Thermodynamics - 1

Lecture 21

Refrigerators and Heat pumps, Clausius Statement of 2nd law (Ch-6)

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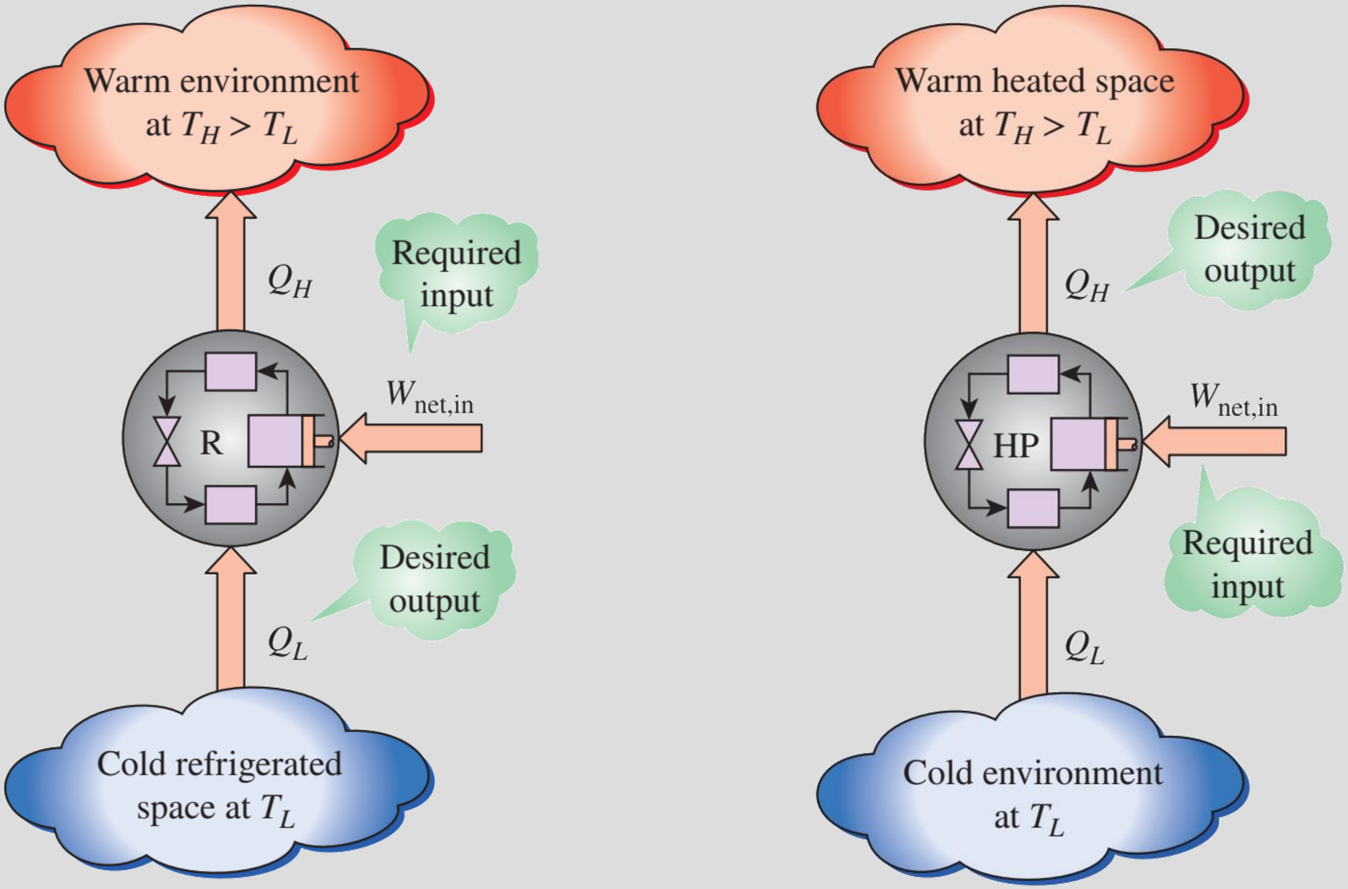
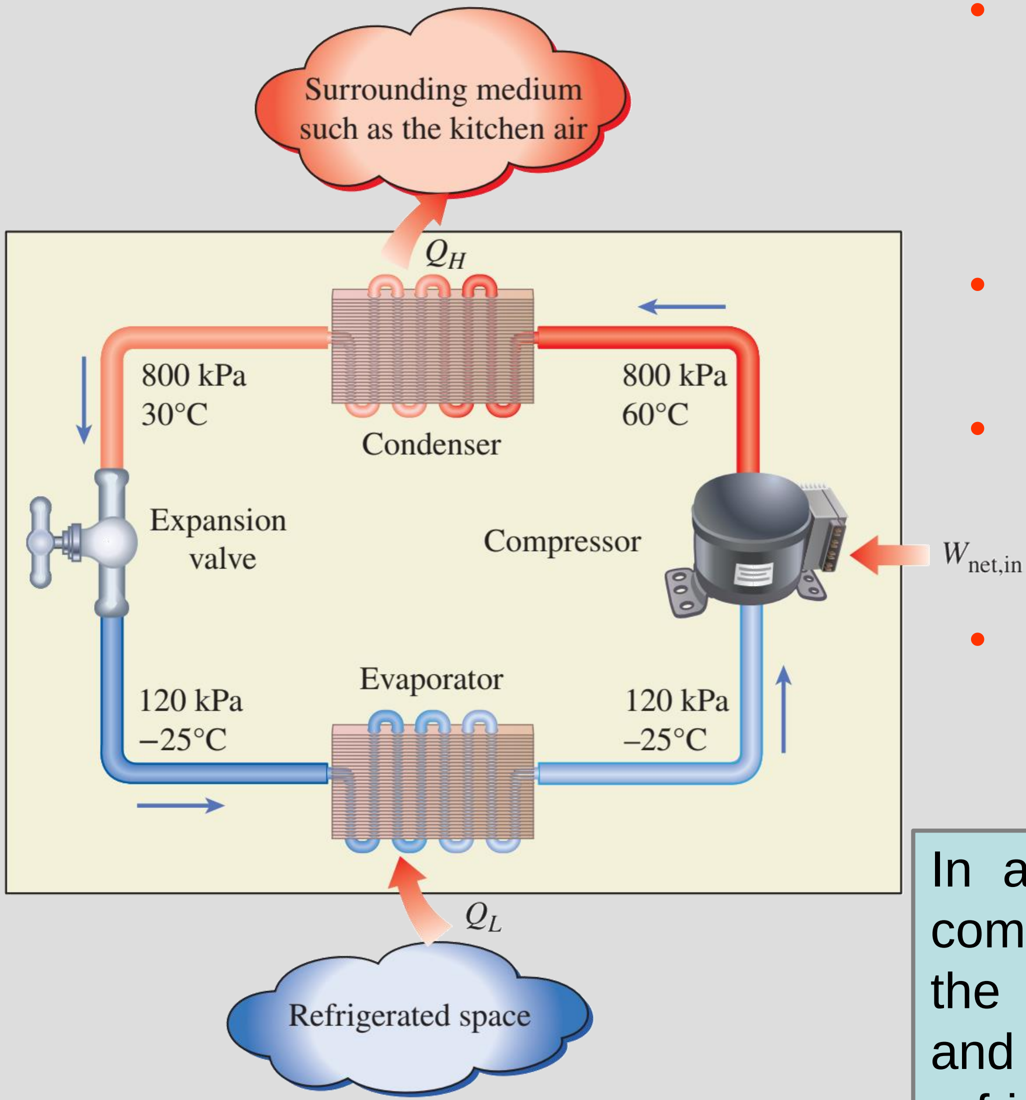
Reversed Heat Engine: Refrigeration Cycle and Heat Pump Cycle



