For Foam Plastic Insulation, Extrusion Matters
Performance Equals Resisting Water
XPS Performs Better Than EPS

Technical Bulletin

Polystyrene Insulation Types

There are two types of rigid polystyrene foam plastic insulation, extruded (XPS), and expanded (EPS).

- XPS is manufactured in a continuous extrusion process that produces a homogeneous closed cell cross section (Fig 1).
- EPS is manufactured by expanding spherical beads in a mold, using heat and pressure to fuse the beads together where they touch, leaving open spaces between the beads where they don't touch (Fig. 2).

Although both types are comprised of polystyrene, the two types of manufacturing processes produce finished products with very different performance properties. Of the two types, EPS absorbs more water in laboratory tests and in application resulting in reduced performance. This bulletin explains the important difference between XPS and EPS and demonstrates that extrusion matters.

AASHTO M230, ASTM D6817 and ASTM C578: Water Absorption Differences in XPS and EPS

These widely used industry standards define rigid polystyrene insulation. The standards are the basis of design for a variety of construction insulation applications for both building and geo-technical polystyrene foam or "geofoam".

Both XPS and EPS are manufactured to meet the physical property specifications in ASTM C578[1], ASTM D6871[5] and AASHTO M230[2]. For any type of construction it is important that the rigid insulation chosen for use possess properties that are suitable for the application. That is particularly critical when rigid insulation will be exposed to water as in protected membrane roofing, or below grade uses including foundations, frost protected shallow foundations, and geotechnical applications such as under pavement and lightweight fill replacement.

The most important difference between EPS and XPS is the amount of water absorbed by each. Although some EPS manufacturers attempt to disguise it, EPS absorbs more water than XPS. Absorbed water results in lost insulation power (R-value). Lost R-value results in reduced performance. The industry standards separate EPS and XPS types so that important physical property differences like water absorption can be identified for specifications purposes. See Table 1.

Table 1

Water Absorption as Defined by Industry Standards (volume %)			
	XPS	EPS	Difference
ASTM C578	0.3	3.0 to 4.0	10 -13 X
AASHTO M230	0.3	3.0	10 X
ASTM D6817	Does not address water absorption or thermal performance		

Resisting Water Absorption is Critical for High Performance Insulation

Over the lifetime of a building or paved surface water gets into, and lingers in, the soil around the construction. Therefore, where the purpose of the insulation is to insulate, the most important characteristic of the insulation is its ability to retain R-value and continue to insulate even when exposed to water for long periods of time. Water is an excellent conductor of heat, so if insulation is water soaked, R-value is lost. If absorbed water freezes and thaws the insulation structure will breakdown over time and structural integrity can be compromised.

There are two keys to resisting water absorption:

- The plastic itself must be hydrophobic (repels water), not hydrophilic (attracts water), and,
- The cell structure must be continuous and closed.

What Closed Cell Means

Some specifications are written to require compliance with AASHTO M230 "except the extrusion process is not required…". Actually, the extrusion process is the most important difference between EPS and XPS and it results in one of the most important performance differences which is water absorption.

Both XPS and EPS are manufactured using polystyrene which is a hydrophobic polymer that repels water. The big difference that causes EPS to absorb more water than XPS is a result of the manufacturing process. The XPS continuous extrusion process produces a homogeneous "closed cell" matrix with each cell fully enclosed by polystyrene walls. The EPS bead molding process, although individual beads are closed cell, leaves open voids between beads where water enters.

Figure 1: Extruded Polystyrene Cell Structure

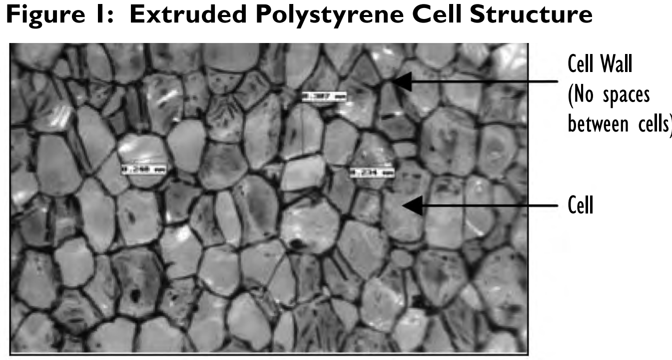
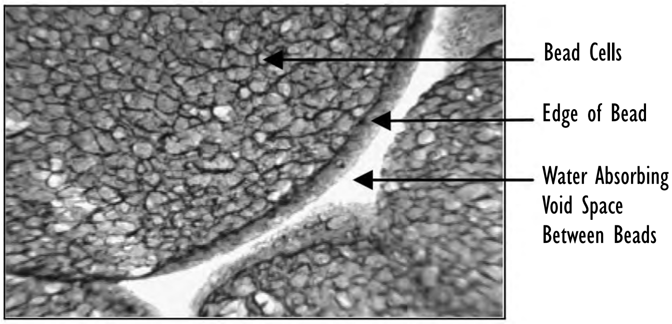


