Chapter 1
BASICS OF HEAT TRANSFER

Thermodynamics and Heat Transfer

1-1C Thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another. Heat transfer, on the other hand, deals with the rate of heat transfer as well as the temperature distribution within the system at a specified time.

1-2C (a) The driving force for heat transfer is the temperature difference. (b) The driving force for electric current flow is the electric potential difference (voltage). (a) The driving force for fluid flow is the pressure difference.

1-3C The caloric theory is based on the assumption that heat is a fluid-like substance called the "caloric" which is a massless, colorless, odorless substance. It was abandoned in the middle of the nineteenth century after it was shown that there is no such thing as the caloric.

1-4C The *rating* problems deal with the determination of the *heat transfer rate* for an existing system at a specified temperature difference. The *sizing* problems deal with the determination of the *size* of a system in order to transfer heat at a *specified rate* for a *specified temperature difference*.

1-5C The experimental approach (testing and taking measurements) has the advantage of dealing with the actual physical system, and getting a physical value within the limits of experimental error. However, this approach is expensive, time consuming, and often impractical. The analytical approach (analysis or calculations) has the advantage that it is fast and inexpensive, but the results obtained are subject to the accuracy of the assumptions and idealizations made in the analysis.

1-6C Modeling makes it possible to predict the course of an event before it actually occurs, or to study various aspects of an event mathematically without actually running expensive and time-consuming experiments. When preparing a mathematical model, all the variables that affect the phenomena are identified, reasonable assumptions and approximations are made, and the interdependence of these variables are studied. The relevant physical laws and principles are invoked, and the problem is formulated mathematically. Finally, the problem is solved using an appropriate approach, and the results are interpreted.

1-7C The right choice between a crude and complex model is usually the *simplest* model which yields *adequate* results. Preparing very accurate but complex models is not necessarily a better choice since such models are not much use to an analyst if they are very difficult and time consuming to solve. At the minimum, the model should reflect the essential features of the physical problem it represents.

Heat and Other Forms of Energy

1-8C The rate of heat transfer per unit surface area is called heat flux $\dot{q}$. It is related to the rate of heat transfer by $\dot{Q} = \int_A \dot{q} dA$.

1-9C Energy can be transferred by heat, work, and mass. An energy transfer is heat transfer when its driving force is temperature difference.

1-10C Thermal energy is the sensible and latent forms of internal energy, and it is referred to as heat in daily life.

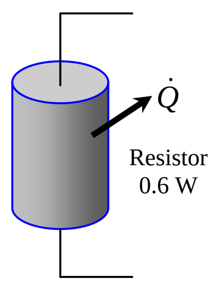
1-11C For the constant pressure case. This is because the heat transfer to an ideal gas is $mC_p\Delta T$ at constant pressure and $mC_p\Delta T$ at constant volume, and C_p is always greater than C_v.

1-12 A cylindrical resistor on a circuit board dissipates 0.6 W of power. The amount of heat dissipated in 24 h, the heat flux, and the fraction of heat dissipated from the top and bottom surfaces are to be determined.

Assumptions Heat is transferred uniformly from all surfaces.

Analysis (*a*) The amount of heat this resistor dissipates during a 24-hour period is

$$Q = \dot{Q}\Delta t = (0.6 \text{ W})(24 \text{ h}) = \mathbf{14.4 \text{ Wh} = 51.84 \text{ kJ}} \quad \text{(since 1 Wh = 3600 Ws = 3.6 kJ)}$$



(*b*) The heat flux on the surface of the resistor is

$$A_s = 2\frac{\pi D^2}{4} + \pi DL = 2\frac{\pi(0.4 \text{ cm})^2}{4} + \pi(0.4 \text{ cm})(1.5\text{cm}) = 0.251 + 1.885 = 2.136 \text{ cm}^2$$

$$\dot{q}_s = \frac{\dot{Q}}{A_s} = \frac{0.60 \text{ W}}{2.136 \text{ cm}^2} = \mathbf{0.2809 \text{ W/cm}^2}$$

(*c*) Assuming the heat transfer coefficient to be uniform, heat transfer is proportional to the surface area. Then the fraction of heat dissipated from the top and bottom surfaces of the resistor becomes

$$\frac{Q_{\text{top-base}}}{Q_{\text{total}}} = \frac{A_{\text{top-base}}}{A_{\text{total}}} = \frac{0.251}{2.136} = \mathbf{0.118} \quad \text{or} \quad (11.8\%)$$

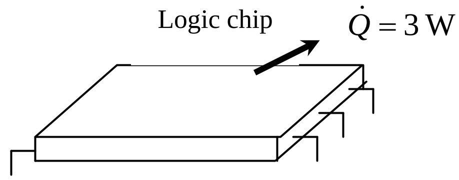
Discussion Heat transfer from the top and bottom surfaces is small relative to that transferred from the side surface.

1-13E A logic chip in a computer dissipates 3 W of power. The amount heat dissipated in 8 h and the heat flux on the surface of the chip are to be determined.

Assumptions Heat transfer from the surface is uniform.

Analysis (*a*) The amount of heat the chip dissipates during an 8-hour period is

$$Q = \dot{Q}\Delta t = (3 \text{ W})(8 \text{ h}) = 24 \text{ Wh} = \mathbf{0.024 \text{ kWh}}$$



(*b*) The heat flux on the surface of the chip is

$$\dot{q}_s = \frac{\dot{Q}}{A_s} = \frac{3 \text{ W}}{0.08 \text{ in}^2} = \mathbf{37.5 \text{ W/in}^2}$$

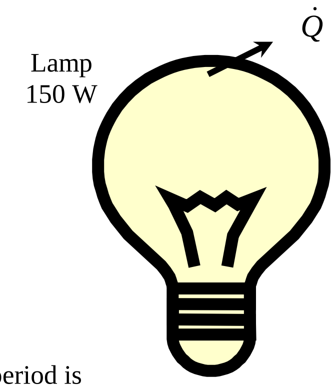
1-14 The filament of a 150 W incandescent lamp is 5 cm long and has a diameter of 0.5 mm. The heat flux on the surface of the filament, the heat flux on the surface of the glass bulb, and the annual electricity cost of the bulb are to be determined.

Assumptions Heat transfer from the surface of the filament and the bulb of the lamp is uniform .

