

PROBLEMS*

Forms of Energy

2-1C Portable electric heaters are commonly used to heat small rooms. Explain the energy transformation involved during this heating process.

2-2C Consider the process of heating water on top of an electric range. What are the forms of energy involved during this process? What are the energy transformations that take place?

2-3C What is the difference between the macroscopic and microscopic forms of energy?

2-4C What is total energy? Identify the different forms of energy that constitute the total energy.

2-5C List the forms of energy that contribute to the internal energy of a system.

2-6C How are heat, internal energy, and thermal energy related to each other?

2-7C What is mechanical energy? How does it differ from thermal energy? What are the forms of mechanical energy of a fluid stream?

2-8 Consider a river flowing toward a lake at an average velocity of 3 m/s at a rate of 500 m³/s at a location 90 m above the lake surface. Determine the total mechanical energy of the river water per unit mass and the power generation potential of the entire river at that location.

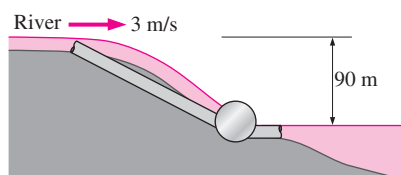


FIGURE P2-8

2-9 Electric power is to be generated by installing a hydraulic turbine-generator at a site 120 m below the free surface of a large water reservoir that can supply water at a rate of 1500 kg/s steadily. Determine the power generation potential.

*Problems designated by a "C" are concept questions, and students are encouraged to answer them all. Problems designated by an "E" are in English units, and the SI users can ignore them. Problems with a CD-EES icon  are solved using EES, and complete solutions together with parametric studies are included on the enclosed DVD. Problems with a computer-EES icon  are comprehensive in nature, and are intended to be solved with a computer, preferably using the EES software that accompanies this text.

2-10 At a certain location, wind is blowing steadily at 10 m/s. Determine the mechanical energy of air per unit mass and the power generation potential of a wind turbine with 60-m-diameter blades at that location. Take the air density to be 1.25 kg/m³.

2-11 A water jet that leaves a nozzle at 60 m/s at a flow rate of 120 kg/s is to be used to generate power by striking the buckets located on the perimeter of a wheel. Determine the power generation potential of this water jet.

2-12 Two sites are being considered for wind power generation. In the first site, the wind blows steadily at 7 m/s for 3000 hours per year, whereas in the second site the wind blows at 10 m/s for 2000 hours per year. Assuming the wind velocity is negligible at other times for simplicity, determine which is a better site for wind power generation. *Hint:* Note that the mass flow rate of air is proportional to wind velocity.

2-13 A river flowing steadily at a rate of 240 m³/s is considered for hydroelectric power generation. It is determined that a dam can be built to collect water and release it from an elevation difference of 50 m to generate power. Determine how much power can be generated from this river water after the dam is filled.

2-14 A person gets into an elevator at the lobby level of a hotel together with his 30-kg suitcase, and gets out at the 10th floor 35 m above. Determine the amount of energy consumed by the motor of the elevator that is now stored in the suitcase.

Energy Transfer by Heat and Work

2-15C In what forms can energy cross the boundaries of a closed system?

2-16C When is the energy crossing the boundaries of a closed system heat and when is it work?

2-17C What is an adiabatic process? What is an adiabatic system?

2-18C A gas in a piston-cylinder device is compressed, and as a result its temperature rises. Is this a heat or work interaction?

2-19C A room is heated by an iron that is left plugged in. Is this a heat or work interaction? Take the entire room, including the iron, as the system.

2-20C A room is heated as a result of solar radiation coming in through the windows. Is this a heat or work interaction for the room?

2-21C An insulated room is heated by burning candles. Is this a heat or work interaction? Take the entire room, including the candles, as the system.

2-22C What are point and path functions? Give some examples.

2-23C What is the caloric theory? When and why was it abandoned?

Mechanical Forms of Work

2-24C A car is accelerated from rest to 85 km/h in 10 s. Would the energy transferred to the car be different if it were accelerated to the same speed in 5 s?

2-25C Lifting a weight to a height of 20 m takes 20 s for one crane and 10 s for another. Is there any difference in the amount of work done on the weight by each crane?

2-26 Determine the energy required to accelerate an 800-kg car from rest to 100 km/h on a level road. *Answer: 309 kJ*

2-27 Determine the energy required to accelerate a 1300-kg car from 10 to 60 km/h on an uphill road with a vertical rise of 40 m.

2-28E Determine the torque applied to the shaft of a car that transmits 450 hp and rotates at a rate of 3000 rpm.

2-29 Determine the work required to deflect a linear spring with a spring constant of 70 kN/m by 20 cm from its rest position.

2-30 The engine of a 1500-kg automobile has a power rating of 75 kW. Determine the time required to accelerate this car from rest to a speed of 100 km/h at full power on a level road. Is your answer realistic?

2-31 A ski lift has a one-way length of 1 km and a vertical rise of 200 m. The chairs are spaced 20 m apart, and each chair can seat three people. The lift is operating at a steady speed of 10 km/h. Neglecting friction and air drag and assuming that the average mass of each loaded chair is 250 kg, determine the power required to operate this ski lift. Also estimate the power required to accelerate this ski lift in 5 s to its operating speed when it is first turned on.