Figure 2: Expanded Polystyrene Cell Structure

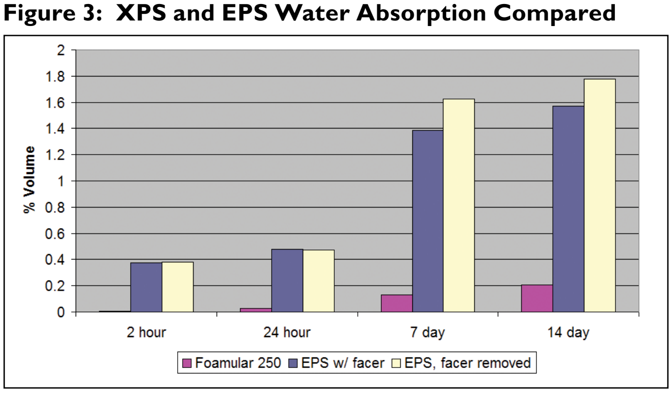


Compare XPS (Fig. 1) to EPS (Fig. 2). Because of the homogeneous cross section of XPS, very little water is absorbed into the cell structure. "Closed cell" means very little R-value reducing water will be absorbed into the insulation board. The XPS extrusion process produces that closed cell structure. The EPS expansion process does not, therefore, EPS should be considered an open void structure.

Closed Cell versus Open Cell: The Impact on Water Absorption

Both ASTM C578 and AASHTO M230 require that polystyrene insulation be tested for water absorption in accordance with ASTM C272[3]. C272 requires the sample to be fully immersed in water for 24 hours, and weighed immediately upon removal from immersion to determine the amount of absorbed water. Figure 3 shows the dramatically higher EPS water absorption rate when tested in accordance with the industry mandated standard.

Figure 3: XPS and EPS Water Absorption Compared



Tested in accordance with ASTM C272

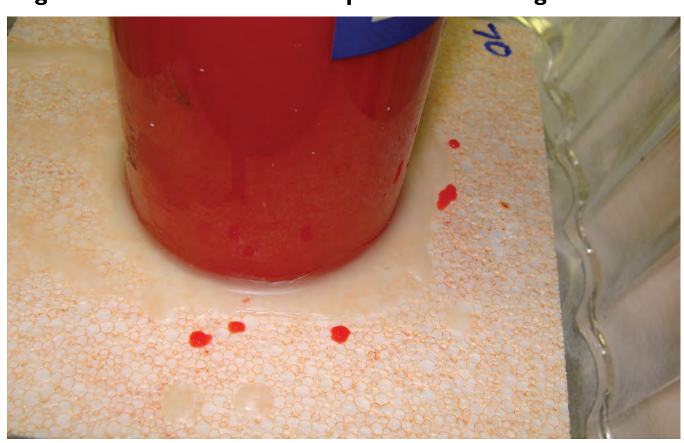
EPS Water Absorption via Capillary Action and Wicking

Although industry standards require that water absorption be measured after full immersion, what happens if EPS boards are not fully immersed? What happens if only a partial area of EPS insulation is exposed to water? The answer is, EPS wicks water into its open void structure even when only a small surface area is exposed to water.

To demonstrate, columns of colored water were sealed over a small surface area of three different densities of EPS (See Fig. 4a). With only a small surface area of EPS exposed to the water column, the colored water traveled by capillary action through voids in the EPS then wicked throughout the entire sample (See Fig. 4b). Using the same method, FOAMULAR® XPS showed no water movement into or through its closed cell structure neither by capillary action nor wicking. This demonstration shows the important water absorption differences that result from the EPS bead expansion process compared to the XPS extrusion process.

