

# 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 insulating 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 age, temperature, and moisture on both EPS and XPS, the following conclusions are drawn:

- The R-value for EPS was constant over time and the R-value for XPS decreased by approximately 14% over 50 years.
- The R-values for EPS and XPS increase when the mean temperature decreases below 75°F (24°C). At a mean temperature of 40°F (4°C), the R-values for EPS and XPS increase by approximately 10%.
- The R-values for both EPS and XPS decrease by approximately 10% 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 due to out-gassing of blowing agents.



**Aging**  
The R-value of EPS is constant over time, and the R-value of XPS decreases over time.



**Temperature**  
The R-value of EPS and XPS increases when the mean temperature decreases below 75°F (24°C).



**Moisture**  
Similar R-value reductions occur for EPS and XPS in below grade applications.

# Introduction

The primary purpose of insulation 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 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. A higher R-value translates into lower heating and cooling costs and reduced pollution.

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 various moisture conditions. The U.S. Federal Trade Commission (FTC) has an "R-value Rule" regarding advertised R-values for insulation materials to consumers<sup>1</sup>. The R-value Rule requires that R-value testing is conducted on samples at a mean temperature of 75° F (24°C). This temperature is not intended to reflect the mean temperature of insulations in building applications but rather to provide a uniform basis that allows consumers to compare different insulations at standard laboratory conditions. Per the R-value Rule, R-values are most often measured using ASTM C518<sup>2</sup> or ASTM C177<sup>3</sup> test methods.

Unfortunately, the R-values derived from these ASTM standard laboratory scale tests do not provide a full representation of the performance of insulation in buildings because the tests do not account for the age of the insulation or its exposure to other temperatures and moisture after installation in a building.

Standard test methods are available for determining the impact of age<sup>4-6</sup> through methods that estimate the long-term R-values of foam plastics. The ULC and ASTM methods are most commonly used in North America to provide an estimate of the long-term thermal resistance (LTTR) of insulation at five years. The use of a five-year estimate of the R-value is an improvement over the use of a short-term R-value, but it is insufficient for predicting the R-value of extruded polystyrene foam over the life of a building, particularly since building professionals expect buildings to last at least 50 years<sup>7</sup>.



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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 the thermal conductivity adjustment method recognized in international standard ISO 10456<sup>8</sup>.

Expanded polystyrene (EPS) and extruded polystyrene (XPS) used as insulation in buildings are considered. These products are recognized in the United States by U.S. product standard ASTM C578<sup>9</sup> and in Canada by CAN/ULC S701.1<sup>10</sup>. There are a wide range of EPS and XPS insulation types covered in the North America Standards, but this document focuses on EPS Types II, IX, and XPS Types X, IV per ASTM C578. These are the EPS and XPS types with 15 psi or 25 psi compressive strengths commonly used in building applications. Although not covered here, the methodology provided applies to other EPS and XPS types covered by ASTM C578 and CAN/ULC S701.1.



Performance Properties	ASTM C578 Material Type			
	EPS		XPS	
	II	IX	X	IV
Compressive Resistance <sup>1</sup> , psi (kPa)	15 (104)	25 (173)	15 (104)	25 (173)
R-value <sup>2</sup> , °F•ft <sup>2</sup> •h/BTU	4.0	4.2	5.0	5.0
RSI <sup>3</sup> , °C•m <sup>2</sup> /W	0.70	0.74	0.88	0.88
Analogous CAN/ULC S701.1 Type <sup>4</sup>	2	3	2	4

<sup>1</sup> See ASTM C578 for details.

<sup>2</sup> Thermal resistance per 1.00 in (25.4mm). See ASTM C578 for details.

<sup>3</sup> Thermal resistance per 25.4 mm per ASTM C578. CAN/ULC S701.1 thermal resistance for XPS types 2, 3 and 4 are lower. See standard for complete details.

