# Polystyrene Foam Insulation in Long-Term Building Applications – Effective R-values

**Executive Summary**

The primary purpose of insulation is to isolate a building’s interior environment from either warm or cold exterior conditions. In many building applications, polystyrene foam insulation is protected from moisture, and the R-values determined under dry laboratory conditions are appropriate. This document provides a methodology that uses short-term, laboratory-determined R-values with adjustment factors to account for the long-term conditions of buildings when a more detailed analysis is desired. The focus is on the insulation or R-value performance of expanded polystyrene (EPS) and extruded polystyrene (XPS) foam products used in long-term building applications. A methodology is presented in which the laboratory-determined R-value is multiplied by three adjustment factors to determine the long-term effective R-value of installed insulation. After considering the impact of temperature, age, and moisture on both EPS and XPS, the following conclusions are drawn:

* The R-values for EPS and XPS increase when the mean temperature decreases below 75 oF. At a mean temperature of 40 o F, the R-values for EPS and XPS increase by approximately 10%.
* The R-value for EPS was constant over time, and the R-value for XPS decreased by approximately 14% over time.
* The R-values for both EPS and XPS is approximated to decrease by10% due to the absorption of water in below-grade applications.

The magnitudes of the adjustments to the R-values were not extremely large, but the analysis demonstrated that the R-value performance of EPS was preserved better than that of XPS when all factors were considered. The prime contributor to this difference was the loss of R-value by XPS that occurred with age.

**Introduction**

The primary purpose of insulation it is to isolate a building’s interior environment from either warm or cold exterior conditions, i.e., to keep a building warm when it is cold outside or to keep a building cool when it is extremely hot outside. R-value, or thermal resistance, is a measure of the ability of insulation to resist the flow of heat. The higher the R-value, the greater the resistance to heat flow is. A higher R-value translates into lower heating and cooling costs and reduced pollution.



Figure . Insulation Performance in Winter and Summer

It is very important to understand the differences in the R-values of polystyrene foam insulations in various building applications over time, at various temperatures, and at various moisture conditions. The U.S. Federal Trade Commission (FTC) has an “R-value Rule” regarding advertised R-values for insulation materials to consumers (Federal Trade Commission, 2005). The R-value Rule requires that R-value testing be conducted on samples at a mean temperature of 75° F. The 75F is not intended to reflect the mean temperature of insulations in all building applications. The R-value Rule simply uses this temperature to provide a uniform basis that allows consumers to compare different insulations at standard laboratory conditions. In accordance with the R-value Rule, R-values most often are measured using ASTM C518 (ASTM, 2017) or ASTM C177 (ASTM, 2013). Unfortunately, the resulting R-values derived from these ASTM standard laboratory scale tests do not provide a full understanding of the performance of insulation in buildings because the tests do not account for the age of the insulation or its exposure to various temperatures and moisture after it is installed in a building. A research paper (Crandell, 2010) provides a review of documented research on polystyrene foam and R-value adjustments for frost-protected foundations, but it is focused on water absorption and gives limited consideration to the effects of aging or climate conditions.

Some standard test methods are available for determining the impact of age (ULC Standards 2015; ASTM, 2015; ISO, 1999) through methods that estimate the long-term R-values of various products. The ULC and ASTM methods are most commonly used in North America to provide an estimate of the long-term thermal resistance (LTTR) of an insulation at five years. The use of a five-year estimate of the R-value is clearly an improvement over the use of a short-term R-value, but it is insufficient for predicting the R-value of polystyrene foam over the life of a building, particularly since building professionals expect buildings to last at least 50 years (Connor, 2004).

A methodology that uses short-term, laboratory-determined R-values along with adjustment factors to account for specific building conditions is warranted when a detailed analysis is needed. The R-value adjustment factor method discussed herein is analogous to a thermal conductivity adjustment method recognized in international standard ISO 10456 (ISO, 2007). The R-values noted throughout this paper have the customary units for the U.S., i.e., F·ft2·hr/BTU.

Both polystyrene foam products used in insulation applications in buildings, expanded polystyrene (EPS) and extruded polystyrene (XPS), will be considered. These products are recognized in the United States by U.S. product standard ASTM C578 (ASTM, 2017) and in Canada by CAN/ULCS701.1 (ULC Standards, 2017). There is a wide range of types of EPS and XPS insulation types covered in the North America Standards, so this document will focus on EPS Types II and IX and XPS Types X and IV in accordance with ASTM C578. These are the EPS and XPS types with either 15 psi or 25 psi compressive strengths commonly used in building applications. Although not covered here, the methodology provided is applicable to other EPS and XPS types covered by ASTM C578.

