Solutions Manual for

Thermodynamics: An Engineering Approach
9th Edition
Yunus A. Çengel, Michael A. Boles, Mehmet Kanoğlu
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Chapter 2
ENERGY, ENERGY TRANSFER, AND GENERAL ENERGY ANALYSIS

Forms of Energy

2-1C The *macroscopic* forms of energy are those a system possesses as a whole with respect to some outside reference frame. The *microscopic* forms of energy, on the other hand, are those related to the molecular structure of a system and the degree of the molecular activity, and are independent of outside reference frames.

2-2C The sum of all forms of the energy a system possesses is called *total energy*. In the absence of magnetic, electrical and surface tension effects, the total energy of a system consists of the kinetic, potential, and internal energies.

2-3C The internal energy of a system is made up of sensible, latent, chemical and nuclear energies. The sensible internal energy is due to translational, rotational, and vibrational effects.

2-4C Thermal energy is the sensible and latent forms of internal energy, and it is referred to as heat in daily life.

2-5C The *mechanical energy* is the form of energy that can be converted to mechanical work completely and directly by a mechanical device such as a propeller. It differs from thermal energy in that thermal energy cannot be converted to work directly and completely. The forms of mechanical energy of a fluid stream are kinetic, potential, and flow energies.

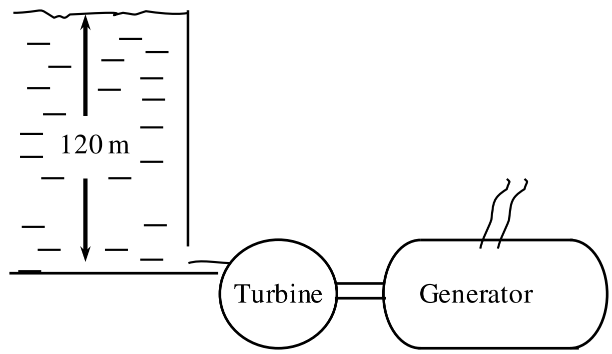
2-6C In electric heaters, electrical energy is converted to sensible internal energy.

2-7C Hydrogen is also a fuel, since it can be burned, but it is not an energy source since there are no hydrogen reserves in the world. Hydrogen can be obtained from water by using another energy source, such as solar or nuclear energy, and then the hydrogen obtained can be used as a fuel to power cars or generators. Therefore, it is more proper to view hydrogen is an energy carrier than an energy source.

2-8C Initially, the rock possesses potential energy relative to the bottom of the sea. As the rock falls, this potential energy is converted into kinetic energy. Part of this kinetic energy is converted to thermal energy as a result of frictional heating due to air resistance, which is transferred to the air and the rock. Same thing happens in water. Assuming the impact velocity of the rock at the sea bottom is negligible, the entire potential energy of the rock is converted to thermal energy in water and air.

2-9 A hydraulic turbine-generator is to generate electricity from the water of a large reservoir. The power generation potential is to be determined.

Assumptions **1** The elevation of the reservoir remains constant. **2** The mechanical energy of water at the turbine exit is negligible.



Analysis The total mechanical energy water in a reservoir possesses is equivalent to the potential energy of water at the free surface, and it can be converted to work entirely. Therefore, the power potential of water is its potential energy, which is gz per unit mass, and $\dot{m}gz$ for a given mass flow rate.

$$e_{\text{mech}} = pe = gz = (9.81 \text{ m/s}^2)(120 \text{ m})\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 1.177 \text{ kJ/kg}$$

Then the power generation potential becomes

$$\dot{W}_{\text{max}} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (1500 \text{ kg/s})(1.177 \text{ kJ/kg})\left(\frac{1 \text{ kW}}{1 \text{ kJ/s}}\right) = \mathbf{1766 \text{ kW}}$$

Therefore, the reservoir has the potential to generate 1766 kW of power.

Discussion This problem can also be solved by considering a point at the turbine inlet, and using flow energy instead of potential energy. It would give the same result since the flow energy at the turbine inlet is equal to the potential energy at the free surface of the reservoir.

2-10E The specific kinetic energy of a mass whose velocity is given is to be determined.

Analysis According to the definition of the specific kinetic energy,

$$\text{ke} = \frac{V^2}{2} = \frac{(100 \text{ ft/s})^2}{2}\left(\frac{1 \text{ Btu/lbm}}{25{,}037 \text{ ft}^2/\text{s}^2}\right) = \mathbf{0.200 \text{ Btu/lbm}}$$

2-11 The specific kinetic energy of a mass whose velocity is given is to be determined.

Analysis Substitution of the given data into the expression for the specific kinetic energy gives

$$\text{ke} = \frac{V^2}{2} = \frac{(30\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{0.45\ kJ/kg}$$

2-12E The total potential energy of an object that is below a reference level is to be determined.

Analysis Substituting the given data into the potential energy expression gives

$$\text{PE} = mgz = (100\text{ lbm})(31.7\text{ ft/s}^2)(-20\text{ ft})\left(\frac{1\text{ Btu/lbm}}{25{,}037\text{ ft}^2/\text{s}^2}\right) = \mathbf{-2.53\ Btu}$$

2-13 The specific potential energy of an object is to be determined.

Analysis The specific potential energy is given by

$$\text{pe} = gz = (9.8\text{ m/s}^2)(50\text{ m})\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{0.49\ kJ/kg}$$

2-14 The total potential energy of an object is to be determined.

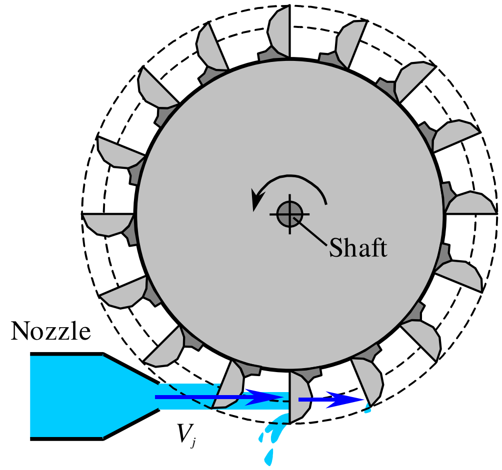
Analysis Substituting the given data into the potential energy expression gives

$$\text{PE} = mgz = (100\text{ kg})(9.81\text{ m/s}^2)(20\text{ m})\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{19.6\ kJ}$$

2-15 A water jet strikes the buckets located on the perimeter of a wheel at a specified velocity and flow rate. The power generation potential of this system is to be determined.

Assumptions Water jet flows steadily at the specified speed and flow rate.