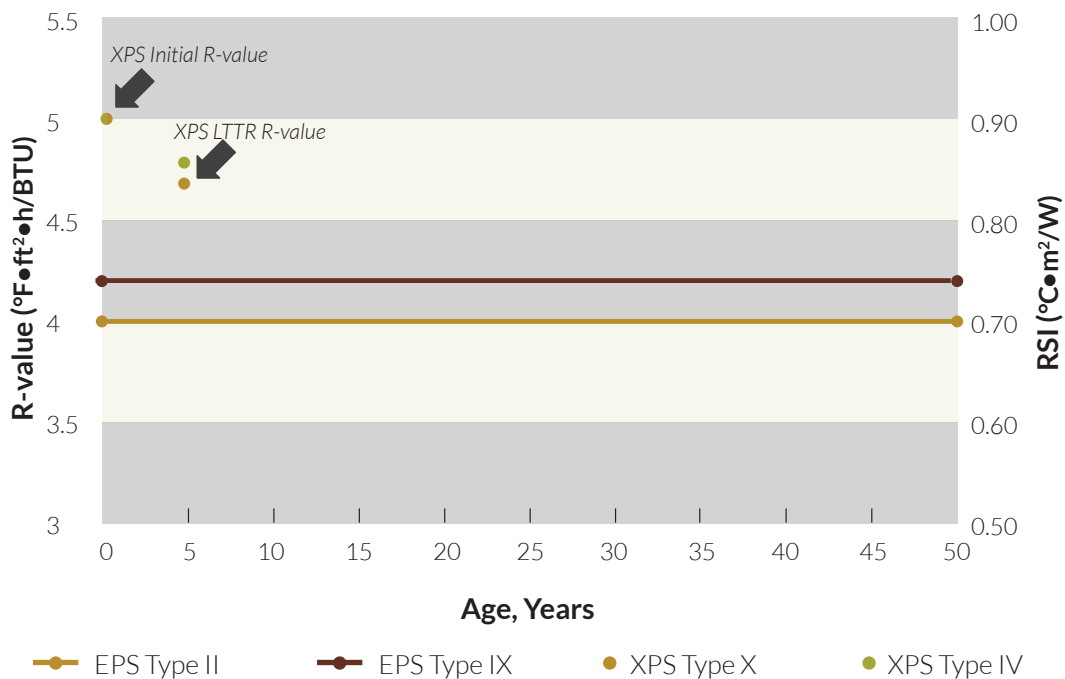
<sup>4</sup> The requirements of ASTM C578 and CAN/ULC are not identical, but they are very similar.

**Table 1. EPS and XPS Types Commonly Used in Building Applications**

## Impact of Aging

The FTC's R-value Rule requires that the published R-value of insulation fully reflects 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 dissipate causing the R-value of XPS to decrease. In contrast, EPS contains only air, so its R-values do not decrease over time.

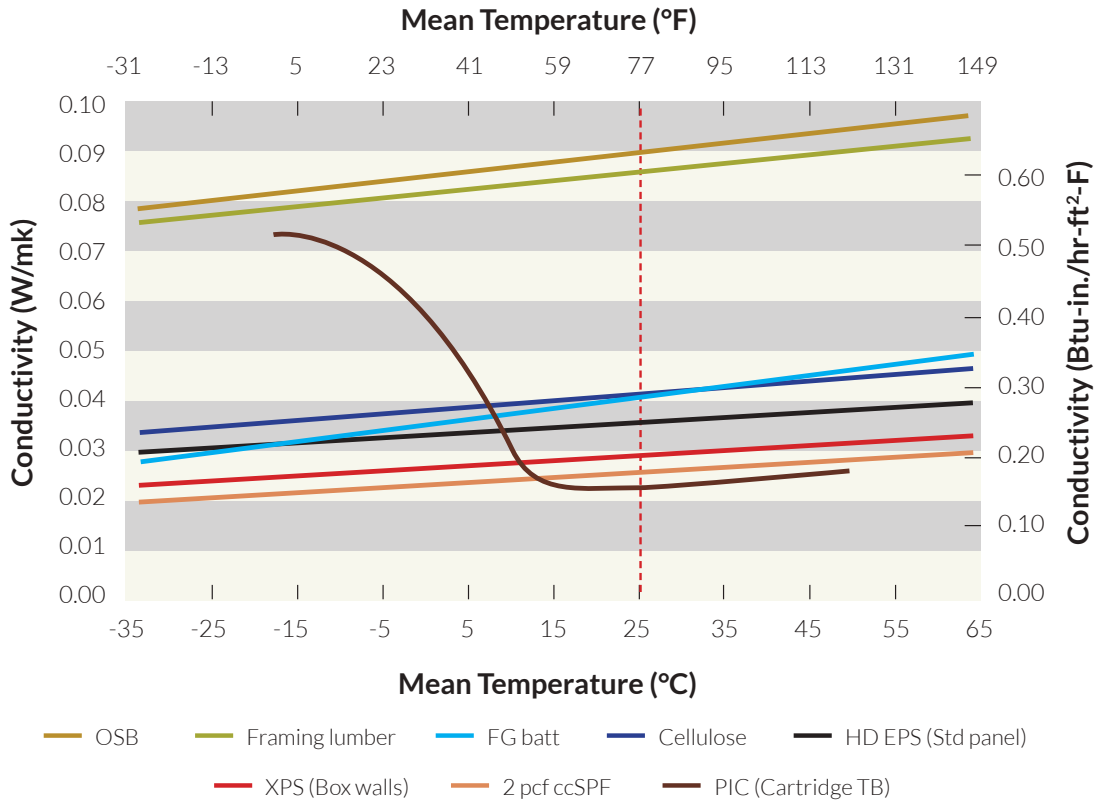
In Canada, XPS manufacturers are required to publish long-term thermal resistance (LTTR), which is an estimate of the product's R-value at five years of age. The LTTR requirement is distinct from the insulation's initial R-value or an R-value determined by a short-term conditioning method. Nonetheless, 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 1 shows the R-value for EPS Types II, IX and XPS Types IV, X over time.



