional Roofing* articles about polyisocyanurate insulation's R-value and for links to the research referenced in this article and a table of NRCA's newly recommended design R-values, log on to www.professionalroofing.net.

Mark S. Graham is NRCA's associate executive director of technical services.

Roofing No. 3004

Subject: Roof Spanability

Date: January 2008 (Revised January 2019)

A minimum thickness of ThermaFoam R-Control roof insulation is required to span metal deck flutes. The table below provides the minimum recommended thickness of ThermaFoam R-Control insulation to span flutes for various metal deck types.

MINIMUM THICKNESS TO SPAN METAL DECK FLUTES					
PowerFoam R-Control	Deck Type	Type A	Type F	Type B	Type N
	Flute Span	1.00 in.	1.75 in.	2.50 in.	2.75 in.
100		1-1/4"	2-1/4"	3-1/4"	3-1/2"
130		1-1/4"	2"	3"	3-1/4"
150		1"	2"	2-3/4"	3"
250		1"	1-3/4"	2-1/2"	2-3/4"

The table is used for normal occurring metal roof deck situations where ThermaFoam R-Control insulation thicknesses of 3" or less are required. The table assumes normally occurring roof traffic and proper staging during installation of the roofing system. Some minor deformation may occur in heavy traffic areas. If special requirements need to be met, please contact your local ThermaFoam R-Control insulation supplier before installation.

When approved coverboards are used, the minimum thickness of the ThermaFoam R-Control insulation can be 1" for all Types if the metal deck flute span is less than 3".

Roofing No. 3006

Subject: Low Temperature R-Values

Date: January 2008 (Revised January 2019)

The following chart has been assembled to aid in the design of ThermaFoam R-Control insulation applications in low temperature conditions.

POWERFOAM R-CONTROL	Temperature			
	40°F (4.4°C)	25°F (-3.9°C)	0°F (-17.8°C)	-25°F (-31.7°C)
100	4.2	4.4	4.5	4.7
130	4.4	4.6	4.7	4.8
150	4.6	4.7	4.8	5.0
250	4.8	5.0	5.1	5.3

Roofing No. 3007

Subject: Long Term R-value of Polyisocyanurate Insulation

Date: January 2008 (Revised January 2019)

There has been extensive debate regarding the long-term or "In-Service" R-value of polyisocyanurate insulations. Numerous scientific studies have been conducted by scientists, researchers, and professional associations attempting to determine the actual performance of polyisocyanurate insulation when applied as roof, wall and other insulation applications. The central issue is whether polyisocyanurate retains its R-value over its useful life. It is argued by many that polyisocyanurate loses R-value due to loss of its low conductance blowing agents early in its life, while continuing to lose R-value as normal atmosphere infiltrates its cell structure. Many organizations have come out with published recommendations that polyisocyanurate does in fact lose R-value, and if used it should be designed with the long term R-value.

ThermaFoam R-Control has had occasion to test samples of polyisocyanurate taken from an 8 year old roof from the Northwestern part of the United States. The insulation was used under a light colored single ply roofing membrane. Nominal 4" samples were submitted to an independent laboratory for R-value Testing under ASTM Standard C518-91, "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus." The polyisocyanurate samples were in excellent condition. They were dry and contained relatively no moisture. The density of the samples exceeded 2.5 lbs. per cubic foot and were faced with felt paper on both sides.

The tests confirmed that polyisocyanurate insulation* does undergo thermal drift and does indeed lose significant R-value. One sample tested at 5.48 R-value per inch, the second tested at 5.26 R-value per inch, having an average of 5.37 @ 75°F per inch. The total R-value for the samples (actual average thickness measured 3.8") averaged 20.45.

Reminder:

ThermaFoam R-Control insulation does not experience thermal drift and subsequent R-value loss. ThermaFoam R-Control insulation has a stable R-value due to its processing technique which captures normal atmosphere within its cell structure, thereby making for stable R-values.

Update:

The same samples were resubmitted to an independent laboratory for further R-value analysis when the samples were ten years old. The samples tested in December of 1994 had an average R-value of 5.37 per inch. Testing of the same samples after 10 years average an R-value of 5.18. Thermal loss was still occurring.

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Roofing No. 3010

Subject: **R-value and Long Term R-value – Background**

Date: **January 2008 (Revised January 2019)**

The blowing agents used in extruded polystyrene, polyisocyanurate, and polyurethane foams provide for an initial high R-value. During the life of the foam, air from the atmosphere diffuses into the cells of the foam and reduces the R-value. In addition, the blowing agents themselves diffuse out of the foam, further reducing the R-value.

Two test methods have been developed to help provide information and standardize the reporting of R-value for materials with blowing agents other than air. The following test methods have been developed:

ASTM C1303 Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation.

CAN/ULC-S770 Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Insulating Foams.

Both test methods provide a similar method to predict the Long Term Thermal Resistance (LTTR) or long term R-value of insulations.

Diffusion theory for gases establishes that the diffusion of gases in foam is mathematically dependent upon the thickness. Each of the methods involves cutting thin sections approximately 10 mm (3/8") from a sample of thicker insulation such as 100 mm (4"). Due to the relative size of the thin samples, diffusion of air into the foam and blowing agents out of the foam is quicker than for the original thick sample. The measurement of thermal resistance for the thin samples along with mathematical relations allows for the prediction of the LTTR or long term R-value. However, in each method long term is defined only as 5 years.

ASTM C1303 excerpt: "The values produced by the Prescriptive Method correspond to the thermal resistance at an age of five years"

CAN/ULC-S770 excerpt: "This procedure defines the long-term thermal resistance (LTTR) of a foam product as the value measured after 5-year storage..."

As noted above, the LTTR value commonly published from testing to ASTM C1303 or CAN/ULC-S770 is an prediction for the R-value of the insulation after 5 years.

Many insulation manufacturers are promoting LTTR without providing a clear understanding that LTTR is an prediction for the R-value of the material after only 5 years. The concept of a 5 year R-value being equal to the "time-weighted 15 year average" is also often used by Polyiso and XPS manufacturers. This approach assumes that the higher R-value established in years 1-4 is weighted by the inevitably lower R-value of the insulation in years 6-15.

Neither the 5 year R-value, nor the time-weighted 15 year average approach is appropriate for use in building design. This is due to the fact that the R-values of Polyiso and XPS continue to decline below the LTTR published 5 year numbers. Starting in year 5 and for the remaining life of the insulation, the R-values of Polyiso and XPS are below LTTR published R-values.

Most insulation users are interested in a true long-term thermal R-value for their insulations. A 50 year R-value is a more suitable long-term R-value for use in building design. The 50 year R-value can easily be determined using the existing protocol described in ASTM C1303 or CAN/ULC-S770.

Specify a 50 year R-value for a reliable long-term R-value for building design.

Roofing No. 3011

Subject: **R-value and Long Term R-value – Polyisocyanurate Insulation**

Date: **January 2008 (Revised January 2019)**

Manufacturers of Polyisocyanurate insulation are promoting the use of the long term R-value techniques in ASTM C1303 and CAN/ULC S770. The Polyisocyanurate Insulation Manufacturers Association, PIMA, is promoting using some form of time weighted average over 15 years[1]. Their literature states that "using techniques in ASTM C1303, CAN/ULC S770" provides the following long term R-values for some Polyisocyanurate insulations.

Average LTTR Values for Polyiso with Hydrocarbon Blowing Agents[1]	
POLYISO THICKNESS (inches)	**LTTR R-VALUE**
1	6.0
2	12.1
3	18.5
4	25.0

The exact variations from the standard test methods are not described. As is well known, deviations from standard test methods make the results unreliable for comparison.

Although this is a step forward for the Polyisocyanurate insulation industry to recognize that estimates of long term R-value, the use of their 'modified' test method only allows for Polyisocyanurate insulation manufacturers to compare performance among Polyisocyanurate insulations. The use of the modified PIMA method DOES NOT provide for determination of a long term R-value, such as after 50 years. The PIMA method only provides for the determination of the R-value after 5 years.

The R-value published by polyisocyanurate insulation manufacturers is ONLY for 5 years.

The long term R-value for polyisocyanurate insulations is LOWER than that represented by the PIMA published information.

[1] Refer to Polyiso Performs - PIMA (Polyisocryanurate Insulation Manufactureres Association) - 2002

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Roofing No. 3012

Subject: Use of ThermaFoam R-Control Insulation Direct to Deck Application & UL Construction 458

Date: January 2008 (Revised January 2019)

ThermaFoam R-Control insulation can be applied directly to a fluted metal deck without a thermal barrier and be in compliance with the building code. This bulletin explains the recognition of ThermaFoam R-Control insulation installed directly to a metal deck as part of a UL fire classified roof deck construction or an ICC-ES code report.