Figure 4a: EPS Water Absorption via Wicking

Figure 4b: EPS Water Absorption via Wicking

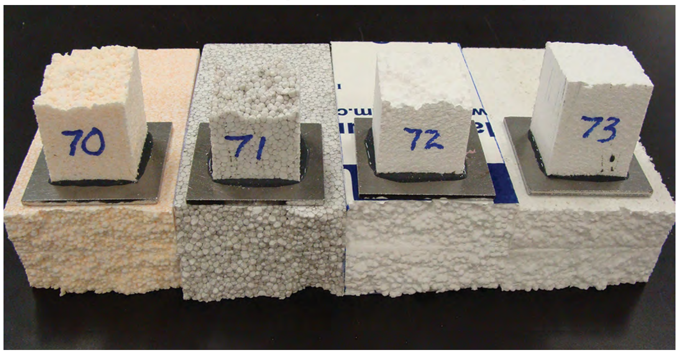


The Effect of Water Absorption on R-Value

It has been demonstrated that EPS absorbs significantly more water than XPS. Although the individual beads of EPS are closed cell, the voids between the beads absorb significant amounts of water, which reduces the already lower in-service R-value of EPS compared to XPS. How much R-value does EPS lose after it absorbs water?

To measure R-value after water absorption samples of EPS were half-submerged in a tray of water for three weeks. (See EPS representative samples in Fig. 5. Tested samples were the standard size for thermal testing, 12 x 12.)

Figure 5: EPS Water Absorption and R-Value Samples



EPS Sample ID: Sample 70 is ASTM C578 Type II, density 1.64 pcf; 71 was identified as Type IX by its manufacturer, but measured 1.62 pcf which is a high density version of Type II; 72 is Type XIV, 2.55 pcf; 73 is Type XV, 2.71 pcf

The samples were periodically removed from the water tray and weighed to determine the amount of water absorbed, and to measure the R-value of the wet EPS sample. For each EPS sample the results show significant water absorption during the first week, continuing water absorption in subsequent weeks, and a corresponding loss of R-value due to the intrusion of highly conductive water into the open voids of the EPS. In three of the four EPS samples note that over the extended test time the amount of water absorbed exceeded the maximum allowed by industry standards. This demonstrates that long term exposure to water and the resulting absorption is a concern regardless of manufacturer claims to the contrary. (See Figures 6a through 6d)

Figure 6: EPS Water Absorption and R-Value Loss

Fig. 6a: EPS Type II, ASTM C578 (Sample 70)

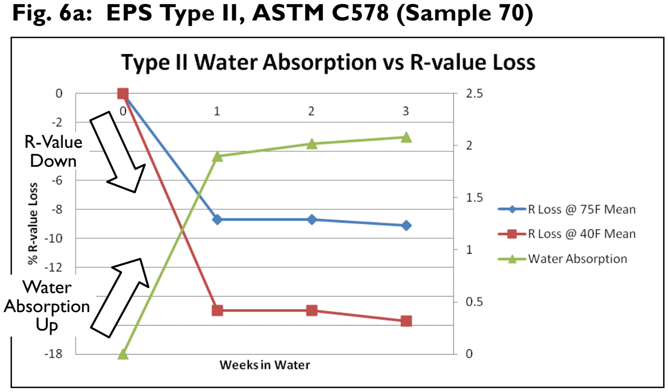


Fig. 6b: EPS Type IX, ASTM C578 (Sample 71)

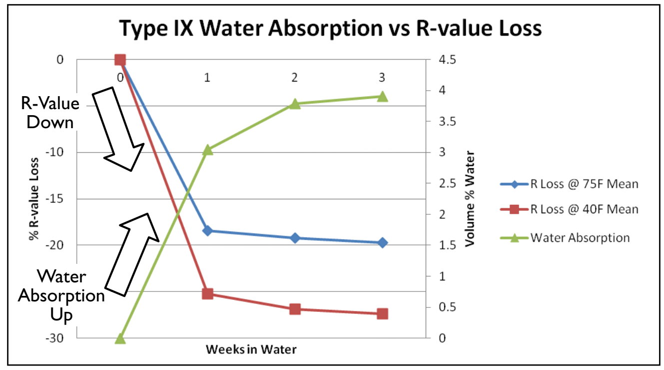


Fig. 6c: EPS Type XIV, ASTM C578 (Sample 72)