**Figure 1. R-value Over Time for EPS and XPS**

# Temperature

Building insulation performance differs when tested at mean temperatures other than 75°F (24°C). This behavior is recognized in ASTM standards, by manufacturers, and by authoritative publications<sup>2,3,9,11-13</sup>. The mean temperature at which the thermal resistance of insulation is measured is a key factor to consider when used in buildings exposed to both cold and hot conditions, which is the prevailing case across North America.



**Figure 2. Thermal Conductivity of Building Materials as a Function of Mean Temperature<sup>14</sup>**

Figure 2 shows that the thermal conductivity of many building materials decreases as the mean temperature decreases<sup>14</sup>. 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 60°F (16°C), its thermal conductivity increases significantly, and thus the R-value decreases significantly.

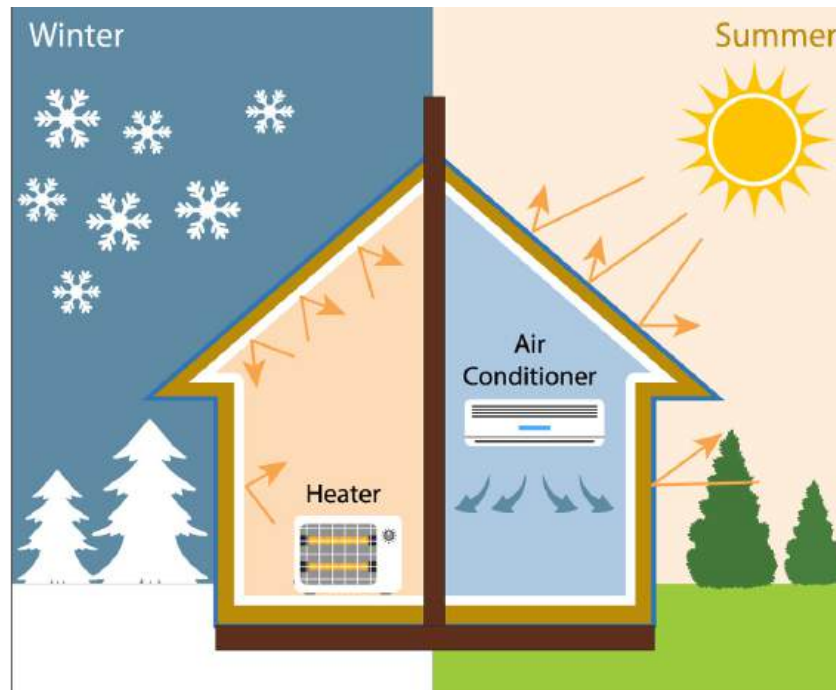
It is important to adjust the R-value for the actual conditions when conducting a detailed analysis of the building at conditions with a mean temperature other than 75°F (24°C). This analysis may require further consideration of both winter and summer conditions. Alternatively, the lowest R-value based on 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 climate conditions and an interior temperature of 72°F (22°C).

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

**Table 2. Mean Temperatures as a Function of Climate Condition<sup>15</sup>**

It is immediately apparent that the various climate conditions across North America do not correlate well with a mean temperature of 75°F (24°C). A mean temperature of less than 40°F (4°C) would be appropriate for winter conditions in very cold climates, and a mean temperature of 90°F (32°C) or higher would be appropriate for summer conditions in a hot climate.

With insulation generally installed between the exterior and interior of the building envelope, the mean temperature of the insulation depends largely upon the exterior temperature. As Figure 2 shows, insulation performance depends on the mean temperature, which is especially important for those products with a non-linear temperature dependence. The mean temperature applied should be based on climate conditions as well as the insulation location within the building envelope.



**Figure 3. Winter & Summer Climate Conditions**

# 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 below grade 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 10456.

When the average moisture absorption is known, the adjustment of R-value due to this moisture can be calculated by Equation 1.

Equation 1  $R\text{-value moisture adjustment factor} = 1/e^{(a \cdot \text{Moisture \% by volume})}$

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

## Effective R-value

The discussion on aging, temperature, and moisture 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 the thermal conductivity adjustment method recognized in international standard ISO 10456.

The R-value determined in the laboratory ( $R_{LAB}$ ) following the FTC R-value Rule is multiplied by three adjustment factors which determine the effective R-value ( $R_{EFFECTIVE}$ ). There is an adjustment factor for aging ( $F_{AGE}$ ) where this value is a number equal to or less than one since the R-value decreases over time for some products due to the loss of captive blowing agents. There is an adjustment factor for temperature ( $F_{TEMP}$ ) 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 (24°C). There is an adjustment factor for moisture ( $F_{H2O}$ ) where this value is a number less than or equal to one since moisture reduces the R-value.

Equation 2  $R_{EFFECTIVE} = R_{LAB} \times F_{AGE} \times F_{TEMP} \times F_{H2O}$

where:

$R_{EFFECTIVE}$  = effective R-value under the specific conditions considered

Note: This equation is applicable to R-values (U.S. units) or RSI values (SI units).

