xrgy
Seeing the Big Picture

Heat Pumps – The Basics

Gert Nielsen
Managing Geek
Xrgy AS
gert.nielsen@xrgy.no

Agenda of the day

- Boasting
- Basic thermodynamics and use of logp,h-charts
- Break
- Behaviour of heating systems. Example from office building.
- Refrigerants
- Break
- Compressors
- Expansion devices
- Design of heating systems

Who am I?

- A very good question, I am still working on it. The facts
- Name : Gert Nielsen (gert.nielsen@xrgy.no)

- Education : B.E-honours from Aalborg University. Thermomechanical construction
- Self-tought geek in thermal systems.
- Passionate about natural refrigerant. So you know where my bias is.

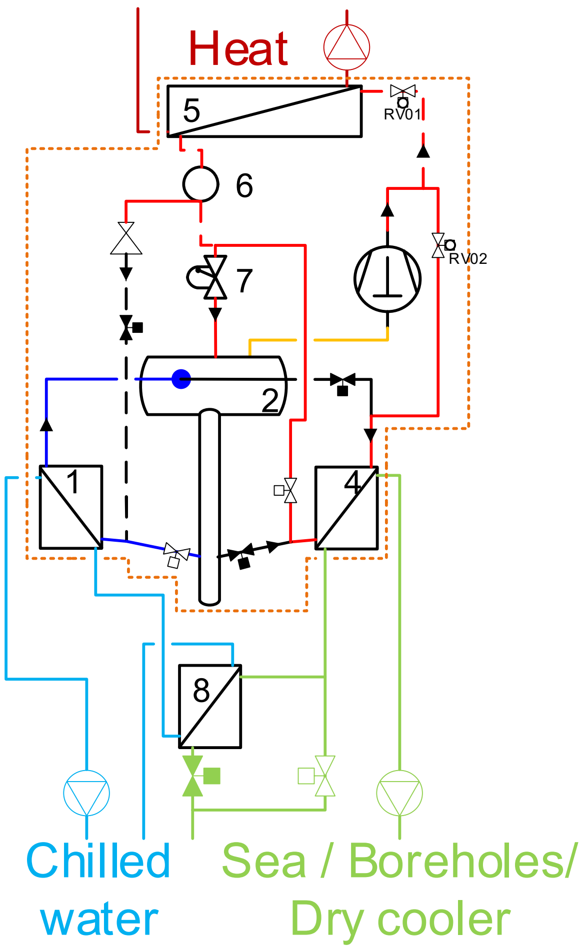
- Previous jobs : Subject responsible refrigeration, high school teacher, salesman, sales support, system designer, program developer, refrigeration consultant, postman.
- Today : Trying to run my own thermal systems consultancy. Thermal systems design, design of chiller and heat pump machinery
- Lead engineer heat production in the Norwegian HVAC association.

- Good at surprising angles
- Always question established truths (pain in the ....)

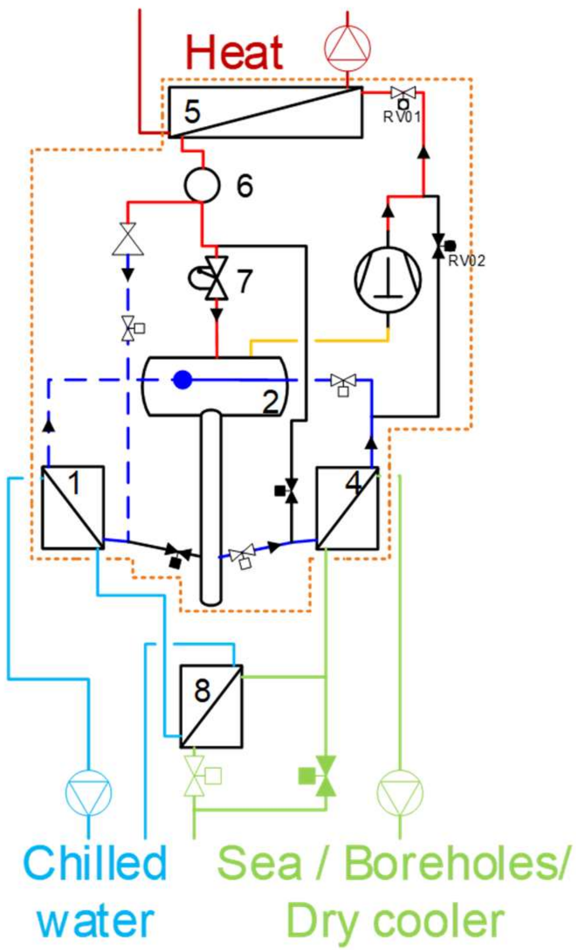
Previous work. Three exchanger heat pump

1 : Water chiller
2 : Liquid separator
3 : Compressor
4 : Heat rejection / heat injection
5 : Water heater
6 : Pilot reciever
7 : High pressure float valve
8 : Free cooling heat exchanger
Electronic expansionvalve
On/off valve. Open
On/off valve. Closed
Modulating valve.

Chiller mode

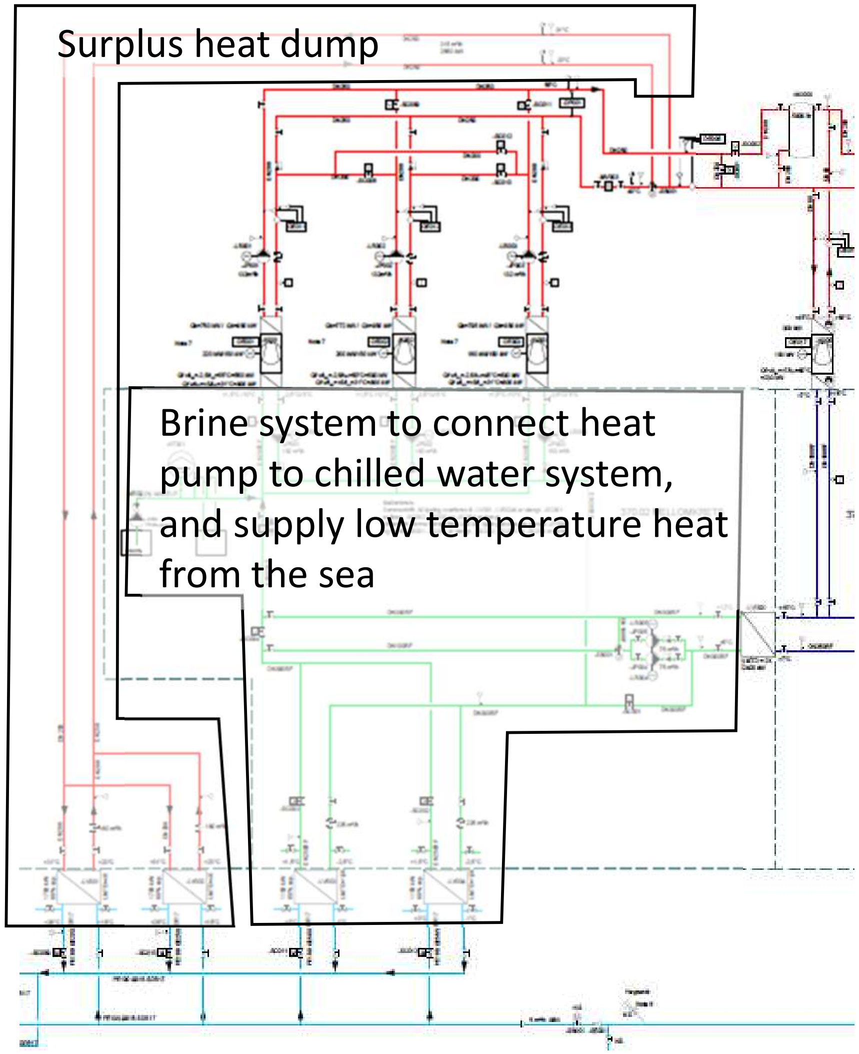


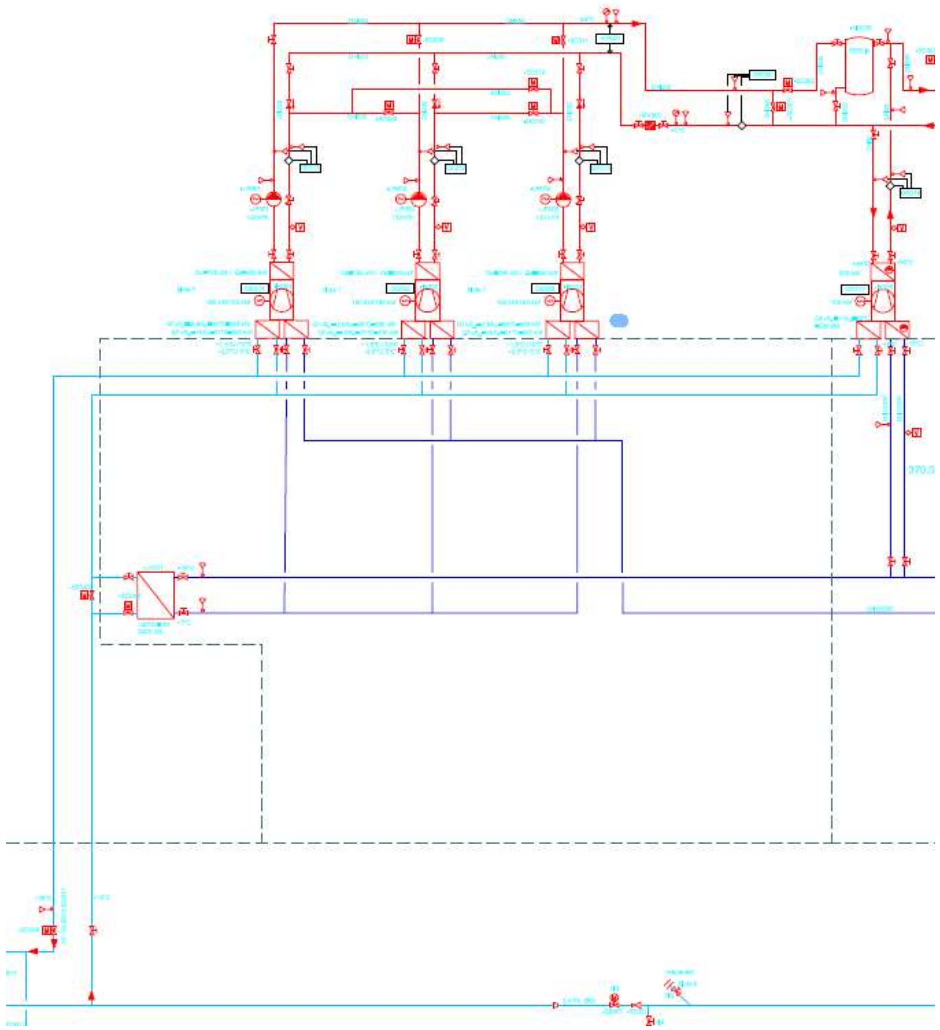
Heat pump mode



Previous work. Three exchanger heat pump

xrgy
Seeing the Big Picture





Previous work. Thermal system Bergen University College

- System designer for the system as it is today. Won the Norwegian Heat Pump Award in 2016.

- Prerequisite
  - Keep the energy within the system boundaries.
  - Use the chillers as heat pumps.
  - Ammonia as refrigerant.

- Borehole system headache
- Optimised for heat pump 80 holes of 200 m
- Optimised as heat dump 171 holes of 200 m

- Reduced machinery demand by using thermal storage from 3 000 kW to 1 400 kW. Using PCM having phase change temperature at 10°C

- Borehole system 81 holes of 200 m, fits both summer and winter.

- No dry coolers => Architects so thrilled they almost wet themselves. I was quoted on that in the local newspaper

- Cold machinery steps, 200 kW, 400 kW and 800 kW.
- All using VSD => steady operation from 100 kW up to 1 400 kW.
- 1 600 kW from thermal storage.

History

- 1834 Perkins (US) seeks patent for his cooling machine.
- 1844 Gorrie (US) cold air machine. Air as refrigerant
- 1852 Thomson (Ir) proposes the use of heat pumps for building heating.
- 1854 Perkins' machine is built.
- 1859 Carré (Fr) proposes th absorpsions refrigeration machine
- 1866 Lowe (US) first machine to run on CO_2. No succes.
- 1867 Carré uses ammonia as refrigerant as the first
- 1870 von Linde (Ge) builds the first reliable cold machine.
- 1874 Pictet (Sw) uses SO_2 as refrigerant as a first
- 1874 von Linde builds his first ammonia machine.
- 1881 von Linde builds his first CO_2 machine.
- 1893 Swartz (Be) publicises formulars to modify HC-molecules to the artificial refrigerants used later
- 1930 Freon is introduced as a brand name. R11, R12, R13, R21, R113 and R114 are launched.
- 1936 R22 is developed. Market entry after the war.

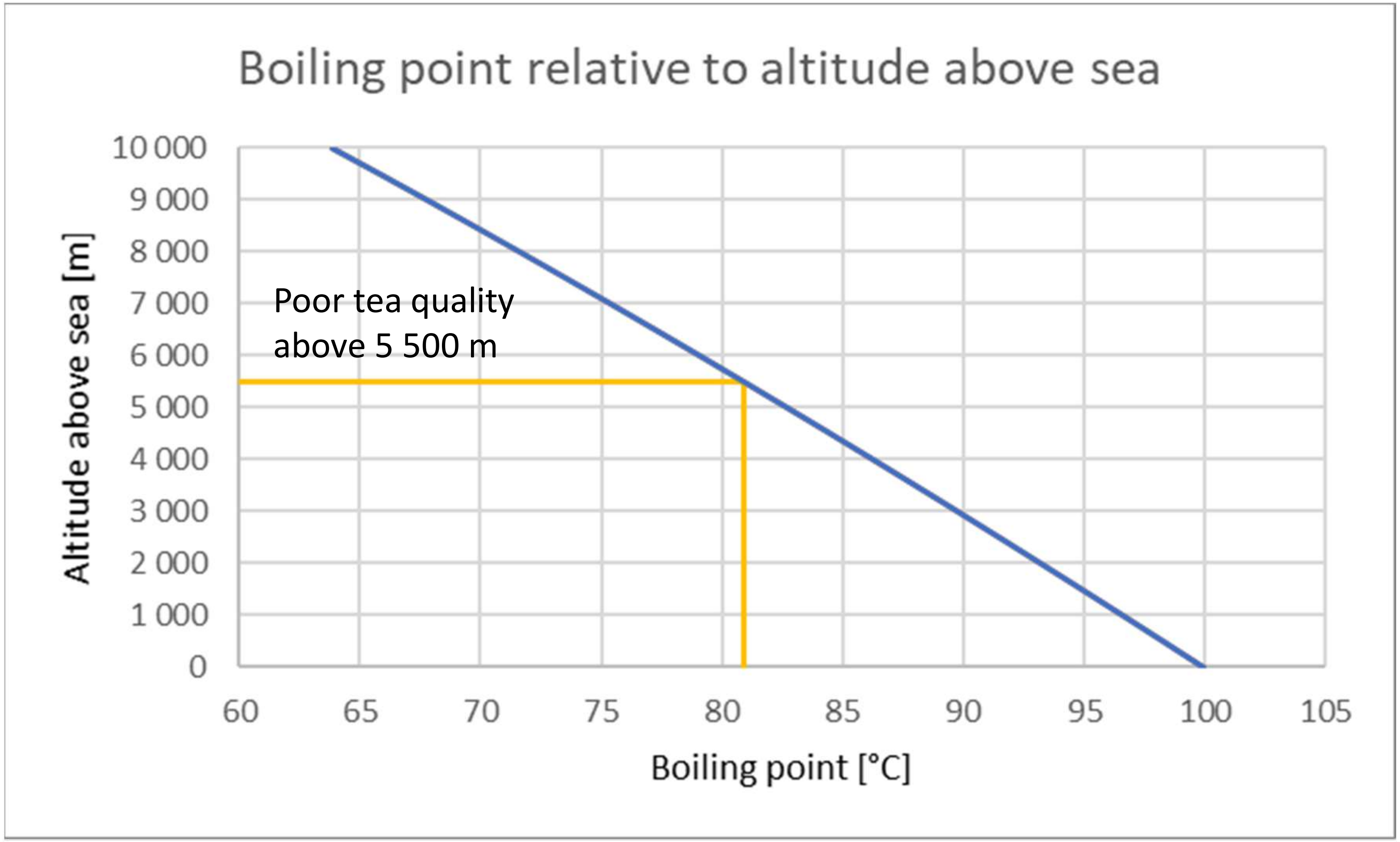
History

- Artificial refrigerant are making in-roads in the commercial and domestic markets. Non-toxic and non-flammable
- Ammonia stays in the industrial marked.
- CO_2 disappears due to high pressures and low critical point.
- The Montreal Protocol from 1987 starts the phase-out of CFC refrigerants, best known is R12. Phase-out in the EEC during the 90es.
- The Kyoto agreement puts boundaries on the release of greenhouse gases.
- F-gas regulations are launched in the EU in 2006, details ready during 2008.
- From 1/1-2007 artifiacial refrigerant charges above10 kg are banned i Denmark. The industry got 6 months warning.

Basic thermodynamics

- What do we actually do when cooling?
- We move heat from a colder environment to a warmer.
- If we are mostly interested in heat removal it is a refrigeration plant, if the primary interest is heating it is a heat pump.
- AND NO..a heat pump is NOT a reversed refrigerator.
- IT IS a refrigerator.
- Heat pump is a very good name, as we pump heat “uphill”.
- How do we do this?
- We manipulate the boiling point of the fluid inside the machine.
- And that is done by manipulating the pressure.
- In regions where boiling and condensation occurs there is a fixed relation between boiling temperature and pressure.

Basic thermodynamics.
Poor tea at mount Everest.

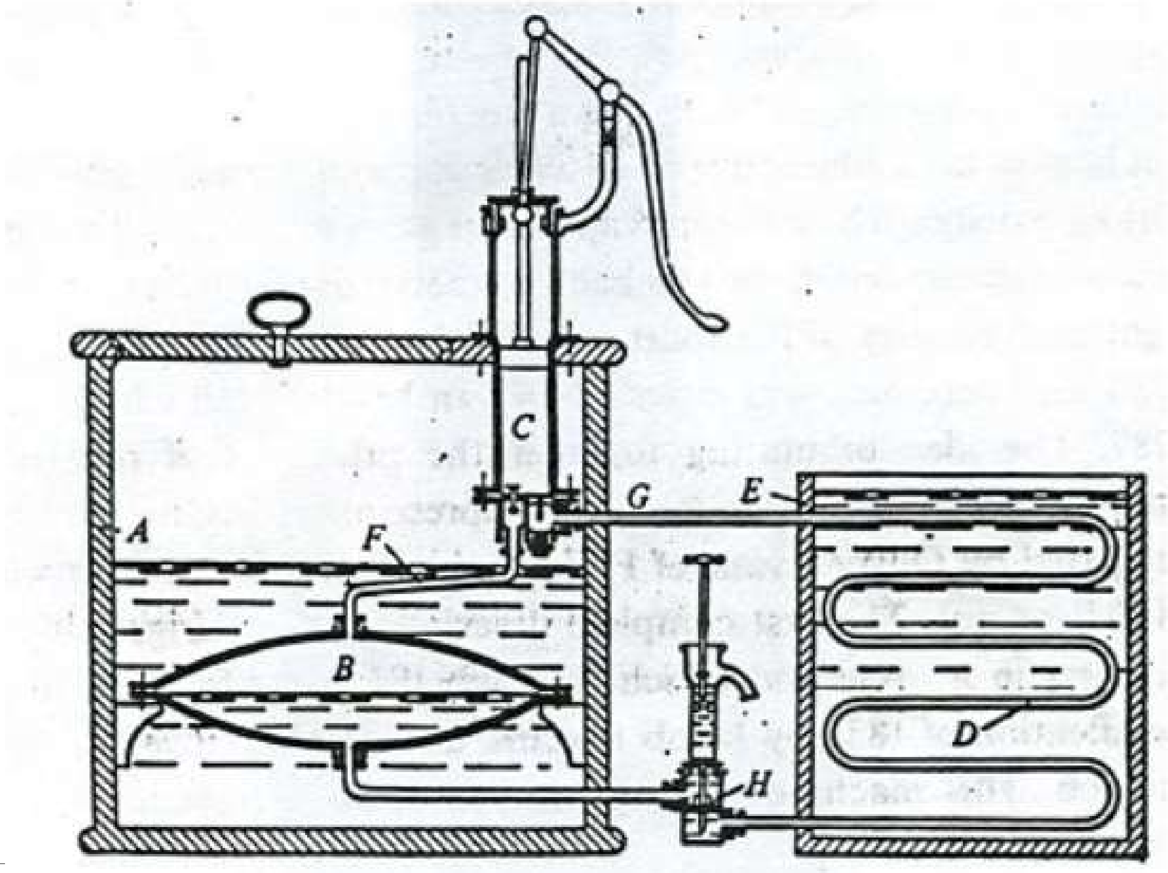


Basic thermodynamics

- Why boiling and condensation?
- Big energy exchange in phase change.
- Evaporating 1 kg/s of water will move app. 2 450 kW at constant temperature.
- Moving the same heat rate in a chilled water system with $\Delta T = 5K$ will require 117 kg/s.
- Easy control of the process. The temperature levels around the evaporator and the condensor determine the process.

Refrigeration technology is almost as old as the steam engine.

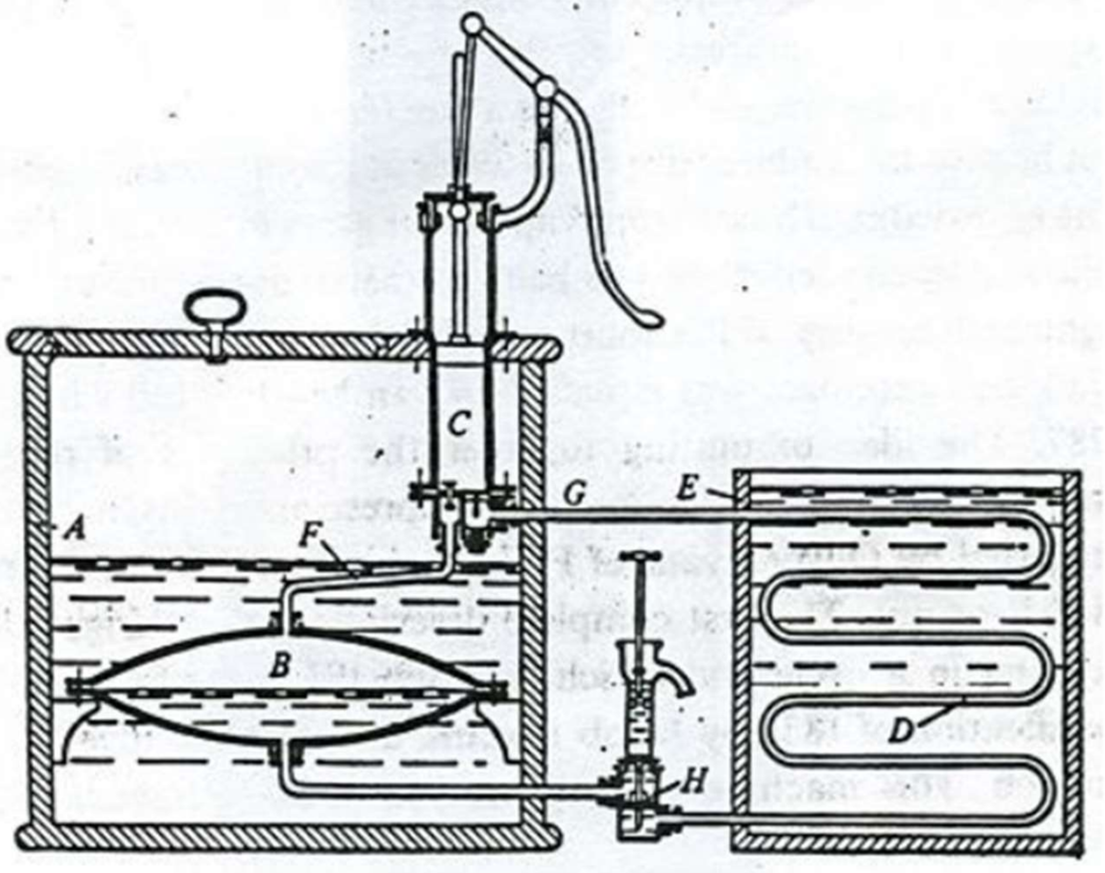
- Perkins patent from 1834 shows all the main components included in a cold machine today

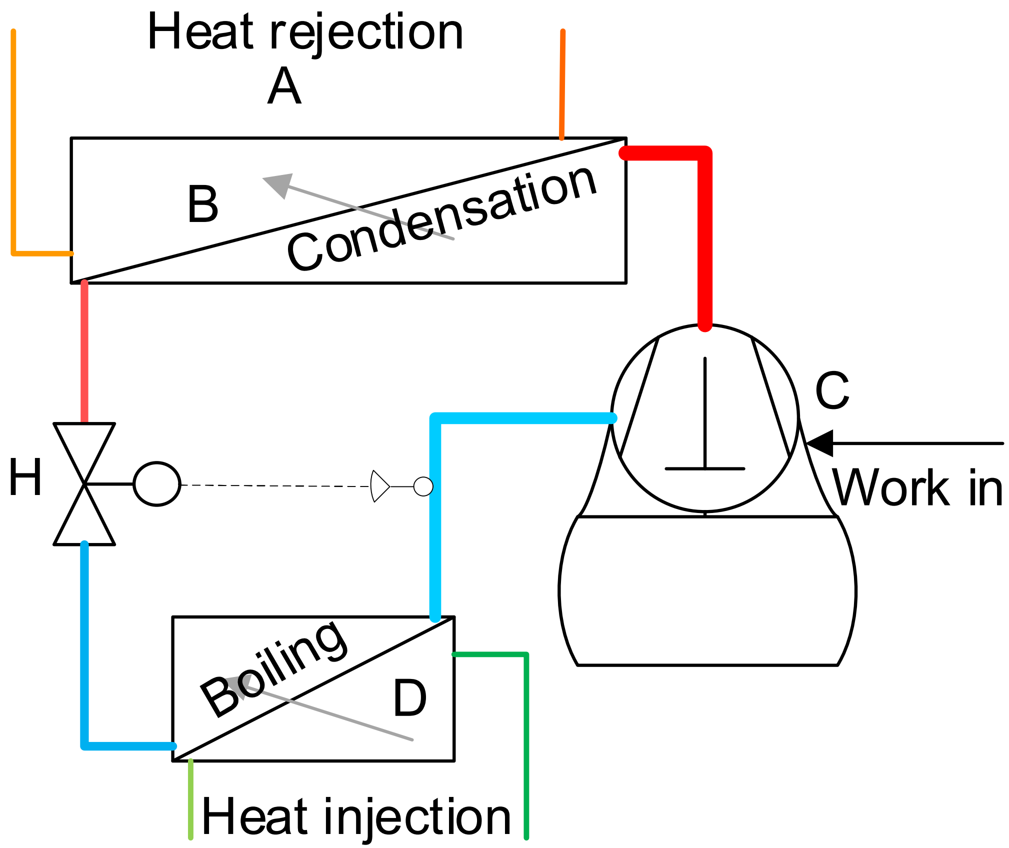


- A Hot water container
- B Condensor
- C Compressor (bicycle pump)
- D Evaporator
- E Chilled water tank
- H Expansion valve.
- Refrigerant ethylether

Nothing new….in the process that is.