Analysis Kinetic energy is the only form of harvestable mechanical energy the water jet possesses, and it can be converted to work entirely. Therefore, the power potential of the water jet is its kinetic energy, which is $V^2/2$ per unit mass, and $\dot{m}V^2/2$ for a given mass flow rate:



$$e_{\text{mech}} = ke = \frac{V^2}{2} = \frac{(60\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 1.8\text{ kJ/kg}$$

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}}$$

$$= (120\text{ kg/s})(1.8\text{ kJ/kg})\left(\frac{1\text{ kW}}{1\text{ kJ/s}}\right) = \mathbf{216\ kW}$$

Therefore, 216 kW of power can be generated by this water jet at the stated conditions.

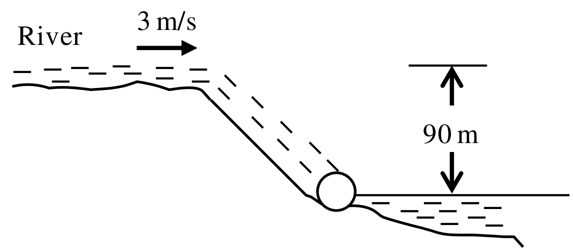
Discussion An actual hydroelectric turbine (such as the Pelton wheel) can convert over 90% of this potential to actual electric power.

2-16 A river is flowing at a specified velocity, flow rate, and elevation. The total mechanical energy of the river water per unit mass, and the power generation potential of the entire river are to be determined.

Assumptions **1** The elevation given is the elevation of the free surface of the river. **2** The velocity given is the average velocity. **3** The mechanical energy of water at the turbine exit is negligible.

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

Analysis Noting that the sum of the flow energy and the potential energy is constant for a given fluid body, we can take the elevation of the entire river water to be the elevation of the free surface, and ignore the flow energy. Then the total mechanical energy of the river water per unit mass becomes



$$e_{\text{mech}} = pe + ke = gh + \frac{V^2}{2} = \left((9.81\text{ m/s}^2)(90\text{ m}) + \frac{(3\text{ m/s})^2}{2}\right)\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{0.887\ kJ / kg}$$

The power generation potential of the river water is obtained by multiplying the total mechanical energy by the mass flow rate,

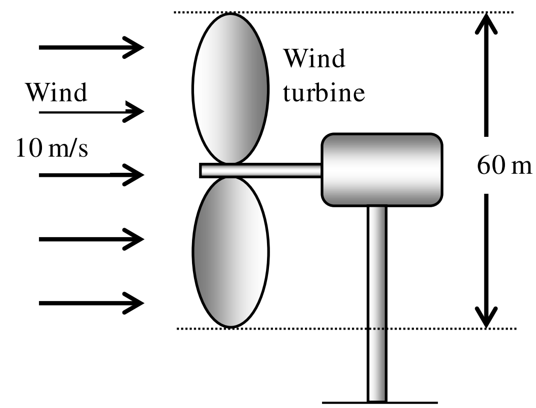
$$\dot{m} = \rho\dot{V} = (1000\text{ kg/m}^3)(500\text{ m}^3/\text{s}) = 500{,}000\text{ kg/s}$$

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (500{,}000\text{ kg/s})(0.887\text{ kJ/kg}) = 444{,}000\text{ kW} = \mathbf{444\ \ MW}$$

Therefore, 444 MW of power can be generated from this river as it discharges into the lake if its power potential can be recovered completely.

Discussion Note that the kinetic energy of water is negligible compared to the potential energy, and it can be ignored in the analysis. Also, the power output of an actual turbine will be less than 444 MW because of losses and inefficiencies.

2-17 Wind is blowing steadily at a certain velocity. The mechanical energy of air per unit mass and the power generation potential are to be determined.



Assumptions The wind is blowing steadily at a constant uniform velocity.

Properties The density of air is given to be $\rho = 1.25$ kg/m^3.

Analysis Kinetic energy is the only form of mechanical energy the wind possesses, and it can be converted to work entirely. Therefore, the power potential of the wind is its kinetic energy, which is $V^2/2$ per unit mass, and $\dot{m}V^2/2$ for a given mass flow rate:

$$e_{\text{mech}} = ke = \frac{V^2}{2} = \frac{(10\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 0.050\text{ kJ/kg}$$

$$\dot{m} = \rho VA = \rho V\frac{\pi D^2}{4} = (1.25\text{ kg/m}^3)(10\text{ m/s})\frac{\pi(60\text{ m})^2}{4} = 35{,}340\text{ kg/s}$$

$$\dot{W}_{\max} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (35{,}340\text{ kg/s})(0.050\text{ kJ/kg}) = \mathbf{1770\ kW}$$

Therefore, 1770 kW of actual power can be generated by this wind turbine at the stated conditions.

Discussion The power generation of a wind turbine is proportional to the cube of the wind velocity, and thus the power generation will change strongly with the wind conditions.

Energy Transfer by Heat and Work

2-18C 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.

2-19C Energy can cross the boundaries of a closed system in two forms: heat and work.

2-20C An adiabatic process is a process during which there is no heat transfer. A system that does not exchange any heat with its surroundings is an adiabatic system.

2-21C The form of energy that crosses the boundary of a closed system because of a temperature difference is heat; all other forms are work.

2-22C (*a*) The car's radiator transfers heat from the hot engine cooling fluid to the cooler air. No work interaction occurs in the radiator.

(*b*) The hot engine transfers heat to cooling fluid and ambient air while delivering work to the transmission.

(*c*) The warm tires transfer heat to the cooler air and to some degree to the cooler road while no work is produced. No work is produced since there is no motion of the forces acting at the interface between the tire and road.

(*d*) There is minor amount of heat transfer between the tires and road. Presuming that the tires are hotter than the road, the heat transfer is from the tires to the road. There is no work exchange associated with the road since it cannot move.

(*e*) Heat is being added to the atmospheric air by the hotter components of the car. Work is being done on the air as it passes over and through the car.

2-23C It is a work interaction since the electrons are crossing the system boundary, thus doing electrical work.

2-24C It is a heat interaction since it is due to the temperature difference between the sun and the room.

2-25C Compressing a gas in a piston-cylinder device is a work interaction.

2-26 The power produced by an electrical motor is to be expressed in different units.

