Thermo 1 (MEP 261)

Thermodynamics An Engineering Approach

Yunus A. Cengel & Michael A. Boles

7th Edition, McGraw-Hill Companies,

ISBN-978-0-07-352932-5, 2008

Sheet 6:Chapter 6

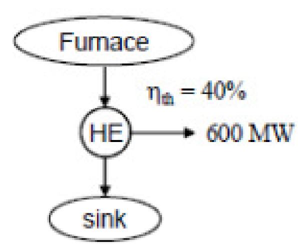
6–17 A 600-MW steam power plant, which is cooled by a nearby river, has a thermal efficiency of 40 percent. Determine the rate of heat transfer to the river water. Will the actual heat transfer rate be higher or lower than this value? Why?

6-17 The power output and thermal efficiency of a power plant are given. The rate of heat rejection is to be determined, and the result is to be compared to the actual case in practice.

Assumptions **1** The plant operates steadily. **2** Heat losses from the working fluid in the pipes and other components are negligible.

Analysis The rate of heat supply to the power plant is determined from the thermal efficiency relation,

$$\dot{Q}_H = \frac{\dot{W}_{\text{net,out}}}{\eta_{\text{th}}} = \frac{600\ \text{MW}}{0.4} = 1500\ \text{MW}$$



The rate of heat transfer to the river water is determined from the first law relation for a heat engine,

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{\text{net,out}} = 1500 - 600 = \mathbf{900\ \ MW}$$

In reality the amount of heat rejected to the river will be **lower** since part of the heat will be lost to the surrounding air from the working fluid as it passes through the pipes and other components.

6–18 A steam power plant receives heat from a furnace at a rate of 280 GJ/h. Heat losses to the surrounding air from the steam as it passes through the pipes and other components are estimated to be about 8 GJ/h. If the waste heat is transferred to the cooling water at a rate of 145 GJ/h, determine (a) net power output and (b) the thermal efficiency of this power plant. **Answers: (a) 35.3 MW, (b) 45.4 percent.**

6-18 The rates of heat supply and heat rejection of a power plant are given. The power output and the thermal efficiency of this power plant are to be determined.

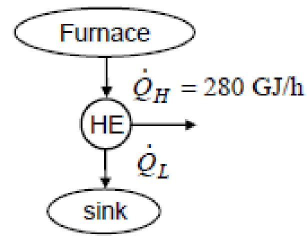
Assumptions **1** The plant operates steadily. **2** Heat losses from the working fluid in the pipes and other components are taken into consideration.

Analysis (*a*) The total heat rejected by this power plant is

$$\dot{Q}_L = 145 + 8 = 153 \text{ GJ/h}$$

Then the net power output of the plant becomes

$$\dot{W}_{\text{net,out}} = \dot{Q}_H - \dot{Q}_L = 280 - 153 = 127 \text{ GJ/h} = \mathbf{35.3\ MW}$$



(*b*) The thermal efficiency of the plant is determined from its definition,

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_H} = \frac{127 \text{ GJ/h}}{280 \text{ GJ/h}} = 0.454 = \mathbf{45.4\%}$$

6–20 A steam power plant with a power output of 150 MW consumes coal at a rate of 60 tons/h. If the heating value of the coal is 30,000 kJ/kg, determine the overall efficiency of this plant. **Answer: 30.0 percent.**

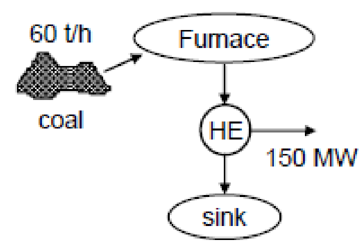
Solution The power output and fuel consumption rate of a power plant are given. The thermal efficiency is to be determined.

Assumption The plant operates steadily.

Properties The heating value of coal is given to be 30,000 kJ/kg.