2-32 Determine the power required for a 2000-kg car to climb a 100-m-long uphill road with a slope of 30° (from horizontal) in 10 s (a) at a constant velocity, (b) from rest to

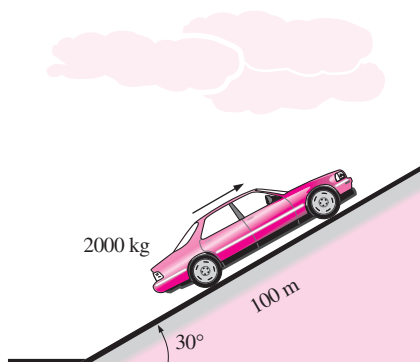


FIGURE P2-32

a final velocity of 30 m/s, and (c) from 35 m/s to a final velocity of 5 m/s. Disregard friction, air drag, and rolling resistance. *Answers: (a) 98.1 kW, (b) 188 kW, (c) -21.9 kW*

2-33 A damaged 1200-kg car is being towed by a truck. Neglecting the friction, air drag, and rolling resistance, determine the extra power required (a) for constant velocity on a level road, (b) for constant velocity of 50 km/h on a 30° (from horizontal) uphill road, and (c) to accelerate on a level road from stop to 90 km/h in 12 s. *Answers: (a) 0, (b) 81.7 kW, (c) 31.3 kW*

The First Law of Thermodynamics

2-34C For a cycle, is the net work necessarily zero? For what kind of systems will this be the case?

2-35C On a hot summer day, a student turns his fan on when he leaves his room in the morning. When he returns in the evening, will the room be warmer or cooler than the neighboring rooms? Why? Assume all the doors and windows are kept closed.

2-36C What are the different mechanisms for transferring energy to or from a control volume?

2-37 Water is being heated in a closed pan on top of a range while being stirred by a paddle wheel. During the process, 30 kJ of heat is transferred to the water, and 5 kJ of heat is lost to the surrounding air. The paddle-wheel work amounts to 500 N·m. Determine the final energy of the system if its initial energy is 10 kJ. *Answer: 35.5 kJ*

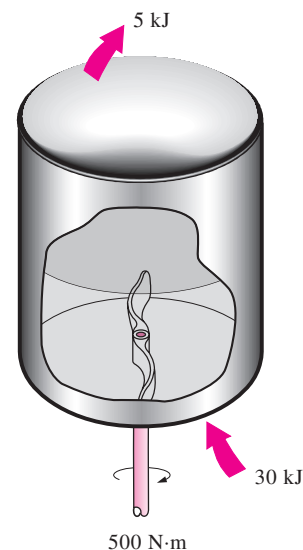


FIGURE P2-37

2-38E A vertical piston–cylinder device contains water and is being heated on top of a range. During the process, 65 Btu

of heat is transferred to the water, and heat losses from the side walls amount to 8 Btu. The piston rises as a result of evaporation, and 5 Btu of work is done by the vapor. Determine the change in the energy of the water for this process.

Answer: 52 Btu

2-39 A classroom that normally contains 40 people is to be air-conditioned with window air-conditioning units of 5-kW cooling capacity. A person at rest may be assumed to dissipate heat at a rate of about 360 kJ/h. There are 10 lightbulbs in the room, each with a rating of 100 W. The rate of heat transfer to the classroom through the walls and the windows is estimated to be 15,000 kJ/h. If the room air is to be maintained at a constant temperature of 21°C, determine the number of window air-conditioning units required. **Answer:** 2 units

2-40 The lighting requirements of an industrial facility are being met by 700 40-W standard fluorescent lamps. The lamps are close to completing their service life and are to be replaced by their 34-W high-efficiency counterparts that operate on the existing standard ballasts. The standard and high-efficiency fluorescent lamps can be purchased in quantity at a cost of \$1.77 and \$2.26 each, respectively. The facility operates 2800 hours a year, and all of the lamps are kept on during operating hours. Taking the unit cost of electricity to be \$0.08/kWh and the ballast factor to be 1.1 (i.e., ballasts consume 10 percent of the rated power of the lamps), determine how much energy and money will be saved per year as a result of switching to the high-efficiency fluorescent lamps. Also, determine the simple payback period.

2-41 The lighting needs of a storage room are being met by 6 fluorescent light fixtures, each fixture containing four lamps rated at 60 W each. All the lamps are on during operating hours of the facility, which are 6 AM to 6 PM 365 days a year. The storage room is actually used for an average of 3 h a day. If the price of electricity is \$0.08/kWh, determine the amount of energy and money that will be saved as a result of installing motion sensors. Also, determine the simple payback period if the purchase price of the sensor is \$32 and it takes 1 hour to install it at a cost of \$40.

2-42 A university campus has 200 classrooms and 400 faculty offices. The classrooms are equipped with 12 fluorescent tubes, each consuming 110 W, including the electricity used by the ballasts. The faculty offices, on average, have half as many tubes. The campus is open 240 days a year. The classrooms and faculty offices are not occupied an average of 4 h a day, but the lights are kept on. If the unit cost of electricity is \$0.082/kWh, determine how much the campus will save a year if the lights in the classrooms and faculty offices are turned off during unoccupied periods.

2-43 Consider a room that is initially at the outdoor temperature of 20°C. The room contains a 100-W lightbulb, a 110-W TV set, a 200-W refrigerator, and a 1000-W iron.

Assuming no heat transfer through the walls, determine the rate of increase of the energy content of the room when all of these electric devices are on.

2-44 A fan is to accelerate quiescent air to a velocity of 10 m/s at a rate of 4 m³/s. Determine the minimum power that must be supplied to the fan. Take the density of air to be 1.18 kg/m³. **Answer:** 236 W

2-45E Consider a fan located in a 3 ft × 3 ft square duct. Velocities at various points at the outlet are measured, and the average flow velocity is determined to be 22 ft/s. Taking the air density to 0.075 lbfm/ft³, estimate the minimum electric power consumption of the fan motor.

2-46 A water pump that consumes 2 kW of electric power when operating is claimed to take in water from a lake and pump it to a pool whose free surface is 30 m above the free surface of the lake at a rate of 50 L/s. Determine if this claim is reasonable.

2-47  The driving force for fluid flow is the pressure difference, and a pump operates by raising the pressure of a fluid (by converting the mechanical shaft work to flow energy). A gasoline pump is measured to consume 5.2 kW of electric power when operating. If the pressure differential between the outlet and inlet of the pump is measured to be 5 kPa and the changes in velocity and elevation are negligible, determine the maximum possible volume flow rate of gasoline.