In reversed heat engines the thermodynamic cycle removes heat from a low-temperature body and delivers heat to high temperature body. To accomplish this energy, the heat pump receives external energy in the form of work from surroundings.

Reversed Heat Engine: REFRIGERATORS AND HEAT PUMPS



Basic components of a refrigeration system and typical operating conditions.

- The transfer of heat from a low-temperature medium to a high-temperature one requires special devices called **refrigerators**.
- Refrigerators, like heat engines, are cyclic devices.
- The working fluid used in the refrigeration cycle is called a **refrigerant**.
- The most frequently used refrigeration cycle is the *vapor-compression refrigeration cycle*.

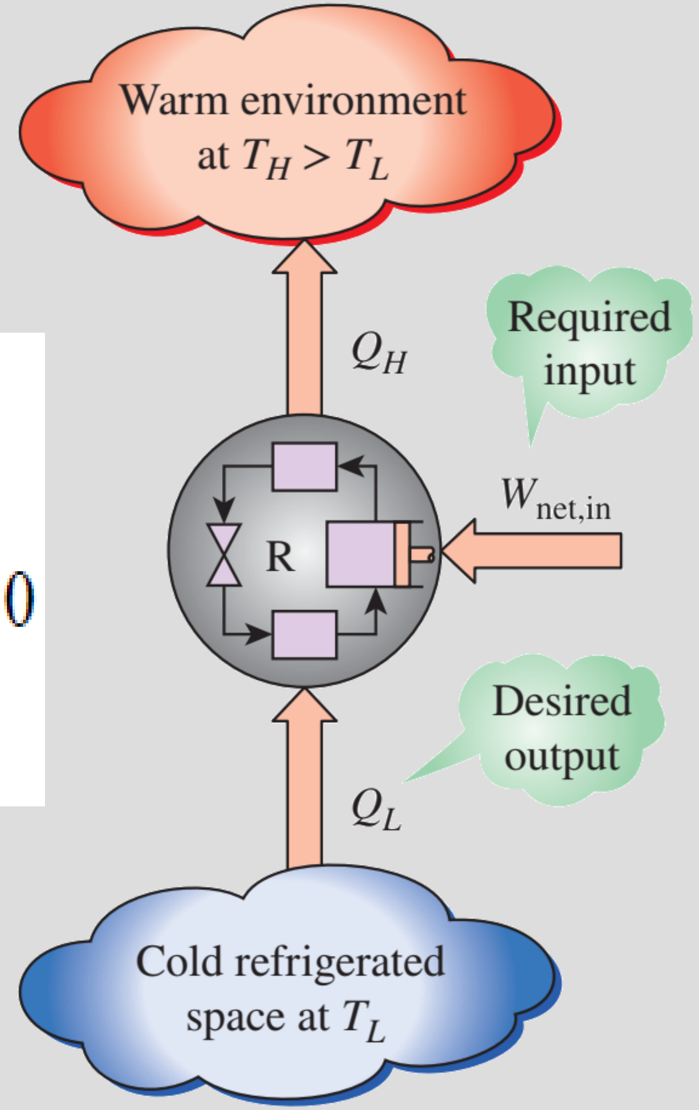
In a household refrigerator, the freezer compartment where heat is absorbed by the refrigerant serves as the evaporator, and the coils usually behind the refrigerator where heat is dissipated to the kitchen air serve as the condenser.