Analysis The rate of heat supply to this power plant is

$$\dot{Q}_H = \dot{m}_{\text{coal}} u_{\text{coal}} = (60{,}000 \text{ kg/h})(30{,}000 \text{ kJ/kg}) = 1.8 \times 10^9 \text{ kJ/h} = 500 \text{ MW}$$



Then the thermal efficiency of the plant becomes

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_H} = \frac{150 \text{ MW}}{500 \text{ MW}} = 0.300 = \mathbf{30.0\%}$$

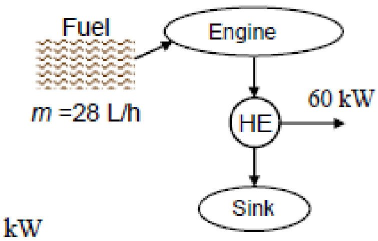
6–21 An automobile engine consumes fuel at a rate of 28 *l*/h and delivers 60 kW of power to the wheels. If the fuel has a heating value of 44,000 kJ/kg and a density of 0.8 g/cm^3, determine the efficiency of this engine. **Answer: 21.9 percent**

Solution The power output and fuel consumption rate of a car engine are given. The thermal efficiency of the engine is to be determined.

Assumption The car operates steadily.

Properties The heating value of the fuel is given to be 44,000 kJ/kg.

Analysis The mass consumption rate of the fuel is



$$\dot{m}_{\text{fuel}} = (\rho\dot{V})_{\text{fuel}} = (0.8 \text{ kg/L})(28 \text{ L/h}) = 22.4 \text{ kg/h}$$

The rate of heat supply to the car is

$$\dot{Q}_H = \dot{m}_{\text{coal}} u_{\text{coal}} = (22.4 \text{ kg/h})(44{,}000 \text{ kJ/kg}) = 985{,}600 \text{ kJ/h} = 273.78 \text{ kW}$$

Then the thermal efficiency of the car becomes

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_H} = \frac{60 \text{ kW}}{273.78 \text{ kW}} = 0.219 = \mathbf{21.9\%}$$

6–29C What is the difference between a refrigerator and a heat pump?

6-29C The difference between the two devices is one of purpose. The purpose of a refrigerator is to remove heat from a cold medium whereas the purpose of a heat pump is to supply heat to a warm medium.

6–39 A household refrigerator with a COP of 1.2 removes heat from the refrigerated space at a rate of 60 kJ/min. Determine (a) the electric power consumed by the refrigerator and (b) the rate of heat transfer to the kitchen air.

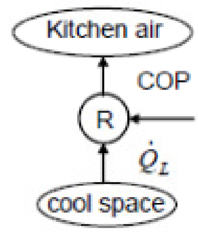
Answers: (a) 0.83 kW, (b) 110 kJ/min

Solution The COP and the refrigeration rate of a refrigerator are given. The power consumption and the rate of heat rejection are to be determined.

Assumptions The refrigerator operates steadily.

Analysis (*a*) Using the definition of the coefficient of performance, the power input to the refrigerator is determined to be

$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_L}{\text{COP}_R} = \frac{60 \text{ kJ/min}}{1.2} = 50 \text{ kJ/min} = \mathbf{0.83 \text{ kW}}$$



(*b*) The heat transfer rate to the kitchen air is determined from the energy balance,

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{\text{net,in}} = 60 + 50 = \mathbf{110 \text{ kJ/min}}$$

6–40 An air conditioner removes heat steadily from a house at a rate of 750 kJ/min while drawing electric power at a rate of 6 kW. Determine (a) the COP of this air conditioner and (b) the rate of heat transfer to the outside air.

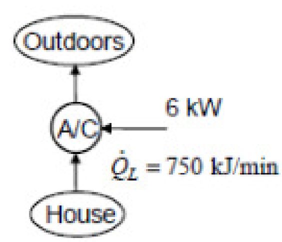
Answers: (a) 2.08, (b) 1110 kJ/min

Solution The power consumption and the cooling rate of an air conditioner are given. The COP and the rate of heat rejection are to be determined.

Assumption The air-conditioner operates steadily.

