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Selecting Polystyrene Foam Where Moisture Exposure Occurs

by John Woestman

Photo courtesy Kingspan

The purpose of building insulation is to reduce heating and cooling energy consumption, contribute to durability, and provide comfort for occupants. However, there are numerous locations where significant exposure to moisture—which severely affects a material's thermal performance—occurs, such as in protected membrane roofs, vegetative assemblies, below grade, and frost-protected shallow foundations (FPSFs). Polystyrene foam insulation has unique properties differentiating it from other such materials, making it a suitable choice for such applications.

When specifying polystyrene foam insulation for building applications where exposure to moisture is expected, it is important to understand ASTM C578, *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*. This industry standard lists all polystyrene foam insulation types, defining the minimum physical properties for each. Both extruded polystyrene (XPS) and expanded polystyrene (EPS) foam insulation are represented, as shown in Figure 1.

Figure 1

	XPS					EPS					
TYPE (PER ASTM C578)	**X**	**IV**	**VI**	**VII**	**V**	**I**	**VIII**	**II**	**IX**	**XIV**	**XV**
Minimum thermal resistance for 1 in. thickness ([F sf h/Btu] at 75 F) *ASTM C518*	5	5	5	5	5	3.6	3.8	4	4.2	4.2	4.3
Minimum compressive resistance at 10% or yield (psi) *ASTM D1621*	15	25	40	60	100	10	13	15	25	40	60
Maximum water absorption (by volume) *ASTM C272*	0.3%	0.3%	0.3%	0.3%	0.3%	4%	3%	3%	2%	2%	2%
Minimum density (pcf) *ASTM D1622*	1.3	1.45	1.8	2.2	3	0.9	1.15	1.35	1.8	2.4	3

Key properties listed in ASTM C578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation.

There are important differences between the different offerings of XPS and EPS insulations. The former is available in Types IV, V, VI, VII, and X, all with minimum R-values of 5.0 per inch, and minimum compressive strengths ranging from 104 to 690 kPa (15 to 100 psi). EPS, on the other hand, comes in Types I, II, VIII, IV, XIV, and XV, with minimum R-values ranging from 3.6 to 4.3 per inch, and minimum compressive strengths ranging from 69 to 414 kPa (10 to 60 psi).

ASTM C578 requires XPS insulation allow no more than 0.3 percent water absorption (by volume), whereas EPS must allow no more than two to four percent water absorption (by volume), depending on the material type—this is six to 13 times more than XPS. This is because there are fundamental differences between the properties of XPS and EPS that are critical to understanding which material to specify for applications requiring high resistance to moisture intrusion.

XPS is manufactured through an extrusion process. Essentially, a molten material is extruded through a die where it expands into a uniform closed-cell rigid foam insulation board with no voids or pathways for moisture to enter. EPS is manufactured with small foam beads placed in a mold and steam-expanded into a large form from which foam boards are cut. This method of manufacture can result in interconnected voices between the beads that can provide pathways for water to penetrate into the insulation. The water-resistance specifications for XPS and EPS in ASTM C578 are reflective of the physical structures of the two materials (Figure 2).

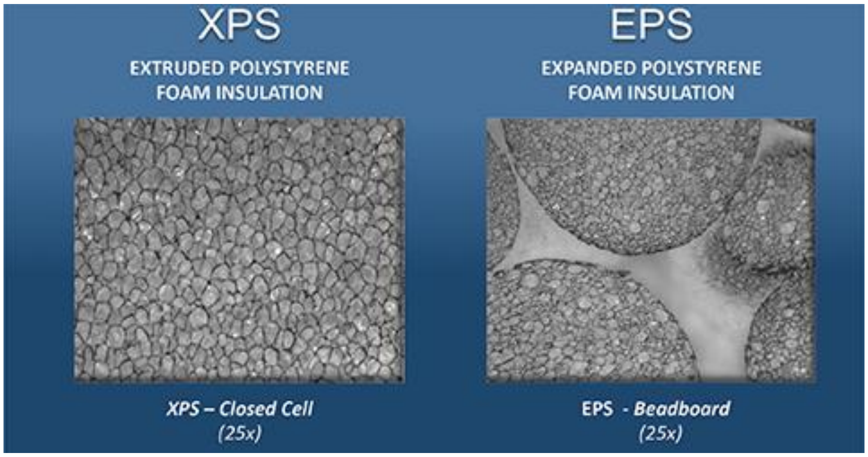

Figure 2: *Cellular structure differences between extruded and expanded polystyrene (XPS and EPS) foam insulations. Images courtesy XPSA*