Refrigeration and Heat Pump Cycles: Net Work Output

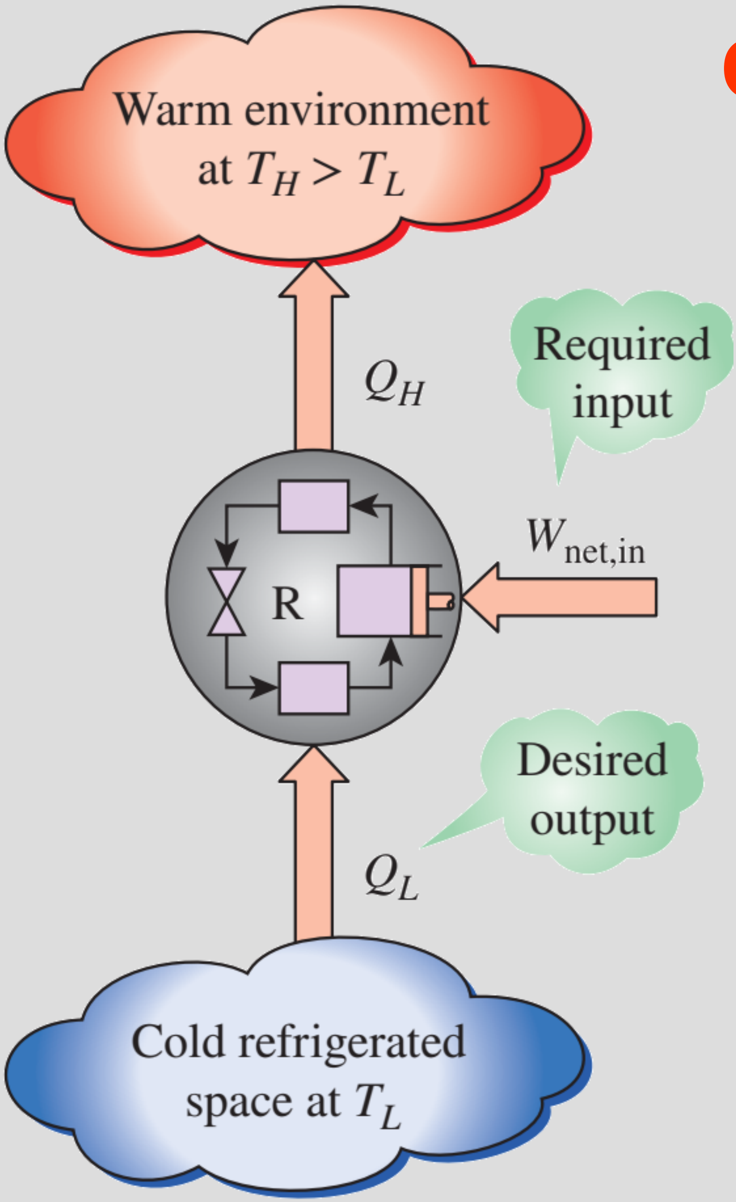
Now apply the first law to the cyclic refrigerator.

$$(Q_L - Q_H) - (0 - W_{in}) = \Delta U_{cycle} = 0$$

$$W_{in} = W_{net,in} = Q_H - Q_L$$



Coefficient of Performance



The *efficiency* of a refrigerator is expressed in terms of the ***coefficient of performance*** (COP).

The objective of a refrigerator is to remove heat (Q_L) from the refrigerated space.

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

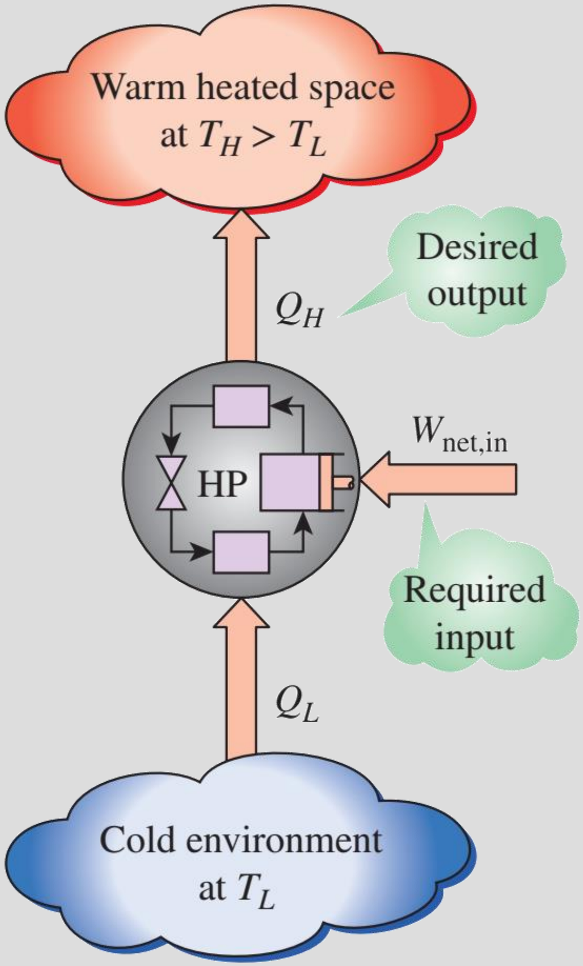
$$W_{\mathrm{net,in}} = Q_H - Q_L \qquad \text{(kJ)}$$

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

The objective of a refrigerator is to remove Q_L from the cooled space.

