TECHNICAL BULLETIN

UNIVERSITY OF ALASKA CASE STUDY

COMPARISON OF POLYSTYRENE EXPANDED AND EXTRUDED FOAM INSULATION IN ROADWAY AND AIRPORT EMBANKMENTS

EXECUTIVE SUMMARY

The University of Alaska conducted a study using previous data and new samples of in situ EPS and XPS to document that EPS absorbs and retains significantly more moisture in below-grade applications. Thermal performance of samples, including moisture content when extracted from various sites, was used to refine recommendations of increased insulation needed when using EPS to offset the lower performance due to moisture.

INTRODUCTION

Climatic conditions in Alaska pose significant challenges for even the highest-performing building materials. Permafrost must be protected and insulated in roadways and foundations across the tundra. This presents extreme temperature, moisture, and structural demand on insulating materials. The University of Alaska Fairbanks recently completed a multi-year study comparing insulating materials for roadway/below-grade applications. Comparing in situ materials that had been in place for 20+ years has provided insight into real-world performance in moisture absorption and long-term thermal performance.

METHODS

Because the opportunity to reclaim insulation from below-grade installation for research is rare, this study used data from previous samples as well as newly extracted samples. The new test samples were secured from:

- Dalton Highway at approximately mile 10—an Expanded Polystyrene product placed in 2013
- Cripple Creek at Chena Ridge Road, Fairbanks—Expanded Polystyrene product placed in 1997
- Golovin Airport, Golovin—Extruded Polystyrene product place in 1987.

Previous studies used in the evaluation of samples include:

- Cai, S., Zhang, B., & Cremaschi, L. (2017). Review of moisture behavior and thermal performance of polystyrene insulation in building applications. Building and Environment, 123, 50–65. https://doi.org/10.1016/j.buildenv.2017.06.034
- Esch, D. C. (1986). Insulation performance beneath roads and airfields in Alaska (No. FHWA-AK-RD-87-17). Department of Transportation and Public Facilities.
- Poulot, N., & Savard, Y. (2003). High Density Expanded Polystyrene Boards as Road Insulation, Phase I, Performance Evaluation of Expanded Polystyrene on Road 161 in Saints-Martyrs-Canadiens. Performance Follow-Up Report, Quebec: Ministry of Transport, Quebec.

Sample polystyrene was exhumed and double-bagged in polyethylene bags, then sent to a third-party lab for evaluation according to ASTM C518[1]—the mutual standard for thermal performance for both Extruded Polystyrene and Expanded Polystyrene according to ASTM C578[2]. Following thermal testing, each sample was dried to a constant mass that demonstrated the moisture content of each sample. The results of this data were added to results of previous studies and compiled in the chart below.

Expanded Polystyrene Insulation

Sample	Years in Service	Water by Volume (%)	R-Value per Inch
Quebec 1[4]	1	0.51	3.61
Minnesota Dr. 2[3]	3	2.9	3.8
Quebec 2[4]	3	0.8	3.8
Minnesota Dr. 1[3]	3	5.88	2.78
Quebec 3[4]	5	2.7	4.66
Dalton 4	5	4.6	3.7
Dalton 3	5	8.73	3.36
Dalton 2	5	8.88	3.47
Dalton 1	5	11.41	3.13
Fairhill 1	15	1.48	3.44
Fairhill 1	15	5.15	3.13
Cripple Creek 7	21	4.72	3.36
Cripple Creek 3	21	11.25	2.42
Cripple Creek 2	21	11.88	2.51
Cripple Creek 1	21	13.23	2.04
Cripple Creek 6	21	17.55	2.17
Cripple Creek 8	21	19.41	1.74
Cripple Creek 5	21	20.62	1.92
Cripple Creek 4	21	21.51	1.78

