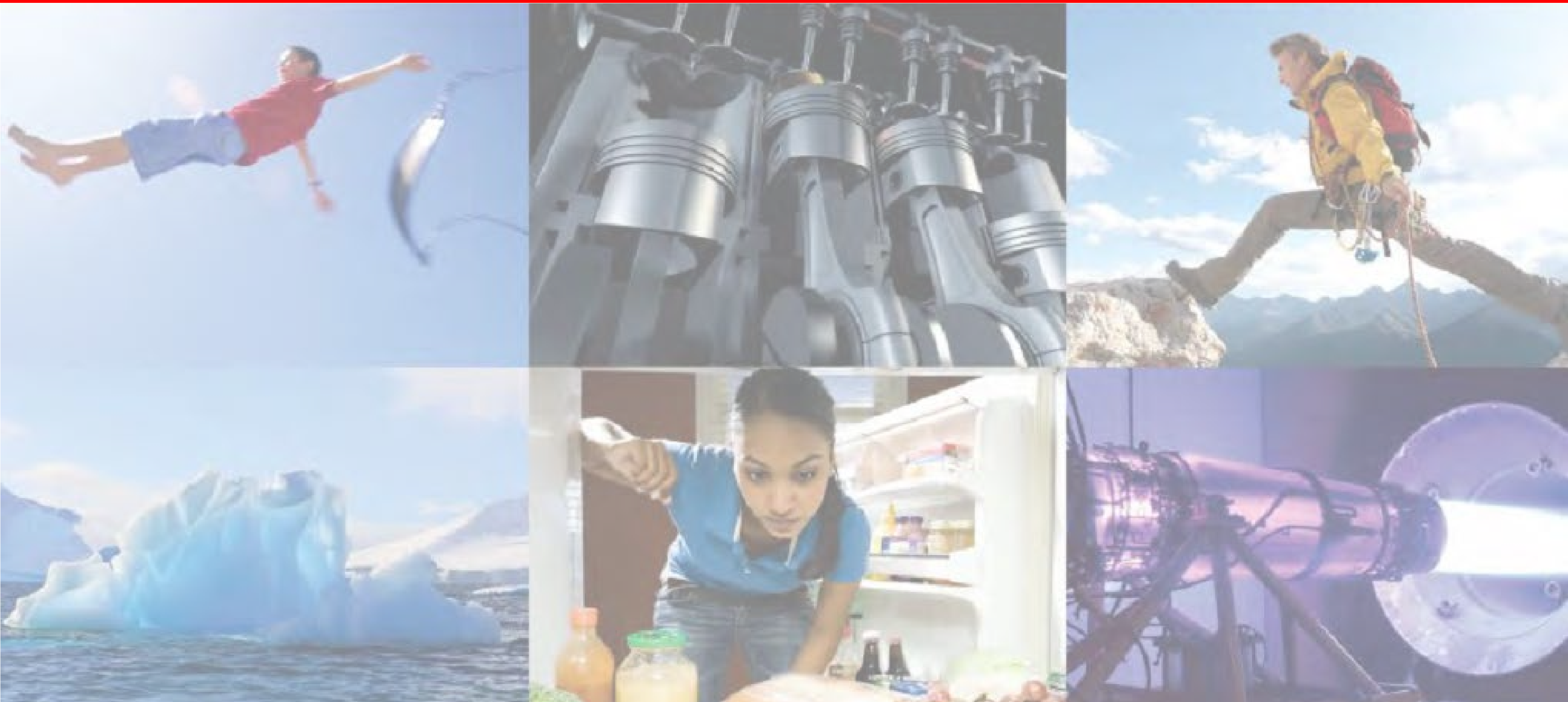


Second Law Of Thermodynamics

By Ertanto Vetra

Outlines

- The second law of thermodynamics
- Heat Engine/Power Cycle
  - Efficiency
- Heat Pumps/Refrigeration Cycle
  - Coefficient of Performance
- Reversibility
- Carnot Cycle
- Claus/Kelvin-Planck Statement
- Thermodynamic Temperature Scale

Introductions

- As pointed out repeatedly in previous chapters ,energy is a conserved property, and no process is known to have taken place in violation of the first law of thermodynamics.
- Therefore, it is reasonable to conclude that a process must satisfy the first law to occur.
- However, as explained here, satisfying the first law alone **does not ensure** that the process will actually take place.

Introductions

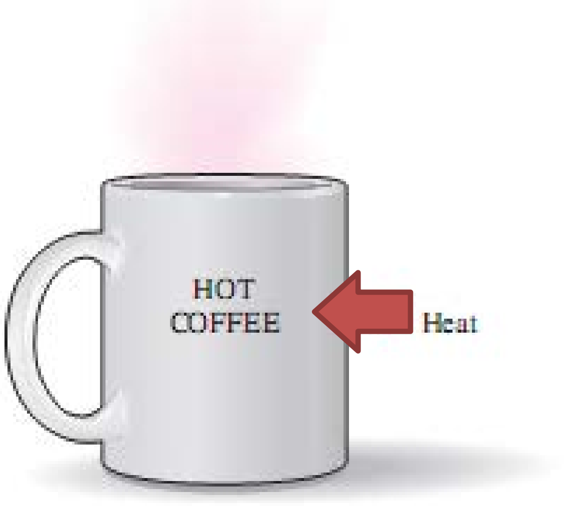


FIGURE 6–1

FIGURE 6–2

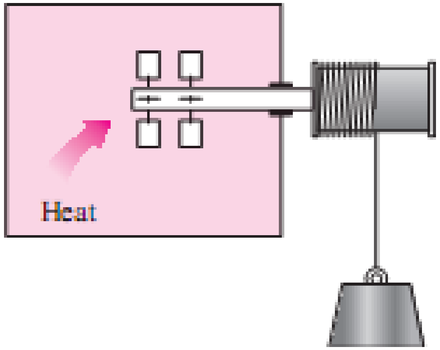


FIGURE 6–3

- All of above processes **satisfies** the first law of thermodynamics

Introductions

- It is clear from these arguments that processes proceed in **a certain direction** and not in the reverse direction.
- The first law places no restriction on the direction of a process, but **satisfying the first law does not ensure that the process can actually occur**.
- This inadequacy of the first law to identify whether a process can take place is remedied by introducing another general principle:

THE SECOND LAW OF THERMODYNAMICS

Introductions

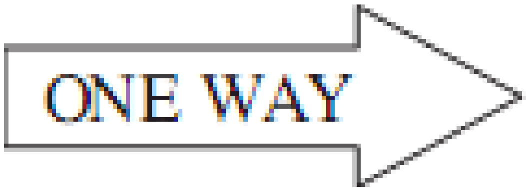


FIGURE 6–4

Processes occur in a certain direction, and not in the reverse direction.