Analysis (*a*) The coefficient of performance of the air-conditioner (or refrigerator) is determined from its definition,

$$\text{COP}_R = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} = \frac{750 \text{ kJ/min}}{6 \text{ kW}}\left(\frac{1 \text{ kW}}{60 \text{ kJ/min}}\right) = \mathbf{2.08}$$



(*b*) The rate of heat discharge to the outside air is determined from the energy balance,

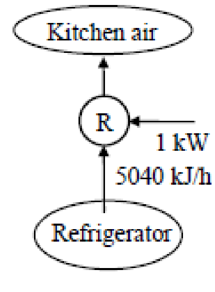
$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{\text{net,in}} = (750 \text{ kJ/min}) + (6 \times 60 \text{ kJ/min}) = \mathbf{1110 \text{ kJ/min}}$$

6–46 Determine the COP of a refrigerator that removes heat from the food compartment at a rate of 5040 kJ/h for each kW of power it consumes. Also, determine the rate of heat rejection to the outside air.

Solution The heat removal rate of a refrigerator per kW of power it consumes is given. The COP and the rate of heat rejection are to be determined.

Assumption The refrigerator operates steadily.

Analysis The coefficient of performance of the refrigerator is determined from its definition,



$$\text{COP}_R = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} = \frac{5040 \text{ kJ/h}}{1 \text{ kW}}\left(\frac{1 \text{ kW}}{3600 \text{ kJ/h}}\right) = \mathbf{1.4}$$

The rate of heat rejection to the surrounding air, per kW of power consumed, is determined from the energy balance,

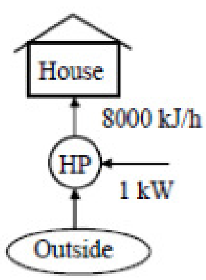
$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{\text{net,in}} = (5040 \text{ kJ/h}) + (1 \times 3600 \text{ kJ/h}) = \mathbf{8640 \text{ kJ/h}}$$

6–47 Determine the COP of a heat pump that supplies energy to a house at a rate of 8000 kJ/h for each kW of electric power it draws. Also, determine the rate of energy absorption from the outdoor air. **Answers: 2.22, 4400 kJ/h**

Solution The rate of heat supply of a heat pump per kW of power it consumes is given. The COP and the rate of heat absorption from the cold environment are to be determined.

Assumption The heat pump operates steadily.

Analysis The coefficient of performance of the refrigerator is determined from its definition,



$$\text{COP}_{HP} = \frac{\dot{Q}_H}{\dot{W}_{\text{net,in}}} = \frac{8000 \text{ kJ/h}}{1 \text{ kW}}\left(\frac{1 \text{ kW}}{3600 \text{ kJ/h}}\right) = \mathbf{2.22}$$

The rate of heat absorption from the surrounding air, per kW of power consumed, is determined from the energy balance,

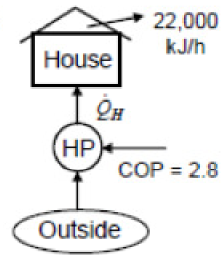
$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{\text{net,in}} = (8{,}000 \text{ kJ/h}) - (1)(3600 \text{ kJ/h}) = \mathbf{4400 \text{ kJ/h}}$$

6–50 A heat pump used to heat a house runs about one third of the time. The house is losing heat at an average rate of 22,000 kJ/h. If the COP of the heat pump is 2.8, determine the power the heat pump draws when running.

Solution The rate of heat loss from a house and the COP of the heat pump are given. The power consumption of the heat pump when it is running is to be determined.

Assumption The heat pump operates one-third of the time.

