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Understanding R Values

Understanding Insulation R-value
By Mason Knowles

Every construction/design architect/engineer (A/E) knows a material's R-value is an important factor when specifying insulation products, with many regulations requiring minimum values for wall, ceiling, and roof assemblies. However, the reliability of these R-values in predicting energy performance is not always as well-understood. To help clear up any misconceptions, this article addresses the test methods used to determine R-values and analyzes their relative degrees of accuracy.

Immeasurable measurements
While R-values are thought of as measurement units, they are not physically measured. Rather, researchers measure a material's K-factor—the thermal conductivity for a unit thickness of material. The measure of resistance to heat flow, a material's insulation R-value, is simply the reciprocal of this factor. In other words, once the K-factor is determined, it is divided into 1 to obtain the R-value—for example, when the former is 0.166, the latter is 6.02. When dealing with K-factors, lower numbers equate better insulation. On the other hand, the higher the R-value, the greater the insulating power.

Once an A/E knows a material's insulation R-value, it becomes much easier to determine the building assembly's overall thermal conductance—its U-factor—by adding the total R-values of each material in the assembly and dividing the total into 1. For measuring K-factor and insulation R-value, ASTM International has developed standards for the most common plastic insulation products, such as cellulose, polyisocyanurate (polyiso) board, expanded polystyrene (EPS) foam, extruded polystyrene (XPS) foam, and spray polyurethane foam (SPF).

The three most frequently used test methods to measure R-value are:
1. ASTM C 177, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus.*
2. ASTM C 518, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.*
3. ASTM C 976, *Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box.*

Another important test is ASTM C 1303, *Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Un-faced Rigid Closed-Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions.* Unlike the above tests, which are actual measurements, ASTM C 1303 is an estimate employing short-term measurements to predict R-values of foam plastics over a longer period.

R-values reported from tests can vary depending on how the samples were prepared, their thickness, and the type of apparatus used. For example, when testing SPF for its R-value according to ASTM C 1029, *Standard Specification for Spray Applied Cellular Polyurethane Insulation,* both ASTM C 518 and ASTM C 177 require a 305 x 305 x 25.4-mm (12 x 12 x 1-in.) sample cut from a sprayed board of foam. After aging the material six months in a controlled environment, the foam's R-value is measured. R-values of this age are accepted by the Federal Trade Commission (FTC) and used by the majority of the SPF industry. Typical aged SPF R-values from ASTM C 518 and ASTM C 177 range from 5.6 to 6.2 per 25.4 mm. However, another test procedure, ASTM C 976, measures the R-value of SPF installed in a 2.4 x 2.4-m (8 x 8-ft) wall at the installed thickness. These tests typically provide higher R-values than ASTM C 518 or ASTM C 177 measurements for SPF thicknesses greater than 50.8 mm (2 in.).

Insulation R-values of some foam plastics, such as XPS, polyiso, and SPF, vary depending on foam thickness, covering systems, and whether measurement includes adhesion to a substrate. Factors affecting the R-value include application thickness (i.e. the thicker the foam, the better the aged R-value) and the substrate and covering systems (i.e. the lower the perm-rated covering/substrate, the higher the aged R-value).

Robert Alumbaugh, Ph.D., PE, a researcher with the U.S. Navy, has studied aged R-values between five and 10 years of SPF on test panels at the Naval Construction Battalion Center (CBC) in Port Hueneme, California. According to his research, SPF sprayed to a high perm-rated substrate (*i.e.* wood or concrete) ranged from 5.8 R-value to 6.2 R-value per 25.4 mm (1 in.) at a 25.4-mm to 76.2-mm (1-in. to 3-in.) thickness. However, the same SPF applied to metal decks ranged from 6.5 R-value to 7.3 R-value per 25.4 mm. Other researchers with the National Research Centre (NRC) of Canada and the U.S. Department of Energy's (DoE's) Oak Ridge National Laboratories (ORNL) have observed similar results.