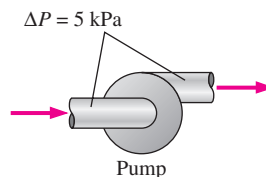


FIGURE P2-47

2-48 The 60-W fan of a central heating system is to circulate air through the ducts. The analysis of the flow shows that the fan needs to raise the pressure of air by 50 Pa to maintain flow. The fan is located in a horizontal flow section whose diameter is 30 cm at both the inlet and the outlet. Determine the highest possible average flow velocity in the duct.

2-49E At winter design conditions, a house is projected to lose heat at a rate of 60,000 Btu/h. The internal heat gain from people, lights, and appliances is estimated to be 6000 Btu/h. If this house is to be heated by electric resistance heaters, determine the required rated power of these heaters in kW to maintain the house at constant temperature.

2-50 An escalator in a shopping center is designed to move 30 people, 75 kg each, at a constant speed of 0.8 m/s at 45° slope. Determine the minimum power input needed to drive

this escalator. What would your answer be if the escalator velocity were to be doubled?

2-51 Consider a 1400-kg car cruising at constant speed of 70 km/h. Now the car starts to pass another car, by accelerating to 110 km/h in 5 s. Determine the additional power needed to achieve this acceleration. What would your answer be if the total mass of the car were only 700 kg? *Answers: 77.8 kW, 38.9 kW*

Energy Conversion Efficiencies

2-52C What is mechanical efficiency? What does a mechanical efficiency of 100 percent mean for a hydraulic turbine?

2-53C How is the combined pump–motor efficiency of a pump and motor system defined? Can the combined pump–motor efficiency be greater than either the pump or the motor efficiency?

2-54C Define turbine efficiency, generator efficiency, and combined turbine–generator efficiency.

2-55C Can the combined turbine-generator efficiency be greater than either the turbine efficiency or the generator efficiency? Explain.

2-56 Consider a 3-kW hooded electric open burner in an area where the unit costs of electricity and natural gas are \$0.07/kWh and \$1.20/therm, respectively. The efficiency of open burners can be taken to be 73 percent for electric burners and 38 percent for gas burners. Determine the rate of energy consumption and the unit cost of utilized energy for both electric and gas burners.

2-57 A 75-hp (shaft output) motor that has an efficiency of 91.0 percent is worn out and is replaced by a high-efficiency 75-hp motor that has an efficiency of 95.4 percent. Determine the reduction in the heat gain of the room due to higher efficiency under full-load conditions.

2-58 A 90-hp (shaft output) electric car is powered by an electric motor mounted in the engine compartment. If the motor has an average efficiency of 91 percent, determine the rate of heat supply by the motor to the engine compartment at full load.

2-59 A 75-hp (shaft output) motor that has an efficiency of 91.0 percent is worn out and is to be replaced by a high-efficiency motor that has an efficiency of 95.4 percent. The motor operates 4368 hours a year at a load factor of 0.75. Taking the cost of electricity to be \$0.08/kWh, determine the amount of energy and money saved as a result of installing the high-efficiency motor instead of the standard motor. Also, determine the simple payback period if the purchase prices of the standard and high-efficiency motors are \$5449 and \$5520, respectively.

2-60E The steam requirements of a manufacturing facility are being met by a boiler whose rated heat input is 3.6×10^6 Btu/h. The combustion efficiency of the boiler is measured to be 0.7 by a hand-held flue gas analyzer. After tuning up the boiler, the combustion efficiency rises to 0.8. The boiler operates 1500 hours a year intermittently. Taking the unit cost of energy to be \$4.35/10⁶ Btu, determine the annual energy and cost savings as a result of tuning up the boiler.

2-61E  Reconsider Prob. 2-60E. Using EES (or other) software, study the effects of the unit cost of energy and combustion efficiency on the annual energy used and the cost savings. Let the efficiency vary from 0.6 to 0.9, and the unit cost to vary from \$4 to \$6 per million Btu. Plot the annual energy used and the cost savings against the efficiency for unit costs of \$4, \$5, and \$6 per million Btu, and discuss the results.

2-62 An exercise room has eight weight-lifting machines that have no motors and four treadmills each equipped with a 2.5-hp (shaft output) motor. The motors operate at an average load factor of 0.7, at which their efficiency is 0.77. During peak evening hours, all 12 pieces of exercising equipment are used continuously, and there are also two people doing light exercises while waiting in line for one piece of the equipment. Assuming the average rate of heat dissipation from people in an exercise room is 525 W, determine the rate of heat gain of the exercise room from people and the equipment at peak load conditions.

2-63 Consider a classroom for 55 students and one instructor, each generating heat at a rate of 100 W. Lighting is provided by 18 fluorescent lightbulbs, 40 W each, and the ballasts consume an additional 10 percent. Determine the rate of internal heat generation in this classroom when it is fully occupied.

2-64 A room is cooled by circulating chilled water through a heat exchanger located in a room. The air is circulated through the heat exchanger by a 0.25-hp (shaft output) fan. Typical efficiency of small electric motors driving 0.25-hp equipment is 54 percent. Determine the rate of heat supply by the fan–motor assembly to the room.

2-65 Electric power is to be generated by installing a hydraulic turbine–generator at a site 70 m below the free surface of a large water reservoir that can supply water at a rate of 1500 kg/s steadily. If the mechanical power output of the turbine is 800 kW and the electric power generation is 750 kW, determine the turbine efficiency and the combined turbine–generator efficiency of this plant. Neglect losses in the pipes.

2-66 At a certain location, wind is blowing steadily at 12 m/s. Determine the mechanical energy of air per unit mass

and the power generation potential of a wind turbine with 50-m-diameter blades at that location. Also determine the actual electric power generation assuming an overall efficiency of 30 percent. Take the air density to be 1.25 kg/m^3 .

2-67  Reconsider Prob. 2-66. Using EES (or other) software, investigate the effect of wind velocity and the blade span diameter on wind power generation. Let the velocity vary from 5 to 20 m/s in increments of 5 m/s, and the diameter vary from 20 to 80 m in increments of 20 m. Tabulate the results, and discuss their significance.