Analysis Since the heat pump runs one-third of the time and must supply heat to the house at an average rate of 22,000 kJ/h, the heat pump supplies heat at a rate of

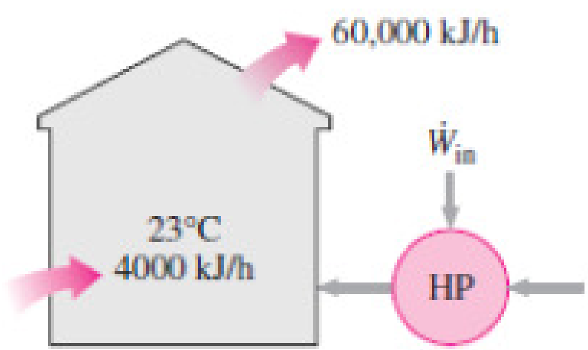


$$\dot{Q}_H = 3\times(22{,}000 \text{ kJ/h}) = 66{,}000 \text{ kJ/h}$$

when running. Thus the power the heat pump draws when it is running is

$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_H}{\text{COP}_{\text{HP}}} = \frac{66{,}000 \text{ kJ/h}}{2.8}\left(\frac{1 \text{ kW}}{3600 \text{ kJ/h}}\right) = \mathbf{6.55 \text{ kW}}$$

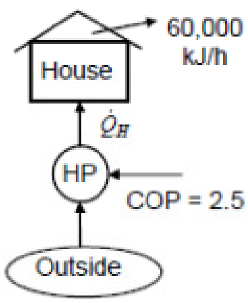
6–51 A heat pump is used to maintain a house at a constant temperature of 23°C. The house is losing heat to the outside air through the walls and the windows at a rate of 60,000 kJ/h while the energy generated within the house from people, lights, and appliances amounts to 4000 kJ/h. For a COP of 2.5, determine the required power input to the heat pump. **Answer: 6.22 kW**



Solution The rate of heat loss, the rate of internal heat gain, and the COP of a heat pump are given. The power input to the heat pump is to be determined.

Assumption The heat pump operates steadily.

Analysis The heating load of this heat pump system is the difference between the heat lost to the outdoors and the heat generated in the house from the people, lights, and appliances,



$$\dot{Q}_H = 60{,}000 - 4{,}000 = 56{,}000 \text{ kJ/h}$$

Using the definition of COP, the power input to the heat pump is determined to be

$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_H}{\text{COP}_{\text{HP}}} = \frac{56{,}000 \text{ kJ/h}}{2.5}\left(\frac{1 \text{ kW}}{3600 \text{ kJ/h}}\right) = \mathbf{6.22 \text{ kW}}$$

6–71 A Carnot heat engine operates between a source at 1000 K and a sink at 300 K. If the heat engine is supplied with heat at a rate of 800 kJ/min, determine (a) the thermal efficiency and (b) the power output of this heat engine.

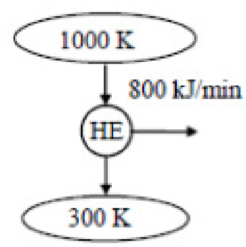
Answers: (a) 70 percent, (b) 9.33 kW.

Solution The source and sink temperatures of a Carnot heat engine and the rate of heat supply are given. The thermal efficiency and the power output are to be determined.

Assumption The Carnot heat engine operates steadily.

Analysis (a) The thermal efficiency of a Carnot heat engine depends on the source and the sink temperatures only, and is determined from

$$\eta_{\text{th,C}} = 1 - \frac{T_L}{T_H} = 1 - \frac{300 \text{ K}}{1000 \text{ K}} = 0.70 \text{ or } \mathbf{70\%}$$



(b) The power output of this heat engine is determined from the definition of thermal efficiency,

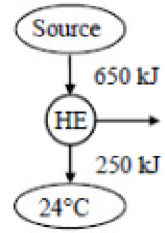
$$\dot{W}_{\text{net,out}} = \eta_{\text{th}} \dot{Q}_H = (0.70)(800 \text{ kJ/min}) = 560 \text{ kJ/min} = \mathbf{9.33 \text{ kW}}$$

6–72 A Carnot heat engine receives 650 kJ of heat from a source of unknown temperature and rejects 250 kJ of it to a sink at 24°C. Determine (a) the temperature of the source and (b) the thermal efficiency of the heat engine.

Solution The sink temperature of a Carnot heat engine and the rates of heat supply and heat rejection are given. The source temperature and the thermal efficiency of the engine are to be determined.