A : Hot water container / Heat rejection B : Condenser C : Compressor D : Evaporator
E : Chilled water tank / Heat injection H : Expansion valve.



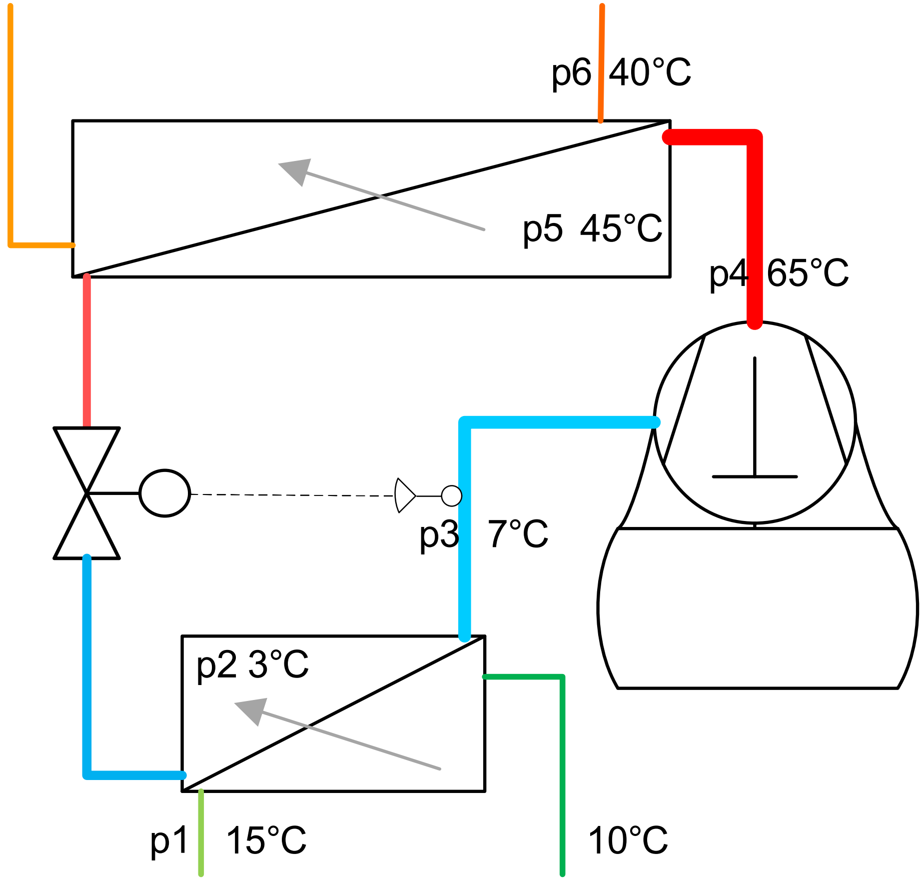


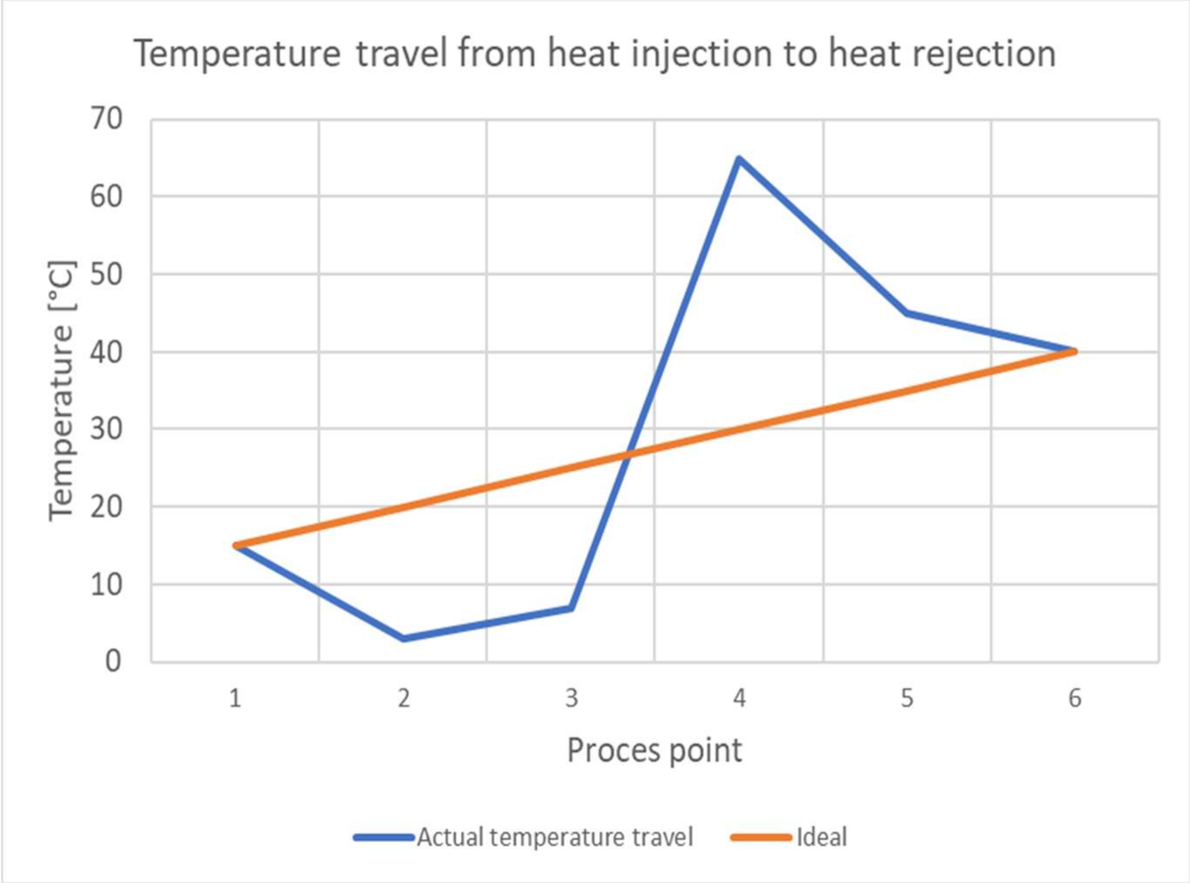
Making heat run "Up hill"

- Water, a ball, a human will fall downwards.
- This is called a Mechanical Potential.
- Heat runs "down hill" from hot to cold
- This is called a Thermal Potential
- Making water, balls and humans go up hill energy needs to be added to overcome the increased potential
- So also for heat.
- The water pump lifts the potential of the water, the compressor increases the thermal potential of the refrigerant.
- How ever, in the heat exchangers no help is available so heat runs "down hill".
- That means that the refrigerant in the evaporator has to be colder than the surroundings and in the condenser, it has to be warmer.

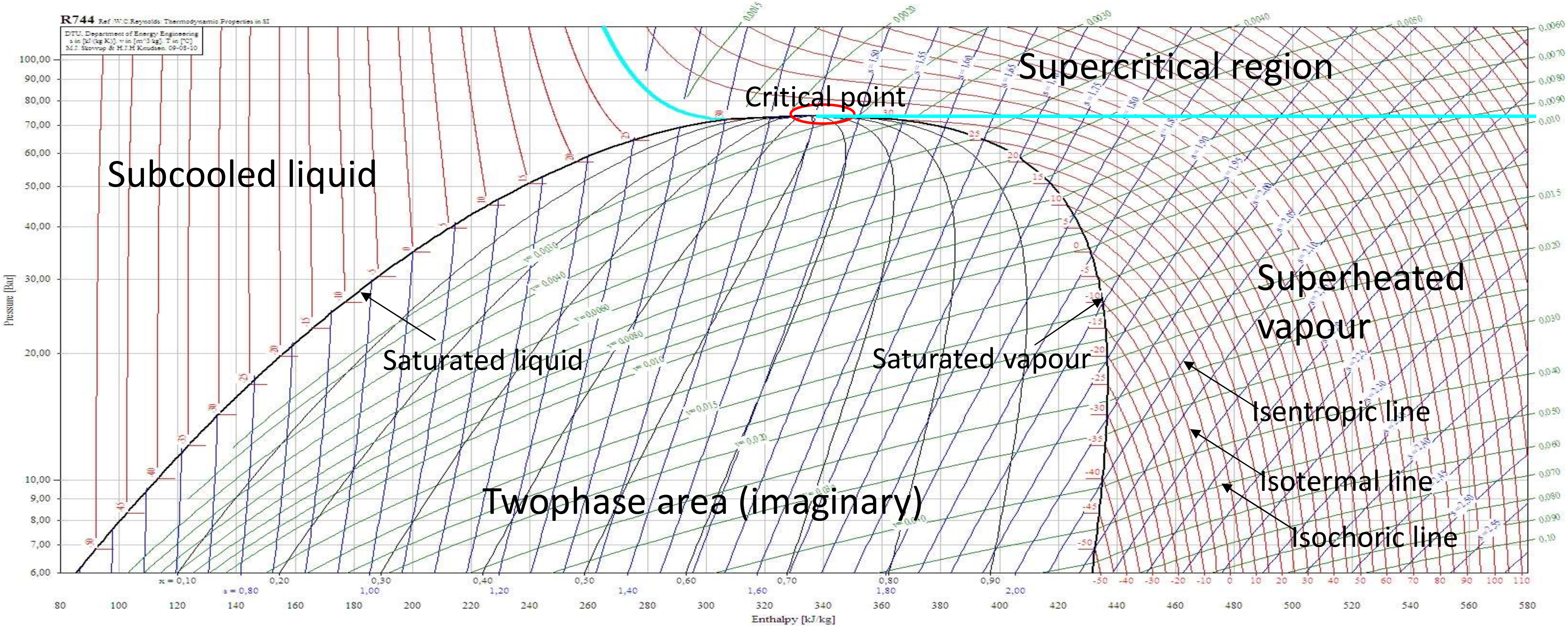
The temperature travel.

- Looking at heat going from 15°C to 40°C through a chiller



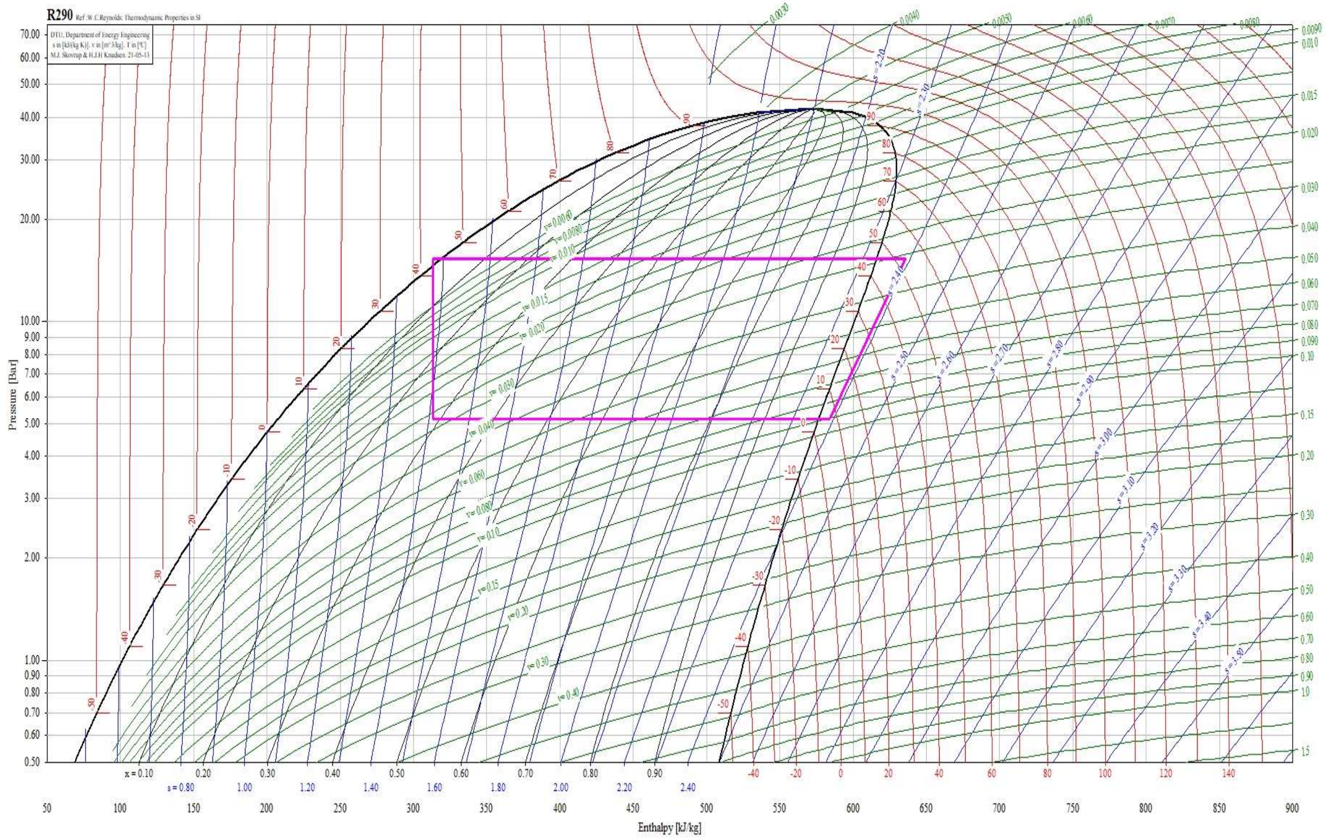


Basic thermodynamics. The logp,h chart



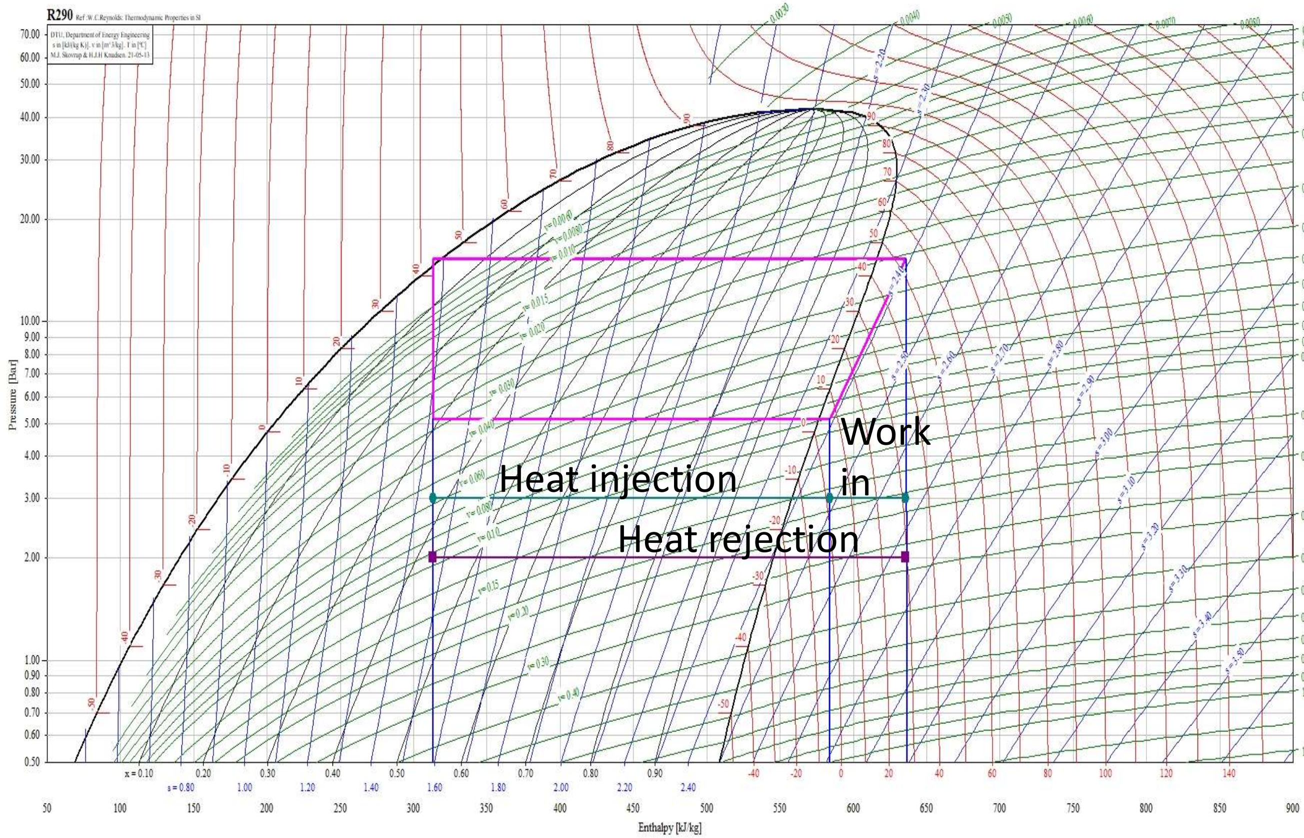
Basic thermodynamics. The logp, h chart

- Drawing the process in the logp,h-chart
  - First draw lines at evaporation and condensation temperature.
  - From the temperature at condenser exit, draw an isenthalp to evaporation. This is the expansion line.
  - From the exit temperature from the evaporator, on the line of the evaporation, draw an isentropic line to the condenser line. This is the isentropic compression line.
  - Clean up.



Basic thermodynamics. The logp, h chart

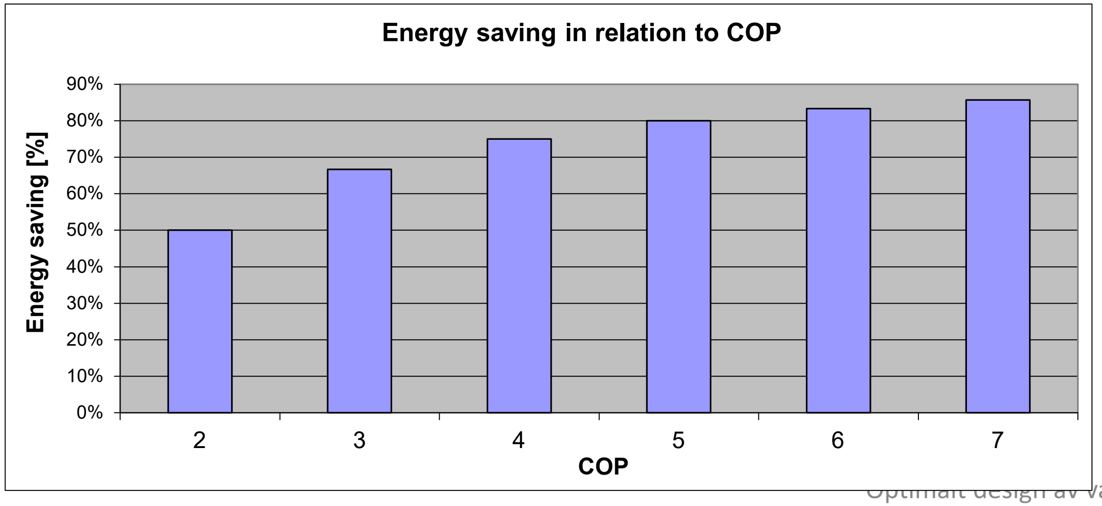
- Using the cycle in the logp,h-chart
- Enthalpy is energy, both thermal and mechanical.
- Extend process endpoints to enthalpy axis.
- The energy exchanged can be mesured directly as the distance between the measure lines.
- This example is based on an isentropic compression, theoretical optimum, but never occurs.
- How can we guess closer to reality?

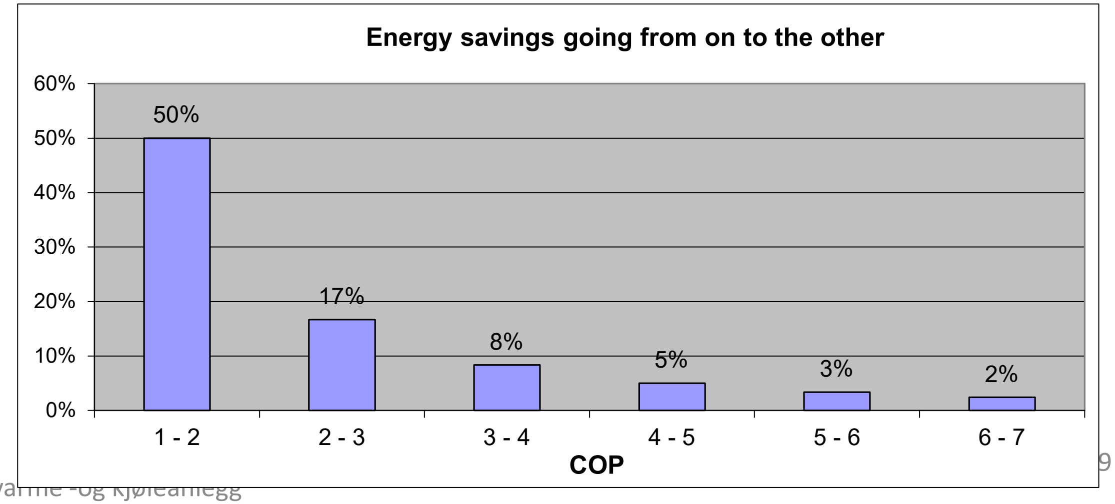


Basic thermodynamics. COP

Coefficient Of Performance / COP ; Energy to Energy Ratio / EER

- COP Cold = EER = Heat injection / work in
- COP Heat = Heat rejection / work in = EER + 1.
- NB. Applies to process ONLY. Does not take powertrain efficiency or heat losses from components.
- COP can be a trickster !!



