CAPTURING THE THERMAL PERFORMANCE OF FOAMULAR® & FOAMULAR® NGX™ EXTRUDED POLYSTYRENE (XPS) VS. POLYISOCYANURATE

Exploring the impact of temperature-dependent R-values on rigid insulation and building performance.

Summary

Extruded polystyrene (XPS) and Polyisocyanurate (polyiso) rigid foam insulation are both designed to provide thermal resistance in residential and commercial building construction applications. For example, in exterior above-grade wall assemblies, a layer of rigid insulation is often specified to comply with the prescriptive R-value requirements outlined in energy codes and standards, such as the International Energy Conservation Code (IECC) and American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 90.1. However, despite being used in similar applications, XPS and polyiso have very distinct product compositions that can result in significant thermal performance differences.

This technical bulletin describes how the R-value of rigid insulation changes based on the temperature it is exposed to. In other words, it is temperature-dependent. For example, the R-value of XPS improves as the temperature declines. However, the R-value of polyiso can decrease substantially as the temperature declines. New research also illustrates that wall assemblies built with XPS can provide greater thermal performance than those that are built with polyiso. This is especially true in colder climates or in assemblies where cold temperatures are desired, such as cold storage facilities.

Given the significant impact that continuous insulation has on the thermal and moisture performance of a building envelope, the differences in R-value performance between XPS and polyiso deserve careful consideration when selecting a rigid insulation.

Understanding Published R-Values

To help consumers understand and compare the thermal performance of insulation products, the Federal Trade Commission (FTC) requires insulation manufacturers to publish the R-value of their product on the product packaging. R-values shown on packaging reflect the R-value of the product when it is tested at a mean temperature of 75°F.

XPS has a published R-value of R-5.0 per inch, and polyiso is listed at a range of R-5.6 to R-6.0 per inch.[1] Accordingly, for those seeking to specify a product with the highest R-value per inch, polyiso may appear to be the logical choice. However, the third-party building science research described later illustrates that these published R-values can be misleading because they don't describe how products perform at colder temperatures. In other words, we know the R-value of each product at 75°F, but what is it at lower temperatures, such as 15°F?

Science Doesn't Lie

When comparing the R-value of insulating materials, it is helpful to understand the thermal conductivity of each. Thermal conductivity is defined as the rate at which heat transfers through a material between points at different temperatures. Once the thermal conductivity of a material is known, the R-value can be calculated (e.g., R-value per inch = 1 divided by the thermal conductivity of the product). Products with a low rate of thermal conductivity have greater thermal resistance (and higher R-value) than products with a higher rate of thermal conductivity.

Building Science Corporation (BSC) published the Thermal Metric Summary Report[2] regarding its Thermal Metric Project and Reference Wall testing. The long-term goal of this project was to develop a new metric for the thermal performance of building enclosures that better accounts for known physical heat flow mechanisms (particularly natural and forced convection) and operating

Figure 1. Thermal Conductivity Test Results from Building Science Corporation[2]

