Answer to Essential Question 13.6: The conversion factors we need here include 1 BTU = 1055 J; 1 h = 3600 s; 1 m = 3.281 ft; and a change of 1 K is equivalent to a change of 1.8°F. Putting all this together gives us an overall conversion factor of:

$$1\frac{°\text{F h ft}^2}{\text{BTU}} \times \frac{1\text{ K}}{1.8°\text{F}} \times \frac{3600\text{ s}}{1\text{ h}} \times \left(\frac{1\text{ m}}{3.281\text{ ft}}\right)^2 \times \frac{1\text{ BTU}}{1055\text{ J}} = 0.1761\frac{\text{K m}^2}{\text{W}}.$$

Converting 15 °F h ft^2 / BTU requires multiplying the 15 by the conversion factor above, giving an R-value of 2.64 K m^2 / W.

Chapter Summary

Essential Idea: Understanding thermal expansion and energy transfer

In this chapter, we applied simple models to help us understand thermal expansion (the change in size an object experiences when its temperature changes) and energy transfer, especially the process of thermal conduction (energy transferred through a solid object because of a temperature difference).

Temperature scales

Temperature can be measured on various scales. Among the more common temperature scales are the Fahrenheit scale, used in daily life in the United States; the Celsius scale used in daily life in the rest of the world; and the Kelvin scale, which is used in scientific work.

$$T_C = \left(\frac{5°\text{C}}{9°\text{F}}\right)(T_F - 32°\text{F}).$$ (Equation 13.1: **Converting from Fahrenheit to Celsius**)

$$T_F = 32°\text{F} + \left(\frac{9°\text{F}}{5°\text{C}}\right)T_C.$$ (Equation 13.2: **Converting from Celsius to Fahrenheit**)

$$T_C = T_K - 273.16°.$$ (Equation 13.3: **Converting from Kelvin to Celsius**)

Thermal Expansion

When an object's temperature changes, its dimensions also generally change, with most materials expanding as the temperature increases. The model we applied to understand this assumes that each dimension of the object experiences a change in length that depends on the change in temperature, the initial length L_i, and the material the object is made from.

$$\Delta L = L_i \, \alpha \, \Delta T ,$$ (Equation 13.4: **Length change from thermal expansion**)

where α is the thermal expansion coefficient, which depends on the material.

Equations giving the new length, area, or volume are:

$$L = L_i + L_i\alpha\,\Delta T = L_i\left(1+\alpha\,\Delta T\right).$$ (Equation 13.5: **Length thermal expansion**)

$$A = A_0\left(1+2\alpha\,\Delta T\right).$$ (Equation 13.6: **Area thermal expansion**)

$$V = V_0\left(1 + 3\alpha\,\Delta T\right).$$ (Equation 13.7: **Volume thermal expansion**)

A General Method for Solving a Thermal Equilibrium Problem

1. Write out in words a brief description of the various heats involved. This helps to keep track of all the terms.
2. Use the equation $\sum Q = 0$ to write out an equation of the form $Q_1 + Q_2 + \ldots = 0$, where each Q corresponds to one of the brief descriptions you wrote in step 1.
3. Use the equation $Q = m\,c\,\Delta T$ to write expressions for each Q associated with a change in temperature. Express each ΔT as $T_{final} - T_{initial}$ and the sign of that heat term will be built into that temperature change.
4. Use the equation $Q = m\,L_f$ or $Q = m\,L_v$ to write an expression for the heat associated with a change of phase. Use a plus sign if heat must be added to produce the phase change (melting or vaporizing) and a negative sign if heat must be removed (solidifying or condensing).
5. Solve the resulting equation for the unknown.

The method above applies when no heat is transferred between a system and its surroundings. If heat is transferred into or out of a system, we can say that $\sum Q = q$, where q represents heat added to (q is positive) or removed from (q is negative) the system.

Energy-Transfer Mechanisms

Three mechanisms of energy transfer, driven by temperature differences, include:

1. Convection - energy is carried by a flowing fluid.

2. Thermal radiation – energy is given off in the form of electromagnetic radiation. Power radiated by an object is strongly dependent on how its temperature compares to the temperature of its surroundings.

$$P_{net} = P_{radiated} - P_{absorbed} = A\varepsilon\sigma\left(T^4 - T_{env}^4\right),$$ (Equation 13.12: **Net radiated power**)

Where T_{env} is the temperature of the surrounding environment; A is the surface area of the object; the Stefan-Boltzmann constant σ has a value $\sigma = 5.67\times10^{-8}\ \mathrm{W/m^2}$; and ε is known as the emissivity, which depends on the object. If an object readily absorbs or emits radiation then its emissivity is close to 1.

3. Thermal conduction – energy is transferred through a material by the vibrations of atoms and molecules. The rate at which energy is transferred (i.e., the power, P) through a slab of area A, thermal conductivity k, and thickness L is:

$$P = \frac{k\,A}{L}\left(T_H - T_L\right).$$ (Equation 13.13: **Thermal conduction**)

T_H is the temperature at the higher-temperature face of the slab, while T_L is the temperature at the lower-temperature face.