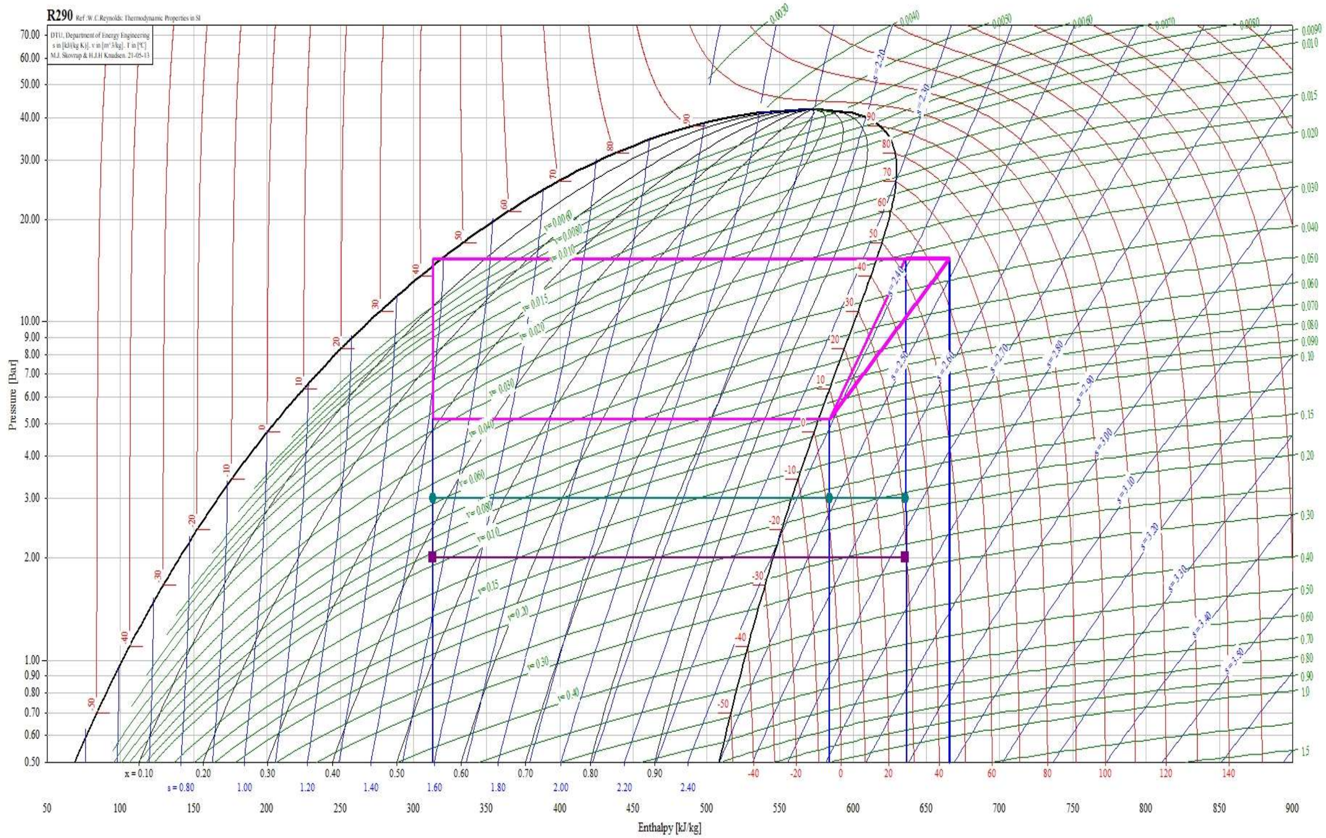


Basic thermodynamics. Carnot

- Coefficient Of Performance / COP ; Energy to Energy Ratio / EER
- Carnot COP applies only temperatures. Absolute temperatures, Kelvin [K]. 0°C = 273.15 K
- Theoretical maximum efficiency.
- $\varepsilon_{CARNOT,COLD} = \frac{T_{EVAP}}{T_{COND} - T_{EVAP}} = \frac{273.15+3}{45-3} = \frac{276.15}{42} = 6.58$
- Real world COP often half of Carnot COP. Useful for an approximation of the real COP.
- COP Cold = EER = Heat injection / work in
- Guess COP Cold = 6.58/2 = 3.29
- Heat injection found as 270 kJ/kg.
- Work in becomes = 270/3.29 = 82 kJ/kg.

Basic thermodynamics. The logp, h chart

- Correcting the new compression line
  - Draw the new measure line for the end point of compression.
  - Draw the new compression line.
  - I checked the compressor exit temperature against the Dorin calculation programme.
  - I read it to app. 66°C
  - Dorin calculated to 64.3°C
  - Pretty close

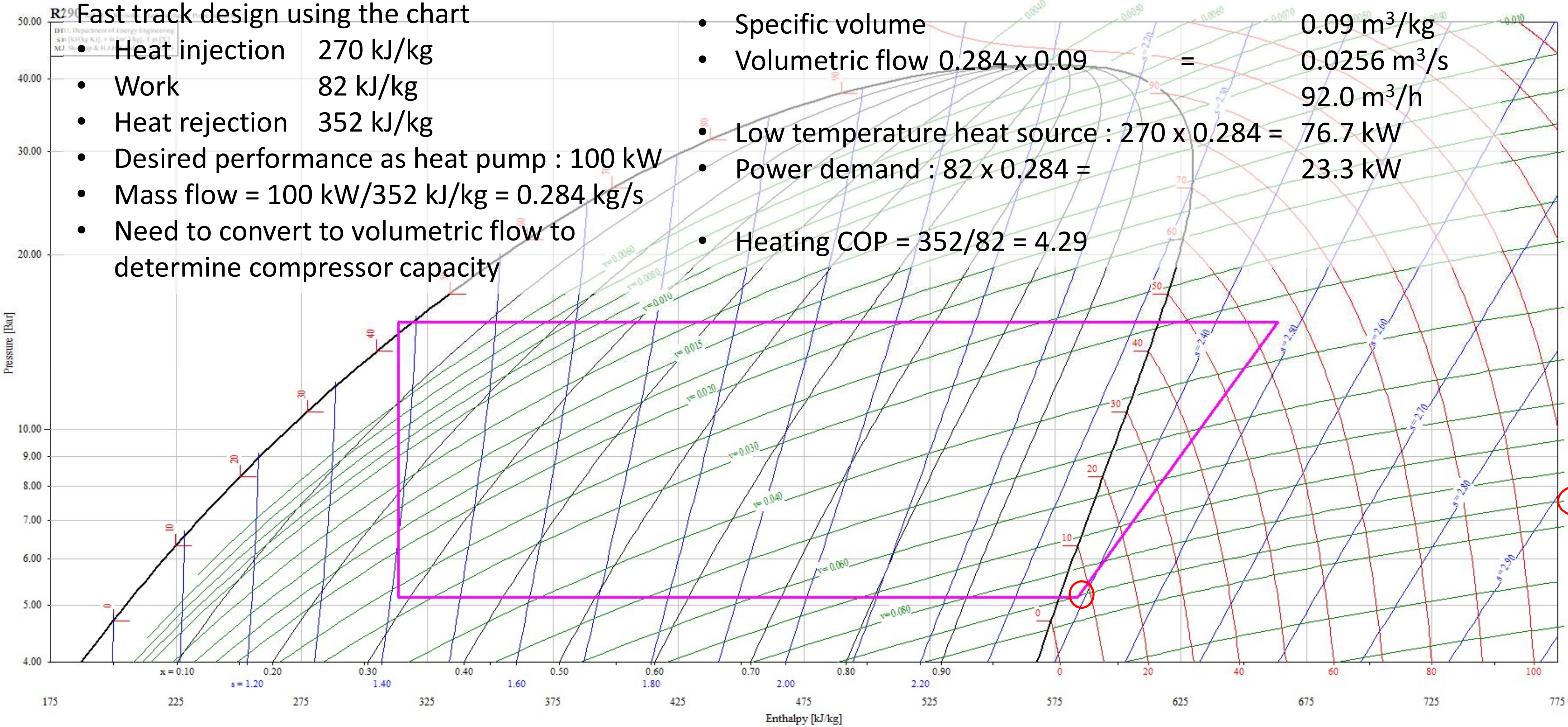


Basic thermodynamics. The logp, h chart

Fast track design using the chart

- Heat injection 270 kJ/kg
- Work 82 kJ/kg
- Heat rejection 352 kJ/kg
- Desired performance as heat pump : 100 kW
- Mass flow = 100 kW/352 kJ/kg = 0.284 kg/s
- Need to convert to volumetric flow to determine compressor capacity

- Specific volume 0.09 m^3/kg
- Volumetric flow 0.284 x 0.09 = 0.0256 m^3/s
  92.0 m^3/h
- Low temperature heat source : 270 x 0.284 = 76.7 kW
- Power demand : 82 x 0.284 = 23.3 kW
- Heating COP = 352/82 = 4.29



Annual 99.6% minimum temperatures according to ASHRAE

• Edinburgh	-5.2°C
• Aberdeen	-4.6°C
• Leicester	-2.4°C
• London	-1.9°C
• Plymouth	-1.4°C
• Stornoway	-1.1°C
• Cardiff	-1.0°C
• Bergen Airport	-7.1°C
• Røràs (inland Norway)	-32.4°C

The UK is not cold in a heat pump matter of speaking.

Air will prove a very good heat source.

I have shown that the economic efficiency of borehole systems on the west coast of Norway is very poor.

The paper on this will be provided after the course

Design demand for the heat pump

- There is NOT a straight forward answer to this.
- It depends on
  - Type of building
    - Dwelling
    - Office building
  - Heat distribution system and temperature demand
    - Radiators. Old buildings typically 80°C/60°C, but generous designed, new buildings often 60°C/40°C
    - Heat convectors
    - Ventilation
    - Under floor heating
  - Age and quality of the building
  - Climate
  - Available low temperature heat source

Design demand for the heat pump

- In principle there is not difference when designing for building heating, whether it be dwellings or offices.
- However..
- The difference is how the building is being used.
- A home rarely sees big changes during the day in how many people are there and how much equipment they use.
- On the other hand that is exactly what happens in an office building.

Design demand for the heat pump

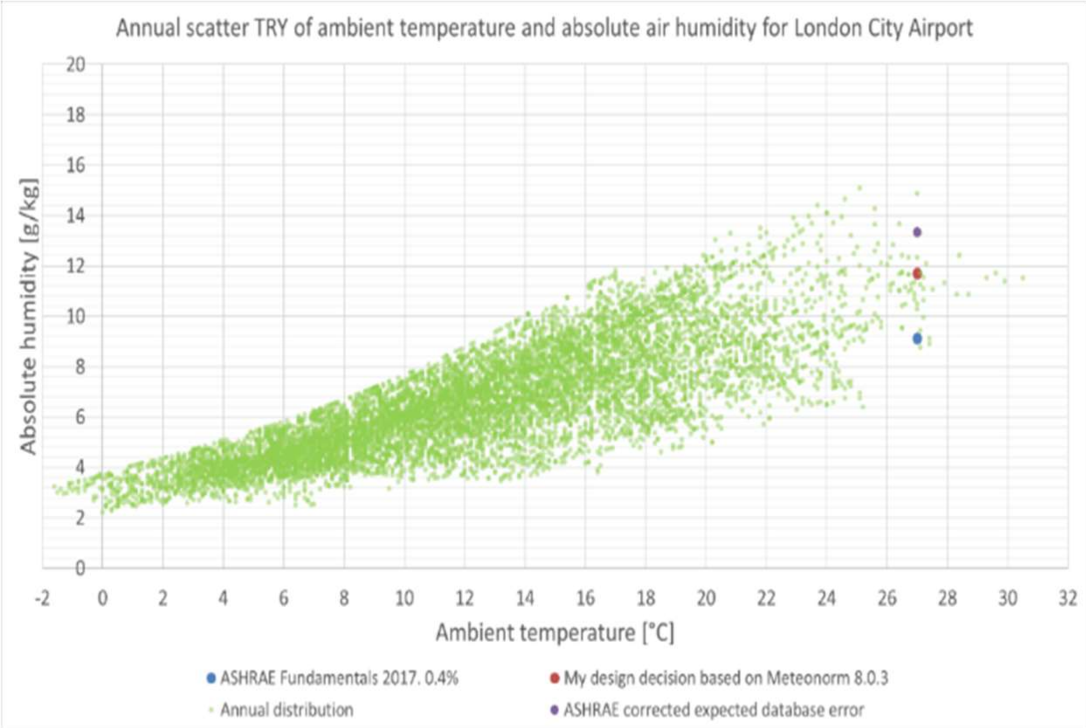
- A boiler and the distribution system around it, is designed to cover the heat loss at design ambient temperature.
- I say temperature, but you have to factor in wind, and that again is linked to the age and the quality of the building, especially windows and doors to take into account the contribution from air leakages in the building.
- The British tradition, that I only know from Morse and such, with openings under the front door is a definite NO NO.
- Usually when it is so cold that we reach winter design ambient it is calm weather.

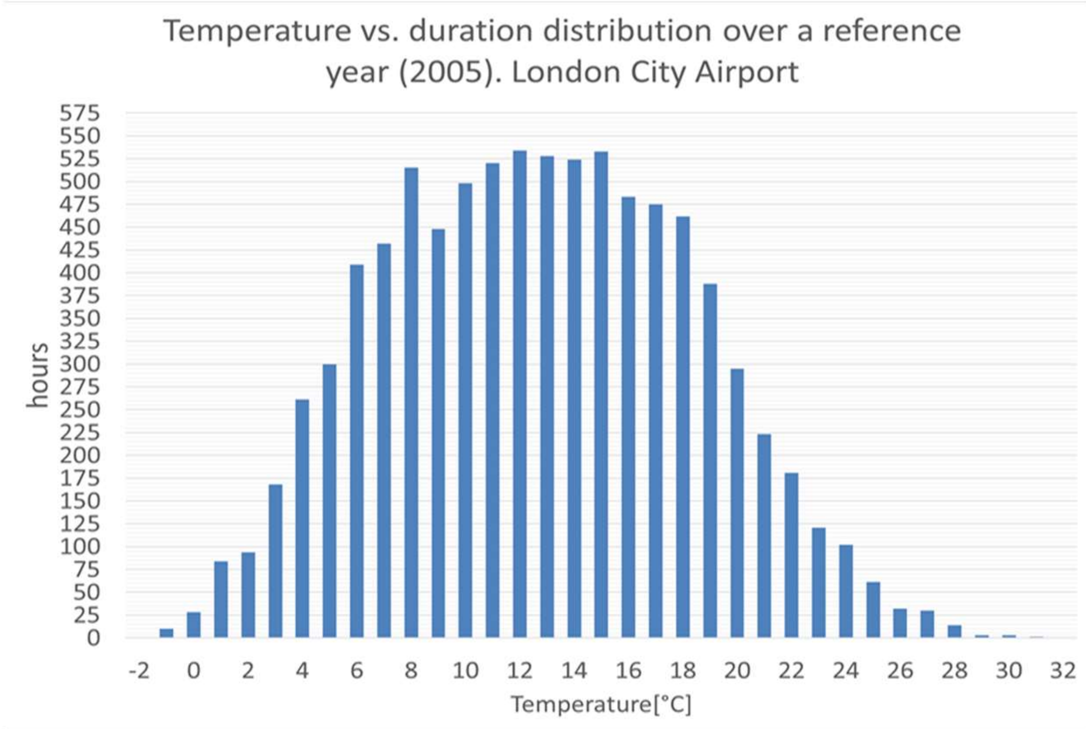
Design demand for the heat pump

- Factoring this in, the design of a boiler system is only dependent on the winter ambient design condition.
- This is not how you determine the design performance of the heat pump.
- The design performance is determined by an energy coverage rate for the heat pump.
- Usually this is between 90% - 95% of the annual net heat demand.
- So to find that, we have to look at the entire year.

Annual ambient conditions. Necessary for heat pump design

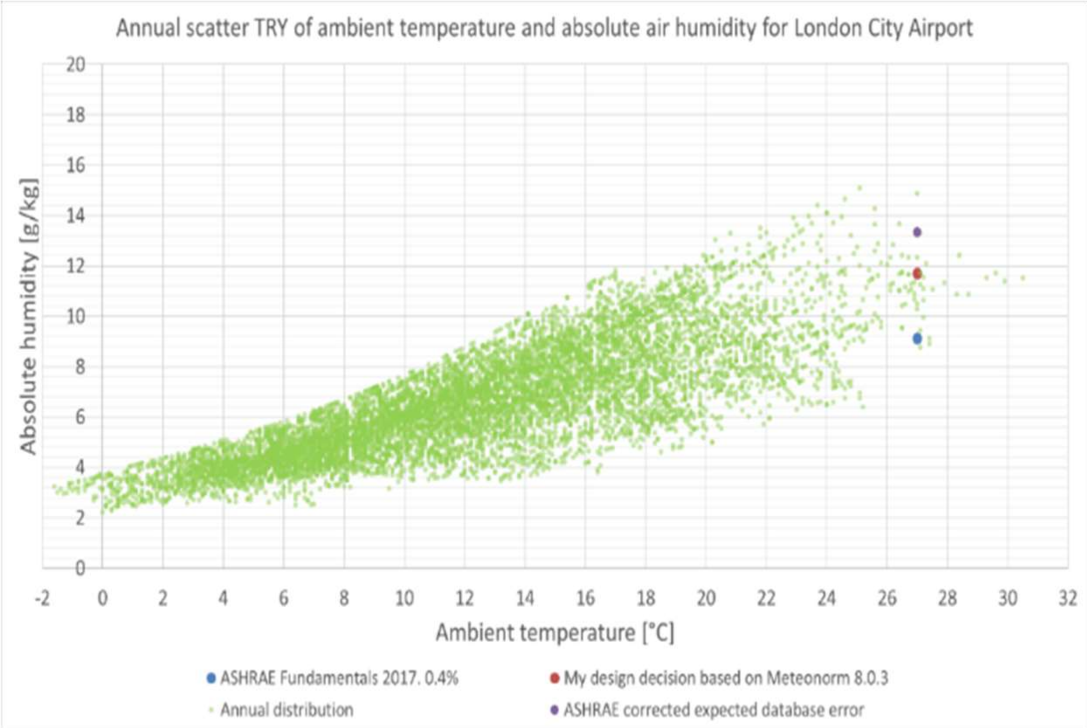
Data from London City Airport. 8760 datapoints, 2005, from Meteonorm 8.0.3

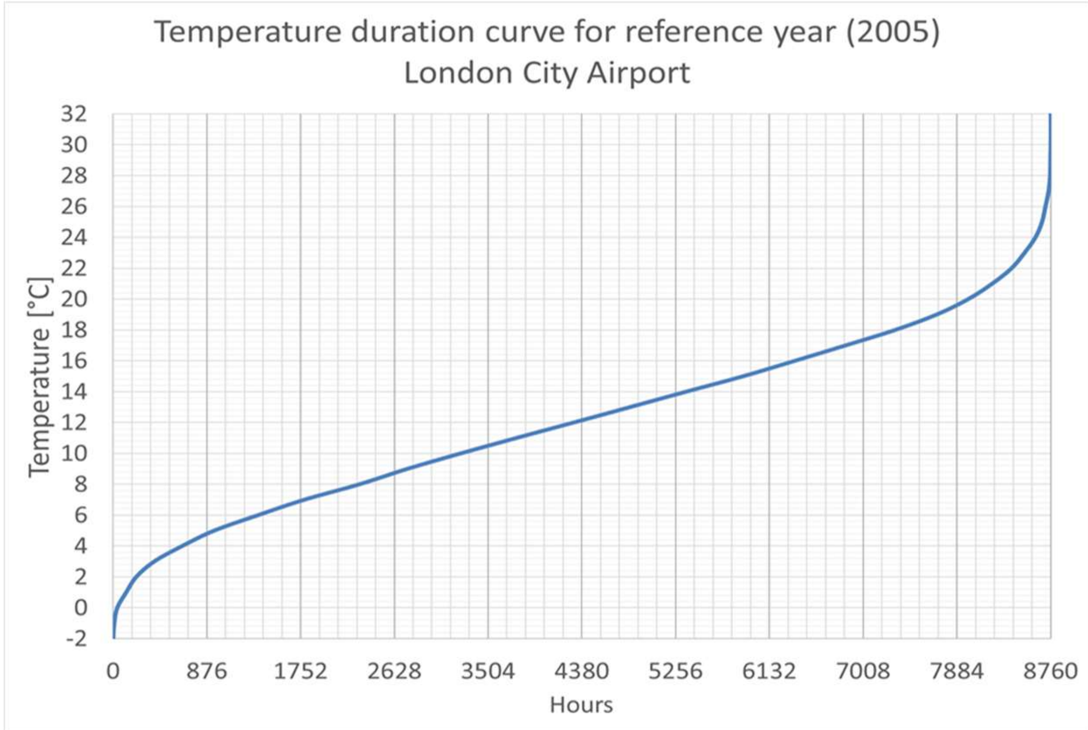




Annual ambient conditions. Necessary for heat pump design

Data from London City Airport. 8760 datapoints, 2005, from Meteonorm 8.0.3



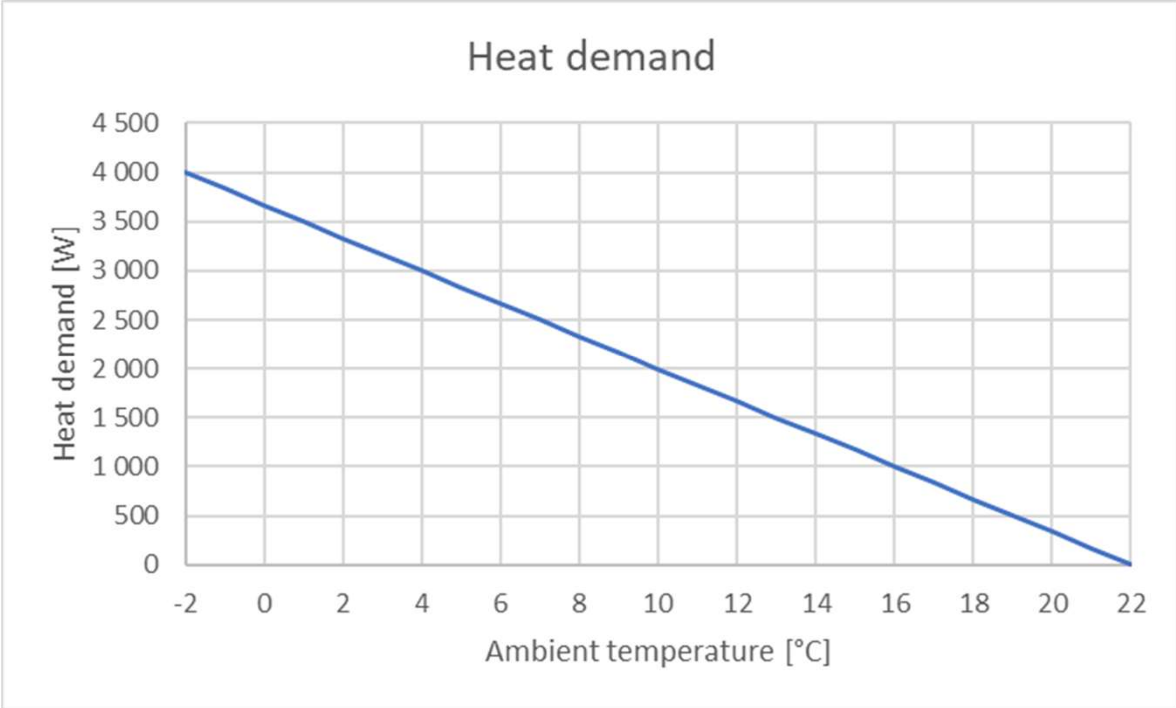


Winter design ambient temperature -2°C

Summer design ambient condition 27°C/50%rH

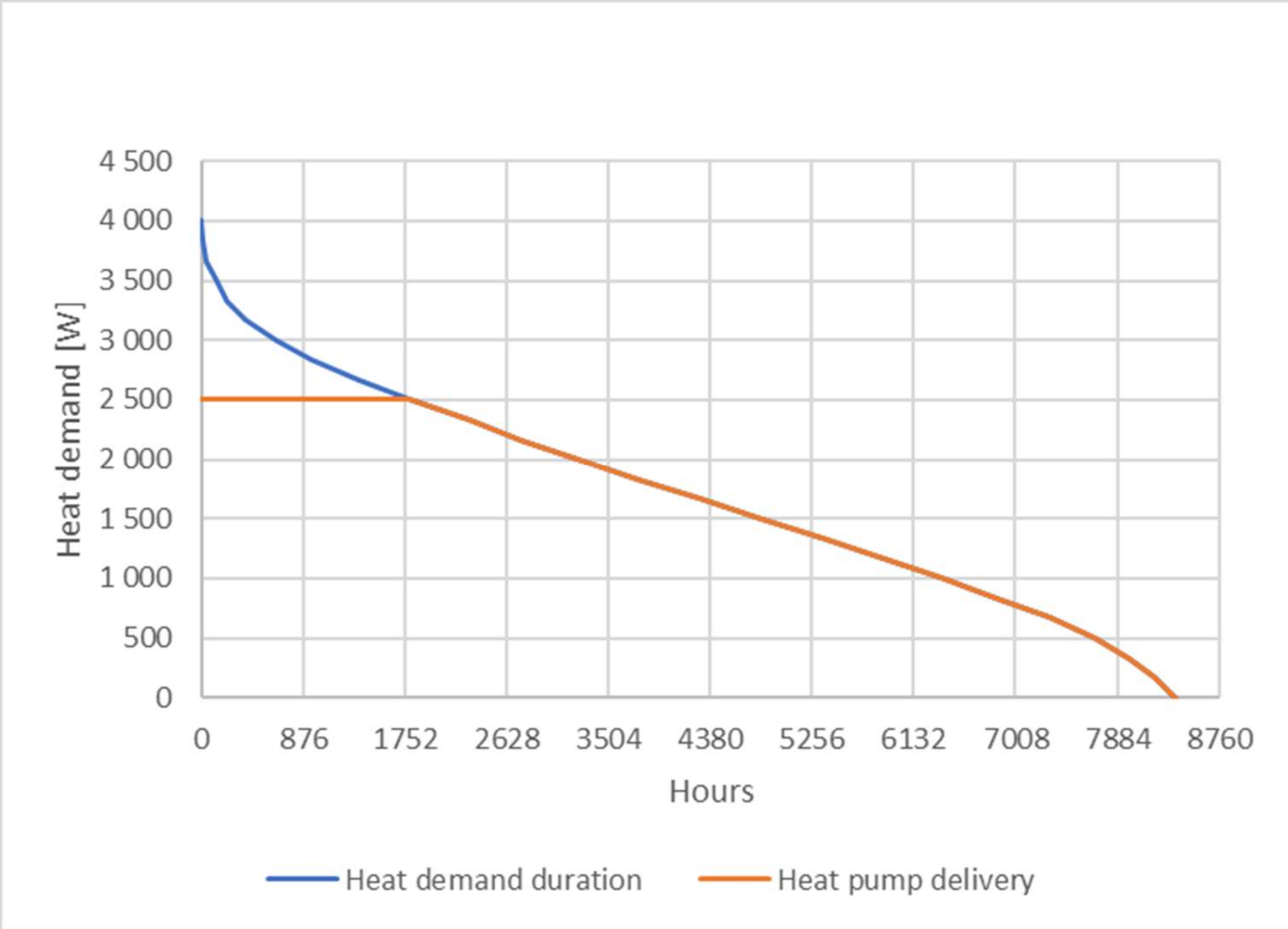
How to determine the design heat pump performance. Dwelling

- Building. 106 m² (1 140 ft²) on two floors.
- 40% of wall area are windows.
- Design heat loss at -2°C ambient and 22°C indoor temperature is 4 000 W.
- We discard internal loads.



