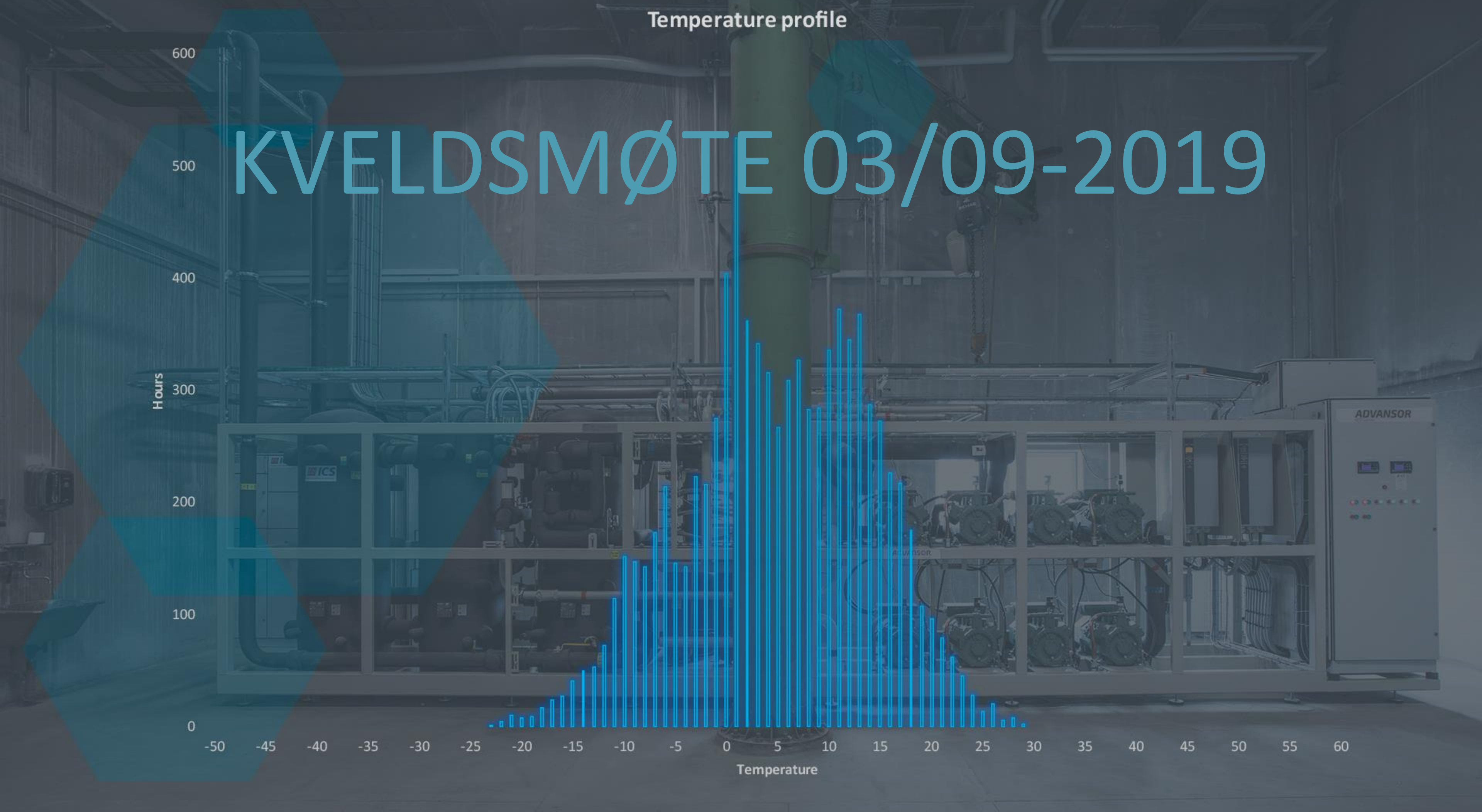
KVELDSMØTE 03/09-2019



Agenda

- SEPR model explanation
- LSPM
- Unloading of cylinders VS frequency inverters
- ULSH (Ultra low superheat).
- Ejector systems
  - High pressure ejector
  - Low pressure ejector
- Questions

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Intro to SEPR

Tool is based on the Eco design Directive 2009/125/EC

Tools is using ASHRAE temperature profiles that has ben converted to bin data (It has been converted to how many hours that are in temperature intervals of 1 K). EDD is only calculating in Strasbourg but we can move around to 1000 different cities in Europe

Load profiles are taken from the standards

COP is calculated based on supermarket MT and LT profile (load of the gas cooler varies at different load profiles).