Analysis Using appropriate conversion factors, we obtain

(*a*) $$\dot{W} = (5\text{ W})\left(\frac{1\text{ J/s}}{1\text{ W}}\right)\left(\frac{1\text{ N}\cdot\text{m}}{1\text{ J}}\right) = \mathbf{5\ N\cdot m/s}$$

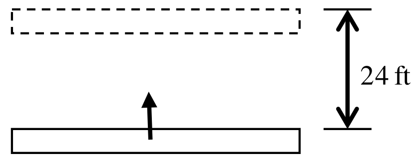
(*b*) $$\dot{W} = (5\text{ W})\left(\frac{1\text{ J/s}}{1\text{ W}}\right)\left(\frac{1\text{ N}\cdot\text{m}}{1\text{ J}}\right)\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right) = \mathbf{5\ kg\cdot m^2/s^3}$$

Mechanical Forms of Work

2-27C The work done (i.e., energy transferred to the car) is the same, but the power is different.

2-28E A construction crane lifting a concrete beam is considered. The amount of work is to be determined considering (a) the beam and (b) the crane as the system.

Analysis (*a*) The work is done on the beam and it is determined from



$$W = mg\Delta z = (3\times 2000\ \text{lbm})(32.174\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.174\ \text{lbm}\cdot\text{ft/s}^2}\right)(24\ \text{ft})$$
$$= \mathbf{144{,}000\ lbf\cdot ft}$$
$$= (144{,}000\ \text{lbf}\cdot\text{ft})\left(\frac{1\ \text{Btu}}{778.169\ \text{lbf}\cdot\text{ft}}\right) = \mathbf{185\ Btu}$$

(*b*) Since the crane must produce the same amount of work as is required to lift the beam, the work done by the crane is

$$W = \mathbf{144{,}000\ lbf\cdot ft} = \mathbf{185\ Btu}$$

2-29E The engine of a car develops 225 hp at 3000 rpm. The torque transmitted through the shaft is to be determined.

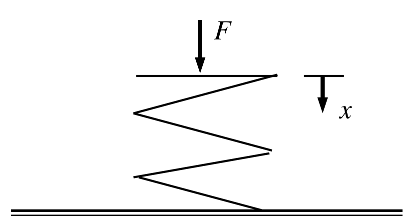
Analysis The torque is determined from

$$\text{T} = \frac{\dot{W}_{\text{sh}}}{2\pi\dot{n}} = \frac{225\ \text{hp}}{2\pi\left(3000/60\right)/\text{s}}\left(\frac{550\ \text{lbf}\cdot\text{ft/s}}{1\ \text{hp}}\right) = \mathbf{394\ lbf\cdot ft}$$

2-30E The work required to compress a spring is to be determined.

Analysis The force at any point during the deflection of the spring is given by $F = F_0 + kx$, where F_0 is the initial force and x is the deflection as measured from the point where the initial force occurred. From the perspective of the spring, this force acts in the direction opposite to that in which the spring is deflected. Then,

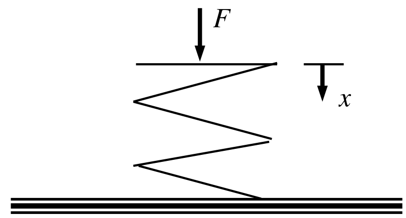
$$W = \int_1^2 Fds = \int_1^2 (F_0 + kx)dx$$
$$= F_0(x_2 - x_1) + \frac{k}{2}(x_2^2 - x_1^2)$$
$$= (100\ \text{lbf})\left[(1-0)\text{in}\right] + \frac{200\ \text{lbf/in}}{2}(1^2 - 0^2)\text{in}^2$$
$$= 200\ \text{lbf}\cdot\text{in}$$
$$= (200\ \text{lbf}\cdot\text{in})\left(\frac{1\ \text{Btu}}{778.169\ \text{lbf}\cdot\text{ft}}\right)\left(\frac{1\ \text{ft}}{12\ \text{in}}\right) = \mathbf{0.0214\ Btu}$$



2-31 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

$$W = \int_1^2 F ds = \int_1^2 kxdx = k\int_1^2 xdx = \frac{k}{2}(x_2^2 - x_1^2)$$
$$= \frac{300 \text{ kN/m}}{2}\left[(0.03 \text{ m})^2 - 0^2\right]$$
$$= 0.135 \text{ kN}\cdot\text{m}$$
$$= (0.135 \text{ kN}\cdot\text{m})\left(\frac{1 \text{ kJ}}{1 \text{ kN}\cdot\text{m}}\right) = \mathbf{0.135\ kJ}$$



2-32 A ski lift is operating steadily at 10 km/h. The power required to operate and also to accelerate this ski lift from rest to the operating speed are to be determined.

Assumptions **1** Air drag and friction are negligible. **2** The average mass of each loaded chair is 250 kg. **3** The mass of chairs is small relative to the mass of people, and thus the contribution of returning empty chairs to the motion is disregarded (this provides a safety factor).

Analysis The lift is 1000 m long and the chairs are spaced 20 m apart. Thus at any given time there are 1000/20 = 50 chairs being lifted. Considering that the mass of each chair is 250 kg, the load of the lift at any given time is

$$\text{Load} = (50\text{ chairs})(250\text{ kg/chair}) = 12{,}500\text{ kg}$$

Neglecting the work done on the system by the returning empty chairs, the work needed to raise this mass by 200 m is

$$W_g = mg(z_2 - z_1) = (12{,}500\text{ kg})(9.81\text{ m/s}^2)(200\text{ m})\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right) = 24{,}525\text{ kJ}$$

At 10 km/h, it will take

$$\Delta t = \frac{\text{distance}}{\text{velocity}} = \frac{1\text{ km}}{10\text{ km/h}} = 0.1\text{ h} = 360\text{ s}$$

to do this work. Thus the power needed is

$$\dot{W}_g = \frac{W_g}{\Delta t} = \frac{24{,}525\text{ kJ}}{360\text{ s}} = \mathbf{68.1\text{ kW}}$$

The velocity of the lift during steady operation, and the acceleration during start up are

$$V = (10\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right) = 2.778\text{ m/s}$$

$$a = \frac{\Delta V}{\Delta t} = \frac{2.778\text{ m/s} - 0}{5\text{ s}} = 0.556\text{ m/s}^2$$

During acceleration, the power needed is

$$\dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(12{,}500\text{ kg})\left((2.778\text{ m/s})^2 - 0\right)\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right)/(5\text{ s}) = 9.6\text{ kW}$$

Assuming the power applied is constant, the acceleration will also be constant and the vertical distance traveled during acceleration will be

$$h = \frac{1}{2}at^2\sin\alpha = \frac{1}{2}at^2\frac{200\text{ m}}{1000\text{ m}} = \frac{1}{2}(0.556\text{ m/s}^2)(5\text{ s})^2(0.2) = 1.39\text{ m}$$

and

$$\dot{W}_g = mg(z_2 - z_1)/\Delta t = (12{,}500\text{ kg})(9.81\text{ m/s}^2)(1.39\text{ m})\left(\frac{1\text{ kJ/kg}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right)/(5\text{ s}) = 34.1\text{ kW}$$

Thus,

$$\dot{W}_{\text{total}} = \dot{W}_a + \dot{W}_g = 9.6 + 34.1 = \mathbf{43.7\text{ kW}}$$

2-33 The engine of a car develops 75 kW of power. The acceleration time of this car from rest to 100 km/h on a level road is to be determined.

