Energy and Environment

2-79C Energy conversion pollutes the soil, the water, and the air, and the environmental pollution is a serious threat to vegetation, wild life, and human health. The emissions emitted during the combustion of fossil fuels are responsible for smog, acid rain, and global warming and climate change. The primary chemicals that pollute the air are hydrocarbons (HC, also referred to as volatile organic compounds, VOC), nitrogen oxides (NOx), and carbon monoxide (CO). The primary source of these pollutants is the motor vehicles.

2-80C Smog is the brown haze that builds up in a large stagnant air mass, and hangs over populated areas on calm hot summer days. Smog is made up mostly of ground-level ozone (O_3), but it also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOC) such as benzene, butane, and other hydrocarbons. Ground-level ozone is formed when hydrocarbons and nitrogen oxides react in the presence of sunlight in hot calm days. Ozone irritates eyes and damage the air sacs in the lungs where oxygen and carbon dioxide are exchanged, causing eventual hardening of this soft and spongy tissue. It also causes shortness of breath, wheezing, fatigue, headaches, nausea, and aggravate respiratory problems such as asthma.

2-81C Fossil fuels include small amounts of sulfur. The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2), which is an air pollutant. The sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight to form sulfuric and nitric acids. The acids formed usually dissolve in the suspended water droplets in clouds or fog. These acid-laden droplets are washed from the air on to the soil by rain or snow. This is known as *acid rain*. It is called “rain” since it comes down with rain droplets.

As a result of acid rain, many lakes and rivers in industrial areas have become too acidic for fish to grow. Forests in those areas also experience a slow death due to absorbing the acids through their leaves, needles, and roots. Even marble structures deteriorate due to acid rain.

2-82C Carbon dioxide (CO_2), water vapor, and trace amounts of some other gases such as methane and nitrogen oxides act like a blanket and keep the earth warm at night by blocking the heat radiated from the earth. This is known as the *greenhouse effect*. The greenhouse effect makes life on earth possible by keeping the earth warm. But excessive amounts of these gases disturb the delicate balance by trapping too much energy, which causes the average temperature of the earth to rise and the climate at some localities to change. These undesirable consequences of the greenhouse effect are referred to as *global warming* or *global climate change*. The greenhouse effect can be reduced by reducing the net production of CO_2 by consuming less energy (for example, by buying energy efficient cars and appliances) and planting trees.

2-83C Carbon monoxide, which is a colorless, odorless, poisonous gas that deprives the body's organs from getting enough oxygen by binding with the red blood cells that would otherwise carry oxygen. At low levels, carbon monoxide decreases the amount of oxygen supplied to the brain and other organs and muscles, slows body reactions and reflexes, and impairs judgment. It poses a serious threat to people with heart disease because of the fragile condition of the circulatory system and to fetuses because of the oxygen needs of the developing brain. At high levels, it can be fatal, as evidenced by numerous deaths caused by cars that are warmed up in closed garages or by exhaust gases leaking into the cars.

2-84E A person trades in his Ford Taurus for a Ford Explorer. The extra amount of CO_2 emitted by the Explorer within 5 years is to be determined.

Assumptions The Explorer is assumed to use 940 gallons of gasoline a year compared to 715 gallons for Taurus.

Analysis The extra amount of gasoline the Explorer will use within 5 years is

$$\begin{aligned}\text{Extra Gasoline} &= \text{(Extra per year)(No. of years)}\\ &= (940 - 715\text{ gal/yr})(5\text{ yr})\\ &= 1125\text{ gal}\\ \text{Extra } CO_2 \text{ produced} &= \text{(Extra gallons of gasoline used)}(CO_2 \text{ emission per gallon})\\ &= (1125\text{ gal})(19.7\text{ lbm/gal})\\ &= \mathbf{22{,}163\ lbm\ CO_2}\end{aligned}$$

Discussion Note that the car we choose to drive has a significant effect on the amount of greenhouse gases produced.

2-85 A power plant that burns natural gas produces 0.59 kg of carbon dioxide (CO_2) per kWh. The amount of CO_2 production that is due to the refrigerators in a city is to be determined.

Assumptions The city uses electricity produced by a natural gas power plant.

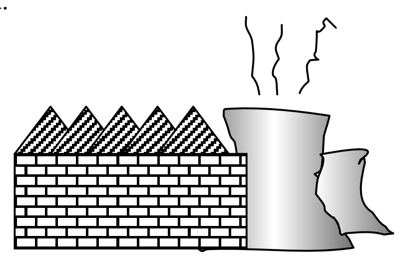
Properties 0.59 kg of CO_2 is produced per kWh of electricity generated (given).

Analysis Noting that there are 200,000 households in the city and each household consumes 700 kWh of electricity for refrigeration, the total amount of CO_2 produced is

$$\begin{aligned}\text{Amount of } CO_2 \text{ produced} &= \text{(Amount of electricity consumed)(Amount of } CO_2 \text{ per kWh)}\\ &= (200{,}000\text{ household})(700\text{ kWh/year household})(0.59\text{ kg/kWh})\\ &= 8.26\times10^7\ CO_2\text{ kg/year}\\ &= \mathbf{82{,}600\ \ CO_2\ ton/year}\end{aligned}$$

Therefore, the refrigerators in this city are responsible for the production of 82,600 tons of CO_2.

2-86 A power plant that burns coal, produces 1.1 kg of carbon dioxide (CO_2) per kWh. The amount of CO_2 production that is due to the refrigerators in a city is to be determined.



Assumptions The city uses electricity produced by a coal power plant.

Properties 1.1 kg of CO_2 is produced per kWh of electricity generated (given).

Analysis Noting that there are 200,000 households in the city and each household consumes 700 kWh of electricity for refrigeration, the total amount of CO_2 produced is

$$\begin{aligned}\text{Amount of } CO_2 \text{ produced} &= \text{(Amount of electricity consumed)(Amount of } CO_2 \text{ per kWh)}\\ &= (200{,}000\text{ household})(700\text{ kWh/household})(1.1\text{ kg/kWh})\\ &= 15.4\times10^7\ CO_2\text{ kg/year}\\ &= \mathbf{154{,}000\ \ CO_2\ ton/year}\end{aligned}$$

Therefore, the refrigerators in this city are responsible for the production of 154,000 tons of CO_2.

2-87E A household uses fuel oil for heating, and electricity for other energy needs. Now the household reduces its energy use by 20%. The reduction in the CO_2 production this household is responsible for is to be determined.

Properties The amount of CO_2 produced is 1.54 lbm per kWh and 26.4 lbm per gallon of fuel oil (given).

Analysis Noting that this household consumes 11,000 kWh of electricity and 1500 gallons of fuel oil per year, the amount of CO_2 production this household is responsible for is

$$\begin{aligned}\text{Amount of CO}_2\text{ produced} &= (\text{Amount of electricity consumed})(\text{Amount of CO}_2\text{ per kWh})\\ &\quad + (\text{Amount of fuel oil consumed})(\text{Amount of CO}_2\text{ per gallon})\\ &= (11{,}000\text{ kWh/yr})(1.54\text{ lbm/kWh}) + (1500\text{ gal/yr})(26.4\text{ lbm/gal})\\ &= 56{,}540\ \text{CO}_2\text{ lbm/year}\end{aligned}$$

Then reducing the electricity and fuel oil usage by 15% will reduce the annual amount of CO_2 production by this household by

$$\begin{aligned}\text{Reduction in CO}_2\text{ produced} &= (0.15)(\text{Current amount of CO}_2\text{ production})\\ &= (0.15)(56{,}540\ \text{CO}_2\text{ kg/year})\\ &= \mathbf{8481\ CO_2\ lbm/year}\end{aligned}$$

Therefore, any measure that saves energy also reduces the amount of pollution emitted to the environment.

2-88 A household has 2 cars, a natural gas furnace for heating, and uses electricity for other energy needs. The annual amount of NO_x emission to the atmosphere this household is responsible for is to be determined.

Properties The amount of NO_x produced is 7.1 g per kWh, 4.3 g per therm of natural gas, and 11 kg per car (given).

Analysis Noting that this household has 2 cars, consumes 1200 therms of natural gas, and 9,000 kWh of electricity per year, the amount of NO_x production this household is responsible for is

$$\begin{aligned}\text{Amount of NO}_x\text{ produced} &= (\text{No. of cars})(\text{Amount of NO}_x\text{ produced per car})\\ &\quad + (\text{Amount of electricity consumed})(\text{Amount of NO}_x\text{ per kWh})\\ &\quad + (\text{Amount of gas consumed})(\text{Amount of NO}_x\text{ per gallon})\\ &= (2\text{ cars})(11\text{ kg/car}) + (9000\text{ kWh/yr})(0.0071\text{ kg/kWh})\\ &\qquad + (1200\text{ therms/yr})(0.0043\text{ kg/therm})\\ &= \mathbf{91.06\ NO_x\ kg/year}\end{aligned}$$

Discussion Any measure that saves energy will also reduce the amount of pollution emitted to the atmosphere.

Special Topic: Mechanisms of Heat Transfer

2-89C The three mechanisms of heat transfer are conduction, convection, and radiation.

2-90C No. It is purely by radiation.

2-91C Diamond has a higher thermal conductivity than silver, and thus diamond is a better conductor of heat.

