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TOPIC: Performance of EPS and XPS Insulation in Below-Ground Applications

PURPOSE: This Tech Talk Bulletin properly characterizes the relative performance of XPS and EPS for below-ground applications and is based on an independent-expert's review of state-of-the-art technical information [1].

ISSUE: While both EPS and XPS are approved for use in below-ground applications, they are not equal in their performance. The superior performance of XPS in below-ground applications is confirmed by and properly addressed in modern building code requirements, design standards, scientific literature, and practical experience. Yet, it is still possible to find marketing claims that deny or distort the body of scientific evidence using spurious sources of data or misleading interpretations.

BACKGROUND: Rigid cellular polystyrene (RCPS) foam insulations are recognized by their proven performance in moist, below-ground applications. These code-approved materials are manufactured with physical properties in accordance with ASTM C 578-08b and are used for a variety of below-ground applications including:

- Foundation insulation to meet building energy code requirements
- Frost-protection of building foundations, underground utilities, and infrastructure such as highways, bridge abutments, equipment support slabs, and retaining walls

There are two basic types of RCPS foam insulation: (1) Extruded Polystyrene (XPS) and (2) Expanded Polystyrene (EPS). While these products use a similar polymer feedstock (i.e., polystyrene), the differences in their respective manufacturing processes result in important differences in their thermal and physical properties as recognized in ASTM C 578. For example, extruded polystyrene is a homogeneous closed-cell foam that is highly impervious to moisture because expanding agents are used to create air bubbles in an otherwise solid mass of extruded polystyrene plastic. EPS foam is made from expanded "beads" of polystyrene that are bonded together under pressure and heat in a mold or form. During this process the beads are fused together as a function of heat, steam and pressure. In the U.S., EPS insulation products are made in large block molds (typically a minimum of 4' wide X 8' long) and then cut into boards of varying thickness using hot wire technology. This practice is important because the quality of the bead fusion can vary throughout the block or cut board. Fusion typically occurs best on the outside edge of the finished block (i.e., the sides in direct contact with the large vacuum mold) and lowest in the center. Depending on the EPS density and other factors, varying degrees of pathways between the beads allow moisture and air to readily enter (and leave) the product in response to surrounding moisture conditions.

In summary, the propensity to pick-up moisture and the distribution of moisture in a given piece of RCPS insulation are governed by (1) the physical properties of the insulation product and (2) the moisture exposure conditions experienced in below-ground applications.

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While the differences between XPS and EPS do not prevent either product from being used in below-ground applications, these differences must be properly understood to ensure appropriate use or specification. The following observations (or facts) elaborate on this concern:

FACT #1: The Building Code and ASCE 32-01 Recognize XPS Performs Better than EPS in Below-Ground Applications

The International Building Code (IBC) and International Residential Code (IRC) are the predominant model building codes used in the United States [2][3]. These codes rely on an American Society of Civil Engineers (ASCE) standard, known as ASCE 32-01 [4], to determine appropriate thermal properties of XPS and EPS insulation when used below-ground on building foundations for long-term protection against frost heave. This standard was developed by a balanced committee of engineers, researchers, builders, manufacturers, and government officials through an American National Standards Institute (ANSI) consensus process.

The commentary of the ASCE 32-01 standard describes the committee's work on below-ground insulation performance as follows:

> *"Insulation materials approved for use in the Standard are extruded or molded polystyrene foams with adequate densities. These materials have exhibited successful performance in moist, below-ground applications. Effective R-values per inch … are based on a survey of numerous studies of below-ground performance of polystyrene insulation materials. The values reported in Table A1 reflect the consensus judgment of the committee in reviewing the available data and the European practice. The effective thermal resistivity values (i.e., R-value per inch) apply to long term use in moist, below-ground conditions…."* [4, p33 – emphasis added]

As a result of the ASCE 32-01 committee's analysis, effective thermal resistivity (R per Inch) values for various types of EPS and XPS were determined as shown in Table 1. These values vary according to installation configurations of "vertical" or "horizontal". Vertical installation refers to application to foundation walls and horizontal refers to insulation laid horizontally in the ground. Both installation conditions are used to prevent heat loss from buildings and the ground and, thus, prevent frost damage when used in accordance with ASCE 32-01. These installation conditions also may be used as a means of meeting energy code requirements for building foundations. The horizontal application results in greater potential exposure to ground moisture depending on soil drainage conditions. Thus, in Table R403.3 (footnote e) of the IRC [3] an extra precaution was taken to only allow the use of XPS in horizontal applications.