The information provided in this document concerning the ASTM C578 Types is analogous to the CAN/ULC S701 types as noted in Table 1..

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Material | EPS | EPS | XPS | XPS |
| ASTM C578 Type | II | IX | X | IV |
| Compressive Resistance1, psi | 15 | 25 | 15 | 25 |
| R-value1, F·ft2·h/BTU | 4.0 | 4.2 | 5.0 | 5.0 |
| Analogous CAN/ULC S701 Type2 | 2 | 3 | 2 | 4 |

1 See ASTM C578 for complete details.  
2 The requirements of ASTM C578 and CAN/ULC are not identical, but they are very similar.

Table . Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS) Foam Types Commonly Used in Building Applications

**Temperature**

Building insulations perform differently when tested at mean temperatures other than 75° F. This behavior is recognized in the ASTM standards, by manufacturers, and by authoritative publications (ASTM, 2017; Building Science Corporation, 2015; The Dow Chemical Company, 2011; Owens Corning, 2015; Holladay, 2013). The mean temperature at which the thermal resistance of an insulation is measured is a key factor that must be considered when the insulation is used in buildings that are exposed to both cold and hot conditions, which is the prevailing case across North America. Figure 2. shows the thermal conductivities of many building materials decrease as the mean temperature decreases (Building Science Corporation, 2015). R-value correlates inversely with thermal conductivity, thus a lower thermal conductivity at colder mean temperatures means that the R-value for the material increases as the temperature decreases. One insulation, polyisocyanurate insulation, does not exhibit this typical behavior. At mean temperatures below approximately 60oF (59o F16o C), its thermal conductivity increases significantly, and the R-value decreases significantly.

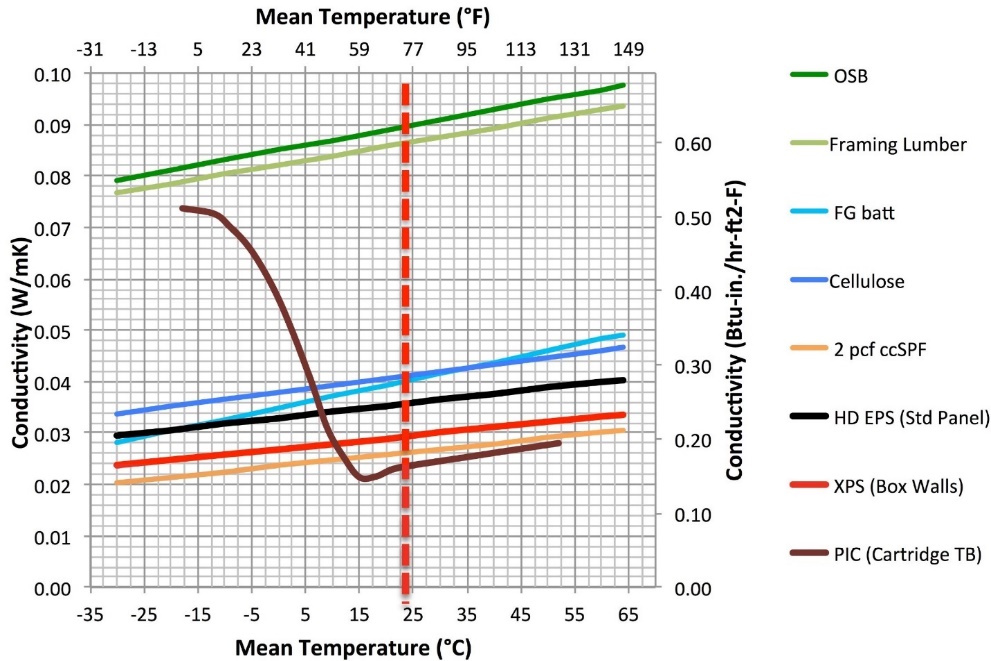


Figure . Thermal Conductivity of insulations as a function of mean temperature (Building Science Corporation, 2015)

[Graphic from Building Science Corporation – editing needed with clarification of abbreviations.]

It is important to adjust the R-value for the actual conditions when conducting a detailed analysis of the building at conditions with a mean temperature other than 75° F. This analysis may further require consideration of both winter and summer conditions. Alternatively, the lowest anticipated R-value based on the anticipated summer and winter conditions of the building may be used as a conservative approach. Table 2 provides example calculations of mean temperatures based on different exterior conditions and an interior temperature of 72° F.

