Basics of Thermal Resistance in Specifying Rigid, Cellular Polystyrene Foam Board Insulations

The Difference between Thermal Resistance and Thermal Conductivity

Basic thermal insulation knowledge begins with a fundamental understanding of heat flow. Arguably, from the viewpoint of a building enclosure consultant, engineer, or architect, the most important material property of RCPS foam board is its thermal resistance.

The heat flow Q per unit area A is directly proportional to the temperature difference ΔT divided by the thermal resistance R_{th}.

Heat flow per unit area: $q = Q/A = \Delta T/R_{th}$

In this equation, R_{th} equals the *R*-value. R_{th} values add in series, similar to electrical resistors. *R*-value is sometimes expressed as *R*-10, *R*-20, and so on, indicating the product of the *R*-value per inch and the thickness of the board in inches.

The Federal Trade Commission (FTC) requires home insulation manufacturers, professional installers, new home sellers, and retailers to provide *R*-value information, based on the results of standard tests, to help inform consumers. The FTC's "*R*-value rule" is formally known as the "Trade Regulation Rule Concerning the Labeling and Advertising of Home Insulation" [1] Manufacturers will list R-value with the explanation "R-value is resistance to heat flow. The greater the R-value, the greater the insulating property" or a variation of this required information.

The reciprocal of thermal resistivity is thermal conductivity [2].

A full understanding of *R*-value is essential to the application of ASTM C578. The following sections review of the basics of thermal resistance values and how to convert from imperial units to RSI units.

Units for R-Value

The basic equation for heat flow per unit area is $Q/A = \Delta T/R$.

Here, R is equal to the R-value multiplied by the thickness. Rearranging the heat flow equation gives the following equation for R-value: R-value × thickness = $(\Delta T/Q) \times A$

In imperial units:

Q has units of energy per unit time (Btu/h)
ΔT has units of degrees Fahrenheit (°F)
Area has units of square feet (ft^2)
Therefore, the units for R-value per unit thickness are (ft^2 × °F)/(BTU/h) = (°F × ft^2 ×h/BTU)

In SI units, RSI has units of (°C × m^2)/W or, equivalently, K × m^2/W.

Converting from Imperial Units to SI Units

To convert from imperial units to SI units, apply the following conversions.

1°F = (5/9) K
1 Btu/h = 0.2931 W
1 ft^2 = 0.0929 m^2
°F × ft^2 × h/Btu = (5/9) × 0.0929/0.2931 K.m^2/W
(°F × ft^2 × h/Btu)/(K × m^2/W) = 0.176
(K × m^2/W)/(°F × ft^2 × h/Btu) = 5.678

R-value (in imperial units) ≈ RSI-value (in SI) × 5.678
RSI-value (in SI) ≈ R-value (in imperial units) × 0.176

To convert to an RSI value in SI units an R-value in imperial units, multiply by 5.678. To convert an R-value in imperial units to an RSI value in SI units, multiply by 0.176.

About Thermal Conductivity

The U-value for an insulator is a measure of thermal conductivity. The inverse of the R-value is also known as the overall heat transfer coefficient.

U-value = (1/R-value) = heat flux/(temperature difference)

For a given temperature difference, a high *U*-value signifies a high heat flux. The heat flux in imperial units is expressed as Btu/h/ft^2. In SI units, the heat flux is expressed as W/m^2. The total heat transferred would be the heat flux multiplied by the area. Heat flow is greatest through areas with low *R*-values. The *U*-value of an assembly such as a wall or entire building enclosure accounts for individual *U*-values and interplay of the assembly components.

A Simple Example

The *R*-value for 1 in. thickness of most materials is less than 1°F × ft^2 × h/Btu. Consider a 1 ft × 1 ft, 1-in.-thick block of material with a 10°F temperature differential on either side of the block. If the *R*-value per inch has a value of 1°F × ft^2 × h/Btu, this block would transfer 10 Btu every hour.

If the block area were 10 ft × 10 ft, the heat loss would be 1000 Btu/h. Increasing this example to 1000 ft^2 (equivalent to the wall area of a small one-bedroom detached home) results in 10,000 Btu/h or 240,000 BTU per day. Poorly insulated homes are notoriously expensive to heat and cool for this reason. In our example, energy loss could add up to $3 to $7 per day ($1,000 to $10,000 per year), accounting for seasonal, fuel type, and regional variability.

At the other extreme, an XPS foam board typically has a thermal resistance five times greater than our hypothetical material. So, in the example, instead of transferring 1000 Btu/h, it would only transfer 200 Btu/h. Moreover, 5 in. would only transfer 40 Btu/h. It is easy to see how polystyrene insulation can dramatically inhibit heat transfer through walls, floor slabs, and roofs, and reduce energy use and waste. Few building materials offer values of thermal insulation as high as those for polystyrene insulation.

References

1. Federal Trade Commission. n.d. “R-Value Rule.” Accessed October 24, 2023. https://www.ftc.gov/legal-library/browse/rules/r-value-rule.

2. Leaman, J., and C. Hendricks, 2022. “Misleading R-Value and the Need to Reframe Insulation Scales.” *Journal of Light Construction*. https://www.jlconline.com/how-to/insulation/misleading-r-value-and-the-need-to-reframe-insulation-scales_o.