The requirements for thermal barrier application with foam plastics are covered by the 2012 International Building Code (IBC). IBC Section 2603.4 requires that foam plastic shall be separated from the interior of a building by an approved thermal barrier unless approved for in sections 2603.4.1 or 2603.9. Thus, most installations of foam plastics in building construction require a thermal barrier. However, the code recognizes that roof deck constructions may not require a thermal barrier when evaluated under recognized test methods.

The code recognized application of foam plastics in roofing without a thermal barrier is covered specifically by section 2603.4.1.5 of the IBC. This section states:

"A thermal barrier is not required for foam plastic insulation that is part of a Class A,B, or C roof-covering assembly, provided the assembly with the foam plastic insulation satisfactorily passes FM4450 or UL1256."

Underwriters Laboratories

Underwriters Laboratories (UL), a leader in the investigation of fire safety issues, has investigated the performance of ThermaFoam R-Control insulation in accordance with UL1256 as required by the building code. As evidence of compliance with UL1256, UL publishes fire classified roof constructions to educate users on suitable roof deck constructions. UL published roof deck Construction no. 458 as a fire resistant assembly in compliance with UL1256. This listing is attached to this bulletin.

As a requirement of Construction 458, the insulation must comply with UL listings for BRYX or TGFU. ThermaFoam R-Control insulation is manufactured under UL file R11812 with compliance to BRYX and TGFU. Thus, ThermaFoam R-Control insulation is suitable roof insulation for use in UL Construction 458.

ICC-ES

ICC-ES publishes evaluation reports to inform Building Officials that the subject products of the evaluation reports are in compliance with the International Building Code (IBC) and International Residential Building Code (IRC). Testing and data evidence submitted to ICC-ES demonstrated that ThermaFoam R-Control insulation met all IBC requirements including ASTM C578, ASTM E84, and most importantly the UL1256 large scale fire test. ICC-ES has recognized ThermaFoam R-Control insulation for application direct to a metal deck without a thermal barrier. Please refer to ICC-ES ESR-1006 for complete details of the ICC-ES recognition including specifications and application requirements.

Historical Note:

Large scale flame spread testing under metal roof decking was first conducted as a combined effort by UL and FM in the 1950's. The original test method employed a 20'x100' building with bar joists and metal decking with a complete roof assembly above the metal deck. This test method was known as the "White House Test" due to the white color of the building. Part i of UL 1256 documents this large scale "White House Test". In addition to the large scale test, UL and FM have developed smaller scale tests to evaluate the flame spread under metal roof decking. These tests are documented in UL 1256 part ii and FM 4450.

Summary

1. Use of foam plastic insulation in a roof assembly without a thermal barrier must comply with the building code by meeting section 2603.1.4.5 of the IBC.
2. Section 2603.1.4.5 of the IBC requires that the assembly be evaluated by FM4450 or UL1256.
3. UL has investigated ThermaFoam R-Control insulation as part of an assembly in accordance with UL1256 full scale fire test.
4. UL published fire classified roof deck Construction 458 as a result of these investigations.

   Foam plastic insulation used in UL Construction 458 must conform to UL listings for BRYX or TGFU.

   ThermaFoam R-Control insulation is listed by UL File R11812 as a BRYX and TGFU compliant material.
5. ICC-ES has recognized ThermaFoam R-Control insulation as part of an as-sembly in accordance with UL1256 large scale fire test.
6. ICC-ES issued ESR-1006 as a result of their evaluation.
7. ThermaFoam R-Control insulation is suitable for direct to metal deck application when installed in conformance with UL Construction 458 or ICC-ES ESR 1006.

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Roofing No. 3013

Subject: **Long-Term R-value for Polyisocyanurate Insulation**

Date: **August 2008 (Revised January 2019)**

The blowing agents used in polyisocyanurate foams provide for an initial high R-value. During the life of the foam, air from the atmosphere diffuses into the cells of the foam and reduces the R-value. In addition, the blowing agents themselves diffuse out of the foam, further reducing the R-value.

Manufacturers of polyisocyanurate insulation promote the use of the long term R-value techniques in ASTM C1303 and CAN/ULC S770. The ASTM C1303 and ULC/CAN S770 standards provides a long term thermal resistance (LTTR) or R-value estimate for the material after 5 years storage. Literature published by PIMA suggests that 2" polyisocyanurate insulation will have an LTTR of 5.7/inch.

Independent testing has been conducted on 2" thick polyisocyanurate insulation that was purchased in May, 2003. At the time of purchase the R-value was 6.4/inch. The samples were subsequently stored under laboratory conditions of 72 °F and 50% humidity. After 1 year, the R-value was 6.1/inch. After 5 years, the R-value was 5.5/inch or it has lost almost 15% of its R-value. As the polyisocyanurate insulation continues to age and off gas blowing agents the R-value will continue to drop.

R-values for Polyisocyanurate Insulation	
Age	**R-value/In.**
Purchase	6.4
3 months	6.2
1 year	6.1
5 year	5.5
10 year	5.4

This independent testing has confirmed that even after only 5 years, the R-value for polyisocyanurate insulation is below the published LTTR or estimated long term thermal resistance.

Architects, specifiers, and building owners should ask their insulation manufacturers for R-values over the life of the building.

In addition, R-value warranties should be examined closely to see if 100% of the R-value is warranted. Unlike other insulations which lose R-value over time and may have limited warranty coverage, ThermaFoam R-Control insulation is warranted for 100% of the R-value for 50 years.

Roofing No. 3014

Subject: **Insulation Fastener Patterns**

Date: **April 2010 (Revised January 2019)**

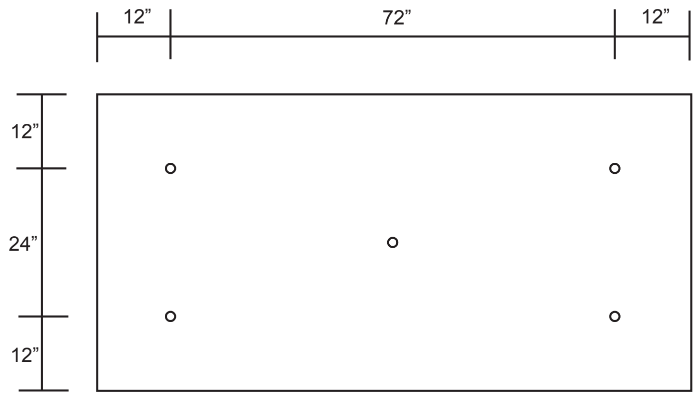
ThermaFoam R-Control roof insulations are suitable for use in commercial roofing systems that are fully adhered, ballasted, or mechanically fastened to structural roof decks. ThermaFoam R-Control insulation can be flat board stock, tapered, unfaced, or have factory applied facings or coverboards. Typical fastener patterns are provided in this bulletin for the installation of ThermaFoam R-Control roof insulations when used as a component in a mechanically fastened commercial roof system.

Fastener, insulation disk, fastening pattern, and fastener location in the section of the roofing assembly shall be as specified by the fastener or roof membrane system manufacturer.

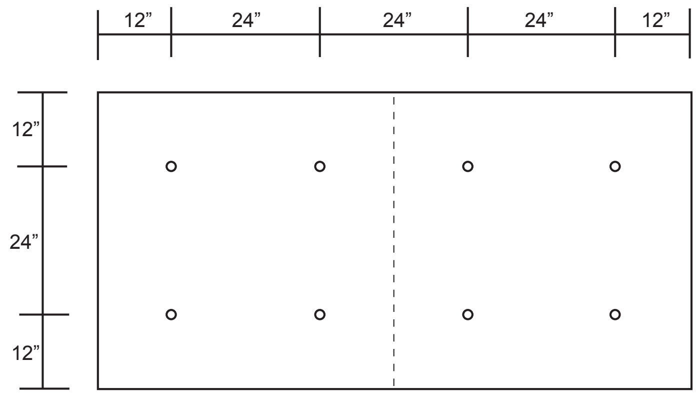
Qualification of the roof assembly to meet FM or UL listings shall be as specified by the roof membrane system manufacturer.

