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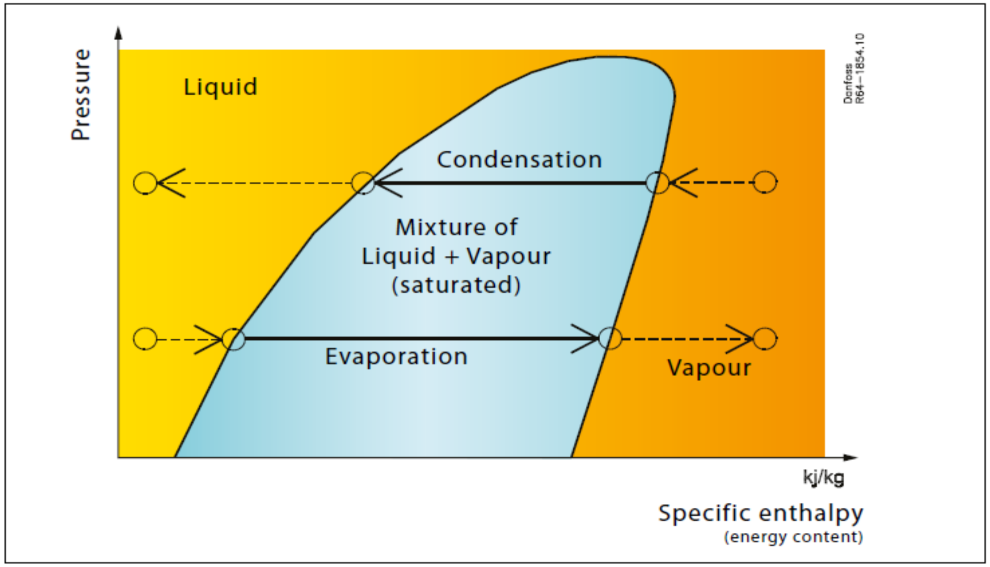


DES
Refrigeration circuit, theory

Lecture 2

Understand the refrigeration process

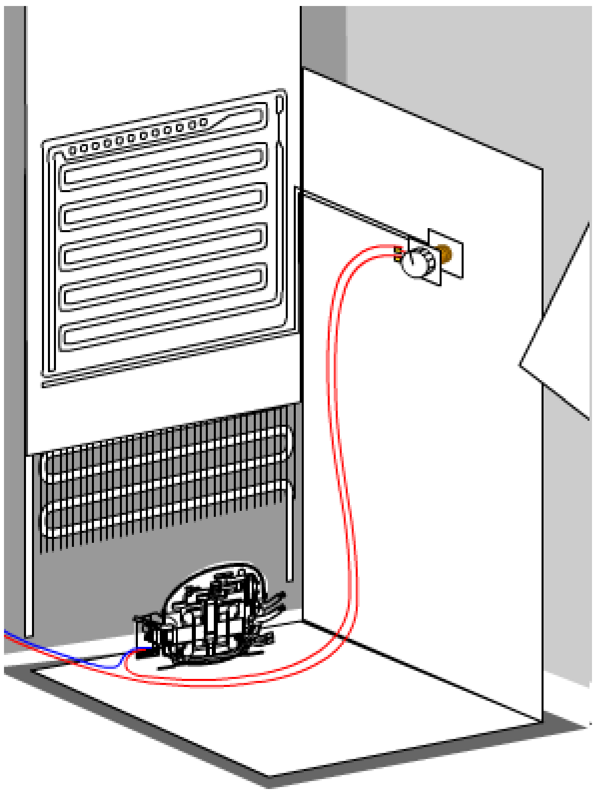
How to use energy energy balance methodology for the process

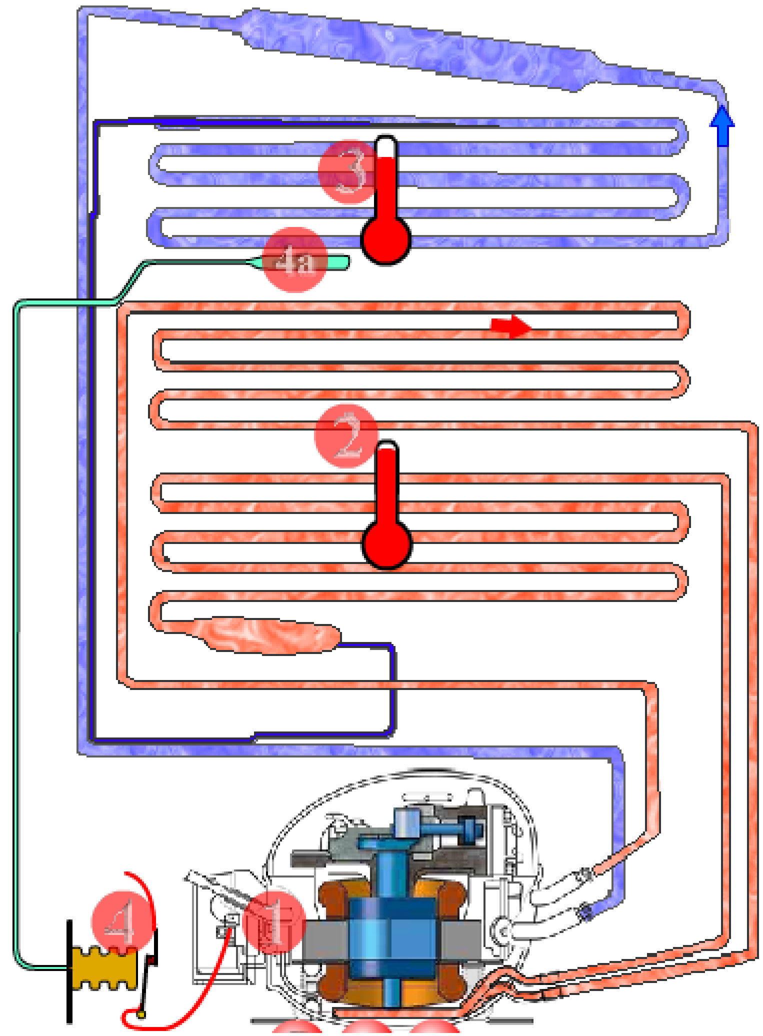
How to use the log P, H diagram (manually and with Cool Pack)

Energy Balance methodology

1. Add numbers to identify the different parts of the process
2. Add know information on eg. massflow, temperatures, pressure to the drawing
3. Draw Control Volumes for the total system and parts of the system to be analyzed.
4. Find enthalpies for latent processes: Refrigerants (log P h-diagram), air with condensation or humidification (hx-diagram). Find cp values for sensible processes: Water, dry air and other substances (tables)
5. Calculate energy flow in and out of each control volume using energy balance equations.

