Bright Ideas on Retrofit Lighting

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Calculating Roof Insulation R-values
Waterproofing and Concrete Balconies
Due to recent findings on the nature of polyisocyanurate (polyiso) off-gassing, the National Roofing Contractors Association (NRCA)—an impartial organization that represents the best interests of the roofing industry—has revised the way the insulation’s R-value is measured.

In the 2011 NRCA Roofing Manual: Membrane Roof Systems, the design R-value recommendations have been updated for polyiso, taking into account the material’s loss of R-value as it emits low conductance gas after it is manufactured. Conversely, expanded polystyrene (EPS) insulation has been shown to retain its R-value over the product’s life.

This article explores both EPS and polyiso insulation; it examines the main reasons specifiers might choose one over another by weighing the advantages and/or limitations.

Overview of two insulations

The raw material of EPS is dry, translucent-colored particles, about the size of table salt, but round and smooth. In the first stage of processing, the raw material is exposed to heat and steam in an expanding vessel. The particles expand approximately 30 times their original size and turn opaque white. They are then stabilized for a minimum of 12 hours and then, with steam and vacuum pressure, the material is molded into large rigid blocks of foam. After this process, they are stabilized for a minimum of 72 hours and then processed into sheets with automated hot wire fabrication equipment.

Polyiso is manufactured in a liquid process where two
Chemicals are brought together at the front end of an extruding line. The chemicals react to one another and begin to turn from a liquid to foam while being pushed through. The extruding line determines the sheet thickness, which is continuous but chopped at 1.2 or 2.4-m (4 or 8-ft) lengths after the foam turns rigid enough.

EPS is typically provided in 1.2 x 1.2-m and 1.2 x 1.4-m sizes up to 965 mm (38 in.) thick. Any thickness beyond 914 mm (36 in.) is typically considered another type of application, such as void fill or geofoam for rooftop landscaping. Essentially, EPS is manufactured in a large block, and then trimmed down to meet various insulation sizes and thicknesses, making it more versatile than polyiso.

The material is manufactured to physical properties called out in ASTM C578, *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*. Type II EPS is the most common product used in commercial roofing applications; it has a density (weight per cubic foot) of 24 kg/m³ (1.5 pcf).

Polyiso is manufactured to physical properties as called out in ASTM C1289, *Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board*. Type 2 is the most common product used in commercial roofing applications and has a density of 32 kg/m³ (2 pcf). The heavier density of the polyiso is the reason it has a slightly higher R-value per inch.

R-value is a measurement of heat loss by conductance. The heat loss is measured in BTUs traveling through 25 mm (1 in.) of a given material.

The longer it takes for BTUs to travel through this portion of the material, the higher the R-value. As manufacturers publish a material’s ‘R-value per inch,’ it is easy for architects and contractors to determine the insulation’s overall thickness needed to match the desired R-value for a building envelope.

At the initial point of manufacture, polyiso has a higher R-value than EPS, but this is only temporary. Both insulation materials use trapped air as the insulating medium. The key difference between the two is that, after the initial point of manufacture, polyiso temporarily traps some of the low-conductance gas (i.e., pentane) used during the extruding process. Over a short period, the gas emits from the material, leaving air as its insulating medium.

From the time that polyiso is manufactured, it immediately begins to lose its R-value until it is installed (and while it remains on the building). The result is the material has the same R-value per inch as other rigid foam insulations (such as EPS) at the same density. Polyiso’s change in R-value over time has thus caused some confusion for specifiers in selecting the appropriate insulation for their project. The published R-value for the material is the ‘fresh’ R-value from the initial point of manufacture, and not its long-term value.

**Measuring R-values**

The R-value of EPS is tested as part of ASTM C578 in ASTM C177, *Standard Test Method for Steady-state Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-hot-plate Apparatus*. Polyiso is manufactured to physical properties as called out in ASTM C1289, however the material’s published R-value comes from what the polyiso industry refers to as long-term thermal resistance (LTTR). This is not an actual tested R-value, however; rather, LTTR is an R-value derived from a mathematical procedure similar to the following three steps:

1. Determine the mean initial thermal resistance of the product ($R_{\text{Product, initial}}$).
2. Determine the aging factor as the ratio between the thermal resistivity of a 6 to 12-mm (¼ to ½-in.) thick slice at the specified time of aging ($R_{\text{Slice, aged}}$) to its initial value ($R_{\text{Slice, initial}}$). The specified time of aging is found using the formula:

   $$\text{Time of aging in days} = 5 \times 365 \left[\frac{\text{Thickness of slice}}{\text{Thickness of full thickness product}}\right]^2$$

   The specified time of aging is found using the formula:
3. LTTR is calculated using the larger of the two aging factors, surface or core: 

\[ R_{LTTR} = \frac{R_{Product, initial} \times R_{Slice, aged}}{R_{Slice, initial}} \]

In the past, EPS has been perceived as a lesser-quality product due to its lower pricing and the occasional difficulties in receiving a membrane warranty—a fact that may have more to do with the industry’s vertical integration than product performance. (The same companies that provide polyiso insulation also sell roofing membranes, but EPS manufacturers only make and sell the insulation, which means a warranty must be obtained elsewhere.)

EPS retains 100 percent of its published R-value. Building owners who are paying the energy bills and design professionals who size HVAC equipment should be aware of this very important information. For example, if the designer sizes the building’s mechanical system to published R-values, rather than the actual R-values, the HVAC may not be able to keep up on the very coldest or hottest days of the year.

When the specification calls for an R-24 roof and the contractor installs 102 mm (4 in.) of polyiso with an actual value of R-20, the system may not adequately heat the building in winter.

In a December 2010 article on Professional Roofing.net, Mark S. Graham, NRCA’s associate executive director of technical services, makes clear the issue of changing R-values:

In 2009, NRCA conducted R-value testing at various temperatures. NRCA’s testing of polyisocyanurate at 25°F, 40°F, 75°F, and 110°F showed actual R-values less than LTTR values. 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.2

For those specifying polyiso, NRCA’s 2011 manual recommends that designers determine the 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. NRCA also advises designers specify polyiso by its desired thickness—rather than its R-value—to avoid possible confusion during procurement.

Bearing this in mind, when comparing the R-value of Type II EPS of 4.55 per inch versus 5.0 per inch for polyiso, it becomes clear the second material does not have a much higher R-value—it works out to about 0.5 R-value per inch of material.3 For example, when one has 127 mm (5 in.) of EPS and the same amount of polyiso, the former is R-22.5 and the latter is R-25. They will perform very similarly, but there will be substantial difference in costs.

In addition to the perceptions about R-values, polyiso is believed to be more fire-resistant than EPS. (This may stem from the fact EPS has a slightly lower melting temperature.) A comparison of ASTM E84,
Standard Test Method for Surface-burning Characteristics of Building Materials, for polyiso insulation to ASTM C578 shows EPS has both lower flame spread and smoke-developed results (Figure 1, page 56). This means in the event of a fire in an EPS-insulated building, the flame will not spread as quickly and the smoke inhalation will have less impact on its occupants than in a facility insulated with polyiso.4

Advantages of polyiso
One clear advantage polyiso maintains over EPS is the market’s familiarity with it. Broader nationwide distribution and easier access to obtain a membrane warranty are the two primary reasons the material has most of the commercial roof insulation market. Membrane warranties are easier to obtain because the insulation and membrane manufacturers are vertically integrated, but this can potentially lead to conflicts of interest.

Polyiso can also be installed in a fully adhered system using solvent-based contact cements without a coverboard, unlike EPS. In this instance, the material has an advantage due to its chemical makeup; solvent-based contact cements can be directly applied to the insulation without compromising it. Polyiso is the only choice when a cover board is not used, and solvent-based adhesives come into contact with the insulation.

Further, EPS distribution is nationally under-served, so it can be challenging to obtain product on short notice. The prevalence of polyiso avoids this situation.

Advantages of EPS
When using NRCA’s new recommendations for R-value calculations, EPS insulation’s R-value costs less per inch than polyiso. EPS is also available in higher densities, such as 172-, 276-, and 414-kPa (25-, 40-, and 60-psi) comprehensive strengths.

The 25-psi density of Type IX EPS, versus 104 kPa (15 psi) of Type II, is important for providing durability. The more durable Type II EPS matches the physical characteristics of Type 2 polyiso and helps contractors avoid jobsite breakage.

