Refrigeration cycle

Objectives

- Know basic of refrigeration
- Able to analyze the efficiency of refrigeration system
-

contents

Ideal Vapor-Compression Refrigeration Cycle

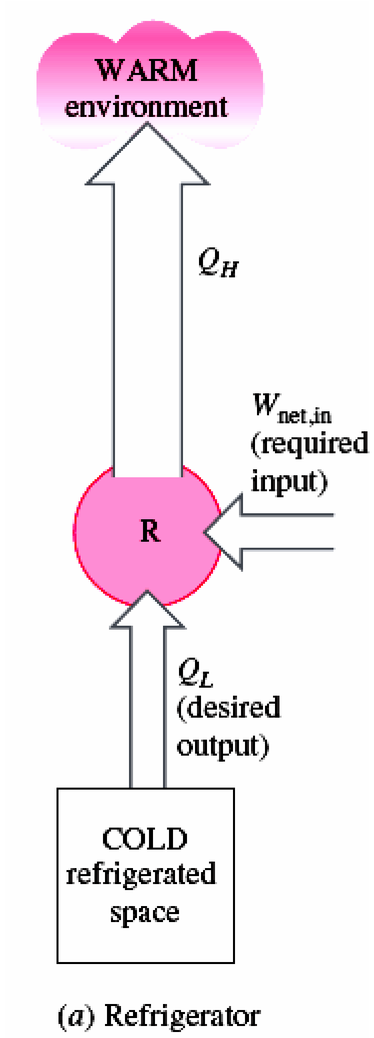
Actual Vapor-Compression Refrigeration Cycle

Cascade refrigeration systems

Multistage compression refrigeration systems

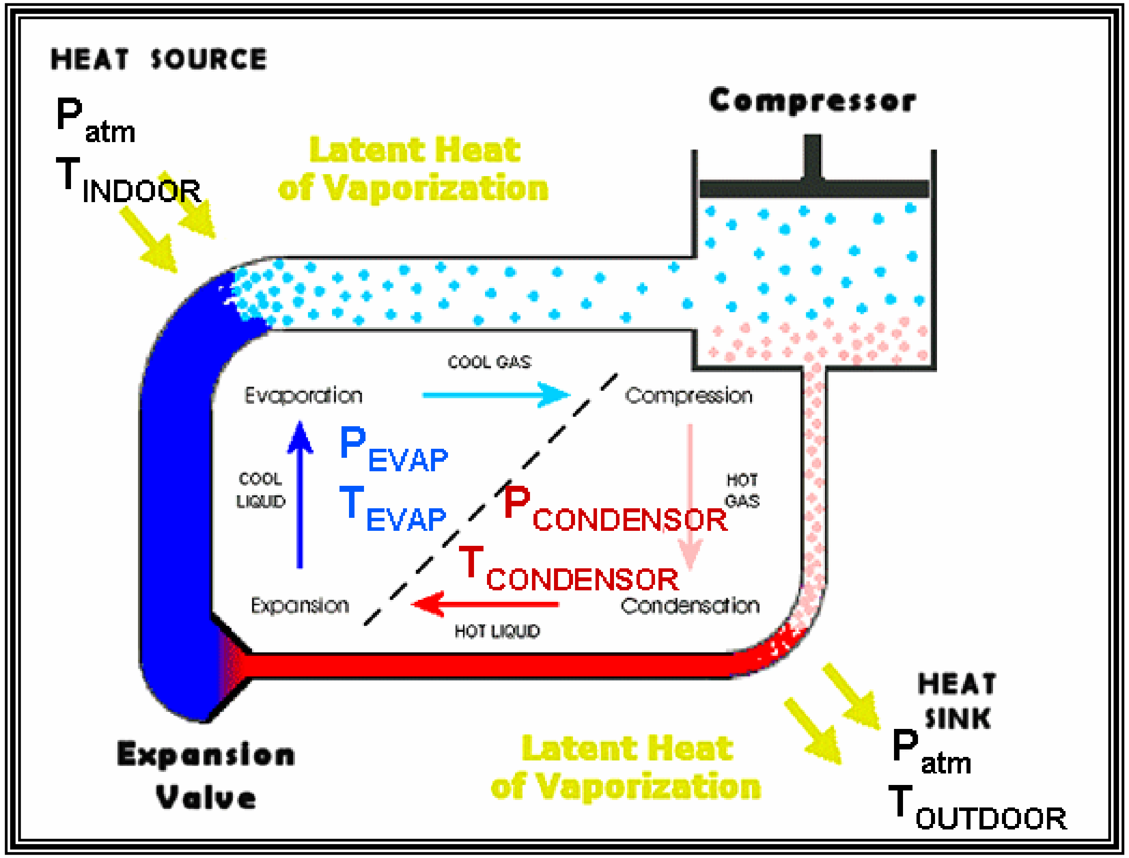
Refrigeration cycle

- ❑ Refrigeration is the transfer of heat from a lower temperature region to a higher temperature region



