Solutions for Assignment#1

2-19C (*a*) From the perspective of the contents, heat must be removed in order to reduce and maintain the content's temperature. Heat is also being added to the contents from the room air since the room air is hotter than the contents.

(*b*) Considering the system formed by the refrigerator box when the doors are closed, there are three interactions, electrical work and two heat transfers. There is a transfer of heat from the room air to the refrigerator through its walls. There is also a transfer of heat from the hot portions of the refrigerator (i.e., back of the compressor where condenser is placed) system to the room air. Finally, electrical work is being added to the refrigerator through the refrigeration system.

(*c*) Heat is transferred through the walls of the room from the warm room air to the cold winter air. Electrical work is being done on the room through the electrical wiring leading into the room.

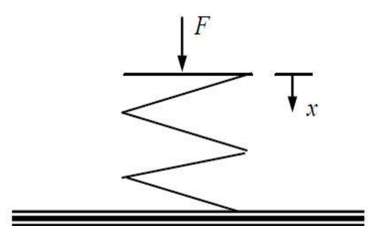
2-29E The work required to compress a spring is to be determined.

Analysis Since there is no preload, $F = kx$. Substituting this into the work expression gives

$$W = \int_1^2 F ds = \int_1^2 kx dx = k\int_1^2 x dx = \frac{k}{2}(x_2^2 - x_1^2)$$

$$= \frac{200 \text{ lbf/in}}{2}\left[(1 \text{ in})^2 - 0^2\right]\left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = \mathbf{8.33 \text{ lbf} \cdot \text{ft}}$$

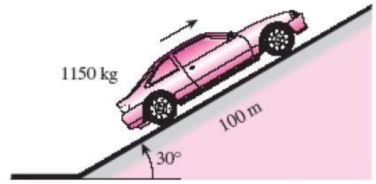
$$= (8.33 \text{ lbf} \cdot \text{ft})\left(\frac{1 \text{ Btu}}{778.169 \text{ lbf} \cdot \text{ft}}\right) = \mathbf{0.0107 \text{ Btu}}$$



2-36 A car is to climb a hill in 12 s. The power needed is to be determined for three different cases.

Assumptions Air drag, friction, and rolling resistance are negligible.

Analysis The total power required for each case is the sum of the rates of changes in potential and kinetic energies. That is,



$$\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g$$

(*a*) $\dot{W}_a = 0$ since the velocity is constant. Also, the vertical rise is h = (100 m)(sin 30°) = 50 m. Thus,

$$\dot{W}_g = mg(z_2 - z_1)/\Delta t = (1150\text{ kg})(9.81\text{ m/s}^2)(50\text{ m})\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(12\text{ s}) = 47.0\text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = 0 + 47.0 = \mathbf{47.0\ kW}$

(*b*) The power needed to accelerate is

$$\dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(1150\text{ kg})\left[(30\text{ m/s})^2 - 0\right]\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(12\text{ s}) = 43.1\text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = 47.0 + 43.1 = \mathbf{90.1\ kW}$

(*c*) The power needed to decelerate is

$$\dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(1150\text{ kg})\left[(5\text{ m/s})^2 - (35\text{ m/s})^2\right]\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(12\text{ s}) = -57.5\text{ kW}$$

and $\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = -57.5 + 47.1 = \mathbf{-10.5\ kW}$ (breaking power)

2-39 Water is heated in a pan on top of a range while being stirred. The energy of the water at the end of the process is to be determined.

Assumptions The pan is stationary and thus the changes in kinetic and potential energies are negligible.

Analysis We take the water in the pan as our system. This is a closed system since no mass enters or leaves. Applying the energy balance on this system gives

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

$$Q_{\text{in}} + W_{\text{sh,in}} - Q_{\text{out}} = \Delta U = U_2 - U_1$$

$$30\text{ kJ} + 0.5\text{ kJ} - 5\text{ kJ} = U_2 - 10\text{ kJ}$$

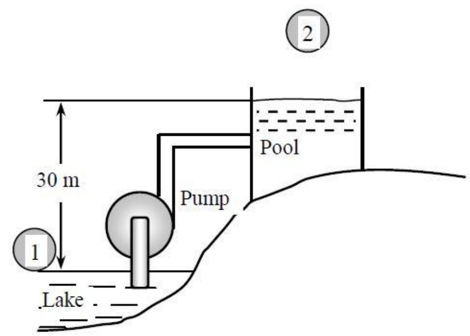
$$U_2 = \mathbf{35.5\ kJ}$$

Therefore, the final internal energy of the system is 35.5 kJ.

2-43 A water pump is claimed to raise water to a specified elevation at a specified rate while consuming electric power at a specified rate. The validity of this claim is to be investigated.