Analysis The work needed to accelerate a body is the change in its kinetic energy,

$$W_a = \frac{1}{2}m\left(\mathbf{V}_2^2 - \mathbf{V}_1^2\right) = \frac{1}{2}(1500\text{ kg})\left(\left(\frac{100{,}000\text{ m}}{3600\text{ s}}\right)^2 - 0\right)\left(\frac{1\text{ kJ}}{1000\text{ kg}\cdot\text{m}^2/\text{s}^2}\right) = 578.7\text{ kJ}$$

Thus the time required is

$$\Delta t = \frac{W_a}{\dot{W}_a} = \frac{578.7\text{ kJ}}{75\text{ kJ/s}} = \mathbf{7.72\ s}$$

This answer is not realistic because part of the power will be used against the air drag, friction, and rolling resistance.

2-34 A damaged car is being towed by a truck. The extra 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*) Zero.

(*b*) $\dot{W}_a = 0$. Thus,

$$\dot{W}_{\text{total}} = \dot{W}_g = mg(z_2 - z_1)/\Delta t = mg\frac{\Delta z}{\Delta t} = mgV_z = mgV\sin 30^\circ$$

$$= (1200\ \text{kg})(9.81\text{m/s}^2)\left(\frac{50{,}000\ \text{m}}{3600\ \text{s}}\right)\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)(0.5)$$

$$= \mathbf{81.7\ kW}$$

(*c*) $\dot{W}_g = 0$. Thus,

$$\dot{W}_{\text{total}} = \dot{W}_a = \frac{1}{2}m(V_2^2 - V_1^2)/\Delta t = \frac{1}{2}(1200\ \text{kg})\left(\left(\frac{90{,}000\ \text{m}}{3600\ \text{s}}\right)^2 - 0\right)\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)/(12\ \text{s}) = \mathbf{31.3\ kW}$$

2-35 As a spherical ammonia vapor bubble rises in liquid ammonia, its diameter increases. The amount of work produced by this bubble is to be determined.

Assumptions **1** The bubble is treated as a spherical bubble. **2** The surface tension coefficient is taken constant.

Analysis Executing the work integral for a constant surface tension coefficient gives

$$
\begin{aligned}
W &= \sigma \int_1^2 dA = \sigma(A_2 - A_1) = \sigma 4\pi(r_2^2 - r_1^2) \\
&= 4\pi(0.02\ \text{N/m})\left[(0.015\ \text{m})^2 - (0.005\ \text{m})^2\right] \\
&= 5.03\times10^{-5}\ \text{N}\cdot\text{m} \\
&= (5.03\times10^{-5}\ \text{N}\cdot\text{m})\left(\frac{1\ \text{kJ}}{1000\ \text{N}\cdot\text{m}}\right) \\
&= \mathbf{5.03\times10^{-8}\ kJ}
\end{aligned}
$$

2-36 The work required to stretch a steel rod in a specified length is to be determined.

Assumptions The Young's modulus does not change as the rod is stretched.

Analysis The original volume of the rod is

$$
V_0 = \frac{\pi D^2}{4}L = \frac{\pi(0.005\ \text{m})^2}{4}(10\ \text{m}) = 1.963\times10^{-4}\ \text{m}^3
$$

The work required to stretch the rod 3 cm is

$$
\begin{aligned}
W &= \frac{V_0 E}{2}(\varepsilon_2^2 - \varepsilon_1^2) \\
&= \frac{(1.963\times10^{-4}\ \text{m}^3)(21\times10^4\ \text{kN/m}^2)}{2}\left[\left(\frac{0.03\ \text{m}}{10\ \text{m}}\right)^2 - 0^2\right] \\
&= 1.855\times10^{-4}\ \text{kN}\cdot\text{m} = 1.855\times10^{-4}\ \text{kJ} = \mathbf{0.1855\ J}
\end{aligned}
$$

The First Law of Thermodynamics

2-37C Energy can be transferred to or from a control volume as heat, various forms of work, and by mass transport.

2-38C No. This is the case for adiabatic systems only.

2-39C Warmer. Because energy is added to the room air in the form of electrical work.

2-40 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

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

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

$$30 \text{ kJ} + 0.5 \text{ kJ} - 5 \text{ kJ} = U_2 - 12.5 \text{ kJ}$$

$$U_2 = \mathbf{38.0\ kJ}$$

Therefore, the final internal energy of the system is 38.0 kJ.

2-41 The specific energy change of a system which is accelerated is to be determined.

Analysis Since the only property that changes for this system is the velocity, only the kinetic energy will change. The change in the specific energy is

$$\Delta \text{ke} = \frac{V_2^2 - V_1^2}{2} = \frac{(30 \text{ m/s})^2 - (0 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = \mathbf{0.45\ kJ/kg}$$

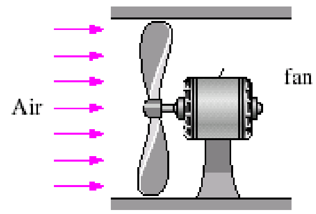
2-42 A fan is to accelerate quiescent air to a specified velocity at a specified flow rate. The minimum power that must be supplied to the fan is to be determined.

Assumptions The fan operates steadily.

Properties The density of air is given to be $\rho = 1.18\ \text{kg/m}^3$.

Analysis A fan transmits the mechanical energy of the shaft (shaft power) to mechanical energy of air (kinetic energy). For a control volume that encloses the fan, the energy balance can be written as

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



$$\dot{W}_{\text{sh, in}} = \dot{m}_{\text{air}}\text{ke}_{\text{out}} = \dot{m}_{\text{air}}\frac{V_{\text{out}}^2}{2}$$

where

$$\dot{m}_{\text{air}} = \rho\dot{V} = (1.18\ \text{kg/m}^3)(9\ \text{m}^3/\text{s}) = 10.62\ \text{kg/s}$$

Substituting, the minimum power input required is determined to be

$$\dot{W}_{\text{sh, in}} = \dot{m}_{\text{air}}\frac{V_{\text{out}}^2}{2} = (10.62\ \text{kg/s})\frac{(8\ \text{m/s})^2}{2}\left(\frac{1\ \text{J/kg}}{1\ \text{m}^2/\text{s}^2}\right) = 340\ \text{J/s} = \mathbf{340\ W}$$

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 because of the losses associated with the conversion of mechanical shaft energy to kinetic energy of air.