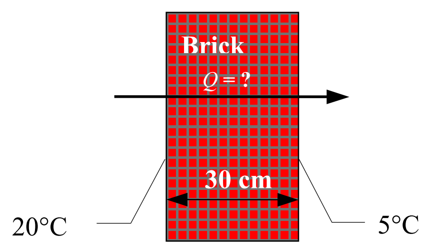
2-92C In forced convection, the fluid is forced to move by external means such as a fan, pump, or the wind. The fluid motion in natural convection is due to buoyancy effects only.

2-93C Emissivity is the ratio of the radiation emitted by a surface to the radiation emitted by a blackbody at the same temperature. Absorptivity is the fraction of radiation incident on a surface that is absorbed by the surface. The Kirchhoff's law of radiation states that the emissivity and the absorptivity of a surface are equal at the same temperature and wavelength.

2-94C A blackbody is an idealized body that emits the maximum amount of radiation at a given temperature, and that absorbs all the radiation incident on it. Real bodies emit and absorb less radiation than a blackbody at the same temperature.

2-95 The inner and outer surfaces of a brick wall are maintained at specified temperatures. The rate of heat transfer through the wall is to be determined.

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



Properties The thermal conductivity of the wall is given to be k = 0.69 W/m·°C.

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

$$\dot{Q}_{\text{cond}} = kA\frac{\Delta T}{L} = (0.69\text{ W/m}\cdot{}^\circ\text{C})(5\times 6\text{ m}^2)\frac{(20-5)^\circ\text{C}}{0.3\text{ m}} = \mathbf{1035\ W}$$

2-96 The inner and outer surfaces of a window glass are maintained at specified temperatures. The amount of heat transferred through the glass in 5 h is to be determined.

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

Properties The thermal conductivity of the glass is given to be k = 0.78 W/m·°C.

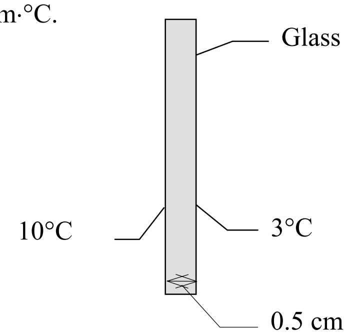
Analysis Under steady conditions, the rate of heat transfer through the glass by conduction is

$$\dot{Q}_{\text{cond}} = kA\frac{\Delta T}{L} = (0.78\text{ W/m}\cdot{}^\circ\text{C})(2\times 2\text{ m}^2)\frac{(10-3)^\circ\text{C}}{0.005\text{ m}} = 4368\text{ W}$$

Then the amount of heat transferred over a period of 5 h becomes

$$Q = \dot{Q}_{\text{cond}}\Delta t = (4.368\text{ kJ/s})(5\times 3600\text{s}) = \mathbf{78{,}600\ kJ}$$

If the thickness of the glass is doubled to 1 cm, then the amount of heat transferred will go down by half to **39,300 kJ**.

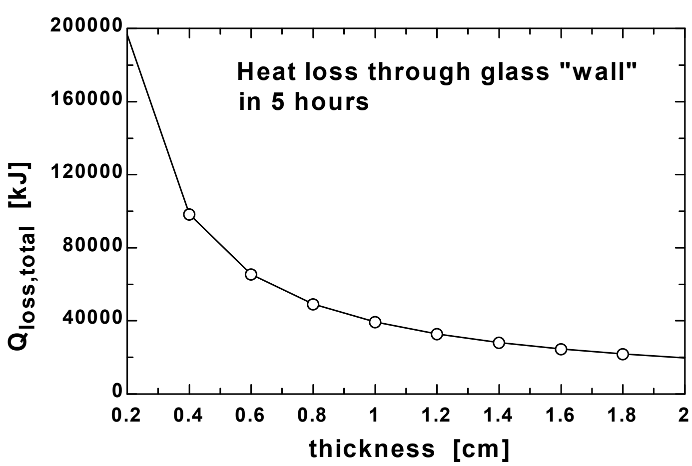


2-97 EES Reconsider Prob. 2-96. Using EES (or other) software, investigate the effect of glass thickness on heat loss for the specified glass surface temperatures. Let the glass thickness vary from 0.2 cm to 2 cm. Plot the heat loss versus the glass thickness, and discuss the results.

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

```
FUNCTION  klookup(material$)
If material$='Glass'  then klookup:=0.78
If material$='Brick'  then klookup:=0.72
If material$='Fiber Glass'  then klookup:=0.043
If material$='Air'  then klookup:=0.026
If material$='Wood(oak)'  then klookup:=0.17
END

L=2"[m]"
W=2"[m]"
{material$='Glass'
T_in=10"[C]"
T_out=3"[C]"
k=0.78"[W/m-C]"
t=5"[hr]"
thickness=0.5"[cm]"}
k=klookup(material$)"[W/m-K]"
A=L*W"[m^2]"
Q_dot_loss=A*k*(T_in-T_out)/(thickness*convert(cm,m))"[W]"
Q_loss_total=Q_dot_loss*t*convert(hr,s)*convert(J,kJ)"[kJ]"
```

$Q_{loss,total}$ [kJ]	Thickness [cm]
196560	0.2
98280	0.4
65520	0.6
49140	0.8
39312	1
32760	1.2
28080	1.4
24570	1.6
21840	1.8
19656	2



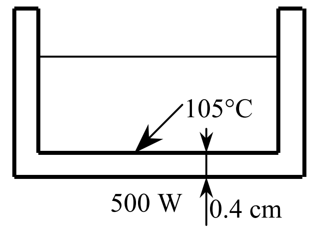
2-98 Heat is transferred steadily to boiling water in the pan through its bottom. The inner surface temperature of the bottom of the pan is given. The temperature of the outer surface is to be determined.

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

Properties The thermal conductivity of the aluminum is given to be $k = 237$ W/m·°C.

Analysis The heat transfer surface area is

$$A = \pi r^2 = \pi(0.1\text{ m})^2 = 0.0314\text{ m}^2$$



Under steady conditions, the rate of heat transfer through the bottom of the pan by conduction is

$$\dot{Q} = kA\frac{\Delta T}{L} = kA\frac{T_2 - T_1}{L}$$

Substituting, $$500\text{ W} = (237\text{ W/m}\cdot^\circ\text{C})(0.0314\text{ m}^2)\frac{T_2 - 105^\circ\text{C}}{0.004\text{ m}}$$

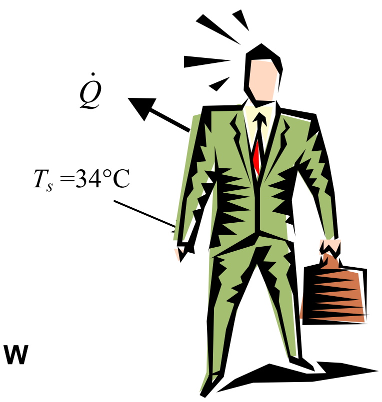
which gives $T_2 =$ **105.3°C**

2-99 A person is standing in a room at a specified temperature. The rate of heat transfer between a person and the surrounding air by convection is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The environment is at a uniform temperature.

Analysis The heat transfer surface area of the person is

$$A = \pi DL = \pi(0.3\text{ m})(1.70\text{ m}) = 1.60\text{ m}^2$$



Under steady conditions, the rate of heat transfer by convection is

$$\dot{Q}_{\text{conv}} = hA\Delta T = (15\text{ W/m}^2\cdot{}^\circ\text{C})(1.60\text{ m}^2)(34-20)^\circ\text{C} = \mathbf{336\ W}$$

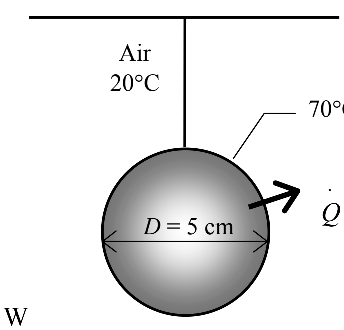
2-100 A spherical ball whose surface is maintained at a temperature of 70°C is suspended in the middle of a room at 20°C. The total rate of heat transfer from the ball is to be determined.

Assumptions **1** Steady operating conditions exist since the ball surface and the surrounding air and surfaces remain at constant temperatures. **2** The thermal properties of the ball and the convection heat transfer coefficient are constant and uniform.

Properties The emissivity of the ball surface is given to be $\varepsilon = 0.8$.