Typical Insulation Fastener Patterns

5 Fasteners/Bd. (4x8)



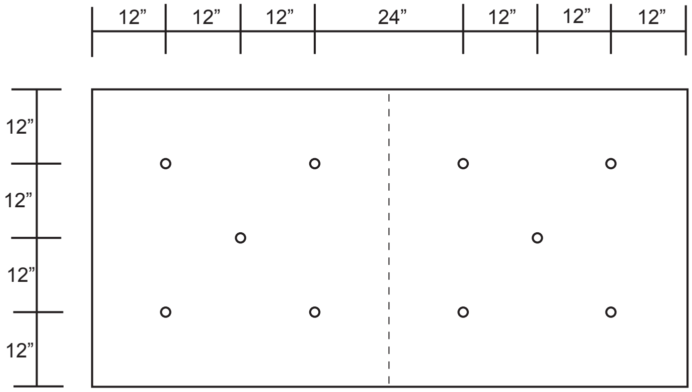
8 Fasteners/Bd. (4x8)
4 Fasteners/Bd. (4x4)



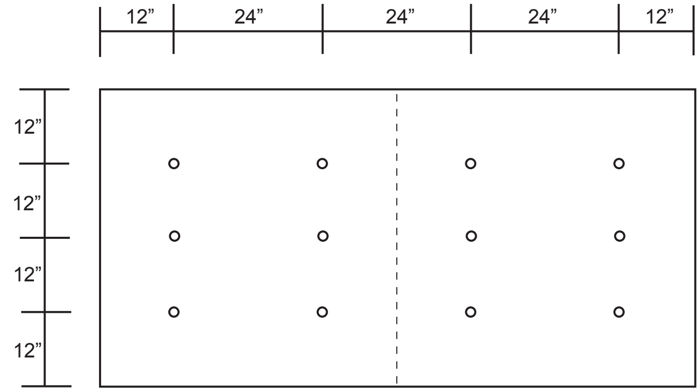
NOTE: Roofing membrane system manufacturer specifications must be consulted to determine the proper application of ThermaFoam R-Control roof insulations when used as a component in their roofing membrane assemblies. Consult the ThermaFoam R-Control roof insulations TechData for specifications and limitations.

Typical Insulation Fastener Patterns (Cont'd)

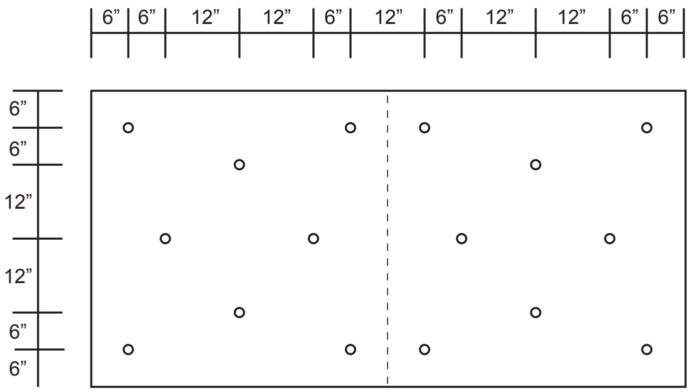
10 Fasteners/Bd. (4x8)
5 Fasteners/Bd. (4x4)



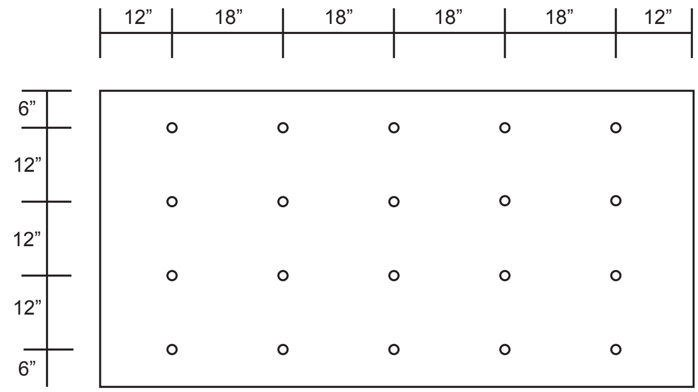
12 Fasteners/Bd. (4x8)
6 Fasteners/Bd. (4x4)



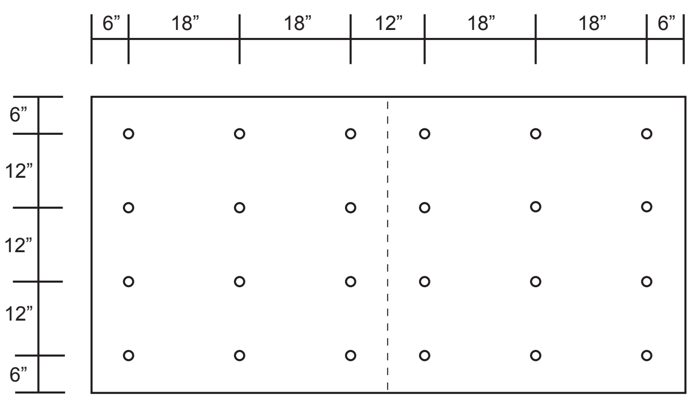
16 Fasteners/Bd. (4x8)
8 Fasteners/Bd. (4x4)



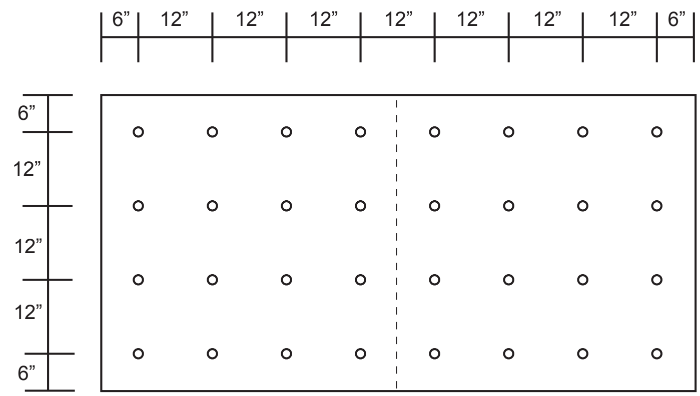
20 Fasteners/Bd. (4x8)



24 Fasteners/Bd. (4x8)
12 Fasteners/Bd. (4x4)



32 Fasteners/Bd. (4x8)
16 Fasteners/Bd. (4x4)



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Roofing No. 3015

Subject: Compatible Roofing Adhesives

Date: July 2012 (Revised January 2019)

ThermaFoam R-Control insulation is often used as a component of a roof assembly and is attached with the use of mechanical fasteners or adhesives. Adhesives provide a convenient method for installation of ThermaFoam R-Control insulation products, however, the use of adhesives which are specifically designed for use with polystyrene foams must be used. Some roofing adhesives contain solvents or other additives which can damage polystyrene foams.

The following adhesive manufacturers recommend specific products for use with polystyrene foams. Please contact both the adhesive and roofing membrane system manufacturers directly for their installation recommendations.

3M

3M Brand Adhesives

(800) 362-3550

www.3M.com/industrial

ADCO North America

Milleniium Brand Adhesives

(800) 248-4010

www.adcocorp.com

Ashland Chemical

Pliodeck Brand Adhesives

(888) 364-5053

www.ashland.com

BASF

Ameriglue Brand Adhesives

(888) 900-3626

www.spf.basf.com

Dow Building Solutions

INSTA STIK Brand Adhesives

(866) 583-2583

building.dow.com

Henry Company

InsulBond Brand Adhesives

(800) 486-1278

us.henry.com

OMG, Inc.

Olybond Brand Adhesives

(800) 633-3800

www.olyfast.com

The list is provided only as a courtesy to ThermaFoam R-Control insulation users and is not necessarily exhaustive is being made.

No warranty with respect to the suitability of the above products. Please contact the adhesive manufacturer to confirm the compatibility of their adhesive with polystyrene foams.

Roofing No. 3016

Subject: **Impact of Temperature on the R-value for Polyisocyanurate Insulation**

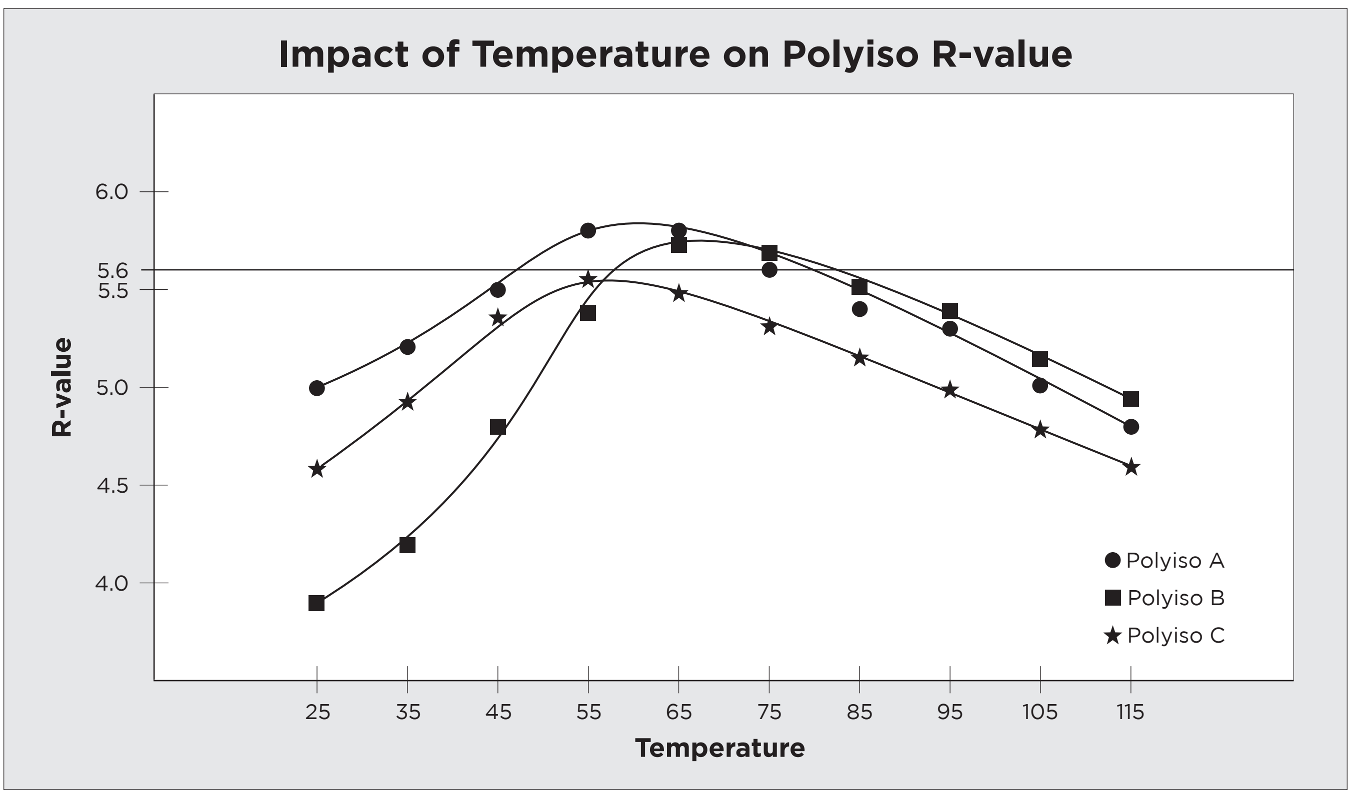
Date: **February 2014 (Revised January 2019)**