Assumptions **1** The water pump operates steadily. **2** Both the lake and the pool are open to the atmosphere, and the flow velocities in them are negligible.

Properties We take the density of water to be $\rho = 1000\ \text{kg/m}^3 = 1\ \text{kg/L}$.



Analysis For a control volume that encloses the pump-motor unit, the energy balance can be written as

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

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

$$\dot{W}_{\text{in}} + \dot{m}\text{pe}_1 = \dot{m}\text{pe}_2 \quad \rightarrow \quad \dot{W}_{\text{in}} = \dot{m}\Delta\text{pe} = \dot{m}g(z_2 - z_1)$$

since the changes in kinetic and flow energies of water are negligible. Also,

$$\dot{m} = \rho\dot{V} = (1\ \text{kg/L})(50\ \text{L/s}) = 50\ \text{kg/s}$$

Substituting, the minimum power input required is determined to be

$$\dot{W}_{\text{in}} = \dot{m}g(z_2 - z_1) = (50\ \text{kg/s})(9.81\ \text{m/s}^2)(30\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = 14.7\ \text{kJ/s} = \mathbf{14.7\ kW}$$

which is much greater than 2 kW. Therefore, the claim is **false.**

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the power required will be considerably higher than 14.7 kW because of the losses associated with the conversion of electrical-to-mechanical shaft and mechanical shaft-to-potential energy of water.

2-44 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.

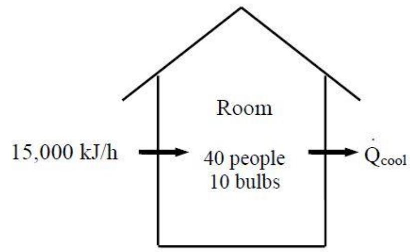
Assumptions There are no heat dissipating equipment (such as computers, TVs, or ranges) in the room.

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

$$\dot{Q}_{\text{lights}} = 10 \times 100 \text{ W} = 1 \text{ kW}$$
$$\dot{Q}_{\text{people}} = 40 \times 360 \text{ kJ/h} = 4 \text{ kW}$$
$$\dot{Q}_{\text{heat gain}} = 15{,}000 \text{ kJ/h} = 4.17 \text{ kW}$$



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

Thus the number of air-conditioning units required is

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

2-47 A room contains a light bulb, a TV set, a refrigerator, and an iron. The rate of increase of the energy content of the room when all of these electric devices are on is to be determined.

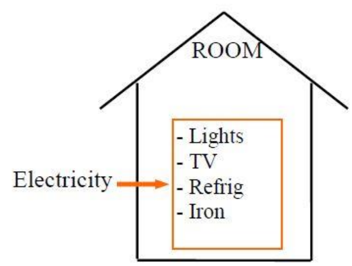
Assumptions **1** The room is well sealed, and heat loss from the room is negligible. **2** All the appliances are kept on.

Analysis Taking the room as the system, the rate form of the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} \rightarrow dE_{\text{room}}/dt = \dot{E}_{in}$$

since no energy is leaving the room in any form, and thus $\dot{E}_{out} = 0$. Also,

$$\dot{E}_{\text{in}} = \dot{E}_{\text{lights}} + \dot{E}_{\text{TV}} + \dot{E}_{\text{refrig}} + \dot{E}_{\text{iron}}$$
$$= 40 + 110 + 300 + 1200 \text{ W}$$
$$= 1650 \text{ W}$$



Substituting, the rate of increase in the energy content of the room becomes

$$dE_{\text{room}}/dt = \dot{E}_{\text{in}} = \textbf{1650 W}$$

Discussion Note that some appliances such as refrigerators and irons operate intermittently, switching on and off as controlled by a thermostat. Therefore, the rate of energy transfer to the room, in general, will be less.

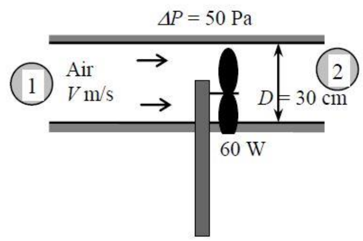
2-49 The fan of a central heating system circulates air through the ducts. For a specified pressure rise, the highest possible average flow velocity is to be determined.

Assumptions **1** The fan operates steadily. **2** The changes in kinetic and potential energies across the fan are negligible.