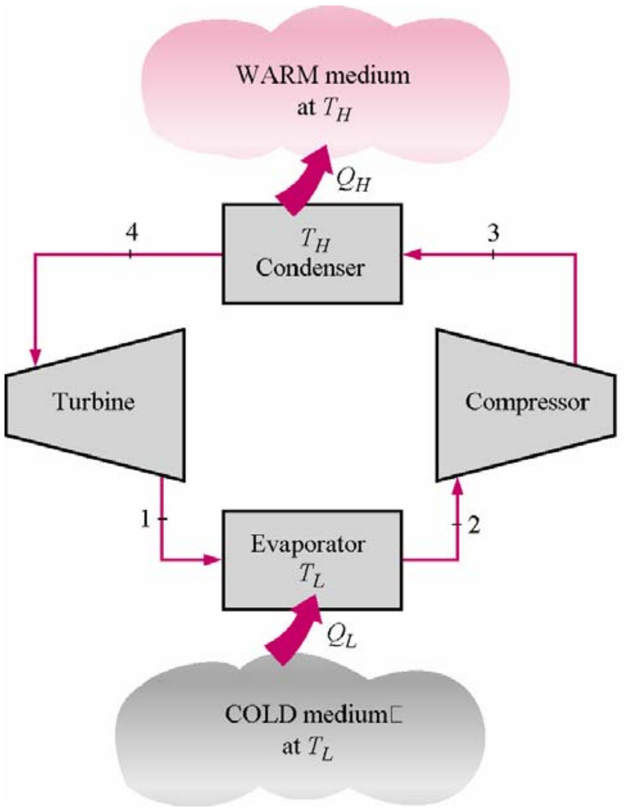
(*a*) Refrigerator

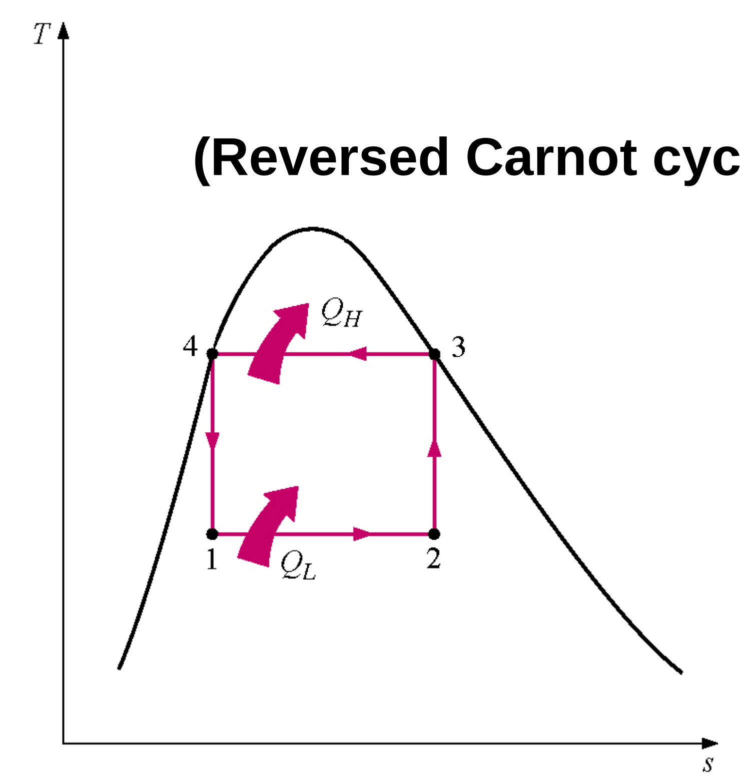
- ❑ Refrigeration cycle is the vapor-compression refrigeration cycle, where the refrigerant is vaporized and condenses alternately and is compressed in the vapor phase.



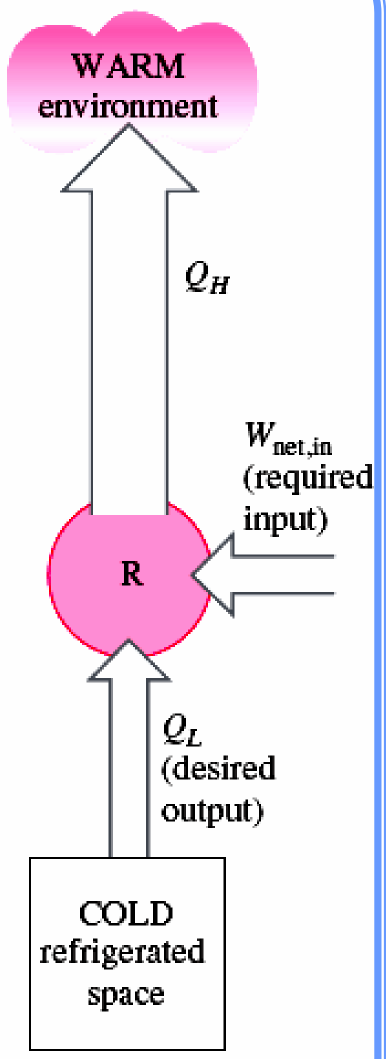
Refrigerator and Heat Pump

- Cyclic refrigeration device operating between two constant temperature reservoirs.
- In the Carnot cycle heat transfers take place at constant temperature.
- If our interest is the **cooling load**, the cycle is called the Carnot **refrigerator**.
- If our interest is the **heat load**, the cycle is called the Carnot **heat pump**.