The blowing agents used in polyisocyanurate (polyiso) foam insulations provide an initial high R-value. However, immediately after production and continuing throughout the life of the polyiso foam, air from the atmosphere diffuses into the cells of the foam and the internal blowing agents diffuse out of the foam. This change in the internal gas composition results in a loss of R-value for polyiso foams over time.

In addition to loss of R-value over time from blowing agent loss, the R-value performance of polyiso insulation is also very dependent on temperature. Understanding the temperature dependence of polyiso is an overlooked consideration.

R-value claims are commonly reported at a mean temperature of 75°F. The use of a 75°F mean temperature for simple comparisons between products is useful, but it is also obvious that buildings are subjected to temperature variations. R-values at other temperatures are important to building design.

R-value testing was conducted on 2 in. thick samples of polyiso roof insulation sourced from three of the largest U.S. suppliers to investigate the impact of temperature on the R-value of polyiso insulation. ASTM C518 testing was conducted on the polyiso samples at mean temperatures from 25°F to 115°F in increments of 10°F.



It is clear that polyiso insulation performs best at temperatures near 75°F but as the polyiso insulation is subjected to colder or warmer temperatures its performance is diminished. Similar results have also been published by the NRCA[1] and Building Science Corporation[2]. Attached to this bulletin are their results for reference.

It is important to understand that a mean temperature of 40°F is representative of an insulation used in cold weather regions. Considering the results above and the results published by the NRCA and Building Science Corporation, lower R-value should be specified for polyiso insulations used in cold weather regions.

It is important to understand that a mean temperature of 90°F is representative of an insulation used in warm weather regions. Considering the results above and the results published by the NRCA and Building Science Corporation, lower R-value should be specified for polyiso insulations used in warm weather regions.

In contrast to polyisocyanurate insulations, the R-value for ThermaFoam R-Control 150 increases at lower mean temperatures. In fact, the R-value of ThermaFoam R-Control 150 at 40°F is very close to the R-value of polyiso insulations at 40°F and even greater than the R-value of polyiso at 25°F. In addition, the pricing of ThermaFoam R-Control insulation is significantly lower than polyiso insulation which can lead to significant costs savings when specifying a roof insulation system for use in cold weather regions.

R-value Comparison

Insulation	Temperature		
	75°F	40°F	25°F
PowerFoam R-CONTROL 150	4.2	4.6	4.8
Polyiso*	5.6	5.0	4.5

*Based on average results above

References:

1. Building Science Corporation Information Sheet 502, "Understanding the Temperature Dependence of R-values for Polyisocyanurate Roof Insulation", September 2013.
2. Professional Roofing, "Testing R-values, Polyisocyanurate's R-values are found to be less than their LTTR values", March 2015.

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Testing R-values

Polyisocyanurate's R-values are found to be less than their LTTR values

by Mark S. Graham

In late 2014, NRCA conducted limited R-value testing of polyisocyanurate insulation products. The test results show R-values lower than the product manufacturers' published long-term thermal resistance (LTTR) values.

For an article related to this topic, see: "R-value concerns," May 2010 issue, page 24

2014 testing

NRCA obtained seven 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.

The samples were provided to a nationally recognized R-value testing laboratory, R & D Services Inc., Cookeville, Tenn., for R-value testing according to ASTM C518, "Standard Test Method for Steady-State Thermal Resistance Properties by Means of the Heat Flow Meter Apparatus." The samples were tested "as received," meaning without additional aging. The samples ranged in age from three months to 19 months at the time of testing.

R-values were tested at a 75 F mean reference temperature, as well as at 25 F, 40 F and 110 F. Although R-values tested at the 75 F mean reference temperature typically are reported in insulation product manufacturers' literature, NRCA views the additional test temperatures as being more representative of actual in-service conditions.

Data from this testing is provided in the figure.

Sample number	R-value, per inch thickness (2-inch specimens)			
	25 F	40 F	75 F	110 F
1	3.765	4.757	5.774	5.118
2	3.909	4.719	5.444	4.958
3	4.737	5.350	5.371	4.810
4	3.506	4.509	5.828	5.227
5	4.221	5.269	5.522	4.929
6	3.775	4.854	5.889	5.247
7	4.431	4.878	5.058	4.581
Average (mean)	4.049	4.905	5.555	4.981
Standard deviation	0.432	0.302	0.297	0.239

Data from NRCA's 2014 polyisocyanurate R-value testing

Analysis

Review of the 75 F data reveals the average of the results are less than the products' published LTTR values. Only three of the seven specimens have R-values greater than 5.7 per inch for a 2-inch-thickness.

The LTTR concept is intended to replicate a 15-year time-weighted average of a product's R-value, which corresponds to a product's R-value after five years of aging. Because none of the products tested were even close to 5 years old at the time of testing, all their tested R-values at 75 F should be somewhat above their published LTTR values.

In 2009, NRCA conducted similar R-value testing of polyisocyanurate insulation samples, and the results were much the same.

Review of the current test data at 25 F, 40 F and 110 F shows tested R-values are notably lower than those tested at 75 F.

Comparing current test data with the 2009 test data reveals the current test values are somewhat lower. For example, the average of the current 25 F R-values is 4.049 compared with 4.744 in 2009. At 40 F, the average of the current R-values is 4.905 compared with 5.39 in 2009.

NRCA's recommendations

Although the 75 F mean test temperature may be useful for product comparison and labeling purposes, based on NRCA's testing, it is clear this parameter is not representative of in-service conditions. For this reason, NRCA recommends designers consider polyisocyanurate insulation products' in-service R-values for the specific climate where a building is located.

NRCA recommends designers using polyisocyanurate insulation determine thermal insulation requirements using an in-service R-value of 5.0 per inch thickness in heating conditions and 5.6 per inch thickness in cooling conditions.

Furthermore, NRCA recommends designers specify polyisocyanurate insulation by its desired thickness rather than its R-value or LTTR value to avoid possible confusion during procurement.

Additional information regarding the use of polyisocyanurate insulation is provided in *The NRCA Roofing Manual: Membrane Roof Systems—2015.*

MARK S. GRAHAM is NRCA's associate executive director of technical services.

BSC Information Sheet 502

Understanding the Temperature Dependence of R-values for Polyisocyanurate Roof Insulation

Polyisocyanurate insulation is a common commercial and residential roof and wall insulation. It has one of the highest R-values per inch of thickness among common insulations.

However, labeled R-value differs from in-service R-value for many insulations. Building Science Corporation (BSC) and others have been examining this difference. BSC has found significant thermal performance differences between different manufacturers of insulation products and significant differences based on in-service temperature. The following discussion relates to BSC's work to date with polyisocyanurate roof insulation.

How are Label R-values Determined?

Most label R-values are based on testing that does not account for real-life temperature conditions and real-life installations.