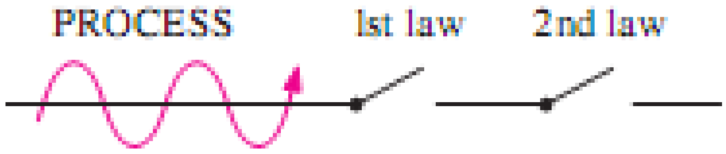


FIGURE 6–5

A process must satisfy both the first and second laws of thermodynamics to proceed.

Use of Second Law of Thermodynamics

- Identifying direction of a process
- Asserts that energy has a quality ,as well as quantity (Electromagnet>Mechanical>Chemical>Heat)
- Determining the best theoretical performance of cycles, engines, and other devices.
- Predicting the degree of completion of chemical reactions
- And many more…

Thermal Energy/Heat Reservoirs

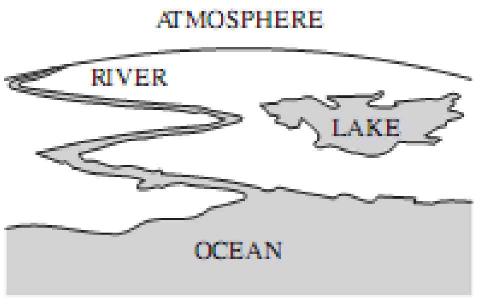


FIGURE 6–6
Bodies with relatively large thermal masses can be modeled as thermal energy reservoirs.

- Thermal Energy Reservoirs: a hypothetical body with a relatively large thermal energy capacity (mass x specific heat) that can **supply** or **absorb** finite amounts of heat **without undergoing any change in temperature**

A reservoir that :

- supplies energy in the form of heat is called a **source**, and
- absorbs energy in the form of heat is called a **sink**

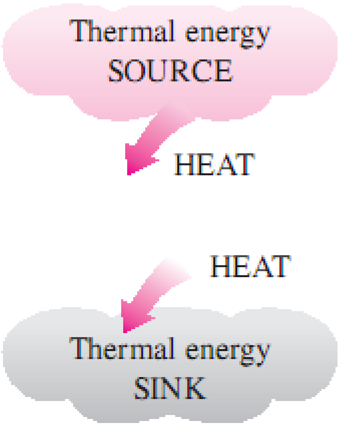
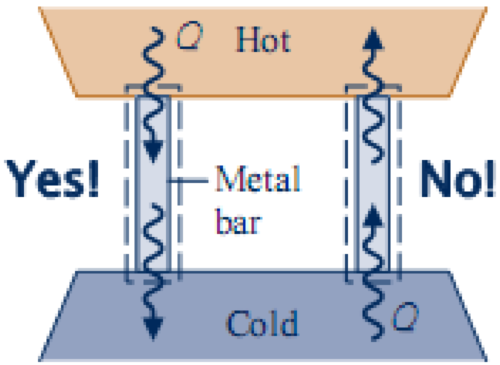


FIGURE 6–7
A source supplies energy in the form of heat, and a sink absorbs it.

Statements of the Second Law

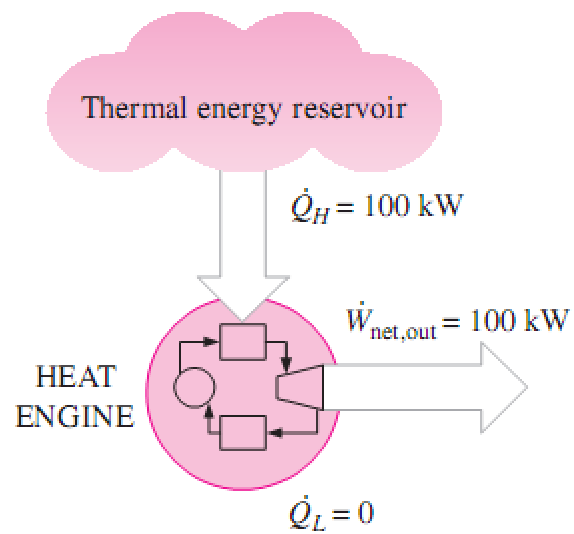


Clausius' Statement

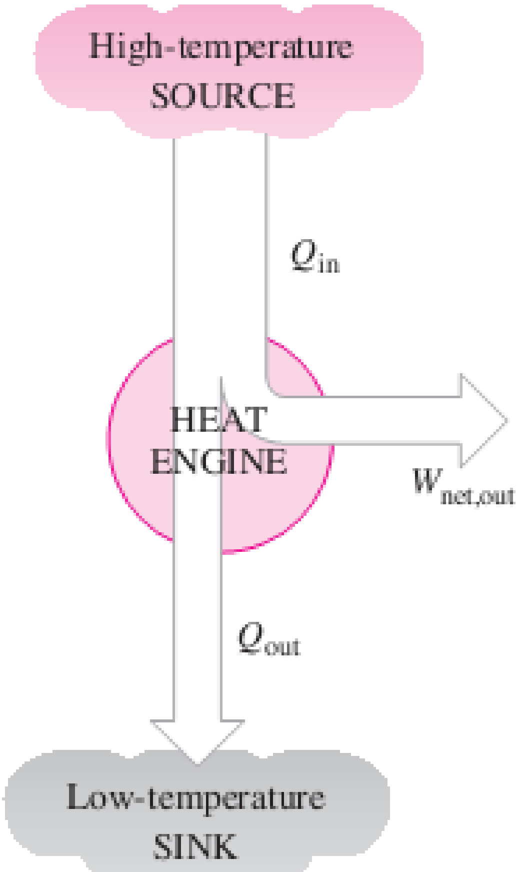
It is impossible for any system to operate in such a way that the sole result would be an energy transfer by heat from a cooler to a hotter body.

Kelvin-Planck's Statement

It is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of energy by work to its surroundings while receiving energy by heat transfer from a single thermal reservoir.