Analysis (*a*) The heat transfer surface area and the heat flux on the surface of the filament are

$$A_s = \pi DL = \pi(0.05 \text{ cm})(5 \text{ cm}) = 0.785 \text{ cm}^2$$

$$\dot{q}_s = \frac{\dot{Q}}{A_s} = \frac{150 \text{ W}}{0.785 \text{ cm}^2} = 191 \text{ W/cm}^2 = \mathbf{1.91 \times 10^6 \text{ W/m}^2}$$



(*b*) The heat flux on the surface of glass bulb is

$$A_s = \pi D^2 = \pi(8 \text{ cm})^2 = 201.1 \text{ cm}^2$$

$$\dot{q}_s = \frac{\dot{Q}}{A_s} = \frac{150 \text{ W}}{201.1 \text{ cm}^2} = 0.75 \text{ W/cm}^2 = \mathbf{7500 \text{ W/m}^2}$$

(*c*) The amount and cost of electrical energy consumed during a one-year period is

$$\text{Electricity Consumption} = \dot{Q}\Delta t = (0.15 \text{ kW})(365 \times 8 \text{ h / yr}) = 438 \text{ kWh / yr}$$

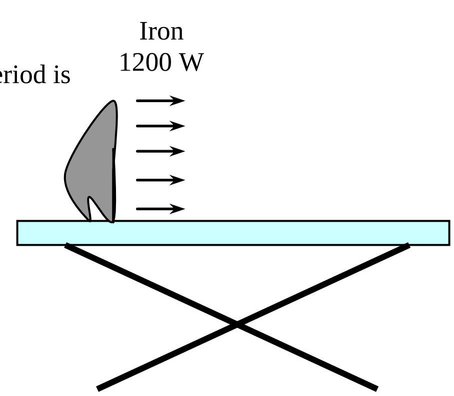
$$\text{Annual Cost} = (438 \text{ kWh / yr})(\$0.08 \text{ / kWh}) = \mathbf{\$35.04 \text{ / yr}}$$

1-15 A 1200 W iron is left on the ironing board with its base exposed to the air. The amount of heat the iron dissipates in 2 h, the heat flux on the surface of the iron base, and the cost of the electricity are to be determined.

Assumptions Heat transfer from the surface is uniform.

Analysis (*a*) The amount of heat the iron dissipates during a 2-h period is

$$Q = \dot{Q}\Delta t = (1.2 \text{ kW})(2 \text{ h}) = \mathbf{2.4 \text{ kWh}}$$



(*b*) The heat flux on the surface of the iron base is

$$\dot{Q}_{\text{base}} = (0.9)(1200 \text{ W}) = 1080 \text{ W}$$

$$\dot{q} = \frac{\dot{Q}_{\text{base}}}{A_{\text{base}}} = \frac{1080 \text{ W}}{0.015 \text{ m}^2} = \mathbf{72{,}000 \text{ W / m}^2}$$

(*c*) The cost of electricity consumed during this period is

$$\text{Cost of electricity} = (2.4 \text{ kWh}) \times (\$0.07 \text{ / kWh}) = \mathbf{\$0.17}$$

1-16 A 15 cm × 20 cm circuit board houses 120 closely spaced 0.12 W logic chips. The amount of heat dissipated in 10 h and the heat flux on the surface of the circuit board are to be determined.

Assumptions **1** Heat transfer from the back surface of the board is negligible. **2** Heat transfer from the front surface is uniform.

Analysis (*a*) The amount of heat this circuit board dissipates during a 10-h period is

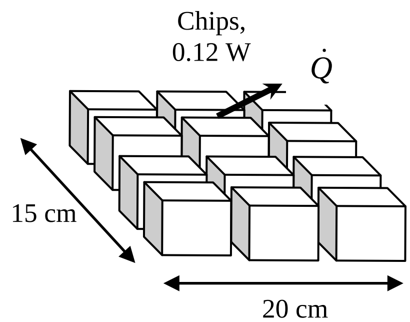
$$\dot{Q} = (120)(0.12\text{ W}) = 14.4\text{ W}$$

$$Q = \dot{Q}\Delta t = (0.0144\text{ kW})(10\text{h}) = \mathbf{0.144\,kWh}$$

(*b*) The heat flux on the surface of the circuit board is

$$A_s = (0.15\text{ m})(0.2\text{ m}) = 0.03\text{m}^2$$

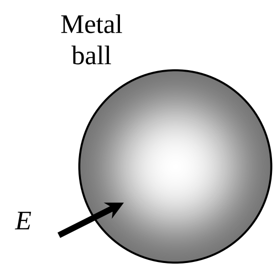
$$\dot{q}_s = \frac{\dot{Q}}{A_s} = \frac{14.4\text{ W}}{0.03\text{m}^2} = \mathbf{480\ W/m^2}$$



1-17 An aluminum ball is to be heated from 80°C to 200°C. The amount of heat that needs to be transferred to the aluminum ball is to be determined.

Assumptions The properties of the aluminum ball are constant.

Properties The average density and specific heat of aluminum are given to be ρ = 2,700 kg/m^3 and $C_p = 0.90$ kJ/kg.°C.



Analysis The amount of energy added to the ball is simply the change in its internal energy, and is determined from

$$E_{\text{transfer}} = \Delta U = mC(T_2 - T_1)$$

where

$$m = \rho V = \frac{\pi}{6}\rho D^3 = \frac{\pi}{6}(2700\text{ kg/m}^3)(0.15\text{ m})^3 = 4.77\text{ kg}$$

Substituting,

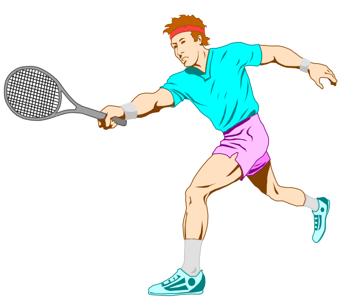
$$E_{\text{transfer}} = (4.77\text{ kg})(0.90\text{ kJ/kg.}^\circ\text{C})(200-80)^\circ\text{C} = \mathbf{515\ kJ}$$

Therefore, 515 kJ of energy (heat or work such as electrical energy) needs to be transferred to the aluminum ball to heat it to 200°C.

1-18 The body temperature of a man rises from 37°C to 39°C during strenuous exercise. The resulting increase in the thermal energy content of the body is to be determined.

