The Role of Insulation for Habitable Basements

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ABSTRACT

The successful realization of a habitable basement requires careful attention to design details. Insulation is often placed on the exterior side of basement walls, where it performs multiple functions: It facilitates movement of exterior moisture to the foundation drainage system; it keeps temperature extremes outside, especially cold temperatures; and it helps prevent condensation of indoor air moisture in the basement. This paper examines basement assemblies useful in the construction of habitable basements with special emphasis on insulation choices within the basement wall assemblies.

Basements serve as the structural foundations of buildings. They are expected to keep the external environment out of the structure, including heat, cold, rainwater, snow melt and ice and they are expected to withstand structural challenges from soil movement, earthquakes, wind events, freezing, and thawing. Furthermore, basement assemblies are expected to prevent condensation of indoor air moisture on the inside of basement walls and floors as well as equipment and furnishings. In other words, basements are expected to keep the outside, outside; and keep the inside, inside, while supporting the building above.

A basement can be an unconditioned storage space, “just a basement,” or it can be a comfortable living space that adds value to a home. The ultimate usability and habitability of the basement depends upon skillful design of basement walls and floors. Success depends conscientious construction using quality materials, which this article will explore.

Research architect Dr. William B. Rose dedicated his life to building science and studies of how water affects buildings. Much of his earlier research is compiled in the handbook “Water in Buildings” [1]. In a recent interview with *Fine Homebuilding* magazine, Dr. Rose advises that before turning to building science for easy answers, it is important to ask the right questions [2]. This paper examines basement assemblies useful in the construction of habitable basements with special emphasis on insulation choices for basement wall assemblies. It endeavors to ask the right question: *What insulation materials help to maintain a habitable basement?*

Functionality of Basements

One of the first questions to be asked when designing a basement foundation is *What is the desired functionality of the basement?*

At one end of the spectrum, a basement may provide comfortable, fully habitable spaces comparable to the above-grade portions of the building (Fig. 1). In the middle of the spectrum, the basement may be less habitable than the main living areas. In other words, it will be cold in the winter and damp much of the year. At the far end of the spectrum, the basement may serve only as a structural foundation and nothing more.

Swinton and Kesik list service criteria and limitations/allowances for different classes of basements [3]. According to their classification system, Class A basements provide a below-grade living space comparable to the living space of the floors above. To ensure long-term performance the design and construction of Class A basements must be virtually defect free and provide critical, redundant moisture control measures. They emphasize that the construction of a comfortable and habitable basement (i.e., a Class A basement) requires much more attention to the components and the system design compared to the design of basements that are not intended to be used as living spaces. There may also be health and safety requirements as well as HVAC requirements, which go beyond the scope of the 2005 Report by Swinton and Kesik.

Figure 1. A habitable basement. (Source: Adobe Stock)

A heathy home begins with a firm foundation that assures structural support for dead and live loads, lateral stability and minimal building movement. In colder climates, the foundation usually extends below the frost line so the home will not significantly move when the ground freezes in the winter. In other words, basements have a role in preventing frost heave that translates to excessive building movement and foundation cracking. Such relatively deep foundations typically result in basements instead of crawl spaces. A full discussion of the structural support and bulk drainage requirements is beyond the scope of the paper.

Thermal Control Challenges

Aside from the structural challenges, the thermal challenges for basements include the following functions: (1) facilitating drainage of moisture at the face of the exterior insulation down to the foundation drainage system, (2) keeping temperature extremes outside the basement wall, especially cold temperatures, and (3) preventing condensation of the basement air onto the interior of walls in the basement. Insulation strategically placed on the exterior side of the foundation plays an especially important role in each of these objectives (Fig. 2).

Figure 2: Exterior insulation and damp-proofing or waterproofing along with effective drainage helps prevent water intrusion into the basement. (Courtesy of Kingspan.)