How to determine the design heat pump performance. Dwelling

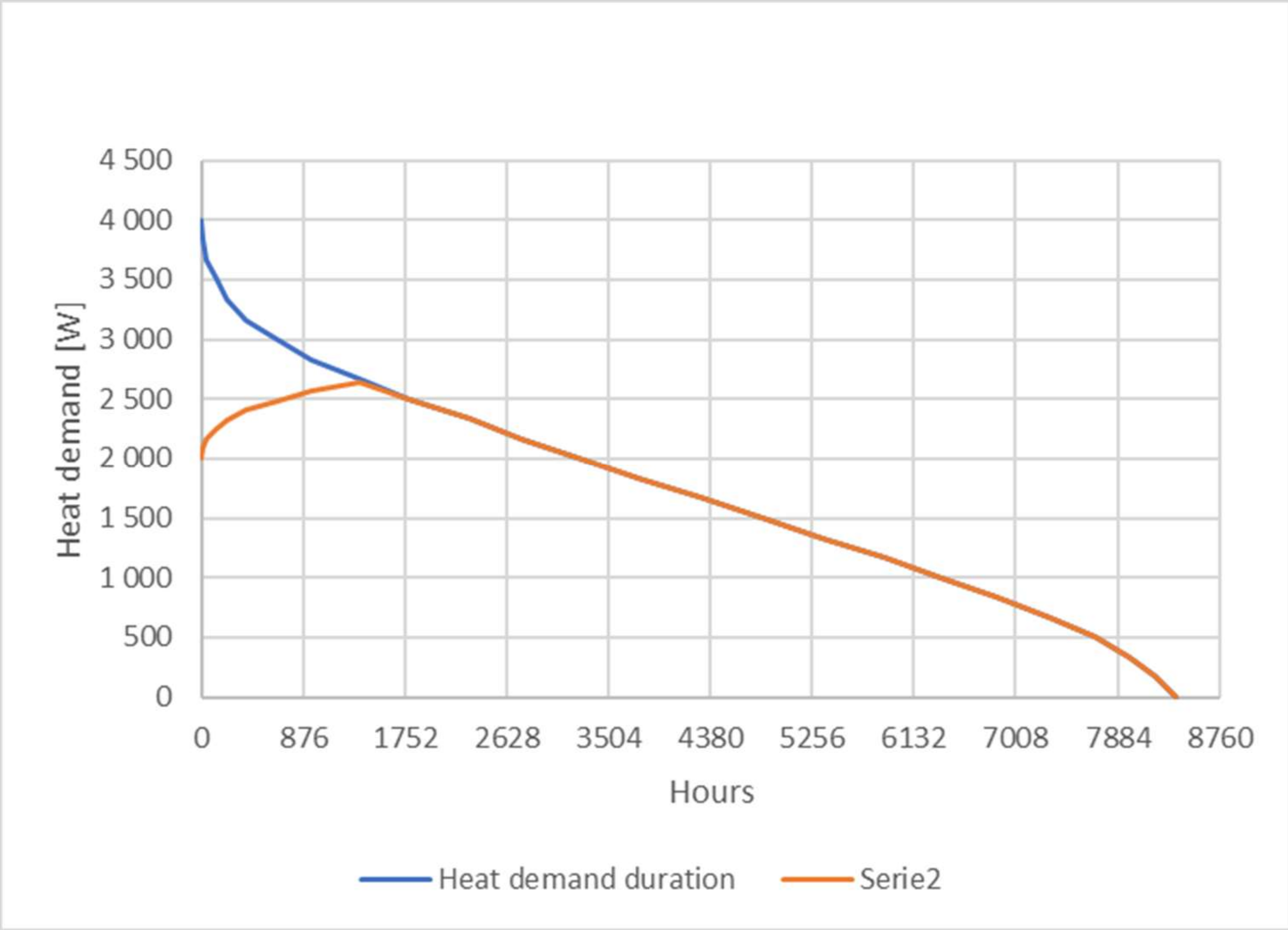
- Annual heat demand: 14 425 kWh
- Desired heat pump coverage : 95%
- Heat pump delivery: 13 700 kWh
- Design heat demand is 4 000 W
- Heat pump design performance is 2 500 W
- Revisiting the heat demand vs. ambient temperature curve shows us that the heat pump covers the entire demand from 7°C and upwards.
- This example does not take into account the loss of performance as the ambient temperature drops.



How to determine the design heat pump performance. Dwelling

Seeing the Big Picture

- Annual heat demand: 14 425 kWh
- Desired heat pump coverage : 95%
- Heat pump delivery: 13 700 kWh
- Design heat demand is 4 000 W
- As a rule of thumb, the performance decreases by 3% when the evaporation temperature drops by 1°C.
- We still want the energy coverage to be 95%.
- To achieve this we have to increase the design performance of the heat pump slightly to 2 640 W, which means that the heat pump will cover the heat demand from app. 6°C and upwards.



How to determine the design heat pump performance. Office

- Building area : 17 000 m^2
- Building heat demand, transmision & infiltration at design ambient : 13.4 W/m^2 = 228 kW[1]
- Minimum hygienic ventilation rate : 6 l/s/person[2] * 850 = 5 100 l/s = 18 360 m^3/h.
- Summer ventilation rate : 98 200 m3/h
- Design winter ventilation rate half the summer ventilation rate : 49 100 m3/h
- Air Handling Unit recuperator efficiency : 0.65
- Supply air temperature after recuperator : 0.65*(22-(-2)) + (-2) = 13.6°C
- Isothermal air supply.
- Ventilation design heat demand : 139 kW
- Total design heat demand : 367 kW

1 From the Norwegian TEK97, energy efficiency minimum requirements from 1997 to 2007

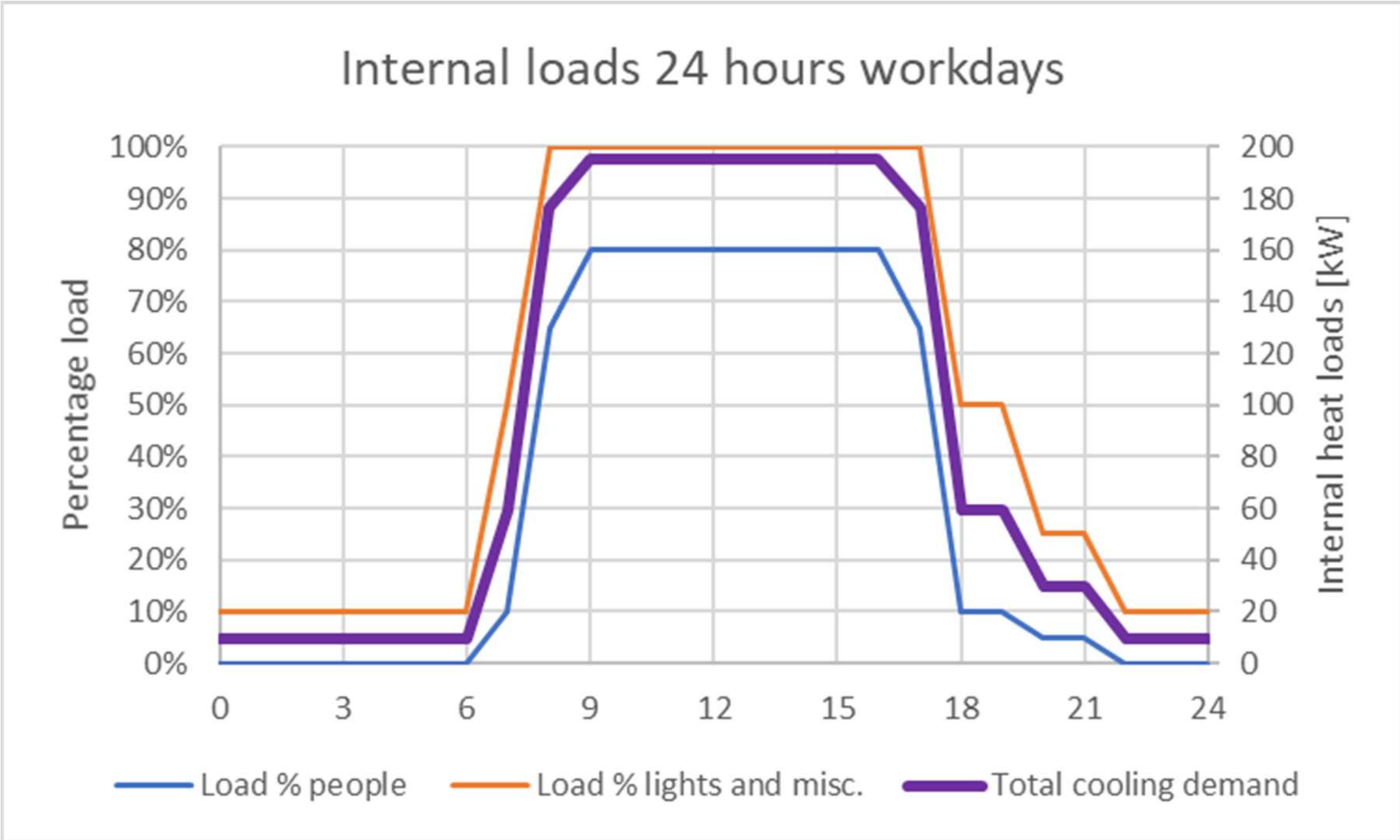
2 Information recieved from IoR.

How to determine the design heat pump performance. Office

- 850 work spaces. (Nobody says anything about how many that actually works)
- 100 W heat loss per person.
- Each person uses a laptop with attached screen. Total heat load of 50 W/person.
- Lights 5 W/m^2.
- Miscellaneous 0.5 W/m^2
- Occupancy 80% => Heat load work day = 0.8*850*(100+50) + 17 000*(5+0.5) = 195 500 W
- Supply air temperature 16°C. Indoor temperature to be maintained at 22°C.
- Necessary air flow to remove surplus heat : 31.9 kg/s = 98 200 m3/h at 27°C/50%rH or 95 400 m3/h through duct work at 16°C/80%rH
- Parasittical load of 1K from fans.
- Temperature of cooling coil 15°C
- Radiators designed for 80°C/60°C.
- Ventilation heating coil designed for 80°C/40°C.

Variation in internal loads

The variations in internal loads are usually very consistent during the work week.



Example. 25th and 26th of January 2005

Ambient variation

Heat loss variation

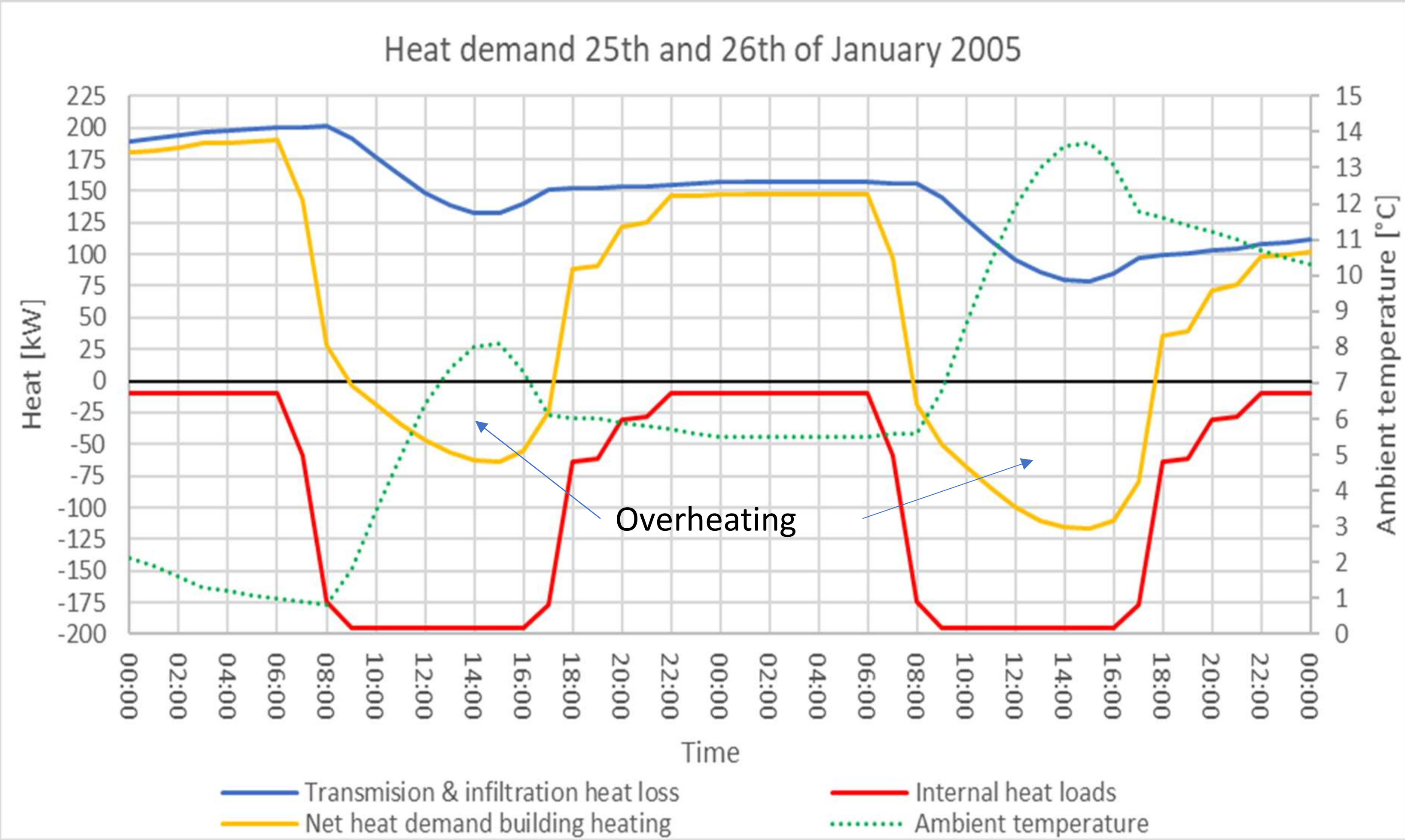
Internal loads

Net building heat demand.

At 2°C ambient the building starts to overheat if we don't do something.

Reduce supply air temperature.

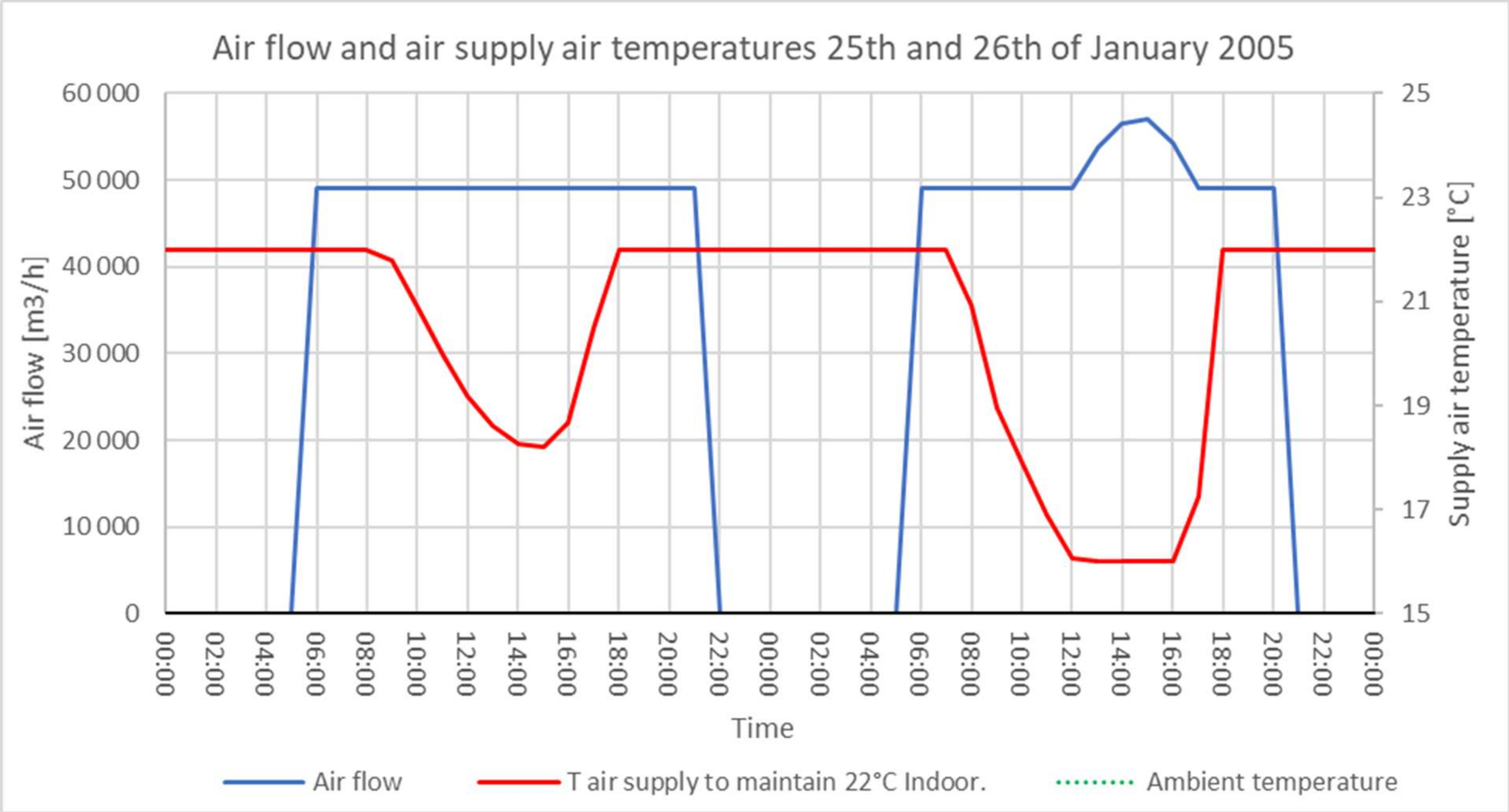
Next step increase air flow.



Example. 25th and 26th of January 2005

Reduce supply air temperature.

Next step increase air flow.

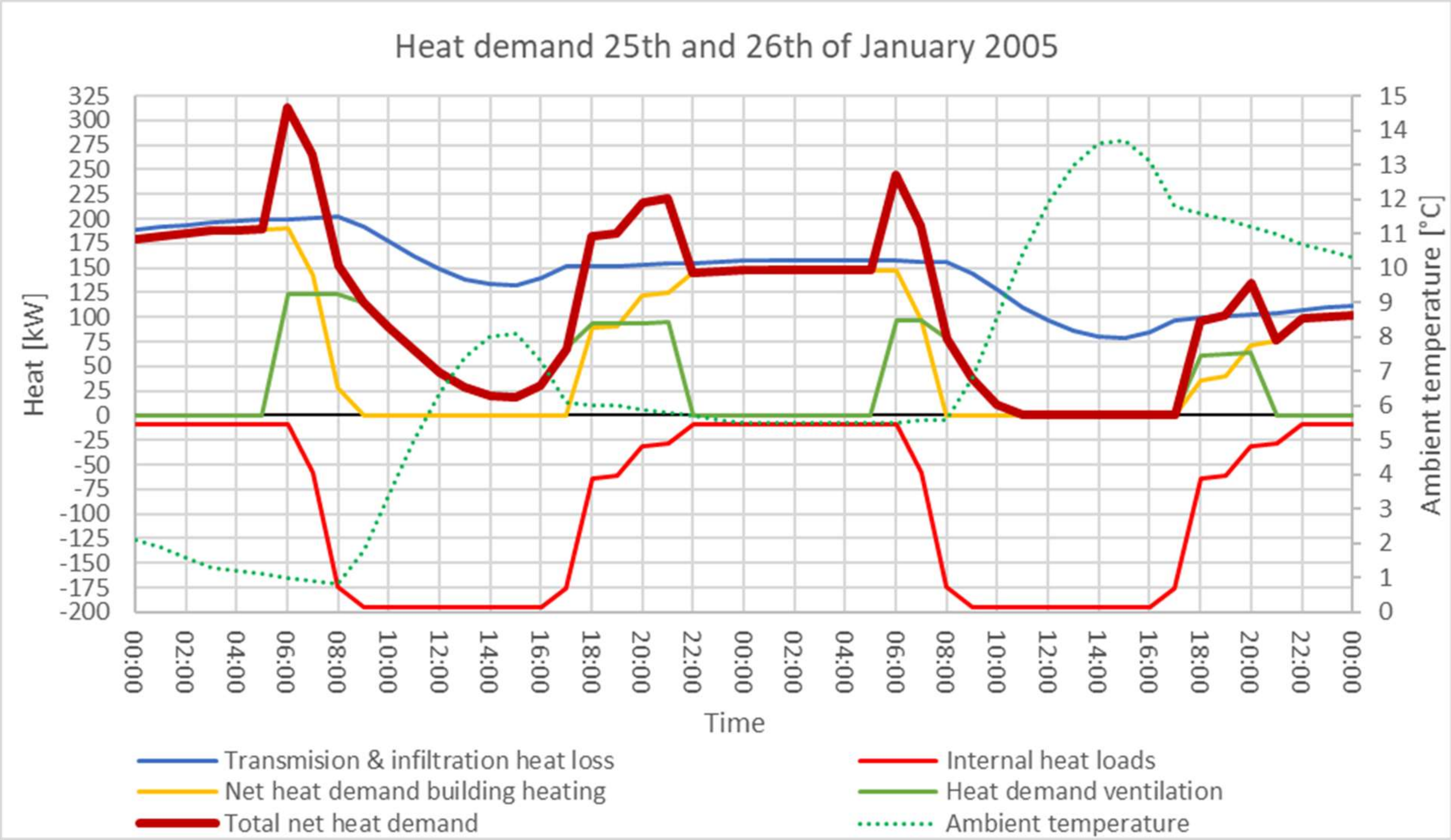


Example. 25th and 26th of January 2005

Ventilation air heat demand.