Overall principle
Refrigerator





Single stage refrigeration circuit Cold store example

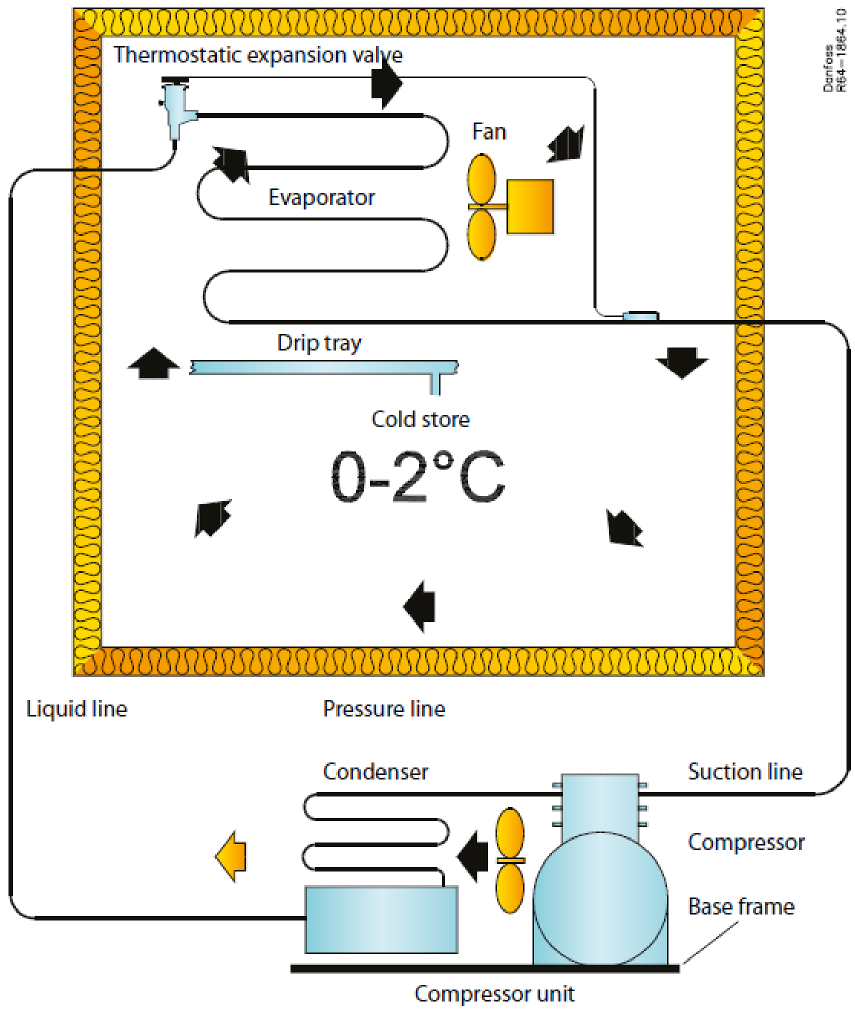
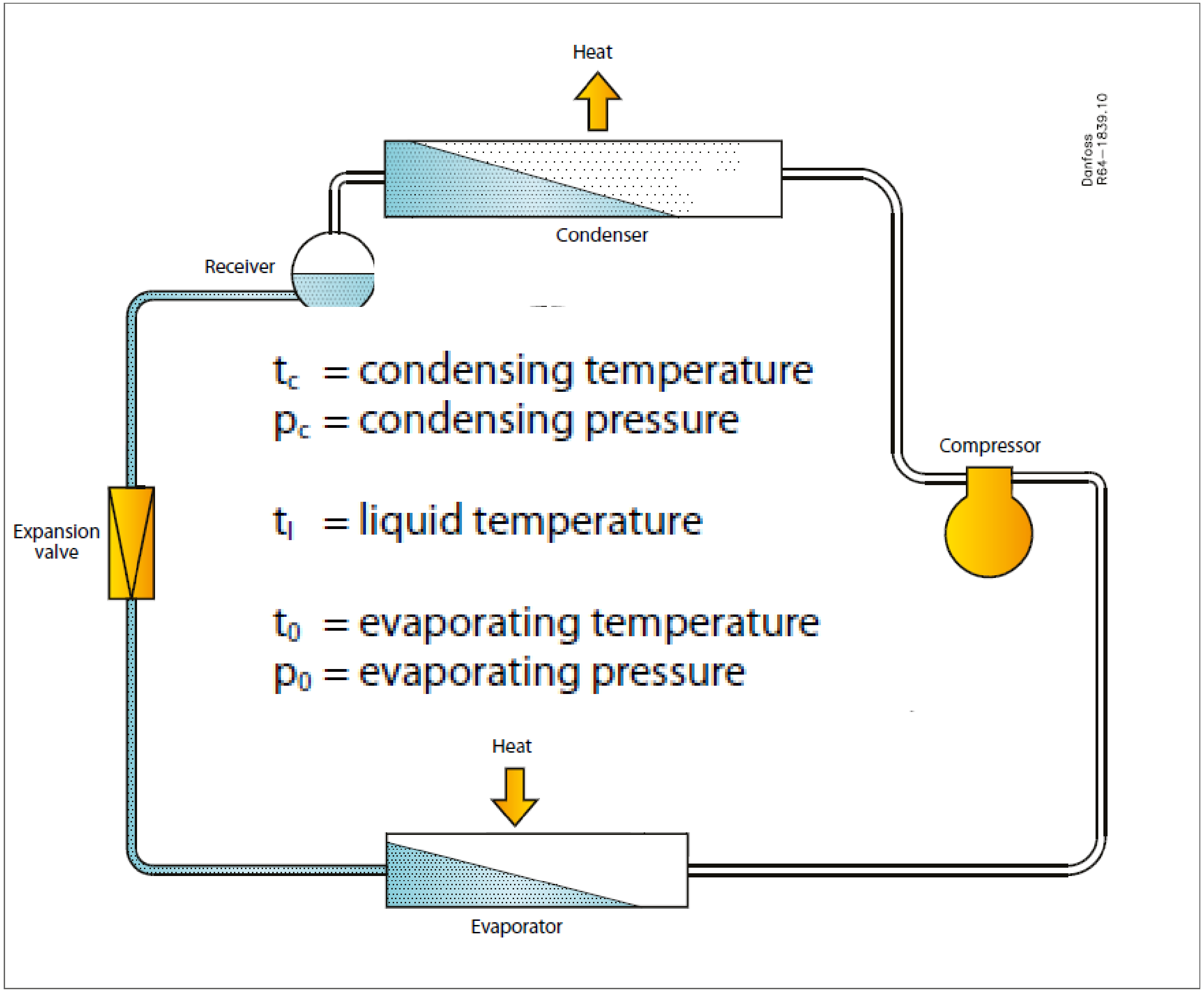