(1) Facilitating movement of exterior moisture to the foundation drainage system

In an IRC Technology Update [4], Swinton *et al.* describe their approach to managing water exposure to basements is in terms of "two lines of defense":

> *The most effective strategy for managing water is to provide two lines of defense. When exterior basement insulation is used, the first line of defense is the exterior surface of the insulation, which supplies a continuous means of managing water from the ground surface down to the gravel and drainpipe at the footing. The second line of defense is the outer face of the foundation (cast-in-place concrete, concrete block, or wood sheathing in a permanent wood foundation), which can handle the incidental quantities of water that may get by the first line of defense.*

Since 1999, much research has been dedicated toward accumulating valid experimental data on how insulations perform when placed on the outside of a basement wall in contact with the earth, and when insulation is placed beneath floor slabs. The continuous monitoring of the thermal performance of thirteen different basement insulation systems by the Institute for Research in Construction throughout two heating seasons provided some answers [4].

The military "two lines of defense" analogy in the IRC Technology Update is apt. The outer lines of defense are expected to protect against liquid water penetration. This outer layer is sometimes referred to as "effective environmental separation." If the first line of defense allows liquid water to reach the second line of defense, then the second line of defense must provide some protection against liquid water penetration. The basement certainly could not be considered a Class A basement.

Drainage does more than help prevent leaks through the basement wall. Drainage helps to address potentially significant reductions in R-values of insulation (up to 50%) due to water absorption and retention – see the section "Getting Practical" later in the paper. However, drainage of water does not address the negative effects of water absorption on R-value entirely. If liquid water and water vapor are not properly managed, then the insulation R-value is reduced.

Summarizing, the defense against liquid water for the structural foundation is an applied layer of damp-proofing or waterproofing. The defense against liquid water for exterior insulation is to assume a reduced R-value and increase the thickness of the exterior insulation accordingly, and to provide proper drainage of liquid water. Highly water absorbent insulation materials are impractical for this application because of the dramatic drop in R-value (due to the presence of water) and reduced longevity after repeated freeze-thaw cycles over the life of the building. Lower absorption insulations such as polystyrene foam are favored exterior insulation materials, and polystyrene foam (XPS or EPS) should have their thickness increased based on reliable data from long-term, in-service studies. Facers could be used to mitigate water absorption in the insulation, but the facers may eventually be compromised over the life of the building, and the insulation thickness adjustment, nonetheless should be applied.

(2) Keeping temperature extremes outside, especially cold temperatures

Structural materials typically perform rather poorly in keeping heat and cold outside. On the contrary, insulation plays a significant role in decreasing heat transfer through basement walls and floors. Heat from the interior of the basement can quickly transfer through basement walls and floors in contact with the surrounding soil if the basement is not sufficiently insulated on the walls below grade.

Insulation of basement walls above grade and insulation beneath the floor slab of the basement are also important in managing basement temperatures, especially when the intention is to create a habitable space. Basement insulation moderates the surface temperatures of basement walls and floors. As for sustainability objectives, insulation reduces the environmental footprint and energy costs by decreasing the heat transfer that occurs in the heating and cooling of basements.

The placement of the insulation on either the interior or exterior of the wall (or both) makes a difference in human comfort. When the interior surface of the basement wall is warm, it feels much more comfortable to the occupant. Placing the insulation on the exterior side of the basement wall keeps the basement wall surface temperature closer to the overall interior temperature of the room.

XPS and EPS do not have the same thermal resistance and are impacted differently by the presence of moisture. R-value is the resistance to heat flow. Higher numbers indicate lower heat flow and better insulation. R-values for XPS and EPS insulation are listed in Table 1. The “dry” EPS and XPS insulation values are what is shown on the insulation label and literature. The “wet” insulation values for EPS and XPS are building code approved reduced R-values that assume long term water absorption over the life of the building. The “wet” insulation values for XPS include both the effects of moisture and aging.

(3) Preventing condensation of interior moisture in the basement

Once the basement wall is protected from liquid water penetration, it is also necessary to protect the basement wall from the condensation of water vapor in the basement air space. Figure 3 shows various basement wall materials. Of course, if the basement wall has already been compromised by a failure to provide protection from bulk water, then such additional measures will not be very effective (Fig. 4). In this sense, the basement wall assembly is a system of components, and each component must be free from defects. No one element is independent of the other.