The R-value Rule

The Federal Trade Commission "R-value Rule" requires that

> *"manufacturers and others who sell home insulation determine and disclose each product's R-value and related information (e.g., thickness, coverage area per package) on package labels and manufacturers' fact sheets."* [1]

The R-value Rule requires that all types of insulation (except aluminum foil) be tested in accordance with one of four standard test methods defined by ASTM, the American Society of Testing and Materials.[2]

The Rule requires that R-value tests be conducted at a mean temperature of 75°F (23.9°C) and a temperature differential of 50°F (27.8°C). This means that insulation is usually tested with the cold side at 50°F (10°C) and the warm side at 100°F (37.8°C).[3]

The R-value Rule only applies to insulation products that are marketed and sold to residential consumers; however it has a strong influence over labeling practices for a wide range of insulation products in the commercial, institutional and residential building industry.

Aged R-values

The R-value Rule recognizes that the thermal performance of some insulation materials changes as they age (e.g. many, but not all, foam insulations) or settle (e.g. some loose-fill insulations). The R-value of polyisocyanurate decreases as some of the gasses in the pores from the manufacturing process diffuse out and are replaced with air. The "gas replacement" process is very slow and takes years to complete (depending on material, assembly and exposure conditions), so samples must be artificially aged before R-value testing if one wishes to predict long-term thermal performance. Several aging methods have been debated over the past decade but most polyisocyanurate manufacturers are currently using one method: Long Term Thermal Resistance (LTTR).[4]

Table 1: Four Polyisocyanurate Manufacturers ALL report the same Label R-values

IP	Thickness	(in.)	1	1.5	2	2.5	3	4
	LTTR	(hr.ft^2.°F/Btu)	6	9	12.1	15.3	18.5	25
SI	Thickness	(mm)	25	38	51	64	76	102
	LTTR	(m^2.K/W)	1.06	1.59	2.13	2.69	3.26	4.40

Published Polyisocyanurate R-values

Table 1 shows the published (i.e. label) R-values for various common thicknesses of polyisocyanurate insulation. The table is based on literature for polyisocyanurate insulation products

1 Federal Trade Commission 16 CFR Part 460, "Labeling and Advertising of Home Insulation: Trade Regulation Rule; Final Rule", May 31, 2005.

2 See ASTM C 177-04, ASTM C 518-04, ASTM C 1363-97, ASTM C 1114-00.

3 The actual language of the Rule permits test temperature differentials of 50°F +/- 10°F for cold side temperatures of 45-55°F and hot side temperatures of 95-105°F.

4 ASTM C-1303-11 and CAN/ULC-S770-09.

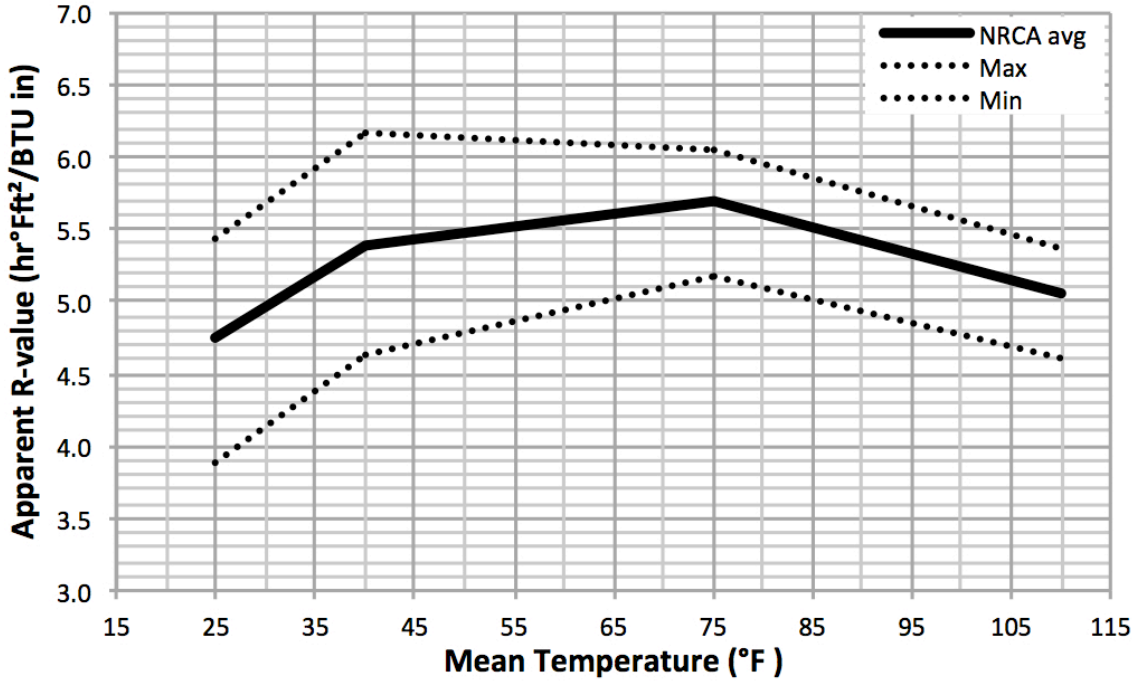


Figure 1: Range of per inch R-values for NRCA test on 15 polyisocyanurate samples

produced by four large national manufacturers.[5] The four manufacturers make a wider variety of board thicknesses than shown in this table; however, all four manufacturers produce boards at these thicknesses and all four reported the same LTTR for each thickness shown.

Not all industry stakeholders are in agreement with the R-6/in. LTTR value published by polyisocyanurate insulation manufacturers for 1 and 1.5 inch thick samples. Since 1987 the National Roofing Contractor's Association (NRCA) has recommended designers use R-5.6/in. as a reasonable estimate of the actual thermal performance of polyisocyanurate insulation over the lifespan of a roof assembly.[6]

Factors Affecting In-Service Thermal Performance

The R-value Rule isn't designed to account for all factors that affect the in-service performance of an insulation product. Rather, it was developed to simplify the many technical issues (e.g. material type, density, thickness, settling, aging) that affect thermal performance so residential consumers can make informed decisions.

The Rule accounts for some properties that can be controlled at the time of manufacture such as material type, and some properties that change over time regardless of application such as settling and gas replacement; however, the Rule does not account for other, application specific, factors that affect in-service performance such as moisture content and temperature.

Temperature Dependency of R-values

Some insulation materials exhibit better thermal performance as temperatures get colder (i.e. the apparent R-value increases as the temperature decreases) and some materials exhibit worse thermal performance as temperature gets colder (i.e., the apparent R-value decreases as the temperature decreases). The latter is the case with polyisocyanurate products. Material properties vary from manufacturer to manufacturer.

[5] Reported R-values from literature for Firestone ISO 95+, Atlas ACFoam-III, JM Enrgy 3 AGF, Carlisle SecurShield.

[6] Graham, M., "Comparing polyiso R-values", Professional Roofing, April 2003. More recently NRCA revised this recommendation to R-5.6 / in. for warm climates and R-5.0 / in. for cold climates.

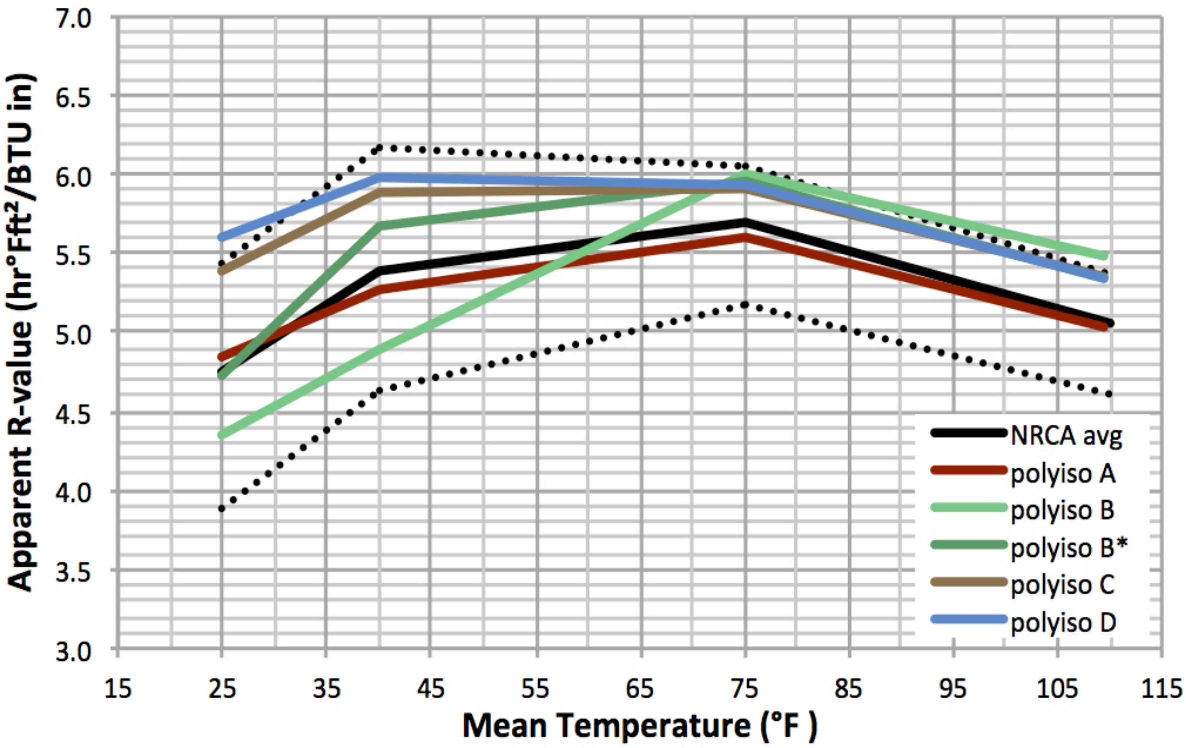


Figure 2: BSC and NCRA average mean temperature R-value test results for 2 in. samples