2-43E Water is heated in a cylinder on top of a range. The change in the energy of the water during this 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 cylinder as the system. This is a closed system since no mass enters or leaves. Applying the energy balance on this system gives

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

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

$$65\ \text{Btu} - 5\ \text{Btu} - 8\ \text{Btu} = \Delta U$$

$$\Delta U = U_2 - U_1 = \mathbf{52\ \ Btu}$$

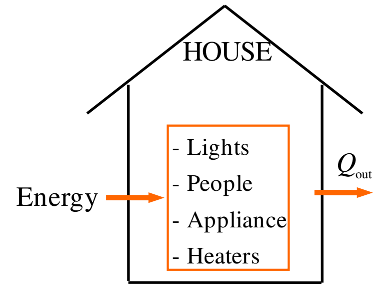
Therefore, the energy content of the system increases by 52 Btu during this process.

2-44E The heat loss from a house is to be made up by heat gain from people, lights, appliances, and resistance heaters. For a specified rate of heat loss, the required rated power of resistance heaters is to be determined.

Assumptions **1** The house is well-sealed, so no air enters or heaves the house. **2** All the lights and appliances are kept on. **3** The house temperature remains constant.

Analysis Taking the house as the system, the energy balance can be written as

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



where

$$\dot{E}_{out} = \dot{Q}_{out} = 60,000 \text{ Btu/h}$$

and

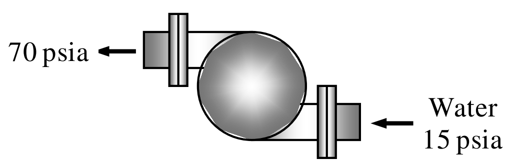
$$\dot{E}_{in} = \dot{E}_{people} + \dot{E}_{lights} + \dot{E}_{appliance} + \dot{E}_{heater} = 6000 \text{ Btu/h} + \dot{E}_{heater}$$

Substituting, the required power rating of the heaters becomes

$$\dot{E}_{heater} = 60,000 - 6000 = 54,000 \text{ Btu/h}\left(\frac{1 \text{ kW}}{3412 \text{ Btu/h}}\right) = \mathbf{15.8 \text{ kW}}$$

Discussion When the energy gain of the house equals the energy loss, the temperature of the house remains constant. But when the energy supplied drops below the heat loss, the house temperature starts dropping.

2-45E A water pump increases water pressure. The power input is to be determined.



Analysis The power input is determined from

$$\begin{aligned}\dot{W} &= \dot{\boldsymbol{V}}(P_2 - P_1) \\ &= (0.8 \text{ ft}^3/\text{s})(70-15)\text{psia}\left(\frac{1 \text{ Btu}}{5.404 \text{ psia}\cdot\text{ft}^3}\right)\left(\frac{1 \text{ hp}}{0.7068 \text{ Btu/s}}\right) \\ &= \mathbf{11.5 \text{ hp}}\end{aligned}$$

The water temperature at the inlet does not have any significant effect on the required power.

2-46 The lighting energy consumption of a storage room is to be reduced by installing motion sensors. The amount of energy and money that will be saved as well as the simple payback period are to be determined.

Assumptions The electrical energy consumed by the ballasts is negligible.

Analysis The plant operates 12 hours a day, and thus currently the lights are on for the entire 12 hour period. The motion sensors installed will keep the lights on for 3 hours, and off for the remaining 9 hours every day. This corresponds to a total of $9 \times 365 = 3285$ off hours per year. Disregarding the ballast factor, the annual energy and cost savings become

$$\begin{aligned}\text{Energy Savings} &= \text{(Number of lamps)(Lamp wattage)(Reduction of annual operating hours)}\\ &= \text{(24 lamps)(60 W/lamp)(3285 hours/year)}\\ &= \mathbf{4730\ kWh/year}\end{aligned}$$

$$\begin{aligned}\text{Cost Savings} &= \text{(Energy Savings)(Unit cost of energy)}\\ &= \text{(4730 kWh/year)(\$0.11/kWh)}\\ &= \mathbf{\$520/year}\end{aligned}$$

The implementation cost of this measure is the sum of the purchase price of the sensor plus the labor,

$$\text{Implementation Cost} = \text{Material} + \text{Labor} = \$32 + \$40 = \$72$$

This gives a simple payback period of

$$\text{Simple payback period} = \frac{\text{Implementation cost}}{\text{Annual cost savings}} = \frac{\$72}{\$520\text{ / year}} = \mathbf{0.138\ year}\ \ \text{(1.66 months)}$$

Therefore, the motion sensor will pay for itself in less than 2 months.

2-47 The classrooms and faculty offices of a university campus are not occupied an average of 4 hours a day, but the lights are kept on. The amounts of electricity and money the campus will save per year if the lights are turned off during unoccupied periods are to be determined.

Analysis The total electric power consumed by the lights in the classrooms and faculty offices is

$$\dot{E}_{\text{lighting, classroom}} = \text{(Power consumed per lamp)} \times \text{(No. of lamps)} = (200 \times 12 \times 110\text{ W}) = 264{,}000 = 264\text{ kW}$$

$$\dot{E}_{\text{lighting, offices}} = \text{(Power consumed per lamp)} \times \text{(No. of lamps)} = (400 \times 6 \times 110\text{ W}) = 264{,}000 = 264\text{ kW}$$

$$\dot{E}_{\text{lighting, total}} = \dot{E}_{\text{lighting, classroom}} + \dot{E}_{\text{lighting, offices}} = 264 + 264 = 528\text{ kW}$$

Noting that the campus is open 240 days a year, the total number of unoccupied work hours per year is

$$\text{Unoccupied hours} = \text{(4 hours/day)(240 days/year)} = 960\text{ h/yr}$$

Then the amount of electrical energy consumed per year during unoccupied work period and its cost are

$$\text{Energy savings} = (\dot{E}_{\text{lighting, total}})\text{(Unoccupied hours)} = \text{(528 kW)(960 h/yr)} = 506{,}880\text{ kWh}$$

$$\text{Cost savings} = \text{(Energy savings)(Unit cost of energy)} = \text{(506,880 kWh/yr)(\$0.11/kWh)} = \mathbf{\$55{,}757/yr}$$

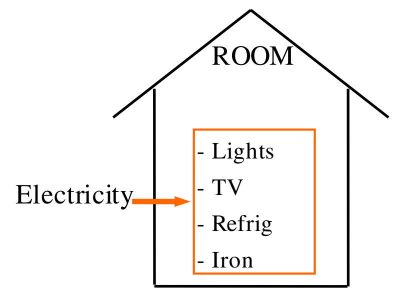
Discussion Note that simple conservation measures can result in significant energy and cost savings.