Table 1: R-values for habitable basements

Material	R-value per inch ($ft^2 \cdot °F \cdot h/BTU$)	Source
"Dry" XPS Above grade applications	Nominal – R-5.0 per inch	ASTM C578 Standard specification for rigid, cellular polystyrene thermal insulation
"Wet" XPS Exterior below-grade application, subject to below-grade moisture	Design R-value - R-4.5 per inch in vertical applications, R-4.0 per inch in horizontal applications [5]	IRC, Table R403.3(1); and ASCE 32-01, Table A1
"Dry" EPS Above grade applications	Nominal – R-4.0 to R-4.3 per inch	ASTM C578 Standard specification for rigid, cellular polystyrene thermal insulation
"Wet" EPS Exterior below-grade application, subject to below-grade moisture	Design R-value - R-3.2 to R-3.4 per inch in vertical applications, R-2.6 to R-2.8 per inch in horizontal applications [5]	IRC, Table R403.3(1); and ASCE 32-01, Table A1

Basements may be prone to high humidity. Interior moisture often is removed using dehumidifiers but that is not a complete solution. If thermal conduction between the masonry or concrete walls and floors to the surrounding soil is excessive, then the masonry or concrete may become cold enough for moisture condensation even at moderate humidity levels.

When moisture condenses on or is absorbed into concrete walls and concrete floor slabs, basements can become cold, dank and musty (Fig. 5). The most reliable long-term solution to prevent condensation is to maintain concrete wall and floor temperatures well above the dew point of the ambient air in the basement space. In this manner, condensation on the concrete wall and floor slab can be avoided.

Depending on the types of insulation and the quantity and locations of the insulation on the basement walls and floor, insulation can have a positive effect on managing the condensation of interior moisture.

Figure 3: Basement walls can be made of concrete blocks (*left*), bricks (*center*) and other materials but most commonly are made of concrete (*right*). Basement walls need to be kept warm to protect them from the condensation of water vapor in the basement air space. (Adobe Stock)

Figure 4: This basement has a water management problem. A habitable basement must have effective environmental separation, meaning bulk water must not penetrate the interior of the basement. (Adobe Stock)

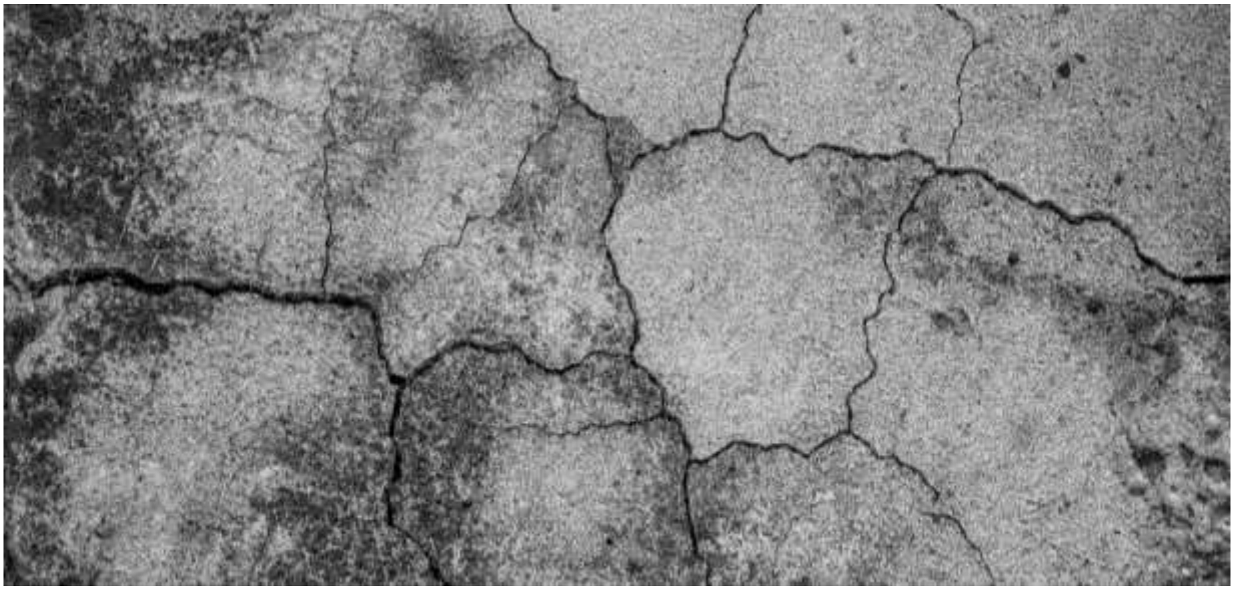

Figure 5: Concrete will absorb moisture and if unchecked will crack over time, resulting in musty smelling basements. (Adobe Stock)

The Key Question: Exterior or Interior Insulation?