Refrigerator & Heat pump



(a) Refrigerator

- **Coefficient of performance, COP**

$$COP = \frac{\text{Desired output}}{\text{Require input}}$$

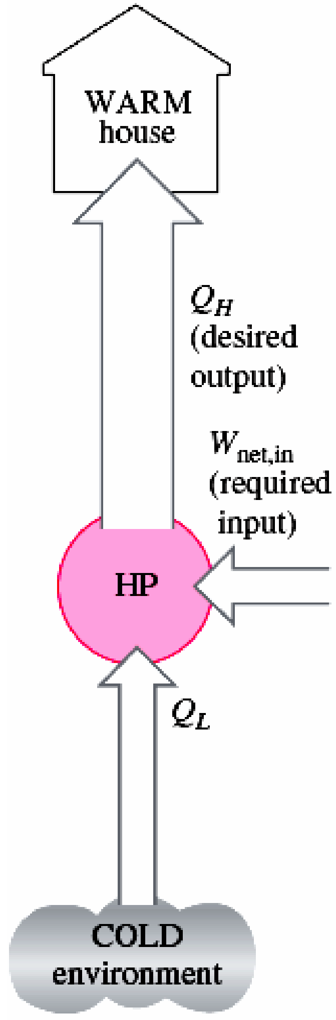
❑ **Refrigerator:** is used to maintain the refrigerated space at a low temperature by removing heat from it

$$COP_R = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

❑ **Heat pump:** heat transfers from a low-temperature medium to a high temperature medium

$$COP_{HP} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$

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



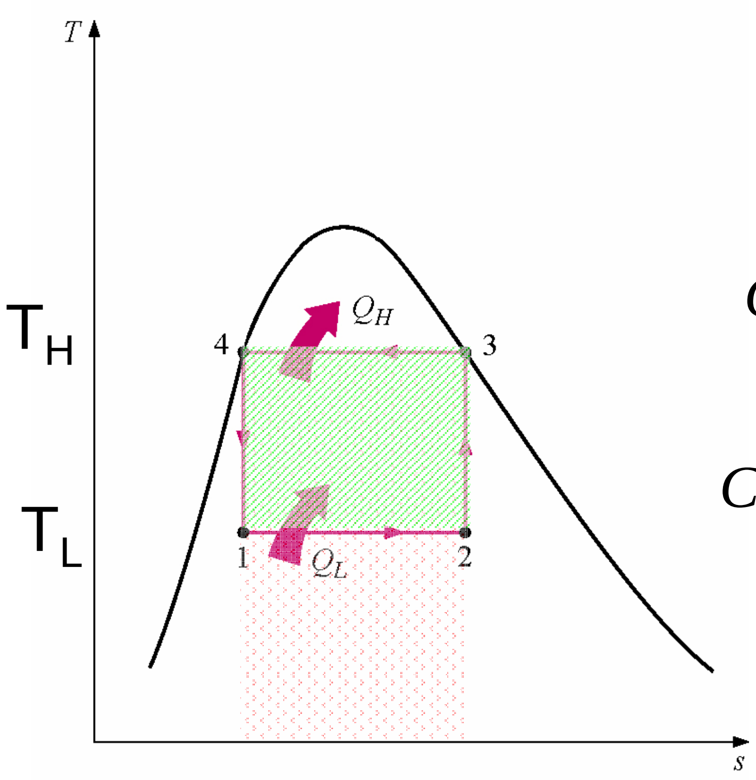
(b) Heat pump

Carnot refrigerator or a Carnot heat pump

The reversed Carnot cycle is the most efficient refrigeration cycle operating between two specified temperature levels.