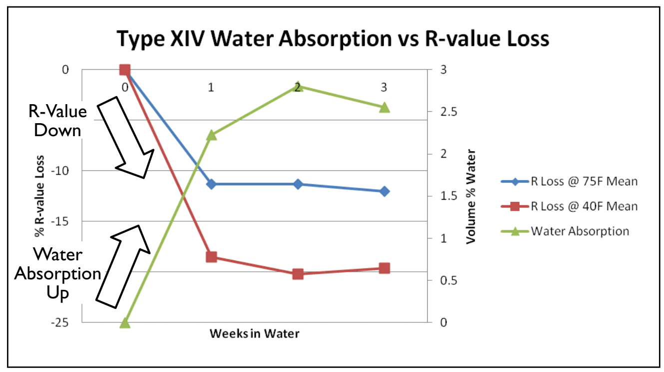


Fig. 6d: EPS Type XV, ASTM C578 (Sample 73)

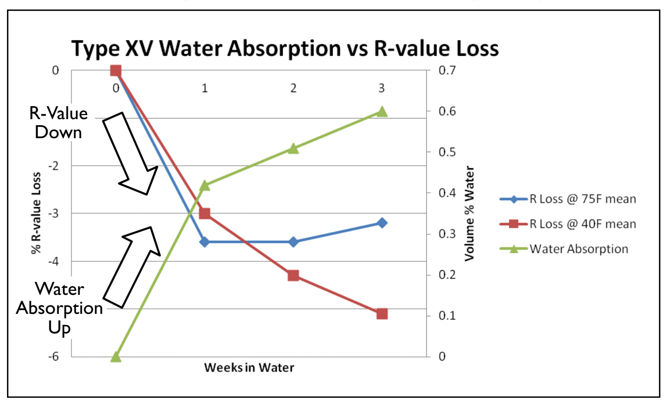
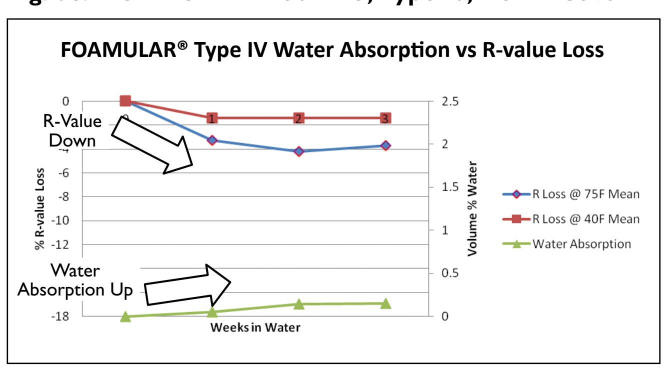


Fig. 6e: FOAMULAR® 250 XPS, Type IV, ASTM C578



Using the same test procedure FOAMULAR® 250 XPS shows minimal water absorption and minimal loss of R-value. (Fig. 6e)

EPS has a Lower R-Value than XPS

As demonstrated, when EPS absorbs water it loses R-value. It must also be noted that dry EPS begins with a lower R-value than XPS. When wetted, the R-value of EPS is even lower making the differences even greater. Dry EPS R-value ranges from 3.1 to 4.3 R per inch depending on density. EPS R-value per inch varies with density because the higher the density, the smaller the open void air spaces between beads, which results in a slightly higher R-value. XPS is a uniform R 5 per inch regardless of density because the XPS cell structure is closed resulting in a uniform and reliable R-value.

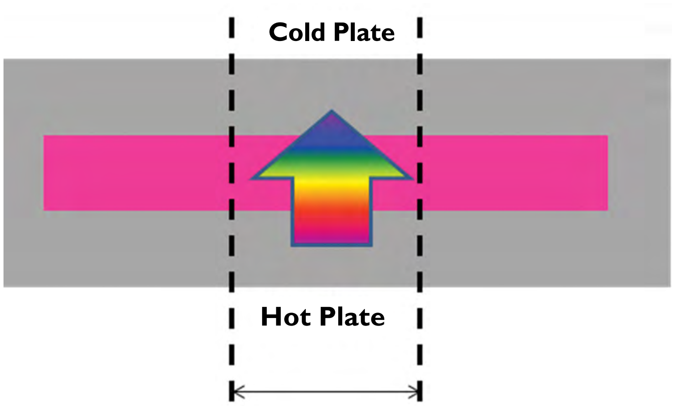
Confusing R-Value Claims Comparing XPS and EPS

EPS manufacturers sometimes make R-value claims based on measurements made a lower mean temperature. They do so in part to make a more favorable comparison to XPS.