2-68 A wind turbine is rotating at 15 rpm under steady winds flowing through the turbine at a rate of $42,000 \text{ kg/s}$. The tip velocity of the turbine blade is measured to be 250 km/h . If 180 kW power is produced by the turbine, determine (a) the average velocity of the air and (b) the conversion efficiency of the turbine. Take the density of air to be 1.31 kg/m^3 .

2-69 Water is pumped from a lake to a storage tank 20 m above at a rate of 70 L/s while consuming 20.4 kW of electric power. Disregarding any frictional losses in the pipes and any changes in kinetic energy, determine (a) the overall efficiency of the pump–motor unit and (b) the pressure difference between the inlet and the exit of the pump.

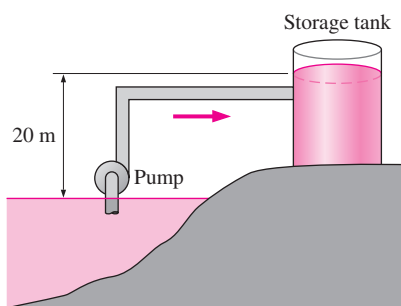


FIGURE P2-69

2-70 A geothermal pump is used to pump brine whose density is 1050 kg/m^3 at a rate of $0.3 \text{ m}^3/\text{s}$ from a depth of 200 m. For a pump efficiency of 74 percent, determine the required power input to the pump. Disregard frictional losses in the pipes, and assume the geothermal water at 200 m depth to be exposed to the atmosphere.

2-71 Consider an electric motor with a shaft power output of 20 kW and an efficiency of 88 percent. Determine the rate at which the motor dissipates heat to the room it is in when the motor operates at full load. In winter, this room is normally heated by a 2-kW resistance heater. Determine if it is necessary to turn the heater on when the motor runs at full load.

2-72 Large wind turbines with blade span diameters of over 100 m are available for electric power generation. Consider a wind turbine with a blade span diameter of 100 m installed at a site subjected to steady winds at 8 m/s . Taking the overall efficiency of the wind turbine to be 32 percent and the air density to be 1.25 kg/m^3 , determine the electric power generated by this wind turbine. Also, assuming steady winds of 8 m/s during a 24-hour period, determine the amount of electric energy and the revenue generated per day for a unit price of $\$0.06/\text{kWh}$ for electricity.

2-73E A water pump delivers 3 hp of shaft power when operating. If the pressure differential between the outlet and the inlet of the pump is measured to be 1.2 psi when the flow rate is $8 \text{ ft}^3/\text{s}$ and the changes in velocity and elevation are negligible, determine the mechanical efficiency of this pump.

2-74 Water is pumped from a lower reservoir to a higher reservoir by a pump that provides 20 kW of shaft power. The free surface of the upper reservoir is 45 m higher than that of the lower reservoir. If the flow rate of water is measured to be $0.03 \text{ m}^3/\text{s}$, determine mechanical power that is converted to thermal energy during this process due to frictional effects.

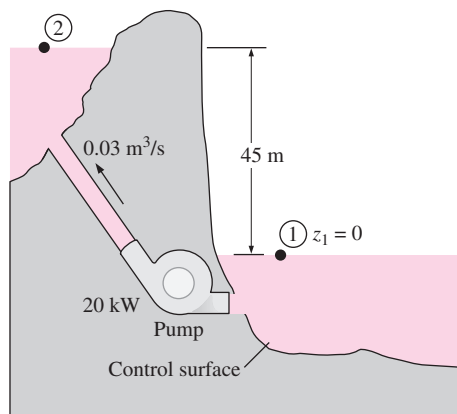


FIGURE P2-74

2-75 A 7-hp (shaft) pump is used to raise water to an elevation of 15 m. If the mechanical efficiency of the pump is 82 percent, determine the maximum volume flow rate of water.

2-76 A hydraulic turbine has 85 m of elevation difference available at a flow rate of $0.25 \text{ m}^3/\text{s}$, and its overall turbine–generator efficiency is 91 percent. Determine the electric power output of this turbine.

2-77 An oil pump is drawing 35 kW of electric power while pumping oil with $\rho = 860 \text{ kg/m}^3$ at a rate of $0.1 \text{ m}^3/\text{s}$. The inlet and outlet diameters of the pipe are 8 cm and 12 cm,

respectively. If the pressure rise of oil in the pump is measured to be 400 kPa and the motor efficiency is 90 percent, determine the mechanical efficiency of the pump.

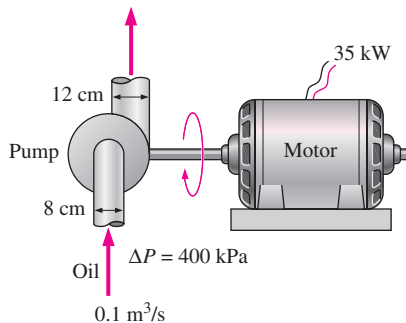


FIGURE P2-77

2-78E A 73-percent efficient pump with a power input of 12 hp is pumping water from a lake to a nearby pool at a rate of 1.2 ft³/s through a constant-diameter pipe. The free surface of the pool is 35 ft above that of the lake. Determine the mechanical power used to overcome frictional effects in piping. *Answer: 4.0 hp*

Energy and Environment

2-79C How does energy conversion affect the environment? What are the primary chemicals that pollute the air? What is the primary source of these pollutants?

2-80C What is smog? What does it consist of? How does ground-level ozone form? What are the adverse effects of ozone on human health?

2-81C What is acid rain? Why is it called a “rain”? How do the acids form in the atmosphere? What are the adverse effects of acid rain on the environment?

2-82C What is the greenhouse effect? How does the excess CO₂ gas in the atmosphere cause the greenhouse effect? What are the potential long-term consequences of greenhouse effect? How can we combat this problem?

2-83C Why is carbon monoxide a dangerous air pollutant? How does it affect human health at low and at high levels?