A refrigerator or heat pump that operates on the reversed Carnot cycle is called a *Carnot refrigerator* or a *Carnot heat pump*

$$COP = \frac{\text{Desired output}}{\text{Require input}}$$

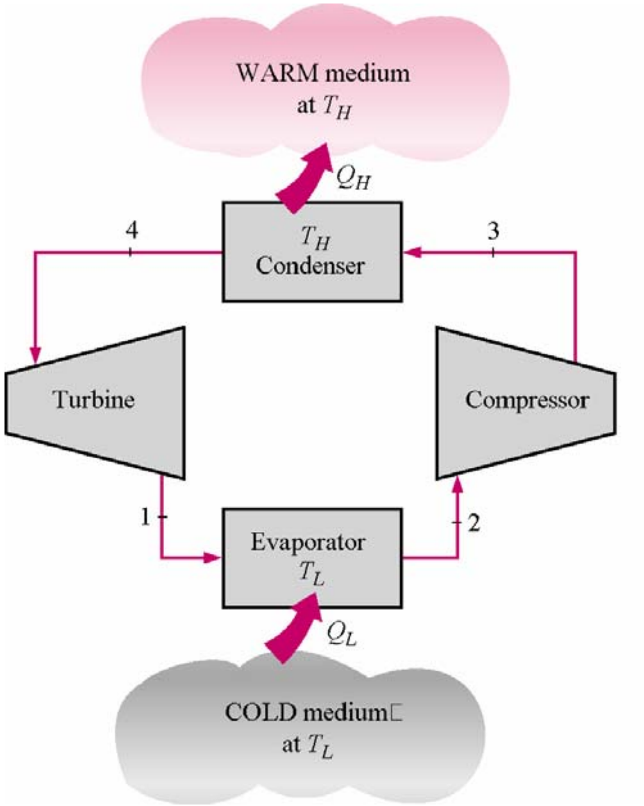


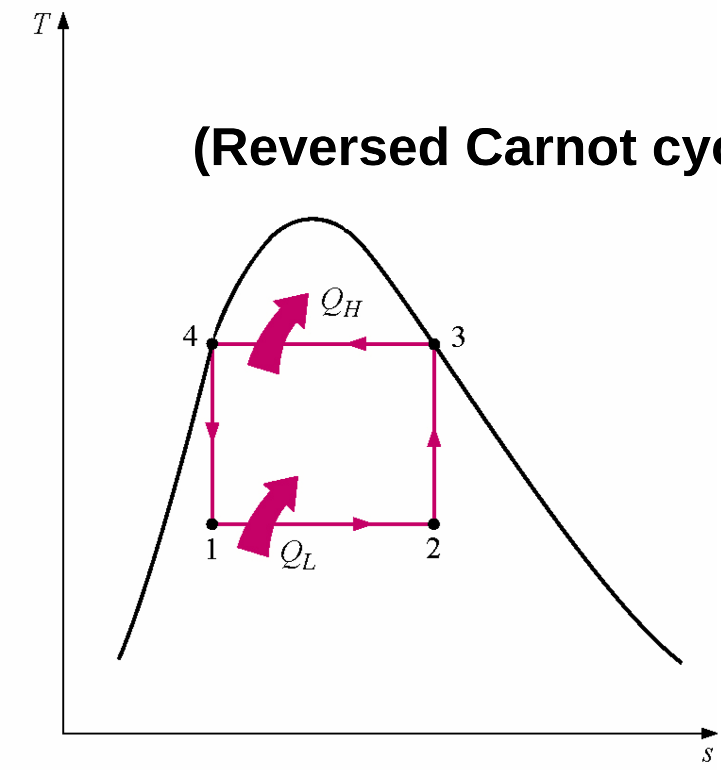
$$COP_{R,Carnot} = \frac{T_L(s_2 - s_1)}{(T_H - T_L)(s_2 - s_1)} = \frac{T_L}{T_H - T_L}$$

$$COP_{HP,Carnot} = \frac{T_H(s_2 - s_1)}{(T_H - T_L)(s_2 - s_1)} = \frac{T_H}{T_H - T_L}$$

