As cavity width increases, the thermal resistance of a confined air space reaches a point where increases in convection heat transfer balance out with decreases in radiative heat transfer. As a result, under most conditions found in building construction, the thermal resistance of a confined air space between nonreflective surfaces is very nearly 1.0 hr · °F · ft^2/Btu (0.176°C · m^2/W). The exception is for cases with very narrow confined air spaces and spaces where one or both confining surfaces is highly reflective.

Total Thermal Resistance

A building structure is composed of different materials that make a construction assembly. For example, a simple residential wall assembly may be constructed of siding, sheathing, studs, insulation, vapor diffusion retarder, and gypsum wallboard. With respect to heat transfer, a construction assembly is considered to act either in series or parallel. When materials are assembled one on top of the other, they are constructed in series. When a construction assembly is constructed in parallel, the thermal conductance values for each material are added and the total energy flow is increased for a given temperature difference. (The concept of parallel flow is introduced later in this chapter.)

The *total thermal resistance (R_t)* is the insulating ability of a construction assembly of materials (e.g., wall, ceiling, floor, roof) or fenestration (e.g., doors, windows), including air films. The total thermal resistance of a construction assembly of materials in series is determined by adding the thermal resistances of each component, including materials, confined air spaces, and surface air films:

$$R_t = R_1 + R_2 + R_3 + \cdots$$

The thermal resistances (R) of a specific material, air space, or boundary air film for each of the various components of a building section are obtained, and then added together to compute the total R-value for the specific construction assembly. Note that k- and C-values for each of the components may not be added. These values must first be converted to an R-value before being added with the R-values of the other components.

Overall Coefficient of Heat Transmission

The *overall coefficient of heat transmission (U)* is the ability of a construction assembly to transfer heat, from exterior to exterior, including air films. The U-factor is the reciprocal of the total thermal resistance of the construction assembly:

$$U = 1/R_t$$

One way to lower the amount of heat transfer through the building envelope is to increase R_t (or decrease U). The only practical means of doing this is to add insulation. Materials used as insulation significantly retard the flow of heat because of their high R-values (or low k-values). Selection of the appropriate R_t is based on temperature difference, cost of insulation, and cost of fuel.

TABLE 2.8 THE RELATIONSHIP BETWEEN TOTAL THERMAL RESISTANCE (R_t) AND THE OVERALL COEFFICIENT OF HEAT TRANSMISSION (U).

Total Thermal R (R_t) $\frac{\text{hr} \cdot °\text{F} \cdot \text{ft}^2}{\text{Btu}}$	Overall Coefficient of Heat Transfer (U) $\frac{\text{Btu}}{\text{hr} \cdot °\text{F} \cdot \text{ft}^2}$	Percentage of Heat Transfer over an R-Value of 1.0
1.0	1.000	100.0%
1.1	0.909	90.9%
1.2	0.833	83.3%
1.3	0.769	76.9%
1.4	0.714	71.4%
1.5	0.667	66.7%
2.0	0.500	50.0%
2.5	0.400	40.0%
3.0	0.333	33.3%
4.0	0.250	25.0%
5.0	0.200	20.0%
6.0	0.167	16.7%
7.0	0.143	14.3%
8.0	0.125	12.5%
9.0	0.111	11.1%
10.0	0.100	10.0%
12.0	0.083	8.3%
15.0	0.067	6.7%
20.0	0.050	5.0%
25.0	0.040	4.0%
30.0	0.033	3.3%
33.0	0.030	3.0%
40.0	0.025	2.5%
50.0	0.020	2.0%
60.0	0.017	1.7%
75.0	0.013	1.3%
100.0	0.010	1.0%

The relationship between values of total thermal resistance (R_t) and the overall coefficient of heat transfer (U) is shown in Table 2.8. A graph of the relationship between total thermal resistance (R_t) and the overall coefficient of heat transfer (U) is provided in Figure 2.4.

Example 2.12

An insulated wall is composed of ½ in wood bevel siding, ½ in plywood sheathing, 3½ in fiberglass insulation, a vapor retarder (plastic film), and ½ in gypsum board. See Figure 2.5. Determine the R_t-value and U-factor for this wall under winter conditions.

The following R-values are found:

Outside air film, 15 mph wind (from Table 2.6)	0.17 hr · °F · ft^2/Btu
½ in wood bevel siding (from Table 2.4)	0.81 hr · °F · ft^2/Btu
½ in plywood sheathing (from Table 2.4)	0.62 hr · °F · ft^2/Btu