$R_{LAB}$  = R-value determined under standard laboratory conditions at 75°F (24°C) mean temperature per the FTC R-value Rule

$F_{AGE}$  = adjustment factor for a product that is 50 years old

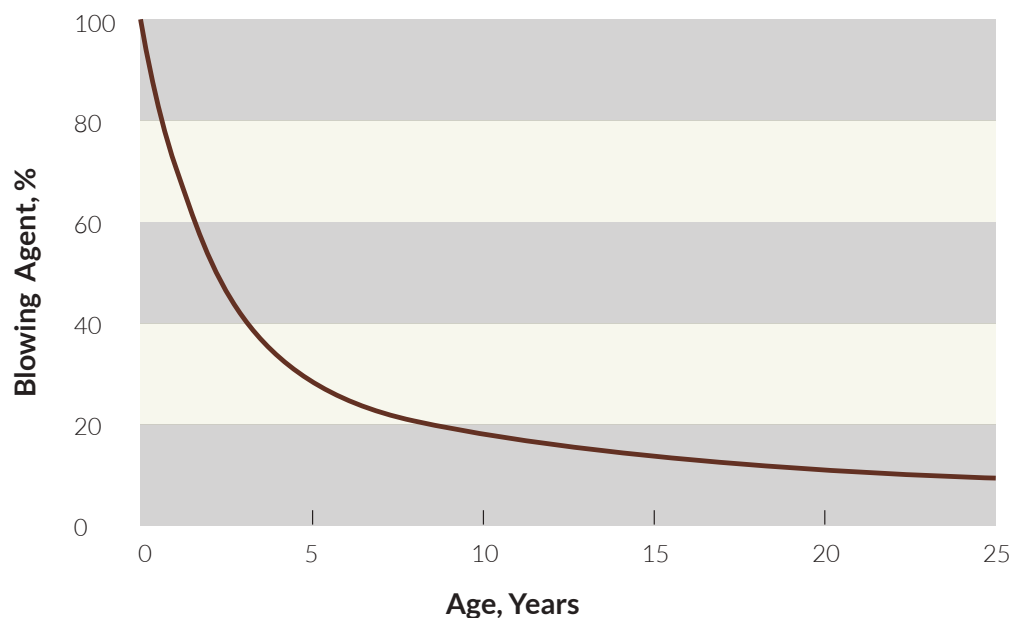
$F_{TEMP}$  = adjustment factor for temperature

$F_{H2O}$  = adjustment factor for moisture based on application

# Aging Adjustment Factor

The R-value of any insulation should account for the impact of R-value aging 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 five years published in CAN/ULC S701.1. The ASTM C578 standard requires XPS producers to determine and report the LTTR following ASTM C1303 values, but this information is not readily available from XPS manufacturers in the US. However, several publications provide insight concerning the R-value of XPS after longer periods due to the loss of blowing agents<sup>16-19</sup> The R-values of insulations that contain only air do not decrease over time. As shown in Figure 1, the R-value of EPS products is constant over a 50 years.



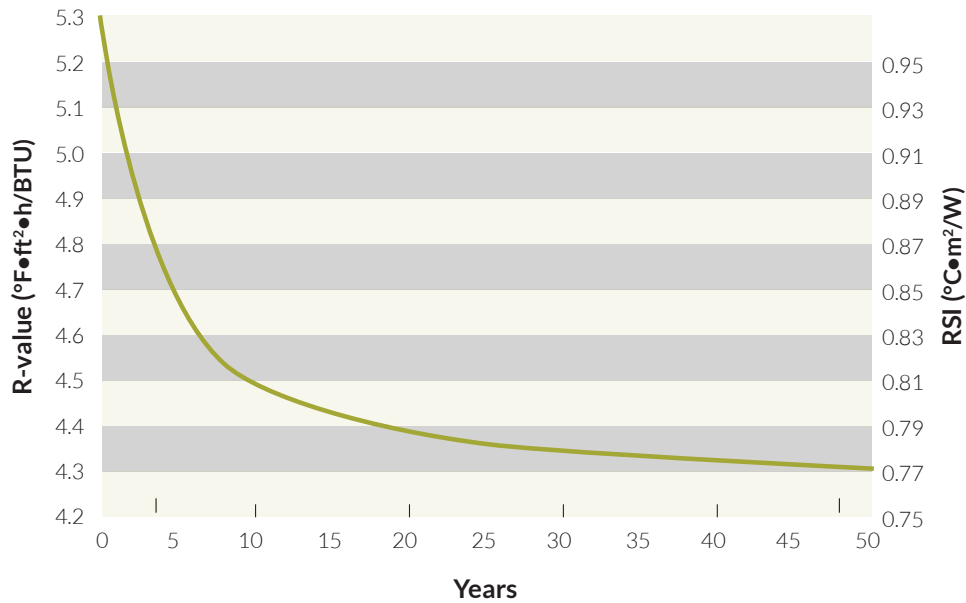
**Figure 4. Blowing Agent Loss of XPS<sup>18</sup>**

Figure 4 shows the decay of blowing agent HFC-134a in an XPS foam where after 25 years over 90% of the blowing agent has been lost. Since the blowing agent is lost over time, the R-value diminishes over time. Similar information on the loss of the blowing agent also has been published by other researchers.