Assumptions The body temperature changes uniformly.

Properties The average specific heat of the human body is given to be 3.6 kJ/kg.°C.



Analysis The change in the sensible internal energy content of the body as a result of the body temperature rising 2°C during strenuous exercise is

$$\Delta U = mC\Delta T = (70\text{ kg})(3.6\text{ kJ/kg.°C})(2\text{°C}) = \mathbf{504\ kJ}$$

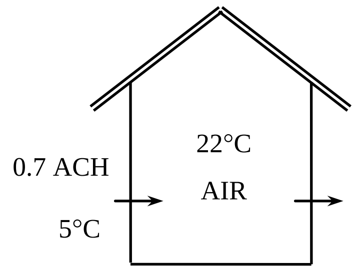
1-19 An electrically heated house maintained at 22°C experiences infiltration losses at a rate of 0.7 ACH. The amount of energy loss from the house due to infiltration per day and its cost are to be determined.

Assumptions **1** Air as an ideal gas with a constant specific heats at room temperature. **2** The volume occupied by the furniture and other belongings is negligible. **3** The house is maintained at a constant temperature and pressure at all times. **4** The infiltrating air exfiltrates at the indoors temperature of 22°C.

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

Analysis The volume of the air in the house is

$$V = \text{(floor space)(height)} = (200\ \text{m}^2)(3\ \text{m}) = 600\ \text{m}^3$$



Noting that the infiltration rate is 0.7 ACH (air changes per hour) and thus the air in the house is completely replaced by the outdoor air 0.7×24 = 16.8 times per day, the mass flow rate of air through the house due to infiltration is

$$\dot{m}_{\text{air}} = \frac{P_o \dot{V}_{\text{air}}}{RT_o} = \frac{P_o(\text{ACH} \times V_{\text{house}})}{RT_o}$$
$$= \frac{(89.6\ \text{kPa})(16.8 \times 600\ \text{m}^3/\text{day})}{(0.287\ \text{kPa.m}^3/\text{kg.K})(5+273.15\text{K})} = 11{,}314\ \text{kg/day}$$

Noting that outdoor air enters at 5°C and leaves at 22°C, the energy loss of this house per day is

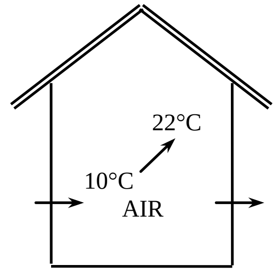
$$\dot{Q}_{\text{infilt}} = \dot{m}_{\text{air}} C_{\text{p}} (T_{\text{indoors}} - T_{\text{outdoors}})$$
$$= (11{,}314\ \text{kg/day})(1.007\ \text{kJ/kg.°C})(22-5)\text{°C} = 193{,}681\ \text{kJ/day} = \mathbf{53.8\ kWh/day}$$

At a unit cost of \$0.082/kWh, the cost of this electrical energy lost by infiltration is

$$\text{Enegy Cost} = \text{(Energy used)(Unit cost of energy)} = (53.8\ \text{kWh/day})(\$0.082/\text{kWh}) = \mathbf{\$4.41/day}$$

1-20 A house is heated from 10°C to 22°C by an electric heater, and some air escapes through the cracks as the heated air in the house expands at constant pressure. The amount of heat transfer to the air and its cost are to be determined.

Assumptions **1** Air as an ideal gas with a constant specific heats at room temperature. **2** The volume occupied by the furniture and other belongings is negligible. **3** The pressure in the house remains constant at all times. **4** Heat loss from the house to the outdoors is negligible during heating. **5** The air leaks out at 22°C.



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

Analysis The volume and mass of the air in the house are

$$V = (\text{floor space})(\text{height}) = (200\ \text{m}^2)(3\ \text{m}) = 600\ \text{m}^3$$

$$m = \frac{PV}{RT} = \frac{(101.3\ \text{kPa})(600\ \text{m}^3)}{(0.287\ \text{kPa.m}^3/\text{kg.K})(10+273.15\ \text{K})} = 747.9\ \text{kg}$$

Noting that the pressure in the house remains constant during heating, the amount of heat that must be transferred to the air in the house as it is heated from 10 to 22°C is determined to be

$$Q = mC_p(T_2 - T_1) = (747.9\ \text{kg})(1.007\ \text{kJ/kg.°C})(22-10)\text{°C} = \mathbf{9038\ kJ}$$

Noting that 1 kWh = 3600 kJ, the cost of this electrical energy at a unit cost of $0.075/kWh is

$$\text{Enegy Cost} = (\text{Energy used})(\text{Unit cost of energy}) = (9038/3600\ \text{kWh})(\$0.075/\text{kWh}) = \mathbf{\$0.19}$$

Therefore, it will cost the homeowner about 19 cents to raise the temperature in his house from 10 to 22°C.

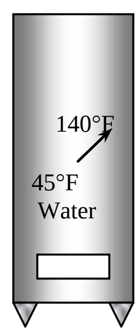
1-21E A water heater is initially filled with water at 45°F. The amount of energy that needs to be transferred to the water to raise its temperature to 140°F is to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats at room temperature. **2** No water flows in or out of the tank during heating.

Properties The density and specific heat of water are given to be 62 lbm/ft^3 and 1.0 Btu/lbm.°F.

Analysis The mass of water in the tank is

$$m = \rho V = (62\ \text{lbm/ft}^3)(60\ \text{gal})\left(\frac{1\ \text{ft}^3}{7.48\ \text{gal}}\right) = 497.3\ \text{lbm}$$



Then, the amount of heat that must be transferred to the water in the tank as it is heated from 45 to140°F is determined to be

$$Q = mC(T_2 - T_1) = (497.3\ \text{lbm})(1.0\ \text{Btu/lbm.°F})(140-45)\text{°F} = \mathbf{47{,}250\ Btu}$$

The First Law of Thermodynamics

1-22C Warmer. Because energy is added to the room air in the form of electrical work.

1-23C Warmer. If we take the room that contains the refrigerator as our system, we will see that electrical work is supplied to this room to run the refrigerator, which is eventually dissipated to the room as waste heat.