Power Cycles/Heat Engine

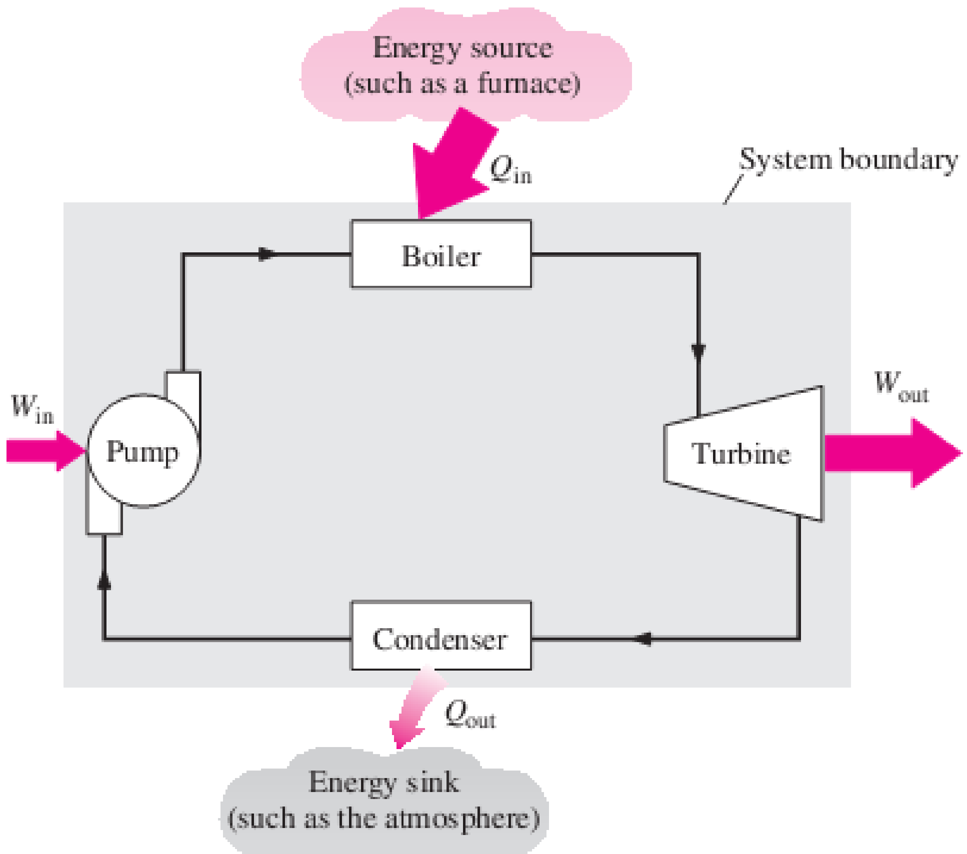


Characteristics:

1. They receive heat from a high-temperature source (solar energy, oil furnace, nuclear reactor, etc.).
2. They convert part of this heat to work (usually in the form of a rotating shaft).
3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).
4. They operate on a cycle.

Heat engines and other cyclic devices usually involve a fluid to and from which heat is transferred while undergoing a cycle. This fluid is called the **working fluid**.

Power Cycles/Heat Engine



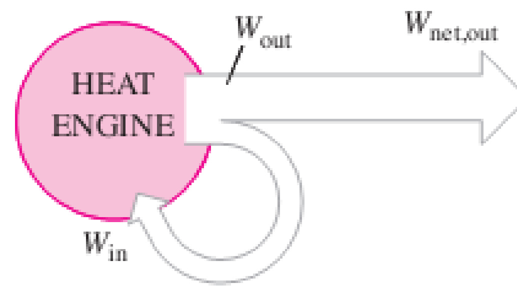


FIGURE 6–11

A portion of the work output of a heat engine is consumed internally to maintain continuous operation.

$$W_{net,out} = W_{out} - W_{in}$$

Thermal Efficiency

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}}$$

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

The thermal efficiencies of work-producing devices are relatively low:

- Ordinary spark-ignition automobile engines: 25% percent.
- Diesel engine: 40 %
- Large gas-turbine plants and: 40 %
- Large combined gas-steam power plants: 60%
- Even with the most efficient heat engines available today, almost one-half of the energy supplied ends up in the rivers, lakes, or the atmosphere as waste or useless energy

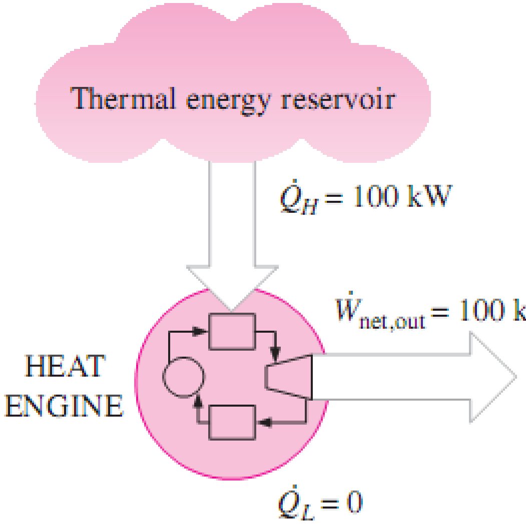
Is it possible, under **ideal condition**, to have a heat engine with 100% thermal efficiency??

Application of Second Law to Heat Engine

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

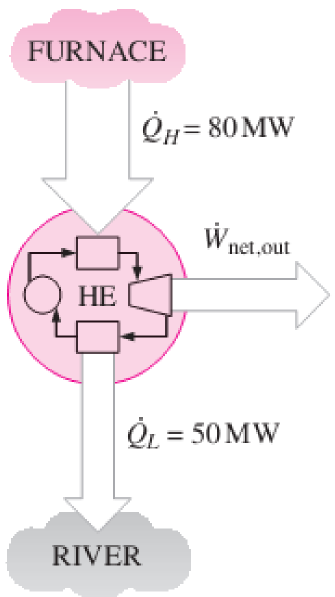
Thermal efficiency will ~ 100% as Q_{out} approaches zero