Table 2: Test temperatures to represent various climate conditions

	Temperature (°F)				Temperature (°C)			
Climate Condition	"Inside" Temp	"Outside" Temp	Temp Diff	Mean Temp	"Inside" Temp	"Outside" Temp	Temp Diff	Mean Temp
Very Cold	72	0	72	36	22	-18	40	2
Cold	72	36	36	54	22	2	20	12
Hot	72	108	36	90	22	42	20	32
Solar Heated	72	144	72	108	22	62	40	42

NRCA Mean Temperature R-value Testing

NRCA identified the temperature dependency of polyisocyanurate R-values.[7] The investigator, Mark Graham, reported on results from R-value testing of fifteen 2 in. (51 mm) thick samples collected from across the United States. The tests were performed on "as received" material (i.e. the material was not aged prior to testing – new samples are usually expected to have higher R-values than aged samples) in accordance with ASTM C-518, at mean temperatures of 25, 40, 75 & 110°F (-3.9, 4.4, 23.9 & 43.3°C), and at a temperature difference of 50°F (27.8°C).

[7] Graham, M., "R-value concerns", Professional Roofing, May 2010.

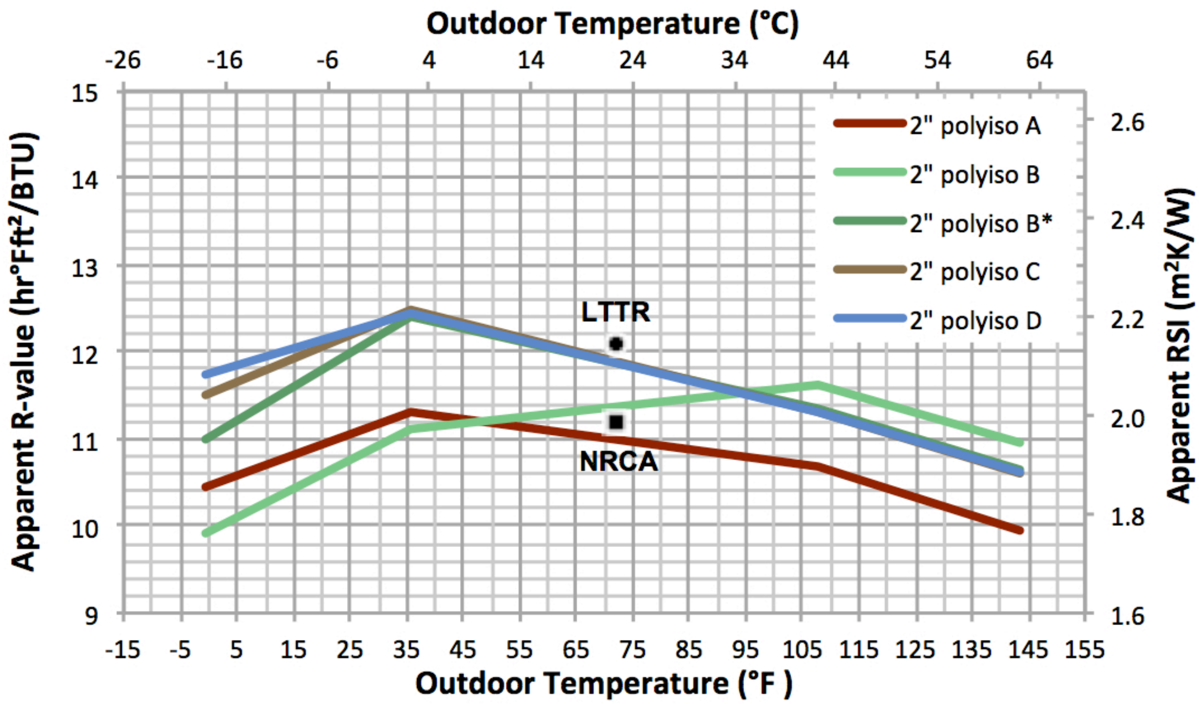


Figure 3: Service temperature R-value test results for nominal R-12.1 (LTTR) / R-11.2 (NRCA) insulation

Graham plotted per inch R-value versus mean temperature (reproduced as the solid black line of Figure 1). The reported values were the average of the results from the fifteen test samples. Graham did not report the range of test results in that article; however, he did report them in a subsequent publication [ref: the 2010 International Roofing Expo]. The dotted black lines of Figure 1 indicate the upper and lower bounds (i.e. the max and min) for NRCA's set of fifteen samples.[8]

BSC Mean Temperature R-value Testing

BSC recently completed similar tests on sixteen 2 in. (51 mm) thick polyisocyanurate insulation samples from four manufacturers and five manufacturing facilities.[9]

Figure 2 presents a comparison of the per inch R-values from the BSC and NRCA tests on 2 in. (51 mm) thick polyiso samples. The BSC test results agree well with the NRCA test results.

The BSC and NRCA test results both suggest that the thermal performance of polyisocyanurate decreases as the mean temperatures deviate from of 75°F (23.9°C), the mean temperature used for label R-value tests.

Temperature Dependency of In-Service Thermal Performance

Testing shows that R-value appears to decrease as temperatures get lower. The relationship between temperature and R-value appears to be non-linear (i.e. it's not a simple straight line) so the mean temperature R-value tests cannot easily be used to predict in-service performance.

Additional "Service Temperature" R-value tests were conducted at temperatures (shown in Table 2) selected to represent a range of climate conditions (i.e. inside and outside temperatures) that are likely to occur throughout North America.

BSC Service Temperature R-value Testing: 2 in. Polyisocyanurate Samples

Figure 3 shows the results of service temperature R-value tests conducted on the same sixteen samples of polyisocyanurate. All four polyisocyanurate manufacturers report an LTTR of R-12.1 (RSI-2.13) for a single, 2 in. (51 mm) thick piece of the tested polyisocyanurate

[8] Data from NRCA presentation "NRCA Technical Program & Issues: Polyisocyanurate Insulation Testing", International Roofing Expo, Feb 22, 2010.

[9] Samples from manufacturer "B" were collected from an East coast plant (noted as "polyisocyanurate B) and a West coast plant (noted as "polyisocyanurate B*).

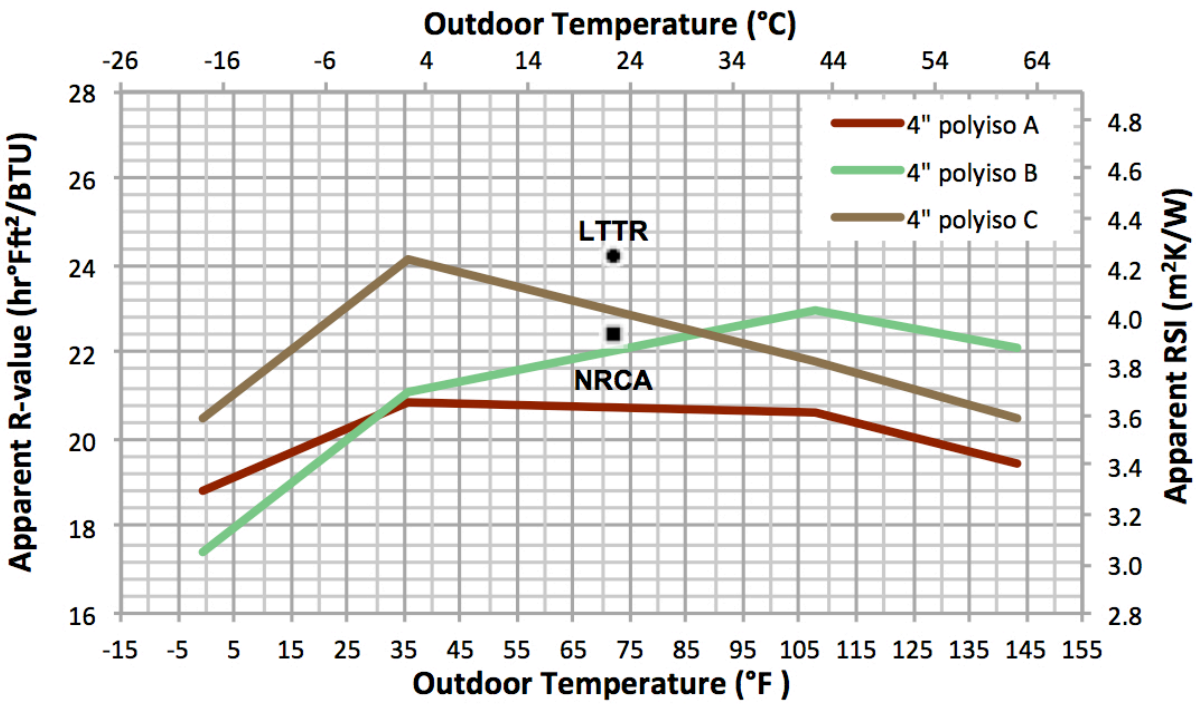


Figure 4: Service temperature R-value test results for nominal R-24.2 (LTTR) / R-22.4 (NCRS) insulation

insulation products. If the NRCA recommendation of R-5.6 / in. is assumed, the 2 in. thick polyiso would be R-11.2 (RSI-1.97). For reference, these two points are marked on the graph at an outdoor temperature of 72°F or 22°C (i.e. a temperature at which the R-value doesn't really matter).