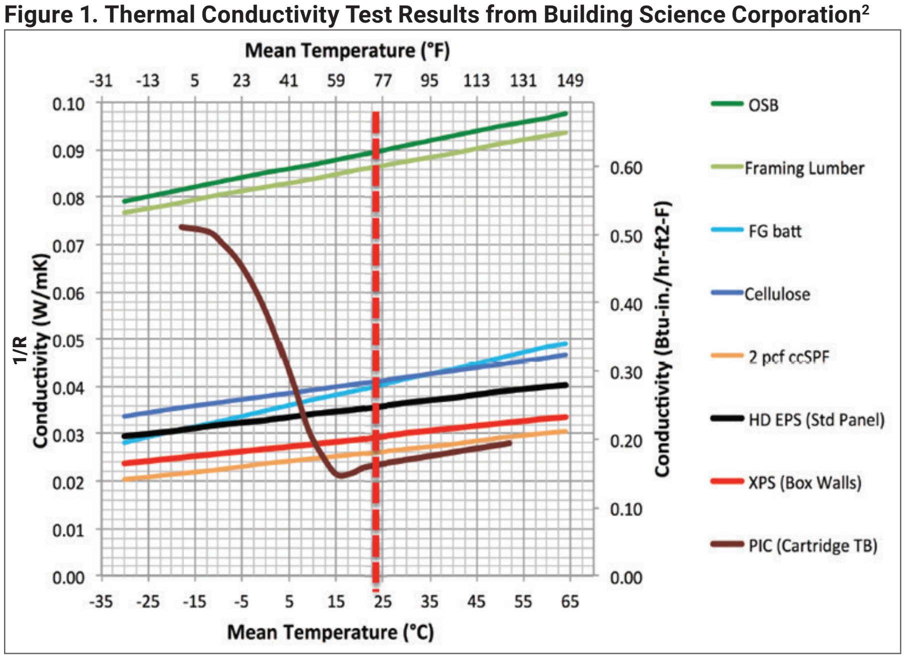


Chart Courtesy of Building Science Corporation (BSC) conditions. This project included a focus on better understanding the thermal conductivity of insulating materials at different mean temperatures. While experts have known for years that the thermal conductivity of insulation changes based on the temperature, they likely did not know how differently XPS and polyiso behave when exposed to cold temperatures. In fact, what BSC discovered was quite revealing. As shown in Figure 1, the thermal conductivity of XPS steadily decreases as the mean temperature declines. However, polyiso (PIC Cartridge TB) does not follow the same pattern. Instead, the thermal conductivity of the polyiso sample actually increases as the temperature declines, resulting in a substantial loss in R-value.

Converting Thermal Conductivity to R-Value

When converting these thermal conductivity results to R-value performance, the differences between XPS and polyiso are readily apparent (see Table 1).

- **XPS:** At a mean temperature of 75°F, the thermal conductivity of XPS correlates well with its published R-value of R-5 per inch. Moreover, the R-value of XPS increases to approximately R-6 as the mean temperature drops to 15°F.
- **Polyiso:** At a mean temperature of 75°F, the polyiso sample also exhibits a level of thermal conductivity that correlates to its published R-value of R-6 per inch. However, as the mean temperature drops to 15°F, the R-value decreases to approximately R-2 per inch, representing a significant 66% loss in R-value.

Why Does the Thermal Performance of Polyiso Decline in Colder Temperatures?

The increased thermal conductivity and inconsistent performance of polyiso is primarily attributed to the amount and type of blowing agent used to manufacture the product. The blowing-agent (insulating) gases that are entrapped within the cells of polyiso begin to condense (change from a gas to a liquid) at colder temperatures, and, as those gases condense, the thermal conductivity of polyiso increases.

The blowing agent (insulating) gases that are entrapped within the cells of the XPS, however, remain as a gas over the tested temperature range. Figure 2 uses averaged data to illustrate the effect of blowing agent boiling point on a foam's insulation value. This data demonstrates one of the advantages of low-boiling blowing agents: improved insulation performance over a broader operating temperature range. And, the better the insulation performance, the lower the energy consumption of products that rely on these high-value foam insulations[3].

Comparing XPS and Polyiso in Wall Assemblies

Taking into account the thermal conductivity data shown above, Owens Corning used WUFI, a leading hygrothermal modeling software program, to explore how wall assemblies that are built with XPS and polyiso would perform in a variety of climates. The study included Chicago, Minneapolis, and Toronto, where winter temperatures are often in the single digits for prolonged periods of time. Two exterior wall types (each with brick veneer cladding) were evaluated, including:

- 2 feet by 4 feet wood-framed, fiberglass-insulated wall with XPS continuous insulation
- 2 feet by 4 feet wood-framed, fiberglass-insulated wall with polyiso continuous insulation