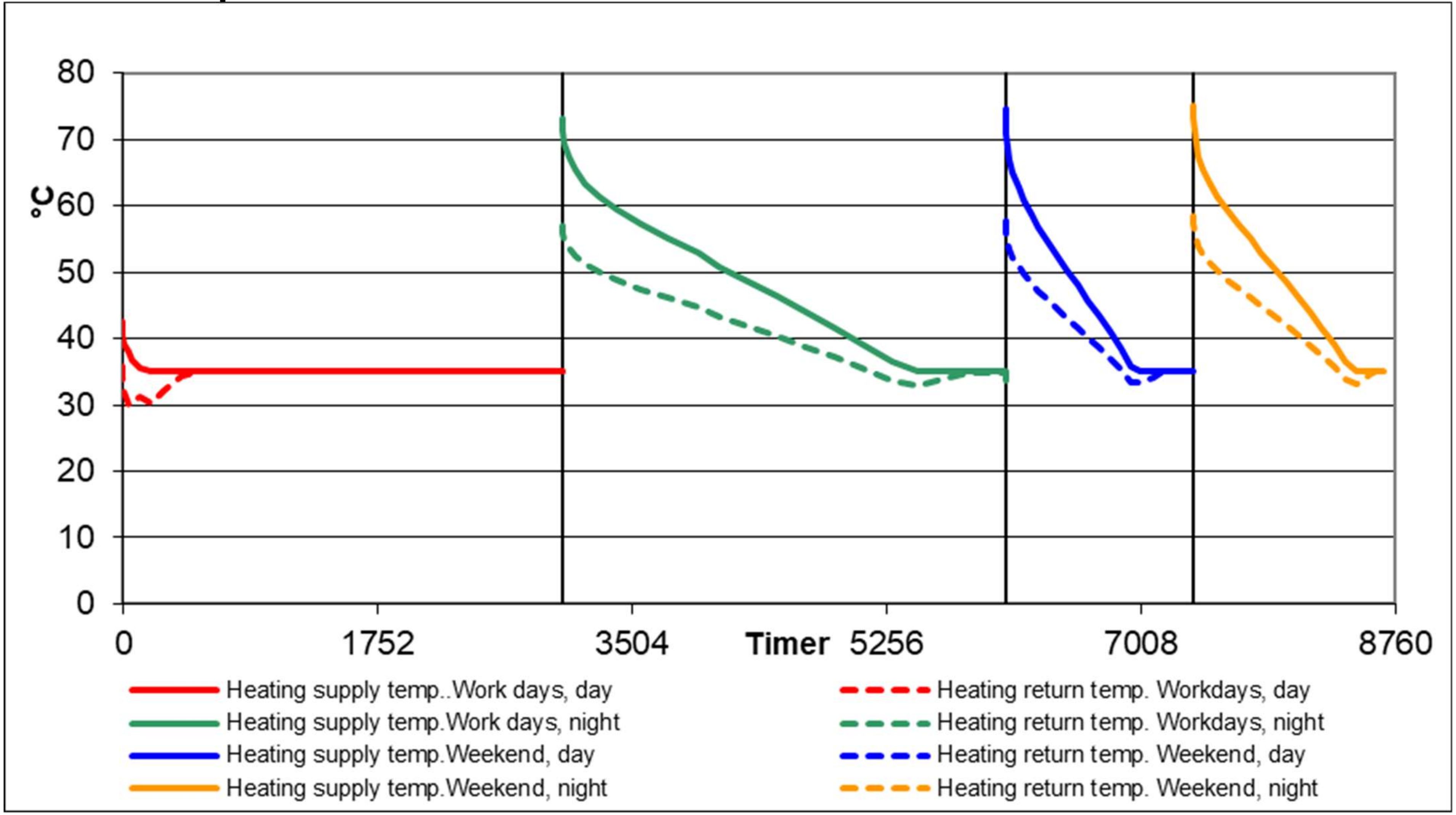
Total net heat demand

Challenging to be the heating system and maintaining 22°C indoor.



Annual heat demand

Temperature demand



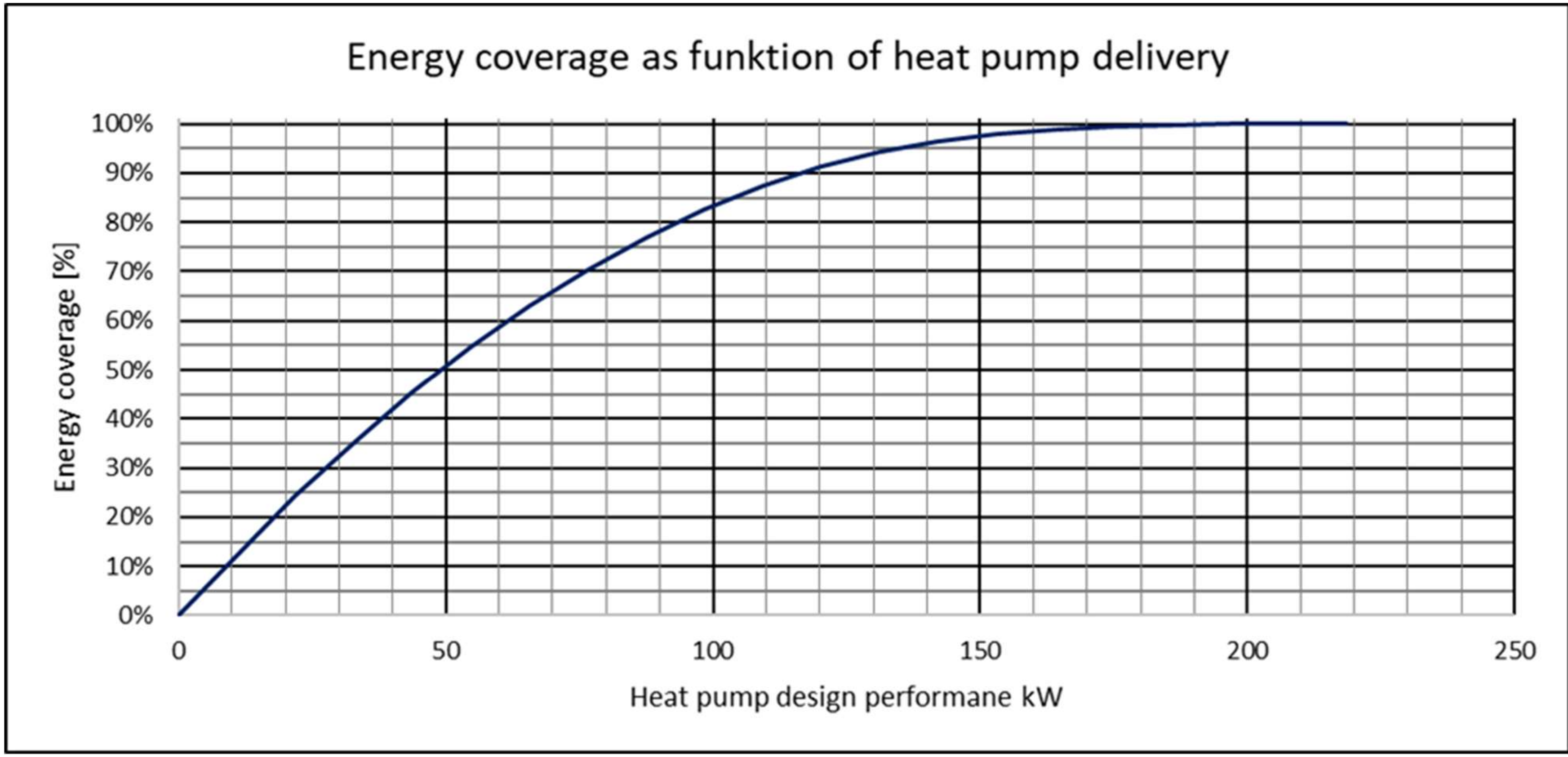
Annual heat demand

Total heat demand : 452 MWh

95% heat pump coverage : 430 MWh

Heat pump performance 132 kW.

Looking at the previous curves, the heat pump must be able to deliver 60°C

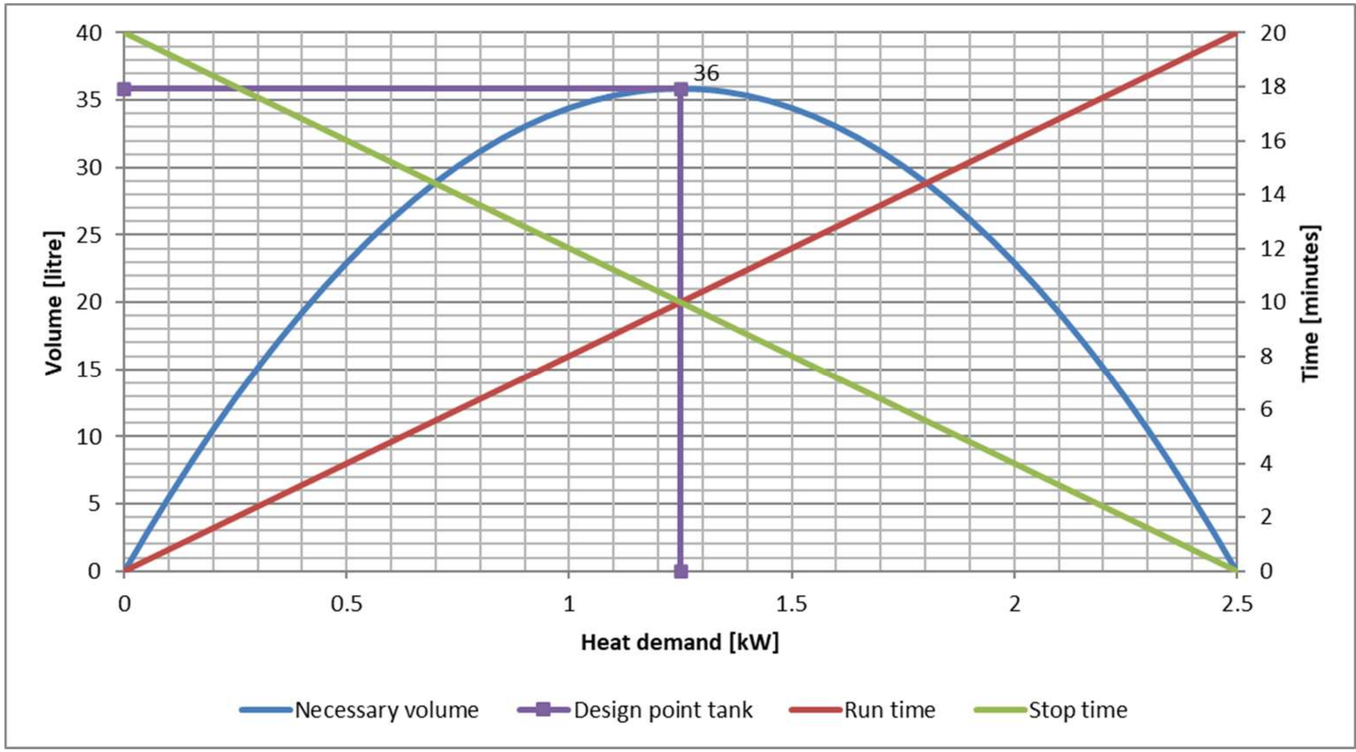


Heating system considerations. Musts

- The heat pump is ALWAYS to be the first heat production devise.
- The heating system must contain enough water to ensure at least 20 minutes between every start and stop.
  - Frequent start/stop cycles are heat pump killers.
- Usually you ensure this by having a sufficiently large tank in the system, and that the cut-in/cut-out ΔT is appropriate.
- Examples

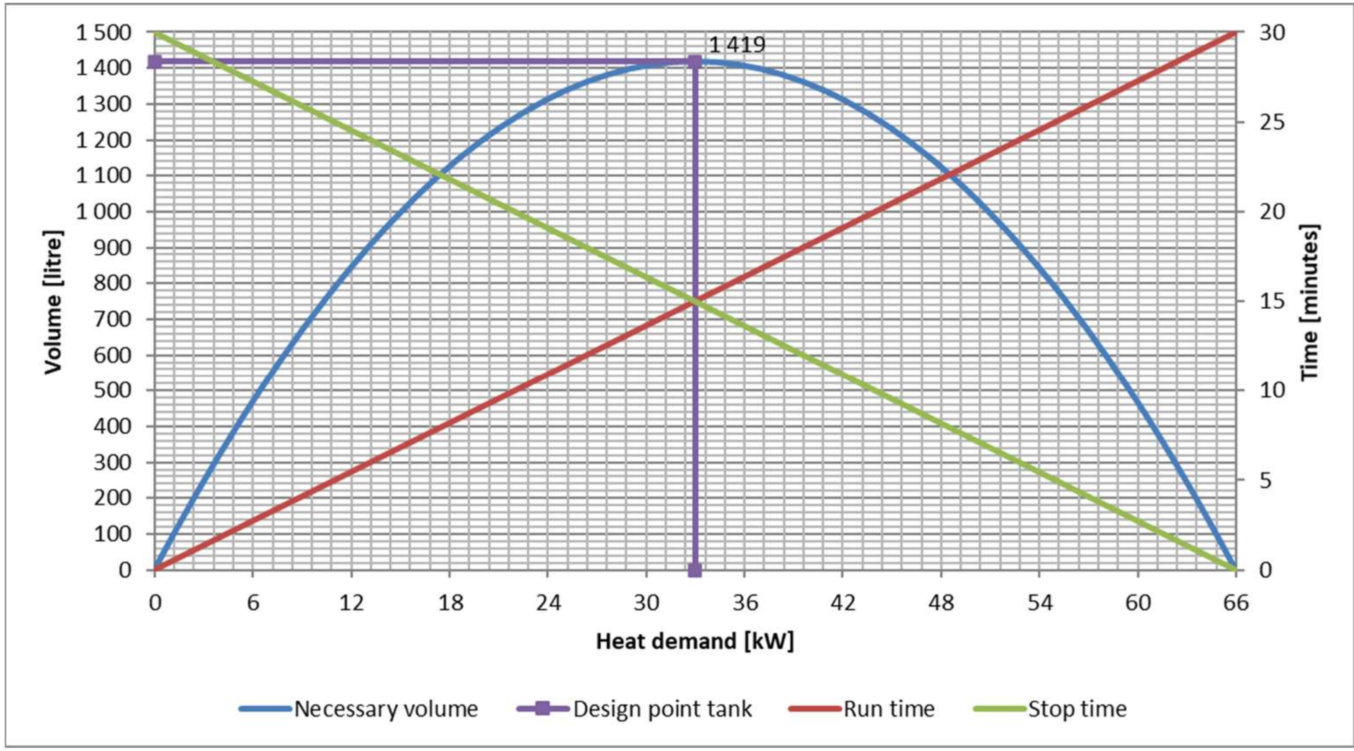
Tank volumes.

- The unit of the dwelling is small, so I would expect an on/off machine.
- An interval of 20 minutes between every stop and subsequent start should be acceptable.
- We need a tank volume of app. 36 litres at a ΔT of 5°C.



Tank volumes.

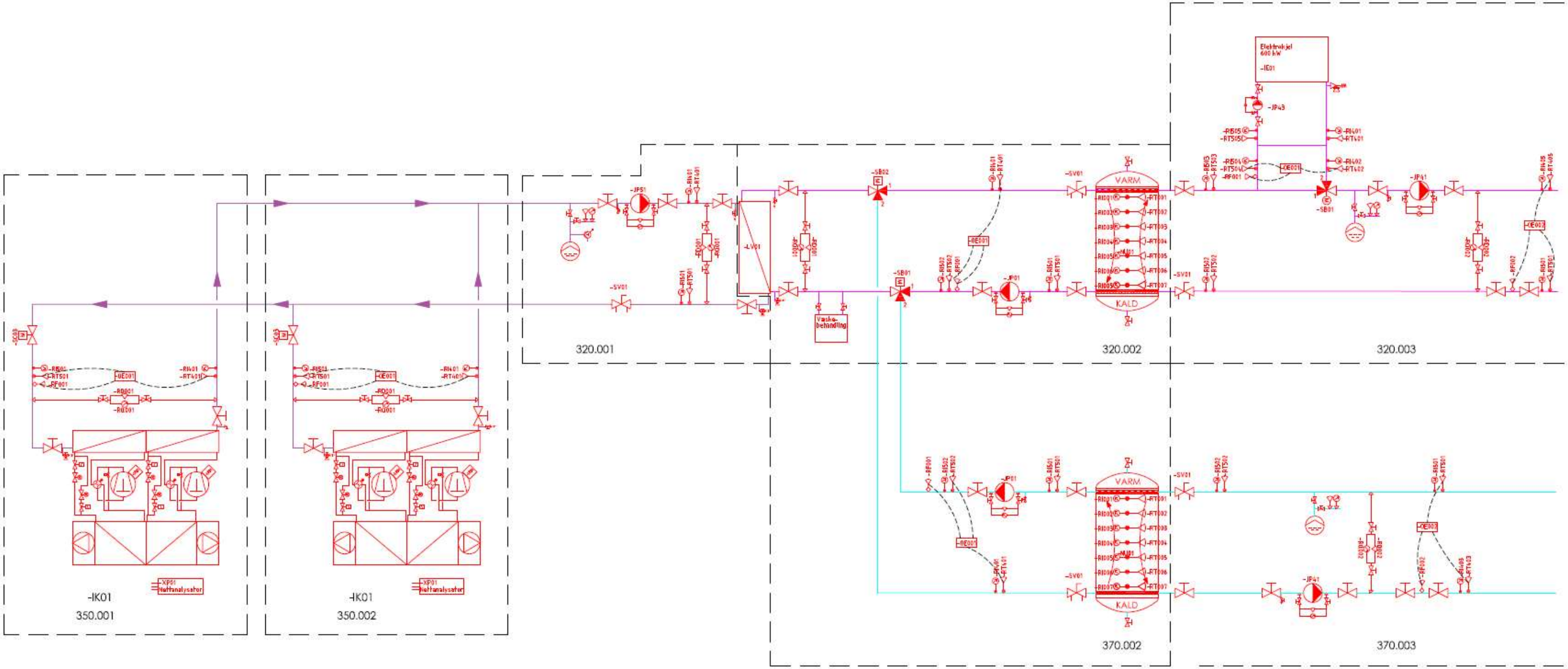
- The unit of the office building is able to run at half capacity, 66 kW
- As it is a fairly big machine, I prefer to have a minimum time frame of 30 minutes between every stop and subsequent start.
- We need a tank volume of app. 1 500 litres a ΔT of 5°C



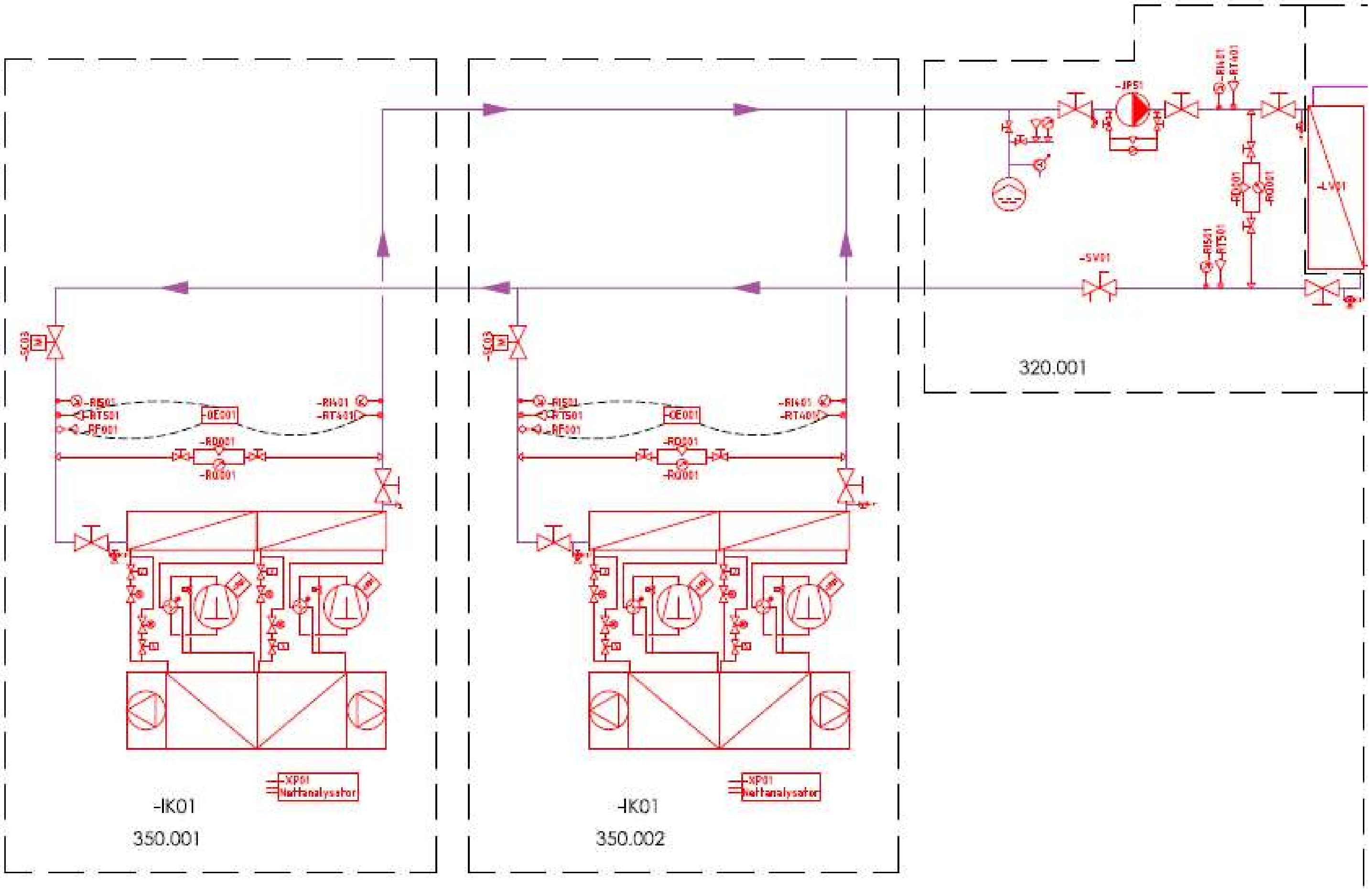
Heating system considerations. Shoulds

- In larger heat pump systems, the tank should be a stratification tank.
- This means that an extra pump will have to be fitted to the system.
- The tank should be fitted with temperature sensors from top to bottom. The heat pump is the controlled by the energy content in the tank

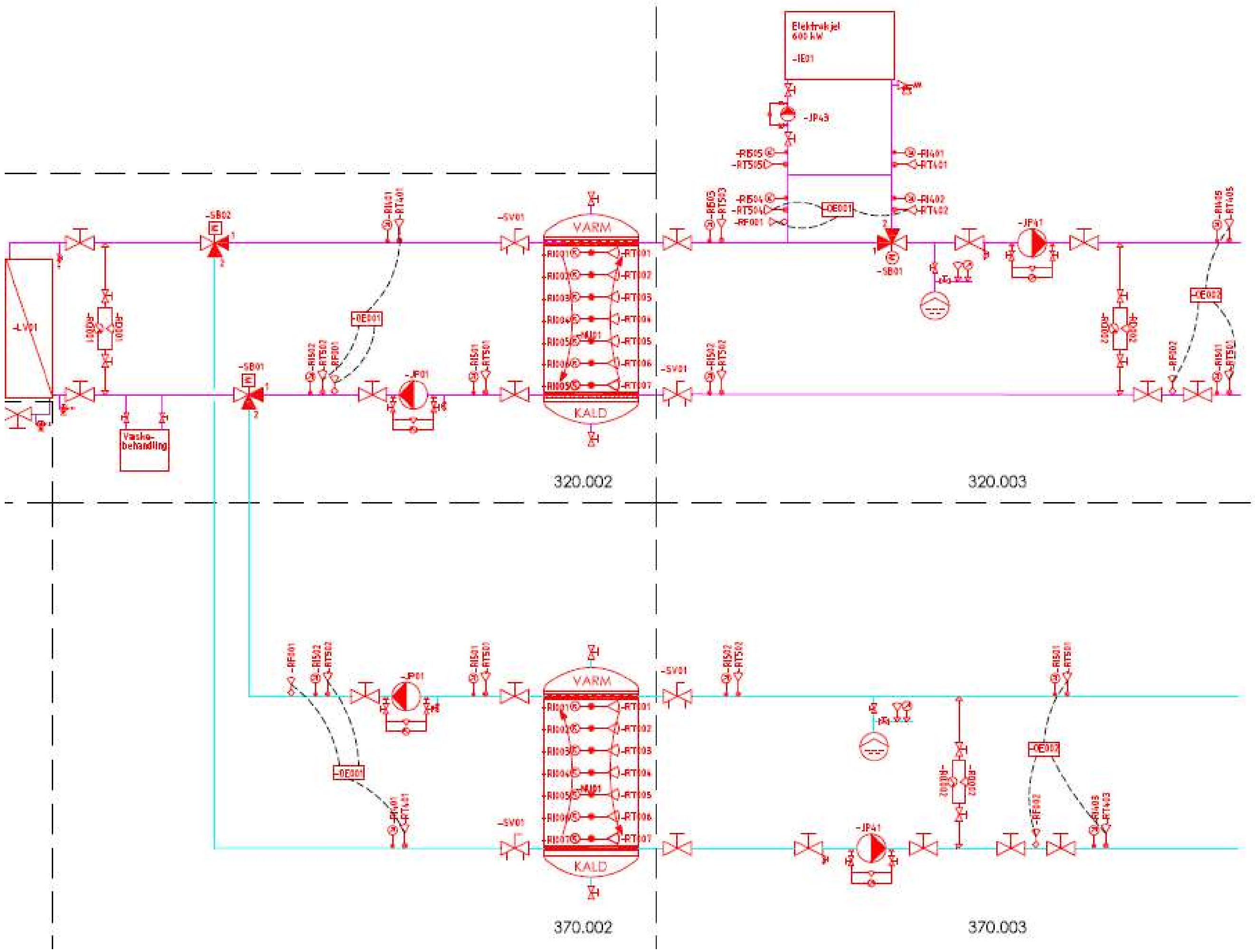
System example.