Why is moisture absorption resistance important? Water is an excellent conductor of heat—a fact illustrated by how people tend to feel cold (or at least cool off) when they get wet. This is the same concept with a building where the insulation absorbs moisture—any moisture absorbed by insulation can degrade that material’s R-value, negatively affecting energy savings and the comfort of those inside the building.

Insulation for roofs

A protected membrane roof (PMR) is an assembly that is designed with the waterproofing membrane installed on the roof deck, and the insulation and ballast installed atop the membrane. In this configuration, the insulation and ballast protect the roof membrane from environmental exposures and physical damage. Consequently, insulation used above the membrane must have superior moisture resistance and durability. For such applications, the moisture-resistive properties of XPS often make it a suitable choice when specifying foam insulation to protect the roof.

Commonly designed as in this PMR setup, vegetative roofs are becoming more common because of their environmental benefits. There are two basic types of these green roofs—extensive and intensive—differing in terms of cost, depth of growing media, and choice of plants.

An example of an application for XPS include within vegetated roofing assemblies. Photo courtesy Owens Coming

Extensive roof cover media varies in depth between 50 and 150 mm (2 and 6 in.), with a weight increase of between 78 to 171 kg/m²(16 to 35 lb/sf) when saturated. Intensive vegetative roof cover media varies in depth between 200 and 600 mm (8 and 24 in.), with a weight increase to 293 to 976 kg/m² (60 to 200 lb/sf) when saturated.

Vegetative roofs provide a thermal mass effect, which in turn saves energy and provides reduced heating and cooling costs. Other benefits include reduced water runoff, extended useful life of the roof (due to reduced exposure of the membrane to harmful ultraviolet [UV] light and weather), and added beauty and usable space.

Among the many sustainability objectives of a vegetative roof, the most critical are retaining water and reducing stormwater discharge, and conserving energy through the cooling and shading of soil and plantings. This reduces heat flow into a building, lowering the load placed on air-conditioning equipment.

Long-term exposure to moisture makes it imperative the insulation of vegetative roof systems retains R-value, possesses adequate compressive strength, and provides other critical properties while exposed to water. For that reason, XPS is almost exclusively used to insulate vegetative roofs.

When specifying, selection may be from ASTM C578 Type VI (276 kPa [40 psi]), Type VII (414 kPa [60 psi]), or Type V (690 kPa [100 psi]) XPS to best fit the roof's design requirements. The material is also durable, making it reusable when removal and reinstallation are needed for maintenance or for repairs to the membrane. For all these characteristics, XPS is typically the only insulation recommended for vegetative roofs where the assembly requires insulation above the waterproofing membrane.

Below-grade applications

The most efficient way to insulate a building foundation is with continuous insulation around the exterior. Moisture resistance is important because precipitation eventually finds its way to the foundation. Since soil holds different amount of moisture, the insulation's moisture resistance is important for energy savings and interior comfort for occupants. Providing drainage does not always negate the need for moisture-resistant insulation.

Insulations used in the foundation application must also withstand significant abuse during the backfilling. The protection the foam insulation provides to the foundation waterproofing membrane during this operation is also important. Foundation insulation must have superior durability and be able to withstand the soil's lateral compressive forces that depend on:

- depth to which the insulation is used;
- soil type; and
- potential for live loads (*e.g.* pedestrians or vehicles).

It is also important to select the appropriate ASTM C578 type based on the required compressive strength satisfying the application's needs. Industry experience has shown XPS to provide superior performance in the exterior foundation insulation application.