Installing insulation with broken corners causes thermal breaks in the insulation and results in reduced energy efficiency. It also can create pockets for moisture to collect under virtually any conditions. Additionally, as is shown in Figure 2 (page 58), Type II EPS also has higher flexural strength (241 kPa [35 psi]) than Type I EPS (25 psi).

When roof drainage is of importance and tapered systems are specified, EPS can be an appealing option because installation is faster (due to fewer pieces and less cutting) and there is not as much jobsite waste. As polyiso is manufactured in limited thicknesses (i.e. not much more than 76 mm [3 in.]), when it is installed in a tapered system, multiple layers must be used to achieve the same taper thickness as one piece of EPS (Figure 3). EPS also saves installation costs when a two- or more layer system is required.

Due to the off-gassing inherent with polyiso and subsequent loss of R-value over time (greater after the initial point of manufacture, though it continues for three to five

<table>
<thead>
<tr>
<th>Type II</th>
<th>Type 2</th>
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<tbody>
<tr>
<td>Density</td>
<td>1.5 pcf</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>15 psi</td>
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<tr>
<td>R-value per inch</td>
<td>4.6</td>
</tr>
<tr>
<td>Cost per BF (flat)*</td>
<td>$0.20</td>
</tr>
<tr>
<td>Cost per BF (taper)*</td>
<td>$0.215</td>
</tr>
</tbody>
</table>

*As of March 2011. Subject to current and location pricing.
Expanded polystyrene can be produced in any thickness and various tapered panel sizes—this means the labor savings to install it can be dramatic.

Years), the manufacturers typically only warrant 80 percent of the material’s R-value for 10 years. Most EPS manufacturers, however, offer a warranty for 100 percent of the R-value for 20 years.

Higher compressive strengths are particularly important for roofs designed to carry heavy traffic and equipment loads. Whereas both insulations are available in compressive strengths higher than 137 kPa (20 psi), polyiso’s compressive strengths above 20 psi come with a dramatic cost premium over EPS.

Expanded polystyrene can be produced in any thickness and various tapered panel sizes so the labor savings to install it can be dramatic over that of polyiso. In terms of the cost premium for sheet insulation for flatstock on an R-20 roof, the contractor will pay approximately 60 percent more for the polyiso. For tapered insulation, the contractor pays about double or a 100 percent premium.

Conclusion
Overall, polyisocyanurate has two clear advantages over expanded polystyrene—it is the only insulation that can be bonded with solvent-based adhesives, and its higher melting temperature makes it a preferred option for hot asphalt systems (installers are also more familiar with its performance in this type of roof system). When it comes to using insulation for drainage purposes, however, EPS can often be the more suitable choice for cost, best drainage, less scrap, and reduced labor. Further, when EPS is used for drainage only (tapered insulation) and the flat sheet insulation is polyiso, there is no concern regarding membrane warranty.

In the end, it is critical for architects and specifiers to understand the differences in roof insulations—from R-value and long-term performance to available sizes, thickness, densities, slope for drainage, and installation characteristics. Knowing these critical topics will ensure the correct insulation is specified, which guarantees consistent, long-term performance that saves the building owner money.
Notes
1 Expanded polystyrene tests reflect the material’s R-value remains the same for 20 years. It is quite possible for this consistency to be indefinite, but the author is not aware of any R-value testing for EPS beyond 30 years.
2 The article, “Revised R-values: NRCA has Revised its Longstanding Design R-value Recommendation for Polyisocyanurate Insulation,” by Mark S. Graham, is also part of the 2011 NRCA Roofing Manual: Membrane Roof Systems; copies can be purchased via NRCA.
3 When considering R-values, one must be sure to compare apples to apples. It is important not to equate, for example, Type I EPS, which has a lower density and lower R-value, to Type 2 polyiso. They are not the same grade of product and have very different densities.
4 The fire from burning polyiso emits cyanide gas and is more toxic than smoke from EPS. However, the space’s contents and finishes have more of an impact on toxicity.

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Abstract
The National Roofing Contractors Association (NRCA) has revised the R-value of polyisocyanurate (ISO) insulation to take into account the material’s loss of thermal properties as it emits low-conductance gas after manufacturing. Conversely, expanded polystyrene (EPS) insulation has been shown to retain its R-value over the life of the product, or indefinitely. This article explores both sides, examining reasons specifiers might choose polyiso over EPS, as well as the advantages of the latter over the former.

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Insulation
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R-value
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