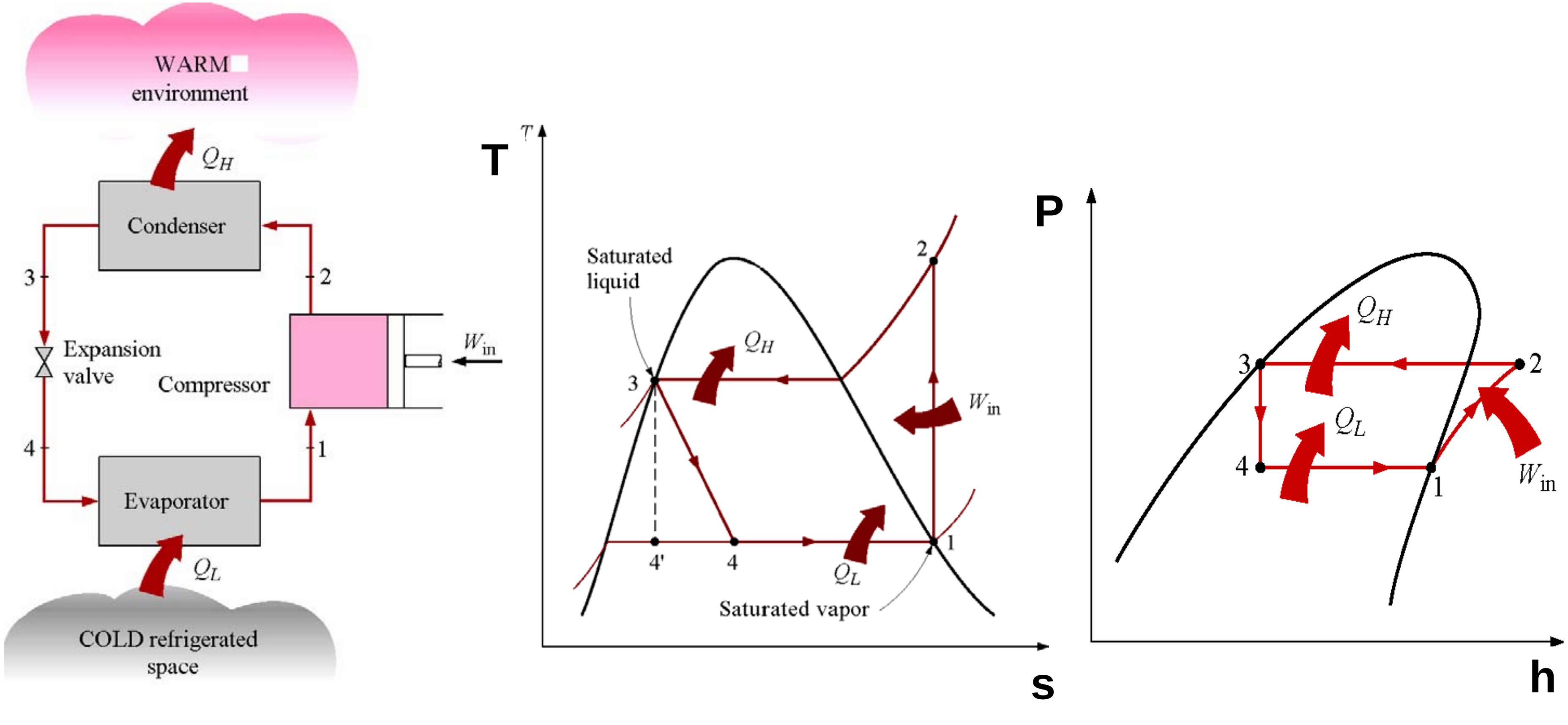
The reversed Carnot cycle is not a suitable model for refrigeration cycle!

- Process 2 – 3 involves the compression of a liquid-vapor mixture, which requires a compressor that will handle two phase.
- Process 4 – 1 involves the expansion of high-moisture-content refrigerant in a turbine.