Analysis The heat transfer surface area is

$$A = \pi D^2 = 3.14\text{x}(0.05\text{ m})^2 = 0.007854\text{ m}^2$$



Under steady conditions, the rates of convection and radiation heat transfer are

$$\dot{Q}_{\text{conv}} = hA\Delta T = (15\text{ W/m}^2\cdot{}^\circ\text{C})(0.007854\text{ m}^2)(70-20)^\circ\text{C} = 5.89\text{ W}$$

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A(T_s^4 - T_o^4) = 0.8(0.007854\text{ m}^2)(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4)[(343\text{ K})^4 - (293\text{ K})^4] = 2.31\text{ W}$$

Therefore,

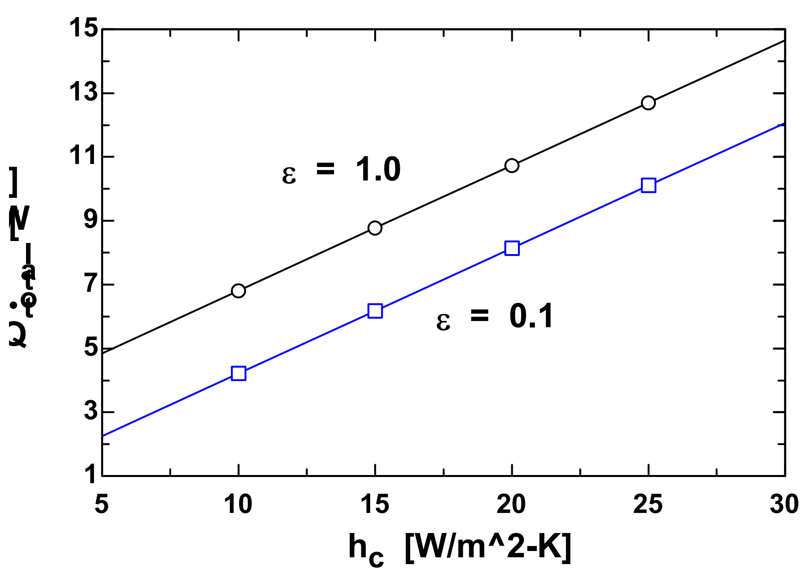
$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 5.89 + 2.31 = \mathbf{8.20\ W}$$

2-101 EES Reconsider Prob. 2-100. Using EES (or other) software, investigate the effect of the convection heat transfer coefficient and surface emissivity on the heat transfer rate from the ball. Let the heat transfer coefficient vary from 5 W/m^2.°C to 30 W/m^2.°C. Plot the rate of heat transfer against the convection heat transfer coefficient for the surface emissivities of 0.1, 0.5, 0.8, and 1, and discuss the results.

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

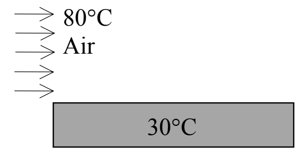
```
sigma=5.67e-8"[W/m^2-K^4]"
{T_sphere=70"[C]"
T_room=20"[C]"
D_sphere=5"[cm]"
epsilon=0.1
h_c=15"[W/m^2-K]"}

A=4*pi*(D_sphere/2)^2*convert(cm^2,m^2)"[m^2]"
Q_dot_conv=A*h_c*(T_sphere-T_room)"[W]"
Q_dot_rad=A*epsilon*sigma*((T_sphere+273)^4-(T_room+273)^4)"[W]"
Q_dot_total=Q_dot_conv+Q_dot_rad"[W]"
```

h_c [W/m^2-K]	Q_{total} [W]
5	2.252
10	4.215
15	6.179
20	8.142
25	10.11
30	12.07



2-102 Hot air is blown over a flat surface at a specified temperature. The rate of heat transfer from the air to the plate is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The convection heat transfer coefficient is constant and uniform over the surface.

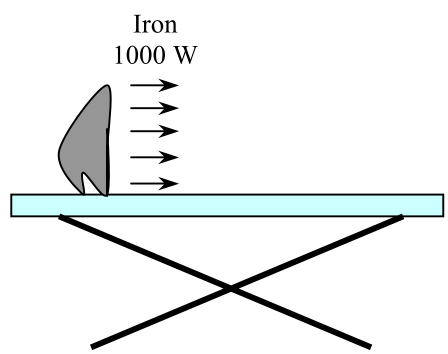


Analysis Under steady conditions, the rate of heat transfer by convection is

$$\dot{Q}_{\text{conv}} = hA\Delta T = (55\ \text{W/m}^2\cdot{}^\circ\text{C})(2\times 4\ \text{m}^2)(80-30)^\circ\text{C} = \mathbf{22{,}000\ W} = \mathbf{22\ kW}$$

2-103 A 1000-W iron is left on the iron board with its base exposed to the air at 20°C. The temperature of the base of the iron is to be determined in steady operation.

Assumptions **1** Steady operating conditions exist. **2** The thermal properties of the iron base and the convection heat transfer coefficient are constant and uniform. **3** The temperature of the surrounding surfaces is the same as the temperature of the surrounding air.



Properties The emissivity of the base surface is given to be ε = 0.6.

Analysis At steady conditions, the 1000 W of energy supplied to the iron will be dissipated to the surroundings by convection and radiation heat transfer. Therefore,

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 1000\ \text{W}$$

where $\dot{Q}_{\text{conv}} = hA\Delta T = (35\ \text{W/m}^2\cdot\text{K})(0.02\ \text{m}^2)(T_s - 293\ \text{K}) = 0.7(T_s - 293\ \text{K})\ \text{W}$

and

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A(T_s^4 - T_o^4) = 0.6(0.02\ \text{m}^2)(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4)[\text{T}_\text{s}^4 - (293\ \text{K})^4]$$
$$= 0.06804\times10^{-8}[T_s^4 - (293\ \text{K})^4]\ \text{W}$$

Substituting, $1000\ \text{W} = 0.7(T_s - 293\ \text{K}) + 0.06804\times10^{-8}[T_s^4 - (293\ \text{K})^4]$

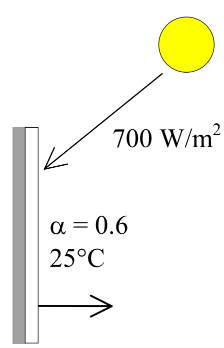
Solving by trial and error gives $T_s = \mathbf{947\ K} = \mathbf{674^\circ C}$

Discussion We note that the iron will dissipate all the energy it receives by convection and radiation when its surface temperature reaches 947 K.

2-104 The backside of the thin metal plate is insulated and the front side is exposed to solar radiation. The surface temperature of the plate is to be determined when it stabilizes.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer through the insulated side of the plate is negligible. **3** The heat transfer coefficient is constant and uniform over the plate. **4** Heat loss by radiation is negligible.

Properties The solar absorptivity of the plate is given to be α = 0.6.



Analysis When the heat loss from the plate by convection equals the solar radiation absorbed, the surface temperature of the plate can be determined from

$$\dot{Q}_{\text{solarabsorbed}} = \dot{Q}_{\text{conv}}$$
$$\alpha\dot{Q}_{\text{solar}} = hA(T_s - T_o)$$
$$0.6\times A\times 700\text{W/m}^2 = (50\text{W/m}^2\cdot{}^\circ\text{C})A(T_s - 25)$$

Canceling the surface area A and solving for T_s gives

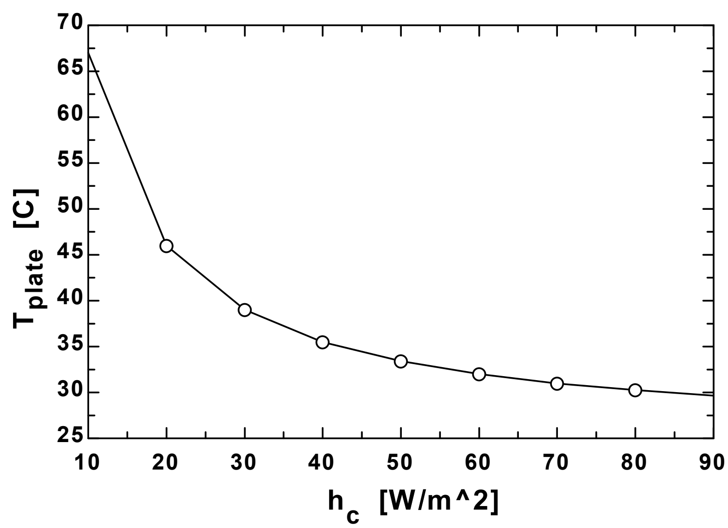
$$T_s = \mathbf{33.4^\circ C}$$

2-105 EES Reconsider Prob. 2-104. Using EES (or other) software, investigate the effect of the convection heat transfer coefficient on the surface temperature of the plate. Let the heat transfer coefficient vary from 10 W/m^2.°C to 90 W/m^2.°C. Plot the surface temperature against the convection heat transfer coefficient, and discuss the results.

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

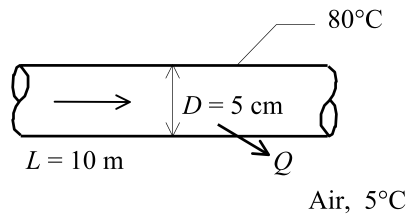
```
sigma=5.67e-8"[W/m^2-K^4]"
"The following variables are obtained from the Diagram Window."
{T_air=25"[C]"
S=700"[W/m^2]"
alpha_solar=0.6
h_c=50"[W/m^2-C]"}

"An energy balance on the plate gives:"
Q_dot_solar=Q_dot_conv"[W]"

"The absorbed solar per unit area of plate"
Q_dot_solar =S*alpha_solar"[W]"

"The leaving energy by convection per unit area of plate"
Q_dot_conv=h_c*(T_plate-T_air)"[W]"
```

h_c [W/m^2-K]	T_{plate} [C]
10	67
20	46
30	39
40	35.5
50	33.4
60	32
70	31
80	30.25
90	29.67



2-106 A hot water pipe at 80°C is losing heat to the surrounding air at 5°C by natural convection with a heat transfer coefficient of 25 W/ m^2.°C. The rate of heat loss from the pipe by convection is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is not considered. **3** The convection heat transfer coefficient is constant and uniform over the surface.