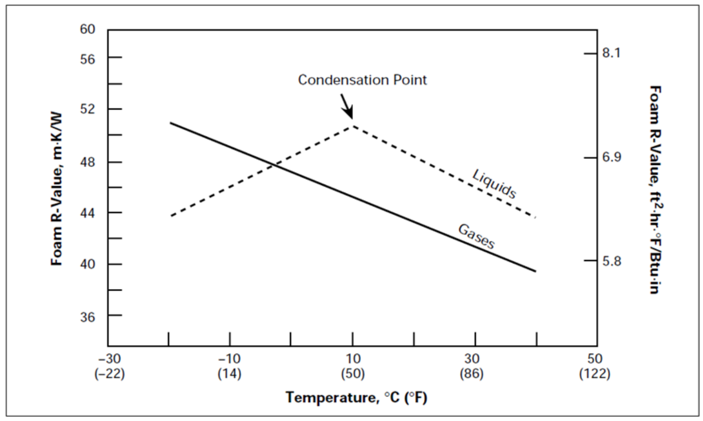
The WUFI results for Chicago (Figure 3) are expressed in terms of

Table 1

RIGID INSULATION	R-VALUE AT 75°F MEAN	R-VALUE AT 15°F MEAN	R-VALUE % CHANGE
XPS	1/.200 = R-5	1/.165 = R-6	+20%
Polyiso	1/.166 = R-6	1/.500 = R-2	- 66%

Note: R-value per inch = 1 divided by thermal conductivity.

Figure 2. Foam Insulation Value vs. Temperature for Liquid and Gaseous Blowing Agents[3]



heat loss and heat gain on a month-by-month basis. As shown, both XPS and polyiso wall assemblies perform about the same during the summer. However, in the winter months, it's clear that walls built with XPS perform better than those constructed with polyiso. On an annual basis, the heat flow results show that 2 inches of XPS is 21% more efficient than polyiso.

Water Absorption

The material standard that defines properties for all XPS and EPS is ASTM C578[4]. It requires that polystyrene insulation be tested for water absorption in accordance with ASTM C272[5]. C272 requires the polystyrene sample to be immersed in water for 24 hours and weighed immediately upon removal from immersion to determine the amount of absorbed water. The material standard for polyiso is ASTM C1289[6]. It requires that polyiso be tested for water absorption in accordance with ASTM C209[7]. C209 requires the polyiso sample to be immersed in water for 2 hours and drained for 10 minutes before weighing for water absorption. Figure 4 shows the significant differences in XPS and polyiso water absorption that result from using different measuring techniques. Note that the water absorption level for polyiso increases greatly when tested by the same method used for XPS. Glass -faced polyiso goes from absorbing 14 times more water than XPS, to absorbing 30 times more water than XPS, when measured using the same method. Foil-faced polyiso goes from absorbing 1.5 times more water than XPS, to absorbing over 7 times more water than XPS. Because the presence of foil makes such a difference in water absorption, the long-term durability of the foil is critical. If the foil is punctured or corrodes while in service, the polyiso core is unprotected from water and is even more prone to higher water absorption, like the condition with glass facers.

Resisting Water Absorption, the Key for High Performance Insulation

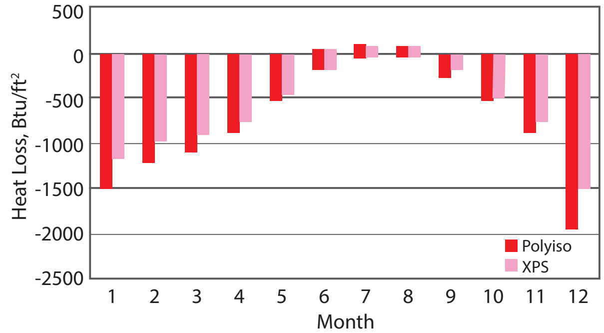
Moisture gets into all types of buildings. Unless the building insulation is highly resistant to water absorption, moisture can degrade insulation R-value and structural integrity, and provide an essential ingredient to support mold growth. Water is a good conductor of energy, so if insulation is water-soaked, R-value is lost. For more examples of this, refer to the University of Alaska Case Study Technical Bulletin. Also, compressive strength may be reduced by water absorption, depending on the make-up of the foam plastic insulation, hydrophobic/closed-cell XPS or hydrophilic/more open-cell polyiso. Therefore, absorbed moisture is to be avoided to achieve sustainable quality construction. One of the greatest attributes of XPS is its ability to retain R-value and compressive strength even when exposed to water.