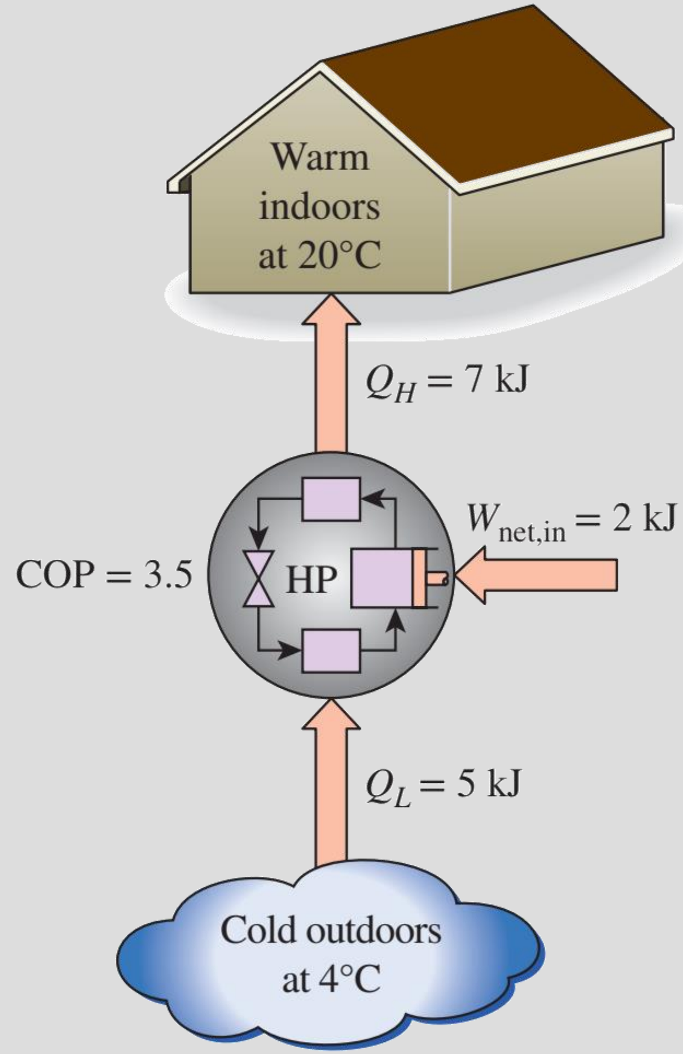
Can the value of $\mathrm{COP_R}$ be greater than unity?

Heat Pumps



The objective of a heat pump is to supply heat Q_H into the warmer space.

The work supplied to a heat pump is used to extract energy from the cold outdoors and carry it into the warm indoors.



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

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

$\mathrm{COP_{HP}} = \mathrm{COP_R} + 1$ for fixed values of Q_L and Q_H

Can the value of $\mathrm{COP_{HP}}$ be lower than unity?

When installed backward, an air conditioner functions as a heat pump.

- Most heat pumps in operation today have a seasonally averaged COP of 2 to 3.
- Most existing heat pumps use the cold outside air as the heat source in winter (*air-source* HP).
- In cold climates their efficiency drops considerably when temperatures are below the freezing point.
- In such cases, *geothermal* (*ground-source*) HP that use the ground as the heat source can be used.
- Such heat pumps are more expensive to install, but they are also more efficient.
- **Air conditioners** are basically refrigerators whose refrigerated space is a room or a building instead of the food compartment.
- The COP of a refrigerator decreases with decreasing refrigeration temperature.
- Therefore, it is not economical to refrigerate to a lower temperature than needed.