Analysis The heat transfer surface area is

$$A = (\pi D)L = 3.14\text{x}(0.05\text{ m})(10\text{ m}) = 1.571\text{ m}^2$$

Under steady conditions, the rate of heat transfer by convection is

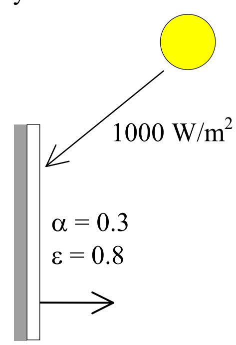
$$\dot{Q}_{\text{conv}} = hA\Delta T = (25\text{ W/m}^2\cdot°\text{C})(1.571\text{ m}^2)(80-5)°\text{C} = \mathbf{2945\ W} = \mathbf{2.95\ kW}$$

2-107 A spacecraft in space absorbs solar radiation while losing heat to deep space by thermal radiation. The surface temperature of the spacecraft is to be determined when steady conditions are reached..

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

Properties The outer surface of a spacecraft has an emissivity of 0.8 and an absorptivity of 0.3.

Analysis When the heat loss from the outer surface of the spacecraft by radiation equals the solar radiation absorbed, the surface temperature can be determined from



$$\dot{Q}_{\text{solarabsorbed}} = \dot{Q}_{\text{rad}}$$

$$\alpha\dot{Q}_{\text{solar}} = \varepsilon\sigma A(T_s^4 - T_{\text{space}}^4)$$

$$0.3\times A\times(1000\text{ W/m}^2) = 0.8\times A\times(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4)[T_s^4-(0\text{ K})^4]$$

Canceling the surface area A and solving for T_s gives

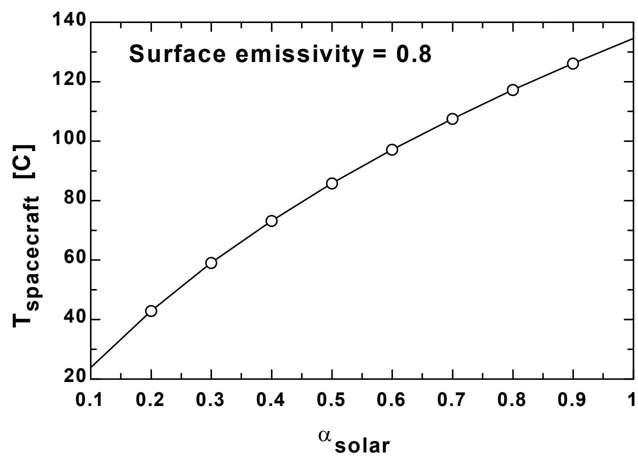
$$T_s = \mathbf{285\ K}$$

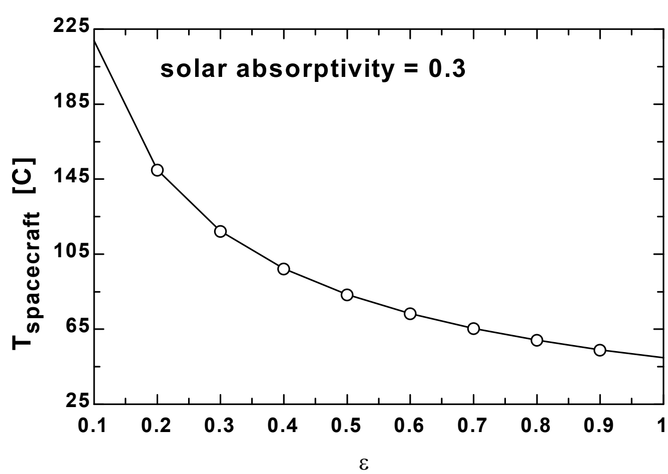
2-108 EES Reconsider Prob. 2-107. Using EES (or other) software, investigate the effect of the surface emissivity and absorptivity of the spacecraft on the equilibrium surface temperature. Plot the surface temperature against emissivity for solar absorptivities of 0.1, 0.5, 0.8, and 1, and discuss the results.

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

```
"Knowns"
sigma=5.67e-8"[W/m^2-K^4]"

"The following variables are obtained from the Diagram Window."
{T_space=10"[C]"
S=1000"[W/m^2]"
alpha_solar=0.3
epsilon=0.8}

"Solution"

"An energy balance on the spacecraft gives:"
Q_dot_solar=Q_dot_out
"The absorbed solar"
Q_dot_solar =S*alpha_solar
"The net leaving radiation leaving the spacecraft:"
Q_dot_out=epsilon*sigma*((T_spacecraft+273)^4-(T_space+273)^4)
```

ε	$T_{spacecraft}$ [C]
0.1	218.7
0.2	150
0.3	117.2
0.4	97.2
0.5	83.41
0.6	73.25
0.7	65.4
0.8	59.13
0.9	54
1	49.71

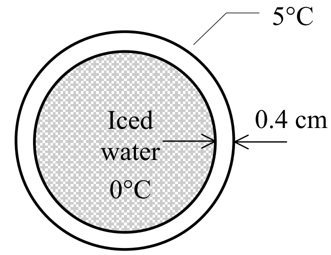




2-109 A hollow spherical iron container is filled with iced water at 0°C. The rate of heat loss from the sphere and the rate at which ice melts in the container are to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Heat transfer through the shell is one-dimensional. **3** Thermal properties of the iron shell are constant. **4** The inner surface of the shell is at the same temperature as the iced water, 0°C.

Properties The thermal conductivity of iron is $k = 80.2$ W/m·°C (Table 2-3). The heat of fusion of water is at 1 atm is 333.7 kJ/kg.



Analysis This spherical shell can be approximated as a plate of thickness 0.4 cm and surface area

$$A = \pi D^2 = 3.14\times(0.2\text{ m})^2 = 0.126\text{ m}^2$$

Then the rate of heat transfer through the shell by conduction is

$$\dot{Q}_{\text{cond}} = kA\frac{\Delta T}{L} = (80.2\text{ W/m}\cdot^\circ\text{C})(0.126\text{ m}^2)\frac{(5-0)^\circ\text{C}}{0.004\text{ m}} = 12{,}632\text{ W}$$

Considering that it takes 333.7 kJ of energy to melt 1 kg of ice at 0°C, the rate at which ice melts in the container can be determined from

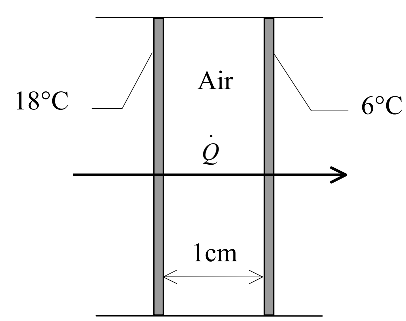
$$\dot{m}_{\text{ice}} = \frac{\dot{Q}}{h_{if}} = \frac{12.632\text{ kJ/s}}{333.7\text{ kJ/kg}} = \mathbf{0.038\ kg/s}$$

Discussion We should point out that this result is slightly in error for approximating a curved wall as a plain wall. The error in this case is very small because of the large diameter to thickness ratio. For better accuracy, we could use the inner surface area (D = 19.2 cm) or the mean surface area (D = 19.6 cm) in the calculations.

2-110 The inner and outer glasses of a double pane window with a 1-cm air space are at specified temperatures. The rate of heat transfer through the window is to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the glass remain constant at the specified values. **2** Heat transfer through the window is one-dimensional. **3** Thermal properties of the air are constant. **4** The air trapped between the two glasses is still, and thus heat transfer is by conduction only.

Properties The thermal conductivity of air at room temperature is $k = 0.026$ W/m.°C (Table 2-3).

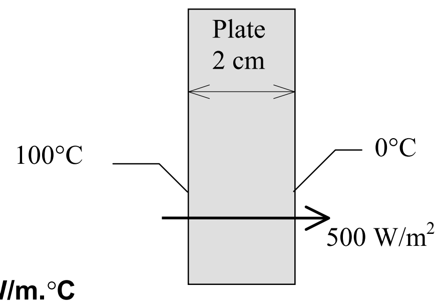


Analysis Under steady conditions, the rate of heat transfer through the window by conduction is

$$\dot{Q}_{\text{cond}} = kA\frac{\Delta T}{L} = (0.026\text{ W/m}\cdot^\circ\text{C})(2\times 2\text{ m}^2)\frac{(18-6)^\circ\text{C}}{0.01\text{ m}}$$
$$= \mathbf{125\ W} = \mathbf{0.125\ kW}$$

2-111 Two surfaces of a flat plate are maintained at specified temperatures, and the rate of heat transfer through the plate is measured. The thermal conductivity of the plate material is to be determined.

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



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

$$\dot{Q} = kA\frac{T_1 - T_2}{L} \rightarrow k = \frac{(\dot{Q}/A)L}{T_1 - T_2} = \frac{(500 \text{ W/m}^2)(0.02 \text{ m})}{(100-0)°\text{C}} = \mathbf{0.1 \ W/m.°C}$$

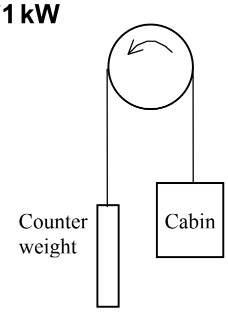
Review Problems

2-112 The weight of the cabin of an elevator is balanced by a counterweight. The power needed when the fully loaded cabin is rising, and when the empty cabin is descending at a constant speed are to be determined.