Considering all of the above thermal challenges, a good question to ask is *Where should the insulation be placed relative to the basement walls and floors?*

The basic challenge for insulation installation is to meet the required or desired R-value. However, this simple challenge is complicated by the presence of moisture. It makes a big difference where the insulation is installed on the basement wall.

During the cold season, insulation installed on the *interior* side of the basement wall will be colder on the side facing the exterior of the building, and the interior side of the insulation will be facing the warmer moist air of the basement's interior. This is a perfect recipe for moisture condensation on the interior side of the basement wall, and condensation of moisture within the insulation. Moisture condensation typically leads to mold and mildew (Fig. 6).

Conversely, insulation installed on the *exterior* side of the basement wall will be exposed to exterior moisture as well as the compressive forces of soil around the building. It may also be exposed to ultraviolet radiation if the insulation is left exposed above grade.

In the final analysis, the advantage of locating insulation on the exterior side of basement walls usually outweighs any advantage of locating insulation on the interior side of basement walls for thermal control. The basement wall will stay much warmer during the winter when the insulation is on the exterior side. Since the basement wall is warmer, moisture condensation is far less likely within the basement and mold and mildew can be prevented from forming, provided the interior relative humidity is controlled.

Figure 6: If basement walls are not insulated from the outside, the wall temperature could drop below the dew point. Moisture condensation in the dark spaces behind interior insulation and sheet rock creates conditions that favor the growth of mold and mildew. (Abobe Stock)

Getting Practical

If the goal is to (1) facilitate drainage, (2) to keep temperature extremes outside and (3) to prevent condensation, then what practical measures must be implemented during basement design?

Start with the polystyrene foam insulation thickness. Table 1 includes R-values for polystyrene foam insulations, including extruded polystyrene (XPS) and expanded polystyrene (EPS) foam insulations. Based on recognized R-values for XPS and EPS, special considerations for insulation thickness adjustments for habitable basement designs are as indicated in Table 2:

Table 2: Insulation Thickness Adjustment Multiplier		
Polystyrene	**Vertical**	**Horizontal**
EPS	1.24	1.50
XPS	1.11	1.25

In general, the thickness of EPS insulation should be increased by 24 percent to achieve desired thermal performance and to prevent condensation when EPS is placed on the outside of below grade walls. Furthermore, EPS thickness must be increased by 50 percent in below grade horizontal applications (*i.e.*, under the floor slab). Remarkably, the thickness of XPS insulation needs to be increased by only 11 percent to achieve desired thermal performance and to prevent condensation when XPS is placed on the outside of below grade walls. XPS thickness need only be increased by 25 percent in below grade horizontal applications (*i.e.*, under the floor slab). More specifically, the following design examples apply to insulation beneath a basement floor slab that requires an insulation design R-value of R-10 and on the exterior side of a basement wall that requires an insulation design R-value of R-20.

Figure 7 shows the EPS and XPS thicknesses required to obtain R-10 design R-value for insulation of a below-grade concrete floor slab. For XPS insulation, 10/5.0 equals 2.0 inches of R-5.0 XPS; adding 25 percent (2.0 + 0.5) gives an adjusted thickness of 2.5 inches for an R-10 design thermal resistance using XPS. For EPS insulation, 10/4.2 equals 2.38 inches of R-4.2 EPS. Adding 50 percent (2.38 +1.19) gives an adjusted thickness of 3.6 inches of EPS for R-10 design thermal resistance.

