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R-VALUES AND U-VALUES

SUMMARY

R-values and U-values are used to quantify the steady-state flow of heat through building elements. R-values are used primarily to describe heat flow through materials while U-values are used to describe heat flow through assemblies. Both terms, however, are used in a variety of ways, making it essential to describe the material or assembly under discussion.

The R-value of a material is commonly measured using a heat-flow meter apparatus. The U-value of an assembly is typically calculated from R-values for the constituent materials and air-film resistances or measured using a hot-box apparatus.

The terms R-value and U-value are used in the analysis of heat flow in a wide variety of situations. R-value is intended to characterize a material or materials in series. U-values are intended for use with assemblies that may contain several paths for heat to move from the warm region to the cold region. Both quantities can be used to calculate steady-state heat flow across an assembly. To avoid confusion, the terms R-value and U-value must be accompanied by a description of the assembly or material being discussed.

The units for R-value and U-value are reciprocals.

R-value has units $ft^2 \cdot hr \cdot °F/BTU$ (in the commonly used U.S. system)

U-value has units $BTU/ ft^2 \cdot hr \cdot °F$

R-values and U-values are used to calculate the rate of heat flow, Q (BTU/hr), across a building element with area “A” having a temperature difference across the building element of ΔT where $\Delta T = T_{hot} – T_{cold}$.

$$Q = U \cdot A \cdot \Delta T \qquad \text{or} \qquad Q = (1/R) \cdot A \cdot \Delta T$$

In this case U equals 1/R.and the quantities are truly reciprocals. The R in the above case is identified as the total thermal resistance between the exterior air mass and the interior air mass.

Very commonly U-values are used to describe heat flow across complex assemblies that contain many materials each with a thermal resistance (R-value). The R-values may be for insulation, framing, masonry element, sheathing, or air films.

For a single material, the R-value is related to the apparent thermal conductivity, k_a, by the following expression
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$$\text{R-value} = L / k_a$$

where L is the thickness of the material in the direction of heat flow. The word “apparent” means that conduction, radiation, and free convection within the material are included. The R-value for materials in series (no 1, no 2, no 3 etc.) is

$$R_{total} = R_1 + R_2 + R_3 + \ldots\ldots\ldots$$

Insulation materials are often discussed using the term R-per-inch of thickness (thermal resistivity or R*). In this case

$$R^* = 1 / k_a \quad \text{and} \quad R\text{-value} = L \cdot R^* .$$

To be meaningful, a discussion of R must be accompanied by a statement about the material or system being described by the R.

Possibilities for R-value:

a) a one-inch thickness of material
b) several inches of material
c) several materials in series
d) a region such as an enclosed reflective air space
e) an assembly including air films

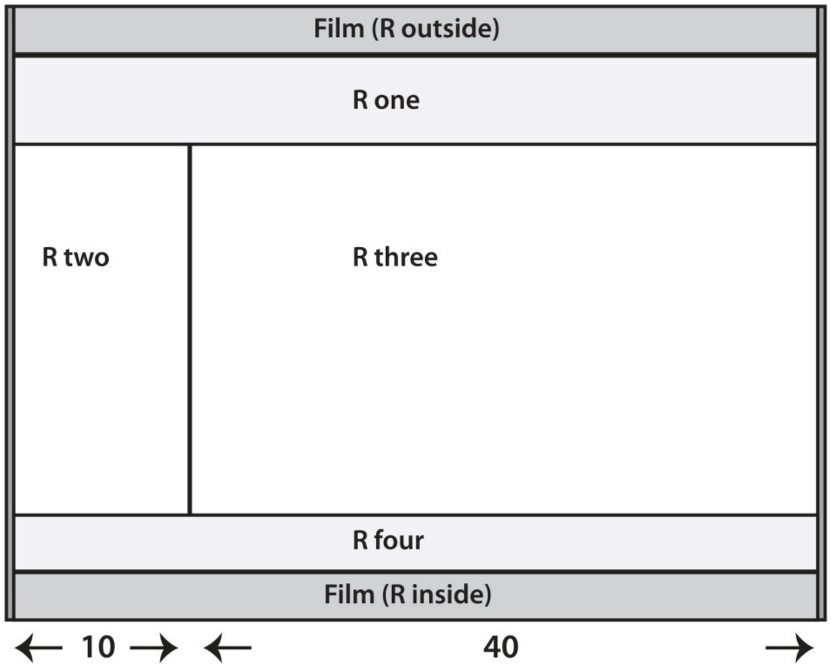
The most common use of U-value is for the calculation of the rate of heat flow (Q) between a warm region and a cool region with area A due to a temperature difference ΔT. The U-value in this case includes all of the thermal resistances between the warm and cool regions including in many cases exterior and interior air-film resistances. The assembly being discussed can be a single material, a series of materials in sequence, or many materials providing many paths for heat flow. U-values are used, for example, to calculate the rate of heat flow across an area of the building envelope (such as a wall). In this case, the warm region could be the outside air and the cool region could be the inside air. The wall likely consists of layers of material such as siding, sheathing, framing, and dry wall. There are well-established equations for combining the individual R-values in an assembly to obtain the U-value for the assembly.

The following figure is an assembly containing six thermal resistances. Two of the resistances are air films. Two of the resistances, R two and R three, are in parallel, and there are five regions in series. The resulting air-to-air R-value for the example is:

$$R_{\text{air-to-air}} = \underset{(1)}{(R\ \text{outside})} + \underset{(2)}{(R\ \text{one})} + \underset{(3)}{1/(\,0.2/R\ \text{two} + 0.8/R\ \text{three})} + \underset{(4)}{(R\ \text{four})} + \underset{(5)}{(R\ \text{inside})}$$

The third term on the right side of the above equation is for two resistances in parallel. The path with thermal resistance R two is 20% (or 0.2) of the cross-sectional area and the path with thermal resistance R three is 80% (0.8) of the cross sectional area. There are several quantities that can be reported for this assembly.

Suppose:	R outside air film	=	0.25
	R one	=	1.20
	R two	=	5.00
	R three	=	13.00
	R four	=	1.50
	R inside air film	=	0.60



$R_{\text{air-to-air}}$ = 0.25 + 1.20 + 9.849 + 1.50 + 0.68 = 13.48 ft²·hr·°F/Btu

U-value ($U_{\text{air-to-air}}$) = 1/ 13.48
= 0.0742 Btu/ft²·hr·°F

$R_{\text{surface-to-surface}}$ = 1.20 + 9.849 + 1.50
= 12.55 ft²·hr·°F/Btu

The term C-value is commonly associated with the reciprocal of $R_{\text{surface-to-surface}}$.
In some cases this is called the surface-to-surface U-value.

C-value = 1/12.55 = 0.0797 Btu/ft²·hr·°F

This example contains eight R-values, a U-value, and a C-value. A diagram or description of the system is essential for understanding what the various “values” represent.

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