1-24C Mass flow rate $\dot{m}$ is the amount of mass flowing through a cross-section per unit time whereas the volume flow rate $\dot{V}$ is the amount of volume flowing through a cross-section per unit time. They are related to each other by $\dot{m} = \rho\dot{V}$ where ρ is density.

1-25 Two identical cars have a head-on collusion on a road, and come to a complete rest after the crash. The average temperature rise of the remains of the cars immediately after the crash is to be determined.

Assumptions **1** No heat is transferred from the cars. **2** All the kinetic energy of cars is converted to thermal energy.

Properties The average specific heat of the cars is given to be 0.45 kJ/kg.°C.

Analysis We take both cars as the system. This is a *closed system* since it involves a fixed amount of mass (no mass transfer). Under the stated assumptions, the energy balance on the system can be expressed as

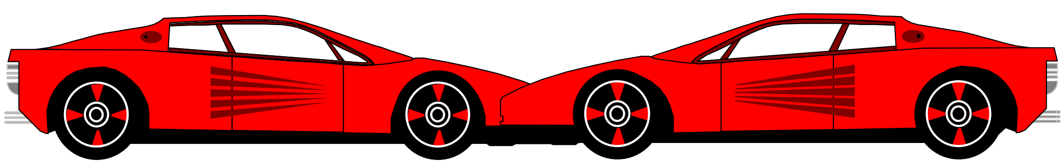
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$0 = \Delta U_{\text{cars}} + \Delta KE_{\text{cars}}$$

$$0 = (mC\Delta T)_{\text{cars}} + [m(0 - V^2)/2]_{\text{cars}}$$

That is, the decrease in the kinetic energy of the cars must be equal to the increase in their internal energy. Solving for the velocity and substituting the given quantities, the temperature rise of the cars becomes

$$\Delta T = \frac{mV^2/2}{mC} = \frac{V^2/2}{C} = \frac{(90{,}000/3600\,\text{m/s})^2/2}{0.45\,\text{kJ/kg.°C}}\left(\frac{1\,\text{kJ/kg}}{1000\,\text{m}^2/\text{s}^2}\right) = \mathbf{0.69°C}$$

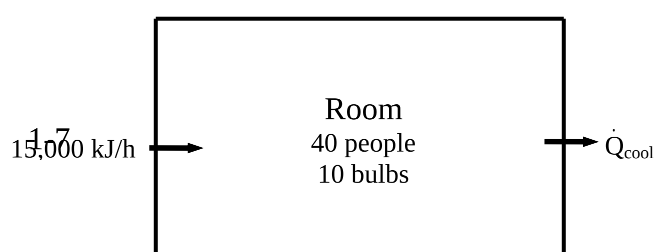


1-26 A classroom is to be air-conditioned using window air-conditioning units. The cooling load is due to people, lights, and heat transfer through the walls and the windows. The number of 5-kW window air conditioning units required is to be determined.

Assumptions There are no heat dissipating equipment (such as computers, TVs, or ranges) in the room.

Analysis The total cooling load of the room is determined from

$$\dot{Q}_{\text{cooling}} = \dot{Q}_{\text{lights}} + \dot{Q}_{\text{people}} + \dot{Q}_{\text{heat gain}}$$



where

$$\dot{Q}_{\text{lights}} = 10 \times 100\ \text{W} = 1\ \text{kW}$$

$$\dot{Q}_{\text{people}} = 40 \times 360\text{kJ/h} = 14{,}400\ \text{kJ/h} = 4\text{kW}$$

$$\dot{Q}_{\text{heatgain}} = 15{,}000\ \text{kJ/h} = 4.17\ \text{kW}$$

Substituting, $\dot{Q}_{\text{cooling}} = 1 + 4 + 4.17 = 9.17\ \text{kW}$

Thus the number of air-conditioning units required is

$$\frac{9.17\ \text{kW}}{5\ \text{kW/unit}} = 1.83 \longrightarrow \mathbf{2\ units}$$

1-27E The air in a rigid tank is heated until its pressure doubles. The volume of the tank and the amount of heat transfer are 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, $\Delta pe \cong \Delta ke \cong 0$. **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 gas constant of air is R = 0.3704 psia.ft^3/lbm.R = 0.06855 Btu/lbm.R (Table A-1).

Analysis (a) We take the air in the tank as our system. This is a *closed system* since no mass enters or leaves. The volume of the tank can be determined from the ideal gas relation,

$$V = \frac{mRT_1}{P_1} = \frac{(20\text{lbm})(0.3704\text{psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(80+460\text{R})}{50\text{psia}} = \mathbf{80.0ft^3}$$

(b) Under the stated assumptions and observations, the energy balance becomes

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$Q_{in} = \Delta U \longrightarrow Q_{in} = m(u_2 - u_1) \cong mC_v(T_2 - T_1)$$

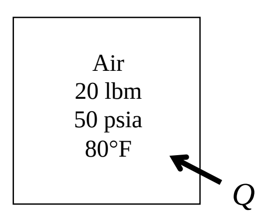
The final temperature of air is

$$\frac{P_1V}{T_1} = \frac{P_2V}{T_2} \longrightarrow T_2 = \frac{P_2}{P_1}T_1 = 2 \times (540\ \text{R}) = 1080\ R$$

The specific heat of air at the average temperature of T_{ave} = (540+1080)/2= 810 R = 350°F is

$C_{\text{v,ave}} = C_{\text{p,ave}} - R$ = 0.2433 - 0.06855 = 0.175 Btu/lbm.R. Substituting,

Q = (20 lbm)(0.175 Btu/lbm.R)(1080 - 540) R = **1890 Btu**



1-28 The hydrogen gas in a rigid tank is cooled until its temperature drops to 300 K. The final pressure in the tank and the amount of heat transfer are to be determined.

Assumptions **1** Hydrogen is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -240°C and 1.30 MPa. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$.

Properties The gas constant of hydrogen is R = 4.124 kPa.m^3/kg.K (Table A-1).