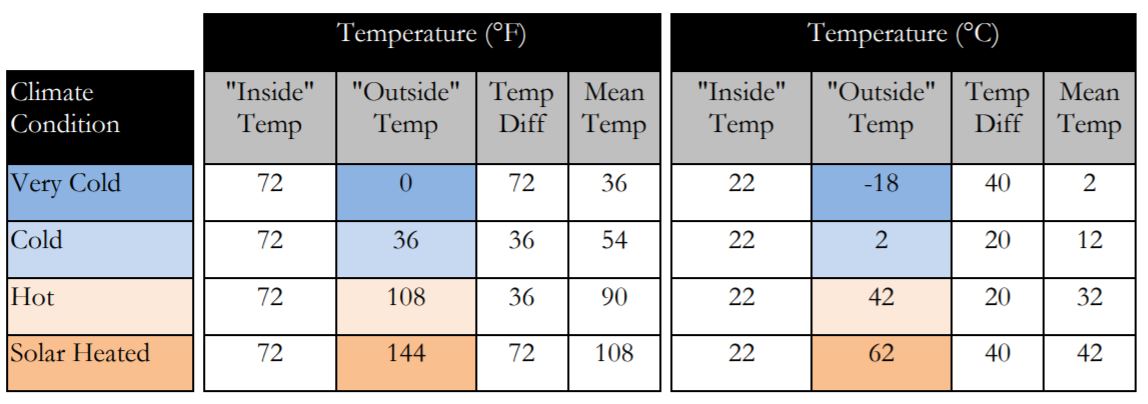


Table 2. Mean Temperatures as a Function of Climate Condition (Building Science Corporation)

It is immediately apparent that normal weather conditions across North America do not correlate well with a mean temperature of 75 ° F. A mean temperature of less than 40° F would be appropriate for winter conditions in very cold climates, and a mean temperature of 90° F or higher would be appropriate for summer conditions in a hot climate.

Insulation boards are commonly installed somewhere between the exterior and the interior of the building envelope, thus the resulting temperature difference across the insulation is less, and more importantly the mean temperature is often more closely tied to the exterior temperature. This is important to consider for products that do not exhibit a linear response to mean temperature change as shown in Figure 2. The mean temperature of the insulation should be determined based on both climate conditions and insulation location in the building envelope.

**Impact of Aging**

The FTC’s R-value Rule requires the published R-value of insulation to fully reflect the impact of aging on the insulation. The process of aging causes some insulation to lose its captive blowing agents over time. XPS uses gaseous blowing agents, which initially contribute to better R-values, but, over time, the gases dissipate, causing the R-value of XPS to decrease. In contrast, EPS contains only air, so its R-values do not decrease over time from gaseous exchange.

In Canada, XPS manufacturers must publish a long-term thermal resistance (LTTR), which is an estimate of the product’s R-value at five years of age. This is an improvement and a distinction between the insulation’s initial R-value or an R-value determined by a short-term conditioning method. Nonetheless, LTTR does not reflect the full extent of aging over the life of the insulation when used in buildings that are anticipated to have a minimum lifetime of 50 years. Figure 3 shows the R-value for EPS Type II and IX and XPS Type IV and X over time.

Figure . Loss of R-value Over Time for Polystyrene Insulations

[Graphic needs to be updated with correct reference to Type IV and symbols]

**Moisture**

The R-value of insulation typically is determined under ideal, dry laboratory conditions. In many building applications, polystyrene foam insulation is protected from moisture, and the R-values determined under dry laboratory conditions are appropriate. Examples include insulation under roof membranes and wall insulation covered by a weather-resistive barrier. In these applications, no adjustment to the R-value is needed based on the insulation’s exposure to moisture. Polystyrene foam in ground contact applications may be exposed to moisture, and, in such cases, an adjustment to the laboratory R-value based on these conditions is appropriate. Under these conditions, the reductions in the R-values of both EPS and XPS materials are well documented in international standard ISO/FDIS 10456 (ISO, 2007) and Figure 4 shows the loss of R-value for EPS and XPS as a function of moisture.

Figure . Loss of R-value by Polystyrene Foam Insulation Due to the Absorption of moisture (ISO, 2007)

**Effective R-value**

The discussion on temperature, moisture, and aging demonstrated that R-value is affected by each of these considerations. A methodology that includes all three considerations can be used to determine the effective R-value under specific building conditions.

**Effective R-value Determination**

The adjustment of the R-value from ideal laboratory conditions to the conditions in building applications is straightforward. The Effective R-value determination discussed herein is analogous to a thermal conductivity adjustment method recognized in international standard ISO 10456 (ISO, 2007).