As noted, there is limited data from the U.S. manufacturers of XPS, but some short-term data has been published<sup>19</sup>. There also has been recent aged R-value testing conducted on one U.S. manufactured XPS<sup>20</sup>.

Figure 5 shows the estimated R-value over time for XPS produced in the U.S. based on recent testing<sup>20</sup> and available research<sup>16-19</sup> on the long term performance of XPS produced internationally. The R-value drops significantly over time below the claimed R-value of 5.0 and is in close agreement with the values provided in CAN/ULC S701.1 at 5 years.

Considering all the available data<sup>16-20</sup>, the R-value used in this document to determine the long-term (50-year) aging adjustment factor for XPS is estimated to be 4.3. This value is an estimate and may need adjustment as more data becomes available.



**Figure 5. Estimated R-value over Time for a U.S. 1 inch Type X, IV XPS<sup>16-20</sup>**

The R-values of insulations that contain blowing agents decrease over time. As shown in Figure 5, the R-value of XPS continually decreases over 50 years. The R-values of insulations that contain only air do not decrease over time. The R-value of EPS products is constant over 50 years.

Material	Initial R-value	5-year R-value <sup>1</sup>	50-year R-value <sup>2</sup>
XPS Type X	5.0	4.67	4.3
XPS Type IV	5.0	4.79	4.3
EPS Type II	4.0	4.0	4.0
EPS Type IX	4.2	4.2	4.2

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

<sup>2</sup>Estimated based on available research<sup>16-20</sup>

**Table 3. R-values over Time for XPS and EPS**

The information contained in Table 3 allows for the determination of the aging adjustment factor for EPS and XPS.

Material	EPS	EPS	XPS	XPS
ASTM C578 Type	II	IX	X	IV
F <sub>AGE</sub>	1.0	1.0	0.86	0.86

**Table 4. F<sub>AGE</sub> for EPS Type II, IX and XPS Types IV, X at 50 years**

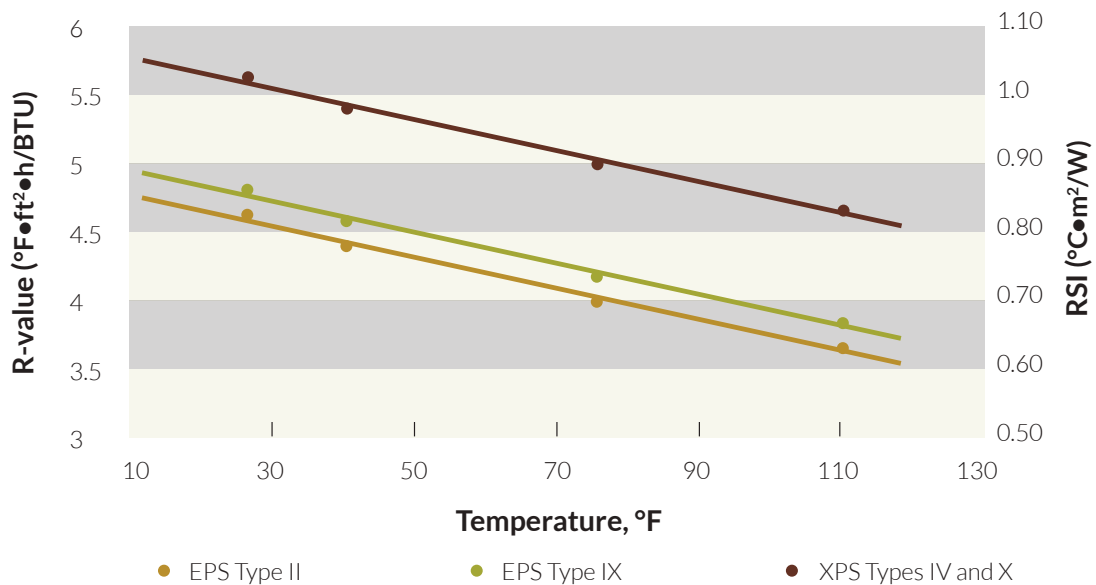
# Temperature Adjustment Factor

The performance of polystyrene foam insulation is well documented in ASTM C578. The R-value of both EPS and XPS increases at mean temperatures colder than 75°F (24°C) and decreases at mean temperatures warmer than 75°F (24°C). Table 5 provides the recognized R-values at 75°F (24°C) for EPS and XPS in compliance with ASTM C578 as well as the R-values at 110°F (43°C), 40°F (4°C), and 25°F (-4°C) mean temperatures.

