1-30 A room is heated by the radiator, and the warm air is distributed by a fan. Heat is lost from the room. The time it takes for the air temperature to rise to 20°C is to be determined.

**Assumptions**
1. Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa.
2. The kinetic and potential energy changes are negligible, \( \Delta ke \equiv \Delta pe \equiv 0 \).
3. Constant specific heats at room temperature can be used for air, \( C_p = 1.007 \) and \( C_v = 0.720 \) kJ/kg·K. This assumption results in negligible error in heating and air-conditioning applications.
4. The local atmospheric pressure is 100 kPa.

**Properties**
The gas constant of air is \( R = 0.287 \) kPa·m³/kg·K (Table A-1). Also, \( C_p = 1.007 \) kJ/kg·K for air at room temperature (Table A-15).

**Analysis**
We take the air in the room as the system. This is a closed system since no mass crosses the system boundary during the process. We observe that the pressure in the room remains constant during this process. Therefore, some air will leak out as the air expands. However, we can take the air to be a closed system by considering the air in the room to have undergone a constant pressure process. The energy balance for this system can be expressed as

\[
\dot{E}_{in} - \dot{E}_{out} = \Delta E_{system} = \Delta E = m(h_2 - h_1) \equiv mC_p(T_2 - T_1)
\]

The mass of air is

\[
\frac{V}{m} = \frac{4 \times 5 \times 7}{(100 \text{ kPa})(140 \text{ m}^3)} = \frac{(0.287 \text{ kPa·m}^3/\text{kg·K})(283 \text{ K})}{172.4 \text{ kg}} = 172.4 \text{ kg}
\]

Using the \( C_p \) value at room temperature,

\[
[(10,000 - 5000)/3600 \text{ kJ/s} + 0.1 \text{ kJ/s}] \Delta t = (172.4 \text{ kg})(1.007 \text{ kJ/kg·°C})(20 - 10)°\text{C}
\]

It yields

\[
\Delta t = 1163 \text{ s}
\]

1-41 The ducts of an air heating system pass through an unheated area, resulting in a temperature drop of the air in the duct. The rate of heat loss from the air to the cold environment is to be determined.

**Assumptions**
1. Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa.
2. The kinetic and potential energy changes are negligible, \( \Delta ke \equiv \Delta pe \equiv 0 \).
3. Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications.

**Properties**
The specific heat of air at room temperature is \( C_p = 1.007 \) kJ/kg·°C (Table A-15).

**Analysis**
We take the heating duct as the system. This is a control volume since mass crosses the system boundary during the process. We observe that this is a steady-flow process since there is no change with time at any point and thus \( \Delta m_{CV} = 0 \) and \( \Delta E_{CV} = 0 \). Also, there is only one inlet and one exit and thus \( \dot{m}_1 = \dot{m}_2 = \dot{m} \).

The energy balance for this steady-flow system can be expressed in the rate form as

\[
\dot{E}_{in} - \dot{E}_{out} = \Delta E_{system} = \Delta E = \dot{m}(h_2 - h_1) = \dot{m}C_p(T_2 - T_1)
\]

Substituting,

\[
\dot{Q}_{out} = \dot{m}C_p \Delta T = (120 \text{ kg/min})(1.007 \text{ kJ/kg·°C})(30°\text{C}) = 363 \text{ kJ/min}
\]
1-43 Water is heated in an insulated tube by an electric resistance heater. The mass flow rate of water through the heater is to be determined.

**Assumptions**
1. Water is an incompressible substance with a constant specific heat.
2. The kinetic and potential energy changes are negligible, $\Delta ke \equiv \Delta pe \equiv 0$.
3. Heat loss from the insulated tube is negligible.

**Properties**
The specific heat of water at room temperature is $C_p = 4.18 \text{ kJ/kg} \cdot ^\circ\text{C}$ (Table A-9).

**Analysis**
We take the tube as the system. This is a control volume since mass crosses the system boundary during the process. We observe that this is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$, there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$, and the tube is insulated. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{system} = 0 \quad \Rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{e,in} + \dot{m}h_1 = \dot{m}h_2 \quad \text{(since $\Delta ke \equiv \Delta pe \equiv 0$)}$$

Thus,

$$\dot{m} = \frac{\dot{W}_{e,in}}{C_p(T_2 - T_1)} = \frac{7 \text{ kJ/s}}{(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})(70 - 15) ^\circ\text{C}} = 0.0304 \text{ kg/s}$$

1-62 The inner and outer surfaces of a brick wall are maintained at specified temperatures. The rate of heat transfer through the wall is to be determined.

**Assumptions**
1. Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values.
2. Thermal properties of the wall are constant.

**Properties**
The thermal conductivity of the wall is given to be $k = 0.69 \text{ W/m} \cdot ^\circ\text{C}$.

**Analysis**
Under steady conditions, the rate of heat transfer through the wall is

$$\dot{Q}_{cond} = kA \frac{\Delta T}{L} = (0.69 \text{ W/m} \cdot ^\circ\text{C})(5 \times 6 \text{ m}^2)(20 - 5) ^\circ\text{C} = 1035 \text{ W}$$

1-82 Two surfaces of a flat plate are maintained at specified temperatures, and the rate of heat transfer through the plate is measured. The thermal conductivity of the plate material is to be determined.

**Assumptions**
1. Steady operating conditions exist since the surface temperatures of the plate remain constant at the specified values.
2. Heat transfer through the plate is one-dimensional.
3. Thermal properties of the plate are constant.

**Analysis**
The thermal conductivity is determined directly from the steady one-dimensional heat conduction relation to be

$$\dot{Q} = kA \frac{T_1 - T_2}{L} \quad \Rightarrow \quad k = \frac{\dot{Q} / A}{L(T_1 - T_2)} = \frac{500 \text{ W/m}^2 \cdot ^\circ\text{C}}{(0.02 \text{ m})(80 - 0) ^\circ\text{C}} = 313 \text{ W/m} \cdot ^\circ\text{C}$$
A person with a specified surface temperature is subjected to radiation heat transfer in a room at specified wall temperatures. The rate of radiation heat loss from the person is to be determined.

**Assumptions**
1. Steady operating conditions exist.
2. Heat transfer by convection is disregarded.
3. The emissivity of the person is constant and uniform over the exposed surface.

**Properties**
The average emissivity of the person is given to be 0.7.

**Analysis**
Noting that the person is completely enclosed by the surrounding surfaces, the net rates of radiation heat transfer from the body to the surrounding walls, ceiling, and the floor in both cases are

(a) \( T_{\text{surr}} = 300 \text{ K} \)
\[
\dot{Q}_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4) \\
= (0.7)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(1.7 \text{ m}^2)((32 + 273)^4 - (300 \text{ K})^4)K^4 \\
= 37.4 \text{ W}
\]

(b) \( T_{\text{surr}} = 280 \text{ K} \)
\[
\dot{Q}_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4) \\
= (0.7)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(1.7 \text{ m}^2)((32 + 273)^4 - (280 \text{ K})^4)K^4 \\
= 169 \text{ W}
\]

**Discussion**
Note that the radiation heat transfer goes up by more than 4 times as the temperature of the surrounding surfaces drops from 300 K to 280 K.