Analysis (*a*) We take the hydrogen in the tank as our system. This is a *closed system* since no mass enters or leaves. The final pressure of hydrogen can be determined from the ideal gas relation,

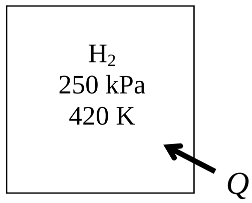
$$\frac{P_1 V}{T_1} = \frac{P_2 V}{T_2} \longrightarrow P_2 = \frac{T_2}{T_1} P_1 = \frac{300\,\text{K}}{420\,\text{K}}(250\,\text{kPa}) = \mathbf{178.6\,kPa}$$

(*b*) The energy balance for this system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$-Q_{out} = \Delta U$$

$$Q_{out} = -\Delta U = -m(u_2 - u_1) \cong mC_v(T_1 - T_2)$$



where

$$m = \frac{P_1 V}{RT_1} = \frac{(250\,\text{kPa})(1.0\,\text{m}^3)}{(4.124\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(420\,\text{K})} = 0.1443\ \text{kg}$$

Using the C_v ($=C_p - R$) = 14.516 – 4.124 = 10.392 kJ/kg.K value at the average temperature of 360 K and substituting, the heat transfer is determined to be

Q_{out} = (0.1443 kg)(10.392 kJ/kg·K)(420 - 300)K = **180.0 kJ**

1-29 A resistance heater is to raise the air temperature in the room from 7 to 25°C within 20 min. The required power rating of the resistance heater 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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. **4** Heat losses from the room are negligible.

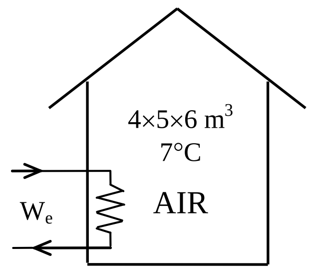
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.007 kJ/kg·K for air at room temperature (Table A-15).

Analysis 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 expansion process. The energy balance for this steady-flow system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{e,in} - W_b = \Delta U$$

$$W_{e,in} = \Delta H = m(h_2 - h_1) \cong mC_p(T_2 - T_1)$$



or,

$$\dot{W}_{e,in}\Delta t = mC_{p,ave}(T_2 - T_1)$$

The mass of air is

$$V = 4 \times 5 \times 6 = 120 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(120 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(280 \text{ K})} = 149.3 \text{ kg}$$

Using C_p value at room temperature, the power rating of the heater becomes

$$\dot{W}_{e,in} = (149.3\,\text{kg})(1.007\,\text{kJ/kg}\cdot^\circ\text{C})(25-7)^\circ\text{C}/(15\times 60\text{ s}) = \mathbf{3.01\,kW}$$

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, $\Delta ke \cong \Delta pe \cong 0$. **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.

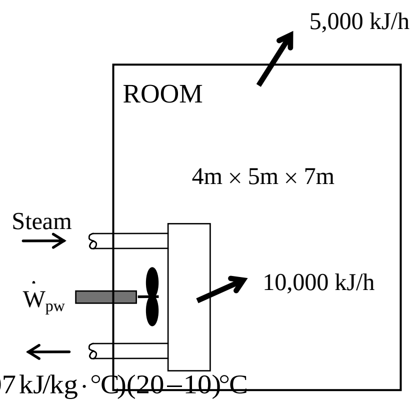
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.007 kJ/kg·K for air at room temperature (Table A-15).

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

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$Q_{in} + W_{e,in} - W_b - Q_{out} = \Delta U$$

$$(\dot{Q}_{in} + \dot{W}_{e,in} - \dot{Q}_{out})\Delta t = \Delta H = m(h_2 - h_1) \cong mC_p(T_2 - T_1)$$



The mass of air is

$$V = 4 \times 5 \times 7 = 140 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(140 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(283 \text{ K})} = 172.4 \text{ kg}$$

Using the C_p value at room temperature,

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

It yields

Δt = **1163 s**

1-31 A student living in a room turns his 150-W fan on in the morning. The temperature in the room when she comes back 10 h later 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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. **4** All the doors and windows are tightly closed, and heat transfer through the walls and the windows is disregarded.

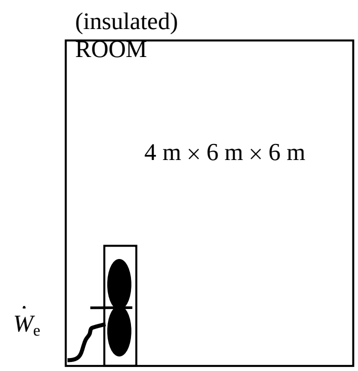
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.007 kJ/kg·K for air at room temperature (Table A-15) and $C_v = C_p - R$ = 0.720 kJ/kg·K.

Analysis We take the room as the system. This is a *closed system* since the doors and the windows are said to be tightly closed, and thus no mass crosses the system boundary during the process. The energy balance for this system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{e,in} = \Delta U$$

$$W_{e,in} = m(u_2 - u_1) \cong mC_v(T_2 - T_1)$$



The mass of air is

$$V = 4 \times 6 \times 6 = 144 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(144 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(288 \text{ K})} = 174.2 \text{ kg}$$

The electrical work done by the fan is

$$W_e = \dot{W}_e \Delta t = (0.15 \text{ kJ / s})(10 \times 3600 \text{ s}) = 5400 \text{ kJ}$$

Substituting and using C_v value at room temperature,

$$5400 \text{ kJ} = (174.2 \text{ kg})(0.720 \text{ kJ/kg.°C})(T_2 - 15)\text{°C}$$

$$T_2 = \mathbf{58.1°C}$$

1-32E A paddle wheel in an oxygen tank is rotated until the pressure inside rises to 20 psia while some heat is lost to the surroundings. The paddle wheel work done is to be determined.

Assumptions **1** Oxygen is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -181°F and 736 psia. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **3** The energy stored in the paddle wheel is negligible. **4** This is a rigid tank and thus its volume remains constant.

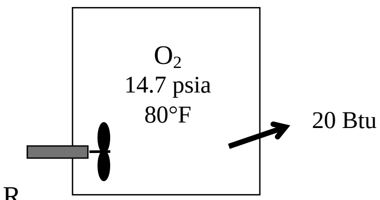
Properties The gas constant of oxygen is R = 0.3353 psia.ft^3/lbm.R = 0.06206 Btu/lbm.R (Table A-1E).