Assumptions **1** The weight of the cables is negligible. **2** The guide rails and pulleys are frictionless. **3** Air drag is negligible.

Analysis (*a*) When the cabin is fully loaded, half of the weight is balanced by the counterweight. The power required to raise the cabin at a constant speed of 1.2 m/s is

$$\dot{W} = \frac{mgz}{\Delta t} = mgV = (400 \text{ kg})(9.81 \text{ m/s}^2)(1.2 \text{ m/s})\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kW}}{1000 \text{ N}\cdot\text{m/s}}\right) = \mathbf{4.71 \ kW}$$



If no counterweight is used, the mass would double to 800 kg and the power would be 2×4.71 = **9.42 kW**.

(*b*) When the empty cabin is descending (and the counterweight is ascending) there is mass imbalance of 400-150 = 250 kg. The power required to raise this mass at a constant speed of 1.2 m/s is

$$\dot{W} = \frac{mgz}{\Delta t} = mgV = (250 \text{ kg})(9.81 \text{ m/s}^2)(1.2 \text{ m/s})\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kW}}{1000 \text{ N}\cdot\text{m/s}}\right) = \mathbf{2.94 \ kW}$$

If a friction force of 800 N develops between the cabin and the guide rails, we will need

$$\dot{W}_{\text{friction}} = \frac{F_{\text{friction}} z}{\Delta t} = F_{\text{friction}} V = (800 \text{ N})(1.2 \text{ m/s})\left(\frac{1 \text{ kW}}{1000 \text{ N}\cdot\text{m/s}}\right) = 0.96 \text{ kW}$$

of additional power to combat friction which always acts in the opposite direction to motion.

Therefore, the total power needed in this case is

$$\dot{W}_{\text{total}} = \dot{W} + \dot{W}_{\text{friction}} = 2.94 + 0.96 = \mathbf{3.90 \ kW}$$

2-113 A decision is to be made between a cheaper but inefficient natural gas heater and an expensive but efficient natural gas heater for a house.

Assumptions The two heaters are comparable in all aspects other than the initial cost and efficiency.

Analysis Other things being equal, the logical choice is the heater that will cost less during its lifetime. The total cost of a system during its lifetime (the initial, operation, maintenance, etc.) can be determined by performing a life cycle cost analysis. A simpler alternative is to determine the simple payback period.

The annual heating cost is given to be \$1200. Noting that the existing heater is 55% efficient, only 55% of that energy (and thus money) is delivered to the house, and the rest is wasted due to the inefficiency of the heater. Therefore, the monetary value of the heating load of the house is

Gas Heater
$\eta_1 = 82\%$
$\eta_2 = 95\%$

Cost of useful heat = (55%)(Current annual heating cost) = 0.55×(\$1200/yr)=\$660/yr

This is how much it would cost to heat this house with a heater that is 100% efficient. For heaters that are less efficient, the annual heating cost is determined by dividing \$660 by the efficiency:

82% heater: Annual cost of heating = (Cost of useful heat)/Efficiency = (\$660/yr)/0.82 = \$805/yr

95% heater: Annual cost of heating = (Cost of useful heat)/Efficiency = (\$660/yr)/0.95 = \$695/yr

Annual cost savings with the efficient heater = 805 - 695 = \$110

Excess initial cost of the efficient heater = 2700 - 1600 = \$1100

The simple payback period becomes

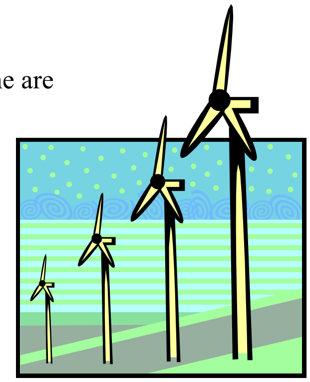
$$\text{Simple payback period} = \frac{\text{Excess initial cost}}{\text{Annaul cost savings}} = \frac{\$1100}{\$110\,/\,\text{yr}} = \mathbf{10\ years}$$

Therefore, the more efficient heater will pay for the \$1100 cost differential in this case in 10 years, which is more than the 8-year limit. Therefore, the purchase of the cheaper and less efficient heater is a better buy in this case.

2-114 A wind turbine is rotating at 20 rpm under steady winds of 30 km/h. The power produced, the tip speed of the blade, and the revenue generated by the wind turbine per year are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The wind turbine operates continuously during the entire year at the specified conditions.

Properties The density of air is given to be $\rho = 1.20\ \text{kg/m}^3$.



Analysis (*a*) The blade span area and the mass flow rate of air through the turbine are

$$A = \pi D^2/4 = \pi(80\ \text{m})^2/4 = 5027\ \text{m}^2$$

$$V = (30\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = 8.333\ \text{m/s}$$

$$\dot{m} = \rho A V = (1.2\ \text{kg/m}^3)(5027\ \text{m}^2)(8.333\ \text{m/s}) = 50{,}270\ \text{kg/s}$$

Noting that the kinetic energy of a unit mass is $V^2/2$ and the wind turbine captures 35% of this energy, the power generated by this wind turbine becomes

$$\dot{W} = \eta\left(\frac{1}{2}\dot{m}V^2\right) = (0.35)\frac{1}{2}(50{,}270\ \text{kg/s})(8.333\ \text{m/s})^2\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = \mathbf{610.9\ kW}$$

(*b*) Noting that the tip of blade travels a distance of πD per revolution, the tip velocity of the turbine blade for an rpm of $\dot{n}$ becomes

$$V_{\text{tip}} = \pi D\dot{n} = \pi(80\ \text{m})(20/\text{min}) = 5027\ \text{m/min} = 83.8\ \text{m/s} = \mathbf{302\ km/h}$$

(*c*) The amount of electricity produced and the revenue generated per year are

$$\text{Electricity produced} = \dot{W}\Delta t = (610.9\ \text{kW})(365\times 24\ \text{h/year})$$
$$= 5.351\times 10^6\ \text{kWh/year}$$

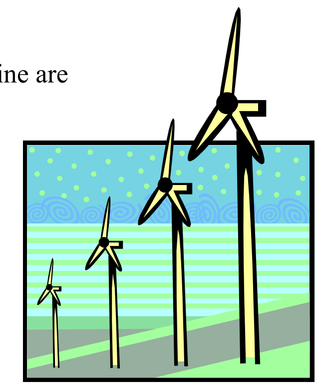
$$\text{Revenue generated} = (\text{Electricity produced})(\text{Unit price}) = (5.351\times 10^6\ \text{kWh/year})(\$0.06/\text{kWh})$$
$$= \mathbf{\$321{,}100/year}$$

2-115 A wind turbine is rotating at 20 rpm under steady winds of 25 km/h. The power produced, the tip speed of the blade, and the revenue generated by the wind turbine per year are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The wind turbine operates continuously during the entire year at the specified conditions.

Properties The density of air is given to be $\rho = 1.20\ \text{kg/m}^3$.

Analysis (*a*) The blade span area and the mass flow rate of air through the turbine are



$$A = \pi D^2/4 = \pi(80\ \text{m})^2/4 = 5027\ \text{m}^2$$

$$V = (25\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = 6.944\ \text{m/s}$$

$$\dot{m} = \rho A V = (1.2\ \text{kg/m}^3)(5027\ \text{m}^2)(6.944\ \text{m/s}) = 41{,}891\ \text{kg/s}$$

Noting that the kinetic energy of a unit mass is $V^2/2$ and the wind turbine captures 35% of this energy, the power generated by this wind turbine becomes

$$\dot{W} = \eta\left(\frac{1}{2}\dot{m}V^2\right) = (0.35)\frac{1}{2}(41{,}891\ \text{kg/s})(6.944\ \text{m/s})^2\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = \mathbf{353.5\ kW}$$

(*b*) Noting that the tip of blade travels a distance of πD per revolution, the tip velocity of the turbine blade for an rpm of $\dot{n}$ becomes

$$V_{\text{tip}} = \pi D\dot{n} = \pi(80\ \text{m})(20/\text{min}) = 5027\ \text{m/min} = 83.8\ \text{m/s} = \mathbf{302\ km/h}$$

(*c*) The amount of electricity produced and the revenue generated per year are

$$\text{Electricity produced} = \dot{W}\Delta t = (353.5\ \text{kW})(365\times 24\ \text{h/year})$$
$$= 3{,}096{,}660\ \text{kWh/year}$$

$$\text{Revenue generated} = (\text{Electricity produced})(\text{Unit price}) = (3{,}096{,}660\ \text{kWh/year})(\$0.06/\text{kWh})$$
$$= \mathbf{\$185{,}800/year}$$

2-116E The energy contents, unit costs, and typical conversion efficiencies of various energy sources for use in water heaters are given. The lowest cost energy source is to be determined.

Assumptions The differences in installation costs of different water heaters are not considered.

Properties The energy contents, unit costs, and typical conversion efficiencies of different systems are given in the problem statement.