TABLE 1
Design Values for FPSF Insulation Materials (based on ASCE 32-01)

Insulation Type per ASTM C578	Effective Resistivity (R per Inch)		Nominal "dry" Resistivity per ASTM C578 (R per Inch)	Ratio of Effective-to-Nominal Values	
	Vertical	Horizontal		Vertical	Horizontal
Expanded Polystyrene (EPS)					
Type II	3.2	2.6	4.0	80%	65%
Type IX	3.4	2.8	4.2	81%	67%
Extruded Polystyrene (XPS)					
Type X	4.5	4.0	5.0	90%	80%
Type IV	4.5	4.0	5.0	90%	80%
Type VI	4.5	4.0	5.0	90%	80%
Type VII	4.5	4.0	5.0	90%	80%
Type V	4.5	4.0	5.0	90%	80%

As seen in Table 1, EPS has an effective resistivity that is 80% and 65% of its nominal ("dry") thermal performance when used below ground for vertical and horizontal installations, respectively. For comparison purposes, XPS retains 90% and 80% of its nominal thermal performance. Again, both products can be used effectively with appropriate design values. But, it is clear that the ASCE 32-01 standard shows XPS to be superior to EPS in moist, below-ground applications. The basis for this difference, as confirmed in the scientific literature, is addressed next.

FACT #2: The Difference Between EPS and XPS Performance is Confirmed by the Body of Recognized Scientific Literature

As mentioned in Fact #1, the ASCE 32-01 committee considered "numerous studies" to (1) properly characterize differences in performance of XPS and EPS and (2) establish appropriate thermal design properties for below-ground use. Detailed findings from the scientific literature supporting the ASCE 32-01 committee's efforts are documented in a separate paper [1]. The following summarizes only the key findings from reliable and representative sources.

Ojanen and Kokko (1997) [5] – From a study of 14 different sites using EPS insulation with a below-ground exposure time ranging from 5 to 18 years, it was found that EPS will typically have a moisture content of 0.5 to 2.5% (volume basis) when soils are well drained. In two cases (not well drained soils), moisture contents of EPS exceeded 5% resulting in an R per inch of as low as 1.9 in comparison to a nominal ("dry") value of 4.2 R/in. However, under well-drained conditions EPS could be expected to have an R per inch of not less than 3.2. The value used in ASCE 32-01 is 2.6 R per Inch which accounts for uncertainty in soil drainage conditions in a manner consistent with the data presented by Ojanen and Kokko (1997).

Sandberg (1986) [6] – In well-drained highway subsoil conditions, horizontal EPS and XPS insulations (total of 24 different samples) were studied for moisture pick-up and thermal properties after an 8 to 16 year exposure time. The densities of these products were both high (greater than 2 lbs/ft^3). In this case, both EPS and XPS tended to pick-up similar amounts of moisture in the range of 2% by volume on average (with EPS slightly less). However, the distribution of moisture in the EPS material was more uniformly distributed through thickness whereas the moisture in the XPS was concentrated more toward the outer surfaces (a trend also reported by others). Thus, the thermal impact was less for XPS than EPS. The average observed thermal resistivity of EPS was 3.7 R per Inch which is about 88% of the nominal ("dry") value of 4.2 R per Inch per ASTM C 578. The average observed thermal resistivity of XPS was 4.7 R per Inch which is about 94% of the nominal ("dry") value of 5.0 R per Inch. This data still shows a clear trend of XPS performing better than EPS, although at higher densities the differences appear to be less significant. These findings are reasonably consistent with ASCE 32-01 (see Table 1).

Sterling (1986) [7] – In a study by the University of Minnesota of data from more than 60 sources, it was found that EPS could experience (on average) as much as 13.2% and 9.9% moisture content after 18 months of exposure in horizontal and vertical installations, respectively. A resistivity value of 2.8 R per Inch was recommended for EPS with a further recommendation that EPS is best suited for well-drained soil conditions and vertical installations. This recommendation was echoed in the *Building Foundation Design Handbook* by the U.S. Department of Energy, Oakridge National Laboratory [8]. These recommendations are reasonably consistent with ASCE 32-01 (see Table 1).