The R-value determined in the laboratory (RLAB) by following the FTC R-value Rule is multiplied by three adjustment factors to determine the effective R-value (REFFECTIVE). There is an adjustment factor for moisture (FH20) where this value is a number less than or equal to one, since moisture will have a negative impact on the R-value. There is an adjustment factor for temperature (FTEMP) where this value may be less than or greater than one depending on the change in performance relative to the R-value determined at the mean temperature of 75°F. There is an adjustment factor for aging (FAGE)where this value is a number equal to or less than one since the R-value will decrease over time for some products due to the loss of captive blowing agents.

REFFECTIVE = RLAB x FTEMP x FAGE x FH20

where:

REFFECTIVE = effective R-value under the specific conditions considered

RLAB = R-value determined under standard laboratory conditions at 75 °F mean temperature in accordance with the FTC R-value Rule

FTEMP = adjustment factor for temperature

FAGE = adjustment factor for a product that is 50 years old

FH20 = adjustment factor for moisture based on application

**Temperature Adjustment Factor**

The performance of polystyrene foam insulation is well documented in ASTM C578 (ASTM, 2017). The R-value performance of both EPS and XPS increases at mean temperatures colder than 75 °F and decreases at mean temperatures warmer than75 °F. The table below provides the recognized R-values at 75 °F for polystyrene in compliance with ASTM C578 as well as the R-values at 110, 40, and 25 °F mean temperatures.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Material | EPS | EPS | XPS | XPS |
| ASTM C578 Type | II | IX | X | IV |
| R-value at 110 °F | 3.65 | 3.85 | 4.65 | 4.65 |
| R-value at 75 °F | 4.0 | 4.2 | 5.0 | 5.0 |
| R-value at 40 °F | 4.4 | 4.6 | 5.4 | 5.4 |
| R-value at 25 °F | 4.6 | 4.8 | 5.6 | 5.6 |

Table 3. ASTM C578 R-values at Various Mean Temperatures

Plotting the various R-values in ASTM C578 in Figure 5 shows that there is a linear relationship of R-value with temperature that allows the R-value to be predicted at any mean temperature within the range of 25 to110 °F.

Figure . R-value vs. Mean Temperature for Type II, IV, IX, and X Polystyrene Insulation

The best fit of the ASTM C578 data leads to equations that can be used to determine the temperature adjustment factor at temperatures other than 75 °F:

For Type II EPS,

Equation FTEMP = 1.214– (0.0028 x Mean Temperature)

For Type IX EPS,

Equation FTEMP = 1.204 – (0.0026 x Mean Temperature)

For Type X or IV XPS,

Equation FTEMP = 1.172 – (0.0022 x Mean Temperature)

Table 4 provides the temperature adjustment factor, FTEMP, using Equations 1 through 3 for mean temperatures from 20 to 110°F.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Material | EPS | EPS | XPS | XPS |
| ASTM C578 Type | II | IX | X | IV |
| FTEMP for 20 oF | 1.16 | 1.15 | 1.13 | 1.13 |
| FTEMP for 30 oF | 1.13 | 1.12 | 1.11 | 1.11 |
| FTEMP for 40 oF | 1.10 | 1.10 | 1.08 | 1.08 |
| FTEMP for 50 oF | 1.08 | 1.07 | 1.06 | 1.06 |
| FTEMP for 60 oF | 1.05 | 1.05 | 1.04 | 1.04 |
| FTEMP for 70 oF | 1.02 | 1.02 | 1.02 | 1.02 |
| FTEMP for 80 oF | 0.99 | 0.99 | 0.99 | 0.99 |
| FTEMP for 90 oF | 0.96 | 0.97 | 0.97 | 0.97 |
| FTEMP for 100 oF | 0.94 | 0.94 | 0.95 | 0.95 |
| FTEMP for 110 oF | 0.91 | 0.91 | 0.93 | 0.93 |

Table 4. FTEMP for Polystyrene Foams at Temperatures Between 20 and 110 o F

**Aging Adjustment Factor**

It is important that the R-value of any insulation account for the impact of R-value aging loss when used on buildings with a design life of 50 years. Aging is a process during which certain insulations with captive blowing agents lose those blowing agents over time. Since the blowing agents can contribute to the R-value of certain insulations, the R-value of these types of insulation decrease over time. Extruded polystyrene (XPS) contains a blowing agent that is lost over time, so its R-value must be adjusted.