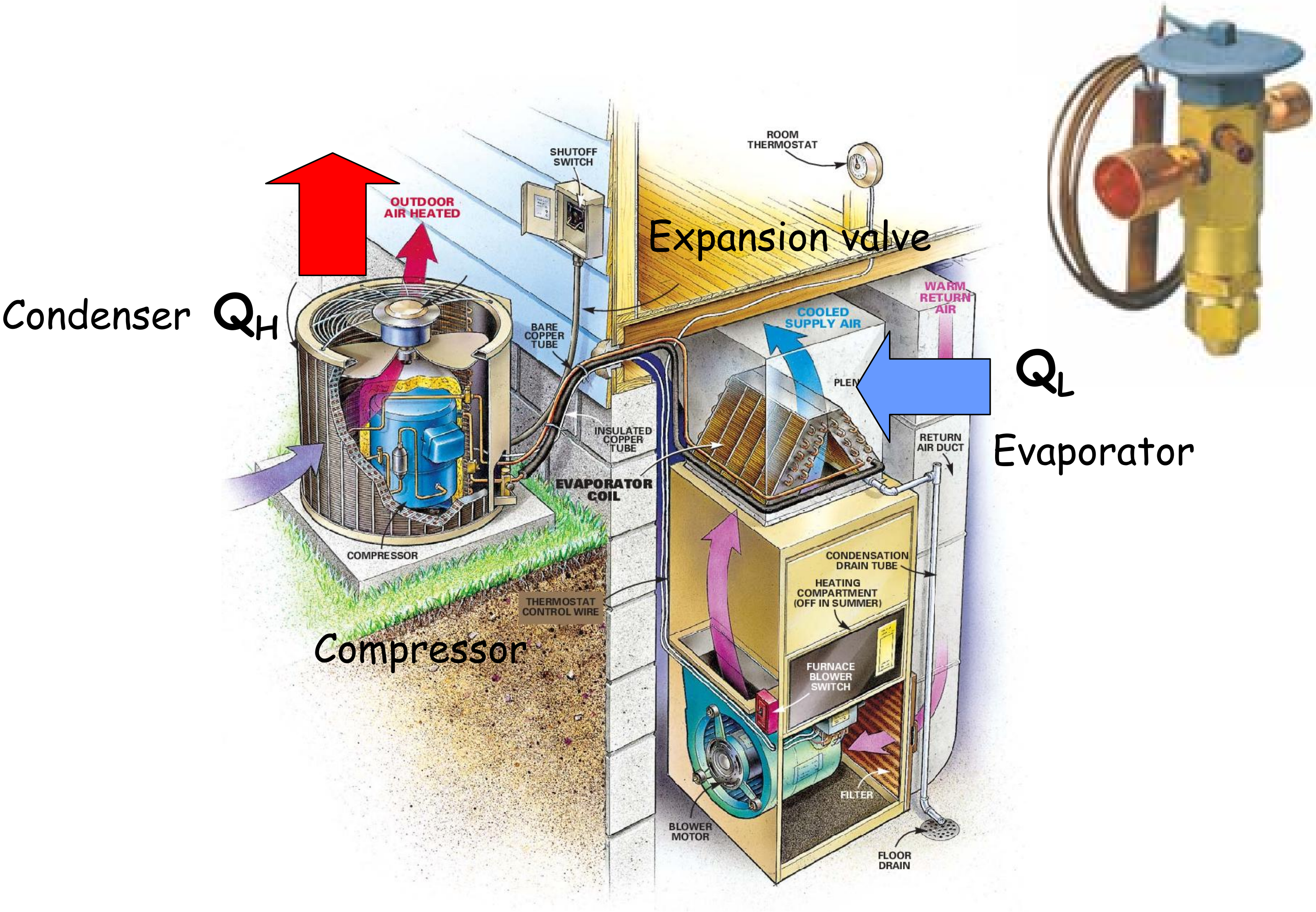




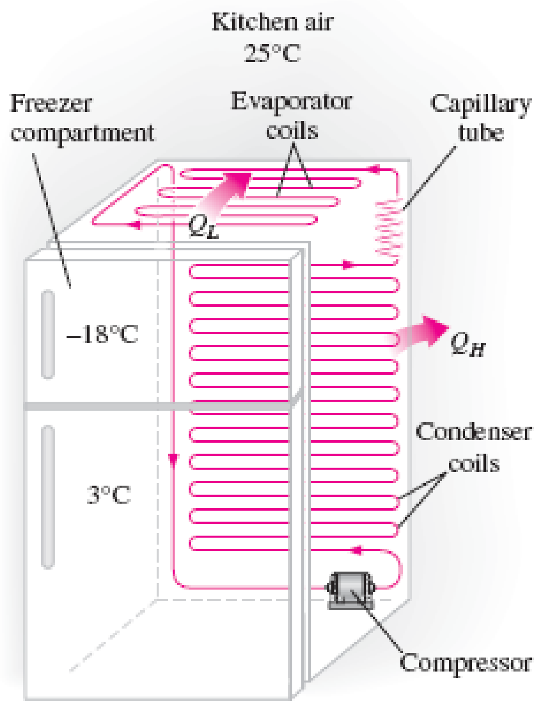
Ideal Vapor-Compression Refrigeration Cycle



Process	Description
1-2	Isentropic compression
2-3	Constant pressure heat rejection in the condenser
3-4	Throttling in an expansion valve
4-1	Constant pressure heat addition in the evaporator

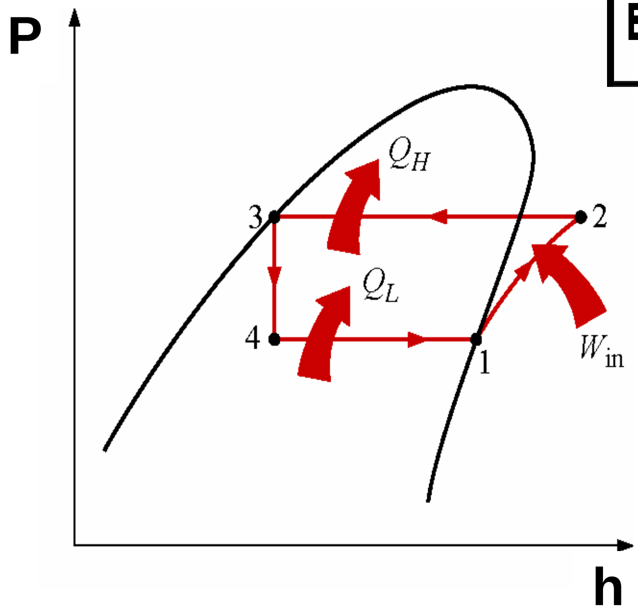

Condenser Q_H
Expansion valve
Q_L
Evaporator
Compressor
OUTDOOR AIR HEATED
SHUTOFF SWITCH
ROOM THERMOSTAT
BARE COPPER TUBE
COOLED SUPPLY AIR
WARM RETURN AIR
INSULATED COPPER TUBE
EVAPORATOR COIL
RETURN AIR DUCT
COMPRESSOR
CONDENSATION DRAIN TUBE
HEATING COMPARTMENT (OFF IN SUMMER)
THERMOSTAT CONTROL WIRE
FURNACE BLOWER SWITCH
FILTER
BLOWER MOTOR
FLOOR DRAIN