The blowing agent also affects the R-value. Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and hydrocarbon-blown SPF range within the values described above, while water-blown foams typically have much lower R-values. Blends of these blowing agents with water can also affect the R-value.

Finding a common test method
With the various testing methods available, there is bound to be confusion over why there is no singular way universally accepted for measuring insulation R-values. Unfortunately, there is no one test that works best for all products. Instead, we are left with the process of determining the most appropriate methods, sample preparations, and conditioning procedures that are accurate, reproducible, and relevant to specific material's actual field performance.

It is this last criterion that is hardest to satisfy. One must remember R-values measure heat conduction, rather than radiation or convection. Typically, one starts with the R-value from small sample testing and, through other test procedures, determines the insulation efficiency reduction based on air infiltration, thermal bridging, and additional considerations.

However, test results can vary widely depending on assumptions made. For example, in the 1980s and 1990s, the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) surveyed 'typical' residential construction for air leakage using a blower door test. Their survey results were published as a table in the ASHRAE *Fundamentals Handbook*, concluding the typical house had between 1 and 1.5 air exchanges per hour.

This is the equivalent of having a 50.8-mm (2-in.) hole in each of one's 2.4 x 2.4-m (8 x 8-ft) wall assemblies. In moderate climates, such as southern California or Hawaii, this may be an insignificant factor, but in southern Texas or northern Minnesota the air leakage would greatly reduce the building's energy efficiency. Conversely, ORNL's more recent survey concluded the total air exchanges in new houses is closer to 0.32 air exchanges per hour—the equivalent of a 12.7-mm (0.5-in.) hole in the same 2.4 x 2.4-m assembly. ORNL attributes the tighter housing to improved construction techniques and sealing materials such as foam sealants and housewrap (e.g. polyolefins).

ASHRAE also published a table referenced in the 2003 International Energy Conservation Code (IECC), calculating the reduction of R-value based on thermal bridging. In roofing applications, thermal bridging (brought on by gaps in insulation boards, and fasteners) can reduce the R-value by five to 35 percent, depending on the size of the gaps, and the amount/type of fasteners.

The tools to more accurately predict energy efficiency of building products and assemblies continue to improve. However, it is the A/E's task to take advantage of these tools, and obtain the design's required R-value.

About the Author
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ASTM International's R-value Measurement Tests

1. ASTM C 177, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties of the Guarded-Hot-Plate Apparatus.*

This test measures the steady-state heat flux through homogeneous flat specimens. Two test specimens (as identical as possible) are placed on both sides of a 'guarded' hot plate and in contact on the other side with a 'cold surface assembly.' This test requires the establishment of steady-state conditions and the measurement of heat flow in one direction. It is used to measure the thermal resistance of thin-sliced test specimens at short time intervals (up to six months). However, its measurements can be used to estimate the predicted aged R-value for longer periods, typically 2.5 to 40 years.

2. ASTM C 518, *Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.*

This test measures steady-state thermal transmission through flat slab specimens using a heat flow meter. One test specimen is placed between a cold plate and a hot plate. (One or more heat flux transducers can be employed.) As with ASTM C 177, it is used to measure the thermal resistance of thin-sliced test specimens at short time intervals, but its findings can be used as the foundation for aged values.

3. ASTM C 976, *Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box.*

This test measures heat transfer through a specimen under controlled air temperature, air velocity, and radiation conditions established in a metering chamber on one side and in a climatic chamber on the other side.

The calibrated hotbox method is specially suited for large non-homogeneous specimens such as building structures and composite assemblies. It can also be used for measurements of individual building elements such as windows and doors. The chamber can be configured for attics and floors or wall assemblies.

4. ASTM C 1303, *Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Un-faced Rigid Closed Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions.*

This test allows for estimates of long-term change in thermal resistance of un-faced foam plastic by reducing the sample thickness to accelerate aging under controlled laboratory conditions. Some products, such as polyisocyanurate (polyiso) board with facers and spray polyurethane foam (SPF), may be inappropriate for this method due to their non-homogenic nature, and their adherence to facers or substrates.