2-84E A Ford Taurus driven 15,000 miles a year will use about 715 gallons of gasoline compared to a Ford Explorer that would use 940 gallons. About 19.7 lbm of CO₂, which causes global warming, is released to the atmosphere when a gallon of gasoline is burned. Determine the extra amount of CO₂ production a man is responsible for during a 5-year period if he trades his Taurus for an Explorer.

2-85 When a hydrocarbon fuel is burned, almost all of the carbon in the fuel burns completely to form CO₂ (carbon dioxide), which is the principal gas causing the greenhouse

effect and thus global climate change. On average, 0.59 kg of CO₂ is produced for each kWh of electricity generated from a power plant that burns natural gas. A typical new household refrigerator uses about 700 kWh of electricity per year. Determine the amount of CO₂ production that is due to the refrigerators in a city with 200,000 households.

2-86 Repeat Prob. 2-85 assuming the electricity is produced by a power plant that burns coal. The average production of CO₂ in this case is 1.1 kg per kWh.

2-87E Consider a household that uses 11,000 kWh of electricity per year and 1500 gallons of fuel oil during a heating season. The average amount of CO₂ produced is 26.4 lbm/gallon of fuel oil and 1.54 lbm/kWh of electricity. If this household reduces its oil and electricity usage by 15 percent as a result of implementing some energy conservation measures, determine the reduction in the amount of CO₂ emissions by that household per year.

2-88 A typical car driven 12,000 miles a year emits to the atmosphere about 11 kg per year of NO_x (nitrogen oxides), which cause smog in major population areas. Natural gas burned in the furnace emits about 4.3 g of NO_x per therm, and the electric power plants emit about 7.1 g of NO_x per kWh of electricity produced. Consider a household that has two cars and consumes 9000 kWh of electricity and 1200 therms of natural gas. Determine the amount of NO_x emission to the atmosphere per year for which this household is responsible.

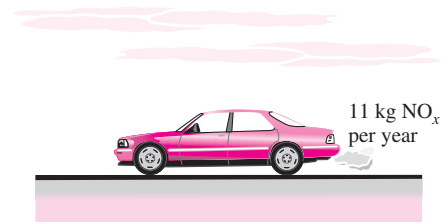


FIGURE P2-88

Special Topic: Mechanisms of Heat Transfer

2-89C What are the mechanisms of heat transfer?

2-90C Does any of the energy of the sun reach the earth by conduction or convection?

2-91C Which is a better heat conductor, diamond or silver?

2-92C How does forced convection differ from natural convection?

2-93C Define emissivity and absorptivity. What is Kirchhoff's law of radiation?

2-94C What is blackbody? How do real bodies differ from a blackbody?

2-95 The inner and outer surfaces of a 5-m $\times$ 6-m brick wall of thickness 30 cm and thermal conductivity $0.69 \text{ W/m} \cdot ^\circ\text{C}$ are maintained at temperatures of 20°C and 5°C , respectively. Determine the rate of heat transfer through the wall, in W.

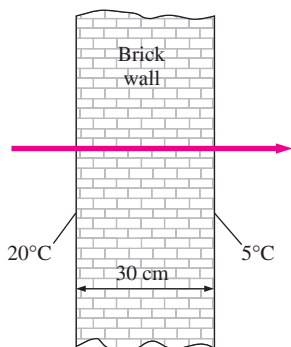


FIGURE P2-95

2-96 The inner and outer surfaces of a 0.5-cm-thick 2-m $\times$ 2-m window glass in winter are 10°C and 3°C , respectively. If the thermal conductivity of the glass is $0.78 \text{ W/m} \cdot ^\circ\text{C}$, determine the amount of heat loss, in kJ, through the glass over a period of 5 h. What would your answer be if the glass were 1-cm thick?

2-97  Reconsider Problem 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 to 2 cm. Plot the heat loss versus the glass thickness, and discuss the results.

2-98 An aluminum pan whose thermal conductivity is $237 \text{ W/m} \cdot ^\circ\text{C}$ has a flat bottom whose diameter is 20 cm and thickness 0.4 cm. Heat is transferred steadily to boiling water in the pan through its bottom at a rate of 500 W. If the inner surface of the bottom of the pan is 105°C , determine the temperature of the outer surface of the bottom of the pan.

2-99 For heat transfer purposes, a standing man can be modeled as a 30-cm diameter, 170-cm long vertical cylinder with both the top and bottom surfaces insulated and with the side surface at an average temperature of 34°C . For a convection heat transfer coefficient of $15 \text{ W/m}^2 \cdot ^\circ\text{C}$, determine the rate of heat loss from this man by convection in an environment at 20°C . *Answer: 336 W*

2-100 A 5-cm-diameter spherical ball whose surface is maintained at a temperature of 70°C is suspended in the middle of a room at 20°C . If the convection heat transfer coefficient is $15 \text{ W/m}^2 \cdot ^\circ\text{C}$ and the emissivity of the surface is 0.8, determine the total rate of heat transfer from the ball.

2-101  Reconsider Problem 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 to $30 \text{ W/m}^2 \cdot ^\circ\text{C}$. 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.

2-102 Hot air at 80°C is blown over a 2-m $\times$ 4-m flat surface at 30°C . If the convection heat transfer coefficient is $55 \text{ W/m}^2 \cdot ^\circ\text{C}$, determine the rate of heat transfer from the air to the plate, in kW.

2-103 A 1000-W iron is left on the ironing board with its base exposed to the air at 20°C . The convection heat transfer coefficient between the base surface and the surrounding air is $35 \text{ W/m}^2 \cdot ^\circ\text{C}$. If the base has an emissivity of 0.6 and a surface area of 0.02 m^2 , determine the temperature of the base of the iron.