2-48 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

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



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

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

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

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

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 An inclined escalator is to move a certain number of people upstairs at a constant velocity. The minimum power required to drive this escalator is to be determined.

Assumptions **1** Air drag and friction are negligible. **2** The average mass of each person is 75 kg. **3** The escalator operates steadily, with no acceleration or breaking. **4** The mass of escalator itself is negligible.

Analysis At design conditions, the total mass moved by the escalator at any given time is

$$\text{Mass} = (50 \text{ persons})(75 \text{ kg/person}) = 3750 \text{ kg}$$

The vertical component of escalator velocity is

$$V_{\text{vert}} = V \sin 45° = (0.6 \text{ m/s})\sin 45°$$

Under stated assumptions, the power supplied is used to increase the potential energy of people. Taking the people on elevator as the closed system, the energy balance in the rate form can be written as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}} / dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0 \;\rightarrow\; \dot{E}_{\text{in}} = dE_{\text{sys}} / dt \cong \frac{\Delta E_{\text{sys}}}{\Delta t}$$

$$\dot{W}_{\text{in}} = \frac{\Delta PE}{\Delta t} = \frac{mg\Delta z}{\Delta t} = mgV_{\text{vert}}$$

That is, under stated assumptions, the power input to the escalator must be equal to the rate of increase of the potential energy of people. Substituting, the required power input becomes

$$\dot{W}_{\text{in}} = mgV_{\text{vert}} = (3750 \text{ kg})(9.81 \text{ m/s}^2)(0.6 \text{ m/s})\sin 45°\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 12.5 \text{ kJ/s} = \mathbf{15.6\ kW}$$

When the escalator velocity is doubled to V = 1.2 m/s, the power needed to drive the escalator becomes

$$\dot{W}_{\text{in}} = mgV_{\text{vert}} = (3750 \text{ kg})(9.81 \text{ m/s}^2)(1.2 \text{ m/s})\sin 45°\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 25.0 \text{ kJ/s} = \mathbf{31.2\ kW}$$

Discussion Note that the power needed to drive an escalator is proportional to the escalator velocity.

2-50 A car cruising at a constant speed to accelerate to a specified speed within a specified time. The additional power needed to achieve this acceleration is to be determined.

Assumptions **1** The additional air drag, friction, and rolling resistance are not considered. **2** The road is a level road.

Analysis We consider the entire car as the system, except that let's assume the power is supplied to the engine externally for simplicity (rather that internally by the combustion of a fuel and the associated energy conversion processes). The energy balance for the entire mass of the car can be written in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}} / dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0 \rightarrow \dot{E}_{\text{in}} = dE_{\text{sys}} / dt \cong \frac{\Delta E_{\text{sys}}}{\Delta t}$$

$$\dot{W}_{\text{in}} = \frac{\Delta KE}{\Delta t} = \frac{m(V_2^2 - V_1^2)/2}{\Delta t}$$

since we are considering the change in the energy content of the car due to a change in its kinetic energy (acceleration). Substituting, the required additional power input to achieve the indicated acceleration becomes

$$\dot{W}_{\text{in}} = m\frac{V_2^2 - V_1^2}{2\Delta t} = (2100 \text{ kg})\frac{(110/3.6 \text{ m/s})^2 - (70/3.6 \text{ m/s})^2}{2(5 \text{ s})}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 117 \text{ kJ/s} = \mathbf{117 \text{ kW}}$$

since 1 m/s = 3.6 km/h. If the total mass of the car were 700 kg only, the power needed would be

$$\dot{W}_{\text{in}} = m\frac{V_2^2 - V_1^2}{2\Delta t} = (700 \text{ kg})\frac{(110/3.6 \text{ m/s})^2 - (70/3.6 \text{ m/s})^2}{2(5 \text{ s})}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = \mathbf{38.9 \text{ kW}}$$

Discussion Note that the power needed to accelerate a car is inversely proportional to the acceleration time. Therefore, the short acceleration times are indicative of powerful engines.

2-51E The high rolling resistance tires of a car are replaced by low rolling resistance ones. For a specified unit fuel cost, the money saved by switching to low resistance tires is to be determined.

Assumptions **1** The low rolling resistance tires deliver 2 mpg over all velocities. **2** The car is driven 15,000 miles per year.

Analysis The annual amount of fuel consumed by this car on high- and low-rolling resistance tires are

$$\text{Annual Fuel Consumption}_{\text{High}} = \frac{\text{Miles driven per year}}{\text{Miles per gallon}} = \frac{15{,}000 \text{ miles/year}}{35 \text{ miles/gal}} = 428.6 \text{ gal/year}$$

$$\text{Annual Fuel Consumption}_{\text{Low}} = \frac{\text{Miles driven per year}}{\text{Miles per gallon}} = \frac{15{,}000 \text{ miles/year}}{37 \text{ miles/gal}} = 405.4 \text{ gal/year}$$

Then the fuel and money saved per year become

$$\begin{aligned}\text{Fuel Savings} &= \text{Annual Fuel Consumption}_{\text{High}} - \text{Annual Fuel Consumption}_{\text{Low}} \\ &= 428.6 \text{ gal/year} - 405.4 \text{ gal/year} = 23.2 \text{ gal/year}\end{aligned}$$

$$\text{Cost savings} = (\text{Fuel savings})(\text{Unit cost of fuel}) = (23.2 \text{ gal/year})(\$3.5/\text{gal}) = \mathbf{\$81.1 / year}$$

Discussion A typical tire lasts about 3 years, and thus the low rolling resistance tires have the potential to save about $150 to the car owner over the life of the tires, which is comparable to the installation cost of the tires.

Energy Conversion Efficiencies

2-52C *Mechanical efficiency* is defined as the ratio of the mechanical energy output to the mechanical energy input. A mechanical efficiency of 100% for a hydraulic turbine means that the entire mechanical energy of the fluid is converted to mechanical (shaft) work.