Fig. A

Symbols, units and terms

- Φ_o kW Cooling capacity
- Φ_c kW Condenser performance
- P_i kW Compressor shaft power
- q_o kJ/kg Specific refrigeration capacity
- q_c kJ/kg Specific condensation capacity
- w_i kJ/kg Specific work of the compressor
- p_o bar Evaporator pressure
- p_c bar Condenser pressure
- t_o °C Evaporator temperature
- t_c °C Condenser temperature
- $q_{m,R}$ kg/s Mass flow rate of refrigerant
- $q_{m,w}$ kg/s Mass flow rate of cooling water
- q_{ma} kg/s Mass flow rate of cooling air

Refrigeration circuit



Energy balance

$$\Phi_o + \Phi_c + P_i = 0$$

The equation is valid for a steady process.

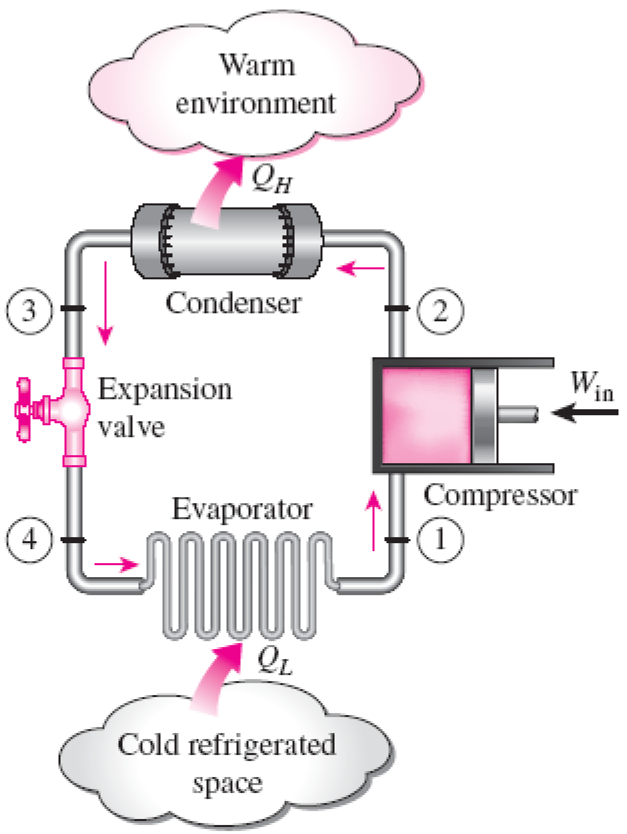
If we use specific form, meaning quantity of energy per kg refrigerant, we get:

$$q_o + q_c + w_i = 0$$

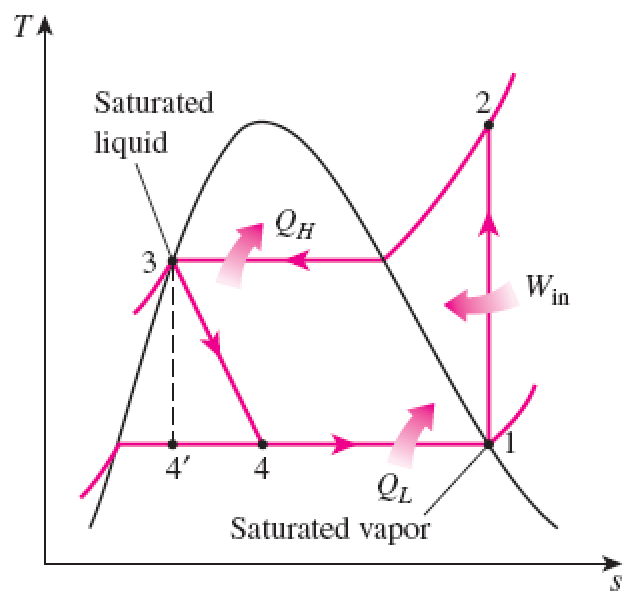
It is presupposed that the compression process is uncooled, meaning it is an adiabatic process.

THE IDEAL VAPOR-COMPRESSION REFRIGERATION CYCLE

The **vapor-compression refrigeration cycle** is the ideal model for refrigeration systems. Unlike the reversed Carnot cycle, the refrigerant is vaporized completely before it is compressed and the turbine is replaced with a throttling device.



1-2	Isentropic compression in a compressor
2-3	Constant-pressure heat rejection in a condenser
3-4	Throttling in an expansion device
4-1	Constant-pressure heat absorption in an evaporator



This is the most widely used cycle for refrigerators, A-C systems, and heat pumps.

Schematic and *T-s* diagram for the ideal vapor-compression refrigeration cycle.

Cooling capacity

For a given refrigerant mass flow qmR the following applies:
The cooling capacity:

$$\Phi_o = q_{mR}\,(h_1 - h_4) = q_{mR}\,q_o$$

The condenser capacity:

$$\Phi_c = q_{mR}\,(h_2 - h_3) = q_{mR}\,q_c$$

The throttling process (ideal):

$$h_3 = h_4$$

The compressor shaft power:

$$P_i = q_{mR}\,(h_2 - h_1) = q_{mR}\,w_i$$

Refrigerant mass flow

Refrigerant mass flow q_{mR} is calculated from evaporator or condenser capacity.