Nearly all materials have a lower conductivity rate at a lower mean temperature. This is true for XPS and EPS. However, it is not true for water. More about that later.

R-value for rigid insulation board is typically measured in accordance with ASTM C518[4]. The test places a foam board sample horizontally between two parallel plates, one "hot", one "cold", and at consistent but different temperatures. (See Fig. 7)

Figure 7: R-Value Measurement, ASTM C518



R-value is measured through the center section of the sample

"R-value" is reported based on the mean temperature of the two plates. Generally, the lower the mean temperature, the higher the R-value due to slower heat transfer occurring as the mean temperature gets colder.

Better R at Lower Mean Temperature? Not Always.

The phenomenon of "lower mean temperature, higher R-value" generally holds true for all insulation products unless water is absorbed into the sample. Water is one of a few materials for which thermal resistance gets worse rather than better when it gets colder. When the insulation boards are dry, free of absorbed water, EPS and XPS R-values get higher as the mean temperature gets colder. However, when EPS absorbs water, its R-value actually decreases or, goes lower. Re-examine Figures 6a through 6d and see that wet EPS has more R-value loss at 40°F mean temperature compared to the loss at 75°F mean temperature.

Re-examine Fig. 6e and see that the R-value for wetted XPS at 40°F mean temperature remains higher than the R-value at 75°F mean temperature. Why? Because of the dramatically lower water absorption rate of XPS. The XPS absorbed virtually no water.

R-Value Warranty Claims, EPS versus XPS

Warranties are often another confusing point when comparing R-value claims. Some EPS manufacturers claim their product has an R-value that is comparable to XPS. The EPS claims are based on EPS achieving and retaining 100 percent of claimed R, and, based on it never getting wet. Table 2 shows the warranted R-value comparison that is always based on dry insulation.

Data presented in this bulletin shows that EPS gets wet and loses R. Therefore, the shaded columns in Table 2, although not claimed in warranties, show what the R-value claims might be if they were based on real in-service wet conditions. In real applications, particularly below grade, insulation gets wet. Recognition of real world conditions is important when assessing performance.

Table 2

Warranted R-Value Comparison (at 75°F mean temperature)				
	Published R	Dry R Warranty	Wet R	Wet R Warranty
FOAMULAR® XPS	5.0	90% = 4.5	4.92	90% = 4.43
EPS (2.4 pcf)	4.2	100% = 4.2	3.36	100% = 3.36

Notes: Lower density EPS will have a lower R than shown in this table. Shaded columns are not based on actual warranty claims, but are projections of what warranty claims might be if actual in-service wetting was considered.

EPS warranted R-value per inch varies from 3.1(ASTM C578 Type XI) to 4.3 (Type XV). EPS warranties are sometimes prorated with dollar value coverage diminishing as the warranty progresses toward termination. Others invalidate warranty coverage if water absorption exceeds 3 percent. None address the reduced EPS R-value that results from in-service water absorption.

Water Absorption in Actual Below Grade Contact

Although laboratory test data enables controlled and repeatable product comparisons between EPS and XPS, it is useful to conduct ad-hoc ground contact experiments to verify the real differences that are exposed by laboratory testing.

As explained in this bulletin, lab data repeatedly demonstrates that EPS absorbs more water than XPS. To further verify, a limited scope ground contact study was conducted using multiple samples of EPS and FOAMULAR® XPS buried in an outdoor 12" deep trench. The samples were exposed to the ambient ground water in an otherwise unremarkable commercial building yard condition. During the three week study one sample per week was removed from the trench and weighed to determine the amount water absorbed. The results (Table 3) show that the EPS samples of different densities immediately absorbed ground water at varying rates while the XPS sample absorbed virtually no water during the study.