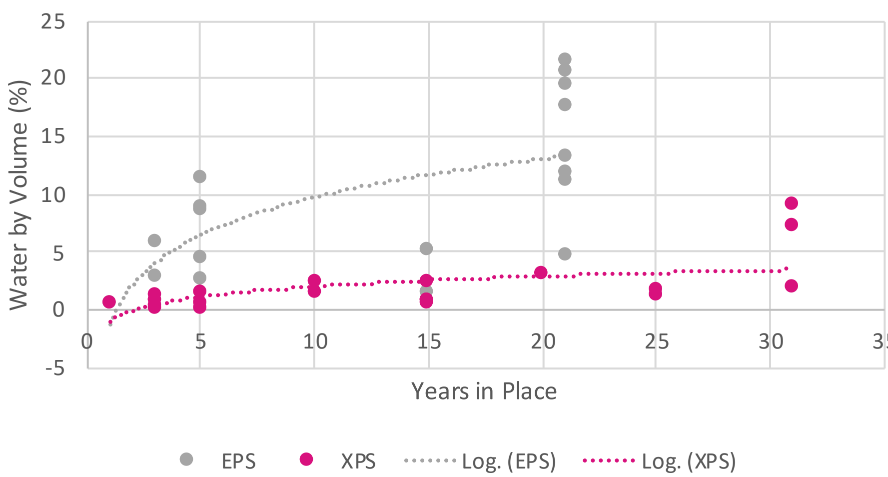
1 ASTM C518 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
2 ASTM C578 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation.
3 Data derived from Esch Study.
4 Data derived from Pouliot and Savard Study.

Extruded Polystyrene Insulation

Sample	Years in Service	Water by Volume (%)	R-Value per Inch
Quebec 1[2]	1	0.67	4.98
Buckland 2[1]	3	0.23	4.81
Buckland 1[1]	3	0.41	4.98
Quebec 2[2]	3	0.73	4.81
Deering 1	3	1.37	4.98
Fairhill 2[1]	5	0.2	4.66
Fairhill 1[1]	5	0.5	4.51
Quebec 3[2]	5	1.5	5.15
Bonanza Creek 1[1]	10	1.48	4.01
Bonanza Creek 2[1]	10	2.38	4.01
Chitina 1[1]	15	0.71	4.24
Chitina 2[1]	15	0.88	3.9
Kotzebue 2[1]	15	0.89	5.15
Kotzebue 1[1]	15	2.38	4.66
Bonanza Creek 3[1]	20	3.1	3.8
Chitina 3[1]	25	1.36	4.24
Chitina 4[1]	25	1.72	4.12
Golivan 3	31	2.08	4.44
Golivan 2	31	7.18	3.94
Golivan 1	31	9.09	4.17

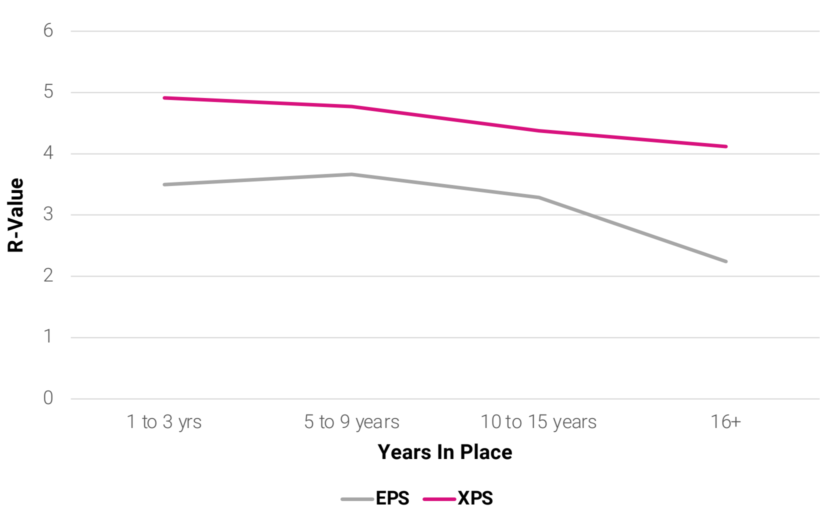
1 Data derived from Esch Study
2 Data Derived from Pouliot and Savard Study

Water Absorption of Samples Overtime



As the chart above shows, data accumulated over multiple studies with multiple in situ samples highlights that Expanded Polystyrene (EPS) gains more water over time than Extruded Polystyrene (XPS). As water is highly conductive, its presence in insulation reduces the effective R-value of the product. This is demonstrated by the chart below, showing the average tested R-values of the same samples.