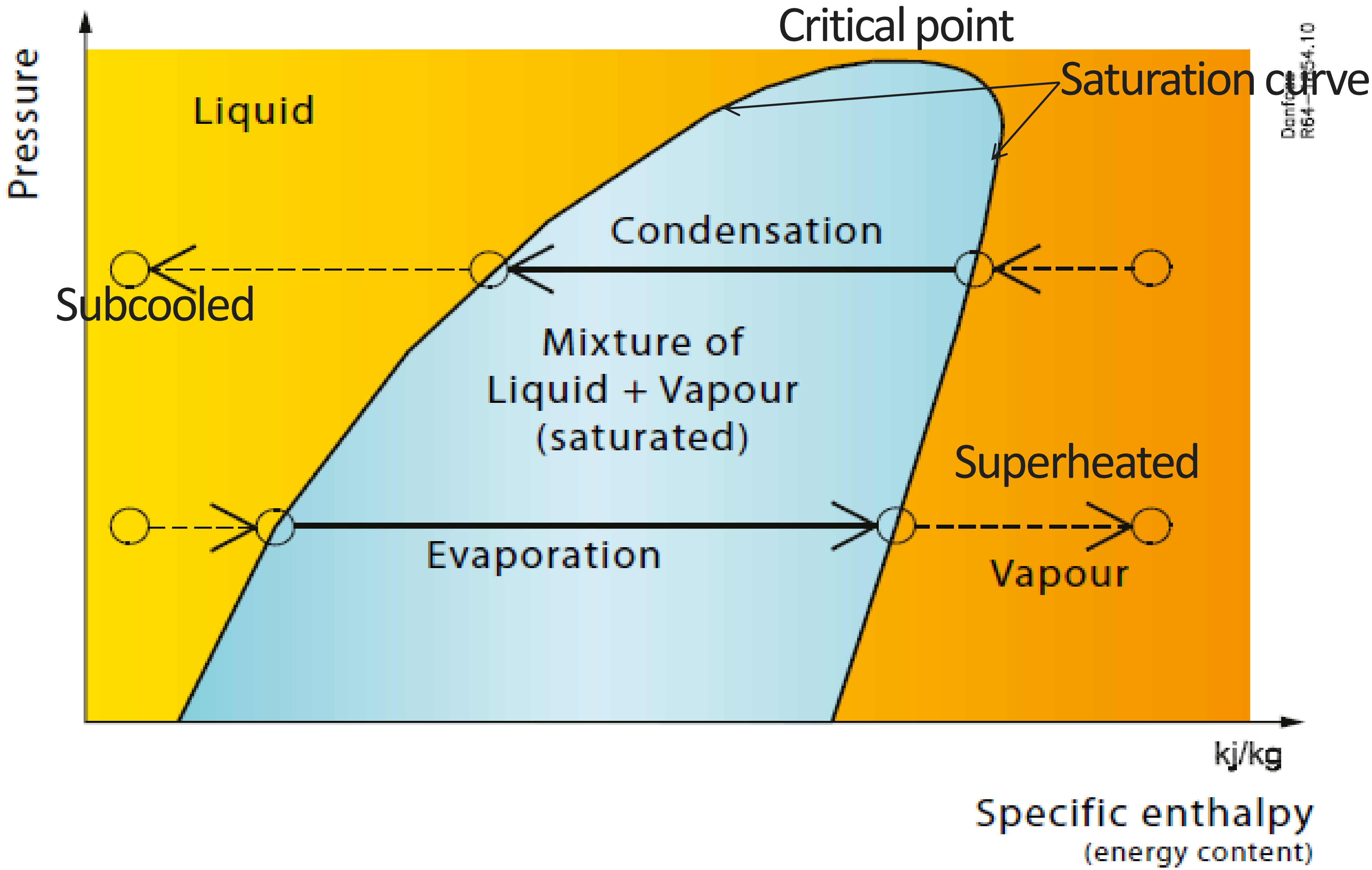
For a **<u>refrigeration system</u>** given cooling capacity Φ_o is needed:

$$q_{mR} = \frac{\Phi_o}{h_1 - h_4}$$

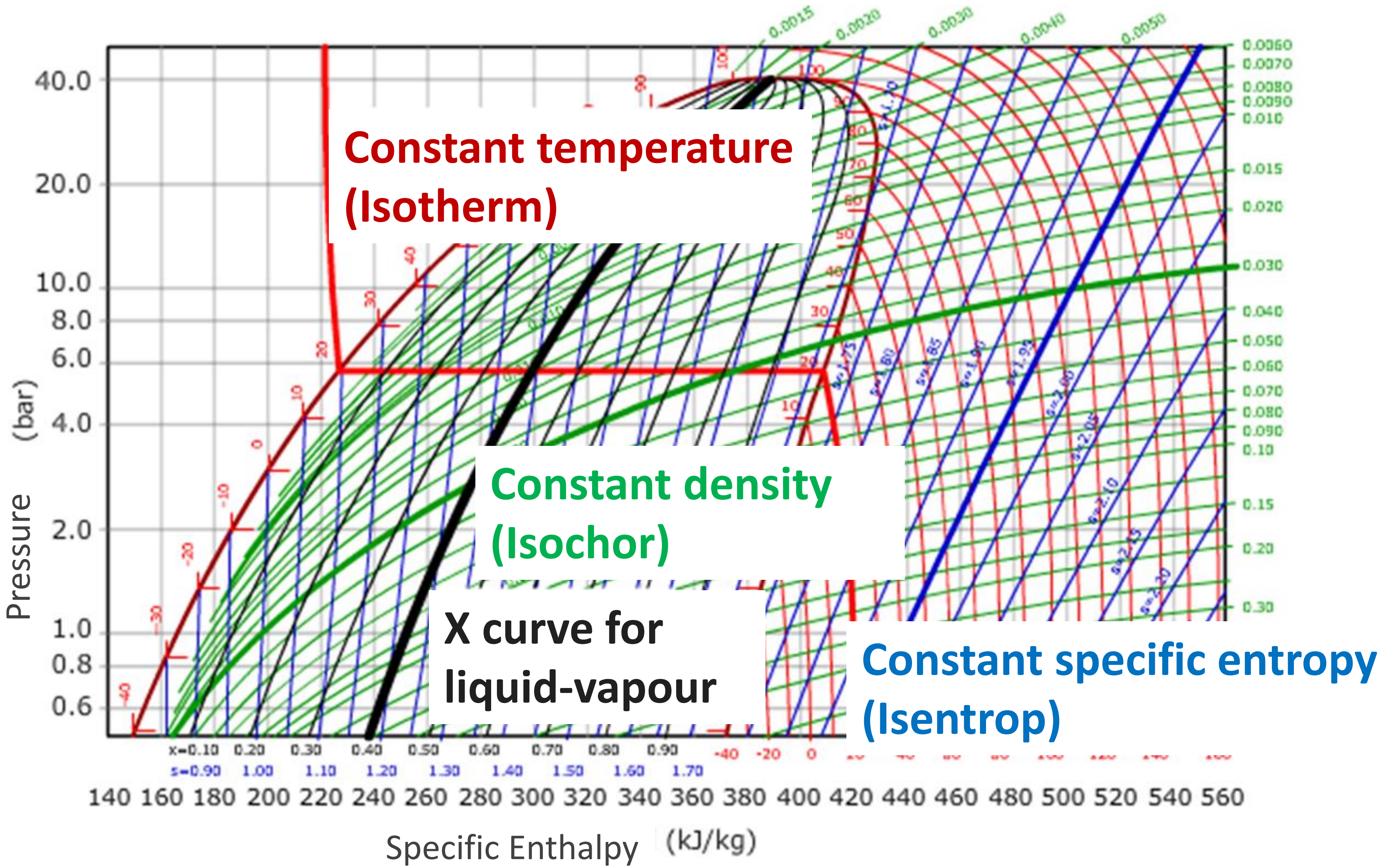
For a **<u>heat pump</u>** a given condenser capacity Φ_c is needed:

$$q_{mR} = \frac{\Phi_c}{h_2 - h_3}$$

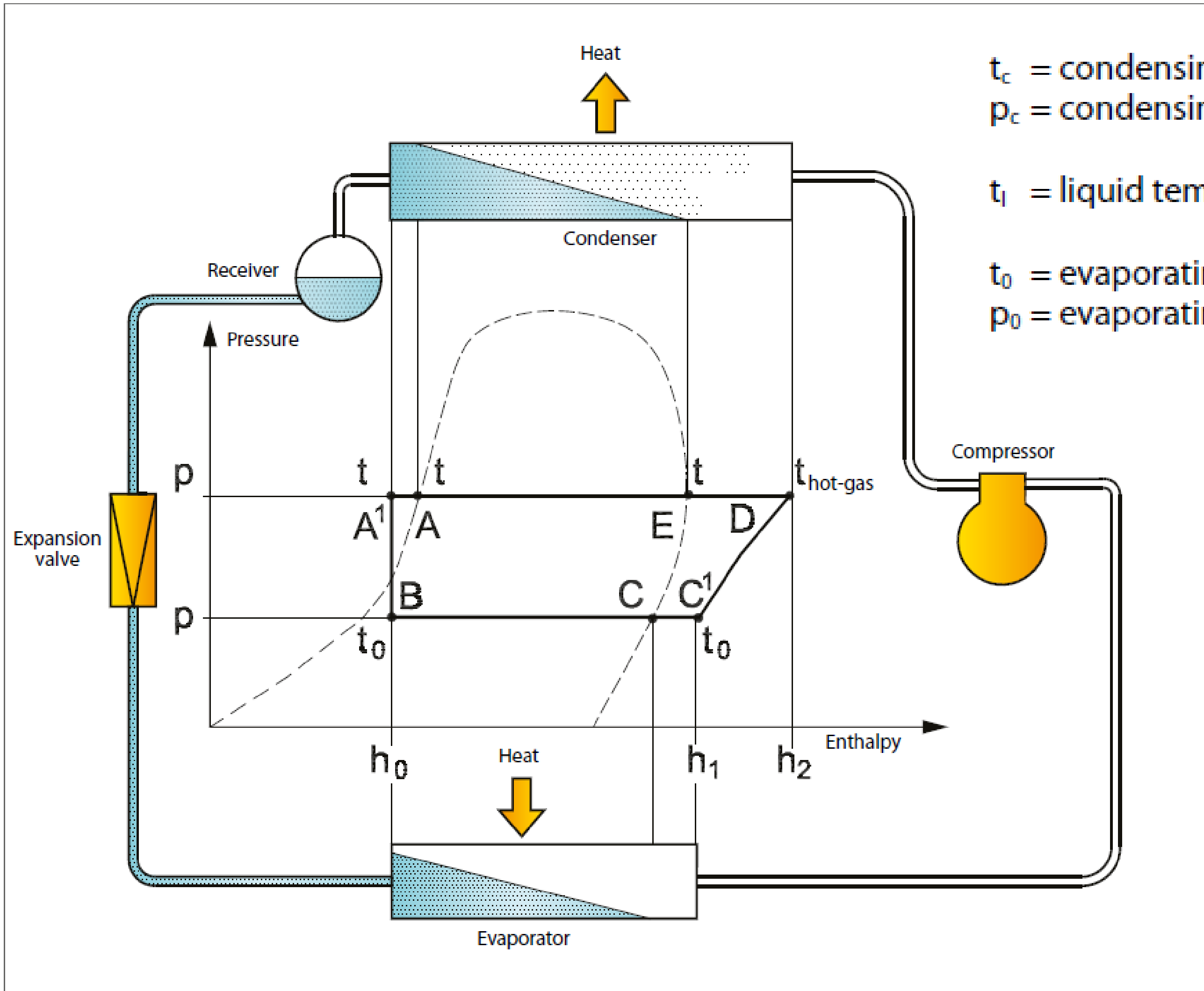
Log P-h diagram Overview



Log P-h diagram



Refrigeration circuit in log P-h diagram



t_c = condensing temperature
p_c = condensing pressure

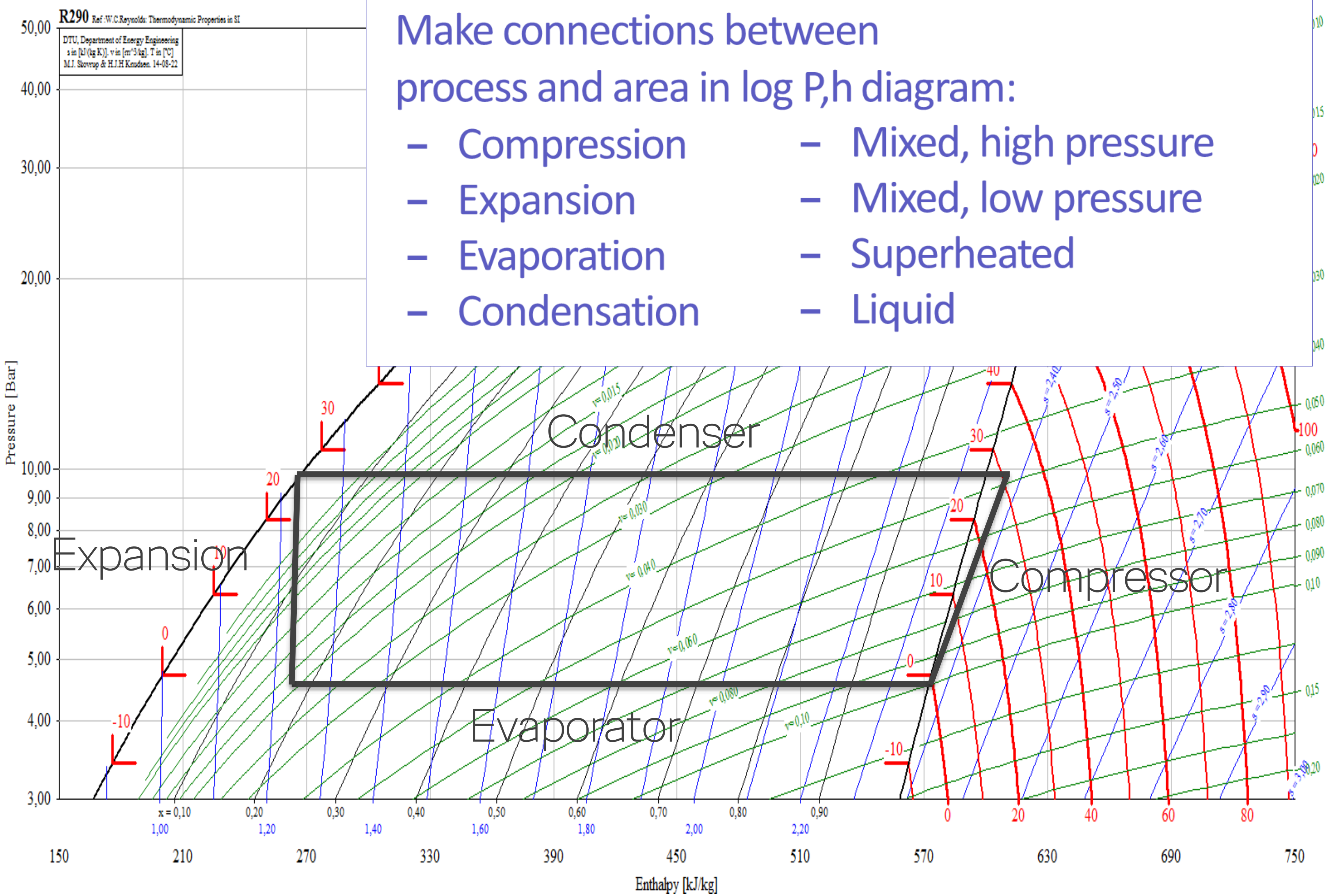
t_l = liquid temperature

t_0 = evaporating temperature
p_0 = evaporating pressure