Assumption The Carnot heat engine operates steadily.

Analysis (a) For reversible cyclic devices we have $\left(\frac{Q_H}{Q_L}\right)_{rev} = \left(\frac{T_H}{T_L}\right)$



Thus the temperature of the source T_H must be

$$T_H = \left(\frac{Q_H}{Q_L}\right)_{rev} T_L = \left(\frac{650 \text{ kJ}}{250 \text{ kJ}}\right)(297 \text{ K}) = \mathbf{772.2 \text{ K}}$$

(*b*) The thermal efficiency of a Carnot heat engine depends on the source and the sink temperature only, and is determined from

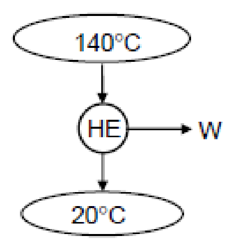
$$\eta_{th,C} = 1 - \frac{T_L}{T_H} = 1 - \frac{297 \text{ K}}{772.2 \text{ K}} = 0.615 \text{ or } \mathbf{61.5\%}$$

6–77 An innovative way of power generation involves the utilization of geothermal energy—the energy of hot water that exists naturally underground—as the heat source. If a supply of hot water at 140°C is discovered at a location where the environmental temperature is 20°C, determine the maximum thermal efficiency a geothermal power plant built at that location can have. **Answer: 29.1 percent**

Solution The source and sink temperatures of a geothermal power plant are given. The maximum thermal efficiency is to be determined.

Assumption The power plant operates steadily.

Analysis The highest thermal efficiency a heat engine operating between two specified temperature limits can have is the Carnot efficiency, which is determined from



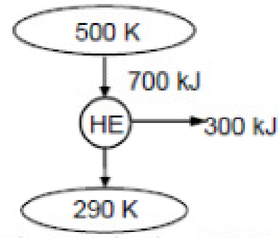
$$\eta_{th,max} = \eta_{th,C} = 1 - \frac{T_L}{T_H} = 1 - \frac{20 + 273 \text{ K}}{140 + 273 \text{ K}} = 0.291 \text{ or } \mathbf{29.1\%}$$

6–78 An inventor claims to have developed a heat engine that receives 700 kJ of heat from a source at 500 K and produces 300 kJ of net work while rejecting the waste heat to a sink at 290 K. Is this a reasonable claim? Why?

Solution An inventor claims to have developed a heat engine. The inventor reports temperature, heat transfer, and work output measurements. The claim is to be evaluated.

Analysis The highest thermal efficiency a heat engine operating between two specified temperature limits can have is the Carnot efficiency, which is determined from

$$\eta_{th,max} = \eta_{th,C} = 1 - \frac{T_L}{T_H} = 1 - \frac{290 \text{ K}}{500 \text{ K}} = 0.42 \text{ or } \mathbf{42\%}$$



The actual thermal efficiency of the heat engine in question is

$$\eta_{th} = \frac{W_{net}}{Q_H} = \frac{300 \text{ kJ}}{700 \text{ kJ}} = 0.429 \text{ or } \mathbf{42.9\%}$$

which is greater than the maximum possible thermal efficiency. Therefore, this heat engine is a PMM2 and the claim is **false**.

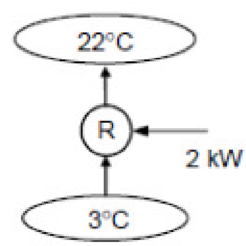
6–86 A Carnot refrigerator operates in a room in which the temperature is 22°C and consumes 2 kW of power when operating. If the food compartment of the refrigerator is to be maintained at 3°C, determine the rate of heat removal from the food compartment.

Solution The refrigerated space and the environment temperatures of a Carnot refrigerator and the power consumption are given. The rate of heat removal from the refrigerated space is to be determined.

Assumption The Carnot refrigerator operates steadily.