Average R-Value of Samples Overtime



Validating Previous Data and Contributing to a Larger Body of Knowledge

Previous studies predicted the outcome of higher moisture content and lower R-value in EPS compared to XPS. These predictions aided in estimating performance and ultimately led to design recommendations when using EPS or XPS insulation. This new data uncovered in Alaska further validates and refines the historic performance data and moisture uptake of polystyrene types in below-grade applications over time.

Refining Design Recommendations

As prescriptive R-value is generally used to meet thermal performance requirements, both EPS and XPS report R-value per inch thickness and are often specified by thickness in order to meet these requirements.

Standard XPS meets an R-value of 5 per inch thickness per ASTM C578. Standard EPS ranges from a minimum R-value of 3.10 up to 4.3 per inch thickness related to product type per ASTM C578.

For comparison in this study, both EPS and XPS samples with the same specified 40 psi compressive strength were analyzed. The minimum R-value of type XIV EPS (40 psi) is R-4.2 per inch thickness. Therefore, thermal performance of the type XIV EPS begins at a lower R-value per inch thickness than the comparable type VI XPS at R-5.0 per inch thickness. The differences begin to increase from here.

Impact on Below-Grade Building Insulation

As an example, if a below-grade wall or heated slab requires a minimum R-value of R-20 per IECC 2018, the thickness needed for XPS would be 4 inches. EPS would need 4¾ inches to meet the same requirement.

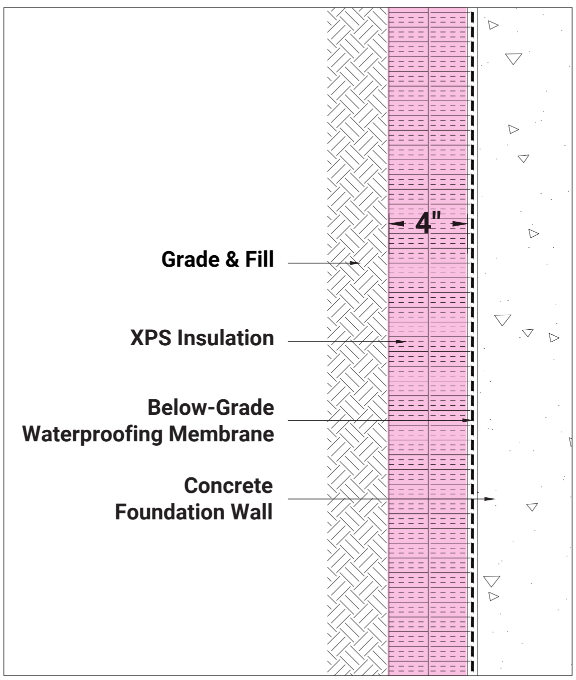


Figure 1: R-20 XPS Foundation Wall (4")

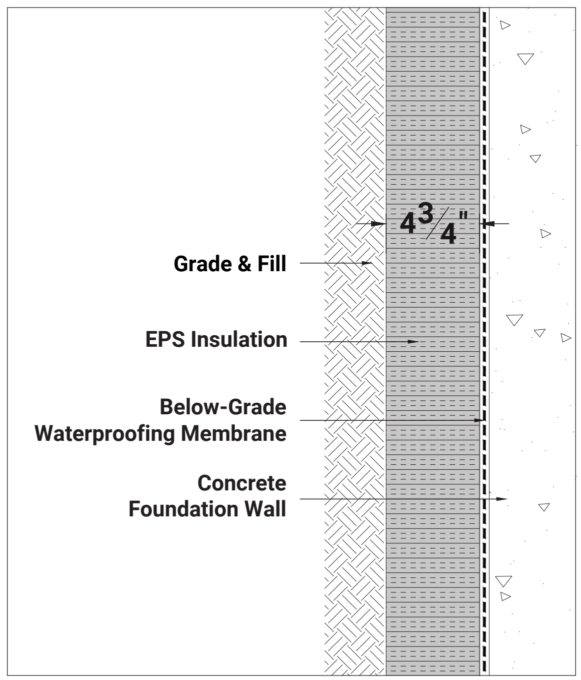


Figure 2: R-20 EPS Foundation Wall (4.75")