R-value data is limited for XPS insulations in North America beyond five years. However, there are estimates of R-values at 5-years published in the Canadian Standard for XPS products (ULC Standards, 2017). The ASTM C578 standard requires XPS producers to determine and report its LTTR following ASTM C1303 (ASTM, 2015) values, but this information is not readily available from XPS manufacturers in the US. However, there are several publications that provide insight concerning the R-values of XPS after longer time periods due to the loss of blowing agents (Zhu, 2009; Kang; VO & Paquet, 2004; AFM Corporation, December 2017). Figure 6 shows the decay of blowing agent HCFC142b in an XPS foam where, after 50 years, over 50% of the blowing agent has been lost (VO & Paquet, 2004). Since the blowing agent is lost over time, the R-value will diminish over time. Similar information on the loss of the blowing agent also has been published by other researchers (Kang).

Figure . Loss of HCFC142b Blowing Agent Over Time in an Extruded Polystyrene Foam (VO & Paquet, 2004)

As expected, the R-value of the XPS decreases significantly over time from the R-value at the time of production, as shown in Figure 7 (VO & Paquet 2004)

Figure . Loss of R-value Over Time for an Extruded Polystyrene Foam with HCFC142b (VO & Paquet, 2004)

The information presented in Figure 7 was based on information published in Europe and an XPS with HCFC142b, so a comparison to U.S. performance is required. As noted previously, there are limited data from the U.S. manufacturers of XPS, but some short-term data have been published, and they are shown in Figure 8. Figure 8 shows that, in just a few years, the performance of XPS produced in the U.S. has deteriorated to well below the European data points shown in Figure 7

Figure . Decrease in the R-values over time for four U.S. extruded polystyrene foams produced in 2013

Information published by Kang suggests that the R-value of XPS after 50 years will be approximately 4.3 to 4.5. Considering the information from the sources presented here, the 50-year R-value estimate used to determine the long-term adjustment factor for XPS will be 4.3. In addition, the 50-year R-value may vary among different XPS products based on their variable performances as noted in Figure 8.

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Initial R-value | 5-year R-value1 | 50-year R-value |
| ASTM C578 Type X | 5.0 | 4.67 | 4.3 |
| ASTM C578 Type IV | 5.0 | 4.79 | 4.3 |

1Estimated based on CAN/ULC-S701.1 Types since ASTM Types are similar to CAN/ULC-S701.1 Types.

Table 5. Long-term Estimates of the R-values of XPS Insulation (ULC Standards, 2017) (Zhu, 2009)

The R-values of insulations that contain only air do not decrease over time. The R-values of expanded polystyrene insulation, which is filled with air, do not decrease over time.

As shown in Table 6, the R-value of EPS products are constant over a 50-year period.

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Initial R-value | 5-year R-value | 50-year R-value |
| ASTM C578 Type II | 4.0 | 4.0 | 4.0 |
| ASTM C578 Type IX | 4.2 | 4.2 | 4.2 |

Table 6. Long term R-values of EPS insulations

The information contained inn Tables 5 and 6 allow the determination of the aging adjustment factor for EPS and XPS.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Material | EPS | EPS | XPS | XPS |
| ASTM C578 Type | II | IX | X | IV |
| FAGE | 1.0 | 1.0 | 0.86 | 0.86 |

Table 7. FAGE for Type II, IV, IX, and X Polystyrene Foams

**Moisture Adjustment Factor**

The R-value of insulation typically is determined under ideal, dry, laboratory conditions. In many building applications, insulations are protected from moisture. Examples include roof insulation under membranes and wall insulation under weather-resistive barriers. In these applications, no R-value adjustment for moisture is needed. In below-grade and ground-contact applications, insulation may be exposed to moisture, and adjustments to the R-value based on these conditions are necessary.

The adjustment factor for moisture can be determined by knowing the moisture absorption of polystyrene foams over long periods of time, coupled with an understanding of the decrease in the R-value associated with the absorption of moisture.

Many building professionals often refer to ASTM C578 (ASTM, 2017) water absorption values published for polystyrene foam products. These values are the results of short-term quality control tests, and they should not be used as the values for the expected water absorption in building applications. As early as 1983, researchers from Dow Chemical concluded “that moisture gain in perimeter insulation cannot be predicted accurately by any one laboratory test” (Forgues, 1983).

Numerous studies on the field performance of polystyrene foams have been conducted around the world. The findings of many of those studies are not directly applicable to products produced in North America, because the standards for the manufacture of polystyrene foam products in the U.S. and Canada are not aligned with international standards.