All of the samples show a decrease in R-value as "outside" temperatures go below freezing.[10] It appears that the "peak" R-value for all samples occurs when outdoor temperatures are closer to the indoor temperature (i.e. between 36°F or 2.2°C and 108°F or 42.2°C). Winter temperatures (i.e. less than 32°F or 0°C) and solar heated roof temperatures (i.e. greater than 113°F or 45°C) result in lower R-values.

[10] The decrease in R-value is thought to be a result of condensation of the gasses that are trapped in the cells or pores during manufacture of the foam insulation; if the walls of the cells are coated in a highly conductive condensate (a liquid), heat transfer will increase and the R-value will go down. The mix of pore gasses probably condenses over a range of temperatures with condensation first starting at temperatures above freezing. Further BSC testing seeks to study this phenomenon further and establish a conductivity vs temperature curve for various polyisocyanurate insulation products.

BSC Service Temperature R-value Testing: 4 in. Polyisocyanurate Samples

Further service temperature R-value tests were conducted on three pairs of the original samples. The samples were stacked (i.e. double 2 in. samples) in pairs to permit the testing of 4 in. of polyisocyanurate insulation. The manufacturers of the products all reported an LTTR of R-25 (RSI-2.13) for a single, 4 in. (102 mm) thick piece of polyisocyanurate insulation; however, BSC tested a double 2 in. (51 mm) layer so the appropriate LTTR is 2 x 12.1 = R-24.2 (RSI-4.26). If the NRCA recommendation of R-5.6 / in. is assumed, 4 in. of polyisocyanurate will be R-22.4 (RSI-3.95), regardless of how many layers are used.

Figure 4 shows the results of the service temperature R-value testing on the double 2 in. polyisocyanurate samples. Again, all of the polyisocyanurate samples exhibit a significant decrease in thermal performance when the outdoor temperature is colder.

Implications

For cold service temperatures the following recommendations are offered:

- Use thicker layers of polyisocyanurate insulation to ensure that the performance meets expectations. NRCA's most recent recommendations are to assume that polyisocyanurate has R-5.6 / in. when designing for warm climates and R-5.0 / in. when designing for cold climates. [11]
- Use a hybrid insulation approach – install cold temperature-tolerant insulation over top of the polyisocyanurate insulation to increase the mean temperature of the polyisocyanurate.

BSC continues research into the temperature dependency of different insulation materials and products. Future publications will address exterior insulating sheathing products for residential and commercial wall systems.

Related Documents

See also these documents on buildingscience.com:

RR-0901: Thermal Metrics for High Performance Walls-The Limitations of R-Value

BSD-011: Thermal Control in Buildings

The Thermal Metric Project

[11] Graham, M., "Revised R-values", Professional Roofing, Dec 2010.

Roofing No. 3017

Subject: **Comparing Polyiso and Molded Polystyrene from the past to today.**

Date: **August 2016 (Revised January 2019)**

Insulation is a key component of the exterior building envelopes of commercial buildings. The performance of roof insulation is particularly important in large commercial buildings where the roof area is a large percentage of the overall building envelope. Roof systems and the roof insulation contained in them are often replaced as part of regular roof maintenance programs. Roofing replacement projects provide an ideal opportunity to investigate the performance of the insulation many years after the initial installation.

A school building located in Minnesota was undergoing a roofing system replacement in 2016 and it provided a perfect opportunity to evaluate the performance of the existing roof insulations. The school was originally built in 1999 and consisted of a combination of polyio and molded polystyrene roof insulation. Samples of both products were removed from the roof and evaluated for R-value at various temperatures (See figures on page 3).

Testing was conducted following ASTM C518 at mean temperatures of 75°F, 40°F, and 25°F.

R-value per inch[1] for 17 year old roof insulation

Product	Temperature[2]		
	75°F	40°F	25°F
Polyiso	5.0	5.6	5.7
Molded Polystyrene (Type VIII)	3.8	4.1	4.2

[1] R-value units are °F·ft²·h/Btu
[2] Mean Temperature

It is clear that the 17 year old polyiso R-value of R-5.0 at 75°F is well below the published R-value for polyiso of R-5.6. This is not surprising since polyiso insulation loses blowing agents and R-value with age. At colder temperatures, the R-value of the polyiso improved slightly.

The R-value for the 17 year old molded polystyrene at 75°F meets the published R-value of 3.8 for a Type VIII molded polystyrene product. This is not surprising since the R-value of molded polystyrene does not change with time. At colder temperatures, the R-value of the molded polystyrene increased.

In addition to testing old insulation samples, samples of the new polyiso roof insulation installed on the roof and molded polystyrene from a local manufacturer were sourced for testing. Samples of both products were evaluated for R-value at various temperatures.

R-value per inch[1] for "new" roof insulation

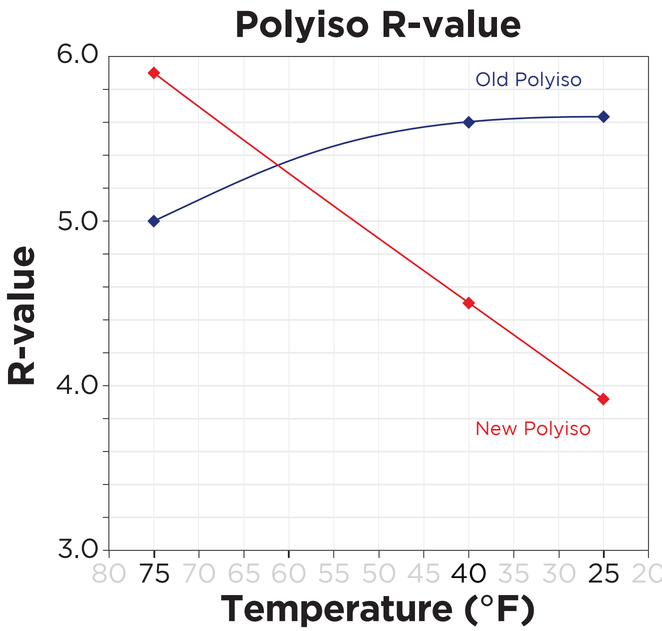
Product	Temperature[2]		
	75°F	40°F	25°F
Polyiso	5.8	4.5	3.9
Molded Polystyrene (Type VIII)	3.9	4.2	4.3

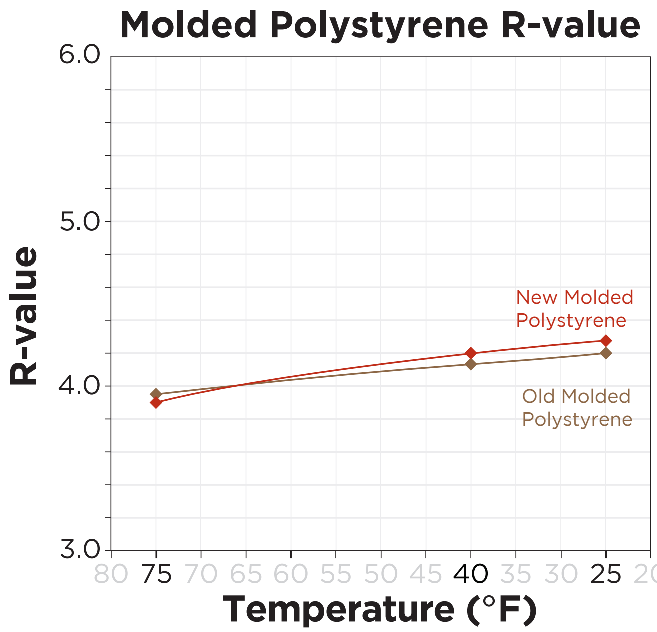
[1] R-value units are °F·ft²·h/Btu
[2] Mean Temperature

It is clear that the R-value of "new" polyiso of 5.8 at 75°F meets the the published R-value for polyiso of R-5.6. This is not surprising since the polyiso insulation is new and has not yet lost its blowing agents and R-value which will occur with age. At colder temperatures, the R-value of the polyiso decreased dramatically. This loss of R-value for polyiso is a known phenomenon and has been documented extensively[1,2].