Analysis We take the oxygen in the tank as our system. This is a *closed system* since no mass enters or leaves. The energy balance for this system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$W_{pw,in} - Q_{out} = \Delta U$$

$$W_{pw,in} = Q_{out} + m(u_2 - u_1) \cong Q_{out} + mC_v(T_2 - T_1)$$



The final temperature and the number of moles of oxygen are

$$\frac{P_1 V}{T_1} = \frac{P_2 V}{T_2} \longrightarrow T_2 = \frac{P_2}{P_1} T_1 = \frac{20 \text{ psia}}{14.7 \text{ psia}}(540 \text{ R}) = 735 \text{ R}$$

$$m = \frac{P_1 V}{RT_1} = \frac{(14.7 \text{ psia})(10 \text{ ft}^3)}{(0.3353 \text{ psia} \cdot \text{ft}^3 / \text{lbmol} \cdot \text{R})(540 \text{ R})} = 0.812 \text{ lbm}$$

The specific heat ofoxygen at the average temperature of T_{ave} = (735+540)/2= 638 R = 178°F is

$C_{v,ave} = C_p - R$ = 0.2216-0.06206 = 0.160 Btu/lbm.R. Substituting,

$W_{\text{pw,in}}$ = (20 Btu) + (0.812 lbm)(0160 Btu/lbm.R)(735 - 540) Btu/lbmol = **45.3 Btu**

Discussion Note that a "cooling" fan actually causes the internal temperature of a confined space to rise. In fact, a 100-W fan supplies a room as much energy as a 100-W resistance heater.

1-33 It is observed that the air temperature in a room heated by electric baseboard heaters remains constant even though the heater operates continuously when the heat losses from the room amount to 7000 kJ/h. The power rating of the heater 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, $\Delta ke \cong \Delta pe \cong 0$. **3** We the temperature of the room remains constant during this process.

Analysis We take the room as the system. The energy balance in this case reduces to

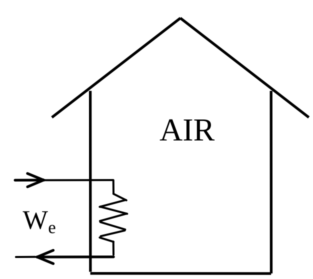
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$W_{e,in} - Q_{out} = \Delta U = 0$$

$$W_{e,in} = Q_{out}$$

since $\Delta U = mC_v\Delta T = 0$ for isothermal processes of ideal gases. Thus,

$$\dot{W}_{e,in} = \dot{Q}_{out} = 7000 \text{kJ/h}\left(\frac{1 \text{kW}}{3600 \text{kJ/h}}\right) = \mathbf{1.94\,kW}$$



1-34 A hot copper block is dropped into water in an insulated tank. The final equilibrium temperature of the tank is to be determined.

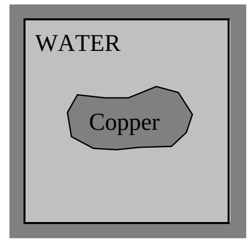
Assumptions **1** Both the water and the copper block are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$ and $\Delta E = \Delta U$. **3** The system is well-insulated and thus there is no heat transfer.

Properties The specific heats of water and the copper block at room temperature are $C_{p,\ water}$ = 4.18 kJ/kg·°C and $C_{p,\ Cu}$ = 0.386 kJ/kg·°C (Tables A-3 and A-9).

Analysis We observe that the volume of a rigid tank is constant We take the entire contents of the tank, water + copper block, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance on the system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$0 = \Delta U$$



or, $$\Delta U_{Cu} + \Delta U_{water} = 0$$

$$[mC(T_2 - T_1)]_{Cu} + [mC(T_2 - T_1)]_{water} = 0$$

Using specific heat values for copper and liquid water at room temperature and substituting,

$$(50\ \text{kg})(0.386\ \text{kJ/kg}\cdot°\text{C})(T_2 - 70)°\text{C} + (80\ \text{kg})(4.18\ \text{kJ/kg}\cdot°\text{C})(T_2 - 25)°\text{C} = 0$$

T_2 = **27.5°C**

1-35 An iron block at 100°C is brought into contact with an aluminum block at 200°C in an insulated enclosure. The final equilibrium temperature of the combined system is to be determined.

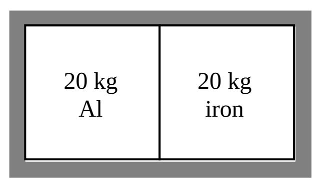
Assumptions **1** Both the iron and aluminum block are incompressible substances with constant specific heats. **2** The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$ and $\Delta E = \Delta U$. **3** The system is well-insulated and thus there is no heat transfer.

Properties The specific heat of iron is given in Table A-3 to be 0.45 kJ/kg.°C, which is the value at room temperature. The specific heat of aluminum at 450 K (which is somewhat below 200°C = 473 K) is 0.973 kJ/kg.°C.

Analysis We take the entire contents of the enclosure iron + aluminum blocks, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance on the system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$0 = \Delta U$$



$$\Delta U_{\text{iron}} + \Delta U_{\text{Al}} = 0$$

or, $$[mC(T_2 - T_1)]_{\text{iron}} + [mC(T_2 - T_1)]_{\text{Al}} = 0$$

Substituting,

$$(20\ \text{kg})(0.450\ \text{kJ / kg}\cdot°\text{C})(T_2 - 100)°\text{C} + (20\ \text{kg})(0.973\ \text{kJ / kg}\cdot°\text{C})(T_2 - 200)°\text{C} = 0$$

T_2 = **168 °C**

1-36 An unknown mass of iron is dropped into water in an insulated tank while being stirred by a 200-W paddle wheel. Thermal equilibrium is established after 25 min. The mass of the iron is to be determined.

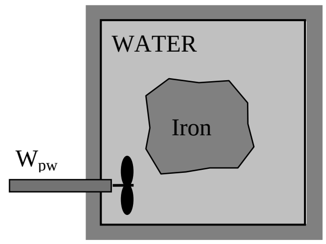
Assumptions **1** Both the water and the iron block are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$ and $\Delta E = \Delta U$. **3** The system is well-insulated and thus there is no heat transfer.

Properties The specific heats of water and the iron block at room temperature are $C_{p,\ water}$ = 4.18 kJ/kg·°C and $C_{p,\ iron}$ = 0.45 kJ/kg·°C (Tables A-3 and A-9). The density of water is given to be 1000 kg/m³.