Analysis The coefficient of performance of a Carnot refrigerator depends on the temperature limits in the cycle only, and is determined from

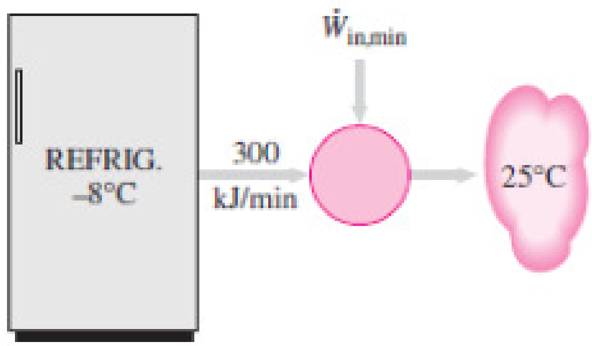
$$\text{COP}_{R,C} = \frac{1}{(T_H/T_L)-1} = \frac{1}{(22+273\text{K})/(3+273\text{K})-1} = 14.5$$



The rate of heat removal from the refrigerated space is determined from the definition of the coefficient of performance of a refrigerator,

$$\dot{Q}_L = \text{COP}_R \dot{W}_{net,in} = (14.5)(2 \text{ kW}) = 29.0 \text{ kW} = \mathbf{1740 \ kJ/min}$$

6–87 A refrigerator is to remove heat from the cooled space at a rate of 300 kJ/min to maintain its temperature at -8°C. If the air surrounding the refrigerator is at 25°C, determine the minimum power input required for this refrigerator. **Answer: 0.623 kW**

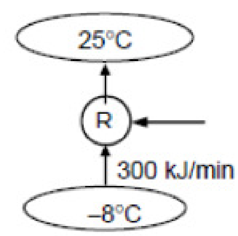


Solution The refrigerated space and the environment temperature for a refrigerator and the rate of heat removal from the refrigerated space are given. The minimum power input required is to be determined.

Assumption The refrigerator operates steadily.

Analysis The power input to a refrigerator will be a minimum when the refrigerator operates in a reversible manner. The coefficient of performance of a reversible refrigerator depends on the temperature limits in the cycle only, and is determined from

$$COP_{R,rev} = \frac{1}{(T_H/T_L)-1} = \frac{1}{(25+273\text{ K})/(-8+273\text{ K})-1} = 8.03$$



The power input to this refrigerator is determined from the definition of the coefficient of performance of a refrigerator,

$$\dot{W}_{net,in,min} = \frac{\dot{Q}_L}{COP_{R,max}} = \frac{300\text{ kJ/min}}{8.03} = 37.36\text{ kJ/min} = \mathbf{0.623\ kW}$$

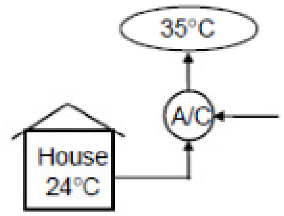
6–88 An air-conditioning system operating on the reversed Carnot cycle is required to transfer heat from a house at a rate of 750 kJ/min to maintain its temperature at 24°C. If the outdoor air temperature is 35°C, determine the power required to operate this air-conditioning system**. Answer: 0.46 kW.**

Solution The cooled space and the outdoors temperature for a Carnot air-conditioner and the rate of heat removal from the air-conditioned room are given. The power input required is to be determined.

Assumption The air-conditioner operates steadily.

Analysis The COP of a Carnot air-conditioner (or Carnot refrigerator) depends on the temperature limits in the cycle only, and is determined from

$$\mathrm{COP}_{R,C} = \frac{1}{(T_H/T_L)-1} = \frac{1}{(35+273\ \mathrm{K})/(24+273\ \mathrm{K})-1} = 27.0$$



The power input to this refrigerator is determined from the definition of the coefficient of performance of a refrigerator,

$$\dot{W}_{\mathrm{net,in}} = \frac{\dot{Q}_L}{\mathrm{COP}_{R,\max}} = \frac{750\ \mathrm{kJ/min}}{27.0} = 27.8\ \mathrm{kJ/min} = \mathbf{0.463\ kW}$$