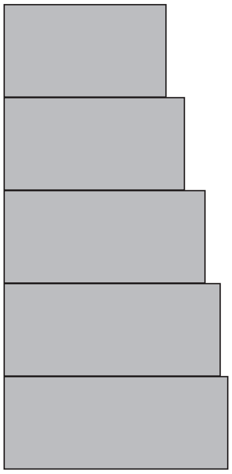
Previous studies referenced in this paper, however, propose a multiplier to account for reduction in performance over time.

RECOMMENDED MULTIPLIERS PER PREVIOUS STUDIES	EPS	XPS
Esch (1986) based on average R-value	1.36	1
Pouliot & Savard (2003) based on average R-value	1.23	1

Using the above multipliers in the example below-grade application,

EPS would require:
R-20/4.2 per inch thickness = 4.762" * 1.36 = 6.476" (Esch)
R-20/4.2 per inch thickness = 4.762" * 1.23 = 5.857" (Pouliot & Savard)

Compared to XPS:
R-20/5 per inch thickness = 4" * 1 = 4" (Both Esch & Pouliot & Savard)



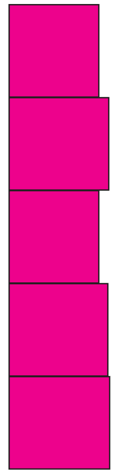
1.5x[a] — 7.143" EPS Required
[a]Average based on data

1.67x[b] — 7.952" EPS Required
[b]Ratio of average to 4.5 specification

1.86x[c] — 8.857" EPS Required
[c]Average minus 1 standard deviation OR Ratio of asymptotic values

2x[d] — 9.524" EPS Required
[d]Based on ration of asymptotic value

2.07x[e] — 9.857" EPS Required
[e]Ratio of average minus 1 standard deviation



1x[a] — 4" XPS Required
[a]Average based on data

1.11x[b] — 4.44" XPS Required
[b]Ratio of average to 4.5 specification

1x[c] — 4" XPS Required
[c]Average minus 1 standard deviation OR Ratio of asymptotic values

1.1x[d] — 4.4" XPS Required
[d]Based on ration of asymptotic value

1.12x[e] — 4.48" XPS Required
[e]Ratio of average minus 1 standard deviation

The new study recommended more multipliers based on various ratios after further scrutiny and evaluation of existing data.[3]

ADDITIONAL MULTIPLIER OPTIONS	EPS	XPS
Average, based on all data, including data from this study	1.5	1
Average, 1 standard deviation based on all data	1.86	1
Ratio of asymptotic values from Figure 3*	1.86	1
Ratio of average to 4.5 specification	1.67	1.11
Ratio of average minus 1 standard deviation to 4.5 specification	2.07	1.12
Based on ratio of asymptotic value from Figure 3 to 4.5 specification	2.0	1.1

*(The study referenced a common specification of R-4.5 per inch thickness for rigid foam insulation for the applications studied.)

Applying these multipliers results in further variations in the required insulation:

EPS
R-20/4.2 per inch thickness = 4.762" * 1.5 = 7.143"
R-20/4.2 per inch thickness = 4.762" * 1.86 = 8.857"
R-20/4.2 per inch thickness = 4.762" * 1.67 = 7.952"
R-20/4.2 per inch thickness = 4.762" * 2.07 = 9.857"
R-20/4.2 per inch thickness = 4.762" * 2 = 9.524"

XPS
R-20/5 per inch thickness = 4" * 1 = 4"
R-20/5 per inch thickness = 4" * 1 = 4"
R-20/5 per inch thickness = 4" * 1.11 = 4.44"
R-20/5 per inch thickness = 4" * 1.12 = 4.48"
R-20/5 per inch thickness = 4" * 1.1 = 4.4"