Figure 8 shows the EPS and XPS thicknesses required to obtain R-15 design R-value for exterior below-grade exterior wall insulation. For XPS insulation, 15/5.0 equals 3.0 inches of R-5.0 XPS; adding 25 percent (3.0 + 0.75”) gives an adjusted thickness of 3.75 inches for an R-15 design thermal resistance using XPS. For EPS insulation, 15/4.2 equals 3.57 inches of R-4.2 EPS. Adding 50 percent (3.57 + 1.78) gives an adjusted thickness of 5.35 inches of EPS for R-20 design thermal resistance.

These thickness adjustments are based on design R-values derived from field data on polystyrene foam insulation in cold climates per the design standard ASCE 32 for frost-protected shallow foundations [6]. The user is responsible to determine if these thickness adjustments are applicable for the local climate zone, rain exposures and other moisture exposure from vegetation or runoff from the building rooftop. While these design values are for frost protected shallow foundations and may not apply to all climate zones, they provide some insights into how moisture absorption affects R-values in below grade applications, including basement insulations.

Don’t assume foundation drainage protects thermal control. Rather, use the right amount of thermal control and plan for the presence of moisture leftover after drainage. Design redundancy with thermal control keeps the basement habitable.

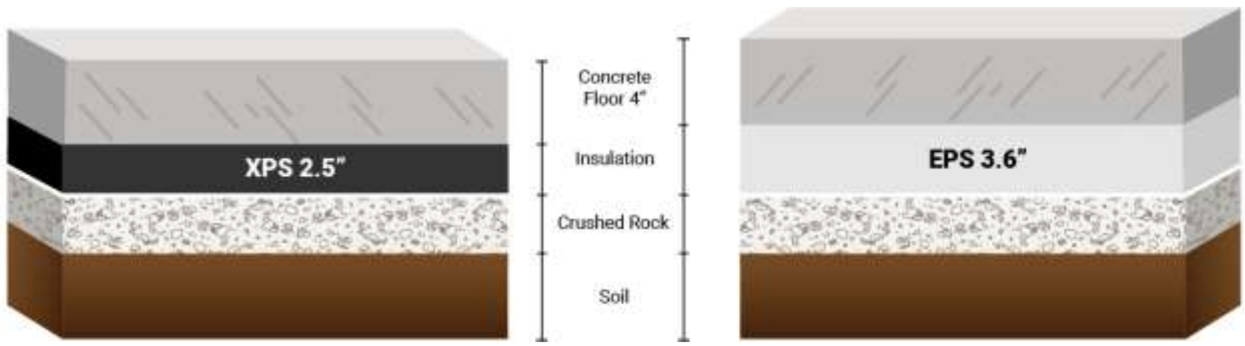

Figure 7: Thickness adjustment for design R-value of R-10 insulation beneath basement floor slab.