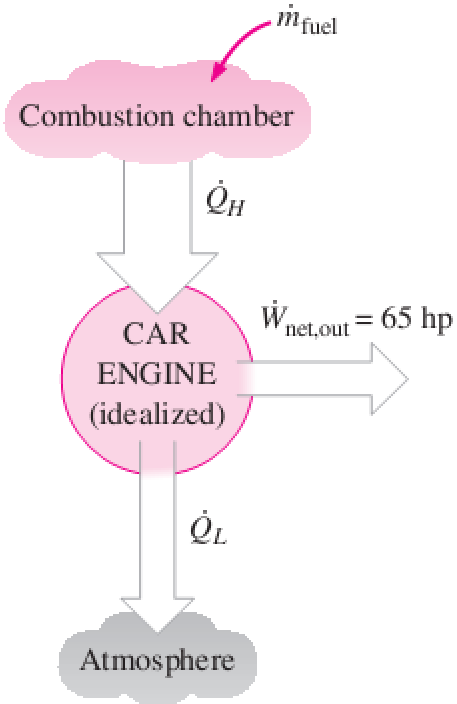
However, it's not possible to have Q_{out}=0, even under ideal condition since it violates the 2nd law of thermodynamic (Kelvin-Planck's Statement)



no heat engine can have a thermal efficiency of 100%

Examples

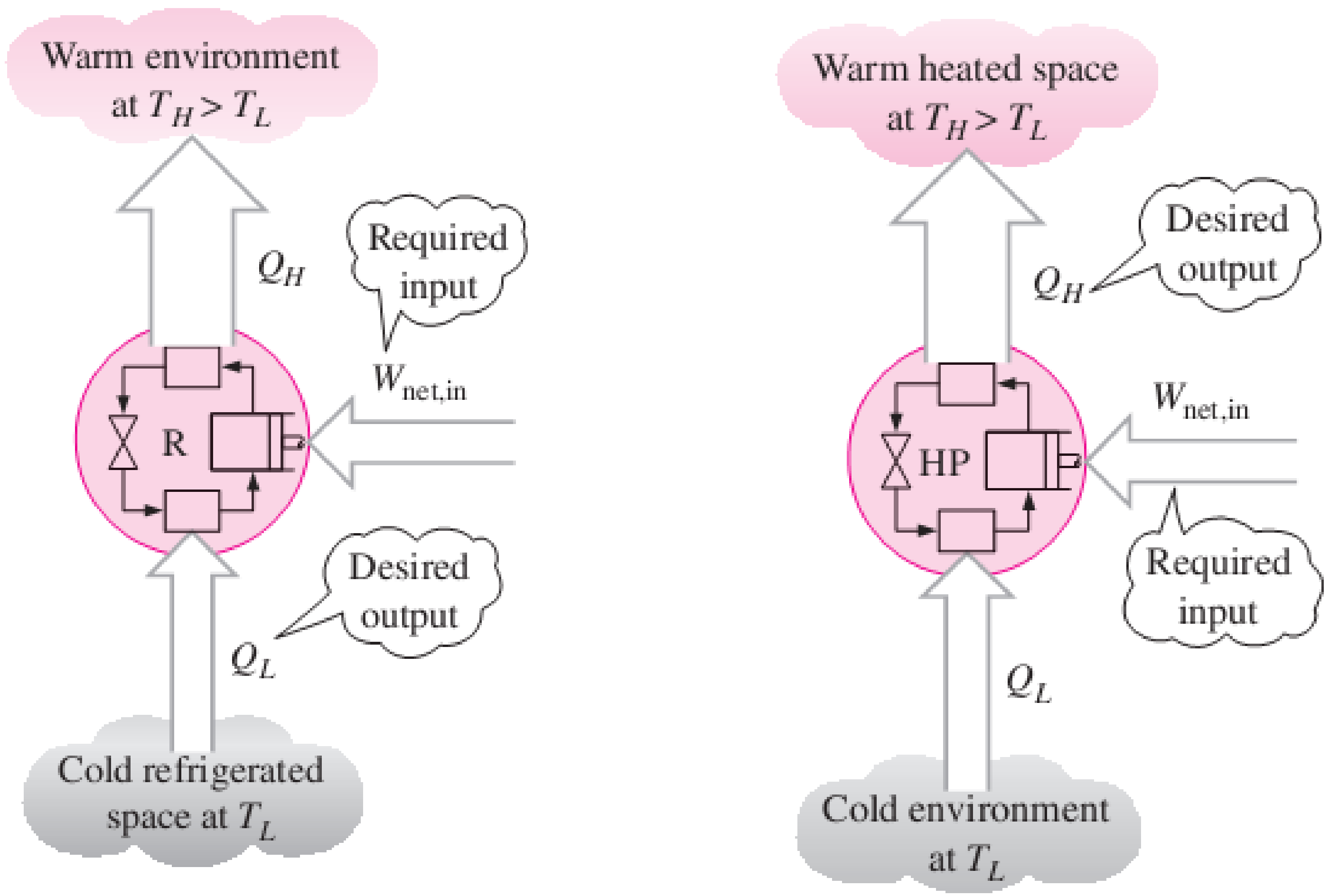




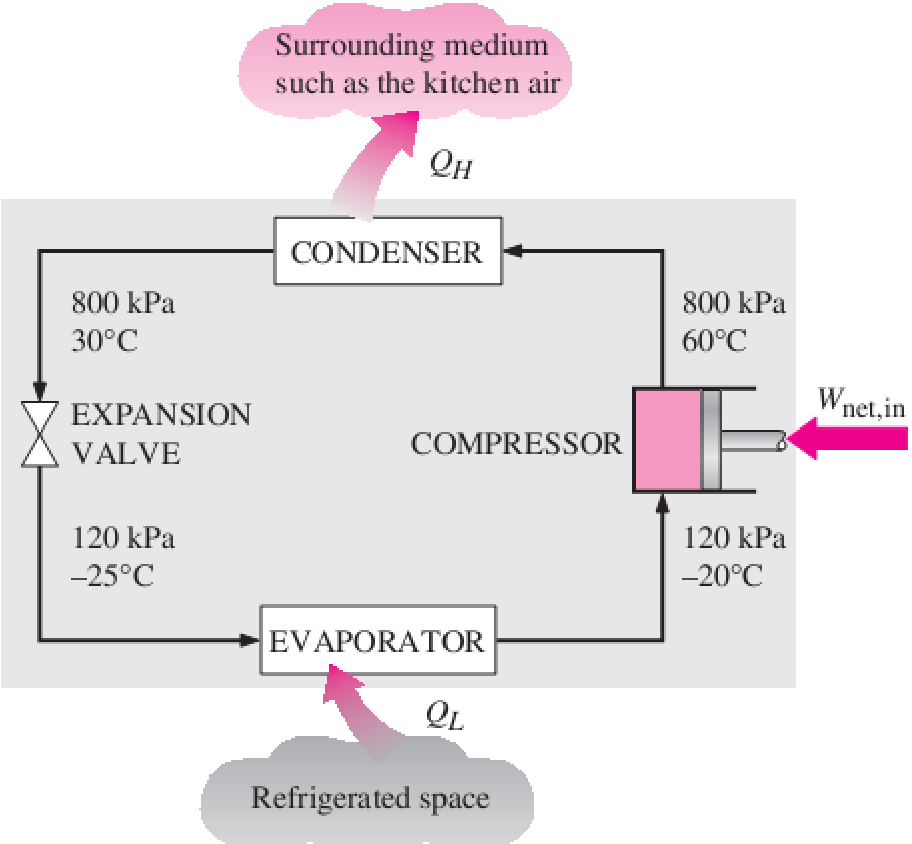
Heat is transferred to a heat engine from a furnace at a rate of 80 MW. If the rate of waste heat rejection to a nearby river is 50 MW, determine the net power output and the thermal efficiency for this heat engine.