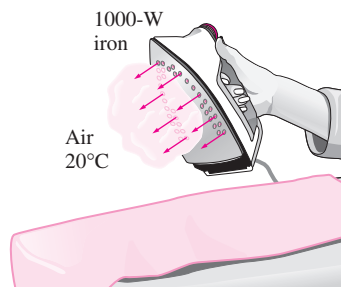


FIGURE P2-103

2-104 A thin metal plate is insulated on the back and exposed to solar radiation on the front surface. The exposed surface of the plate has an absorptivity of 0.6 for solar radiation. If solar radiation is incident on the plate at a rate of

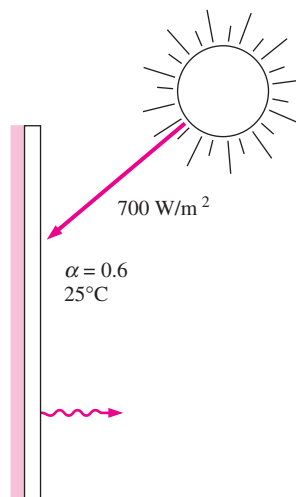


FIGURE P2-104

700 W/m² and the surrounding air temperature is 25°C, determine the surface temperature of the plate when the heat loss by convection equals the solar energy absorbed by the plate. Assume the convection heat transfer coefficient to be 50 W/m² · °C, and disregard heat loss by radiation.

2-105  Reconsider Problem 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 to 90 W/m² · °C. Plot the surface temperature against the convection heat transfer coefficient, and discuss the results.

2-106 A 5-cm-external-diameter, 10-m-long 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/m² · °C. Determine the rate of heat loss from the pipe by natural convection, in kW.

2-107 The outer surface of a spacecraft in space has an emissivity of 0.8 and an absorptivity of 0.3 for solar radiation. If solar radiation is incident on the spacecraft at a rate of 1000 W/m², determine the surface temperature of the spacecraft when the radiation emitted equals the solar energy absorbed.

2-108  Reconsider Problem 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.

2-109 A hollow spherical iron container whose outer diameter is 20 cm and thickness is 0.4 cm is filled with iced water at 0°C. If the outer surface temperature is 5°C, determine the approximate rate of heat loss from the sphere, and the rate at which ice melts in the container.

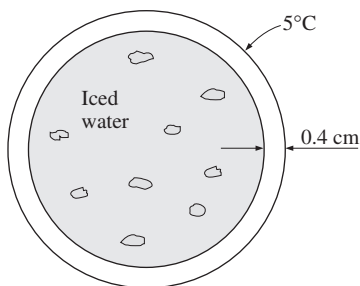


FIGURE P2-109

2-110 The inner and outer glasses of a 2-m × 2-m double pane window are at 18°C and 6°C, respectively. If the 1-cm space between the two glasses is filled with still air, determine the rate of heat transfer through the window, in kW.

2-111 Two surfaces of a 2-cm-thick plate are maintained at 0°C and 100°C, respectively. If it is determined that heat is transferred through the plate at a rate of 500 W/m², determine its thermal conductivity.

Review Problems

2-112 Consider a vertical elevator whose cabin has a total mass of 800 kg when fully loaded and 150 kg when empty. The weight of the elevator cabin is partially balanced by a 400-kg counterweight that is connected to the top of the cabin by cables that pass through a pulley located on top of the elevator well. Neglecting the weight of the cables and assuming the guide rails and the pulleys to be frictionless, determine (a) the power required while the fully loaded cabin is rising at a constant speed of 1.2 m/s and (b) the power required while the empty cabin is descending at a constant speed of 1.2 m/s.

What would your answer be to (a) if no counterweight were used? What would your answer be to (b) if a friction force of 800 N has developed between the cabin and the guide rails?

2-113 Consider a homeowner who is replacing his 25-year-old natural gas furnace that has an efficiency of 55 percent. The homeowner is considering a conventional furnace that has an efficiency of 82 percent and costs \$1600 and a high-efficiency furnace that has an efficiency of 95 percent and costs \$2700. The homeowner would like to buy the high-efficiency furnace if the savings from the natural gas pay for the additional cost in less than 8 years. If the homeowner presently pays \$1200 a year for heating, determine if he should buy the conventional or high-efficiency model.

2-114 Wind energy has been used since 4000 BC to power sailboats, grind grain, pump water for farms, and, more recently, generate electricity. In the United States alone, more than 6 million small windmills, most of them under 5 hp, have been used since the 1850s to pump water. Small windmills have been used to generate electricity since 1900, but the development of modern wind turbines occurred only recently in response to the energy crises in the early 1970s. The cost of wind power has dropped an order of magnitude from about \$0.50/kWh in the early 1980s to about \$0.05/kWh in the mid-1990s, which is about the price of electricity generated at coal-fired power plants. Areas with an average wind speed of 6 m/s (or 14 mph) are potential sites for economical wind power generation. Commercial wind turbines generate from 100 kW to 3.2 MW of electric power each at peak design conditions. The blade span (or rotor) diameter of the 3.2 MW wind turbine built by Boeing Engineering is 320 ft (97.5 m). The rotation speed of rotors of wind turbines is usually under 40 rpm (under 20 rpm for large turbines). Altamont Pass in California is the world's largest wind farm with 15,000 modern wind turbines. This farm and two others in California produced 2.8 billion kWh of electricity in 1991, which is enough power to meet the electricity needs of San Francisco.

**FIGURE P2-114**

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In 2003, 8133 MW of new wind energy generating capacity were installed worldwide, bringing the world's total wind energy capacity to 39,294 MW. The United States, Germany, Denmark, and Spain account for over 75 percent of current wind energy generating capacity worldwide. Denmark uses wind turbines to supply 10 percent of its national electricity.

Many wind turbines currently in operation have just two blades. This is because at tip speeds of 100 to 200 mph, the efficiency of the two-bladed turbine approaches the theoretical maximum, and the increase in the efficiency by adding a third or fourth blade is so little that they do not justify the added cost and weight.

Consider a wind turbine with an 80-m-diameter rotor that is rotating at 20 rpm under steady winds at an average velocity of 30 km/h. Assuming the turbine has an efficiency of 35 percent (i.e., it converts 35 percent of the kinetic energy of the wind to electricity), determine (a) the power produced, in kW; (b) the tip speed of the blade, in km/h; and (c) the revenue generated by the wind turbine per year if the electric power produced is sold to the utility at \$0.06/kWh. Take the density of air to be 1.20 kg/m^3 .