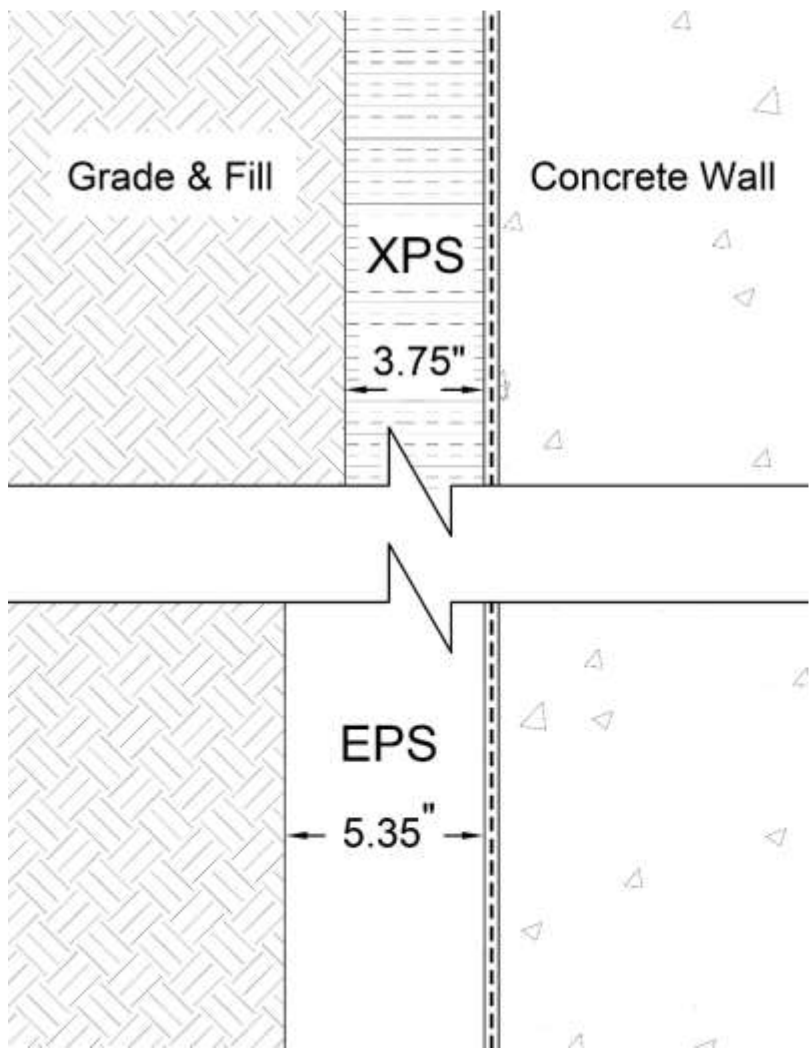

Figure 8: Thickness adjustment for design R-value of exterior R-15 insulation on below-grade foundation wall.

Figure 9: XPS insulation on exterior of basement wall showing damp-proofing, wall insulation and anchors outdoors. (Adobe Stock)

Figures 10: XPS has the toughness and moisture resistance suitable for direct contact with surrounding debris. Here the XPS insulation protects the waterproofing membrane. (Adobe Stock)

Figure 11: XPS Insulation is a key component of any basement wall assembly. The moisture resistance of XPS makes is ideally suited for below grade applications in the construction of habitable basements. (Courtesy of Owens-Corning)

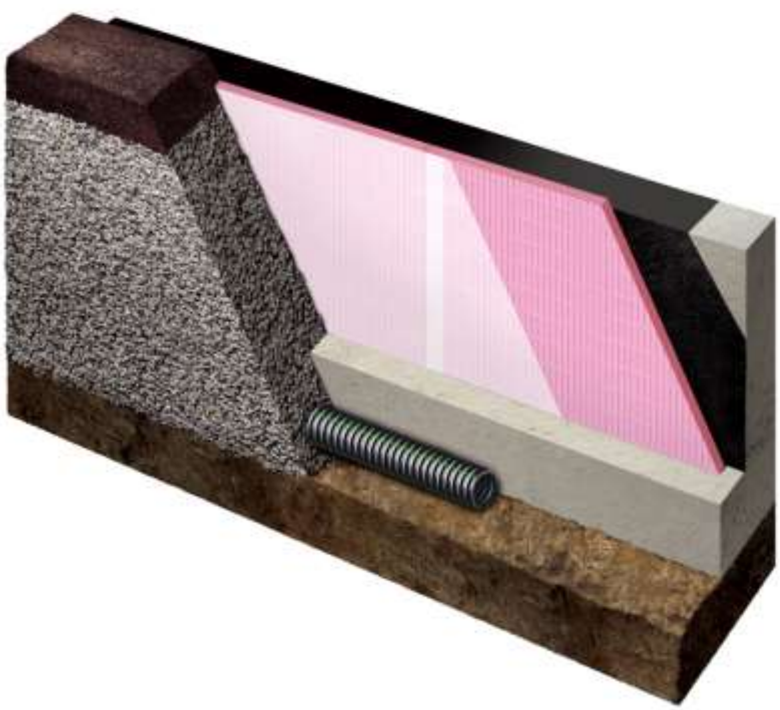

Figure 12: Schematic of a basement wall assembly. (Courtesy of Owens-Corning)

Multipurpose Insulation Materials

As can be seen from the above discussion, there are two sides to a habitable basement design strategy:

- First, keep the outside environment on the outside.
- Second, prevent condensation of interior moisture on the basement walls.

A livable basement must have a basement wall assembly that meets multiple design criteria. It needs to use wall assemblies made with multipurpose materials providing multiple lines of defense and performing multiple functions.