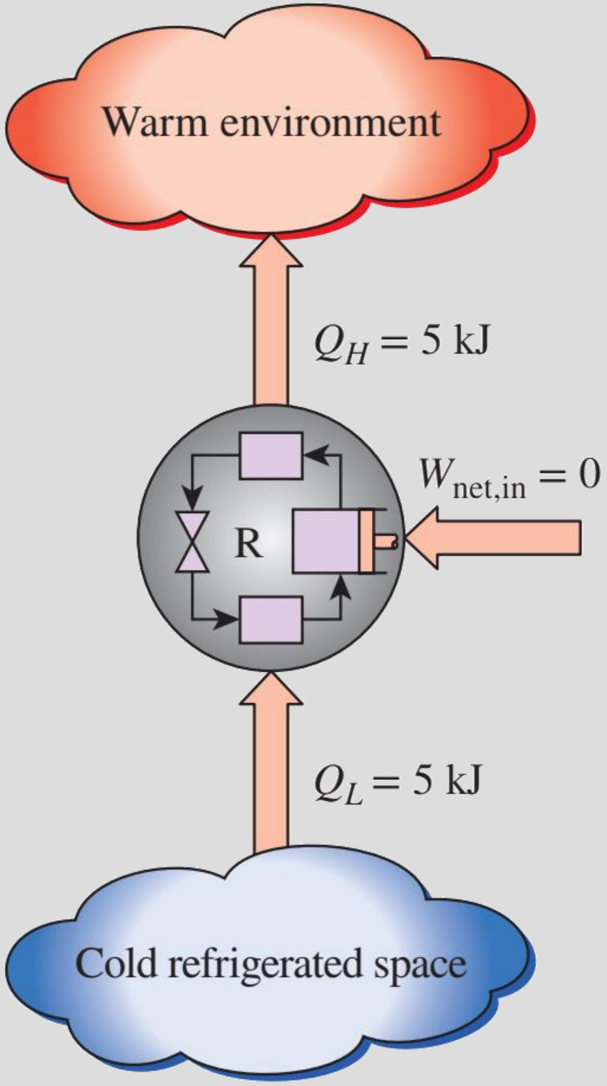
The Second Law of Thermodynamics: Clasius Statement

It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.

It states that a refrigerator cannot operate unless its compressor is driven by an external power source, such as an electric motor.

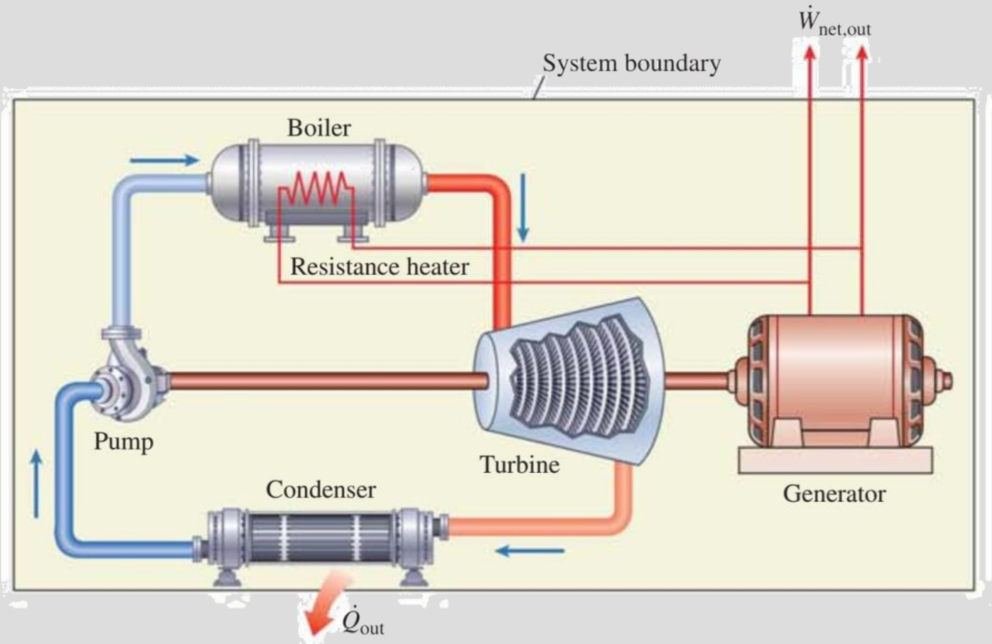
This way, the net effect on the surroundings involves the consumption of some energy in the form of work, in addition to the transfer of heat from a colder body to a warmer one.