Analysis We take the entire contents of the tank, water + iron block, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance on the system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{\text{pw,in}} = \Delta U$$



or, $$W_{\text{pw,in}} = \Delta U_{\text{iron}} + \Delta U_{\text{water}}$$

$$W_{\text{pw,in}} = [mC(T_2 - T_1)]_{\text{iron}} + [mC(T_2 - T_1)]_{\text{water}}$$

where

$$m_{\text{water}} = \rho V = (1000\ \text{kg/m}^3)(0.08\ \text{m}^3) = 80\ \text{kg}$$
$$W_{\text{pw}} = \dot{W}_{\text{pw}}\Delta t = (0.2\ \text{kJ/s})(25 \times 60\ \text{s}) = 300\ \text{kJ}$$

Using specific heat values for iron and liquid water and substituting,

$$(300\text{kJ}) = m_{\text{iron}}(0.45\,\text{kJ/kg}\cdot{}^\circ\text{C})(27-90)^\circ\text{C} + (80\ \text{kg})(4.18\,\text{kJ/kg}\cdot{}^\circ\text{C})(27-20)^\circ\text{C} = 0$$

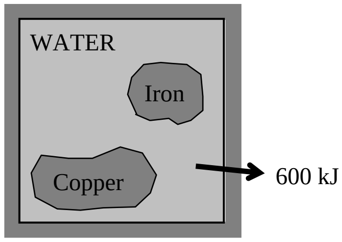
$$m_{\text{iron}} = \mathbf{72.1\ kg}$$

1-37E A copper block and an iron block are dropped into a tank of water. Some heat is lost from the tank to the surroundings during the process. The final equilibrium temperature in the tank is to be determined.

Assumptions **1** The water, iron, and copper blocks are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$ and $\Delta E = \Delta U$.

Properties The specific heats of water, copper, and the iron at room temperature are $C_{p,\ water}$ = 1.0 Btu/lbm·°F, $C_{p,\ Copper}$ = 0.092 Btu/lbm·°F, and $C_{p,\ iron}$ = 0.107 Btu/lbm·°F (Tables A-3E and A-9E).

Analysis We take the entire contents of the tank, water + iron + copper blocks, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance on the system can be expressed as



$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = \Delta U_{\text{copper}} + \Delta U_{\text{iron}} + \Delta U_{\text{water}}$$

or $$-Q_{\text{out}} = [mC(T_2 - T_1)]_{\text{copper}} + [mC(T_2 - T_1)]_{\text{iron}} + [mC(T_2 - T_1)]_{\text{water}}$$

Using specific heat values at room temperature for simplicity and substituting,

$$-600\text{Btu} = (90\text{lbm})(0.092\text{Btu/lbm}\cdot°\text{F})(T_2 - 160)°\text{F} + (50\text{lbm})(0.107\text{Btu/lbm}\cdot°\text{F})(T_2 - 200)°\text{F}$$
$$+ (180\text{lbm})(1.0\text{Btu/lbm}\cdot°\text{F})(T_2 - 70)°\text{F}$$

$$T_2 = \mathbf{74.3\ °F}$$

1-38 A room is heated by an electrical resistance heater placed in a short duct in the room in 15 min while the room is losing heat to the outside, and a 200-W fan circulates the air steadily through the heater duct. The power rating of the electric heater and the temperature rise of air in the duct are 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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. **3** Heat loss from the duct is negligible. **4** The house is air-tight and thus no air is leaking in or out of the room.

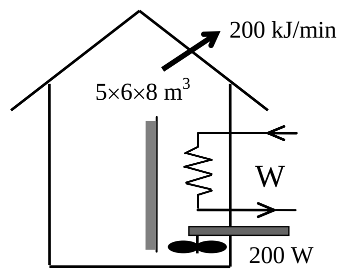
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.007 kJ/kg·K for air at room temperature (Table A-15) and $C_v = C_p - R$ = 0.720 kJ/kg·K.

Analysis (*a*) We first take the air in the room as the system. This is a constant volume *closed system* since no mass crosses the system boundary. The energy balance for the room can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{\text{e,in}} + W_{\text{fan,in}} - Q_{\text{out}} = \Delta U$$

$$(\dot{W}_{\text{e,in}} + \dot{W}_{\text{fan,in}} - \dot{Q}_{\text{out}})\Delta t = m(u_2 - u_1) \cong mC_v(T_2 - T_1)$$



The total mass of air in the room is

$$V = 5 \times 6 \times 8\text{m}^3 = 240\text{m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(98\text{kPa})(240\text{m}^3)}{(0.287\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(288\text{K})} = 284.6\text{kg}$$

Then the power rating of the electric heater is determined to be

$$\begin{aligned}\dot{W}_{\text{e,in}} &= \dot{Q}_{\text{out}} - \dot{W}_{\text{fan,in}} + mC_v(T_2 - T_1)/\Delta t \\ &= (200/60\text{kJ/s}) - (0.2\text{kJ/s}) + (284.6\text{kg})(0.720\text{ kJ/kg}\cdot{}^\circ\text{C})(25-15)^\circ\text{C}/(15\times 60\text{s}) = \mathbf{5.41\,kW}\end{aligned}$$

(*b*) The temperature rise that the air experiences each time it passes through the heater is determined by applying the energy balance to the duct,

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{\text{e,in}} + \dot{W}_{\text{fan,in}} + \dot{m}h_1 = \dot{Q}_{\text{out}}^{\nearrow 0} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{\text{e,in}} + \dot{W}_{\text{fan,in}} = \dot{m}\Delta h = \dot{m}C_p\Delta T$$

Thus,

$$\Delta T = \frac{\dot{W}_{\text{e,in}} + \dot{W}_{\text{fan,in}}}{\dot{m}C_p} = \frac{(5.41 + 0.2)\text{kJ/s}}{(50/60\text{kg/s})(1.007\text{ kJ/kg}\cdot\text{K})} = \mathbf{6.7^\circ C}$$

1-39 The resistance heating element of an electrically heated house is placed in a duct. The air is moved by a fan, and heat is lost through the walls of the duct. The power rating of the electric resistance heater 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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications.

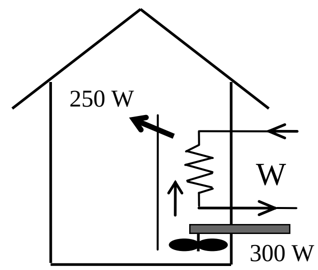
Properties The specific heat of air at room temperature is C_p = 1.007 kJ/kg·°C (Table A-15).