The first line of defense separates the basement wall from the outdoor environment and the second line of defense manages the moisture of the indoor environment in such a way as to provide a livable basement.

These multiple lines of defense need to be carefully modeled in basement wall assemblies for habitable basements that will last. The most workable moisture control strategies will include attention to the selection of quality foam insulation. The foam insulation board needs to allow for drainage, provide high R-value, resist moisture absorption and retain R-values in below grade applications.

Even with a well-designed system of drainage protection, liquid water and water vapor are likely to be present throughout the life of the foundation. Interior basement condensation can be avoided through the proper selection and installation of insulation if the reality of water and ice in the assembly is acknowledged.

According to Table SB1 in the sidebar, the R-values of water, ice and XPS insulation are 0.24 per inch, 0.065 per inch, and 5.0 per inch, respectively. Minimizing the moisture absorption provides the greatest chance of retaining the highest R-value regardless of the presence of exterior moisture. Interior moisture due to condensation also can be minimized by blocking heat loss through the basement wall to the surrounding environment.

Choosing an inexpensive water-permeable insulation and relying solely on drainage to keep it dry risks a potential moisture absorption scenario that may be unintended but nonetheless will be expensive to fix.

For these reasons and others, XPS foam board insulation is recommended for use in habitable basement designs, especially when it is installed exterior to the foundation walls and floor slabs.

References

[1] William B. Rose, “Water in Buildings” (Wiley & Sons, 2005).

[2] Aaron Fagan, “The Fine Homebuilding Interview: William B. Rose,” *Fine Homebuilding*, Issue 305, Feb/Mar 2022.
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[3] “Performance Guidelines for Basement Envelope Systems and Materials: Final Research Report” By Michael C. Swinton, IRC/NRC and Dr. Ted Kesik, University of Toronto (Institute for Research in Construction / National Research Council Canada) October 2005

[4] Swinton, M.C.; Bomberg, M.T.; Kumaran, M.K.; Normandin, N.; Maref, W. “Performance of thermal insulation on the exterior of basement walls,” NRC Construction Technology Update, Number 36, Institute for Research in Construction (1999-12-01).
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[5] Rob Brooks et al., “Effects of Moisture Absorption Mechanisms on In-Service Design R-values of Polystyrene Insulation,” XPS Insulation Performance, Below Grade Series ID: IP-BG-02

[6] SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations, American Society of Civil Engineers, www.asce.org

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Sidebar: R-values Explained

Figure SB1: The R-value of snow keeps the colder temperatures outside. Thirty inches of snow performs about as well as two inches of dry XPS. Most igloos don't survive a long freeze-thaw cycle, but snow blocks are readily available in some climate zones. (Adobe Stock)

R-value is expressed as rate of heat loss per hour per square foot per inch of thickness of material per degree Fahrenheit. R-values can be expressed in metric units (SI units) as well as Imperial (or Inch-Pound) units. The metric thermal resistance is sometimes referred to as the "RSI value." The R-value in I-P units per inch is obtained from the RSI value by multiplying the RSI value by 5.678 / (W/m K) and then by 0.0254 meters/inch to obtain the R-value per inch.

As an example, the thermal conductivity of **ice** (at -1 °C is **2.24 W/(m·K)**. The RSI value of thermal resistance is (1/ 2.24) = 0.446. R-value per inch in I-P units = 5.678 (0.0254 meters/inch) * 0.446 RSI = 0.06.

Table SB1 -- Values of thermal conductivity and R-value per inch for select materials.

Material	Thermal Conductivity (W/m·K)	Thermal Resistance, R-value for 1 in. thickness (ft^2·°F·h/BTU)
XPS	0.029	4.97
fresh snow	0.19	0.76
compact snow	0.43	0.34
ice -1C	2.24	0.06
ice -20C	2.45	0.06
water 20C	0.6	0.24
soil dry	0.8	0.18
soil damp	2	0.07
still air	1.2	0.12
concrete	1.4	0.10
concrete	2.6	0.06
wood	0.115	1.25

*Values adapted from John Straube, "High Performance Building Enclosures," Building Science Press, 2012, Appendix A.

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