A car engine with a power output of 65 hp has a thermal efficiency of 24 percent. Determine the fuel consumption rate of this car if the fuel has a heating value of 19,000 Btu/lbm (that is, 19,000 Btu of energy is released for each lbm of fuel burned).

Refrigeration Cycles/Heat Pump



Coefficient of Performance for Refrigeration Cycle



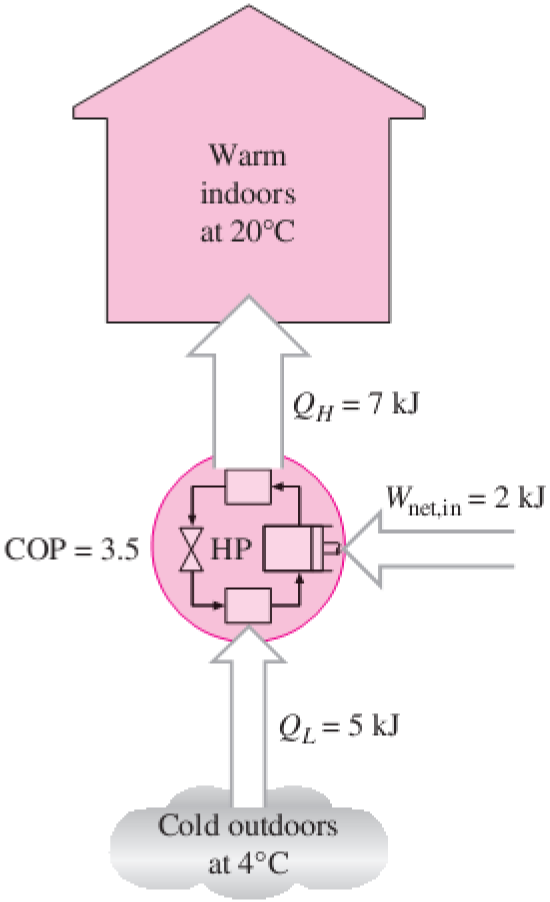
$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{net,in}}$$

Notice that the value of COP_R can be greater than 1 .
That is, heat removed > work input.

In fact, one reason for expressing the efficiency of a refrigerator by another term—the Coefficient of performance—is the desire to avoid the oddity of having efficiencies greater than unity.

The most frequently used refrigeration cycle is the **vapor-compression refrigeration cycle**

Coefficient of Performance for Heat Pumps

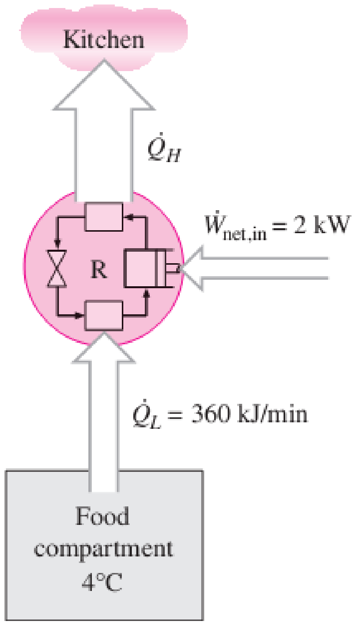


$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = COP_R + 1$$

Most heat pumps in operation today have a seasonally averaged COP of 2 to 3

Examples



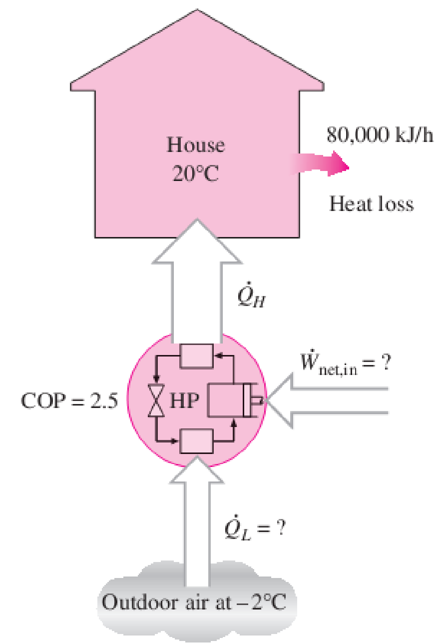
The food compartment of a refrigerator, is maintained at 4°C by removing heat from it at a rate of 360 kJ/min. If the required power input to the refrigerator is 2 kW, determine:

(a) the coefficient of performance of the refrigerator and

(b) the rate of heat rejection to the room that houses the refrigerator.

A heat pump is used to meet the heating requirements of a house and maintain it at 20°C. On a day when the outdoor air temperature drops to 2°C, the house is estimated to lose heat at a rate of 80,000 kJ/h. If the heat pump under these conditions has a COP of 2.5, determine:

(a) the power consumed by the heat pump and (b) the rate at which heat is absorbed from the cold outdoor air.