Log P,h diagram

Make connections between process and area in log P,h diagram:

- Compression
- Expansion
- Evaporation
- Condensation
- Mixed, high pressure
- Mixed, low pressure
- Superheated
- Liquid



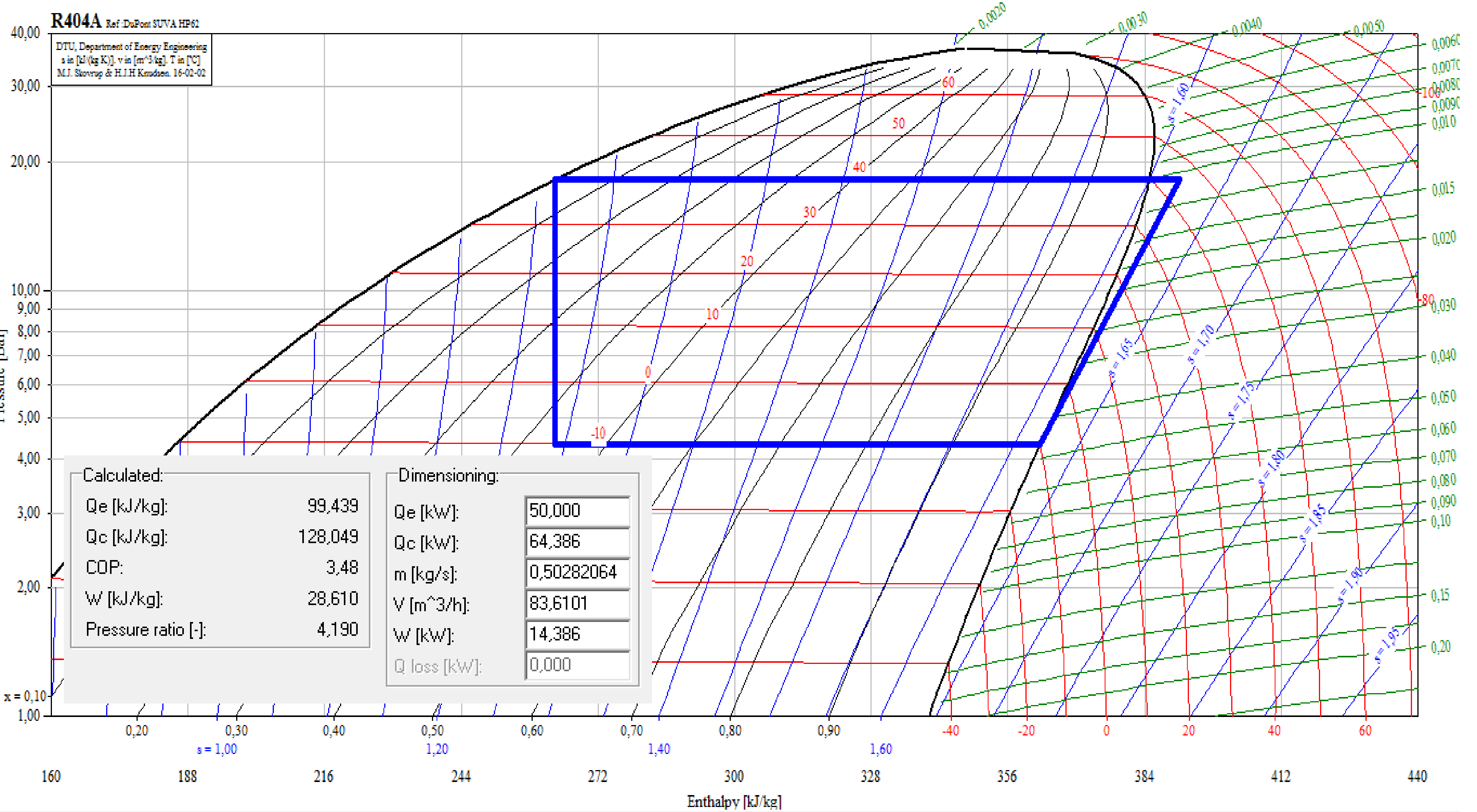
Log P,h diagram exercise
Circuit plot

Assume an ideal refrigeration process has the following data:

- Evaporation temperature: t_0 = -10 °C
- Condensation temperature: t_C = 40 °C
- Ideal means compression is isentropic

Plot the process in the log P, h diagram., let us use R290 (natural refrigerant)

Log P,h diagram exercise. Solution



Log P,h diagram exercise
Cooling capacity, mass flow

An ideal refrigeration process has the following data:

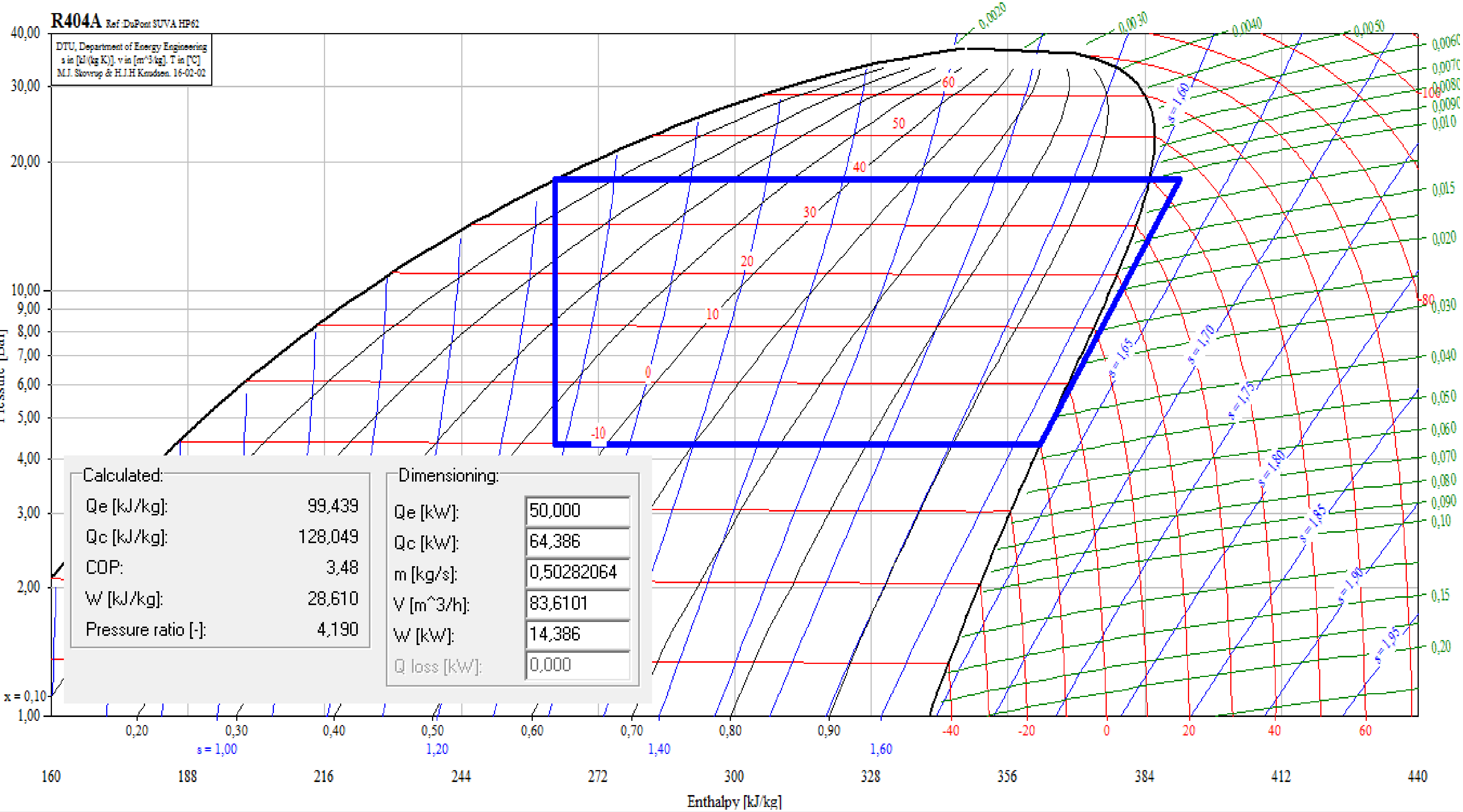
- Evaporation temperature: t_0 = -10 °C
- Condensation temperature: t_C = 40 °C
- Ideal means compression is isentropic

- The cooling capacity is Φ_0 = 50 kW.

Find h_4 and h_1.

Calculate the refrigerant mass flow.

Log P,h diagram exercise. Solution



Coefficient Of Performance
COP

As a measure of the effectiveness of a refrigeration system or a heat pump, Coefficient Of Performance = COP is used.

$$COP = \frac{Useful\ energy}{Suplied\ energy}$$

COP for refrigeration system and heat pump

For a refrigeration system:

$$COP_{cool} = \frac{\Phi_o}{P_i} = \frac{q_o}{w_i}$$

If the efficiency of the electrical motor is included, we get:

$$COP_{cool} = \frac{\Phi_o}{P_{el}}$$

For a heat pump system:

$$COP_{HP} = \frac{\Phi_c}{P_i} = \frac{q_c}{w_i}$$

If the efficiency of the electrical motor is included, we get:

$$COP_{HP} = \frac{\Phi_c}{P_{el}}$$

COP Question

- Condenser capacity: 4 kW
- Evaporator capacity: 3 kW
- Electrical power: 1 kW

Calculate COP for refrigeration and heat pump.

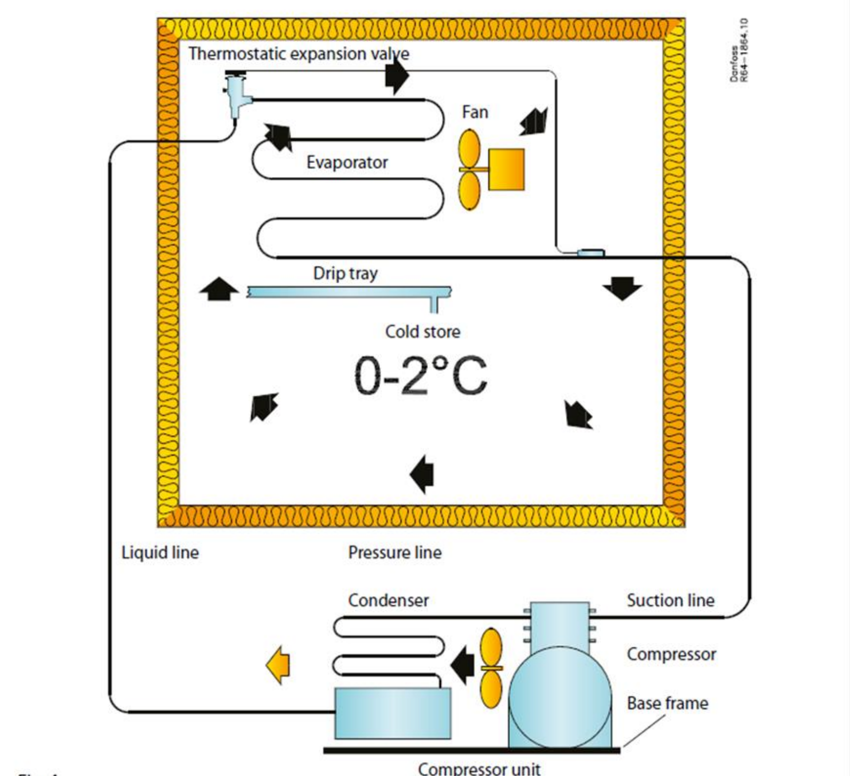


Fig. A

Log P,h diagram COP

An ideal refrigeration process has the following data:

- Evaporation temperature: t_0 = -10 °C
- Condensation temperature: t_C = 40 °C
- Ideal means compression is isentropic

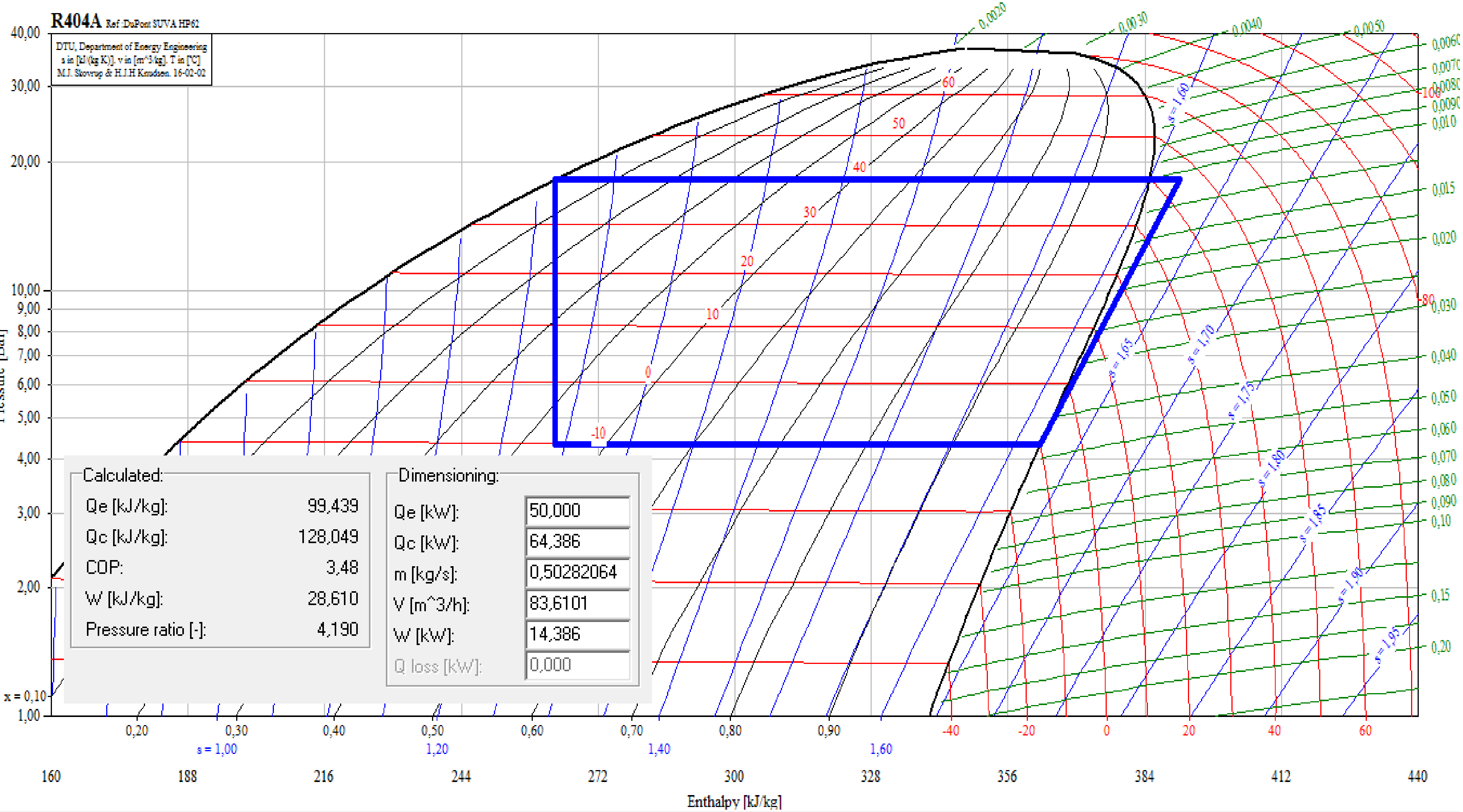
- The cooling capacity is Φ_0 = 50 kW.

Find h_1 and h_2.

Calculate COP for the refrigeration process

Use : R744, R717, R1270, R123, R22

Log P,h diagram exercise. Solution



Superheating and subcooling

Superheating

To avoid liquid in the compressor the gas after the evaporator is often superheated.

We are often dealing with superheating of Δt_{sh} = 2 - 8ºC

Subcooling

Flash gas is avoided if there is a suitable subcooling.

Another benefit of subcooling is increased cooling capacity $\Phi_{o.}$

We are often dealing with subcooling of Δt_{sc} = 2 - 10ºC.

Log P,h diagram
Superheating and subcooling

An ideal refrigeration process has the following data:

- Evaporation temperature: t_0 = -10 °C
- Condensation temperature: t_C = 40 °C
- Ideal means compression is isentropic

- The cooling capacity is Φ_0 = 50 kW.

- Superheating and subcooling is both 5 K.

Calculate the new mass flow if cooling capacity stays the same.
Calculate the new COP.

Log P,h diagram exercise. Solution