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

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

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

$$\dot{W}_{\text{e,in}} = \dot{Q}_{\text{out}} - \dot{W}_{\text{fan,in}} + \dot{m}C_p(T_2 - T_1)$$



Substituting, the power rating of the heating element is determined to be

$$\dot{W}_{\text{e,in}} = (0.25\,\text{kW}) - (0.3\,\text{kW}) + (0.6\text{ kg/s})(1.007\text{kJ/kg}\cdot{}^\circ\text{C})(5^\circ\text{C})$$
$$= \mathbf{2.97\,kW}$$

1-40 Air is moved through the resistance heaters in a 1200-W hair dryer by a fan. The volume flow rate of air at the inlet and the velocity of the air at the exit are 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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. **4** The power consumed by the fan and the heat losses through the walls of the hair dryer are negligible.

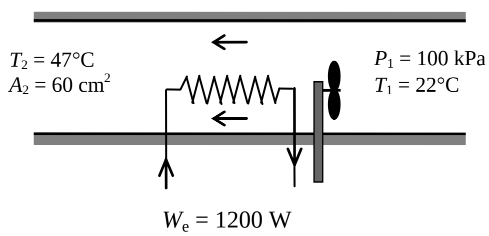
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, C_p = 1.007 kJ/kg·K for air at room temperature (Table A-15).

Analysis (*a*) We take the hair dryer 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 $\Delta E_{CV} = 0$, and 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

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{\text{e,in}} + \dot{W}_{\text{fan,in}}^{\nearrow 0} + \dot{m}h_1 = \dot{Q}_{out}^{\nearrow 0} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{\text{e,in}} = \dot{m}C_p(T_2 - T_1)$$



Thus,

$$\dot{m} = \frac{\dot{W}_{\text{e,in}}}{C_p(T_2 - T_1)} = \frac{1.2\text{kJ/s}}{(1.007\,\text{kJ/kg}\cdot{}^\circ\text{C})(47-22)^\circ\text{C}} = 0.04767\,\text{kg/s}$$

Then,

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(295\text{K})}{(100\text{kPa})} = 0.8467\text{m}^3/\text{kg}$$

$$\dot{V}_1 = \dot{m}v_1 = (0.04767\,\text{kg/s})(0.8467\text{m}^3/\text{kg}) = 0.0404\text{m}^3/\text{s}$$

(*b*) The exit velocity of air is determined from the conservation of mass equation,

$$v_2 = \frac{RT_2}{P_2} = \frac{(0.287\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(320\,\text{K})}{(100\,\text{kPa})} = 0.9184\,\text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_2}A_2\mathbf{V}_2 \longrightarrow \mathbf{V}_2 = \frac{\dot{m}v_2}{A_2} = \frac{(0.04767\,\text{kg/s})(0.9187\,\text{m}^3/\text{kg})}{60\times10^{-4}\,\text{m}^2} = \mathbf{7.30\,m/s}$$

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, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications.

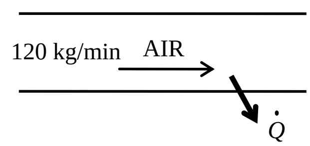
Properties The specific heat of air at room temperature is C_p = 1.007 kJ/kg·°C (Table A-15).

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

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{Q}_{\text{out}} = \dot{m}C_p(T_1 - T_2)$$



Substituting,

$$\dot{Q}_{\text{out}} = \dot{m}C_p \Delta T = (120\text{kg/min})(1.007\text{kJ/kg}\cdot°\text{C})(3°\text{C}) = \mathbf{363\ kJ/min}$$

1-42E Air gains heat as it flows through the duct of an air-conditioning system. The velocity of the air at the duct inlet and the temperature of the air at the exit are 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 -222°F and 548 psia. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air, C_p = 0.2404 and C_v = 0.1719 Btu/lbm·R. This assumption results in negligible error in heating and air-conditioning applications.

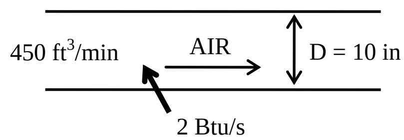
Properties The gas constant of air is R = 0.3704 psia.ft^3/lbm.R (Table A-1). Also, C_p = 0.2404 Btu/lbm·R for air at room temperature (Table A-15E).

Analysis We take the air-conditioning 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 $\Delta E_{CV} = 0$, there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$, and heat is lost from the system. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0 \rightarrow \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad \text{(since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{Q}_{\text{in}} = \dot{m}C_p(T_2 - T_1)$$



(a) The inlet velocity of air through the duct is determined from

$$V_1 = \frac{\dot{V}_1}{A_1} = \frac{\dot{V}_1}{\pi r^2} = \frac{450 \text{ ft}^3\text{/min}}{\pi (5/12 \text{ ft})^2} = \mathbf{825 \text{ ft/min}}$$

(b) The mass flow rate of air becomes

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.3704 \text{psia} \cdot \text{ft}^3\text{/lbm} \cdot \text{R})(510\text{R})}{(15\text{psia})} = 12.6\, ft^3 / lbm$$

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{450 \text{ft}^3\text{/min}}{12.6 \text{ft}^3\text{/lbm}} = 35.7 \text{lbm/min} = 0.595 \text{lbm/s}$$

Then the exit temperature of air is determined to be

$$T_2 = T_1 + \frac{\dot{Q}_{in}}{\dot{m}C_p} = 50°\text{F} + \frac{2 \text{ Btu/s}}{(0.595 \text{lbm/s})(0.2404 \text{Btu/lbm} \cdot °\text{F})} = \mathbf{64.0°F}$$

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, $\Delta ke \cong \Delta pe \cong 0$. **3** Heat loss from the insulated tube is negligible.

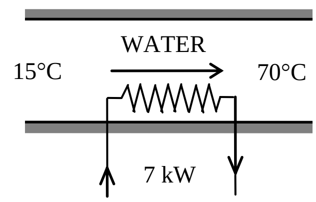
Properties The specific heat of water at room temperature is C_p = 4.18 kJ/kg·°C (Table A-9).

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

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}}\nearrow^{0\ \text{(steady)}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

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

$$\dot{W}_{\text{e,in}} = \dot{m}C_p(T_2 - T_1)$$



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