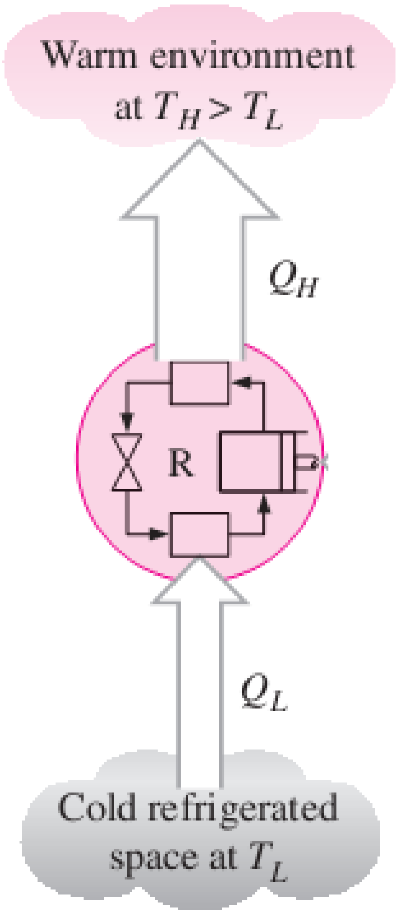


Application of Second Law to Refrigeration Cycles/Heat Pump

$$\text{COP}_\text{R} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{\text{net,in}}}$$

$$\text{COP}_\text{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_H}{W_{\text{net,in}}}$$

- Higher performance is achieved as W_{net} approach zero (lower work input)
- When W_{net} = 0, COP = ∞
- However it violates the 2nd law (Claus' Statement)



Reversible and Irreversible Process

- The second law of thermodynamics states that no heat engine can have an efficiency of 100 percent.
- Then one may ask, What is the highest efficiency that a heat engine can possibly have?
- Before we can answer this question, we need to define an idealized process first, which is called the reversible process.

Reversible and Irreversible Process

- A **reversible process** is defined as a process that can be reversed without leaving any trace on the surroundings That is, both the system and the surroundings are returned to their initial states at the end of the reverse process.
- Processes that are not reversible are called **irreversible processes**

Reversible and Irreversible Process

- Engineers are interested in reversible processes because :
  - work-producing devices such as car engines and gas or steam turbines deliver **the most work** ,
  - work-consuming devices such as compressors, fans, and pumps consume **the least work** when reversible processes are used instead of irreversible ones
- Reversible processes can be viewed as theoretical limits for the corresponding irreversible ones

Irreversibilities

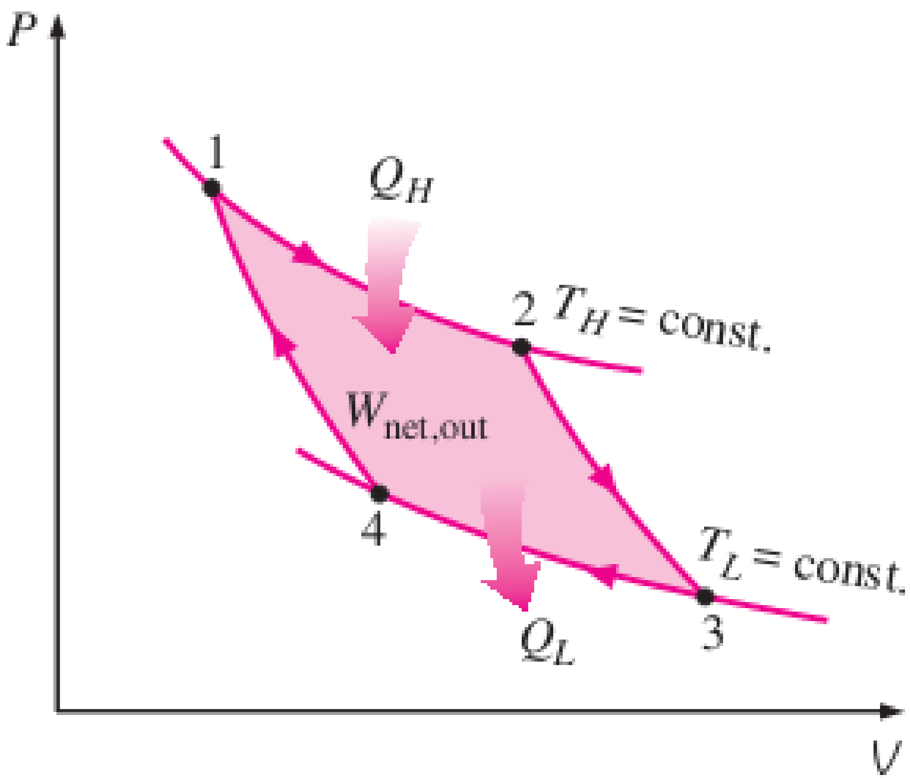
In summary, irreversible processes normally include one or more of the following irreversibilities :

- Heat transfer through a finite temperature difference
- Unrestrained expansion of a gas or liquid to a lower pressure
- Spontaneous chemical reaction
- Spontaneous mixing of matter at different compositions or states
- Friction—sliding friction as well as friction in the flow of fluids
- Electric current flow through a resistance
- Magnetization or polarization with hysteresis
- Inelastic deformation

Totally Reversible Process

- A process is called totally reversible, or simply reversible, if it involves no irreversibilities within the system or its surroundings.
- A totally reversible process involves
  - – no heat transfer through a finite temperature difference
  - – no nonquasi-equilibrium changes, and
  - – no friction or other dissipative effects.

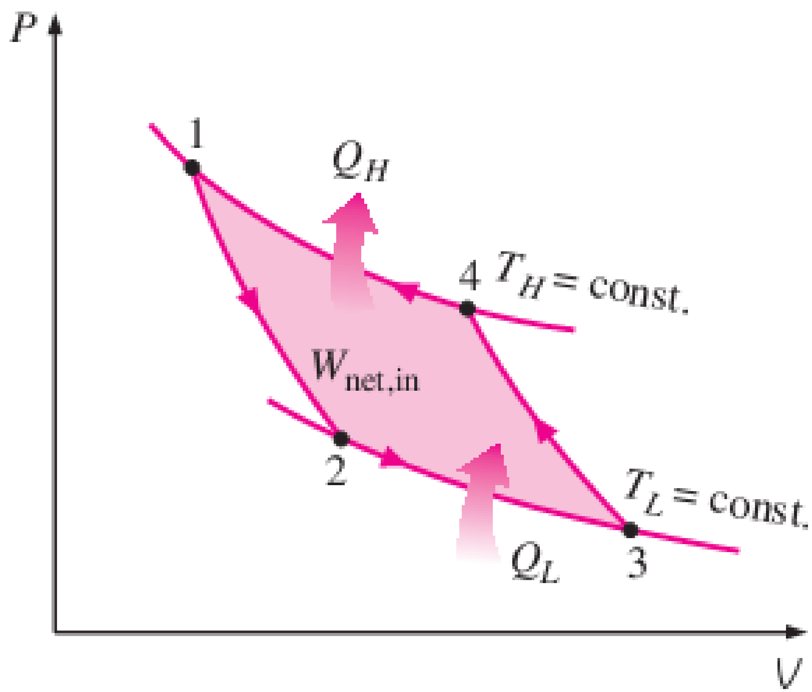
Carnot Cycle



The enclosed area on the p–v diagram, shown shaded, is the net work developed by the cycle per unit of mass