Energy analysis



From 1st and 2nd Law analysis for steady flow

Component	Process	First law results
Compressor	$s = const.$	$\dot{W}_{in} = \dot{m}(h_2 - h_1)$
Condenser	$P = const.$	$\dot{Q}_H = \dot{m}(h_2 - h_3)$
Throttle valve	$\Delta s > 0$	$h_4 = h_3$
	$\dot{W}_{net} = 0$	
	$\dot{Q}_{net} = 0$	
Evaporator	$P = const.$	$\dot{Q}_L = \dot{m}(h_1 - h_4)$



$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$$

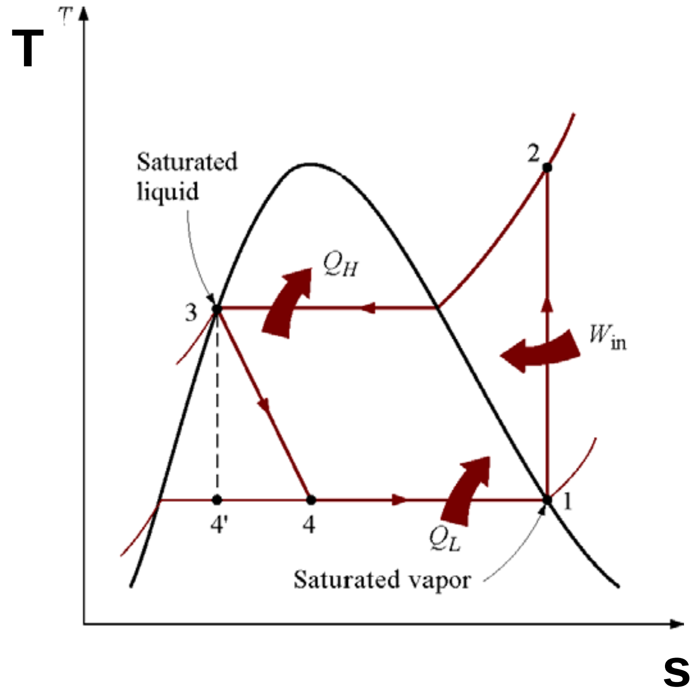
$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1}$$

Example

Refrigerant-134a is the working fluid in an ideal compression refrigeration cycle. The refrigerant leaves the evaporator at -20°C and has a condenser pressure of 0.9 MPa. The mass flow rate is 3 kg/min. Find COP_R and $COP_{R,\ Carnot}$ for the same T_{max} and T_{min}, and the tons of refrigeration.

Use the Refrigerant-134a Tables

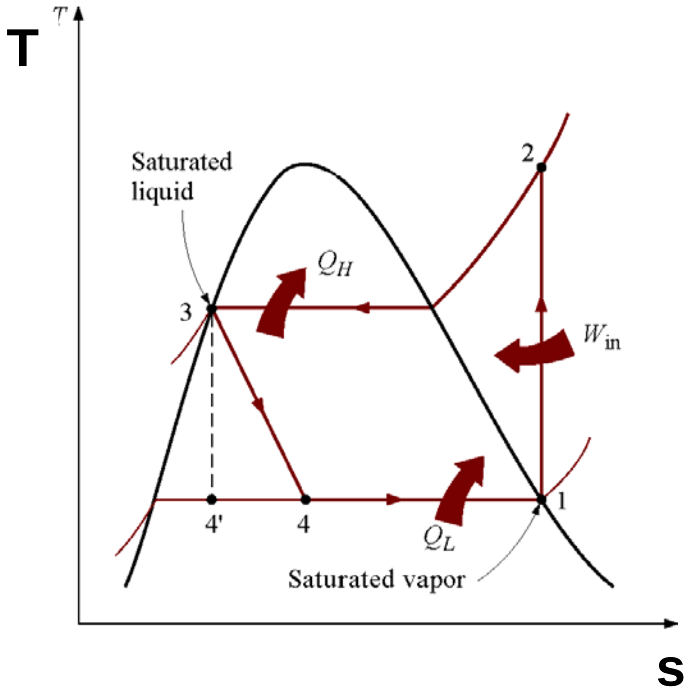
$$\left.\begin{array}{l} State\,1 \\ Compressor\ \ inlet \\ T_1 = -20^o C \\ x_1 = 1.0 \end{array}\right\} \left\{\begin{array}{l} h_1 = 238.41\dfrac{kJ}{kg} \\ s_1 = 0.9456\dfrac{kJ}{kg\cdot K} \end{array}\right.$$



$$\left.\begin{array}{l} State\,2 \\ Compressor\ exit \\ P_{2s} = P_2 = 900\,kPa \\ s_{2s} = s_1 = 0.9456\dfrac{kJ}{kg\cdot K} \end{array}\right\}\begin{cases} h_{2s} = 278.23\dfrac{kJ}{kg} \\ T_{2s} = 43.79^o C \end{cases}$$

$$\left.\begin{array}{l} State\,3 \\ Condenser\ exit \\ P_3 = 900\,kPa \\ x_3 = 0.0 \end{array}\right\}\begin{cases} h_3 = 101.61\dfrac{kJ}{kg} \\ s_3 = 0.3738\dfrac{kJ}{kg\cdot K} \end{cases}$$