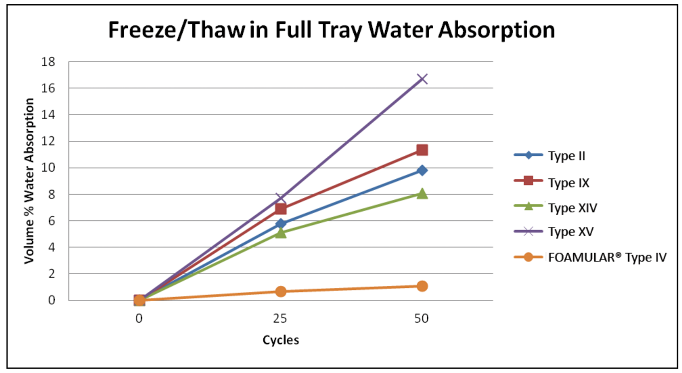
Table 3

Water Absorption, Limited Ground Contact				
	Density (pcf)	Water Absorption (% vol)		
Sample		**Week 1**	**Week 2**	**Week 3**
EPS	1.62	1.77	3.50	3.57
EPS	2.71	0.86	0.65	0.88
FOAMULAR® 250	1.60	0.0	0.0	0.0

Freeze-Thaw Cycling Damages Wet Insulation

Below grade Insulation gets wet. Wet soil and insulation is often subjected to dozens if not hundreds of freeze-thaw cycles per winter season. Water expands when it freezes. When water is absorbed into the open void structure of EPS insulation it freezes and expands, breaking bonds between beads and opening the EPS structure to increasing amounts of water intrusion during the next cycle. More water absorbed during subsequent cycles results in increasingly greater expansion which leads to further reductions in R-value as the cycles continue over the life of the product. FOAMULAR® XPS maintains its closed cell structure, and maintains its resistance to water absorption even under punishing freeze-thaw cycling (See Fig. 8).

Figure 8: Water Absorption After Freeze-Thaw Cycling



Samples fully submerged in water during freezing and thawing.

EPS Sample ID: Sample 70 is ASTM C578 Type II, density 1.64 pcf; 71 was identified as Type IX by its manufacturer, but measured 1.62 pcf which is a high density version of Type II; 72 is Type XIV, 2.55 pcf; 73 is Type XV, 2.71 pcf

Extrusion Matters

Some highway specifications are written to say, *"Insulation Board shall be AASHTO M230, Type VI, except that extrusion is not required and the maximum water absorption by weight is 10%."*

As this paper explains the extrusion process results in a continuous and closed cell structure while the EPS molding process results in an open void structure. Specifying "Type IV" which is an extruded type, but not requiring the insulation to be extruded, forfeits the water resisting benefits of extruded.

This paper has also explained that EPS, an open void rigid insulation board, absorbs significant amounts of water that results in lost R-value. When absorbed water freezes and expands, EPS bead bonds break and open further resulting in increased water absorption and lost structural integrity.

When insulation R-value, and structural durability are important for your below grade, under pavement project, then water resistance is important. When water resistance is important, the extrusion process is important, because water gets into below grade/under pavement applications.

Water can migrate under pavement from above, and it can migrate through soil from below. Although soil moisture content varies seasonally, moisture is always present to some degree in soil. Among the reasons that projects have under pavement insulation is that the underlying soil is poorly drained or holds moisture, resulting in a high moisture content, thus making it, and the pavement above it, susceptible to freeze-thaw cycling/heaving. Dry soil is not as susceptible to freeze-thaw driven heaving because there is no/little water to freeze. Generally dry/well drained road bed conditions have little reason to insulate. However, where it is impractical/impossible to de-water/drain the existing soil bed (meaning poor soil conditions), the other option is to limit the freeze-thaw cycles by insulating. Insulation extends the time to freeze, and extends the time to thaw, thereby limiting cycling.

Another aspect of cold air and cold ground surface temperatures is that it "draws" the moisture to it. So, if there is water in the ground, it will migrate to the surface. Freezing of water in the "pores" of soil begins at grade level as heat is removed from the earth by flowing out of the soil to the cold air mass. As the heat flows, it takes with it moisture that eventually begins to freeze at the surface, forming a frozen impermeable ice lens. The ice lens builds as more heat/moisture flows to it.

An insulations ability to perform in these punishing conditions depends on its ability to effectively resist water absorption like XPS.

Ask Questions. Compare Properties.

This bulletin demonstrates the importance of asking questions to insure that published product claims are directly comparable. It is important to understand significant differences between the extrusion and the expansion process, and between closed cell and open void structure, and to ask about the differences and the claims.