Five independent studies conducted in North America (Esch, 1986)(Energy Division Minnesota Department of Public Service, 1988)(MacMaster & Wrong) (National Research Council Canada, 1999) (Kehrer & Christian, 2012)provide field testing information to determine the water absorption of products produced in North America. Three of the studies include results on EPS (Esch, 1986) (Energy Division Minnesota Department of Public Service, 1988) (National Research Council Canada, 1999), and four studies include results on XPS (Esch, 1986) (MacMaster & Wrong) (Energy Division Minnesota Department of Public Service, 1988) (Kehrer & Christian, 2012). Figure 9 shows the resulting data on EPS and XPS with a 1.35 pcf or greater density which correlates to the EPS Type II and IX and XPS Types X and IV.

Figure . Water Absorption of Polystyrene Foams with Density Above 1.35 pcf Over the Long Term. (Esch, 1986) (Energy Division Minnesota Department of Public Service, 1988) (Kehrer & Christian, 2012) (National Research Council Canada, 1999) (MacMaster & Wrong)

[Figure needs updated to use different symbols]

It is immediately apparent that the water absorption of EPS products appears to be relatively consistent over the 15 years of data that are available. The average water absorption of the EPS data collection is 2.2 volume % with a range of 0.1 - 5.9 volume %. It is anticipated that EPS products absorb some water during extremely wet conditions, but part of this moisture is liberated during dry conditions.

The water absorption of XPS products appears to be relatively low within the first five years, but it increases significantly when the data at 15 years is considered. The average water absorption of the XPS data collection is 2.6 volume % with a range of 0.0 to 6.3 volume %. It is apparent that the initial water absorption of XPS is low, but, over time, water is likely to accumulate in the closed cells of the XPS, and this moisture is not liberated during dry conditions.

It is very telling that the average results from Figure 9 actually are lower than prior data published by The Dow Chemical Co., where it appeared that the average water absorption for XPS is up to 6 volume % in long-term highway applications as shown in Figure 10.

Figure . Water absorption of extruded polystyrene over time in North American highway installations (The Dow Chemical Company)

Based on the analysis of the North American data, it is reasonable to approximate the average long-term moisture absorption for both EPS and XPS in below-grade building applications at 3 volume %. It is reasonable to anticipate that water absorption is negligible in properly installed wall and roof assemblies.

If the average moisture absorption is known, the loss of R-value due to this moisture can be calculated. An R-value adjustment equation for moisture was published in ISO 10456 (ISO, 2007) in which the adjustment for moisture, FH20, can be calculated by:

Equation 4: FH20 = 1/e(a\*Moisture vol%)

where a = 4.0 for EPS and 2.5 for XPS and e is Euler’s number, 2.71828.

|  |  |  |
| --- | --- | --- |
| Material | EPS | XPS |
| Below-grade applications | 3 volume % | 3 volume % |
| FH2O for below-grade applications | 0.89 | 0.93 |
| Above-grade wall applications | 0 volume % | 0 volume % |
| FH2O for above-grade wall applications | 1.0 | 1.0 |
| Roof applications | 0 volume % | 0 volume % |
| FH2O for roof applications | 1.0 | 1.0 |

Table 8. Average moisture absorption and FH20 of polystyrene foam for building applications

**Effective R-value Adjustment Examples**

The adjustment factors for moisture, temperature, and aging can now be used to predict effective R-values in various applications

Example 1

What is the anticipated effective R-value for EPS and XPS in long-term, above-grade wall applications for an extreme summer condition with an outside temperature of 105 o F and an interior temperature of 75 o F?

Reffective = RLAB x FTEMP x FAGEx FH20

RLAB is determined from ASTM C578 values at 75 oF

RLAB = 4.0 for Type II EPS

RLAB = 4.2 for Type IX EPS

RLAB = 5.0 for Type X and IV XPS

The mean temperature will be (105 o F +75 o F)/2 = 90 o F. The values for FTEMP are available from Table 4.

FTEMP = 0.96 for Type II EPS

FTEMP = 0.97 for Type IX EPS

FTEMP = 0.97 for Type X and IV XPS

FAGE for long-term applications is available from Table 7.

FAGE = 1.0 for Type II EPS

FAGE = 1.0 for Type IX EPS

FAGE = 0.86 for Type X and IV XPS

FH20 for wall applications is available from Table 8.

FH20 = 1.0 for Type II EPS

FH20 = 1.0 for Type IX EPS

FH20 = 1.0 for Type X and IV XPS

Thus,

For Type II EPS

REFFECTIVE = 4.0 x 0.96 x 1.0 x 1.0 =3.8, which is a 4% reduction from the lab R-value.