Analysis The unit cost of each Btu of useful energy supplied to the water heater by each system can be determined from

$$\text{Unit cost of useful energy} = \frac{\text{Unit cost of energy supplied}}{\text{Conversion efficiency}}$$

Substituting,

Natural gas heater: $$\text{Unit cost of useful energy} = \frac{\$0.012/\text{ft}^3}{0.55}\left(\frac{1\ \text{ft}^3}{1025\ \text{Btu}}\right) = \$21.3\times10^{-6}\ /\ \text{Btu}$$

Heating by oil heater: $$\text{Unit cost of useful energy} = \frac{\$1.15/\text{gal}}{0.55}\left(\frac{1\ \text{gal}}{138{,}700\ \text{Btu}}\right) = \$15.1\times10^{-6}\ /\ \text{Btu}$$

Electric heater: $$\text{Unit cost of useful energy} = \frac{\$0.084/\text{kWh})}{0.90}\left(\frac{1\ \text{kWh}}{3412\ \text{Btu}}\right) = \$27.4\times10^{-6}\ /\ \text{Btu}$$

Therefore, the lowest cost energy source for hot water heaters in this case is **oil**.

2-117 A home owner is considering three different heating systems for heating his house. The system with the lowest energy cost is to be determined.

Assumptions The differences in installation costs of different heating systems are not considered.

Properties The energy contents, unit costs, and typical conversion efficiencies of different systems are given in the problem statement.

Analysis The unit cost of each Btu of useful energy supplied to the house by each system can be determined from

$$\text{Unit cost of useful energy} = \frac{\text{Unit cost of energy supplied}}{\text{Conversion efficiency}}$$

Substituting,

Natural gas heater: $$\text{Unit cost of useful energy} = \frac{\$1.24/\text{therm}}{0.87}\left(\frac{1\ \text{therm}}{105{,}500\ \text{kJ}}\right) = \$13.5\times10^{-6}\ /\ \text{kJ}$$

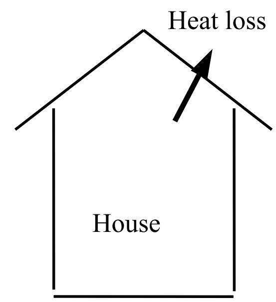
Heating oil heater: $$\text{Unit cost of useful energy} = \frac{\$1.25/\text{gal}}{0.87}\left(\frac{1\ \text{gal}}{138{,}500\ \text{kJ}}\right) = \$10.4\times10^{-6}\ /\ \text{kJ}$$

Electric heater: $$\text{Unit cost of useful energy} = \frac{\$0.09/\text{kWh})}{1.0}\left(\frac{1\ \text{kWh}}{3600\ \text{kJ}}\right) = \$25.0\times10^{-6}\ /\ \text{kJ}$$

Therefore, the system with the lowest energy cost for heating the house is the **heating oil heater**.

2-118 The heating and cooling costs of a poorly insulated house can be reduced by up to 30 percent by adding adequate insulation. The time it will take for the added insulation to pay for itself from the energy it saves is to be determined.

Assumptions It is given that the annual energy usage of a house is \$1200 a year, and 46% of it is used for heating and cooling. The cost of added insulation is given to be \$200.



Analysis The amount of money that would be saved per year is determined directly from

$$\text{Money saved} = (\$1200/\text{year})(0.46)(0.30) = \$166/\text{yr}$$

Then the simple payback period becomes

$$\text{Payback period} = \frac{\text{Cost}}{\text{Money saved}} = \frac{\$200}{\$166/\text{yr}} = \mathbf{1.2\ yr}$$

Therefore, the proposed measure will pay for itself in less than one and a half year.

2-119 Caulking and weather-stripping doors and windows to reduce air leaks can reduce the energy use of a house by up to 10 percent. The time it will take for the caulking and weather-stripping to pay for itself from the energy it saves is to be determined.

Assumptions It is given that the annual energy usage of a house is \$1100 a year, and the cost of caulking and weather-stripping a house is \$50.

Analysis The amount of money that would be saved per year is determined directly from

$$\text{Money saved} = (\$1100/\text{year})(0.10) = \$110/\text{yr}$$

Then the simple payback period becomes

$$\text{Payback period} = \frac{\text{Cost}}{\text{Money saved}} = \frac{\$50}{\$110/\text{yr}} = \mathbf{0.45\ yr}$$

Therefore, the proposed measure will pay for itself in less than half a year.

2-120 It is estimated that 570,000 barrels of oil would be saved per day if the thermostat setting in residences in winter were lowered by 6°F (3.3°C). The amount of money that would be saved per year is to be determined.

Assumptions The average heating season is given to be 180 days, and the cost of oil to be \$40/barrel.

Analysis The amount of money that would be saved per year is determined directly from

$$(570{,}000\ \text{barrel/day})(180\ \text{days/year})(\$40/\text{barrel}) = \mathbf{\$4{,}104{,}000{,}000}$$

Therefore, the proposed measure will save more than 4-billion dollars a year in energy costs.

2-121 A TV set is kept on a specified number of hours per day. The cost of electricity this TV set consumes per month is to be determined.

Assumptions **1** The month is 30 days. **2** The TV set consumes its rated power when on.

Analysis The total number of hours the TV is on per month is

Operating hours = (6 h/day)(30 days) = 180 h

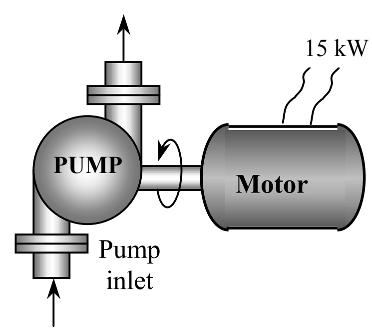
Then the amount of electricity consumed per month and its cost become

Amount of electricity = (Power consumed)(Operating hours)=(0.120 kW)(180 h) =21.6 kWh

Cost of electricity = (Amount of electricity)(Unit cost) = (21.6 kWh)($0.08/kWh) = **$1.73** (per month)

Properties Note that an ordinary TV consumes more electricity that a large light bulb, and there should be a conscious effort to turn it off when not in use to save energy.

2-122 The pump of a water distribution system is pumping water at a specified flow rate. The pressure rise of water in the pump is measured, and the motor efficiency is specified. The mechanical efficiency of the pump is to be determined.



Assumptions **1** The flow is steady. **2** The elevation difference across the pump is negligible. **3** Water is incompressible.

Analysis From the definition of motor efficiency, the mechanical (shaft) power delivered by the he motor is

$$\dot{W}_{\text{pump,shaft}} = \eta_{\text{motor}} \dot{W}_{\text{electric}} = (0.90)(15\ \text{kW}) = 13.5\ \text{kW}$$

To determine the mechanical efficiency of the pump, we need to know the increase in the mechanical energy of the fluid as it flows through the pump, which is

$$\Delta \dot{E}_{\text{mech,fluid}} = \dot{m}(e_{\text{mech,out}} - e_{\text{mech,in}}) = \dot{m}[(Pv)_2 - (Pv)_1] = \dot{m}(P_2 - P_1)v = \dot{\boldsymbol{V}}(P_2 - P_1)$$

$$= (0.050\ \text{m}^3/\text{s})(300 - 100\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = 10\ \text{kJ/s} = 10\ \text{kW}$$

since $\dot{m} = \rho \dot{\boldsymbol{V}} = \dot{\boldsymbol{V}} / v$ and there is no change in kinetic and potential energies of the fluid. Then the pump efficiency becomes

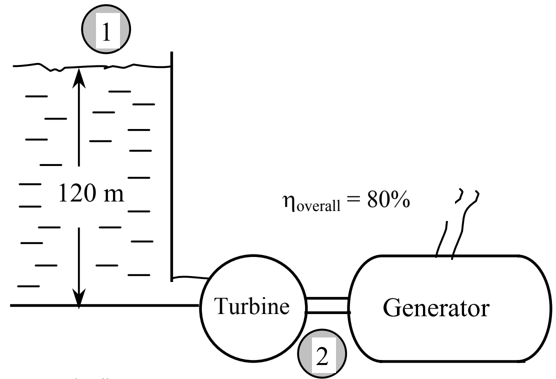
$$\eta_{\text{pump}} = \frac{\Delta \dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{pump, shaft}}} = \frac{10\ \text{kW}}{13.5\ \text{kW}} = 0.741 \quad \text{or} \quad \mathbf{74.1\%}$$

Discussion The overall efficiency of this pump/motor unit is the product of the mechanical and motor efficiencies, which is 0.9×0.741 = 0.667.

2-123 The available head, flow rate, and efficiency of a hydroelectric turbine are given. The electric power output is to be determined.

Assumptions **1** The flow is steady. **2** Water levels at the reservoir and the discharge site remain constant. **3** Frictional losses in piping are negligible.

Properties We take the density of water to be ρ = 1000 kg/m^3 = 1 kg/L.



Analysis The total mechanical energy the water in a dam possesses is equivalent to the potential energy of water at the free surface of the dam (relative to free surface of discharge water), 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.

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

The mass flow rate is

$$\dot{m} = \rho\dot{\boldsymbol{V}} = (1000\,\text{kg/m}^3)(100\,\text{m}^3/\text{s}) = 200{,}000\,\text{kg/s}$$

Then the maximum and actual electric power generation become

$$\dot{W}_{\text{max}} = \dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = (100{,}000\,\text{kg/s})(1.177\,\text{kJ/kg})\left(\frac{1\,\text{MW}}{1000\,\text{kJ/s}}\right) = 117.7\,\text{MW}$$

$$\dot{W}_{\text{electric}} = \eta_{\text{overall}}\dot{W}_{\text{max}} = 0.80(117.7\,\text{MW}) = \mathbf{94.2\ MW}$$

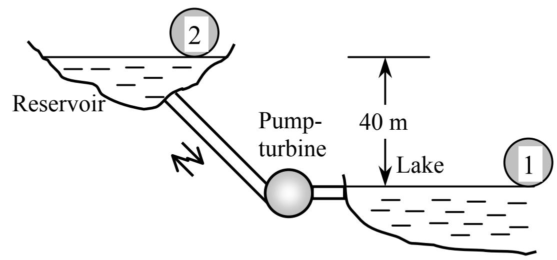
Discussion Note that the power generation would increase by more than 1 MW for each percentage point improvement in the efficiency of the turbine–generator unit.