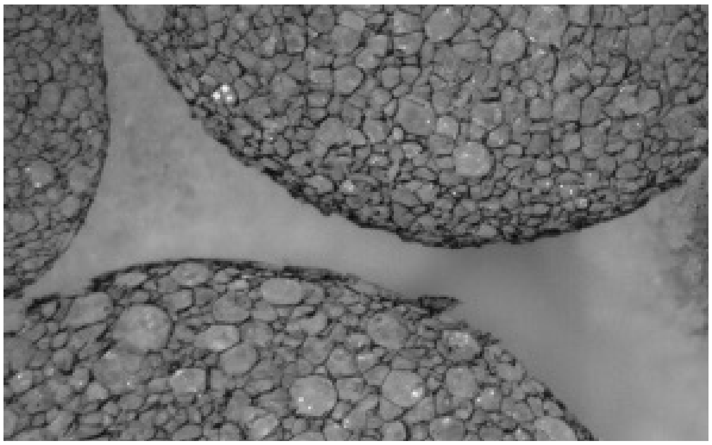
MOISTURE UPTAKE

As designers use these new multipliers for future below-grade design applications. The question is why was less moisture absorbed in XPS than EPS (9% maximum water content in XPS samples versus 22% maximum in EPS samples*)?

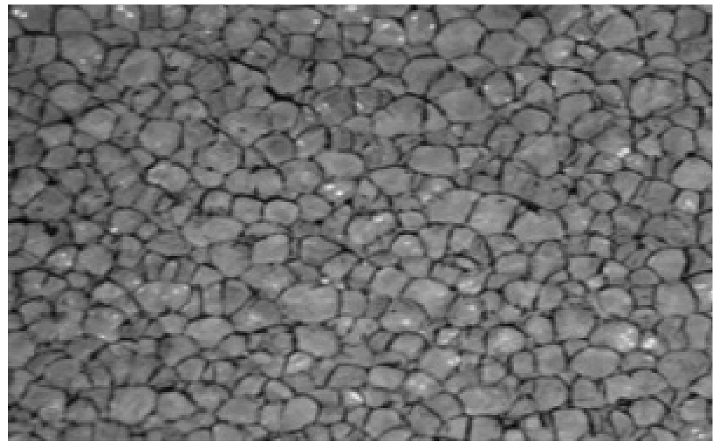
*The maximum 22% moisture content for EPS was reported at the maximum service life of 21 years in EPS samples versus the 9% moisture content in XPS at 31 years of service life!

While the amount of moisture in samples does vary, one observation in the conclusion of the study is that "EPS appears to be more sensitive to moisture content than XPS, resulting in a lower R-value at the same moisture content."

The researcher in this study, Billy Connor, suggests a possible explanation:
While both products are composed of polystyrene their structure is considerably different. EPS is formed through polystyrene beads being expanded in a mold whereas XPS is formed through combining materials with a blowing agent and extruding this product through a die on a conveyor as it cures. The result is a cellular structure with voids between the beads in EPS as opposed to a consistent closed-cell structure in XPS.



EPS Insulation



XPS Insulation

Connor acknowledges that, over time, strong vapor drive—which can vary throughout the year—does force vapor into both polystyrene products. This explains a thermal performance reduction in both products over time though XPS manufacturers may offer a warranty for the R-value of the product to be retained. This has been demonstrated to meet the warranty in this study. For this same reason, it is recommended that XPS be installed in vapor diffusion open assemblies in other applications (see PRMA tech bulletin).

However, where both products are susceptible to vapor, Connor contends that EPS begins moisture-uptake earlier in exposure due to the voids between the "beads" in the structure of the polystyrene. In the past, it has been argued that this is acceptable because the product "drains." The data in this study, however, demonstrates that opportunity for significant drying has not occurred in these samples, impacting the thermal performance of the product.

CONCLUSION

While Connor and researchers of previous studies rightfully call for more studies on this product in below-grade exposure applications, this study further demonstrates the superior moisture-resistance of Extruded Polystyrene insulation compared to Expanded Polystyrene over years of use. This also demonstrates that submersion testing per ASTM C272, while useful in laboratory settings, is not readily translated to actual performance applications.

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