2-115 Repeat Prob. 2-114 for an average wind velocity of 25 km/h.

2-116E The energy contents, unit costs, and typical conversion efficiencies of various energy sources for use in water heaters are given as follows: 1025 Btu/ft³, \$0.012/ft³, and 55 percent for natural gas; 138,700 Btu/gal, \$1.15/gal, and 55 percent for heating oil; and 1 kWh/kWh, \$0.084/kWh, and 90 percent for electric heaters, respectively. Determine the lowest-cost energy source for water heaters.

2-117 A homeowner is considering these heating systems for heating his house: Electric resistance heating with \$0.09/kWh

and 1 kWh = 3600 kJ, gas heating with \$1.24/therm and 1 therm = 105,500 kJ, and oil heating with \$1.25/gal and 1 gal of oil = 138,500 kJ. Assuming efficiencies of 100 percent for the electric furnace and 87 percent for the gas and oil furnaces, determine the heating system with the lowest energy cost.

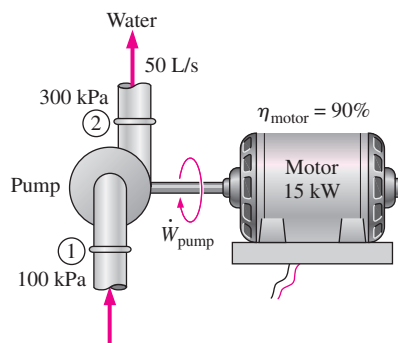
2-118 A typical household pays about \$1200 a year on energy bills, and the U.S. Department of Energy estimates that 46 percent of this energy is used for heating and cooling, 15 percent for heating water, 15 percent for refrigerating and freezing, and the remaining 24 percent for lighting, cooking, and running other appliances. The heating and cooling costs of a poorly insulated house can be reduced by up to 30 percent by adding adequate insulation. If the cost of insulation is \$200, determine how long it will take for the insulation to pay for itself from the energy it saves.

2-119 The U.S. Department of Energy estimates that up to 10 percent of the energy use of a house can be saved by caulking and weatherstripping doors and windows to reduce air leaks at a cost of about \$50 for materials for an average home with 12 windows and 2 doors. Caulking and weatherstripping every gas-heated home properly would save enough energy to heat about 4 million homes. The savings can be increased by installing storm windows. Determine how long it will take for the caulking and weatherstripping to pay for itself from the energy they save for a house whose annual energy use is \$1100.

2-120 The U.S. Department of Energy estimates that 570,000 barrels of oil would be saved per day if every household in the United States lowered the thermostat setting in winter by 6°F (3.3°C). Assuming the average heating season to be 180 days and the cost of oil to be \$40/barrel, determine how much money would be saved per year.

2-121 Consider a TV set that consumes 120 W of electric power when it is on and is kept on for an average of 6 hours per day. For a unit electricity cost of 8 cents per kWh, determine the cost of electricity this TV consumes per month (30 days).

2-122 The pump of a water distribution system is powered by a 15-kW electric motor whose efficiency is 90 percent.

**FIGURE P2-122**

The water flow rate through the pump is 50 L/s. The diameters of the inlet and outlet pipes are the same, and the elevation difference across the pump is negligible. If the pressures at the inlet and outlet of the pump are measured to be 100 kPa and 300 kPa (absolute), respectively, determine the mechanical efficiency of the pump. **Answer: 74.1 percent**

2–123 In a hydroelectric power plant, 100 m³/s of water flows from an elevation of 120 m to a turbine, where electric power is generated. The overall efficiency of the turbine–generator is 80 percent. Disregarding frictional losses in piping, estimate the electric power output of this plant. **Answer: 94.2 MW**

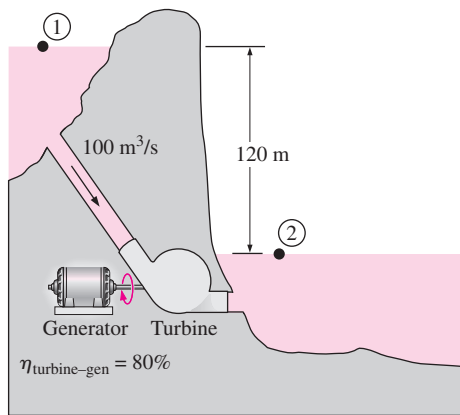


FIGURE P2–123

2–124 The demand for electric power is usually much higher during the day than it is at night, and utility companies often sell power at night at much lower prices to encourage consumers to use the available power generation capacity and to avoid building new expensive power plants that will be used only a short time during peak periods. Utilities are also willing to purchase power produced during the day from private parties at a high price.

Suppose a utility company is selling electric power for \$0.03/kWh at night and is willing to pay \$0.08/kWh for power produced during the day. To take advantage of this opportunity, an entrepreneur is considering building a large reservoir 40 m above the lake level, pumping water from the lake to the reservoir at night using cheap power, and letting the water flow from the reservoir back to the lake during the day, producing power as the pump–motor operates as a turbine–generator during reverse flow. Preliminary analysis shows that a water flow rate of 2 m³/s can be used in either direction. The combined pump–motor and turbine–generator

efficiencies are expected to be 75 percent each. Disregarding the frictional losses in piping and assuming the system operates for 10 h each in the pump and turbine modes during a typical day, determine the potential revenue this pump–turbine system can generate per year.