FOAMULAR® Extruded Polystyrene Insulation

Owens Corning manufactures a complete line of FOAMULAR® Extruded Polystyrene Insulation (XPS) products for use in all types of geotechnical and building construction. Manufactured to meet ASTM C578, and AASHTO M230, the primary difference between FOAMULAR® XPS products is compressive strength. All FOAMULAR® products are water resistant, closed cell, extruded polystyrene. FOAMULAR® XPS has compressive strengths of 15, 25, 40, 60 and 100 psi. The variety of products provides different strengths for use in walls where there is almost no compressive load; or, intermediate strength product for use with modest loads such as around foundations, or in low slope roofs; or, high strength product suitable for use under high load pavement, floors or plaza decks. FOAMULAR® XPS products have an R-value of 5 per inch of thickness, and due to their closed cell structure they resist water absorption, maintaining a high R-value for reliable long term service.

Contact Owens Corning at 1-800-GET-PINK®, or visit www.OCBuildingSpec.com for more information.

References:

1. ASTM C578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation; ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959
2. AASHTO M230, Standard Specification for Extruded Foam Board (Polystyrene)
3. ASTM C272. Standard Test Method for Water Absorption of Core Materials for Sandwich Constructions
4. ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
5. ASTM D6817, Standard Specification for Rigid Cellular Polystyrene Geofoam

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Selecting Polystyrene Foam Where Moisture Exposure Occurs

Photo courtesy Kingspan

by John Woestman

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).

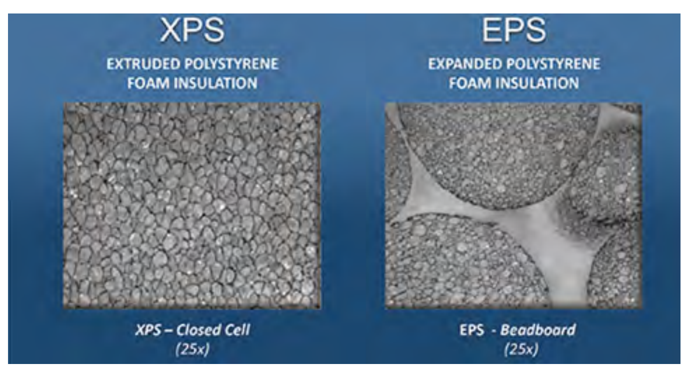

Figure 2: Cellular structure differences between extruded and expanded polystyrene (XPS and EPS) foam insulations. Images courtesy XPSA

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 Corning

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/m^2(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/m^2 (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.

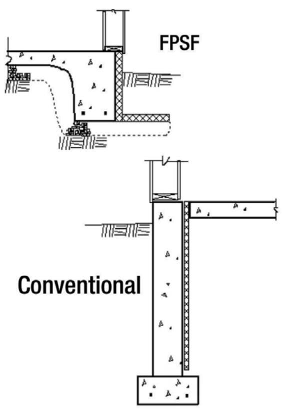

Figure 3: At the top left, a frost-protected shallow foundation (FPSF); at bottom right, a typical foundation.

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, VIII, 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).

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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.

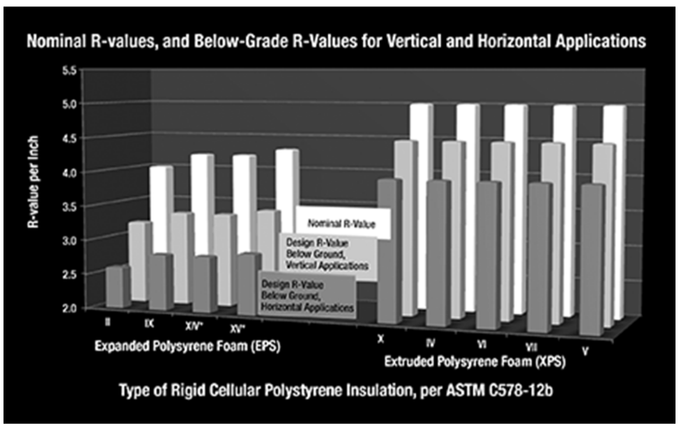

Figure 5: *Based on data published in American Society of Civil Engineers (ASCE) 32-01, Design and Construction of Frost-protected Shallow Foundations, this chart shows the design R-values for XPS and EPS insulation in FPSFs. Image courtesy XPSA*

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.

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Pub. No. 10018681-A. Printed in U.S.A. April 2015.