2-124 An entrepreneur is to build a large reservoir above the lake level, and pump water from the lake to the reservoir at night using cheap power, and let the water flow from the reservoir back to the lake during the day, producing power. The potential revenue this system can generate per year is to be determined.

Assumptions **1** The flow in each direction is steady and incompressible. **2** The elevation difference between the lake and the reservoir can be taken to be constant, and the elevation change of reservoir during charging and discharging is disregarded. **3** Frictional losses in piping are negligible. **4** The system operates every day of the year for 10 hours in each mode.

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

Analysis The total mechanical energy of water in an upper reservoir relative to water in a lower reservoir is equivalent to the potential energy of water at the free surface of this reservoir relative to free surface of the lower reservoir. 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. This also represents the minimum power required to pump water from the lower reservoir to the higher reservoir.



$$\dot{W}_{\text{max, turbine}} = \dot{W}_{\text{min, pump}} = \dot{W}_{\text{ideal}} = \Delta\dot{E}_{\text{mech}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}\Delta pe = \dot{m}g\Delta z = \rho\dot{V}g\Delta z$$

$$= (1000\text{ kg/m}^3)(2\text{ m}^3\text{/s})(9.81\text{ m/s}^2)(40\text{ m})\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kW}}{1000\text{ N}\cdot\text{m/s}}\right) = 784.8\text{ kW}$$

The actual pump and turbine electric powers are

$$\dot{W}_{\text{pump, elect}} = \frac{\dot{W}_{\text{ideal}}}{\eta_{\text{pump-motor}}} = \frac{784.8\text{ kW}}{0.75} = 1046\text{ kW}$$

$$\dot{W}_{\text{turbine}} = \eta_{\text{turbine-gen}}\dot{W}_{\text{ideal}} = 0.75(784.8\text{ kW}) = 588.6\text{ kW}$$

Then the power consumption cost of the pump, the revenue generated by the turbine, and the net income (revenue minus cost) per year become

$$\text{Cost} = \dot{W}_{\text{pump, elect}}\Delta t \times \text{Unit price} = (1046\text{ kW})(365\times 10\text{ h/year})(\$0.03\text{/kWh}) = \$114{,}500\text{/year}$$

$$\text{Reveue} = \dot{W}_{\text{turbine}}\Delta t \times \text{Unit price} = (588.6\text{ kW})(365\times 10\text{ h/year})(\$0.08\text{/kWh}) = \$171{,}900\text{/year}$$

Net income = Revenue – Cost = 171,900 –114,500 = **$57,400/year**

Discussion It appears that this pump-turbine system has a potential to generate net revenues of about $57,000 per year. A decision on such a system will depend on the initial cost of the system, its life, the operating and maintenance costs, the interest rate, and the length of the contract period, among other things.

2-125 A diesel engine burning light diesel fuel that contains sulfur is considered. The rate of sulfur that ends up in the exhaust and the rate of sulfurous acid given off to the environment are to be determined.

Assumptions **1** All of the sulfur in the fuel ends up in the exhaust. **2** For one kmol of sulfur in the exhaust, one kmol of sulfurous acid is added to the environment.

Properties The molar mass of sulfur is 32 kg/kmol.

Analysis The mass flow rates of fuel and the sulfur in the exhaust are

$$\dot{m}_{\text{fuel}} = \frac{\dot{m}_{\text{air}}}{\text{AF}} = \frac{(336 \text{ kg air/h})}{(18 \text{ kg air/kg fuel})} = 18.67 \text{ kg fuel/h}$$

$$\dot{m}_{\text{Sulfur}} = (750\times10^{-6})\dot{m}_{\text{fuel}} = (750\times10^{-6})(18.67 \text{ kg/h}) = \mathbf{0.014 \text{ kg/h}}$$

The rate of sulfurous acid given off to the environment is

$$\dot{m}_{\text{H2SO3}} = \frac{M_{\text{H2SO3}}}{M_{\text{Sulfur}}}\dot{m}_{\text{Sulfur}} = \frac{2\times1+32+3\times16}{32}(0.014 \text{ kg/h}) = \mathbf{0.036 \text{ kg/h}}$$

Discussion This problem shows why the sulfur percentage in diesel fuel must be below certain value to satisfy regulations.

2-126 Lead is a very toxic engine emission. Leaded gasoline contains lead that ends up in the exhaust. The amount of lead put out to the atmosphere per year for a given city is to be determined.

Assumptions 35% of lead is exhausted to the environment.

Analysis The gasoline consumption and the lead emission are

$$\text{Gasoline Consumption} = (10{,}000 \text{ cars})(15{,}000 \text{ km/car - year})(10 \text{ L/100 km}) = 1.5\times10^{7} \text{ L/year}$$

$$\begin{aligned}\text{Lead Emission} &= (\text{GaolineConsumption})m_{\text{lead}}f_{\text{lead}}\\ &= (1.5\times10^{7} \text{ L/year})(0.15\times10^{-3} \text{ kg/L})(0.35)\\ &= \mathbf{788 \text{ kg/year}}\end{aligned}$$

Discussion Note that a huge amount of lead emission is avoided by the use of unleaded gasoline.

Fundamentals of Engineering (FE) Exam Problems

2-127 A 2-kW electric resistance heater in a room is turned on and kept on for 30 min. The amount of energy transferred to the room by the heater is
(a) 1 kJ (b) 60 kJ (c) 1800 kJ (d) 3600 kJ (e) 7200 kJ

Answer (d) 3600 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
We= 2 "kJ/s"
time=30*60 "s"
We_total=We*time "kJ"

"Some Wrong Solutions with Common Mistakes:"
W1_Etotal=We*time/60 "using minutes instead of s"
W2_Etotal=We "ignoring time"
```

2-128 In a hot summer day, the air in a well-sealed room is circulated by a 0.50-hp (shaft) fan driven by a 65% efficient motor. (Note that the motor delivers 0.50 hp of net shaft power to the fan). The rate of energy supply from the fan-motor assembly to the room is
(a) 0.769 kJ/s (b) 0.325 kJ/s (c) 0.574 kJ/s (d) 0.373 kJ/s (e) 0.242 kJ/s

Answer (c) 0.574 kJ/s

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
Eff=0.65
W_fan=0.50*0.7457 "kW"
E=W_fan/Eff  "kJ/s"

"Some Wrong Solutions with Common Mistakes:"
W1_E=W_fan*Eff "Multiplying by efficiency"
W2_E=W_fan "Ignoring efficiency"
W3_E=W_fan/Eff/0.7457 "Using hp instead of kW"
```

2-129 A fan is to accelerate quiescent air to a velocity to 12 m/s at a rate of 3 m^3/min. If the density of air is 1.15 kg/m^3, the minimum power that must be supplied to the fan is

(a) 248 W (b) 72 W (c) 497 W (d) 216 W (e) 162 W

Answer (a) 248 W

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
rho=1.15
V=12
Vdot=3 "m3/s"
mdot=rho*Vdot "kg/s"
We=mdot*V^2/2

"Some Wrong Solutions with Common Mistakes:"
W1_We=Vdot*V^2/2 "Using volume flow rate"
W2_We=mdot*V^2 "forgetting the 2"
W3_We=V^2/2 "not using mass flow rate"
```

2-130 A 900-kg car cruising at a constant speed of 60 km/h is to accelerate to 100 km/h in 6 s. The additional power needed to achieve this acceleration is

(a) 41 kW (b) 222 kW (c) 1.7 kW (d) 26 kW (e) 37 kW

Answer (e) 37 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m=900 "kg"
V1=60 "km/h"
V2=100 "km/h"
Dt=6 "s"
Wa=m*((V2/3.6)^2-(V1/3.6)^2)/2000/Dt "kW"

"Some Wrong Solutions with Common Mistakes:"
W1_Wa=((V2/3.6)^2-(V1/3.6)^2)/2/Dt "Not using mass"
W2_Wa=m*((V2)^2-(V1)^2)/2000/Dt "Not using conversion factor"
W3_Wa=m*((V2/3.6)^2-(V1/3.6)^2)/2000 "Not using time interval"
W4_Wa=m*((V2/3.6)-(V1/3.6))/1000/Dt "Using velocities"
```

2-131 The elevator of a large building is to raise a net mass of 400 kg at a constant speed of 12 m/s using an electric motor. Minimum power rating of the motor should be

(a) 0 kW (b) 4.8 kW (c) 47 kW (d) 12 kW (e) 36 kW

Answer (c) 47 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m=400 "kg"
V=12 "m/s"
g=9.81 "m/s2"
Wg=m*g*V/1000 "kW"