Temperature	ASTM C578 Material Type							
	EPS				XPS			
	II		IX		X		IV	
	R-value	RSI	R-value	RSI	R-value	RSI	R-value	RSI
110°F (43°C)	3.65	0.64	3.85	0.69	4.65	0.82	4.65	0.82
75°F (24°C)	4.0	0.70	4.2	0.74	5.0	0.88	5.0	0.88
40°F (4°C)	4.4	0.77	4.6	0.81	5.4	0.95	5.4	0.95
25°F (-4°C)	4.6	0.81	4.8	0.84	5.6	0.99	5.6	0.99

**Table 5. ASTM C578/CAN S701.1 R-values at Various Mean Temperatures**

Plotting the various R-values in ASTM C578 in Figure 6 shows that there is a linear relationship of R-value with a temperature that allows the prediction of R-value at other temperatures.



**Figure 6. R-value vs. Mean Temperature for EPS Type II, IX and XPS Type IV, X**

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 (24°C):

For Type II EPS:

Equation 3  $F_{TEMP} = 1.214 - (0.0028 \times \text{Mean Temperature}^{\circ}\text{F})$  or  $F_{TEMP} = 1.125 - (0.0050 \times \text{Mean Temperature}^{\circ}\text{C})$

For Type IX EPS:

Equation 4  $F_{TEMP} = 1.204 - (0.0026 \times \text{Mean Temperature}^{\circ}\text{F})$  or  $F_{TEMP} = 1.119 - (0.0048 \times \text{Mean Temperature}^{\circ}\text{C})$

For Type X or IV XPS:

Equation 5  $F_{TEMP} = 1.172 - (0.0022 \times \text{Mean Temperature}^{\circ}\text{F})$  or  $F_{TEMP} = 1.100 - (0.0040 \times \text{Mean Temperature}^{\circ}\text{C})$

Table 6 provides the temperature adjustment factor,  $F_{TEMP}$ , using Equations 3 through 5 for mean temperatures from 20°F (-7°C) to 110°F (43°C).

Temperature	ASTM C578 Material Type			
	EPS		XPS	
	II	IX	X	IV
20°F (-7°C)	1.16	1.15	1.13	1.13
30°F (-1°C)	1.13	1.12	1.11	1.11
40°F (4°C)	1.10	1.10	1.08	1.08
50°F (10°C)	1.08	1.07	1.06	1.06
60°F (16°C)	1.05	1.05	1.04	1.04
70°F (21°C)	1.02	1.02	1.02	1.02
80°F (27°C)	0.99	0.99	0.99	0.99
90°F (32°C)	0.96	0.97	0.97	0.97
100°F (38°C)	0.94	0.94	0.95	0.95
110°F (43°C)	0.91	0.91	0.93	0.93

**Table 6.  $F_{TEMP}$  for EPS and XPS at Temperatures Between 20°F (-7°C) and 110°F (43°C)**

# 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 behind 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, 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 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 single laboratory test”<sup>21</sup>.

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<sup>22-26</sup> provide field testing information on the water absorption of products produced in North America. Three of the studies include results on EPS, and four studies include results on XPS. Figure 8 shows the resulting data on EPS and XPS with a 1.35 pcf or greater density which relates to EPS Types II, IX, and XPS Types X, IV.