A plot of the R-value for the 17 year old polyiso and new polyiso demonstrates the dramatic change in polyiso insulation in recent years. “New” polyiso loses significant R-value at cold temperatures.

In comparison, the R-value for 17 year old molded polystyrene and new molded polystyrene are similar. This demonstrates that molded polystyrene can be trusted to have stable R-value performance.





It is very important to understand that the latest generation of polyiso insulations and molded polystyrene have very similar R-values when used at cold temperatures. This has dramatic implications when selecting your insulation product and its thickness for use in cold weather and cold storage applications.

References:

1. Building Science Corporation Information Sheet 502, “Understanding the Temperature Dependence of R-values for Polyisocyanurate Roof Insulation”, September 2013.
2. Professional Roofing, “Testing R-values, Polyisocyanurate's R-values are found to be less than their LTTR values”, March 2015.

Figure 1. **17 year old Minnesota school**

Figure 2. **Roof replacement in progress**

Figure 3. **Existing roof being removed**

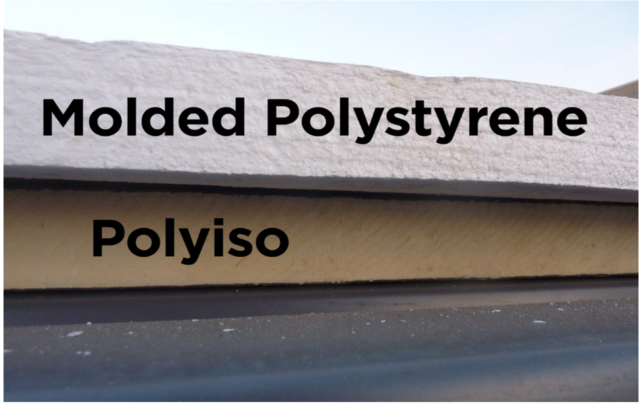


Figure 4. **Existing roof components**

Figure 5. **17 year old polyiso sample**

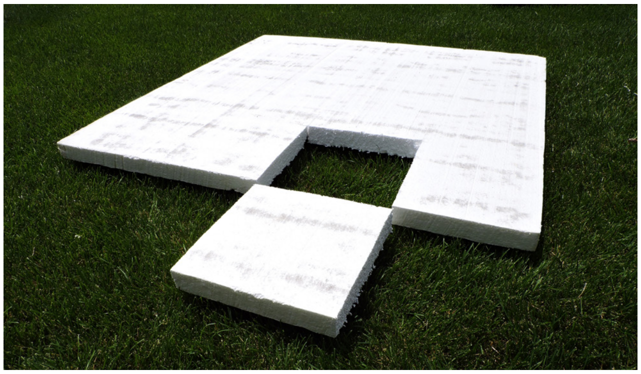


Figure 6. **17 year old Molded polystyrene sample**

Roofing No. 3018

Subject: **Determining Minimum R-value on Tapered Insulation Systems**

Date: **April 2017 (Revised January 2019)**

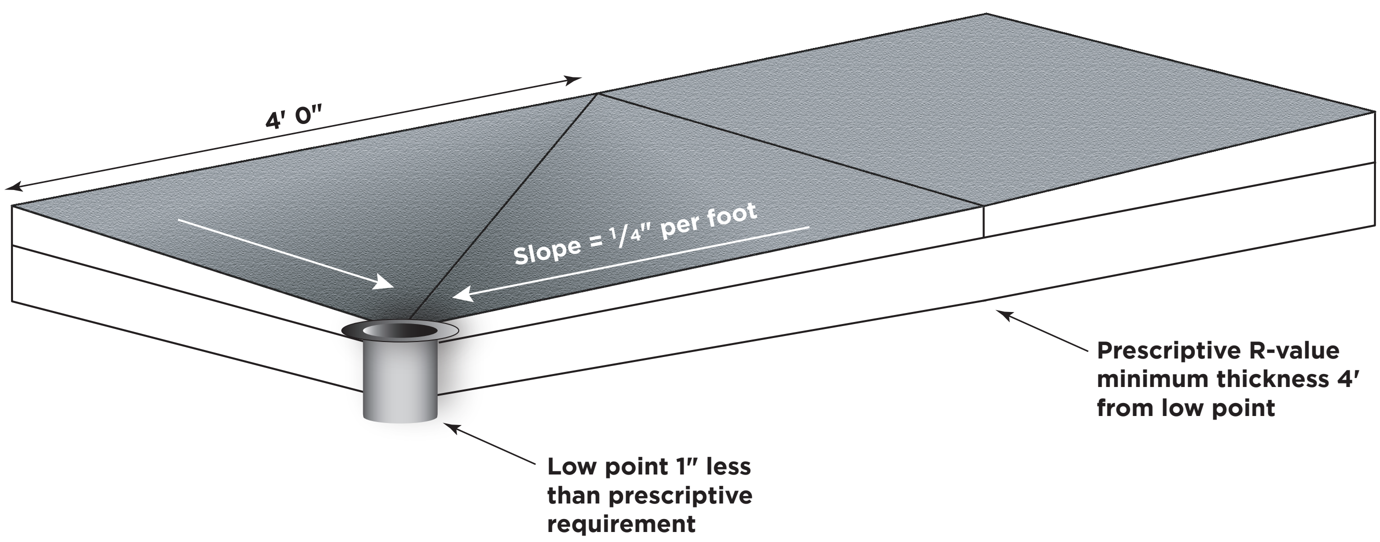
The 2015 International Energy Conservation Code (IECC) has R-value requirements for continuous commercial insulation installed entirely above roof decks based on climate zone. These requirements from IECC Table C402.1.3 are shown below.:

Climate Zone	1	2	3	4 Except Marine	5 And Marine 4	6	7	8
Minimum R-value of Insulation Entirely Above Deck	R-20ci[1]	R-25ci	R-25ci	R-30ci	R-30ci	R-30ci	R-35ci	R-35ci

[1] Group R requirement is R-25ci

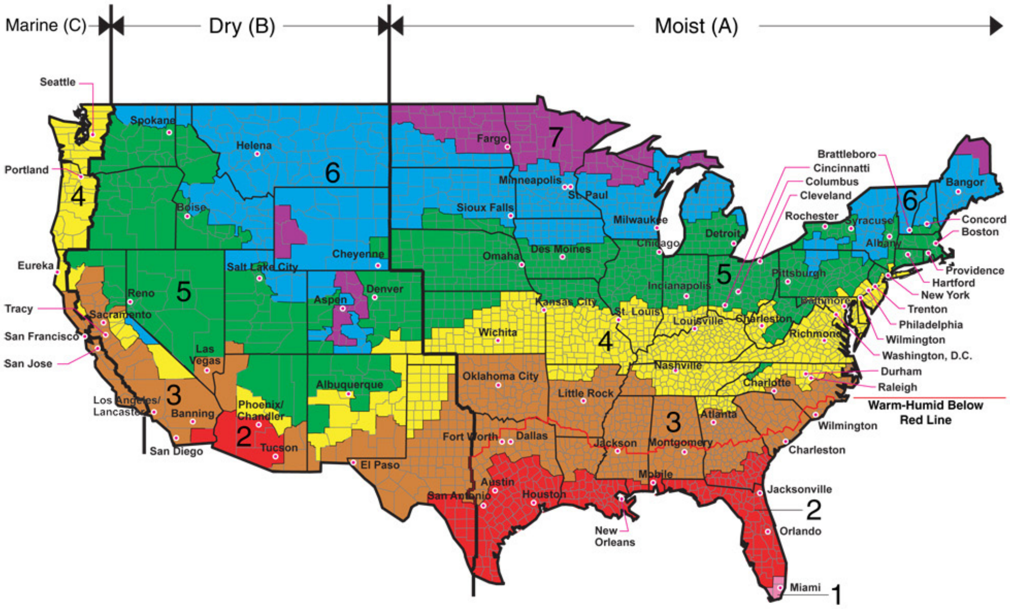
R-value on tapered insulation systems.

The R-values in the table are the minimum required. However, in roofs that include tapered insulation there is an exception that allows the tapered insulation to vary 1 inch from the minimum required. On a roof with a typical 1/4" per foot taper this results in insulation at drain locations being 1 in. thinner than the required minimum IECC thickness. However, the R-value of the roof overall is generally much higher than the minimum requirement as the insulation continues to increase in thickness farther from drain locations.



The table included with this bulletin provides the minimum prescriptive insulation requirements of IECC-2015. Alternative paths for conformance through detailed analysis are also available within the standard. Insulation requirements vary according to Climate Zone.

Climate Zones



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands