Refrigeration Cycles

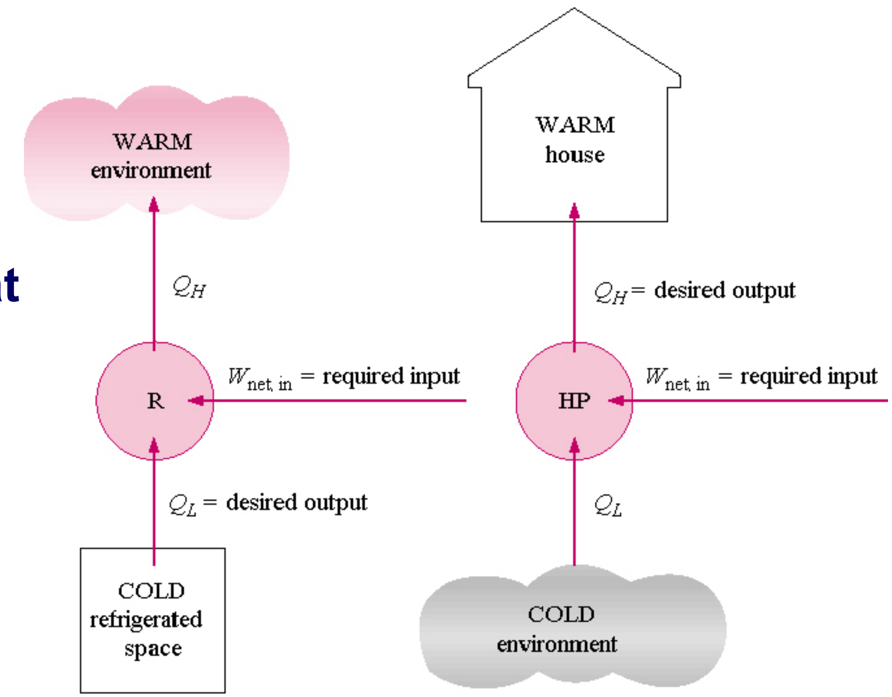
8–14 Refrigerators and Heat Pumps

Refrigerators and heat pumps are essentially the same devices; they differ in their *objectives* only.

$$COP_R = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}}$$

The objective of a refrigerator **is to maintain the refrigerated space at a low temperature by removing heat from it. Discharging this heat to a higher-temperature medium is merely a necessary part of the operation, not the purpose.**



(*a*) Refrigerator (*b*) Heat pump

The objective of a heat pump **is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low-temperature source, such as well water or cold outside air in winter, and supplying this heat to a warmer medium such as a house.**

Cooling capacity of Refrigeration system

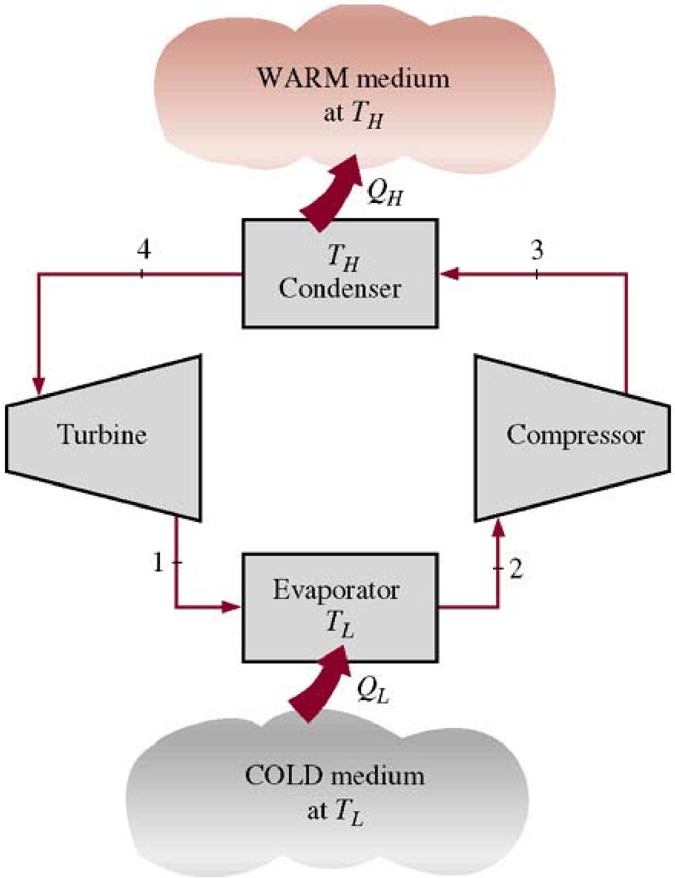
- Cooling capacity of a refrigeration system is often expressed in terms of *tons of refrigeration*, or *RT*.

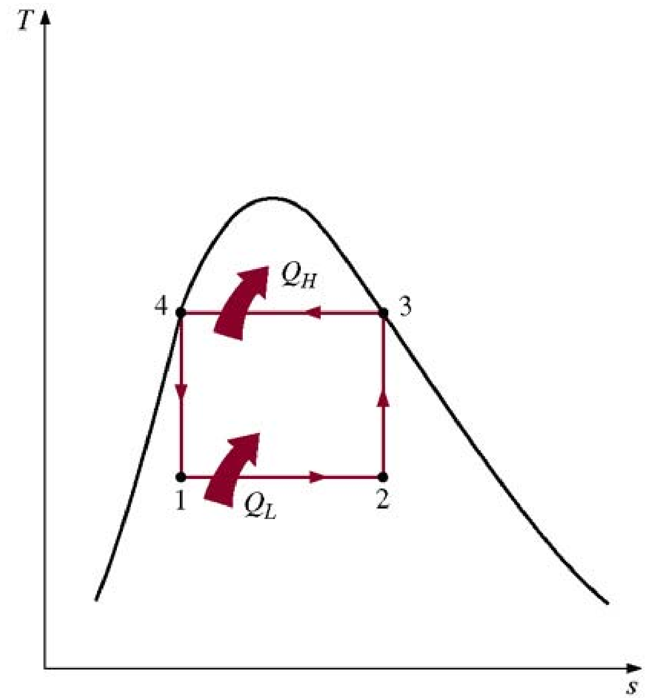
- That is, the capacity of refrigeration system that can freeze 1 ton of liquid water at 0 ^{o}C into ice at 0^{o}C in 24 h is said to be 1 RT).

- **One Ton of refrigeration equals 211 KJ/min**

8−15 The Reversed Carnot Cycle

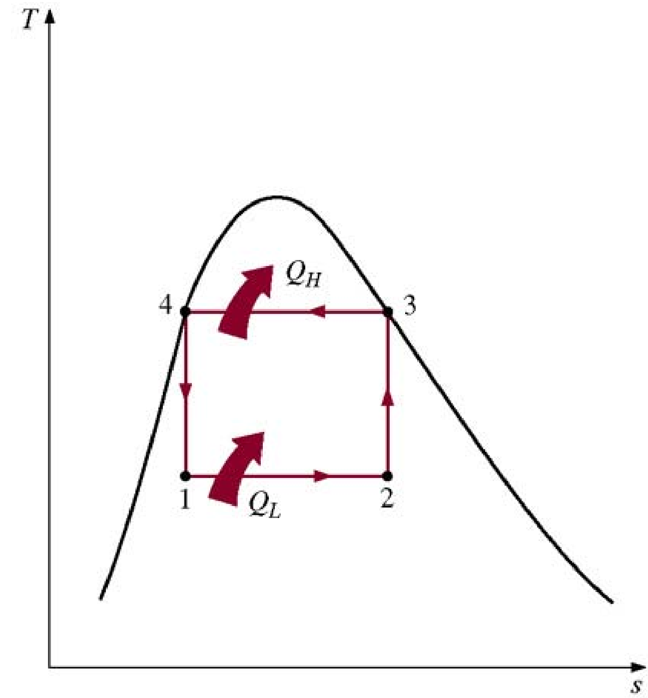
A refrigerator or heat pump that operates on the reversed Carnot cycle is called a Carnot refrigerator or a Carnot heat pump as shown in the figure below.





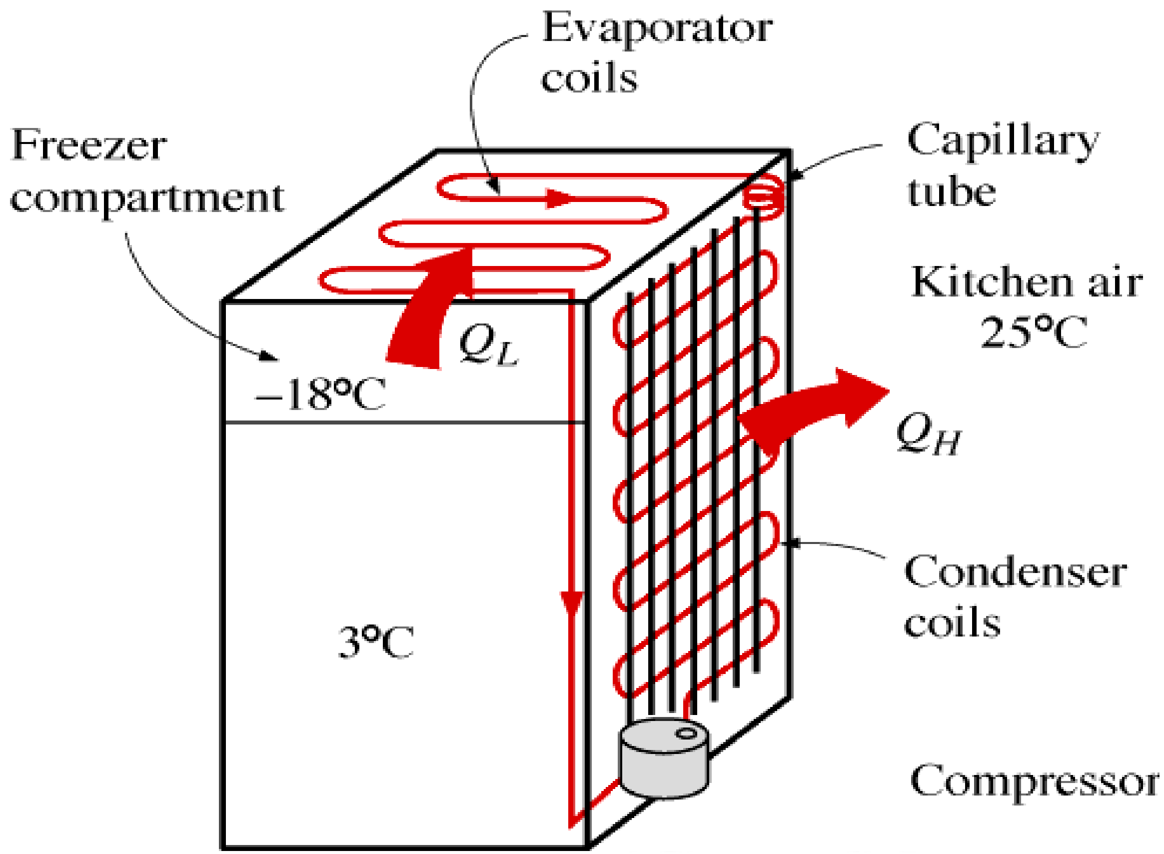
Is the Reversed Carnot Cycle a realistic model for refrigeration cycles? The answer is No. Then Why?

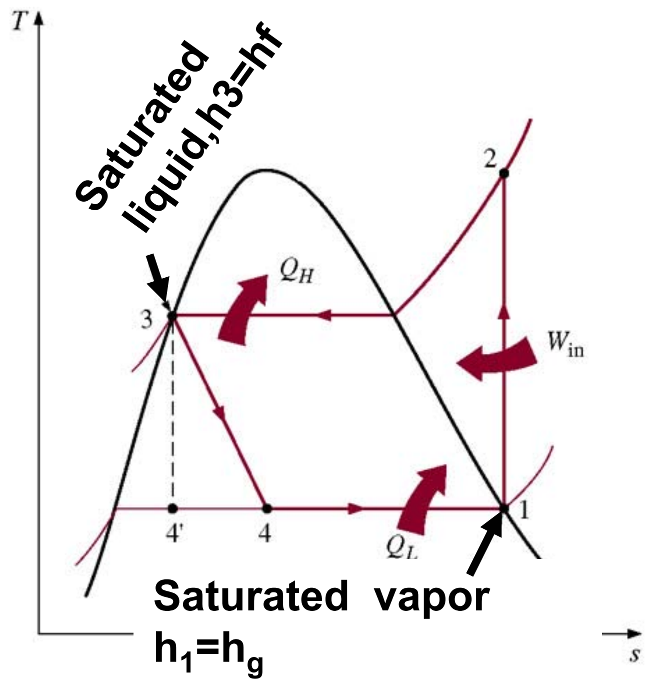
- The two isothermal heat transfer are not difficult to achieve in practice since maintaining a constant pressure automatically fixes the temperature of a two-phase mixture at the saturation value.
- On the other hand, compression of liquid-vapor mixture, and expansion of high-moisture-content refrigerant cannot be approximated closely in practice.
- The reversed Carnot cycle can serve as a standard against which actual refrigeration cycles are compared.



The Ideal Vapor-Compression Refrigeration Cycle

1→2: Isentropic compression in a compressor
2→3: Constant pressure heat rejection in a condenser
3→4: Throttling in an expansion device (why NOT 3→4'?)
4→1: Constant pressure heat absorption in an evaporator





State 2: P2 and s2 => superheated vapor =>interpolate and get h2

State 4: h4=h3 (throttling process)

How to improve the COP a Refrigerator?

$$COP_{R,Carnot} = \frac{Q_L}{W} = \frac{1}{T_H / T_L - 1}$$

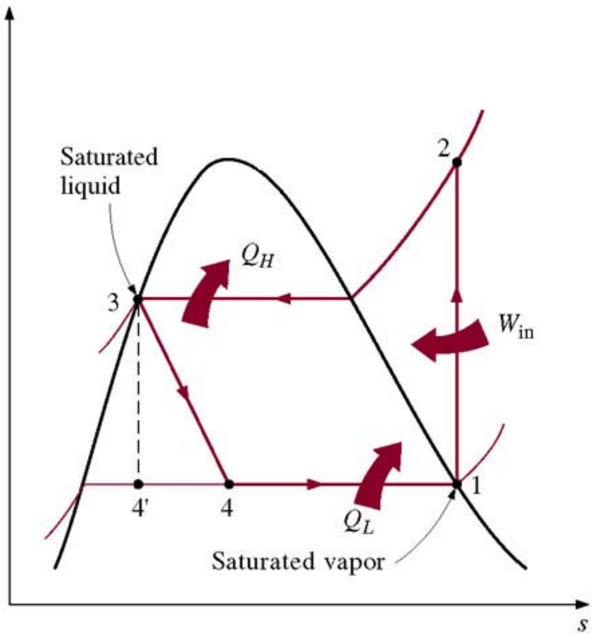
To increase the COP_R, . I need to either:

(1) Increase Q_L. ➔ Increase T_L.

But you have a limit. If TL is -30C, then you can not increase more than -24 C for example. This is because, the food in the freezer should be kept at -18 C and you have to leave 5 to 8 C temperature difference for heat transfer to occur within the freezer.

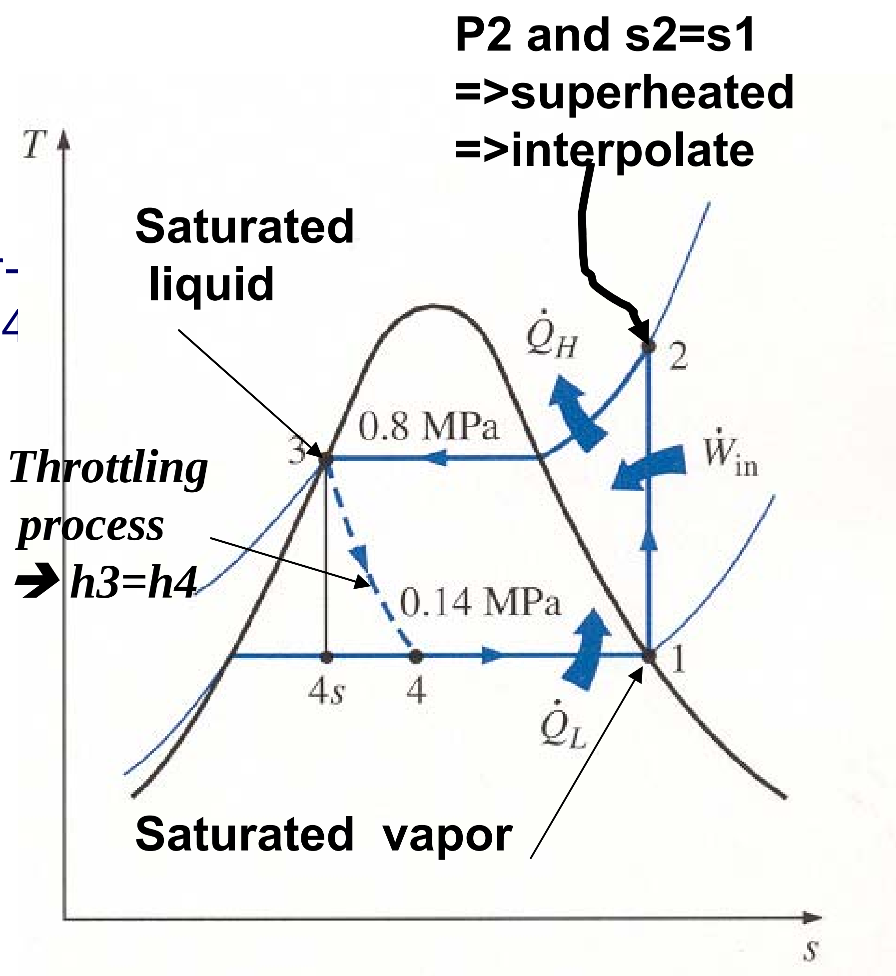
(2) Decrease W. =>decreasing T_H.

That is why a refrigerator performance decreases when the room temperature gets hot. Suppose you decreased Th to 30 C and the room temp increased to 27 C, then condensation process becomes inefficient.



Example: *The Ideal Vapor-Compression Refrigeration Cycle*

A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.14 and 0.8 MPa. If the mass flow rate of the refrigerant is 0.05 kg/s, determine



a) the rate of heat removal from the refrigerated space

$$\dot{Q}_L = \dot{m}q_L = \dot{m}(h_1 - h_4) = 7.13\,kW$$

b) The power input to the compressor,

$$\dot{W}_{in} = \dot{m}w = \dot{m}(h_2 - h_1) = 1.80\ kW$$

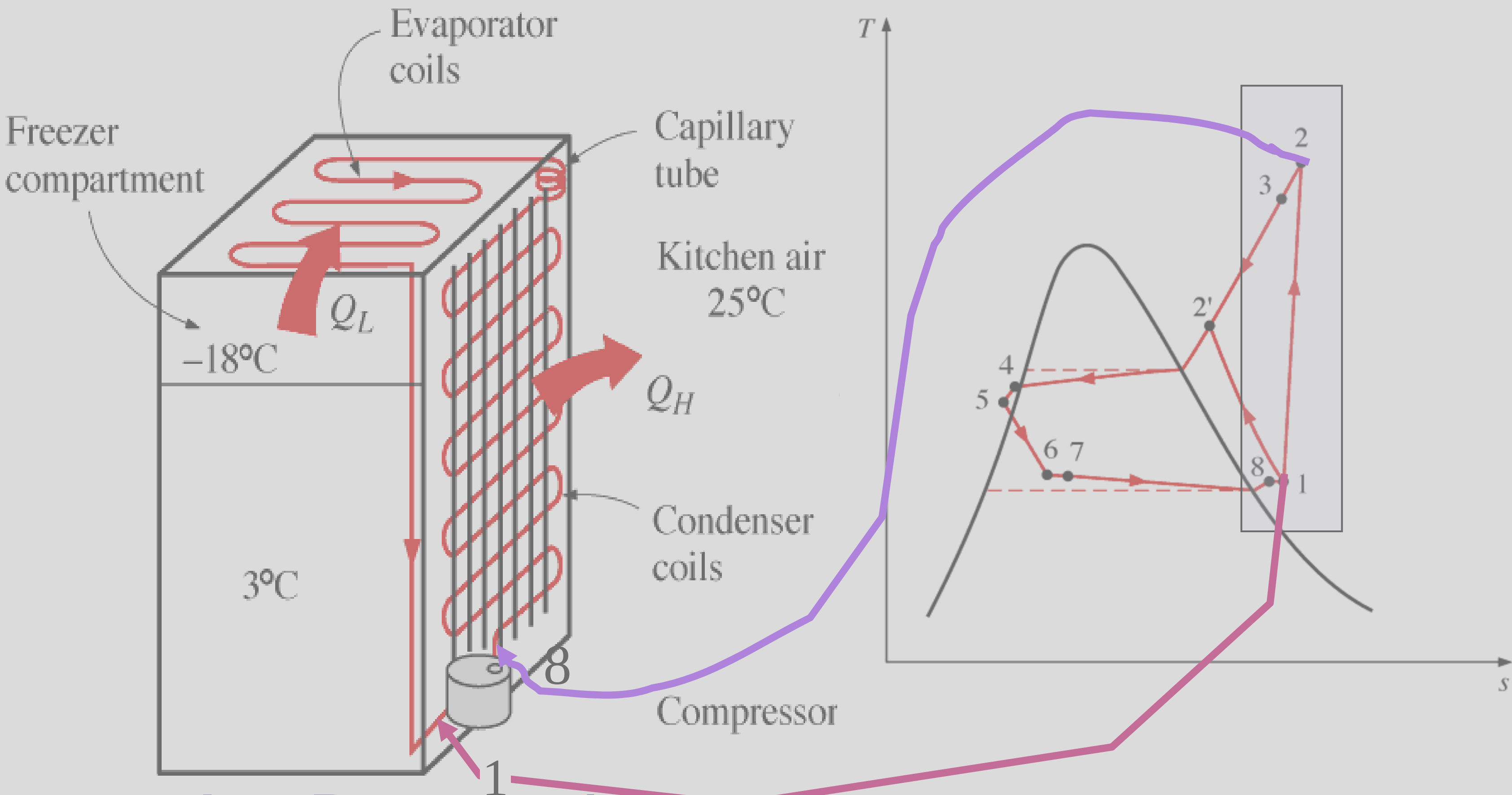
b) the rate of heat rejection to the environment, and

$$\dot{Q}_H = \dot{m}q_H = \dot{m}(h_2 - h_3) = 8.93kW$$

c) the COP of the refrigerator.

$$COP_R = \dot{Q}_L / \dot{W}_{in} = 7.13kW / 1.80kW = 3.96$$

Actual Vapor-Compression Refrigeration Cycles

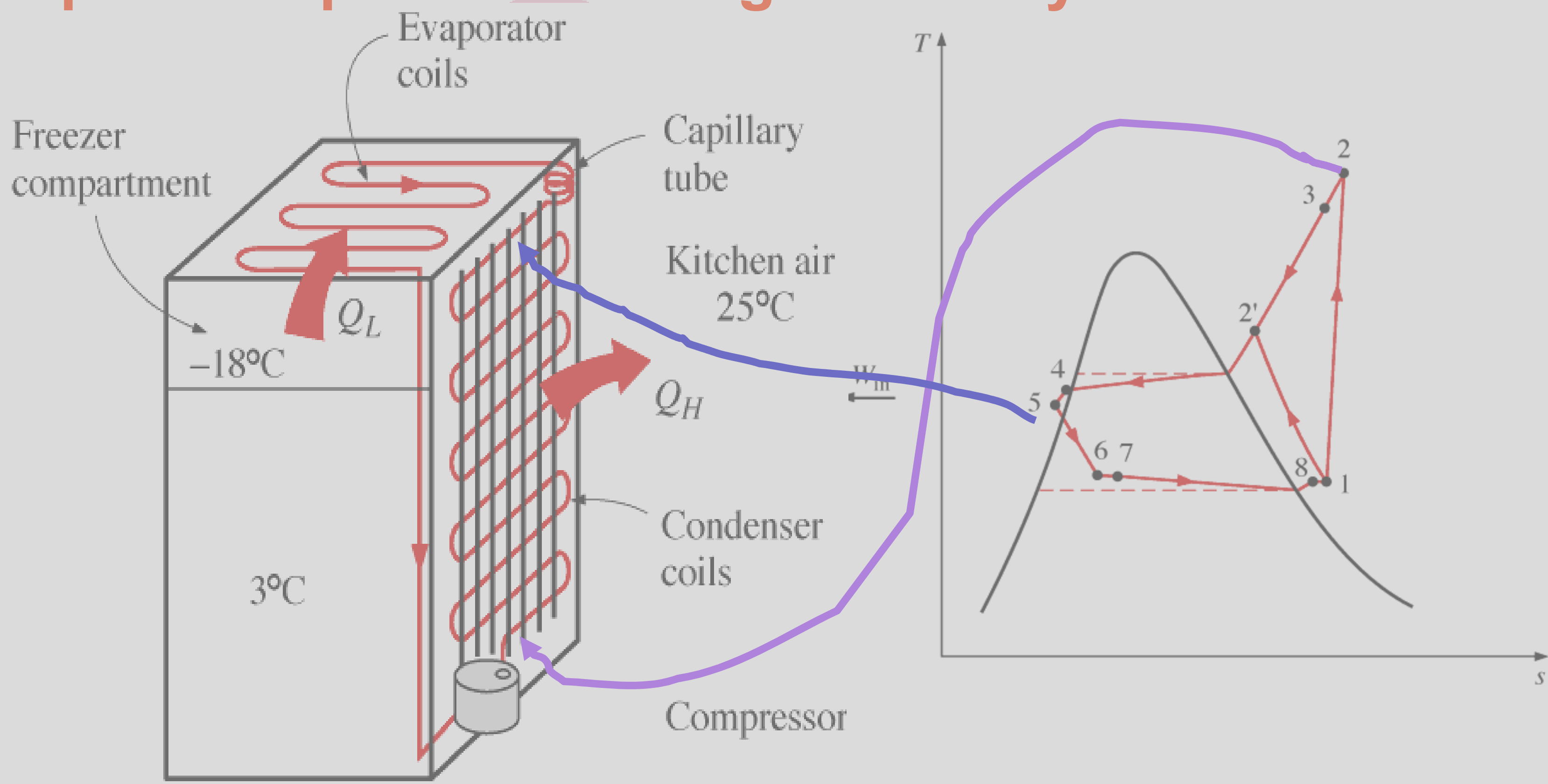


Compression Process 1-2

Ideally, the compression process follows the vertical line 1-3. But, entropy increases due to friction and thus the process deviates to (1-2).

However, if we cool the refrigerant, the entropy will decrease and the process becomes(1-2’). This is better because it reduces the compressor work.

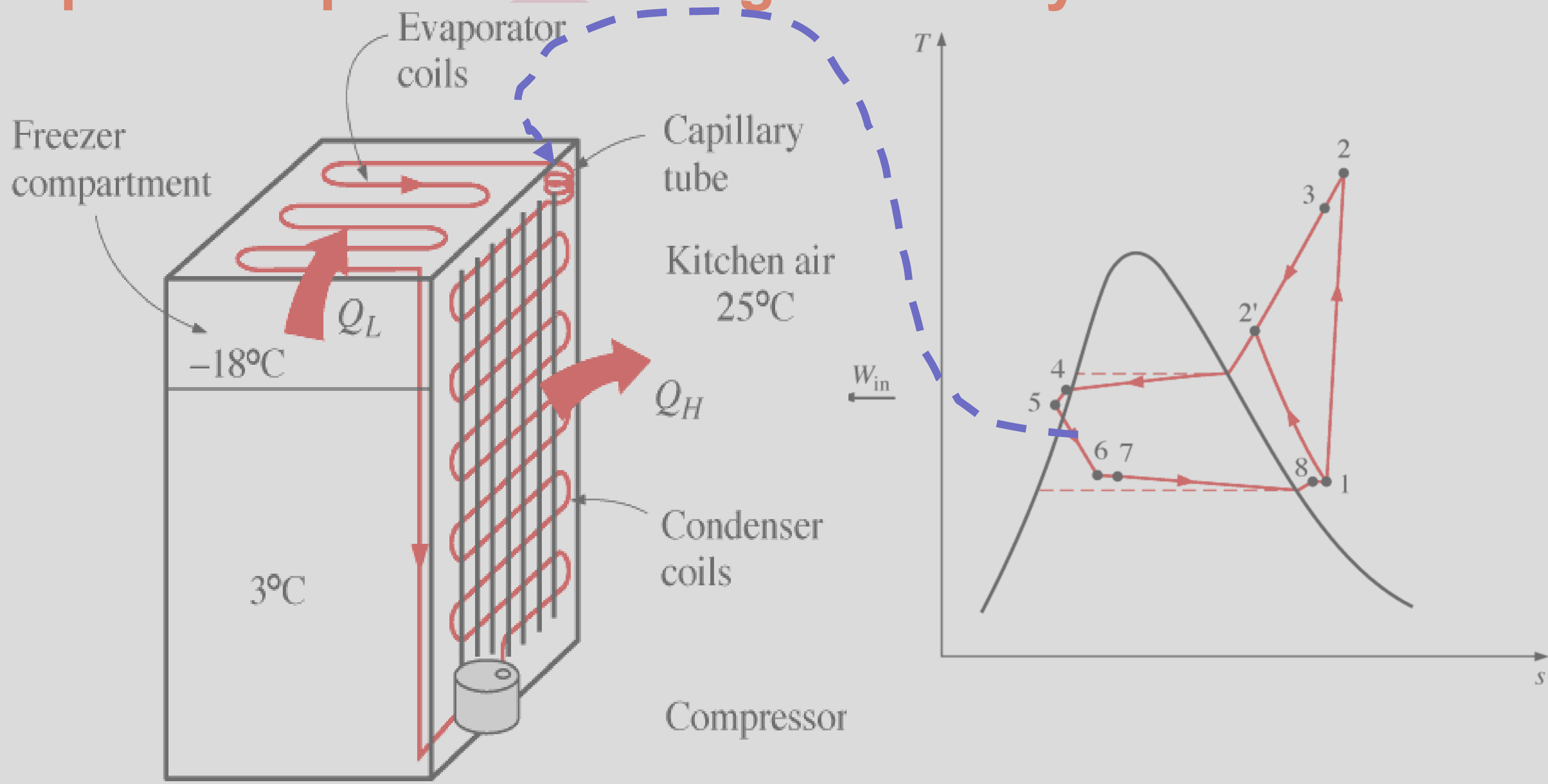
Actual Vapor-Compression Refrigeration Cycles



Condensation Process 2- 4-5

Ideally, the refrigerant leaves the condenser at saturated liquid. Note the following. (1) there will be a pressure drop in the long condenser tube (2-4) and in the fitting connecting the condenser to the throttling valve (4-5)
(2) The condensation process depends on the kitchen temperature. (3) From design point of view, it is difficult to have the refrigerant exiting exactly as sat. liquid. Thus, we design the condenser such that the refrigerant exits completely as subcooled liquid which is favorable.

Actual Vapor-Compression Refrigeration Cycles



Throttling Process 5-6-7

The throttling processes represented by line 5-6. A throttling valve reduces the fluid pressure from P5 to P6 but the enthalpy remains the same (h5=6). A small pressure drop (P6 to P7) occurs in the fitting connecting the capillary tube (throttling device) to the evaporator.

Example:

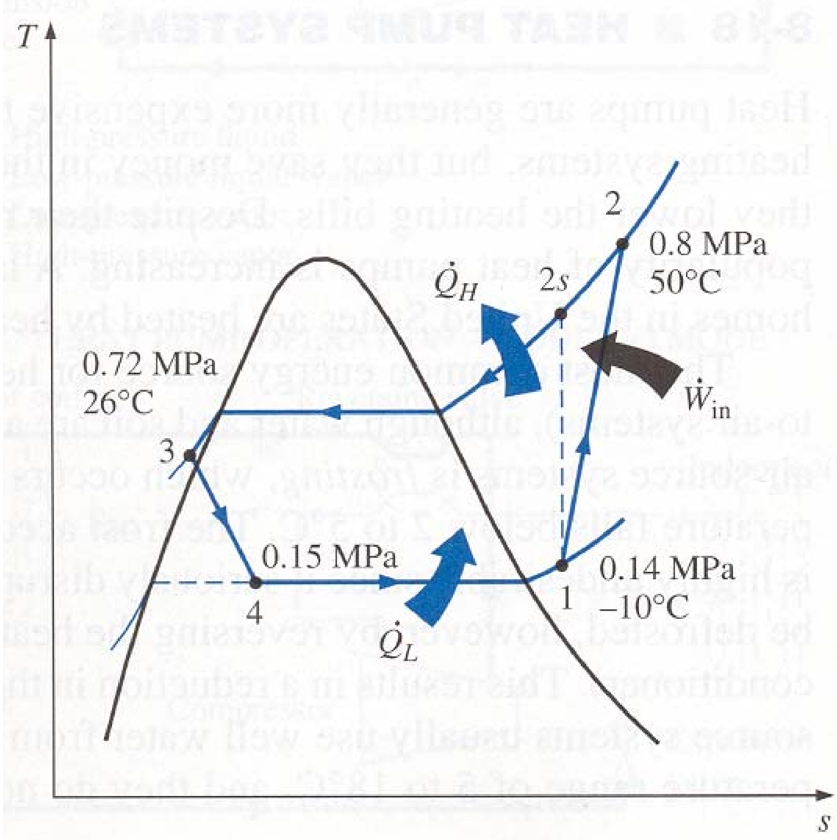
The Actual Vapor-Compression Refrigeration Cycle

Refrigerant-134a enters the compressor of a refrigerator as superheated vapor at 0.14 MPa and -10°C at a rate of 0.05 kg/s and leaves at 0.8 MPa and 50°C. The refrigerant is cooled in the condenser to 26°C and 0.72 MPa and is throttled to 0.15 MPa. Disregarding any heat transfer and pressure drops in the connecting lines between the components, determine

a) the rate of heat removal from the refrigerated space and the power input to the compressor,

b) the adiabatic efficiency of the compressor, and

c) the COP of the refrigerator.



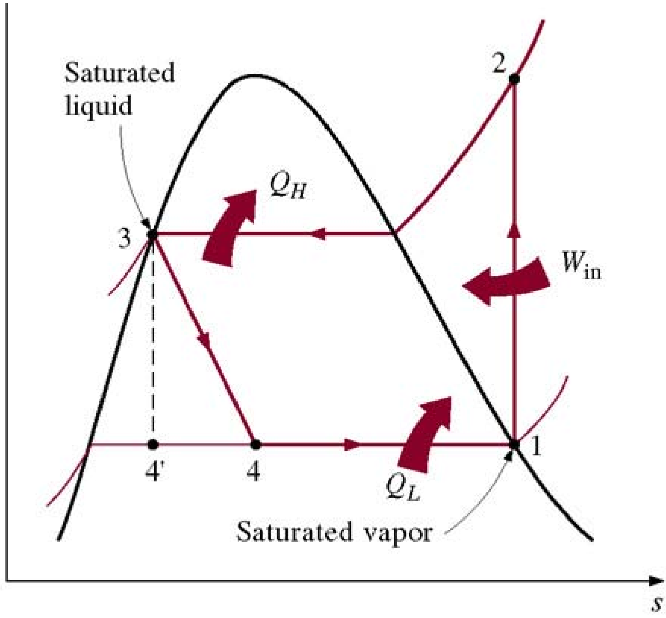
Heat Pump Systems

Introduction

Read pp 575-576

How to improve the COP of a Heat Pump?

$$COP_{HP,Carnot} = \frac{Q_H}{W} = \frac{1}{1 - T_L / T_H}$$

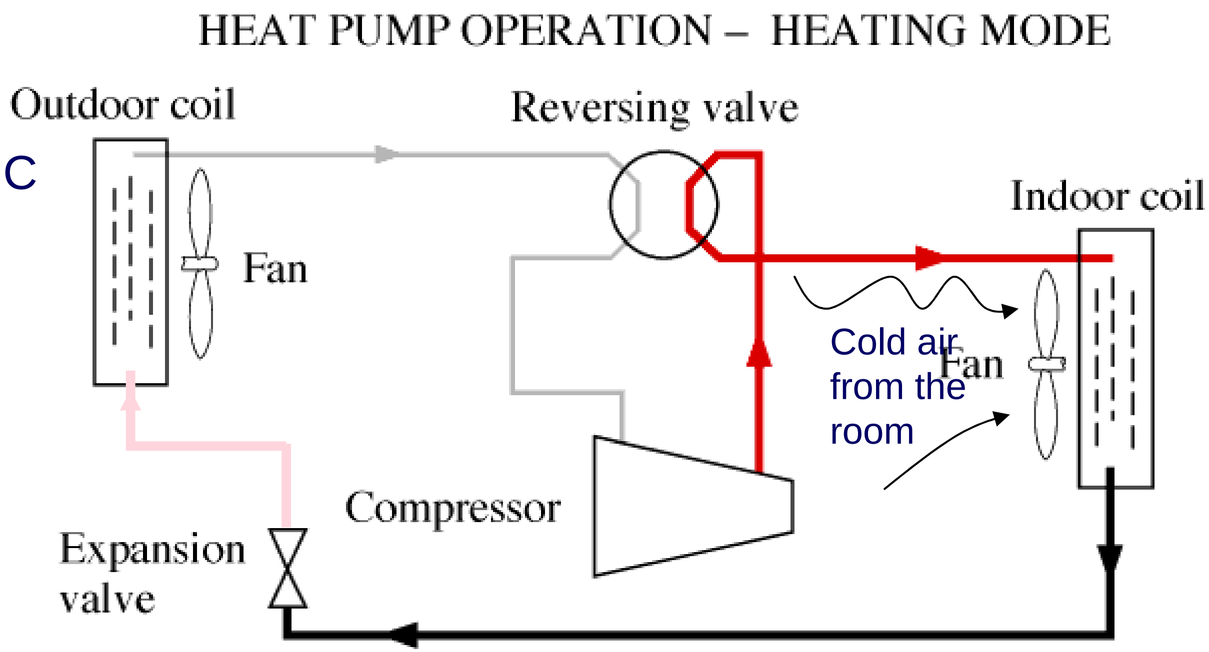


(1) Although increasing Q_H (and thus T_H) seems to increase the COP but the Carnot form of the COP indicates clearly the opposite. **Infact, decreasing Th will increase TL/TH, decrease the denominator and thus increase COP. (Similar result to the refrigerator).**

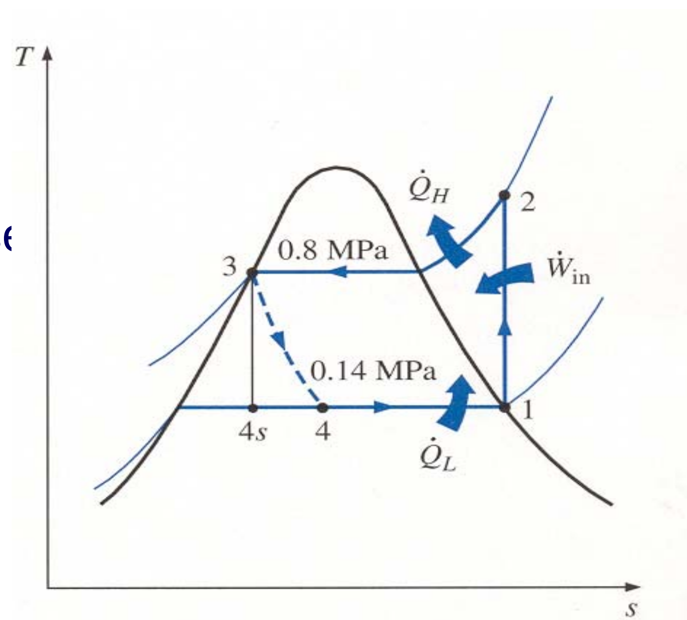
(2) Decrease W. **This is done by increasing T_L**. That is why a heat pump performance decreases when the environment temperature decreases considerably. (also frost problem on the evaporator coils)

How your AC unit works as heat pump

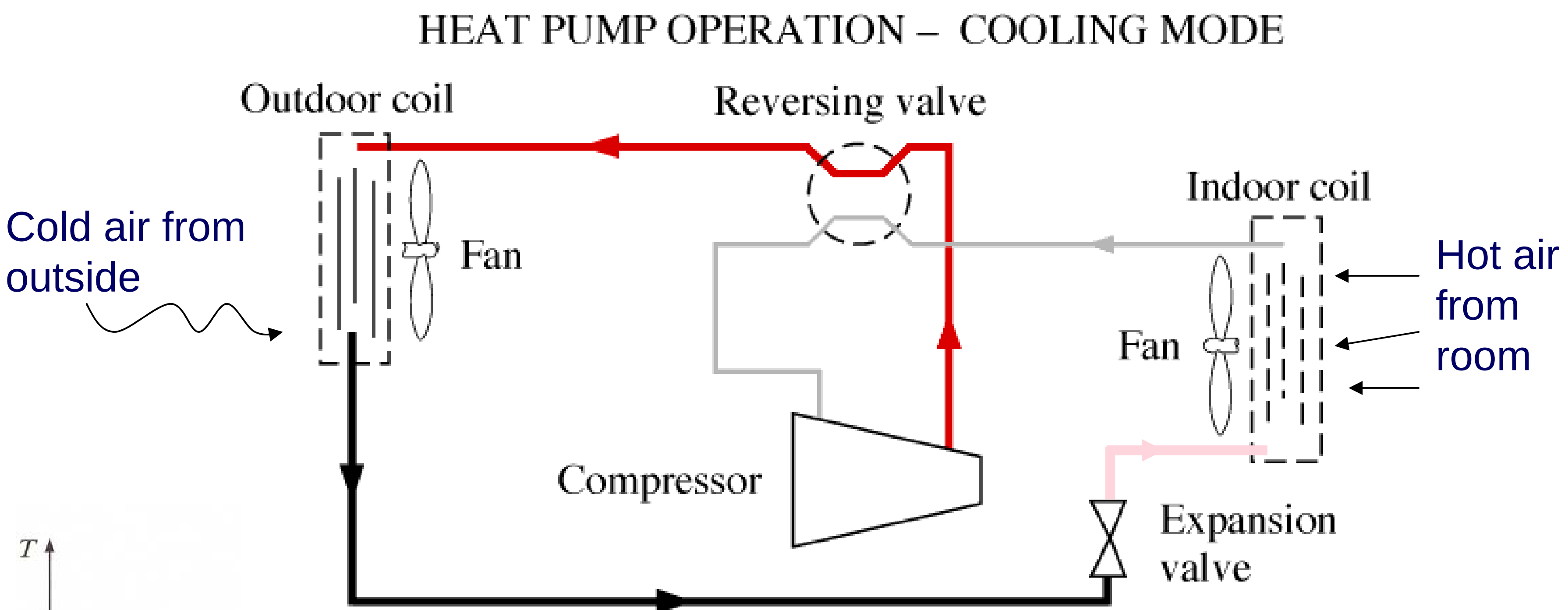
Out door is at -5 C but refrigerant is at – 30 C.

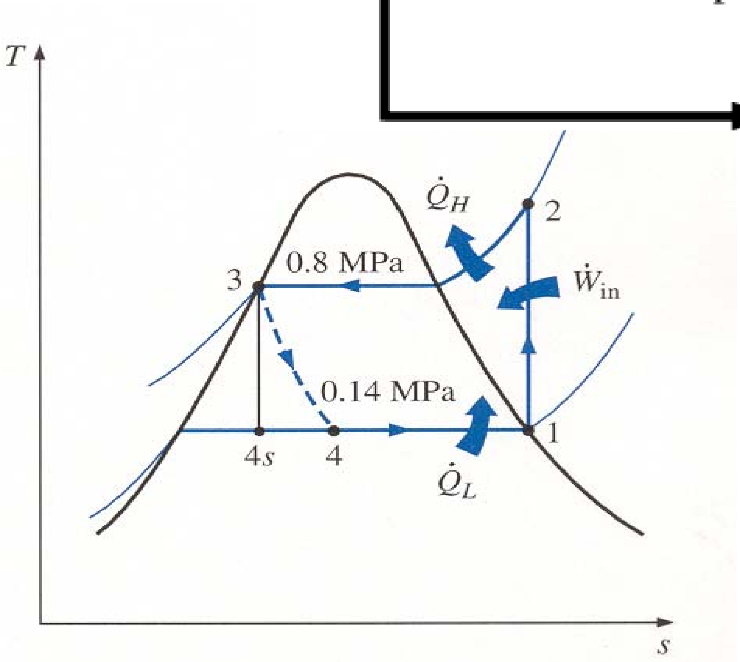


Heat pump heats a house in winter and cools it in summer.



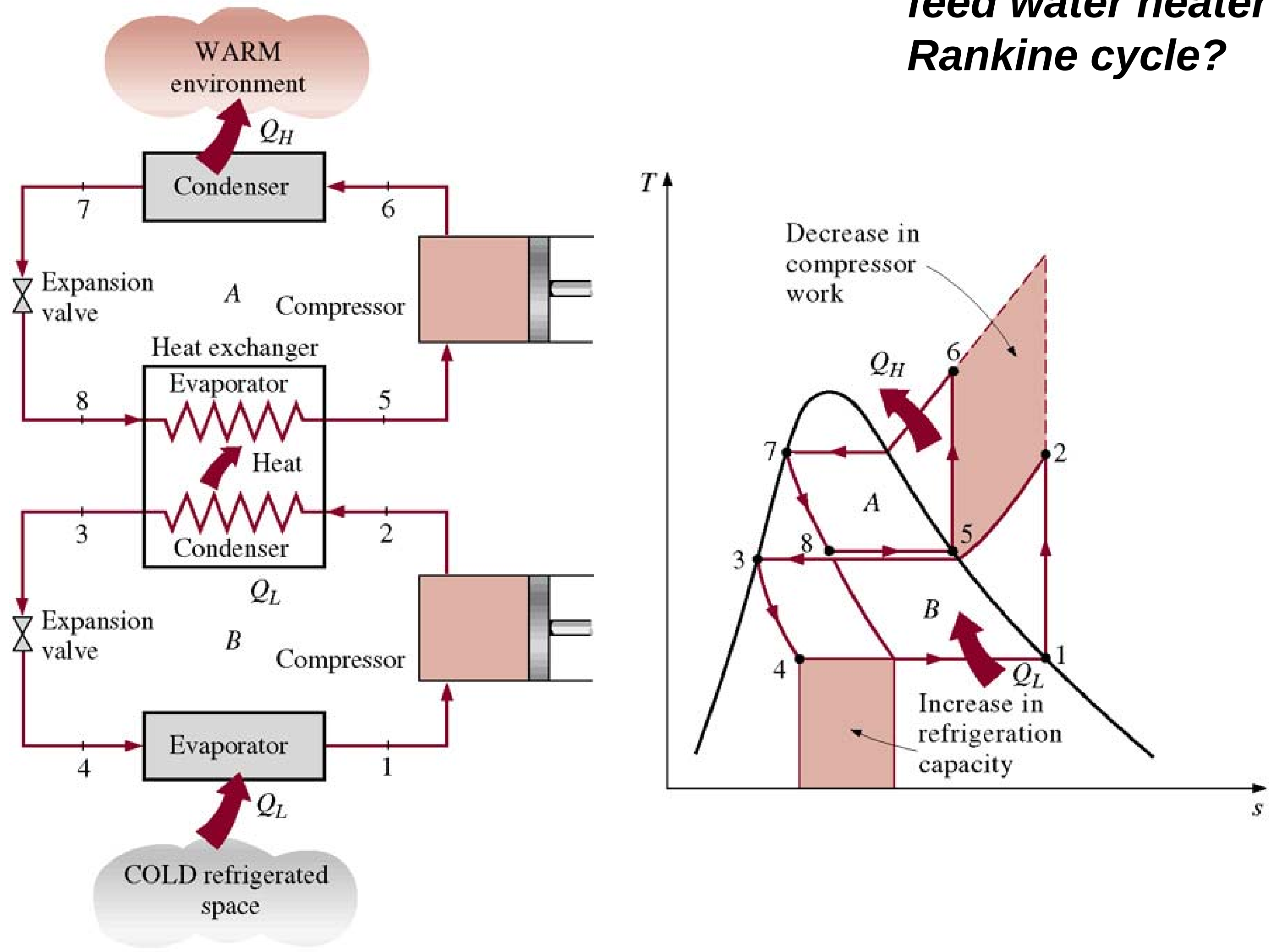
How your AC unit works as Refrigerator





Innovative refrigeration systems: Cascade refrigeration system (regeneration)

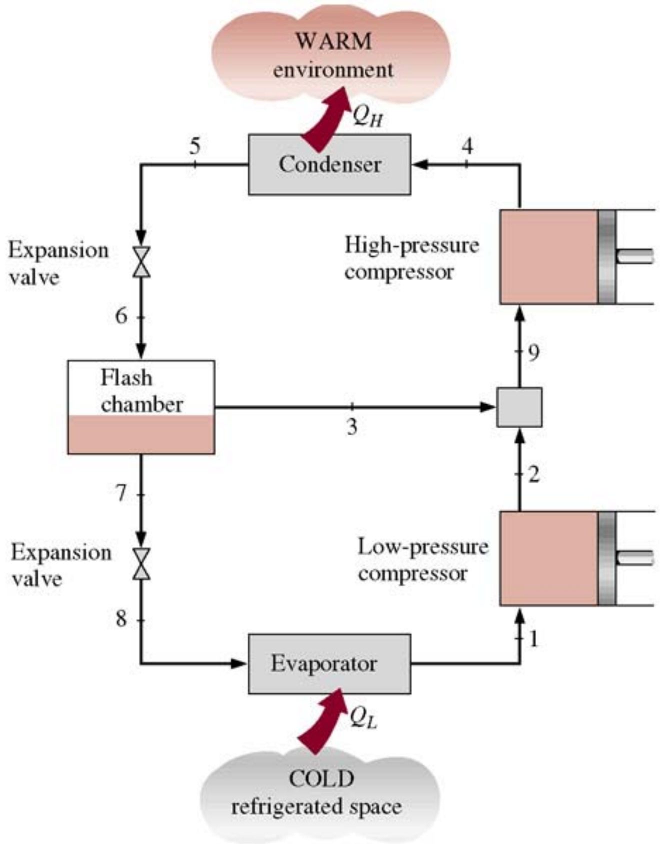
Compare it with closed feed water heater in Rankine cycle?

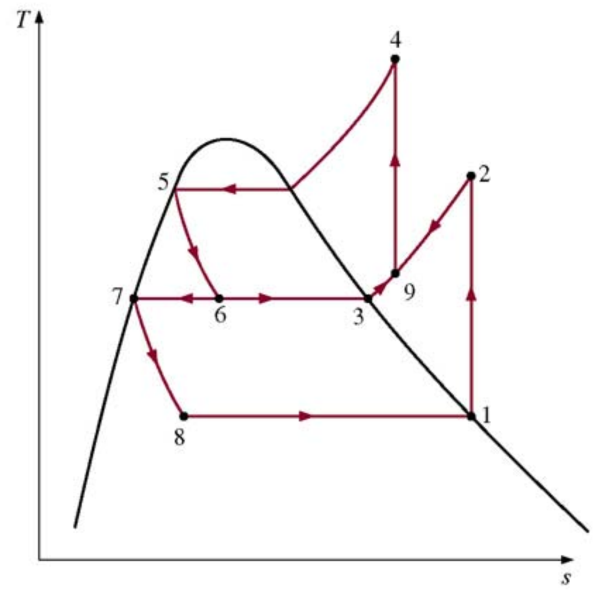


A two-stage cascade refrigeration system with the same refrigerant in both stages. SOLVE EXAMPLE 10-3

Multistage compression refrigeration system with regenerative cooling

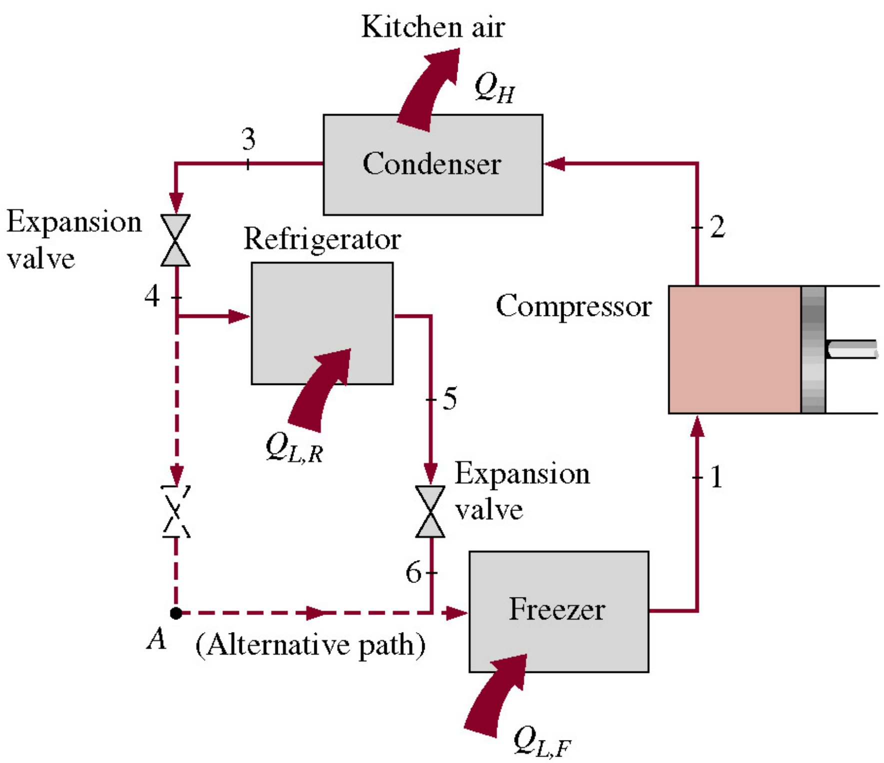
Compare it with intecooling in gas turbine?

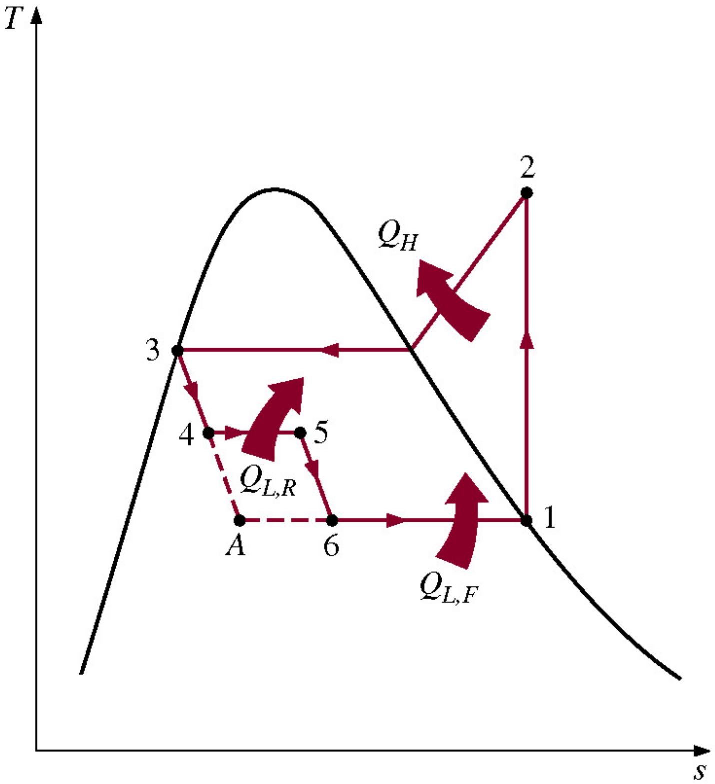




Instead of throttling from 5 to 8' directly, we make two stage throttling (similar to two stage turbines !). We throttle from 5 to 6, use the low temp vapor to cool the compressed vapor from 2 to 9.

Multipurpose refrigeration system with a single compressor

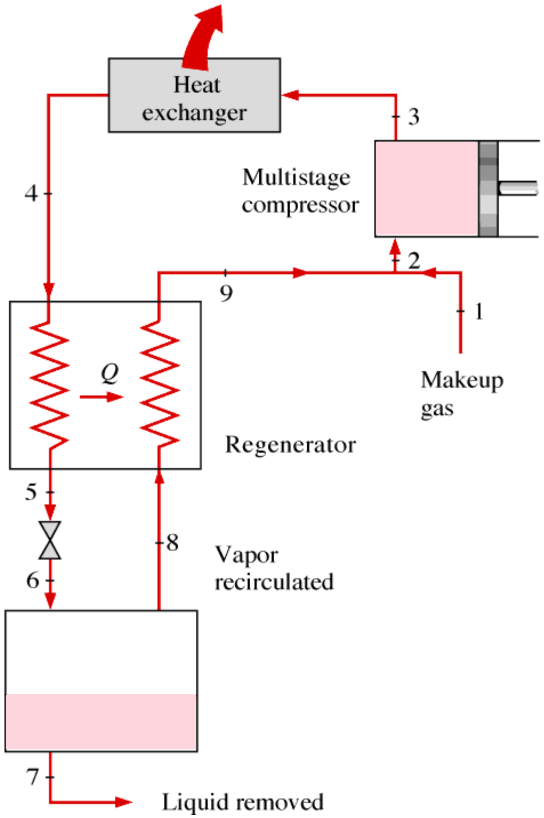




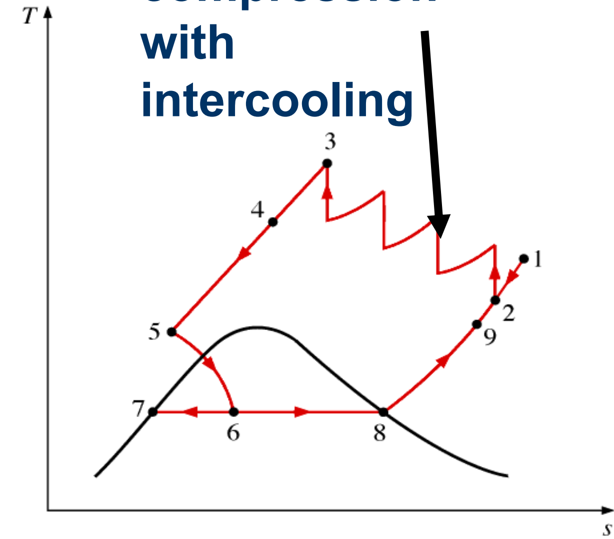
We throttle first from 3 to 4, absorb heat from the refrigerator, then throttle again from 5 to 6 and absorb heat from the freezer.

Linde-Hampson System for Liquefying Gases

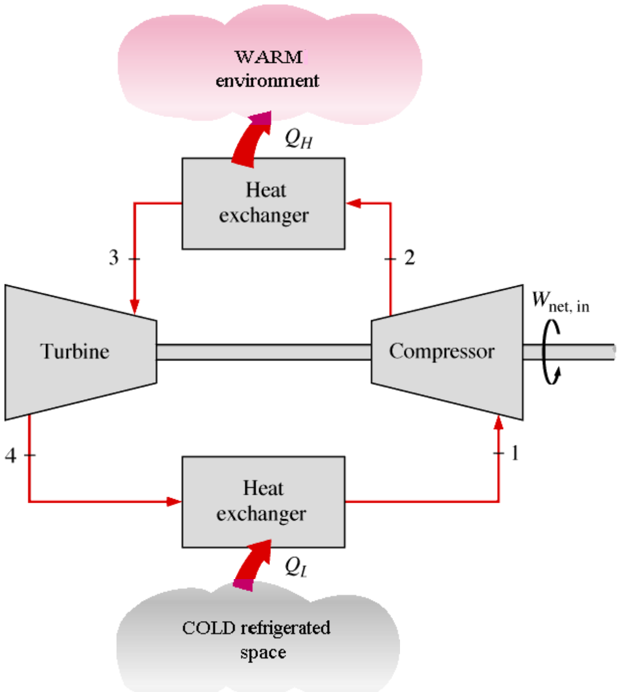
1. ***We compress the gas from state 2 to 3,***
2. ***Cool it from 3 to 4 using heat exchanger with cold medium.***
3. ***Cool it further from 4 to 5 using regenerator.***
4. ***Throttle it from 5 to 6 sat. mixture).***
5. ***Use vapor phase (state 8) to cool the compressed gas and get heated to 9.***
6. ***Mix it with warm Make up gas so final T will be 2.***
7. ***Remove liquid gas at state 7.***

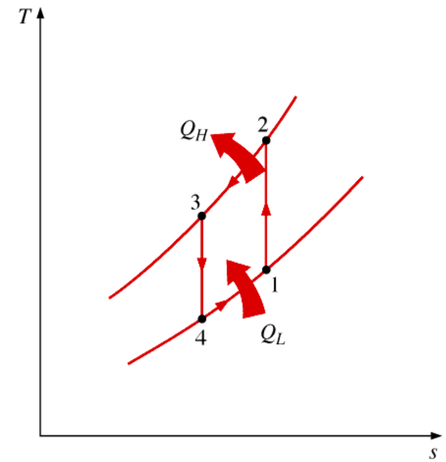


Multistage compression with intercooling



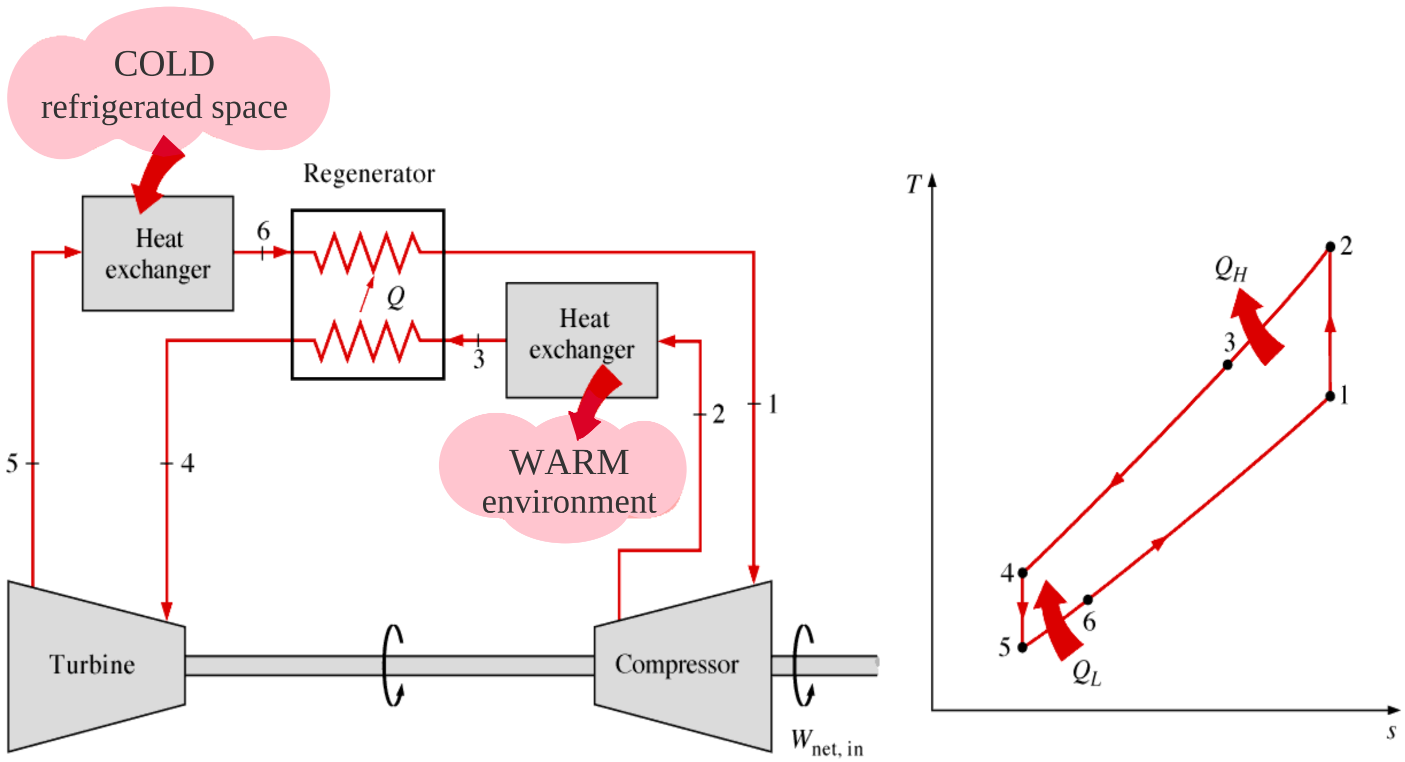
Simple Gas Refrigeration Cycle (Reversed Brayton cycle)





- The power cycles can be used as refrigeration cycles by simply reversing them.
- Of these, the reversed Brayton cycle, which is also known as the gas refrigeration cycle,
- The work output of the turbine can be used to reduce the work input requirements to the compressor.

Gas Refrigeration Cycle With Regeneration



- The *reversed Brayton cycle can also be* used to cool aircraft and to obtain very low (cryogenic) temperatures after it is modified with ***regeneration***.

- **DO EXAMPLE 10-5 .**

✓ Ammonia Absorption Refrigeration Cycle

- Another form of refrigeration that becomes economically attractive when there is a source of inexpensive heat energy at a temperature of 100 to 2000C is *absorption refrigeration*,
- The refrigerant is absorbed by a transport medium and compressed in liquid form.
- The most widely used absorption refrigeration system is the ammonia-water system, where ammonia serves as the refrigerant and water as the transport medium.
- The work input to the pump is usually very small.