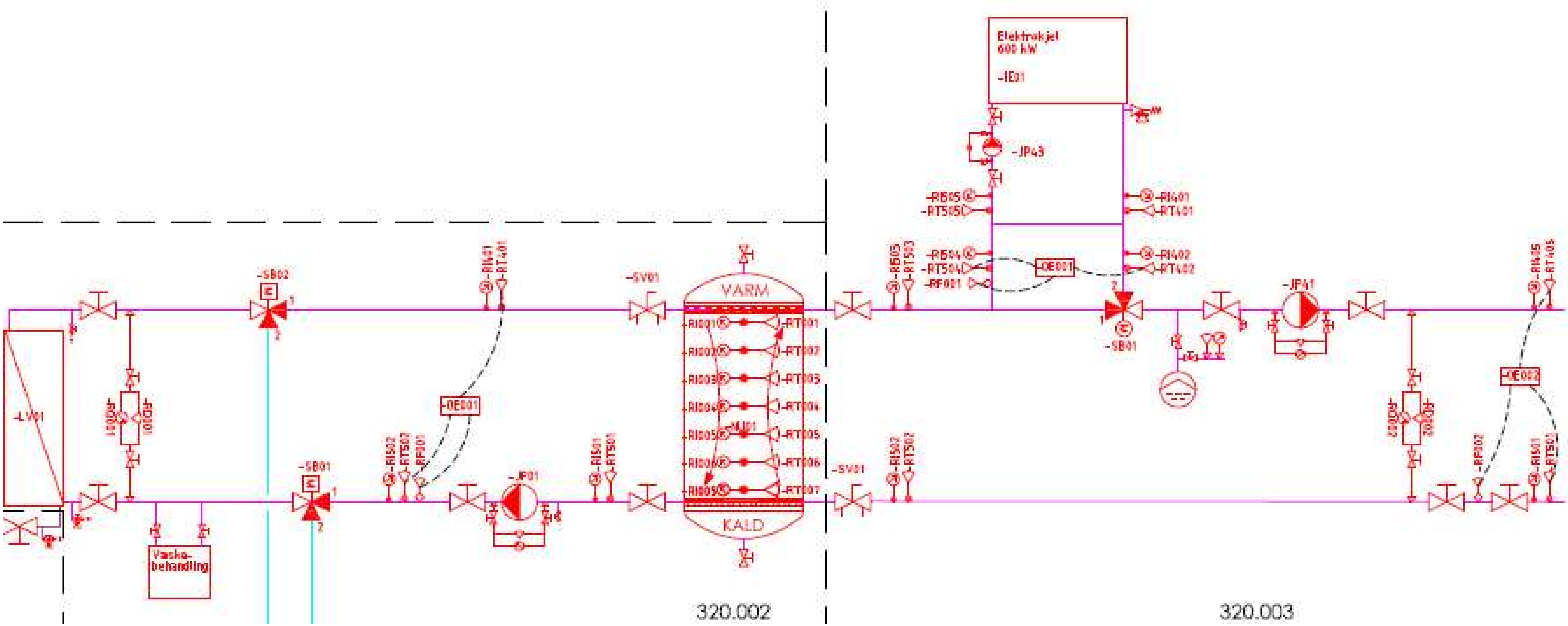
System example.



System example.



System example.



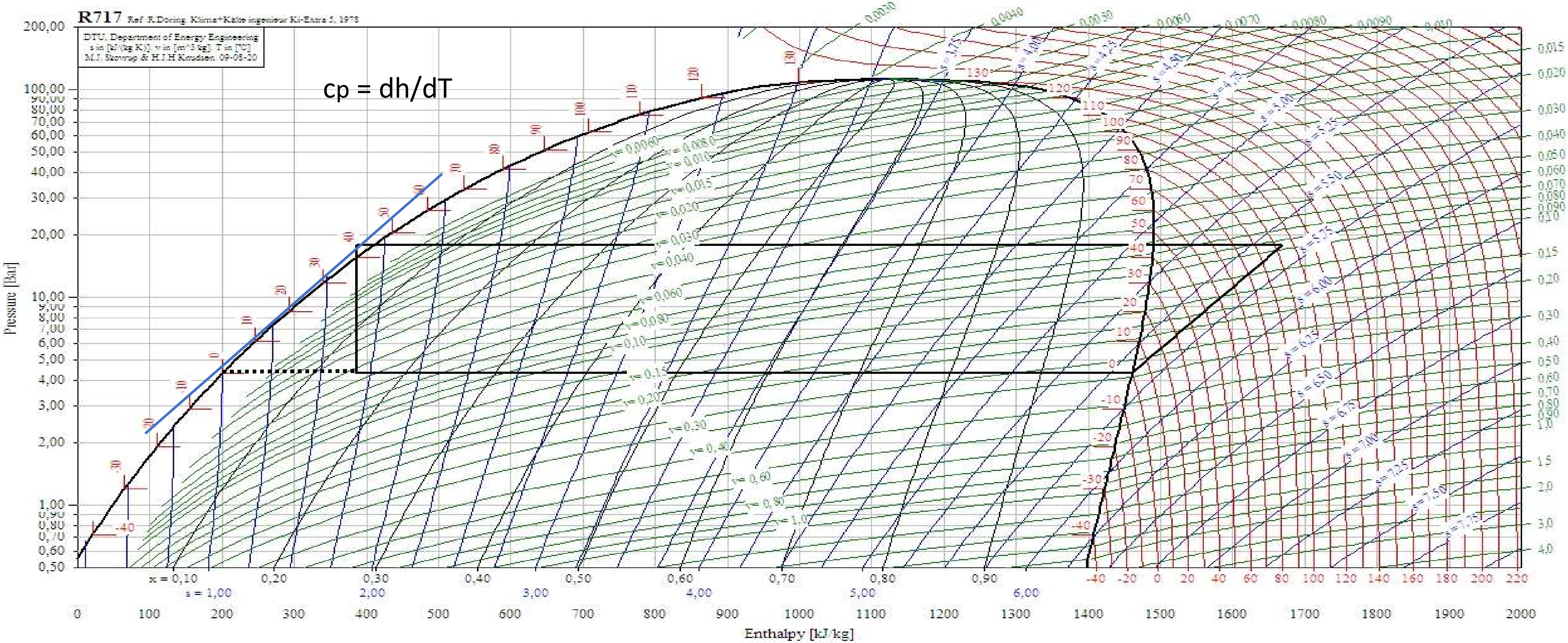
Basic thermodynamics. Choice of refrigerant

- The choice of refrigerant is the most important design decision.
- A questionable choice of compressor can often be mitigated by controls.
- An unfortunate design of evaporator or condenser can usually be mitigated by careful design of the systems surrounding the heat pump.
- Get the refrigerant wrong and you are up ****creek without a paddle.
- So let us examine this minefield.

Basic thermodynamics. Desired refrigerant properties

- Large heat of evaporation
- High vapour density to minimise compressor swept volume
- Low vapour density to achieve best possible compression process.
- Low specific heat in relation to heat of evaporation to minimise flash gas formation

Basic thermodynamics. Desired refrigerant properties



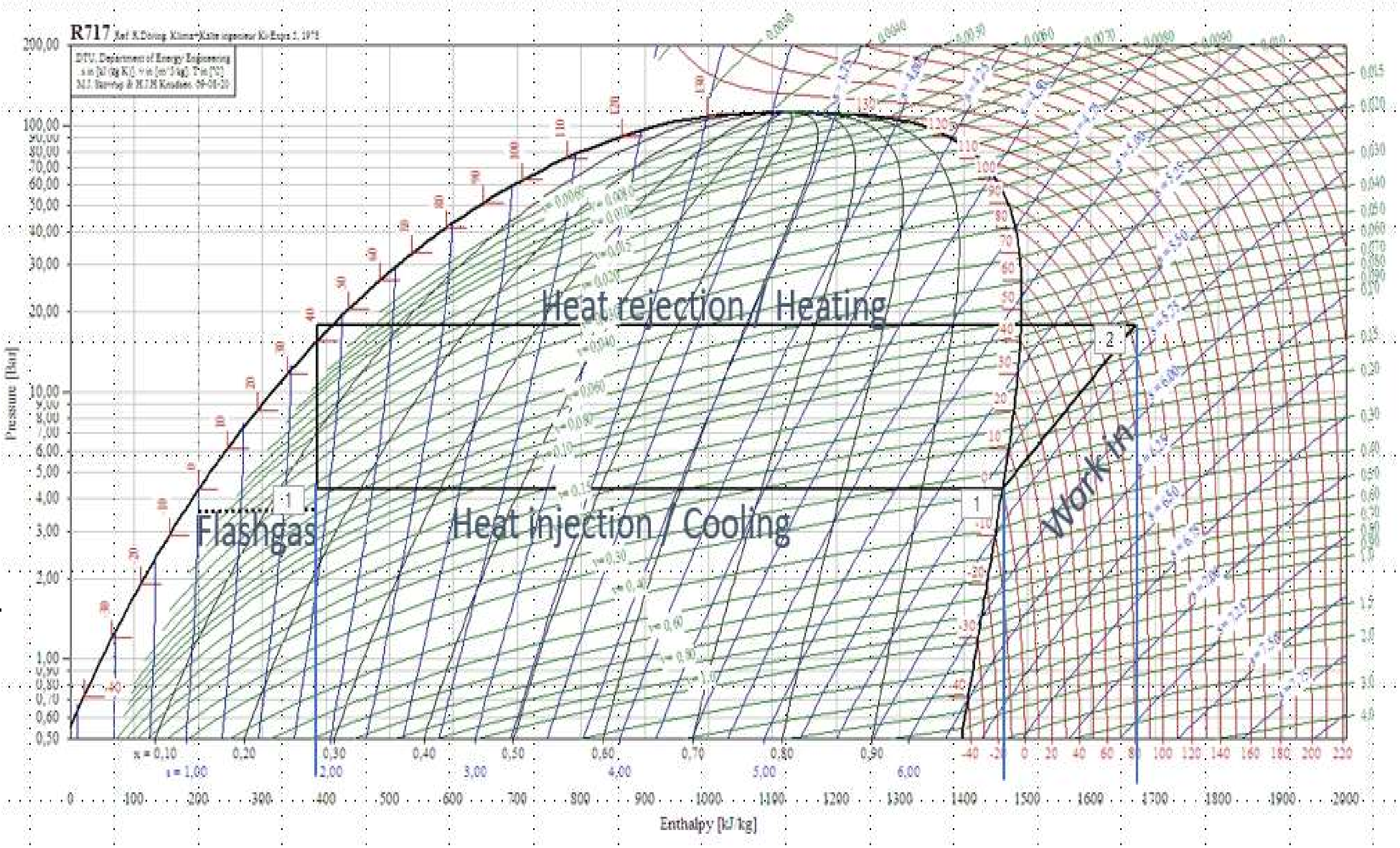
Basic thermodynamics. Desired refrigerant properties

- Large heat of evaporation
- High vapour density to minimise compressor swept volume
- Low vapour density to achieve best possible compression process.
- Low specific heat in relation to heat of evaporation to minimise flash gas formation
- High vapour heat capacity to minimise pressure line temperature.
- High critical pressure
- High critical temperature
- Chemically stable at high temperatures
- Good thermal conductivity in both liquid and gas phase

Basic thermodynamics

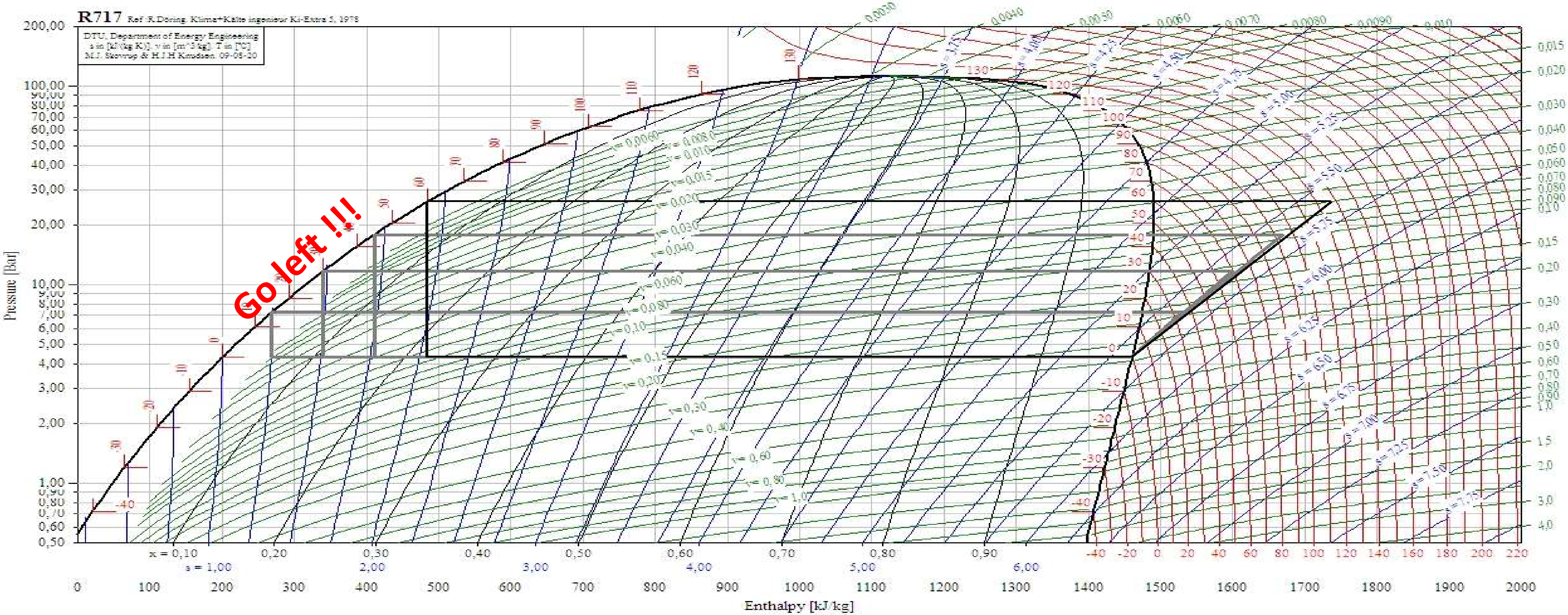
Loss of perfomance by increased temperature lift

- Two causes.
- At reduced evaporation temperature the gas entering the compressor gets thinner.
- Compressores are built to handle volume.
- Thinner gas at the same volumetric flow => smaller mass flow => smaller cooling performance

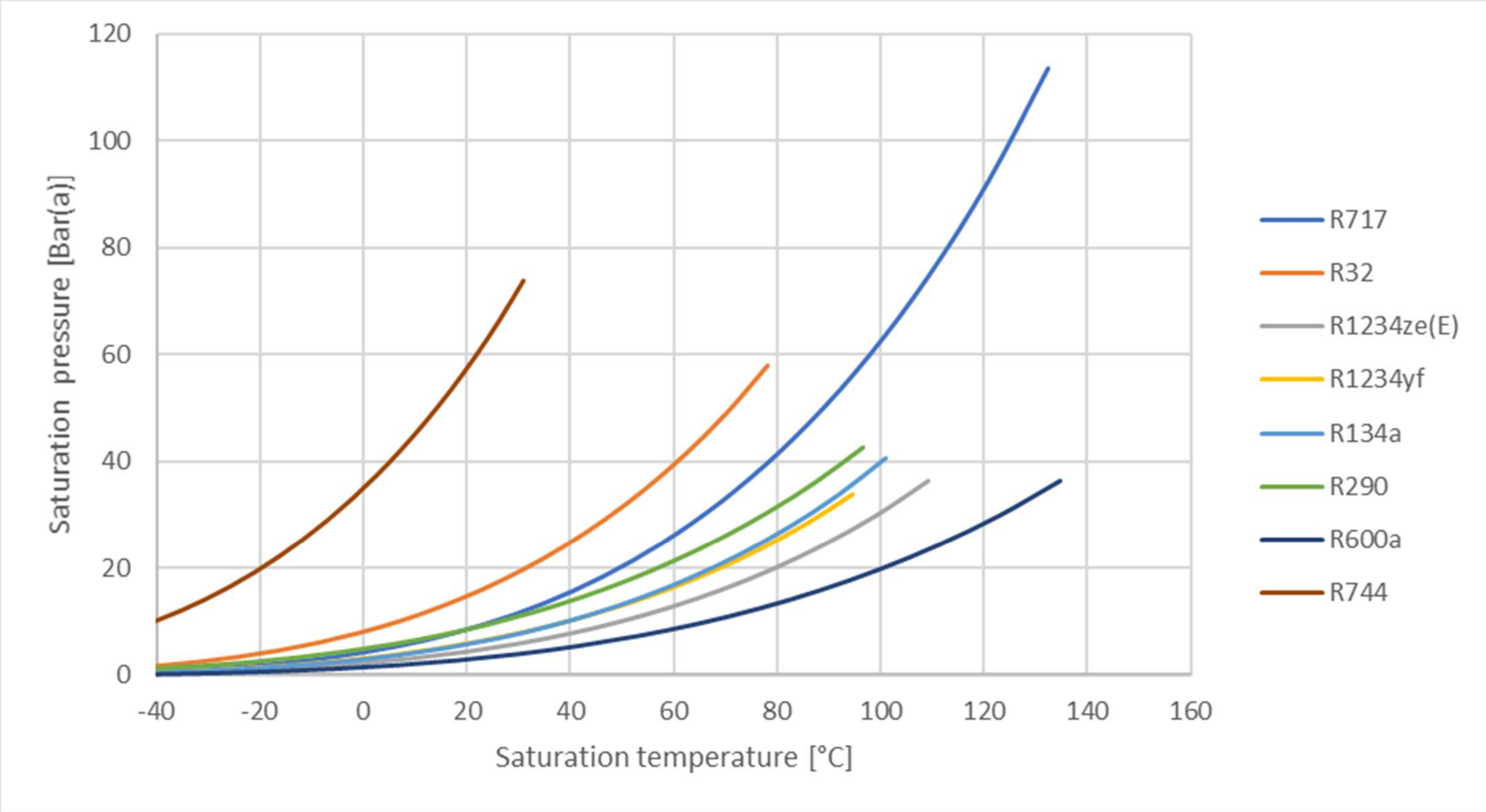


Basic thermodynamics. Desired refrigerant properties

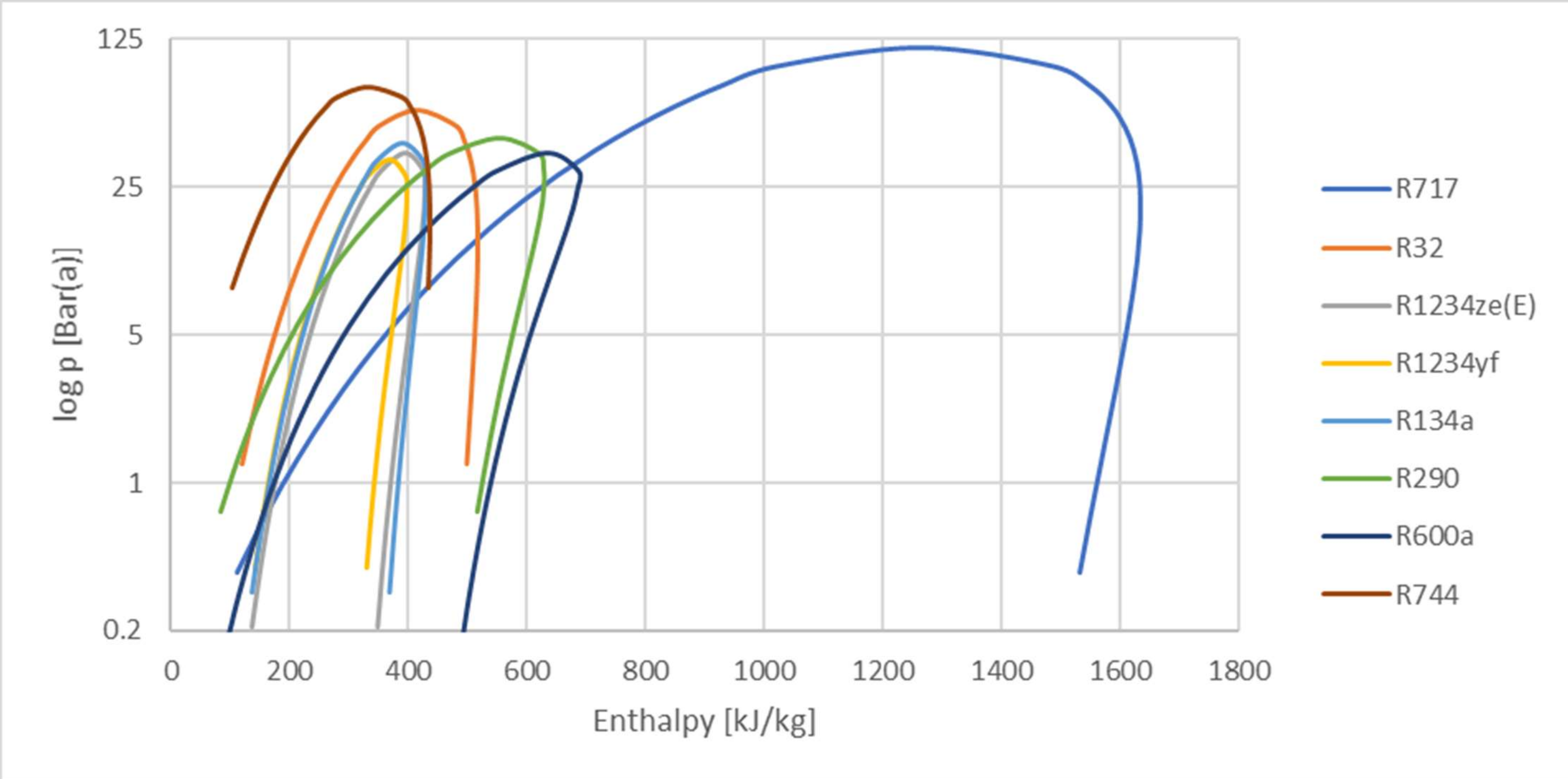
The effect of liquid specific heat on flashing



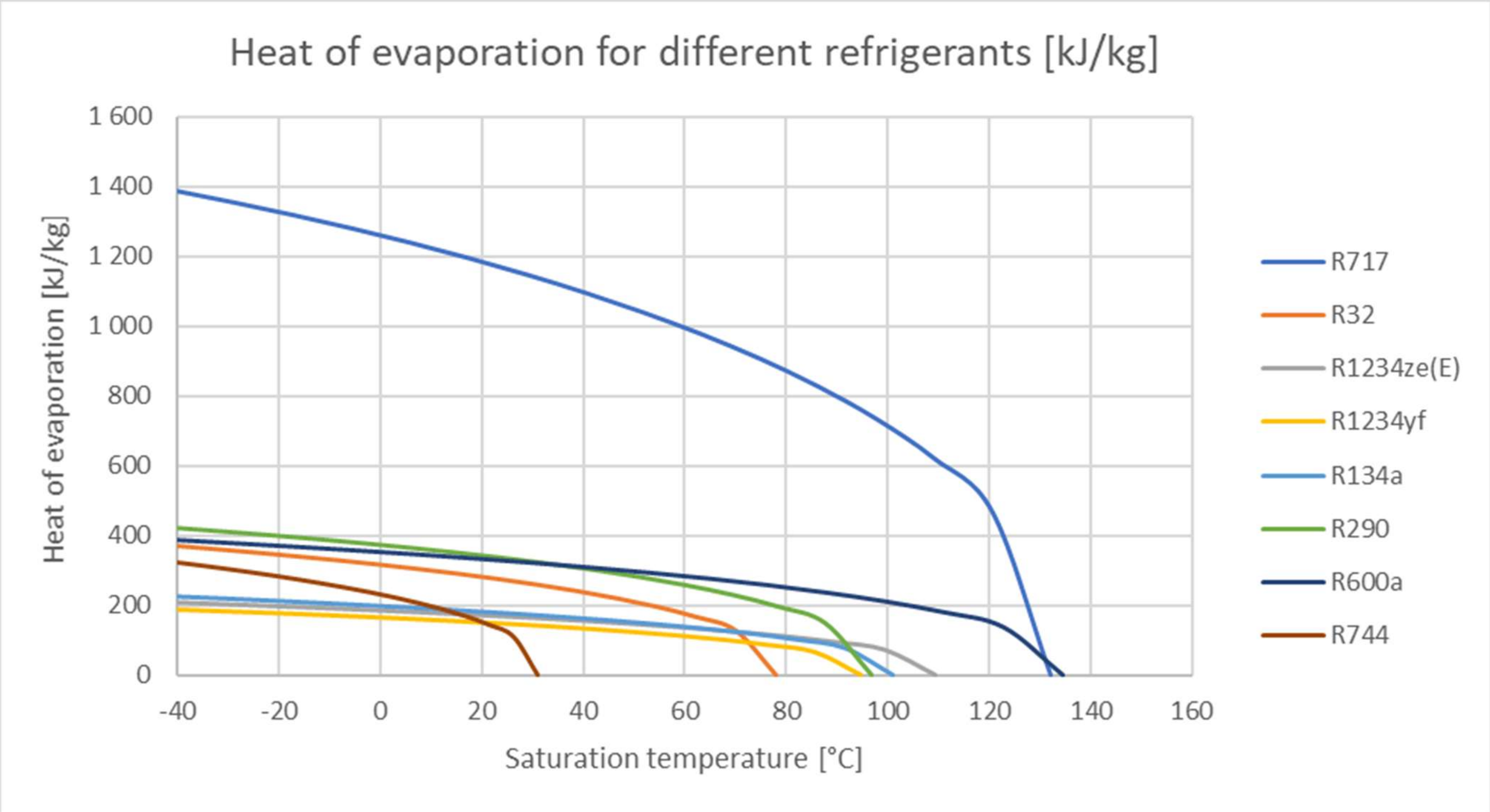
Basic thermodynamics. Refrigerant properties