To date, no experiment has been conducted that contradicts the second law, and this should be taken as sufficient proof of its validity.

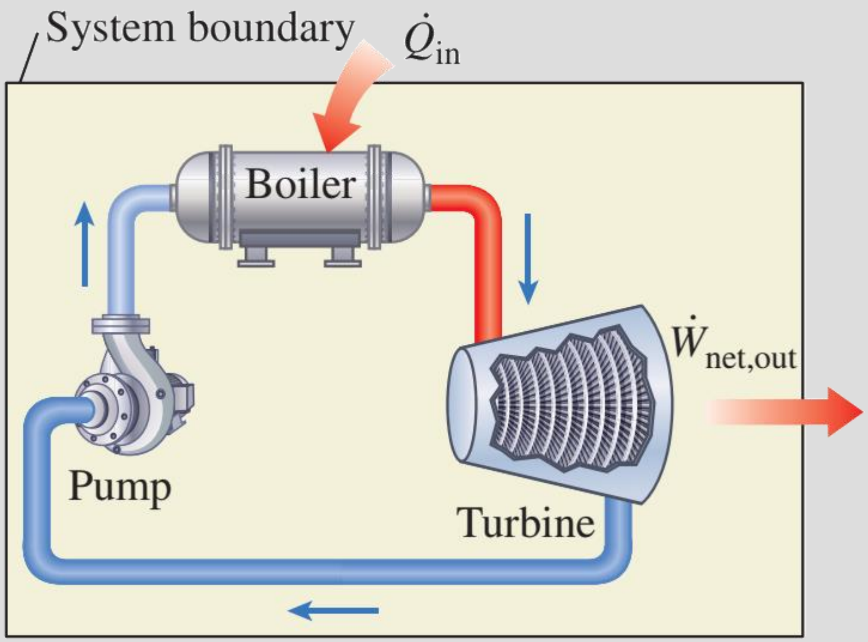


A refrigerator that violates the Clausius statement of the second law.

PERPETUAL-MOTION MACHINES



A perpetual-motion machine that violates the first law (PMM1).



A perpetual-motion machine that violates the second law (PMM2).

Perpetual-motion machine: Any device that violates the first or the second law.

A device that violates the first law (by *creating* energy) is called a PMM1.

A device that violates the second law is called a PMM2.

Despite numerous attempts, no perpetual-motion machine is known to have worked. ***If something sounds too good to be true, it probably is***.

Example 6-3: Heat rejection by a refrigerator

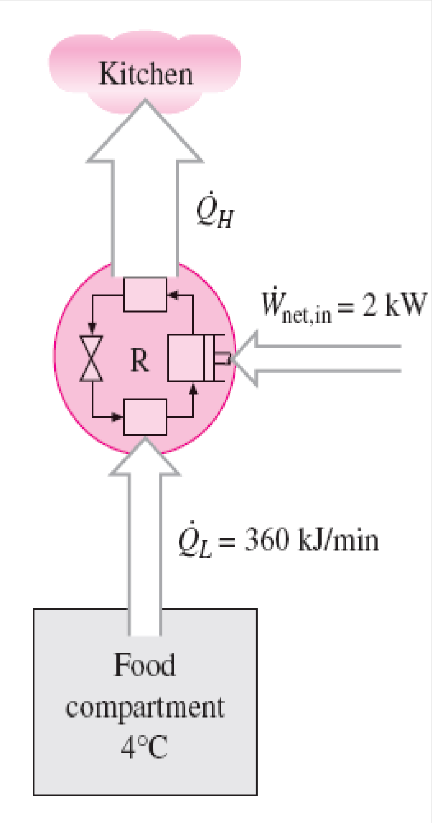
The food compartment of a refrigerator, shown in Fig. 6–24, is maintained at 4°C by removing heat from it at a rate of 360 kJ/min. If the required power input to the refrigerator is 2 kW, determine (*a*) the coefficient of performance of the refrigerator and (*b*) the rate of heat rejection to the room that houses the refrigerator.