6–90 A Carnot refrigerator operates in a room in which the temperature is 25°C. The refrigerator consumes 500 W of power when operating and has a COP of 4.5. Determine (a) the rate of heat removal from the refrigerated space and (b) the temperature of the refrigerated space. **Answers: (a) 135 kJ/min, (b) -29.2°C.**

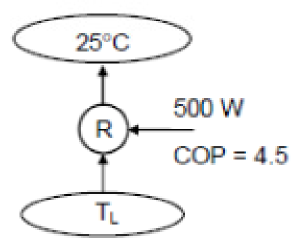
Solution The refrigerated space temperature, the COP, and the power input of a Carnot refrigerator are given. The rate of heat removal from the refrigerated space and its temperature are to be determined.

Assumption The refrigerator operates steadily.

Analysis (*a*) The rate of heat removal from the refrigerated space is determined from the definition of the COP of a refrigerator,

$$\dot{Q}_L = \mathrm{COP}_R \dot{W}_{\mathrm{net,in}} = (4.5)(0.5\ \mathrm{kW}) = 2.25\ \mathrm{kW} = \mathbf{135\ kJ/min}$$

(*b*) The temperature of the refrigerated space T_L is determined from the coefficient of performance relation for a Carnot refrigerator,



$$\mathrm{COP}_{R,\mathrm{rev}} = \frac{1}{(T_H/T_L)-1} \longrightarrow 4.5 = \frac{1}{(25+273\ \mathrm{K})/T_L - 1}$$

It yields

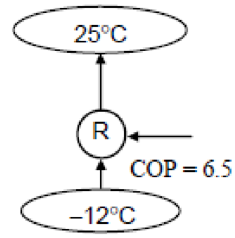
$$T_L = 243.8\ \mathrm{K} = \mathbf{-29.2°C}$$

6–91 An inventor claims to have developed a refrigeration system that removes heat from the closed region at -12°C and transfers it to the surrounding air at 25°C while maintaining a COP of 6.5. Is this claim reasonable? Why?

Solution An inventor claims to have developed a refrigerator. The inventor reports temperature and COP measurements. The claim is to be evaluated.

Analysis The highest coefficient of performance a refrigerator can have when removing heat from a cool medium at −12°C to a warmer medium at 25°C is

$$COP_{R,max} = COP_{R,rev} = \frac{1}{(T_H/T_L)-1} = \frac{1}{(25+273\text{ K})/(-12+273\text{ K})-1} = 7.1$$



The COP claimed by the inventor is 6.5, which is below this maximum value, thus the claim is **reasonable**. However, it is not probable.

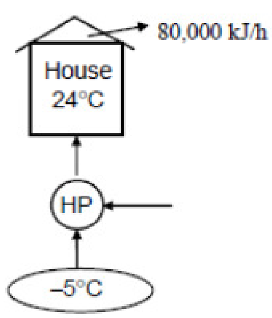
6–94 A heat pump is used to heat a house and maintain it at 24°C. On a winter day when the outdoor air temperature is -5°C, the house is estimated to lose heat at a rate of 80,000 kJ/h. Determine the minimum power required to operate this heat pump.

Solution A heat pump maintains a house at a specified temperature. The rate of heat loss of the house is given. The minimum power input required is to be determined.

Assumption The heat pump operates steadily.

Analysis The power input to a heat pump will be a minimum when the heat pump operates in a reversible manner. The COP of a reversible heat pump depends on the temperature limits in the cycle only, and is determined from

$$COP_{HP,rev} = \frac{1}{1-(T_L/T_H)} = \frac{1}{1-(-5+273\text{ K})/(24+273\text{ K})} = 10.2$$

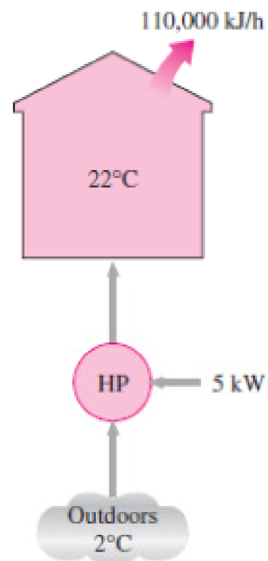


The required power input to this reversible heat pump is determined from the definition of the coefficient of performance to be

$$\dot{W}_{net,in,min} = \frac{\dot{Q}_H}{COP_{HP}} = \frac{80{,}000\text{ kJ/h}}{10.2}\left(\frac{1\text{ h}}{3600\text{ s}}\right) = \mathbf{2.18\ kW}$$

which is the *minimum* power input required.