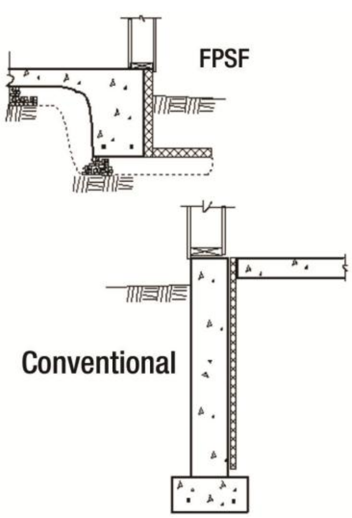

Figure 3: *At the top left, a frost-protected shallow foundation (FPSF); at bottom right, a typical foundation. Image courtesy U.S. Department of Housing and Urban Development*

Frost-protected shallow foundations

In FPSF designs, foam insulation is positioned around the foundation to prevent frost from developing below the foundation wall and footer. Figure 3 illustrates a typical frost-protected shallow foundation compared to a conventional foundation.

During cold weather, frost in the soil leads to the formation of ice lenses that grow, expand, and heave the ground upward. Mild weather thaws the soil and the ice lenses melt and the soil above them sinks. This freeze-thaw cycling causes frost-heave damage to footings, foundations, slabs, and pavement.

For buildings constructed on frost-protected shallow foundations, structural performance greatly depends on the long-term thermal performance of the foundation insulation. FPSFs must be designed with insulation considering the appropriate long-term effective R-values that account for the detrimental effects of moisture absorption, because performance deficiencies can result in more than just higher energy costs and comfort issues.

To maintain the building's structural integrity (and to reduce heating energy consumption), the FPSF insulation must prevent the soil under the foundation from freezing for the life of the building. Therefore, it is important to know the insulation's thermal performance and moisture-resistance properties, along with the long-term effective R-value in these demanding below-grade environments.

The industry-accepted method for FPSF design and construction in climates with seasonal ground freezing is American Society of Civil Engineers (ASCE) 32-01, *Design and Construction of Frost-protected Shallow Foundations*. This standard provides shallow foundation design principles, specific insulation design methods, and—importantly—long-term design R-values for XPS and EPS foam insulations.

The committee responsible for developing that standard completed a comprehensive, objective, and critical review of the in-service thermal performance of XPS and EPS in below-grade applications. The resulting ASCE 32-01 establishes long-term design R-values for both XPS insulation and EPS insulation for FPSFs based on analysis of internationally available research data.

Retention of R-values After Long-Term Exposure in Below-Grade Applications

(ASCE 32-01 values as a % of ASTM C578 R-values)

	Vertical orientation below-grade	Horizontal orientation below-grade
XPS (Represented in ASTM C578 Types X, IV, VI, VII, and V)	90%	80-81%
EPS (Represented in ASTM C578 Types II, IX, XIV*, and XV*)	80%	65-67%

EPS Type XIV and XV are more recent additions to the ASTM C578 standard and are included in the chart for purposes of completeness. The design R-values shown are consistent with the treatment of EPS Types II and IX in the ASCE 32-01 standard.

Figure 4: *Retention of R-values after long-term exposure in below-grade applications is shown here.*

The long-term effective R-value guidelines are grouped into XPS and EPS insulations because of the higher moisture absorption resistance of XPS and the somewhat lower moisture absorption resistance of EPS. The Standard Committee established long-term design R-value guidelines for XPS and EPS insulation installed vertically or installed horizontally for FPSFs due to moisture exposure differences of the two orientations.

For XPS in vertical installations, such as at the perimeter of a concrete slab foundation, the long-term design R-value listed in ASCE 32 is 90 percent of the ASTM C578 minimum R-value specification. The long-term design R-value listed in ASCE 32 for EPS depends on the product Type (for EPS, R-value varies by type), but is 80 percent of the ASTM C578 minimum R-value specification for that product.

When it comes to horizontal installation orientations (*e.g.* the FPSF's 'wing' insulation), the long-term design R-value listed in ASCE 32 for XPS is 80 percent of the ASTM C578 minimum R-value specification. In this instance, the long-term design R-value of EPS listed in ASCE 32 is 67 percent of the ASTM C578 minimum R-value specification for that type of EPS (Figure 4).

The long-term effective R-value guidelines for XPS and EPS insulations listed in ASCE 32 are shown in Figure 5. The tallest set of bars in the back of the chart illustrates the minimum R-value per inch as required by ASTM C578 for XPS (right-hand bars) and EPS (left-hand bars). The lighter gray, mid-height bars in the middle row of the chart represent the long-term design R-value in exterior below-grade vertically oriented FPSF applications, while the darkest gray or shortest bars in front of the chart represent the design R-value (per inch) for exterior below-grade horizontally oriented FPSF applications.

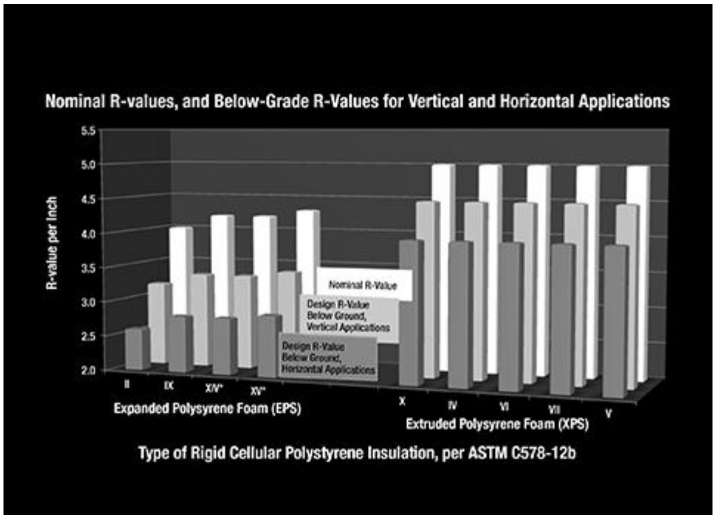

Figure 5: *Based on data published in American Society of Civil Engineers (ASCE) 32-01, Design and Construction of Frost-protected Shallow Foundations, this chart shows the design R-values for XPS and EPS insulation in FPSFs. Image courtesy XPSA*

Sustainability considerations

Due to the thermoplastic nature of XPS insulation, virtually 100 percent of all in-plant scrap is recycled and reused in the primary extrusion process. Additionally, the XPS production process uses post-consumer and post-industrial recycled and/or recovered polystyrene foam. Generally, XPS manufacturers employ up to 30 percent recycled polystyrene in the production of XPS.

Remarkably durable and water-resistant, XPS insulation can find multiple 'lives' in many situations. In commercial roofing applications, XPS insulation is often reused when a new roofing membrane is installed, saving the cost of both replacement insulation and hauling removed insulation to the landfill.

Conclusion

Vegetative roofs and below-grade applications present a challenging environment for insulations because of the exposure to moisture and compressive loading. Polystyrene foam insulation products are available in a wide range of R-value per inch, compressive strengths, and moisture absorption resistance to meet these challenging below-grade insulation requirements, but it is important to remember there are fundamental and important differences between XPS and EPS.

When considering the two materials for applications where moisture absorption resistance is critical, it is important to select the appropriate ASTM C578 type of XPS or EPS based on thermal performance, compressive strength, durability, and moisture absorption resistance. It is also important to specify the appropriate insulation thickness based on ASTM C578 minimum R-value specifications and with consideration given to long-term thermal performance.

John Woestman is director of codes and standards for the Extruded Polystyrene Foam Association (XPSA). He has more than 25 years of experience in the construction and building products industry with various responsibilities in construction, manufacturing, human resources, marketing, and codes, standards, and regulations. Woestman has a diploma in building trades, a degree in mechanical engineering, and an MBA. He is a member of the International Code Council (ICC), ASTM, and the National Fire Prevention Association (NFPA). Woestman can be reached at jwoestman@xpsa.com.