(*a*) The coefficient of performance of the refrigerator is

$$\text{COP}_\text{R} = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} = \frac{360 \text{ kJ/min}}{2 \text{ kW}}\left(\frac{1 \text{ kW}}{60 \text{ kJ/min}}\right) = \mathbf{3}$$

(*b*) The rate at which heat is rejected to the room that houses the refrigerator is determined from the conservation of energy relation for cyclic devices,

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{\text{net,in}} = 360 \text{ kJ/min} + (2 \text{ kW})\left(\frac{60 \text{ kJ/min}}{1 \text{ kW}}\right) = \mathbf{480 \text{ kJ/min}}$$



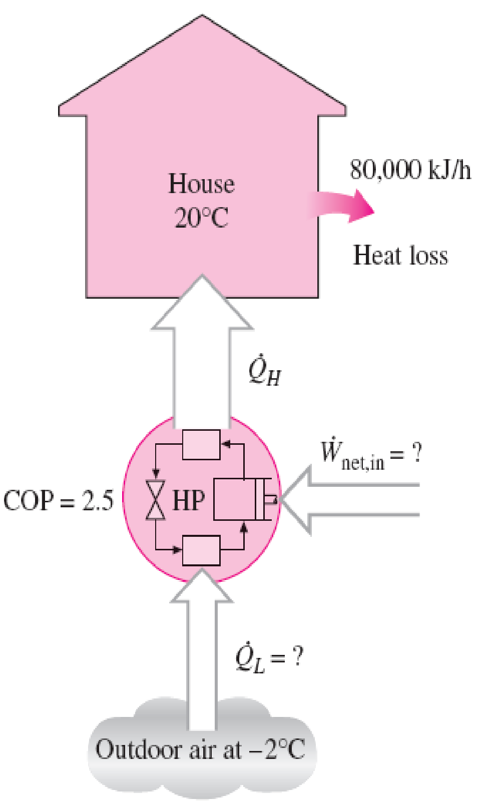
Example 6-4: Heating house by a heat pump

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.

Analysis (*a*) The power consumed by this heat pump, shown in Fig. 6–25, is determined from the definition of the coefficient of performance to be

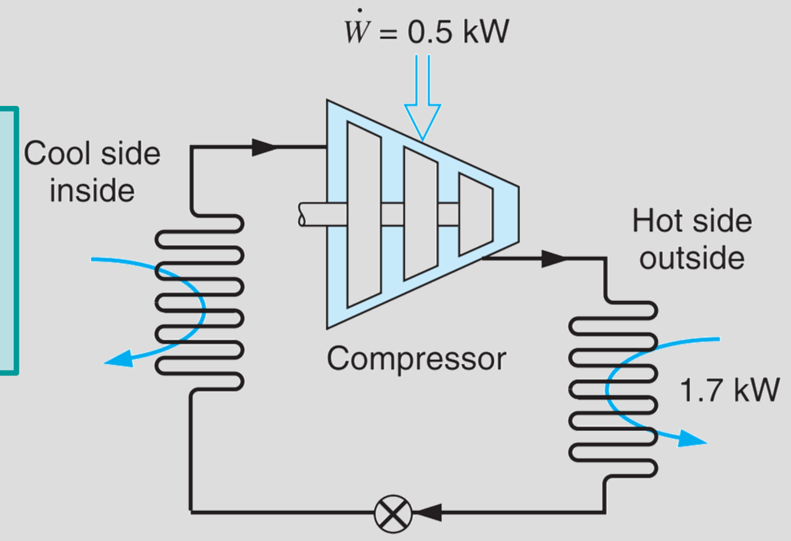
$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_H}{\text{COP}_{\text{HP}}} = \frac{80{,}000 \text{ kJ/h}}{2.5} = \mathbf{32{,}000 \text{ kJ/h}} \text{ (or 8.9 kW)}$$

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{\text{net,in}} = (80{,}000 - 32{,}000) \text{ kJ/h} = \mathbf{48{,}000 \text{ kJ/h}}$$



Practice Problems:

A window air-conditioner discards 1.7 kW to the ambient with a power input of 500 W. Find the rate of cooling and the coefficient of performance.



($\dot{Q}_L$ = 1.2 kW and COP = 2.4

Prove that a cyclic device that violates the Kelvin–Planck statement of the second law also violates the Clausius statement of the second law