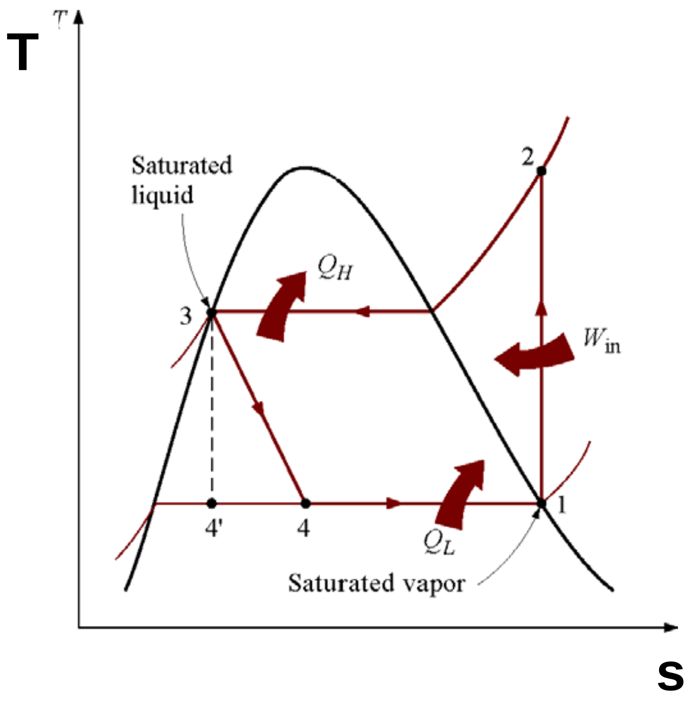
$$\left.\begin{array}{l} State\,4 \\ Throttle\ exit \\ T_4 = T_1 = -20^o C \\ h_4 = h_3 \end{array}\right\}\begin{cases} x_4 = 0.358 \\ s_4 = 0.4053\dfrac{kJ}{kg\cdot K} \end{cases}$$



$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{(238.41 - 101.61)\frac{kJ}{kg}}{(278.23 - 238.41)\frac{kJ}{kg}}$$

$$= 3.44$$



The tons of refrigeration (often called the cooling load or refrigeration effect)

$$\dot{Q}_L = \dot{m}(h_1 - h_4)$$

$$= 3\frac{kg}{\min}(238.41 - 101.61)\frac{kJ}{kg}\frac{1Ton}{211\frac{kJ}{\min}}$$

$$= 1.94 Ton$$

$$COP_{R,\,Carnot} = \frac{T_L}{T_H - T_L}$$

$$= \frac{(-20+273)\,K}{(43.79-(-20))\,K}$$

$$= 3.97$$

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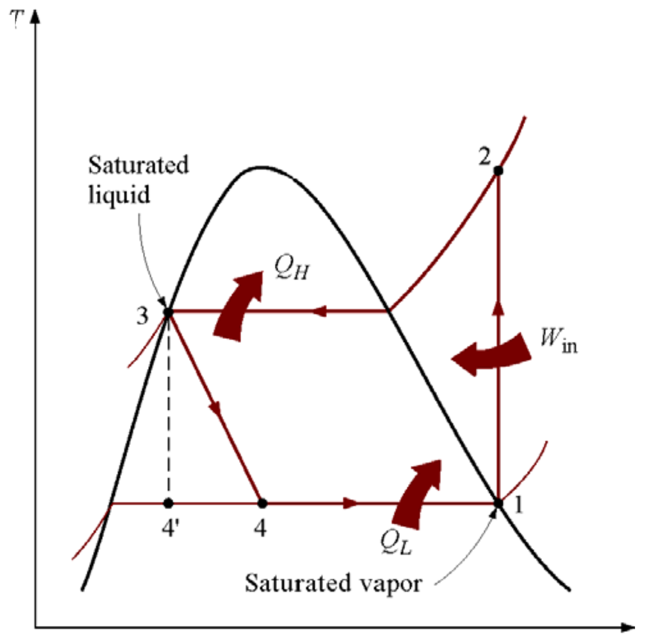

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Another measure of the effectiveness of the refrigeration cycle is how much input power to the compressor, in horsepower, is required for each ton of cooling.

<u>The unit conversion is 4.715 hp per ton of cooling.</u>

$$\frac{\dot{W}_{net,\,in}}{\dot{Q}_L} = \frac{4.715}{COP_R} = \frac{4.715}{3.44}\frac{hp}{Ton} = 1.37\frac{hp}{Ton}$$