For Type IX EPS

REFFECTIVE = 4.2 x 0.97 x 1.0 x 1.0 = 4.1, which is a 3% reduction from the lab R-value.

For Type X or IV XPS

REFFECTIVE = 5.0 x 0.97 x 0.86 x 1.0 = 4.2, which is a 16% reduction from the lab R-value.

Example 2

What is the anticipated effective R-value for EPS and XPS in long-term, above-grade wall applications for an extreme winter condition with an outside temperature of 5 o F and an interior temperature of 75 o F?

Reffective = RLAB x FTEMP x FAGEx FH20

RLAB is determined from ASTM C578 values at 75 oF

RLAB = 4.0 for Type II EPS

RLAB = 4.2 for Type IX EPS

RLAB = 5.0 for Type X and IV XPS

The mean temperature will be (5 o F +75 o F)/2 = 40 o F. The values for FTEMP are available from Table 4.

FTEMP = 1.10 for Type II EPS

FTEMP = 1.10 for Type IX EPS

FTEMP = 1.08 for Type X and IV XPS

FAGE for long-term applications is available from Table 7.

FAGE = 1.0 for Type II EPS

FAGE = 1.0 for Type IX EPS

FAGE = 0.86 for Type X and IV XPS

FH20 for wall applications is available from Table 8.

FH20 = 1.0 for Type II EPS

FH20 = 1.0 for Type IX EPS

FH20 = 1.0 for Type X and IV XPS

Thus,

For Type II EPS

REFFECTIVE = 4.0 x 1.10 x 1.0 x 1.0 =4.4, which is a 10% increase from the lab R-value.

For Type IX EPS

REFFECTIVE = 4.2 x 1.10 x 1.0 x 1.0 = 4.6, which is a 10% increase from the lab R-value.

For Type X or IV XPS

REFFECTIVE = 5.0 x 1.08 x 0.86 x 1.0 = 4.6, which is a 7% reduction from the lab R-value.

Example 3

What is the anticipated effective R-value for EPS and XPS in long-term, below-grade applications

REFFECTIVE = RLAB x FTEMP x FAGEx FH20

RLAB is determined from ASTM C578 values at 75 o F

RLAB = 4.0 for Type II EPS

RLAB = 4.2 for Type IX EPS

RLAB = 5.0 for Type X and IV XPS

The mean temperature is assumed to be (50 oF +70 oF)/2 = 60 oF. The values for FTEMP are available from Table 4.

FTEMP = 1.05 for Type II EPS

FTEMP = 1.05 for Type IX EPS

FTEMP = 1.04 for Type X and IV XPS

FAGE for long-term applications is available from Table 7.

FAGE = 1.0 for Type II EPS

FAGE = 1.0 for Type IX EPS

FAGE = 0.86 for Type X and IV XPS

FH20 for below-grade applications is available from Table 8.

FH20 = 0.89 for Type II EPS

FH20 = 0.89 for Type IX EPS

FH20 = 0.93 for Type X and IV XPS

Thus,

For Type II EPS

REFFECTIVE = 4.0 x 1.05 x 1.0 x 0.89 = 3.7, a 7% reduction from the lab R-value.

For Type IX EPS

REFFECTIVE = 4.2 x 1.05 x 1.0 x 0.89 = 3.9, a 7% reduction from the lab R-value.

For Type X or IV XPS

REFFECTIVE = 5.0 x 1.04 x 0.86 x 0.93 = 4.1, a 17% reduction from the lab R-value.

Summary

Building insulations are subjected to a wide range of temperatures and moisture conditions during their service life. It is important that R-values be sustained, since the purpose of insulation is to isolate a building’s interior environment from either warm or cold exterior conditions. Any deterioration of the R-value could lead to increased heating or cooling costs. After consideration of the impact of temperature, age, and moisture on both EPS and XPS, the following conclusions were apparent:

* The R-value for EPS and XPS increases as the mean temperature decreases below 75 o F. At amean temperature of 40 o F, the R-values for EPS and XPS increase by approximately 10%.
* The R-value for EPS is constant over time, but the R-value for XPS decreases by approximately 14% over time.
* The R-values for both EPS and XPS is approximated to decrease by 10% due to water absorption of 3 volume % in below-grade applications

A methodology was provided to calculate the effective R-value for specific building applications when detailed analysis is desired. An example of above-grade walls was shown with an anticipated reduction in R-value for EPS of 3-4% and a reduction in R-value for XPS of 16%. An example for below-grade walls was shown with an anticipated reduction in R-value for EPS of 7% and a reduction in R-value for XPS of 17%. The magnitudes of the adjustments to the R-values were not extremely large, but it was apparent that the R-value performance of EPS was better preserved than the R-value of XPS. The prime contributor to this difference was the loss of R-value as the XPS products aged.