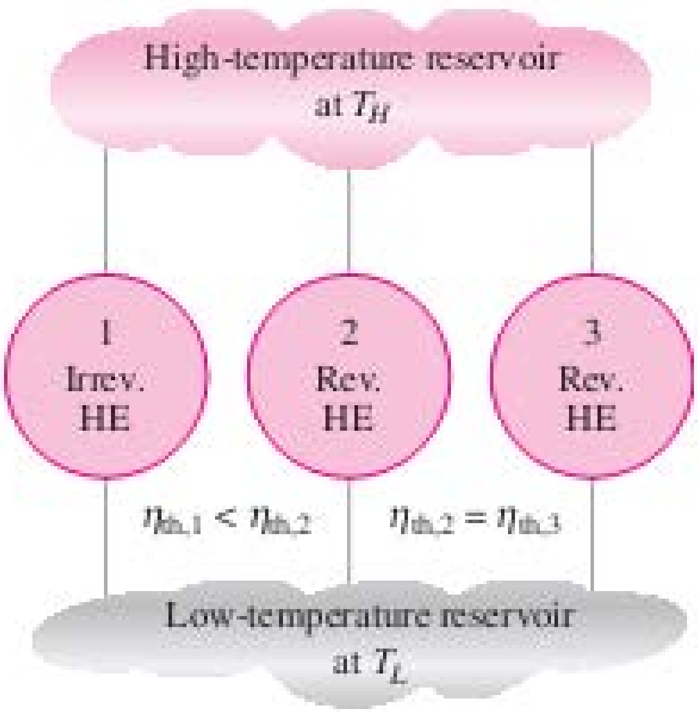
- 1-2=Reversible Isothermal Expansion (T_H = constant)
- 2-3=Reversible Adiabatic Expansion (temperature drops from T_H to T_L)
- 3-4=Reversible Isothermal Compression (T_L = constant).
- 4-1=Reversible Adiabatic Compression (temperature rises from T_L to T_H)

Reversed Carnot Cycle



- If a Carnot power cycle is operated in the opposite direction, the magnitudes of all energy transfers remain the same but the energy transfers are oppositely directed

Carnot Principles



1. The efficiency of an irreversible heat engine is always less than the efficiency of a reversible one operating between the same two reservoirs.
2. The efficiencies of all reversible heat engines operating between the same two reservoirs are the same.

Thermodynamic Temperature Scales

- A temperature scale that is independent of the properties of the substances that are used to measure temperature is called a **thermodynamic temperature scale**

Kelvin Scale

$$\left(\frac{Q_C}{Q_H}\right)_{\substack{\text{rev}\\\text{cycle}}} = \frac{T_C}{T_H}$$

Maximum Performance Measures for Cycles Operating Between Two Reservoirs (Power Cycles)

Being a reversible cycle, the Carnot cycle is the most efficient cycle operating between two specified temperature limits (T_H and T_L)

$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$

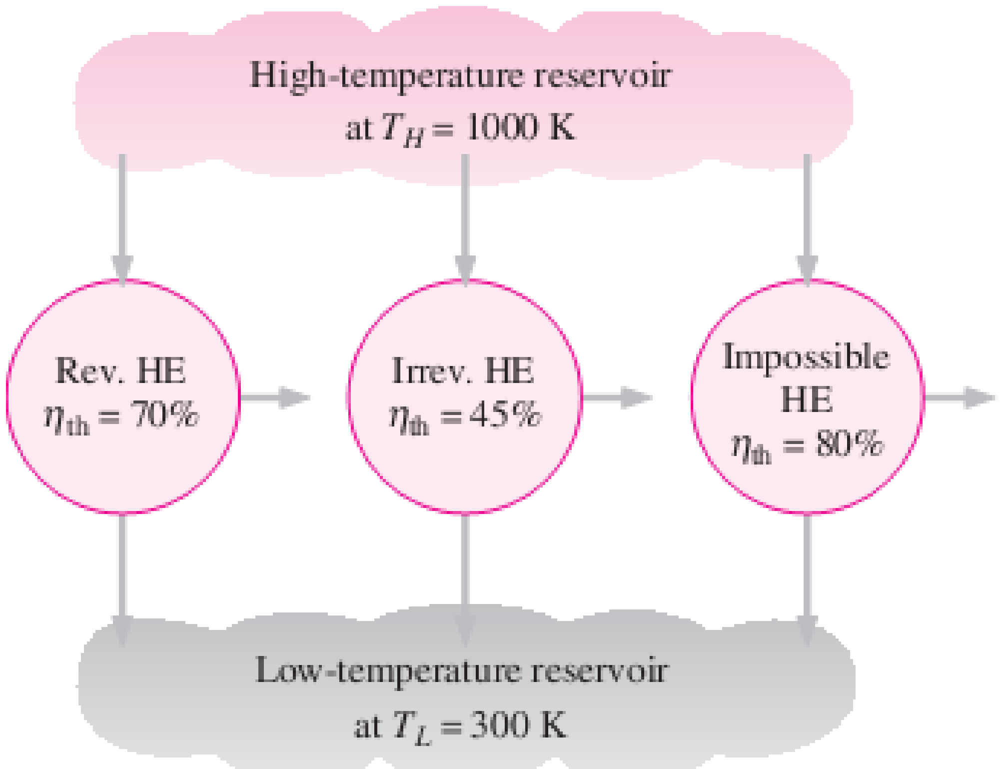
$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

Note that T_L and T_H are absolute temperatures (K or R), not °C or ° F

An actual heat engine cannot reach this maximum theoretical efficiency value because it is impossible to completely eliminate all the irreversibilities associated with the actual cycle