6–95 A heat pump is used to maintain a house at 22°C by extracting heat from the outside air on a day when the outside air temperature is 2°C. The house is estimated to lose heat at a rate of 110,000 kJ/h, and the heat pump consumes 5 kW of electric power when running. Is this heat pump powerful enough to do the job?

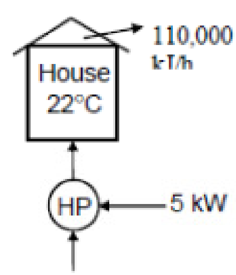


Solution A heat pump maintains a house at a specified temperature. The rate of heat loss of the house and the power consumption of the heat pump are given. It is to be determined if this heat pump can do the job.

Assumption The heat pump operates steadily.

Analysis The power input to a heat pump will be a minimum when the heat pump operates in a reversible manner. The coefficient of performance of a reversible heat pump depends on the temperature limits in the cycle only, and is determined from

$$\mathrm{COP_{HP,rev}} = \frac{1}{1-(T_L/T_H)} = \frac{1}{1-(2+273\ \mathrm{K})/(22+273\ \mathrm{K})} = 14.75$$



The required power input to this reversible heat pump is determined from the definition of the coefficient of performance to be

$$\dot{W}_{\mathrm{net,in,min}} = \frac{\dot{Q}_H}{\mathrm{COP_{HP}}} = \frac{110{,}000\ \mathrm{kJ/h}}{14.75}\left(\frac{1\ \mathrm{h}}{3600\ \mathrm{s}}\right) = \mathbf{2.07\ kW}$$

This heat pump is **powerful enough** since 5 kW > 2.07 kW.

6–96 The structure of a house is such that it loses heat at a rate of 5400 kJ/h per °C difference between the indoors and outdoors. A heat pump that requires a power input of 6 kW is used to maintain this house at 21°C. Determine the lowest outdoor temperature for which the heat pump can meet the heating requirements of this house. **Answer: -13.3°C**

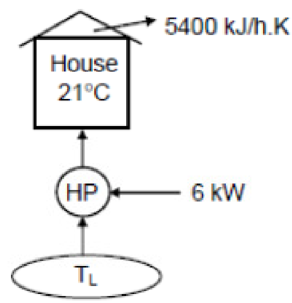
Solution A heat pump that consumes 5-kW of power when operating maintains a house at a specified temperature. The house is losing heat in proportion to the temperature difference between the indoors and the outdoors. The lowest outdoor temperature for which this heat pump can do the job is to be determined.

Assumption The heat pump operates steadily.

Analysis Denoting the outdoor temperature by T_L, the heating load of this house can be expressed as

$$\dot{Q}_H = (5400 \text{ kJ/h} \cdot \text{K})(294 - T_L) = (1.5 \text{ kW/K})(294 - T_L)\text{K}$$

The coefficient of performance of a Carnot heat pump depends on the temperature limits in the cycle only, and can be expressed as



$$\text{COP}_{\text{HP}} = \frac{1}{1-(T_L/T_H)} = \frac{1}{1-T_L/(294 \text{ K})}$$

or, as

$$\text{COP}_{\text{HP}} = \frac{\dot{Q}_H}{\dot{W}_{\text{net,in}}} = \frac{(1.5 \text{ kW/K})(294 - T_L)\text{K}}{6 \text{ kW}}$$

Equating the two relations above and solving for T_L, we obtain

$$T_L = 259.7 \text{ K} = -13.3°\text{C}$$