# References

AFM Corporation. (December 2017). Long-Term Thermal Resistance Data. AFM Corporation.

ASTM. (October 2013). ASTM C177-13 Standard Test Method for Steady-State Heat Flux by Means of the Guarded-Hot-Plate Apparatus.

ASTM. (December 2015). ASTM C1303/C1303M-15 Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insuation. ASTM.

ASTM. (July 2017). ASTM C518 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. ASTM.

ASTM. (September 2017). ASTM C578 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation. ASTM.

Building Science Corporation. (June 18, 2015). Thermal Metric Summary Report. Westford, MA: Building Science Corporation.

Building Science Corporation. (n.d.). BSC Information Sheet 502 Understanding the Temperature Dependence of R-values for Polyisocyanurate Roof Insulation. *www.buildingscience.com*. Building Science Corporation.

Connor, J. (October 2004). Survey of actual service lives for North American buildings. *Woodframe Housing and Durability and Disaster Issues Conference*.

Crandell, J. H. (June 2010). Below-Ground Performance of Rigid Polystyrene Foam Insulation: Review of Effective Thermal Resistivity Values Used in ASCE Standard 32-01 - Design and Construction of Frost-Protected Shallow Foundations. *J. Cold Reg. Engrg.* ASCE.

Energy Division Minnesota Department of Public Service. (November 1988). A Survey of Minnesota Home Exterior Foundation Wall Insulation: Moisture Content and Thermal Performance. Minnesota Department of Public Service.

Esch. (1986, December). Insulation Performance Beneath Roads and Airfields in Alaska.

Federal Trade Commission. (May 31, 2005). 16 CFR Part 460 Labeling and Advertising of Home Insulation: Trade Regulation Rule; Final Rule. *Federal Register*.

Forgues. (1983). Laboratory methods for Determining the Moisture Absorption of Thermal Insulatioans. II: Comparison of Three Water Absorption Test Methods with Field Performance Data. *Journal of Thermal Insulation*.

Holladay, M. (December 13, 2013). In Cold Climates, R-5 Foam Beats R-6. *www.greenbuildingadvisor.com*. Green Building Advisor.

ISO. (July 1, 1999). International Standard ISO 11561 Aging of thermal insulation materials - Determination of the long-term change in thermal resistance fo closed-cell plastics (accelerated laboratory test methods). ISO.

ISO. (2007). Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values. *ISO/FDIS 10456* . ISO.

Kang, C. J. (n.d.). Aging of Thermal Insulation Materials by Accelerated Laboratory Test Methods. Korea Institue of Construction Technology.

Kehrer, & Christian. (April 2012). Measurement of Exterior Foundation Insulation to Assess Durability in Energy-Savings Performance. Oak Ridge National Laboratory.

MacMaster, & Wrong. (n.d.). The Role of Extruded Polystyren in Ontario's Provincial Transporation System. *Transportation Research Record 1146*.

National Research Council Canada. (March 22, 1999). In-Situ Performance Evaluation of Exterior Insulation Basement System (EIBS) - EPS Specimens. National Research Council Canada.

Owens Corning. (2015). Capturing the Thermal Performance of Foamular Extruded Polystyrene (XPS) vs. Polyisocyanurate (Polyiso) FAQs. Owens Corning.

The Dow Chemical Company. (June 2011). Tech Solutions 521.0 Effect of Mean Temperature on R-value Measurement. The Dow Chemical Company.

The Dow Chemical Company. (n.d.). Highway Insulation. The Dow Chemical Company.

ULC Standards. (February 2015). CAN/ULC-S770-15 Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Thermal Insulating Foams. ULC Standards.

ULC Standards. (2017). CAN/ULC-S701.1:2017 Standard for Thermal Insulation, Polystyrene Boards. ULC Standards.

VO, & Paquet. (May 2004). An Evaluation of the Thermal Conductivity of Extruded Polystyrene Foam Blown with HFC-134a or HCFC-142b. *Journal of Cellular Plastics*. Sage Publications.

Zhu, Z. P. (May 2009). Effect of Loss of Blowing Agents on Thermal Insulation Properties of Polystyren Foams. *Journal of Heat Transfer*. ASME.