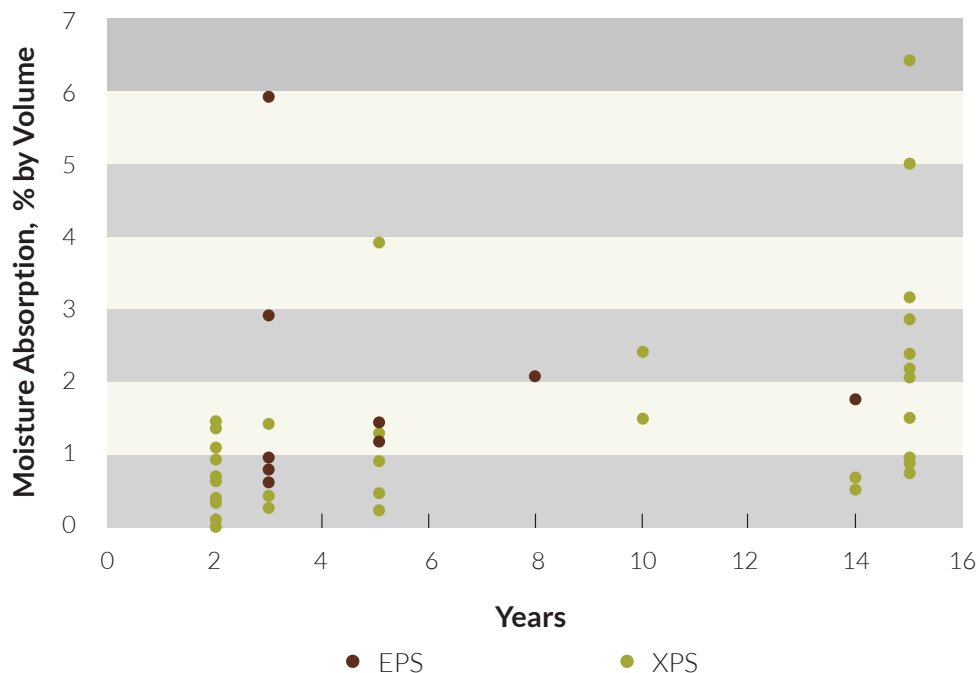


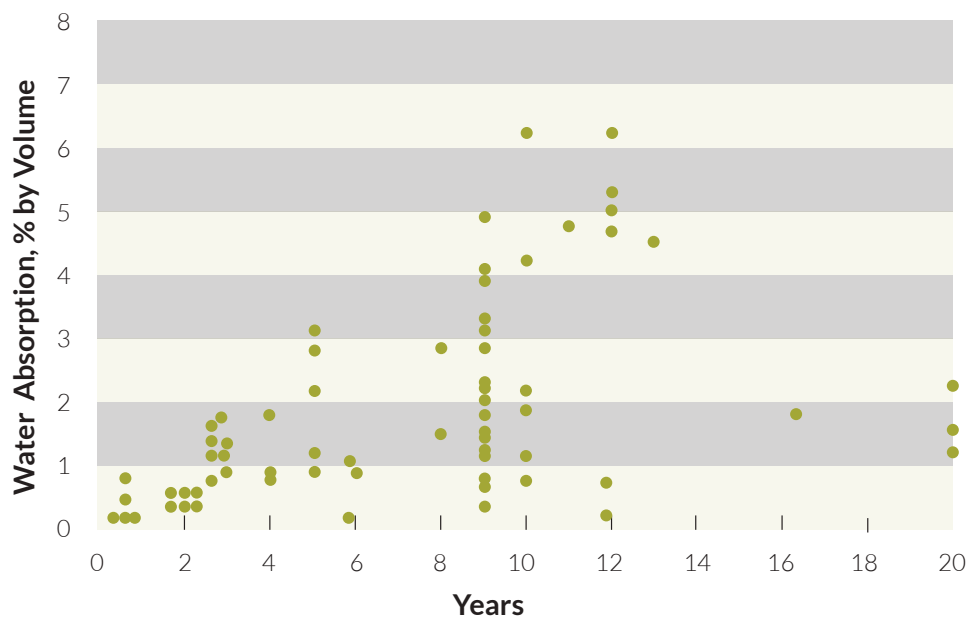
Figure 7. Below-Grade Water Absorption of EPS and XPS with Density Above 1.35 pcf Over the Long Term<sup>23-27</sup>

It is apparent that the water absorption of EPS products is relatively consistent over the 15 years of data that are available. The average water absorption of the EPS data collection is 2.2 % by volume with a range of 0.1 - 5.9% by volume. EPS products absorb some water during extremely wet conditions, but 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 considering the data at 15 years. The average water absorption of the XPS data collection is 2.6% by volume with a range of 0.0 to 6.3% by volume. The data demonstrates the initial water absorption of XPS is low, but over time water accumulates in the XPS.



It is notable that the average results in Figure 7 are lower than data published by The Dow Chemical Co.<sup>27</sup>, where it appeared that the water absorption for XPS is higher in long-term highway applications as shown in Figure 8.



**Figure 8. Water Absorption of XPS over time in North American Highway Installations<sup>27</sup>**

Based on the analysis of the North American data, it is reasonable to approximate the long-term moisture absorption for both EPS and XPS in below-grade building applications at 3% by volume. It is reasonable to anticipate that water absorption is negligible in a properly installed wall or roof assembly. The combination of water absorption by volume along with equation 1 can be used to determine  $F_{H_2O}$  in Table 7.

Equation 1 
$$F_{H_2O} = 1/e^{(a \cdot \text{Moisture vol}\%)}$$

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

Application	ASTM C578 Material Type	
	EPS	XPS
Below-grade applications	3% by volume	3% by volume
$F_{H2O}$	0.89	0.93
Above-grade wall applications	0% by volume	0% by volume
$F_{H2O}$	1.0	1.0
Roof applications	0% by volume	0% by volume
$F_{H2O}$	1.0	1.0

**Table 7. Application Moisture Absorption and  $F_{H2O}$  of EPS and XPS**

## Effective R-value Adjustment Examples

The adjustment factors for aging, temperature, and moisture can now be used to predict the effective R-value,  $R_{EFFECTIVE}$ , in various applications where  $R_{LAB}$  is determined from ASTM C578 values at 75°F (24°C).

Equation 2 
$$R_{EFFECTIVE} = R_{LAB} \times F_{AGE} \times F_{TEMP} \times F_{H2O}$$

### Example 1

Effective R-value in long-term (50-year), above-grade wall applications for a summer condition with an outside temperature of 105°F (40°C) and an interior temperature of 75°F (24°C). The mean temperature will be  $(105°F + 75°F)/2 = 90°F$  [ $(40°C + 24°C)/2 = 32°C$ ].