"Some Wrong Solutions with Common Mistakes:"
W1_Wg=m*V "Not using g"
W2_Wg=m*g*V^2/2000 "Using kinetic energy"
W3_Wg=m*g/V "Using wrong relation"
```

2-132 Electric power is to be generated in a hydroelectric power plant that receives water at a rate of 70 m^3/s from an elevation of 65 m using a turbine–generator with an efficiency of 85 percent. When frictional losses in piping are disregarded, the electric power output of this plant is

(a) 3.9 MW (b) 38 MW (c) 45 MW (d) 53 MW (e) 65 MW

Answer (b) 38 MW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
Vdot=70 "m3/s"
z=65 "m"
g=9.81 "m/s2"
Eff=0.85
rho=1000 "kg/m3"
We=rho*Vdot*g*z*Eff/10^6 "MW"

"Some Wrong Solutions with Common Mistakes:"
W1_We=rho*Vdot*z*Eff/10^6 "Not using g"
W2_We=rho*Vdot*g*z/Eff/10^6 "Dividing by efficiency"
W3_We=rho*Vdot*g*z/10^6 "Not using efficiency"
```

2-133 A 75 hp (shaft) compressor in a facility that operates at full load for 2500 hours a year is powered by an electric motor that has an efficiency of 88 percent. If the unit cost of electricity is \$0.06/kWh, the annual electricity cost of this compressor is

(a) \$7382 (b) \$9900 (c) \$12,780 (d) \$9533 (e) \$8389

Answer (d) \$9533

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
Wcomp=75 "hp"
Hours=2500 “h/year”
Eff=0.88
price=0.06 “$/kWh”
We=Wcomp*0.7457*Hours/Eff
Cost=We*price

"Some Wrong Solutions with Common Mistakes:"
W1_cost= Wcomp*0.7457*Hours*price*Eff “multiplying by efficiency”
W2_cost= Wcomp*Hours*price/Eff “not using conversion”
W3_cost= Wcomp*Hours*price*Eff “multiplying by efficiency and not using conversion”
W4_cost= Wcomp*0.7457*Hours*price “Not using efficiency”
```

2-134 Consider a refrigerator that consumes 320 W of electric power when it is running. If the refrigerator runs only one quarter of the time and the unit cost of electricity is \$0.09/kWh, the electricity cost of this refrigerator per month (30 days) is

(a) \$3.56 (b) \$5.18 (c) \$8.54 (d) \$9.28 (e) \$20.74

Answer (b) \$5.18

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
We=0.320 "kW"
Hours=0.25*(24*30) "h/year"
price=0.09 "$/kWh"
Cost=We*hours*price

"Some Wrong Solutions with Common Mistakes:"
W1_cost= We*24*30*price "running continuously"
```

2-135 A 2-kW pump is used to pump kerosene (ρ = 0.820 kg/L) from a tank on the ground to a tank at a higher elevation. Both tanks are open to the atmosphere, and the elevation difference between the free surfaces of the tanks is 30 m. The maximum volume flow rate of kerosene is
(a) 8.3 L/s (b) 7.2 L/s (c) 6.8 L/s (d) 12.1 L/s (e) 17.8 L/s

Answer (a) 8.3 L/s

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
W=2 "kW"
rho=0.820 "kg/L"
z=30 "m"
g=9.81 "m/s2"
W=rho*Vdot*g*z/1000

"Some Wrong Solutions with Common Mistakes:"
W=W1_Vdot*g*z/1000 "Not using density"
```

2-136 A glycerin pump is powered by a 5-kW electric motor. The pressure differential between the outlet and the inlet of the pump at full load is measured to be 211 kPa. If the flow rate through the pump is 18 L/s and the changes in elevation and the flow velocity across the pump are negligible, the overall efficiency of the pump is
(a) 69% (b) 72% (c) 76% (d) 79% (e) 82%

Answer (c) 76%

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
We=5 "kW"
Vdot= 0.018 "m3/s"
DP=211 "kPa"
Emech=Vdot*DP
Emech=Eff*We
```

The following problems are based on the optional special topic of heat transfer

2-137 A 10-cm high and 20-cm wide circuit board houses on its surface 100 closely spaced chips, each generating heat at a rate of 0.08 W and transferring it by convection to the surrounding air at 40°C. Heat transfer from the back surface of the board is negligible. If the convection heat transfer coefficient on the surface of the board is 10 W/m^2.°C and radiation heat transfer is negligible, the average surface temperature of the chips is

(a) 80°C (b) 54°C (c) 41°C (d) 72°C (e) 60°C

Answer (a) 80°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
A=0.10*0.20 "m^2"
Q= 100*0.08 "W"
Tair=40 "C"
h=10 "W/m^2.C"
Q= h*A*(Ts-Tair) "W"

"Some Wrong Solutions with Common Mistakes:"
Q= h*(W1_Ts-Tair) "Not using area"
Q= h*2*A*(W2_Ts-Tair) "Using both sides of surfaces"
Q= h*A*(W3_Ts+Tair) "Adding temperatures instead of subtracting"
Q/100= h*A*(W4_Ts-Tair) "Considering 1 chip only"
```

2-138 A 50-cm-long, 0.2-cm-diameter electric resistance wire submerged in water is used to determine the boiling heat transfer coefficient in water at 1 atm experimentally. The surface temperature of the wire is measured to be 130°C when a wattmeter indicates the electric power consumption to be 4.1 kW. Then the heat transfer coefficient is

(a) 43,500 W/m^2.°C (b) 137 W/m^2.°C (c) 68,330 W/m^2.°C (d) 10,038 W/m^2.°C
(e) 37,540 W/m^2.°C

Answer (a) 43,500 W/m^2.°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
L=0.5 "m"
D=0.002 "m"
A=pi*D*L "m^2"
We=4.1 "kW"
Ts=130 "C"
Tf=100 "C    (Boiling temperature of water at 1 atm)"
We= h*A*(Ts-Tf) "W"

"Some Wrong Solutions with Common Mistakes:"
We= W1_h*(Ts-Tf) "Not using area"
We= W2_h*(L*pi*D^2/4)*(Ts-Tf) "Using volume instead of area"
We= W3_h*A*Ts "Using Ts instead of temp difference"
```

2-139 A 3-m^2 hot black surface at 80°C is losing heat to the surrounding air at 25°C by convection with a convection heat transfer coefficient of 12 W/m^2.°C, and by radiation to the surrounding surfaces at 15°C. The total rate of heat loss from the surface is

(a) 1987 W (b) 2239 W (c) 2348 W (d) 3451 W (e) 3811 W

Answer (d) 3451 W

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
sigma=5.67E-8 "W/m^2.K^4"
eps=1
A=3 "m^2"
h_conv=12 "W/m^2.C"
Ts=80 "C"
Tf=25 "C"
Tsurr=15 "C"
Q_conv=h_conv*A*(Ts-Tf)  "W"
Q_rad=eps*sigma*A*((Ts+273)^4-(Tsurr+273)^4) "W"
Q_total=Q_conv+Q_rad "W"

"Some Wrong Solutions with Common Mistakes:"
W1_Ql=Q_conv "Ignoring radiation"
W2_Q=Q_rad "ignoring convection"
W3_Q=Q_conv+eps*sigma*A*(Ts^4-Tsurr^4) "Using C in radiation calculations"
W4_Q=Q_total/A "not using area"
```

2-140 Heat is transferred steadily through a 0.2-m thick 8 m by 4 m wall at a rate of 1.6 kW. The inner and outer surface temperatures of the wall are measured to be 15°C to 5°C. The average thermal conductivity of the wall is

(a) 0.001 W/m.°C (b) 0.5 W/m.°C (c) 1.0 W/m.°C (d) 2.0 W/m.°C (e) 5.0 W/m.°C

Answer (c) 1.0 W/m.°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
A=8*4 "m^2"
L=0.2 "m"
T1=15 "C"
T2=5 "C"
Q=1600  "W"
Q=k*A*(T1-T2)/L "W"

"Some Wrong Solutions with Common Mistakes:"
Q=W1_k*(T1-T2)/L "Not using area"
Q=W2_k*2*A*(T1-T2)/L  "Using areas of both surfaces"
Q=W3_k*A*(T1+T2)/L  "Adding temperatures instead of subtracting"
Q=W4_k*A*L*(T1-T2) "Multiplying by thickness instead of dividing by it"
```

2-141 The roof of an electrically heated house is 7 m long, 10 m wide, and 0.25 m thick. It is made of a flat layer of concrete whose thermal conductivity is 0.92 W/m.°C. During a certain winter night, the temperatures of the inner and outer surfaces of the roof are measured to be 15°C and 4°C, respectively. The average rate of heat loss through the roof that night was

(a) 41 W (b) 177 W (c) 4894 W (d) 5567 W (e) 2834 W

Answer (e) 2834 W

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
A=7*10 "m^2"
L=0.25 "m"
k=0.92 "W/m.C"
T1=15 "C"
T2=4 "C"
Q_cond=k*A*(T1-T2)/L "W"

"Some Wrong Solutions with Common Mistakes:"
W1_Q=k*(T1-T2)/L "Not using area"
W2_Q=k*2*A*(T1-T2)/L  "Using areas of both surfaces"
W3_Q=k*A*(T1+T2)/L  "Adding temperatures instead of subtracting"
W4_Q=k*A*L*(T1-T2) "Multiplying by thickness instead of dividing by it"
```

2-142 … 2-148 Design and Essay Problems