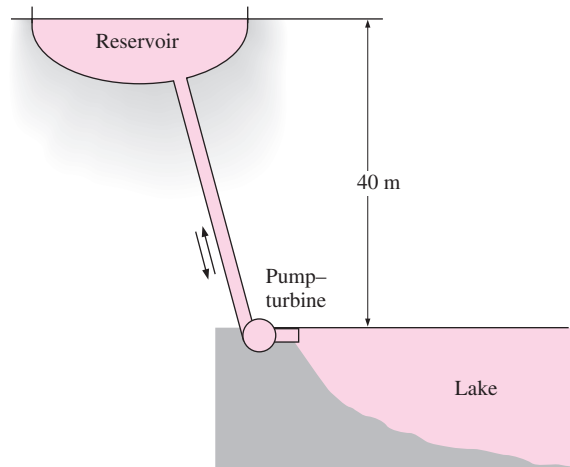


FIGURE P2–124

2–125 A diesel engine with an engine volume of 4.0 L and an engine speed of 2500 rpm operates on an air–fuel ratio of 18 kg air/kg fuel. The engine uses light diesel fuel that contains 750 ppm (parts per million) of sulfur by mass. All of this sulfur is exhausted to the environment where the sulfur is converted to sulfurous acid (H₂SO₃). If the rate of the air entering the engine is 336 kg/h, determine the mass flow rate of sulfur in the exhaust. Also, determine the mass flow rate of sulfurous acid added to the environment if for each kmol of sulfur in the exhaust, one kmol sulfurous acid will be added to the environment. The molar mass of the sulfur is 32 kg/kmol.

2–126 Leaded gasoline contains lead that ends up in the engine exhaust. Lead is a very toxic engine emission. The use of leaded gasoline in the United States has been unlawful for most vehicles since the 1980s. However, leaded gasoline is still used in some parts of the world. Consider a city with 10,000 cars using leaded gasoline. The gasoline contains 0.15 g/L of lead and 35 percent of lead is exhausted to the environment. Assuming that an average car travels 15,000 km per year with a gasoline consumption of 10 L/100 km, determine the amount of lead put into the atmosphere per year in that city. **Answer: 788 kg**

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

2-128 On a hot summer day, the air in a well-sealed room is circulated by a 0.50-hp fan driven by a 65 percent 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

2-129 A fan is to accelerate quiescent air to a velocity to 12 m/s at a rate of 3 m³/min. If the density of air is 1.15 kg/m³, 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

2-130 A 900-kg car cruising at a constant speed of 60 km/s 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

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

2-132 Electric power is to be generated in a hydroelectric power plant that receives water at a rate of 70 m³/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

2-133 A 75-hp compressor in a facility that operates at full load for 2500 h 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

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

2-135 A 2-kW pump is used to pump kerosene ($\rho = 0.820$ 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

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 percent (b) 72 percent (c) 76 percent
(d) 79 percent (e) 82 percent

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/m² · °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

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/m² · °C (b) 137 W/m² · °C
(c) 68,330 W/m² · °C (d) 10,038 W/m² · °C
(e) 37,540 W/m² · °C

2-139 A 3-m² 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/m² · °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

2-140 Heat is transferred steadily through a 0.2-m thick 8 m × 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

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 $0.92 \text{ W/m} \cdot ^\circ\text{C}$. 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

Design and Essay Problems

2-142 An average vehicle puts out nearly 20 lbm of carbon dioxide into the atmosphere for every gallon of gasoline it burns, and thus one thing we can do to reduce global warming is to buy a vehicle with higher fuel economy. A U.S. government publication states that a vehicle that gets 25 rather than 20 miles per gallon will prevent 10 tons of carbon dioxide from being released over the lifetime of the vehicle. Making reasonable assumptions, evaluate if this is a reasonable claim or a gross exaggeration.

2-143 Solar energy reaching the earth is about 1350 W/m^2 outside the earth's atmosphere, and 950 W/m^2 on earth's surface normal to the sun on a clear day. Someone is marketing $2 \text{ m} \times 3 \text{ m}$ photovoltaic cell panels with the claim that a single panel can meet the electricity needs of a house. How do you evaluate this claim? Photovoltaic cells have a conversion efficiency of about 15 percent.

2-144 Find out the prices of heating oil, natural gas, and electricity in your area, and determine the cost of each per kWh of energy supplied to the house as heat. Go through your utility bills and determine how much money you spent for heating last January. Also determine how much your January heating bill would be for each of the heating systems if you had the latest and most efficient system installed.

2-145 Prepare a report on the heating systems available in your area for residential buildings. Discuss the advantages and disadvantages of each system and compare their initial and operating costs. What are the important factors in the selection of a heating system? Give some guidelines. Identify

the conditions under which each heating system would be the best choice in your area.

2-146 The performance of a device is defined as the ratio of the desired output to the required input, and this definition can be extended to nontechnical fields. For example, your performance in this course can be viewed as the grade you earn relative to the effort you put in. If you have been investing a lot of time in this course and your grades do not reflect it, you are performing poorly. In that case, perhaps you should try to find out the underlying cause and how to correct the problem. Give three other definitions of performance from nontechnical fields and discuss them.

2-147 Your neighbor lives in a 2500-square-foot (about 250 m^2) older house heated by natural gas. The current gas heater was installed in the early 1970s and has an efficiency (called the Annual Fuel Utilization Efficiency rating, or AFUE) of 65 percent. It is time to replace the furnace, and the neighbor is trying to decide between a conventional furnace that has an efficiency of 80 percent and costs \$1500 and a high-efficiency furnace that has an efficiency of 95 percent and costs \$2500. Your neighbor offered to pay you \$100 if you help him make the right decision. Considering the weather data, typical heating loads, and the price of natural gas in your area, make a recommendation to your neighbor based on a convincing economic analysis.

2-148 The roofs of many homes in the United States are covered with photovoltaic (PV) solar cells that resemble roof tiles, generating electricity quietly from solar energy. An article stated that over its projected 30-year service life, a 4-kW roof PV system in California will reduce the production of CO_2 that causes global warming by 433,000 lbm, sulfates that cause acid rain by 2900 lbm, and nitrates that cause smog by 1660 lbm. The article also claims that a PV roof will save 253,000 lbm of coal, 21,000 gallons of oil, and 27 million ft^3 of natural gas. Making reasonable assumptions for incident solar radiation, efficiency, and emissions, evaluate these claims and make corrections if necessary.