2-53C The *combined pump-motor efficiency* of a pump/motor system is defined as the ratio of the increase in the mechanical energy of the fluid to the electrical power consumption of the motor,

$$\eta_{\text{pump-motor}} = \eta_{\text{pump}}\eta_{\text{motor}} = \frac{\dot{E}_{\text{mech,out}} - \dot{E}_{\text{mech,in}}}{\dot{W}_{\text{elect,in}}} = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{elect,in}}} = \frac{\dot{W}_{\text{pump}}}{\dot{W}_{\text{elect,in}}}$$

The combined pump-motor efficiency cannot be greater than either of the pump or motor efficiency since both pump and motor efficiencies are less than 1, and the product of two numbers that are less than one is less than either of the numbers.

2-54C No, the combined pump-motor efficiency cannot be greater that either of the pump efficiency of the motor efficiency. This is because $\eta_{\text{pump-motor}} = \eta_{\text{pump}}\eta_{\text{motor}}$, and both η_{pump} and η_{motor} are less than one, and a number gets smaller when multiplied by a number smaller than one.

2-55 A hooded electric open burner and a gas burner are considered. The amount of the electrical energy used directly for cooking and the cost of energy per "utilized" kWh are to be determined.

Analysis The efficiency of the electric heater is given to be 73 percent. Therefore, a burner that consumes 3-kW of electrical energy will supply

$$\eta_{\text{gas}} = 38\%$$

$$\eta_{\text{electric}} = 73\%$$

$$\dot{Q}_{\text{utilized}} = (\text{Energy input}) \times (\text{Efficiency}) = (2.4\text{ kW})(0.73) = \mathbf{1.75\ kW}$$

of useful energy. The unit cost of utilized energy is inversely proportional to the efficiency, and is determined from

$$\text{Cost of utilized energy} = \frac{\text{Cost of energy input}}{\text{Efficiency}} = \frac{\$0.10 / \text{kWh}}{0.73} = \mathbf{\$0.137 / kWh}$$

Noting that the efficiency of a gas burner is 38 percent, the energy input to a gas burner that supplies utilized energy at the same rate (1.75 kW) is

$$\dot{Q}_{\text{input, gas}} = \frac{\dot{Q}_{\text{utilized}}}{\text{Efficiency}} = \frac{1.75\text{ kW}}{0.38} = \mathbf{4.61 kW}\ \ (= 15{,}700\text{ Btu/h})$$

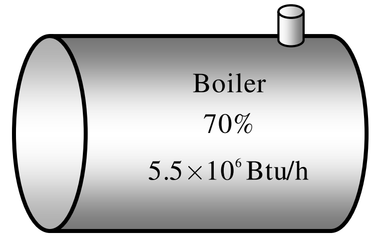
since 1 kW = 3412 Btu/h. Therefore, a gas burner should have a rating of at least 15,700 Btu/h to perform as well as the electric unit. Noting that 1 therm = 29.3 kWh, the unit cost of utilized energy in the case of gas burner is determined the same way to be

$$\text{Cost of utilized energy} = \frac{\text{Cost of energy input}}{\text{Efficiency}} = \frac{\$1.20 / (29.3\text{ kWh})}{0.38} = \mathbf{\$0.108 / kWh}$$

2-56E The combustion efficiency of a furnace is raised from 0.7 to 0.8 by tuning it up. The annual energy and cost savings as a result of tuning up the boiler are to be determined.

Assumptions The boiler operates at full load while operating.

Analysis The heat output of boiler is related to the fuel energy input to the boiler by



Boiler output = (Boiler input)(Combustion efficiency)

or $\dot{Q}_{out} = \dot{Q}_{in}\eta_{furnace}$

The current rate of heat input to the boiler is given to be $\dot{Q}_{in,\ current} = 5.5\times10^6$ Btu/h.

Then the rate of useful heat output of the boiler becomes

$$\dot{Q}_{out} = (\dot{Q}_{in}\eta_{furnace})_{current} = (5.5\times10^6 \text{ Btu/h})(0.7) = 3.85\times10^6 \text{ Btu/h}$$

The boiler must supply useful heat at the same rate after the tune up. Therefore, the rate of heat input to the boiler after the tune up and the rate of energy savings become

$$\dot{Q}_{in,\ new} = \dot{Q}_{out}/\eta_{furnace,\ new} = (3.85\times10^6 \text{ Btu/h})/0.8 = 4.81\times10^6 \text{ Btu/h}$$

$$\dot{Q}_{in,\ saved} = \dot{Q}_{in,\ current} - \dot{Q}_{in,\ new} = 5.5\times10^6 - 4.81\times10^6 = 0.69\times10^6 \text{ Btu/h}$$

Then the annual energy and cost savings associated with tuning up the boiler become

$$\text{Energy Savings} = \dot{Q}_{in,\ saved}\text{(Operation hours)}$$

$$= (0.69\times10^6 \text{ Btu/h})(4200 \text{ h/year}) = \mathbf{2.89\times10^9\ Btu/yr}$$

$$\text{Cost Savings} = \text{(Energy Savings)(Unit cost of energy)}$$

$$= (2.89\times10^9 \text{ Btu/yr})(\$13/10^6 \text{ Btu}) = \mathbf{\$37{,}500/year}$$

Discussion Notice that tuning up the boiler will save $37,500 a year, which is a significant amount. The implementation cost of this measure is negligible if the adjustment can be made by in-house personnel. Otherwise it is worthwhile to have an authorized representative of the boiler manufacturer to service the boiler twice a year.

2-57E Problem 2-56E is reconsidered. The effects of the unit cost of energy and combustion efficiency on the annual energy used and the cost savings as the efficiency varies from 0.7 to 0.9 and the unit cost varies from $12 to $14 per million Btu are the investigated. The annual energy saved and the cost savings are to be plotted against the efficiency for unit costs of $12, $13, and $14 per million Btu.

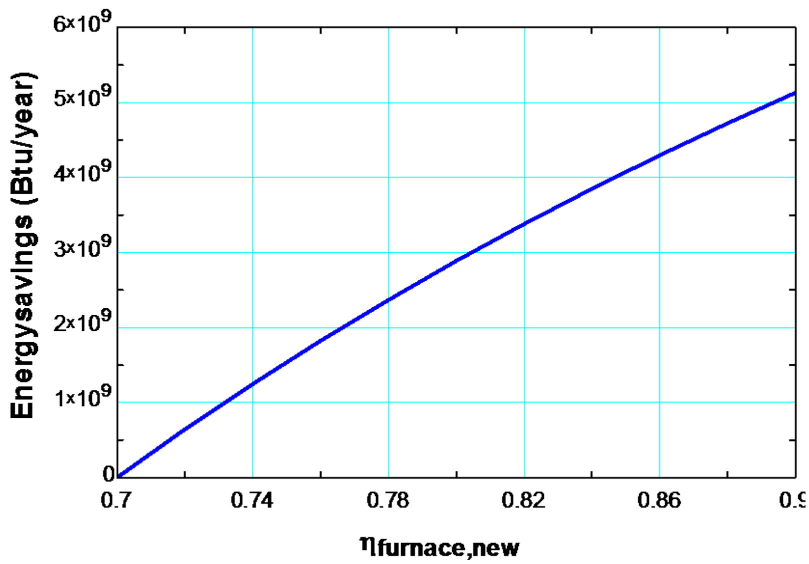
Analysis The problem is solved using EES, and the solution is given below.