Equation Term	ASTM C578 Material Type					
	EPS			XPS		
	II		IX		X, IV	
	R-value	RSI	R-value	RSI	R-value	RSI
$R_{LAB}$ (TABLE 1)	4.0	0.70	4.2	0.74	5.0	0.88
$F_{AGE}$ (Table 4)	1.0	1.0	1.0	1.0	0.86	0.86
$F_{TEMP}$ (TABLE 6)	0.96	0.96	0.97	0.97	0.97	0.97
$F_{H2O}$ (Table 7)	1.0	1.0	1.0	1.0	1.0	1.0
<b><math>R_{EFF}</math></b>	<b>3.8</b>	<b>0.67</b>	<b>4.1</b>	<b>0.72</b>	<b>4.2</b>	<b>0.73</b>
% Change	-4%		-3%		-16%	

**Table 8.  $R_{EFFECTIVE}$  for Long-term, Above-grade Summer Wall Application of EPS and XPS**

## Example 2

Effective R-value in long-term (50-year), above-grade wall applications for a winter condition with an outside temperature of 5°F (-15°C) and an interior temperature of 75°F (24°C). The mean temperature will be  $(5^{\circ}\text{F} + 75^{\circ}\text{F})/2 = 40^{\circ}\text{F}$  [ $(-15^{\circ}\text{C} + 24^{\circ}\text{C})/2 = 4.5^{\circ}\text{C}$ ].

Equation Term	ASTM C578 Material Type					
	EPS				XPS	
	II		IX		X, IV	
	R-value	RSI	R-value	RSI	R-value	RSI
$R_{\text{LAB}}$ (TABLE 1)	4.0	0.70	4.2	0.74	5.0	0.88
$F_{\text{AGE}}$ (Table 4)	1.0	1.0	1.0	1.0	0.86	0.86
$F_{\text{TEMP}}$ (TABLE 6)	1.10	1.10	1.10	1.10	1.08	1.08
$F_{\text{H}_2\text{O}}$ (Table 7)	1.0	1.0	1.0	1.0	1.0	1.0
<b><math>R_{\text{EFF}}</math></b>	<b>4.4</b>	<b>0.77</b>	<b>4.6</b>	<b>0.81</b>	<b>4.6</b>	<b>0.82</b>
% Change	+10%		+10%		-7%	

**Table 9.  $R_{\text{EFFECTIVE}}$  for Long-term, Above-grade Winter Wall Application of EPS and XPS**

## Example 3

Effective R-value in long-term (50-year), below-grade wall applications with a ground temperature of 50°F (10°C) and an interior temperature of 70°F (22°C). The mean temperature will be  $(50^{\circ}\text{F} + 70^{\circ}\text{F})/2 = 60^{\circ}\text{F}$  [ $(10^{\circ}\text{C} + 22^{\circ}\text{C})/2 = 16^{\circ}\text{C}$ ].

Equation Term	ASTM C578 Material Type					
	EPS				XPS	
	II		IX		X, IV	
	R-value	RSI	R-value	RSI	R-value	RSI
$R_{\text{LAB}}$ (TABLE 1)	4.0	0.70	4.2	0.74	5.0	0.88
$F_{\text{AGE}}$ (Table 4)	1.0	1.0	1.0	1.0	0.86	0.86
$F_{\text{TEMP}}$ (TABLE 6)	1.05	1.05	1.05	1.05	1.04	1.04
$F_{\text{H}_2\text{O}}$ (Table 7)	0.89	0.93	0.89	0.89	0.93	0.93
<b><math>R_{\text{EFF}}</math></b>	<b>3.7</b>	<b>0.65</b>	<b>3.9</b>	<b>0.69</b>	<b>4.1</b>	<b>0.73</b>
% Change	-7%		-7%		-17%	

**Table 10.  $R_{\text{EFFECTIVE}}$  for Long-term, Below-grade Wall Application of EPS and XPS**

## Summary

Building insulations are subjected to a wide range of temperatures and moisture conditions during their service life. It is important that R-values are maintained 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 age, temperature, and moisture on both EPS and XPS, the following conclusions were apparent:

- The R-value for EPS is constant over time, but the R-value for XPS decreases by approximately 14% over 50 years.
- The R-value for EPS and XPS increases as the mean temperature decreases below 75°F (24°C). At a mean temperature of 40°F (4°C), the R-values for EPS and XPS increase by approximately 10%.
- The R-values for both EPS and XPS decrease by approximately 10% due to water absorption of 3% by volume in below-grade applications.

A methodology was provided to calculate the effective R-value for specific building applications when a detailed analysis is desired. An example of above-grade summer walls was shown with a reduction in R-value for EPS of 3-4% and a reduction in R-value for XPS of 16%. An example of above-grade winter walls was shown with an increase in R-value for EPS of 10% and a reduction in R-value for XPS of 7%. An example of below-grade walls was shown with a 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.

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