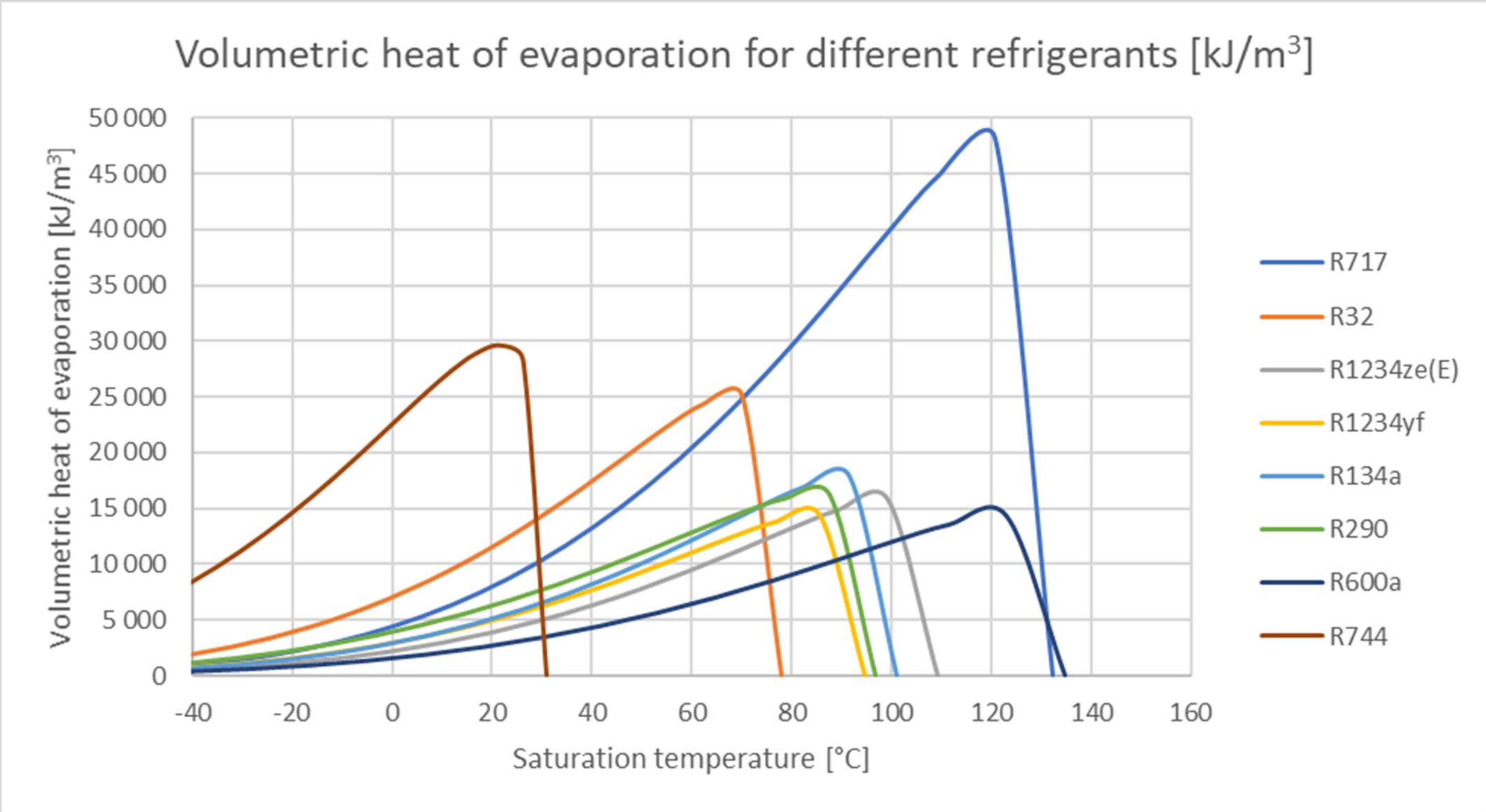
Basic thermodynamics. Desired refrigerant properties
Heat of evaporation



Basic thermodynamics. Desired refrigerant properties
Heat of evaporation

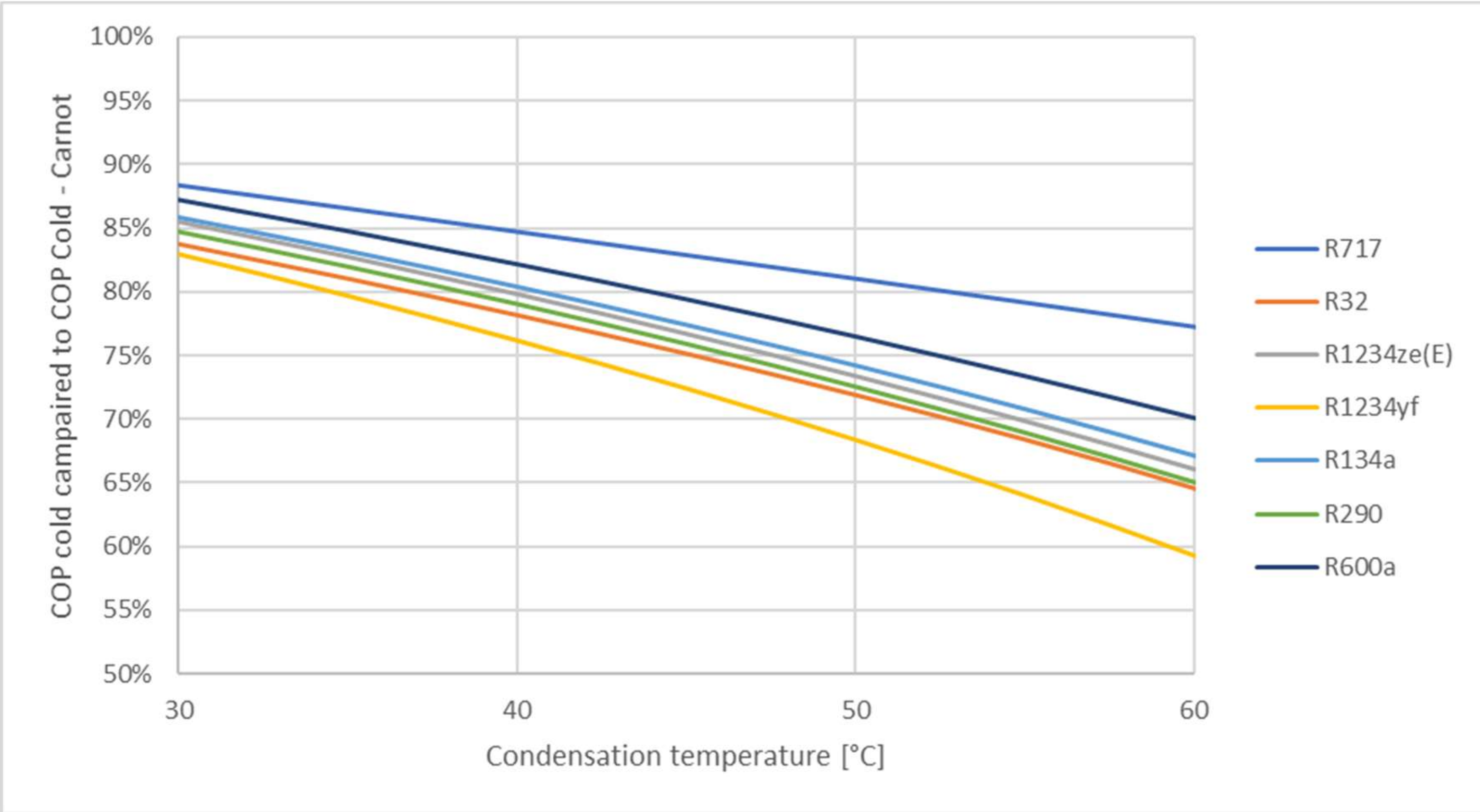


Basic thermodynamics. Desired refrigerant properties
Volumetric heat of evaporation. Compressor and pipe dimensions



Process efficiency

0°C evaporation, no superheat, no subsooling. Isentropic compression



	R717	R32	R1234ze(E)	R1234yf	R134a	R290	R600a
Mol masse	17.03	52.02	114.04	114.04	102.03	44.10	58.12

Why this matters. The tale of a surprise

- Many years ago, back in the time of beyond .... actually, it is just 15 years ago, a research building was being planned next to the hospital i Bergen.
- We moved an industrial solution into the built environment by applying ice tanks in a comfort cooling system. This saved about 35% of the machinery demand
- We worked and set the budget based on ammonia machinery.
  - Demand of Industrial quality on the chillers
- Three – four days before the tender goes out, the project owners changes their minds. They want R134a instead of ammonia.

Why this matters. The tale of a surprise

- @#¤&#¤. (Swearing)

- Should we stick with the demand of industrial quality?
- Yes, they liked the thought that the plant would live long.

- How about the budget? We had set up the budget based on ammonia
- No we agreed, no need to change that now. Keep the budget at 5 000 000 NOK (500 000 £). Ammonia is usually more expensive so thats OK.

Why this matters. The tale of a surprise

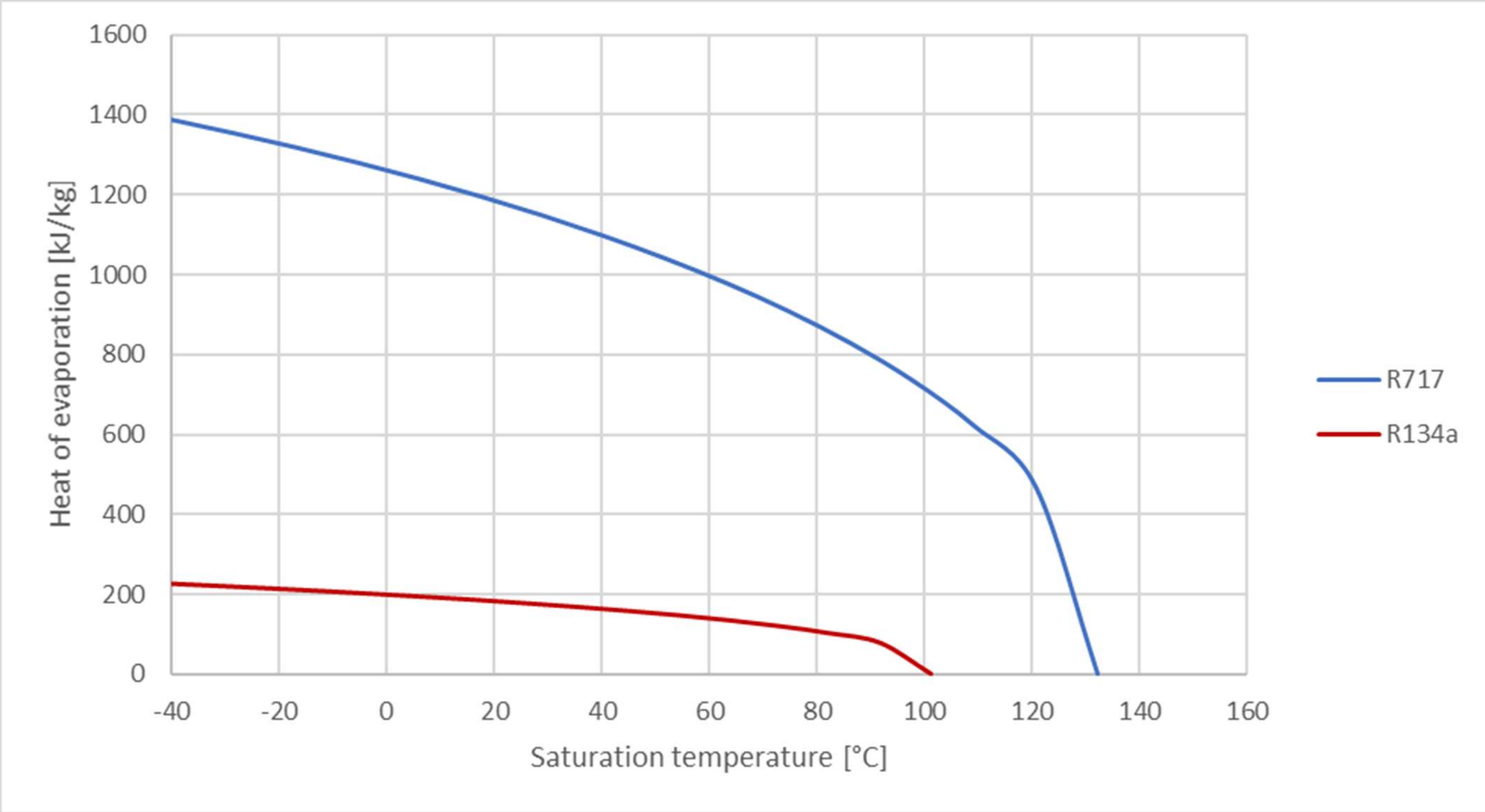
- Two companies submitted an offer.
- The difference was app. 150 000 NOK (15 000 £) so the tender must have been OK.
- The offers were around 9 000 000 NOK (900 000 £)
- WHAT??
- What happend here??

- Incredibly the client was more interested in finding out what happend, than playing the blame game.

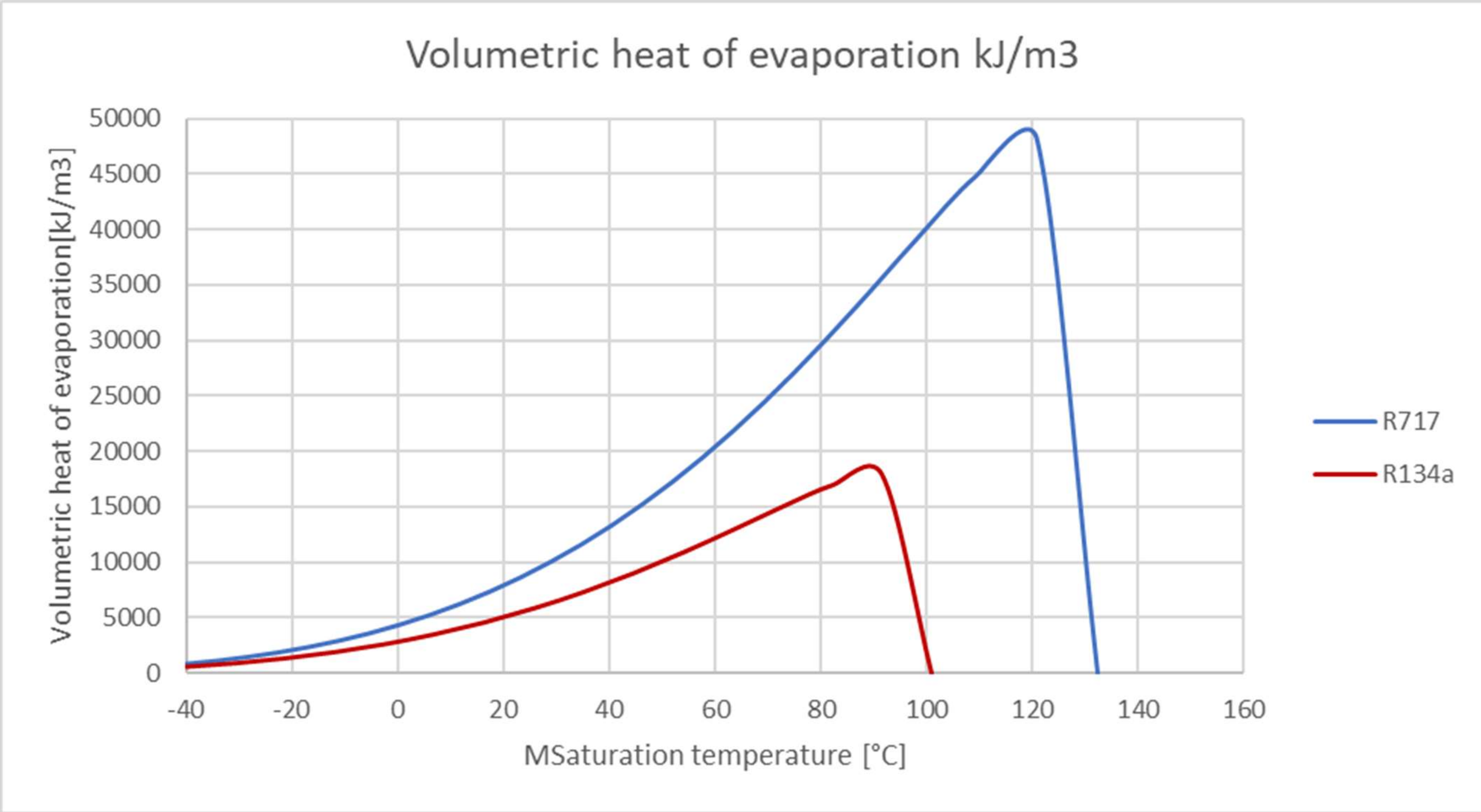
Why this matters. The tale of a surprise

- **What happend was R134a**.
- We were used to that R134a units would cost about 60% of an ammonia/R717 unit with the same performance.
- BUT
- We demanded the same quality of assembly as an ammonia unit.
- Usually articficials like R134a, R410A, R32 and so on are built using soldered copper piping.
- Ammonia has to use welded steel piping. Ammonia eats copper.

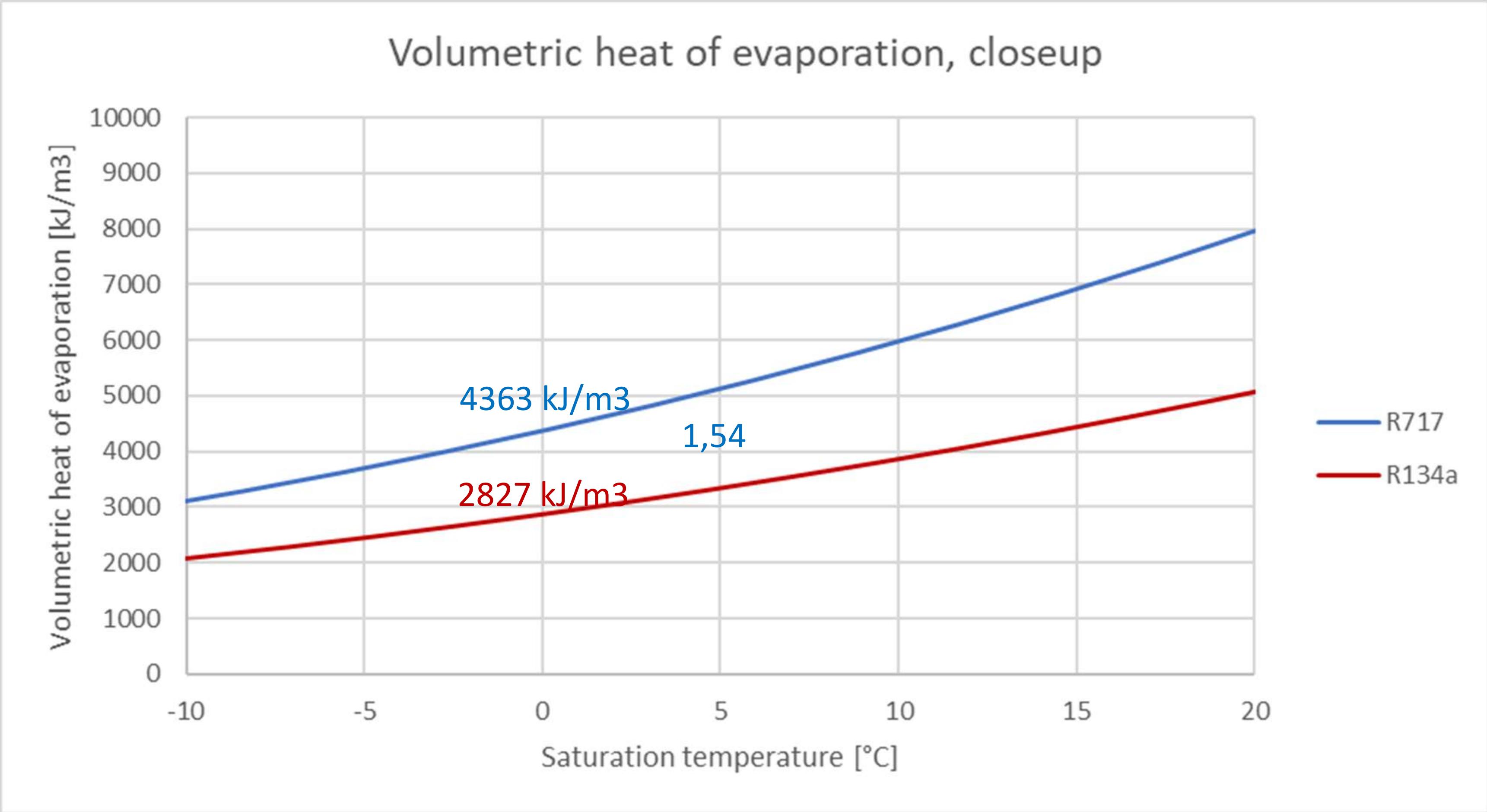
Refrigerant properties



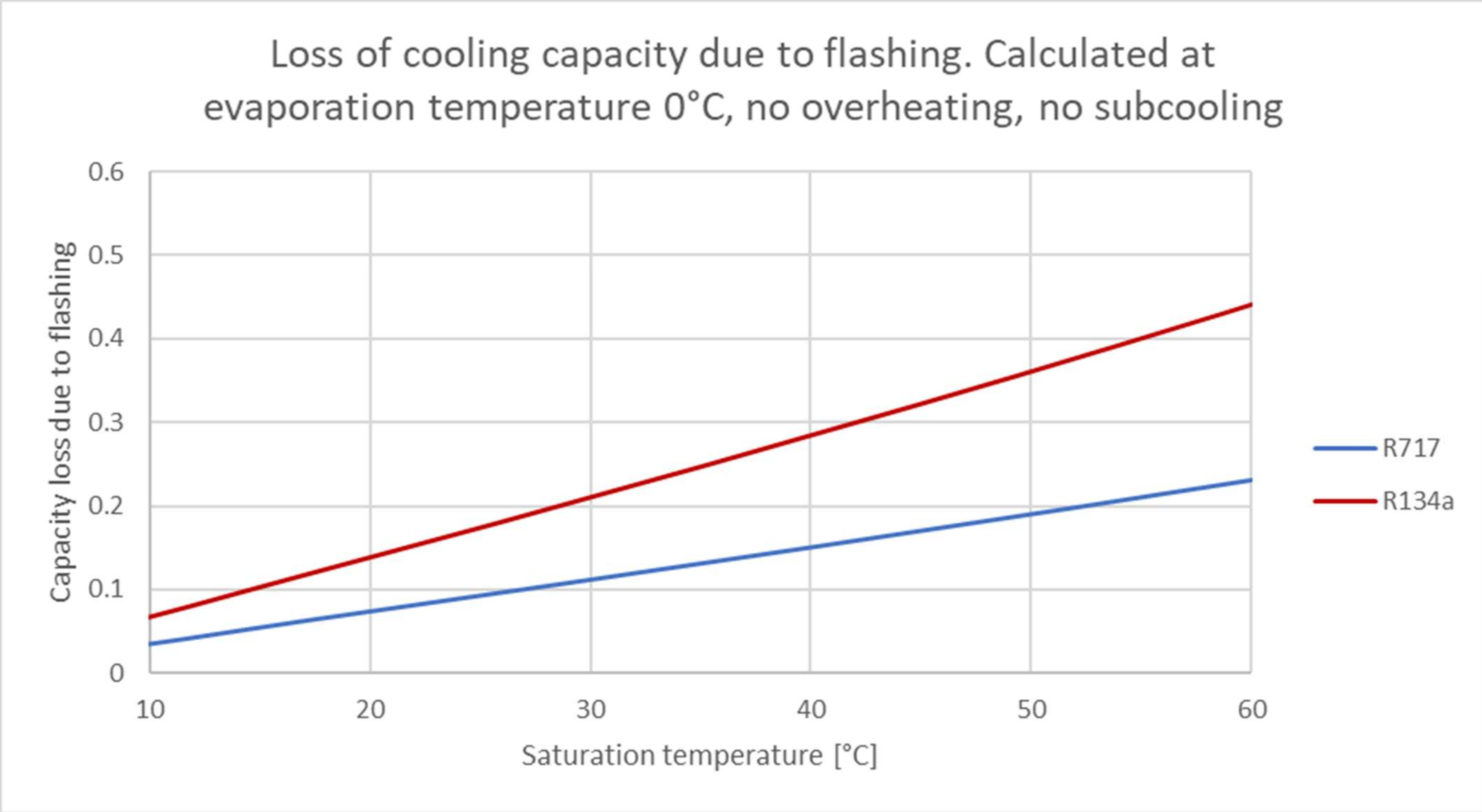
Refrigerant properties



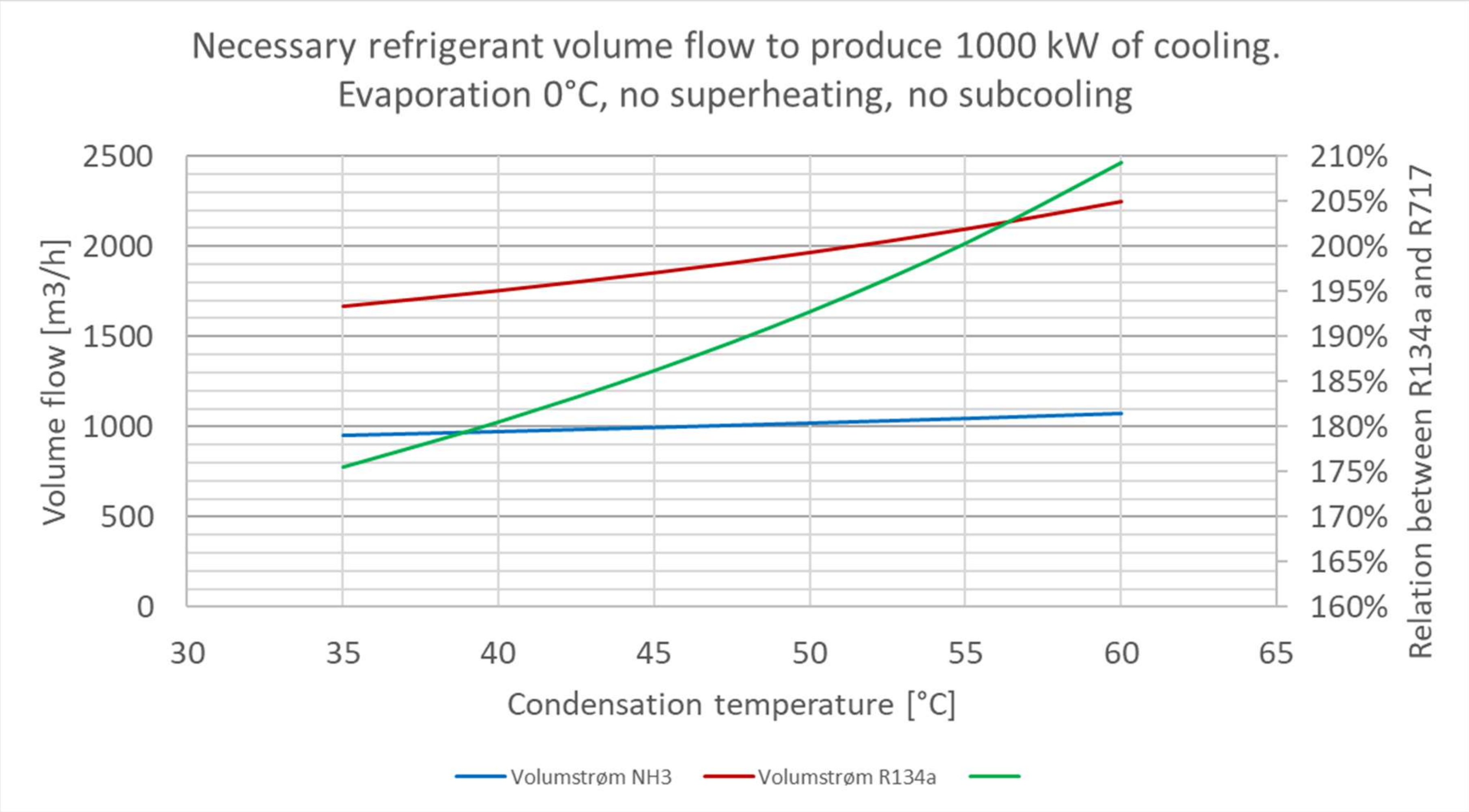
Refrigerant properties



Refrigerant properties



Refrigerant properties



And what does this mean?

1. Pipe dimensions, heat exchangers, compressors, basically everything on the R134a unit is 80% larger than on an ammonia unit.
2. When building in industrial quality ammonia and CO_2 will probably give us the cheapest units
3. The industrial unit on R134a is 3 times more expensive than the standard commercial price.
4. The fact that R134a units can be supplied at 60% of the cost of a corresponding R717 unit can only come from compromises on quality.

Global Warming Potential (GWP)

- OOOh no. Here as well!!
- Oh yes.
- IPCC has established that app. 0.5°C of global warming can be attributed directly to release of refrigerants.
- Not including power consumption.
- By the way, app. 15%-20% of the worlds power consumption is used for cooling purposes.

What does GWP actually mean?

xrgy
Seeing the Big Picture

Code	Name	Type	ODP	GWP
R12		CFC	1	10 900
R22		HCFC	0.05	1 810
R134a		HFC	0	1 430
R290	Propane	HC	0	3.3
R407C		HFC	0	1 774
R410A		HFC	0	2 088
R600a	Isobutane	HC	0	3.0
R717	Ammonia		0	0.0
R718	Water		0	0.2
R744	CO2		0	1.0
R1234-yf		HFO/HFC	0	4.0
R1234-ze		HFO/HFC	0	6.0
R1270	Propylene	HC	0	1.8

Leaving your mark on the world

- The chemical engineer, Thomas Midgley Jr, who was instrumental to the development of R12 was also a key player in developing leaded petrol for cars.
- He contracted polio in 1940, leaving him without use of his legs.
- He divised a system of ropes and pullies to get himself out of bed.
- 1944 he got entangeled in the ropes and was strangled.
- Carma?

https://en.m.wikipedia.org/wiki/Thomas_Midgley_Jr.

Compressor types

- Compressors are generally divided in two main categories
- Variable geometri
  - Variable geometri is reciprocating compressors, or piston compressors, where the pressure ratio across the compressor is determined by the pressure of the refrigerant on the in- and outlet valves
- Fixed geometri
  - These will be scroll and screw compressors where the geometri of the compressor in principle determines the pressure ratio across the compressor.
- The following videos will show the principles of operation

Compressor types

- Recip
- https://www.youtube.com/watch?v=wqNTYLIDaxs
- Screw
- https://www.youtube.com/watch?v=SvKfH2tQ1qs
- Scroll
- https://www.youtube.com/watch?v=A7AMLAqiHB4

Compressor types

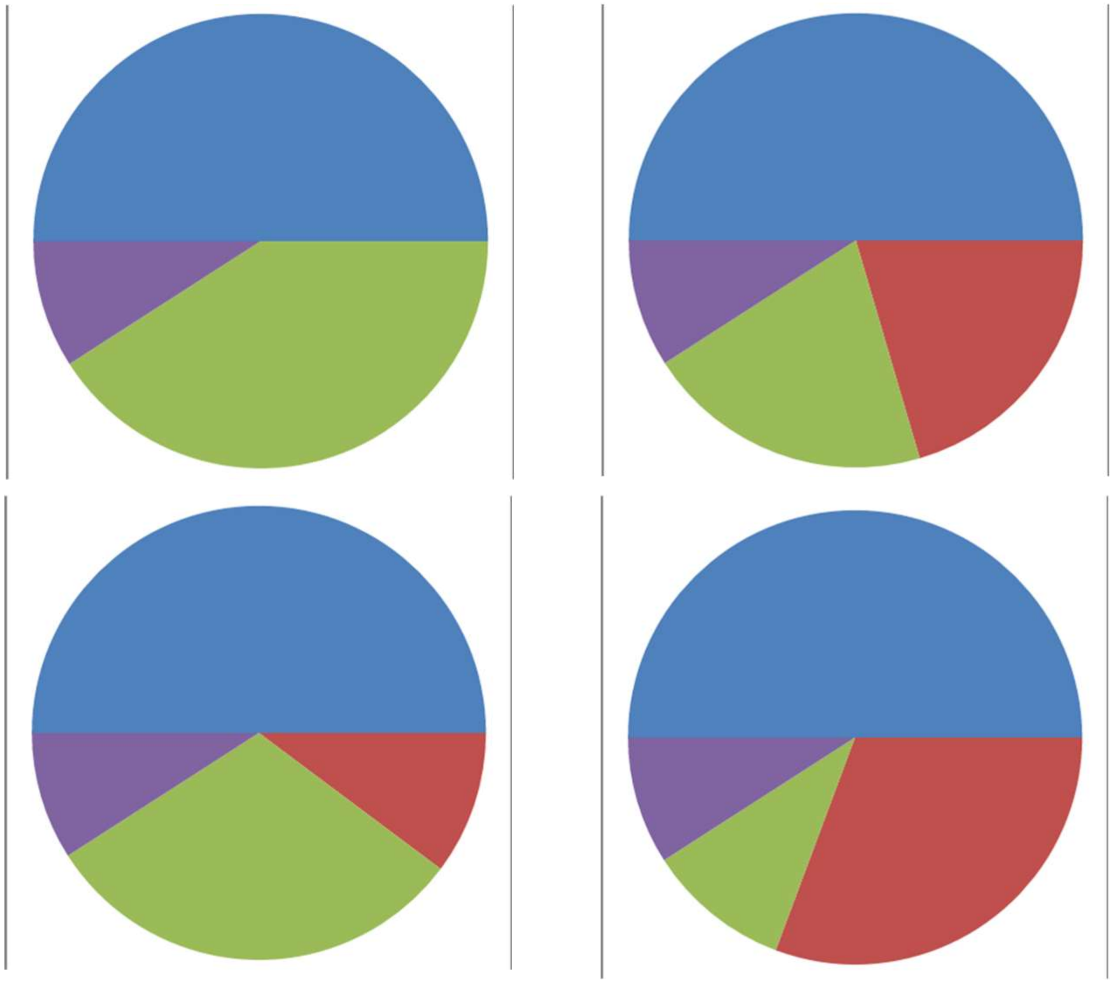
- The screw compressor shown in the video is a high end compressor, more advanced than the usual found in standard commercial units.
- Often they don't operate with slides, and certainly not with Vi slide as in the video.
- Normally they are equipped with magnetic valves to open up to four possible by pass valves back to the suction inlet.
- I am not aware of any possibility to adjust the pressure ratio in scroll compressors.

Compressor types Performance control

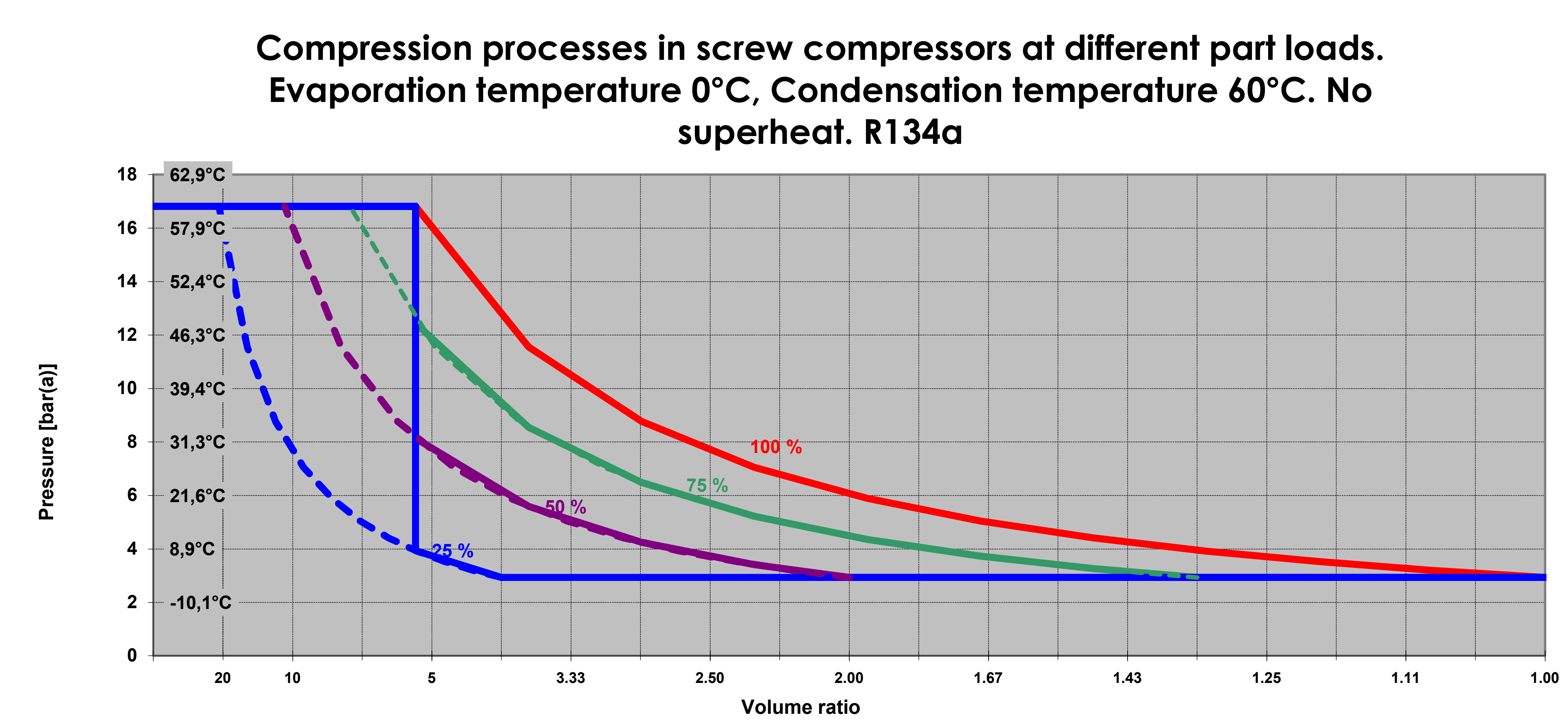
- Performance control is to control the flow through the compressor
- In the recip, pre frequency converters, a hydraulic lifter would hold the valves of surplus cylinders open. This causes the exit temperature to shoot up, because the mechanical losses exist from all cylinders, but less refrigerant will have to handle it.
- In the screw, as seen in the video, return by-pass is used.
- Modern scroll compressors have the possibility to lift the fixed scroll (stator) thereby short circuiting the compressor. In the bad old days, it was only on / off. Often multiple compressors were used to give a stepwise control

Compressor types Performance control

- The back flow by-pass can be detrimental, both to the efficiency and to the servicelife of the screw compressor.
- An example.



Compressor types Performance control



Compression process

Isentropic compression. R717.

Designed for 0°C evaporation,

52°C condensation.

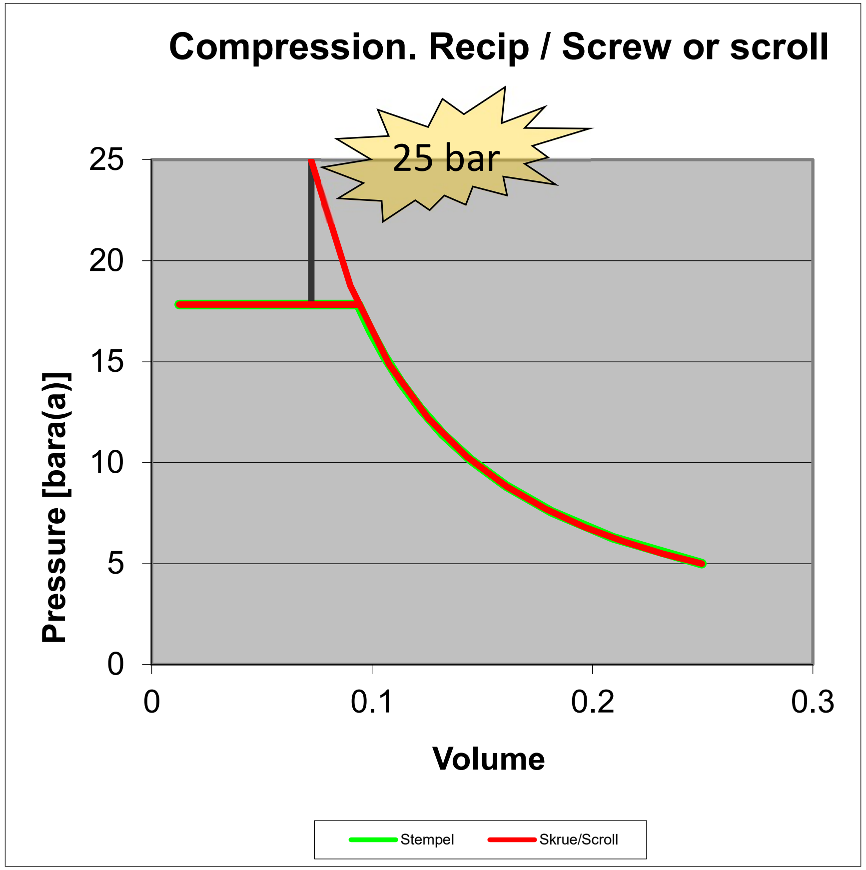
Volume ratio 3,45.

Condensation reduces to 45°C.

Volume ratio locked at 3,45.

Evaporation increases to 4°C.

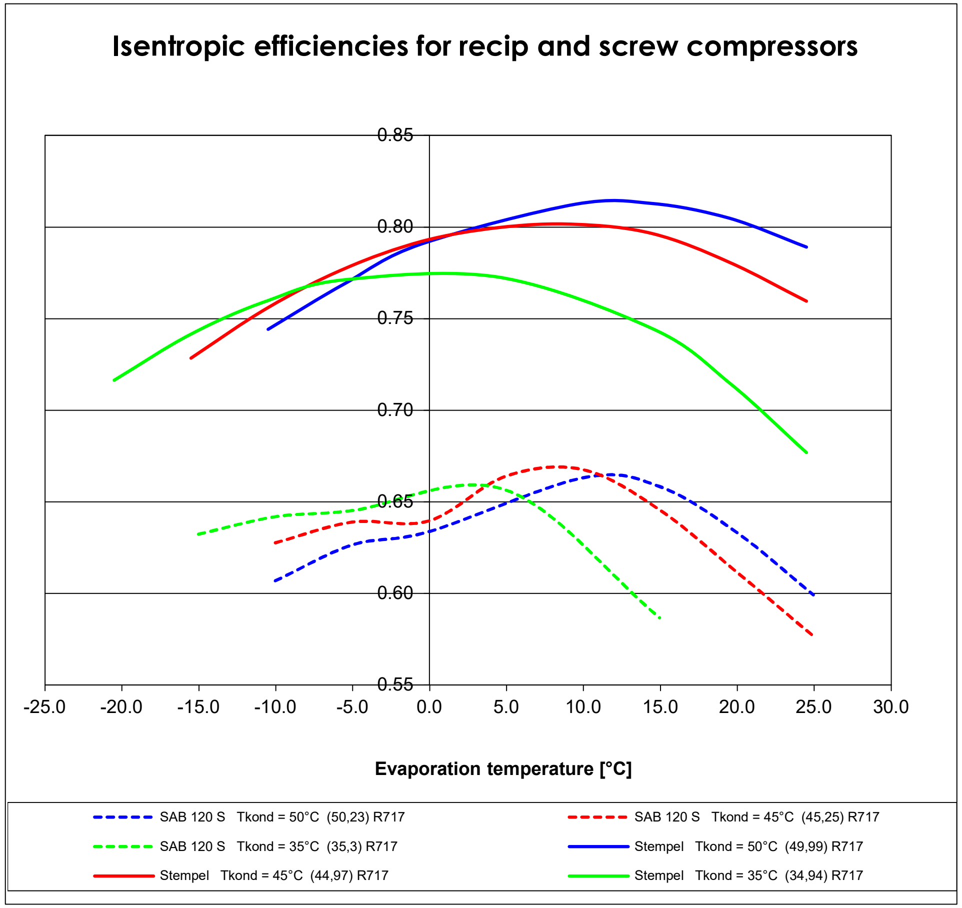
Volume ratio locked at 3,45.

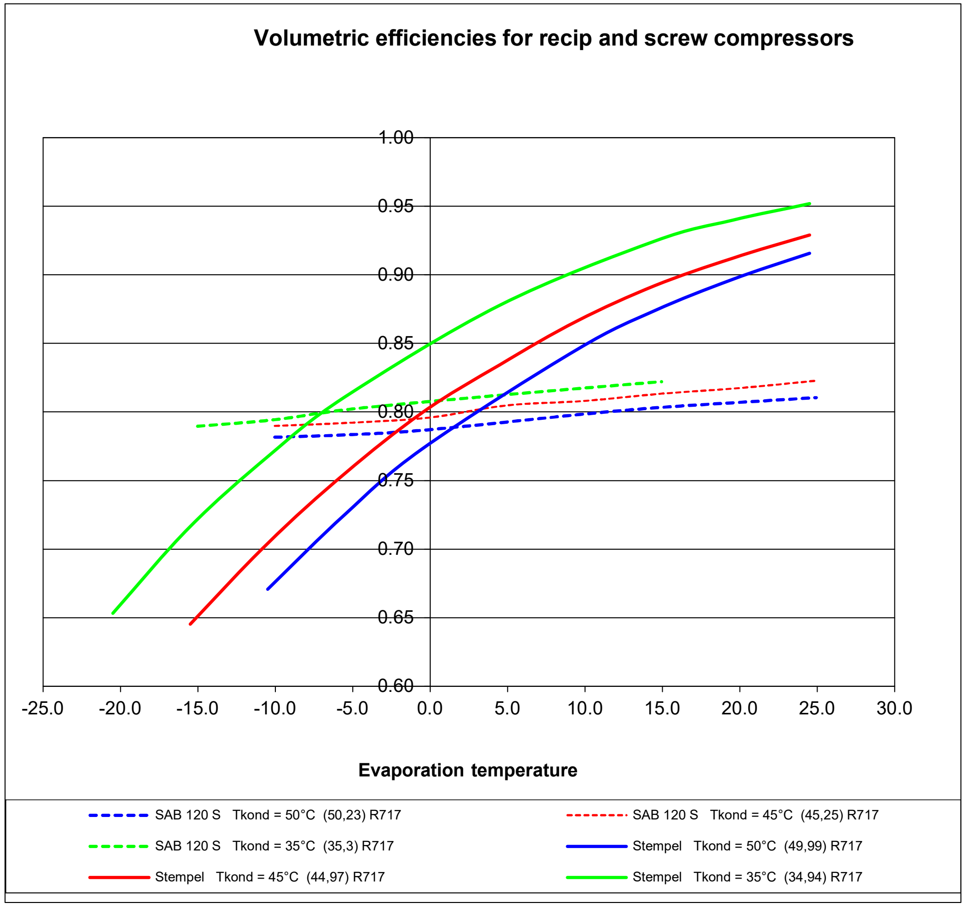


Compression

- By using compressors with locked volume ratio you might experience reduced compressor efficiency when the overall conditions **improve**.
- Any increase in COP is caused by reduced flashing.

Efficiency


Isentropic efficiencies for recip and screw compressors
0.85
0.80
0.75
0.70
0.65
0.60
0.55
-25.0 -20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0 25.0 30.0
Evaporation temperature [°C]
SAB 120 S Tkond = 50°C (50,23) R717
SAB 120 S Tkond = 45°C (45,25) R717
SAB 120 S Tkond = 35°C (35,3) R717
Stempel Tkond = 50°C (49,99) R717
Stempel Tkond = 45°C (44,97) R717
Stempel Tkond = 35°C (34,94) R717


Volumetric efficiencies for recip and screw compressors
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
-25.0 -20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0 25.0 30.0
Evaporation temperature
SAB 120 S Tkond = 50°C (50,23) R717
SAB 120 S Tkond = 45°C (45,25) R717
SAB 120 S Tkond = 35°C (35,3) R717
Stempel Tkond = 50°C (49,99) R717
Stempel Tkond = 45°C (44,97) R717
Stempel Tkond = 35°C (34,94) R717

Choice of compressor. Conclusion

- As heat pump compressor the recip is usually the best choice when the running conditions varies.
- Screw compressors are normally an excellent choice where the load i large or as compressor in cold stores, where large refrigerant flow are the norm. But for smaller units under variing load conditions, the screw will often struggle to deliver an acceptable efficiency.

xrgy
Seeing the Big Picture

Closing remarks

- The development of regulation is heading towards natural refrigerants.
- If you are to help clients to choose, I will strongly suggest that you stay within the future proof natural refrigerants.

- Thank you for your attention, I hope you all take away information that will be useful to you in the future.