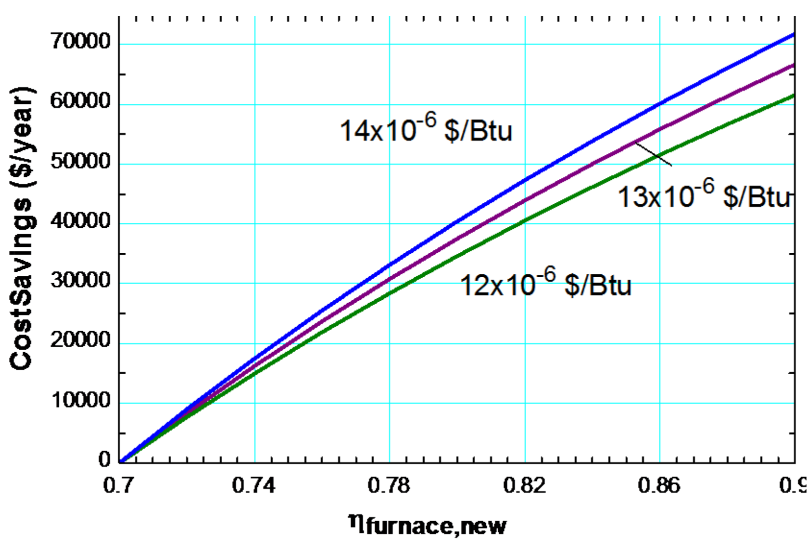
```
"Given"
Q_dot_in_current=5.5E6 [Btu/h]
eta_furnace_current=0.7
eta_furnace_new=0.8
Hours=4200 [h/year]
UnitCost=13E-6 [$/Btu]

"Analysis"
Q_dot_out=Q_dot_in_current*eta_furnace_current
Q_dot_in_new=Q_dot_out/eta_furnace_new
Q_dot_in_saved=Q_dot_in_current-Q_dot_in_new
Energysavings=Q_dot_in_saved*Hours
CostSavings=EnergySavings*UnitCost
```

$\eta_{furnace,new}$	EnergySavings [Btu/year]	CostSavings [$/year]
0.7	0.00E+00	0
0.72	6.42E+08	8342
0.74	1.25E+09	16232
0.76	1.82E+09	23708
0.78	2.37E+09	30800
0.8	2.89E+09	37538
0.82	3.38E+09	43946
0.84	3.85E+09	50050
0.86	4.30E+09	55870
0.88	4.73E+09	61425
0.9	5.13E+09	66733

Table values are for UnitCost=13E-5 [$/Btu]

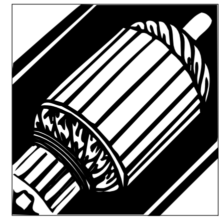




2-58 A worn out standard motor is replaced by a high efficiency one. The reduction in the internal heat gain due to the higher efficiency under full load conditions is to be determined.

Assumptions **1** The motor and the equipment driven by the motor are in the same room. **2** The motor operates at full load so that $f_{load} = 1$.

Analysis The heat generated by a motor is due to its inefficiency, and the difference between the heat generated by two motors that deliver the same shaft power is simply the difference between the electric power drawn by the motors,



$$\dot{W}_{\text{in, electric, standard}} = \dot{W}_{\text{shaft}} / \eta_{\text{motor}} = (75 \times 746 \text{ W})/0.91 = 61{,}484 \text{ W}$$
$$\dot{W}_{\text{in, electric, efficient}} = \dot{W}_{\text{shaft}} / \eta_{\text{motor}} = (75 \times 746 \text{ W})/0.954 = 58{,}648 \text{ W}$$

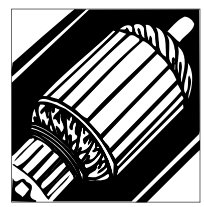
Then the reduction in heat generation becomes

$$\dot{Q}_{\text{reduction}} = \dot{W}_{\text{in, electric, standard}} - \dot{W}_{\text{in, electric, efficient}} = 61{,}484 - 58{,}648 = \mathbf{2836 \text{ W}}$$

2-59 An electric car is powered by an electric motor mounted in the engine compartment. The rate of heat supply by the motor to the engine compartment at full load conditions is to be determined.

Assumptions The motor operates at full load so that the load factor is 1.

Analysis The heat generated by a motor is due to its inefficiency, and is equal to the difference between the electrical energy it consumes and the shaft power it delivers,



$$\dot{W}_{\text{in, electric}} = \dot{W}_{\text{shaft}} / \eta_{\text{motor}} = (90 \text{ hp})/0.91 = 98.90 \text{ hp}$$
$$\dot{Q}_{\text{generation}} = \dot{W}_{\text{in, electric}} - \dot{W}_{\text{shaft out}} = 98.90 - 90 = 8.90 \text{ hp} = \mathbf{6.64 \text{ kW}}$$

since 1 hp = 0.746 kW.

Discussion Note that the electrical energy not converted to mechanical power is converted to heat.

2-60 Several people are working out in an exercise room. The rate of heat gain from people and the equipment is to be determined.

Assumptions The average rate of heat dissipated by people in an exercise room is 600 W.

Analysis The 6 weight lifting machines do not have any motors, and thus they do not contribute to the internal heat gain directly. The usage factors of the motors of the treadmills are taken to be unity since they are used constantly during peak periods. Noting that 1 hp = 745.7 W, the total heat generated by the motors is

$$\dot{Q}_{\text{motors}} = (\text{No. of motors}) \times \dot{W}_{\text{motor}} \times f_{\text{load}} \times f_{\text{usage}} / \eta_{\text{motor}}$$
$$= 7 \times (2.5 \times 746 \text{ W}) \times 0.70 \times 1.0/0.77 = 11{,}870 \text{ W}$$

The heat gain from 14 people is

$$\dot{Q}_{\text{people}} = 14 \times (600 \text{ W}) = 8400 \text{ W}$$

Then the total rate of heat gain of the exercise room during peak period becomes

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{motors}} + \dot{Q}_{\text{people}} = 11{,}870 + 8400 = \mathbf{20{,}270 \text{ W}}$$