Ovstaas, et al. (1983) [9] – A study of various insulation types and configurations on two building foundations in Canada and the U.S. after 18 months of exposure, shows the moisture intake of EPS was varied, ranging from 2.8% to 5.6% on average for vertical installations and 5.3% to 12.2% for horizontal applications with the higher averages occurring for 1" thick material and the lower for 2" thick material. Consequently, the loss in thermal resistivity ranged from 25% to nearly 40% on average. Conversely, XPS had moisture contents ranging from 0.03 to 2.1% (by volume) which resulted in thermal resistivity losses of less than 10% (e.g., retained more than

90% of the nominal "dry" thermal resistivity) irrespective of vertical or horizontal installation or thickness of material (ranging from 1" to 2" thick). These findings also are consistent with trends observed in other studies and the ASCE 32-01 standard (see Table 1).

Farouki (1992)[10] – In this study commissioned by the U.S. Army Corp of Engineers, Cold Regions Research and Engineering Laboratory, below-ground insulation applications and requirements from various European countries (primarily in Scandinavia) were surveyed. In general, a substantial difference between XPS and EPS thermal performance was consistently recognized. Again, XPS was always recognized as having superior design thermal properties for below ground use.

McFadden and Bennett (1991) [11] – In this highly regarded text on cold regions engineering, some stringent field case studies in Alaska are mentioned. In one of these studies, XPS insulation was subject to a 20-year below-ground exposure and an additional 5-year exposure submerged in water below a test road. XPS moisture content after exposure ranged from 1.1 to 2.2 percent by volume. In another study of buried insulation used for the Alaskan pipeline, XPS moisture contents were typically less than 0.5% by volume after a 6-year exposure below ground.

These and other sources considered by the ASCE 32-01 committee confirm the design values for XPS and EPS used in the ASCE 32-01 standard. They also consistently demonstrate a trend of XPS performing better than EPS in below-ground applications.

FACT #3 – Laboratory Index Tests can Differentiate Between XPS and EPS Moisture Resistance but They are Unreliable Indicators of Actual Below-Ground Performance

One of the reasons the ASCE 32-01 committee relied heavily on reputable field studies is the lack of reliable laboratory test methods to predict actual insulation performance in below-ground applications [10]. Actual conditions experienced in the field can vary widely in terms of moisture exposure and freeze-thaw actions. Thus, laboratory test methods using idealized or standardized exposures to moisture and freeze-thaw cycles can easily overstate or understate impacts on thermal properties experienced in end-use. Such index tests are best used as indicators of relative differences in performance of insulation materials [5][6][7]. Even then, the relative differences in performance are subject to somewhat arbitrary decisions regarding the stringency of test conditions.

FACT #4 – Extraordinary Claims Require Extraordinary Evidence

Not all claims are credible because not all evidence is credible. Occasionally, individual sources may report data that appear to contradict the broader set of scientific evidence. In such cases, there may be a variety of reasons for the apparent contradiction. When sources with "extraordinary claims" are carefully scrutinized, potential causes for the apparent contradiction become evident. Common causes include:

- Lack of adherence to scientific method (i.e., insufficient sample size, lack of documentation, improper testing procedures, mishandling of samples, etc.)
- Use of "non-standard" materials or installation methods. For example, proprietary insulation facers may be used to enhance the moisture resistance of insulation.
- Inadequate exposure time or variation in site conditions.
- Improper treatment of statistical variability in presenting or interpreting the significance of test results.

In fact, some extraordinary claims regarding comparative performance of XPS and EPS insulations have been based on as few as 2 or 3 samples from one study site, which is clearly inadequate evidence in view of the larger body of scientific evidence. Contradictory results, especially when based on studies that do not allow for public scrutiny of the study methodology or its original data, should be viewed with skepticism. Sources making extraordinary claims that contradict the body of scientific evidence must present extraordinarily credible evidence to justify those claims.

CONCLUSION:

The scientific evidence from many reputable studies clearly indicates a consistent trend of XPS exhibiting superior performance relative to EPS in below-ground applications. Any claim to the contrary should be viewed with skepticism and subjected to critical inquiry.

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