Maximum Performance Measures for Cycles Operating Between Two Reservoirs (Power Cycles)

$$\eta_{th} \begin{cases} < \eta_{th,rev} & \text{irreversible heat engine} \\ = \eta_{th,rev} & \text{reversible heat engine} \\ > \eta_{th,rev} & \text{impossible heat engine} \end{cases}$$



Maximum Performance Measures for Cycles Operating Between Two Reservoirs (Refrigeration Cycles)

Carnot Refrigerator

$$\mathrm{COP_R} = \frac{1}{Q_H/Q_L - 1}$$

$$\mathrm{COP_{R,rev}} = \frac{1}{T_H/T_L - 1}$$

Carnot Heat Pump

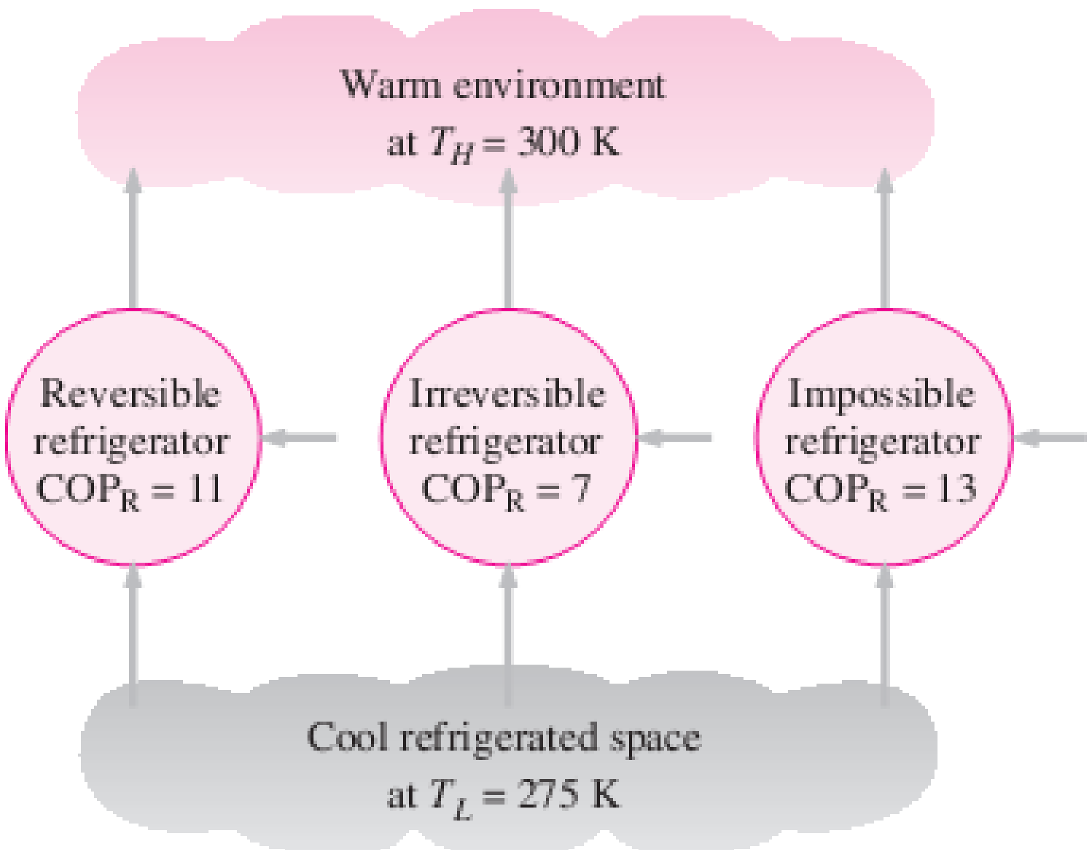
$$\mathrm{COP_{HP}} = \frac{1}{1 - Q_L/Q_H}$$

$$\mathrm{COP_{HP,rev}} = \frac{1}{1 - T_L/T_H}$$

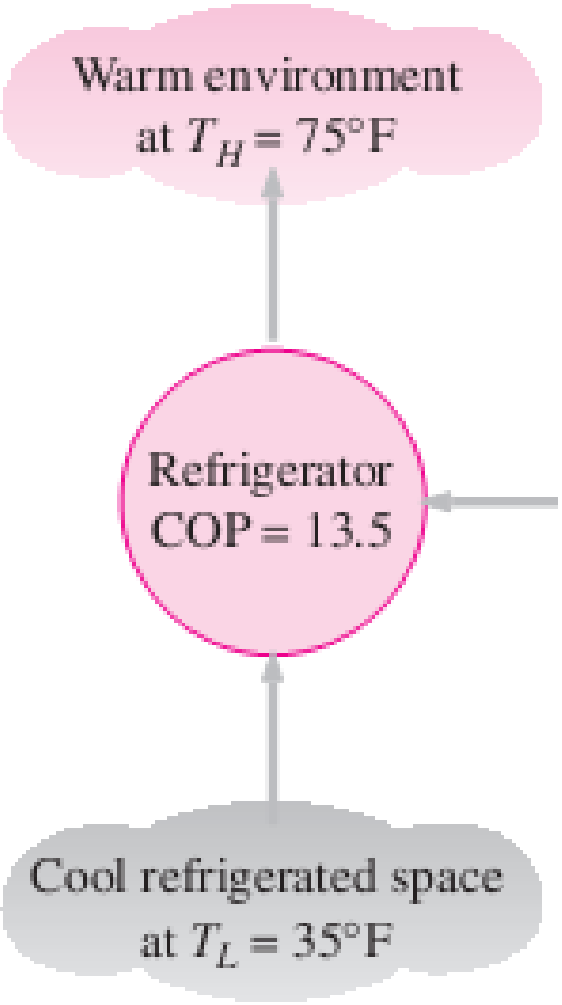
These are the **highest** COP that a refrigerator or a heat pump operating between the temperature limits of T L and T H can have

Maximum Performance Measures for Cycles Operating Between Two Reservoirs (Refrigeration Cycles)

$$COP_R \begin{cases} < COP_{R,rev} & \text{irreversible refrigerator} \\ = COP_{R,rev} & \text{reversible refrigerator} \\ > COP_{R,rev} & \text{impossible refrigerator} \end{cases}$$



Example



An inventor claims to have developed a refrigerator that maintains the refrigerated space at 35°F while operating in a room where the temperature is 75°F and that has a COP of 13.5. Is this claim reasonable?