Conclusion

In the independent BSC testing described previously, the XPS and polyiso samples both performed as expected when tested at a mean temperature of 75°F. However, when tested at lower temperatures, each behaved quite differently. The R-value of XPS improved as the temperature declined, while the R-value of polyiso decreased substantially as the temperature declined. Using further hygrothermal analysis, such as WUFI, illustrates that these differences can have a significant impact on the thermal performance of a construction assembly.

Accordingly, when specifying rigid insulation, it is important to understand the R-value performance of each product being considered. In addition, the design team should consider

Figure 3. (R-10 Board for Both XPS and Polyiso)
Heat Flows — XPS vs. Polyiso



Differences in Heat Flow:
Polyiso Heat Loss or Gain vs. XPS

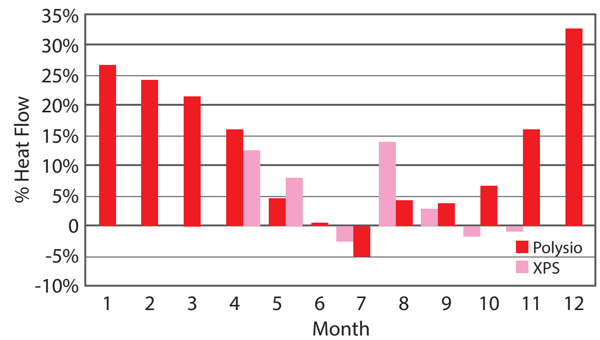
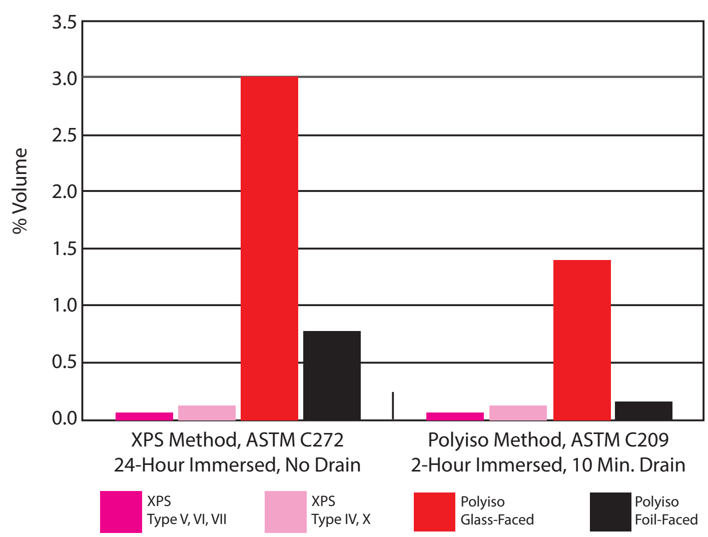


Figure 4. Heat Flow — XPS vs. Polyiso



researching the thermal conductivity of products when they are exposed to cold temperatures (when R-value often matters most), and account for any unusual performance variations when conducting energy modeling. The understanding of this information has led multiple manufacturers to list R-values of products not just at 75°F as required by FTC but also at lower temperatures (often 40°F and 25°F) to represent colder climates or cold storage.

1 http://www.astm.org. C578. C1289.

2 Thermal Metric Summary Report. Building Science Corporation. http://www.buildingscience.com/documents/special/content/thermal-metric/BSCThermalMetric SummaryReport_20131021.pdf, 2013.

3 DuPont™ Formacel®. "Temperature Effect on the Insulation Value of Polyurethane Foams," 2011.

4 ASTM C578-19, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation; ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

5 ASTM C272, Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions; ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

6 ASTM C1289-20, Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board; ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

7 ASTM C209, Test Methods for Cellulosic Fiber Insulating Board; ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

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