Analysis For a control volume that encloses the fan unit, the energy balance can be written as

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

$$\dot{W}_{\text{in}} + \dot{m}(Pv)_1 = \dot{m}(Pv)_2 \quad \rightarrow \quad \dot{W}_{\text{in}} = \dot{m}(P_2 - P_1)v = \dot{V}\,\Delta P$$



since $\dot{m} = \dot{V}/v$ and the changes in kinetic and potential energies of gasoline are negligible, Solving for volume flow rate and substituting, the maximum flow rate and velocity are determined to be

$$\dot{V}_{\text{max}} = \frac{\dot{W}_{\text{in}}}{\Delta\text{P}} = \frac{60\text{ J/s}}{50\text{ Pa}}\left(\frac{1\text{ Pa}\cdot\text{m}^3}{1\text{ J}}\right) = 1.2\text{ m}^3/\text{s}$$

$$V_{\text{max}} = \frac{\dot{V}_{\text{max}}}{A_c} = \frac{\dot{V}_{\text{max}}}{\pi D^2/4} = \frac{1.2\text{ m}^3/\text{s}}{\pi(0.30\text{ m})^2/4} = \mathbf{17.0\,m/s}$$

Discussion The conservation of energy principle requires the energy to be conserved as it is converted from one form to another, and it does not allow any energy to be created or destroyed during a process. In reality, the velocity will be less because of the losses associated with the conversion of electrical-to-mechanical shaft and mechanical shaft-to-flow energy.

2-57 A worn out standard motor is to be replaced by a high efficiency one. The amount of electrical energy and money savings as a result of installing the high efficiency motor instead of the standard one as well as the simple payback period are to be determined.

Assumptions The load factor of the motor remains constant at 0.75.

Analysis The electric power drawn by each motor and their difference can be expressed as

$$\dot{W}_{\text{electric in, standard}} = \dot{W}_{\text{shaft}} / \eta_{\text{standard}} = (\text{Power rating})(\text{Load factor}) / \eta_{\text{standard}}$$

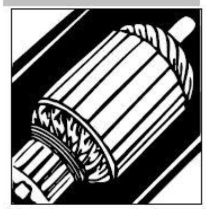
$$\dot{W}_{\text{electric in, efficient}} = \dot{W}_{\text{shaft}} / \eta_{\text{efficient}} = (\text{Power rating})(\text{Load factor}) / \eta_{\text{efficient}}$$

$$\text{Power savings} = \dot{W}_{\text{electric in, standard}} - \dot{W}_{\text{electric in, efficient}}$$

$$= (\text{Power rating})(\text{Load factor})[1/\eta_{\text{standard}} - 1/\eta_{\text{efficient}}]$$

$\eta_{\text{old}} = 91.0\%$

$\eta_{\text{new}} = 95.4\%$



where η_{standard} is the efficiency of the standard motor, and $\eta_{\text{efficient}}$ is the efficiency of the comparable high efficiency motor. Then the annual energy and cost savings associated with the installation of the high efficiency motor are determined to be

Energy Savings = (Power savings)(Operating Hours)

= (Power Rating)(Operating Hours)(Load Factor)($1/\eta_{\text{standard}}$ - $1/\eta_{\text{efficient}}$)

= (75 hp)(0.746 kW/hp)(4,368 hours/year)(0.75)(1/0.91 - 1/0.954)

= **9,290 kWh/year**

Cost Savings = (Energy savings)(Unit cost of energy)

= (9,290 kWh/year)($0.12/kWh)

= **$1114/year**

The implementation cost of this measure consists of the excess cost the high efficiency motor over the standard one. That is,

Implementation Cost = Cost differential = $5,520 - $5,449 = $71

This gives a simple payback period of

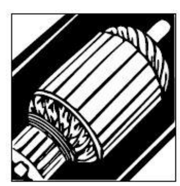
$$\text{Simple payback period} = \frac{\text{Implementation cost}}{\text{Annual cost savings}} = \frac{\$71}{\$1114/\text{year}} = \mathbf{0.0637\ year} \text{ (or 0.76 month)}$$

Therefore, the high-efficiency motor will pay for its cost differential in less than one month.

2-58 An electric motor with a specified efficiency operates in a room. The rate at which the motor dissipates heat to the room it is in when operating at full load and if this heat dissipation is adequate to heat the room in winter are to be determined.

Assumptions The motor operates at full load.

Analysis The motor efficiency represents the fraction of electrical energy consumed by the motor that is converted to mechanical work. The remaining part of electrical energy is converted to thermal energy and is dissipated as heat.



$$\dot{Q}_{\text{dissipated}} = (1-\eta_{\text{motor}})\dot{W}_{\text{in, electric}} = (1-0.88)(20\text{ kW}) = \mathbf{2.4\ kW}$$

which is larger than the rating of the heater. Therefore, the heat dissipated by the motor alone is sufficient to heat the room in winter, and there is no need to turn the heater on.

Discussion Note that the heat generated by electric motors is significant, and it should be considered in the determination of heating and cooling loads.