Standard gas cooler is selected with 2K Δt @ 32 °C ambient. COP is based on calculations @ -10/-30 °C.

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Calculation method

Seasonal **E**nergy **P**erformance **R**atio

$$\mathrm{SEPR} = \frac{\sum_{j=1}^{n} h_j \cdot P_R(T_j)}{\sum_{j=1}^{n} h_j \cdot \left(\frac{P_R(T_j)}{\mathrm{COP}_{PL}(T_j)} \right)}$$

$\mathrm{EER}_{PL(Chiller)}$

$$\mathrm{SEPR} = \frac{\text{annual cooling demand (kWh)}}{\text{annual electricity consumption (kWh)*}}$$

$COP_{PL}(T_j)$ = COP values of the condensing unit for the corresponding BIN temperature T_j

EER_{PL} = EER values of the chiller for the corresponding BIN temperatur T_j

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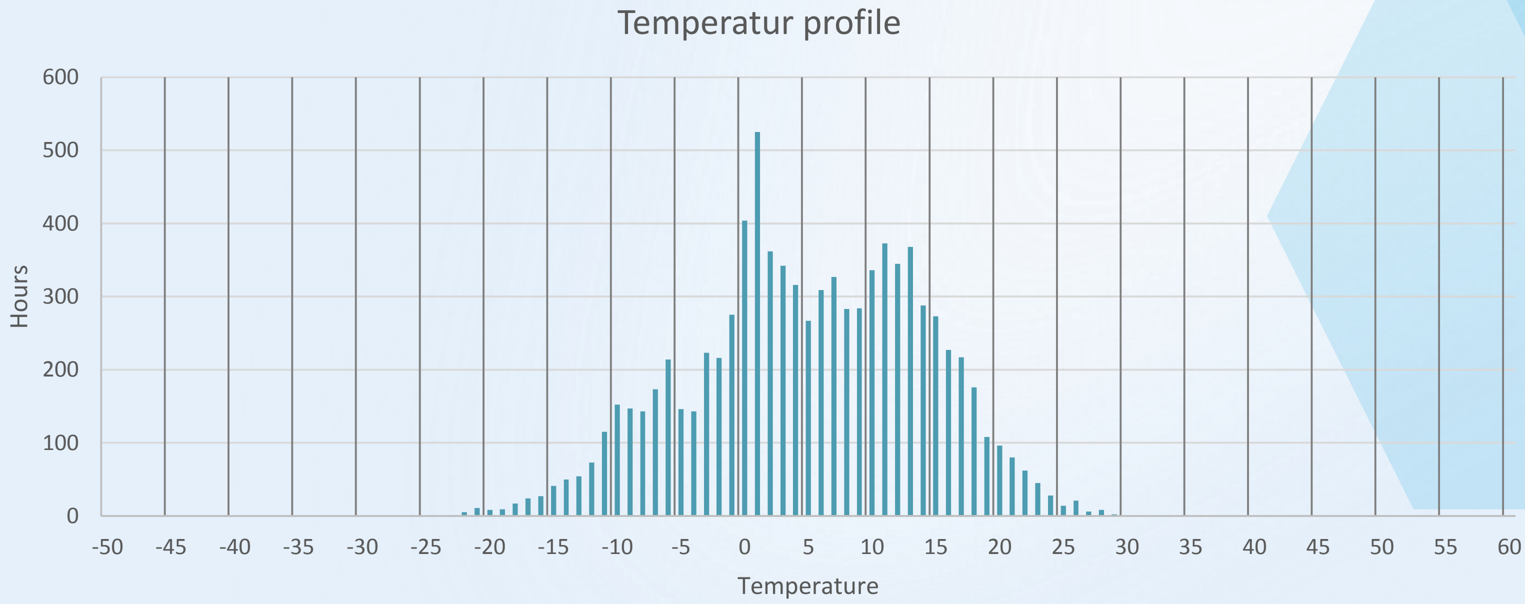
Temperature profile Oslo



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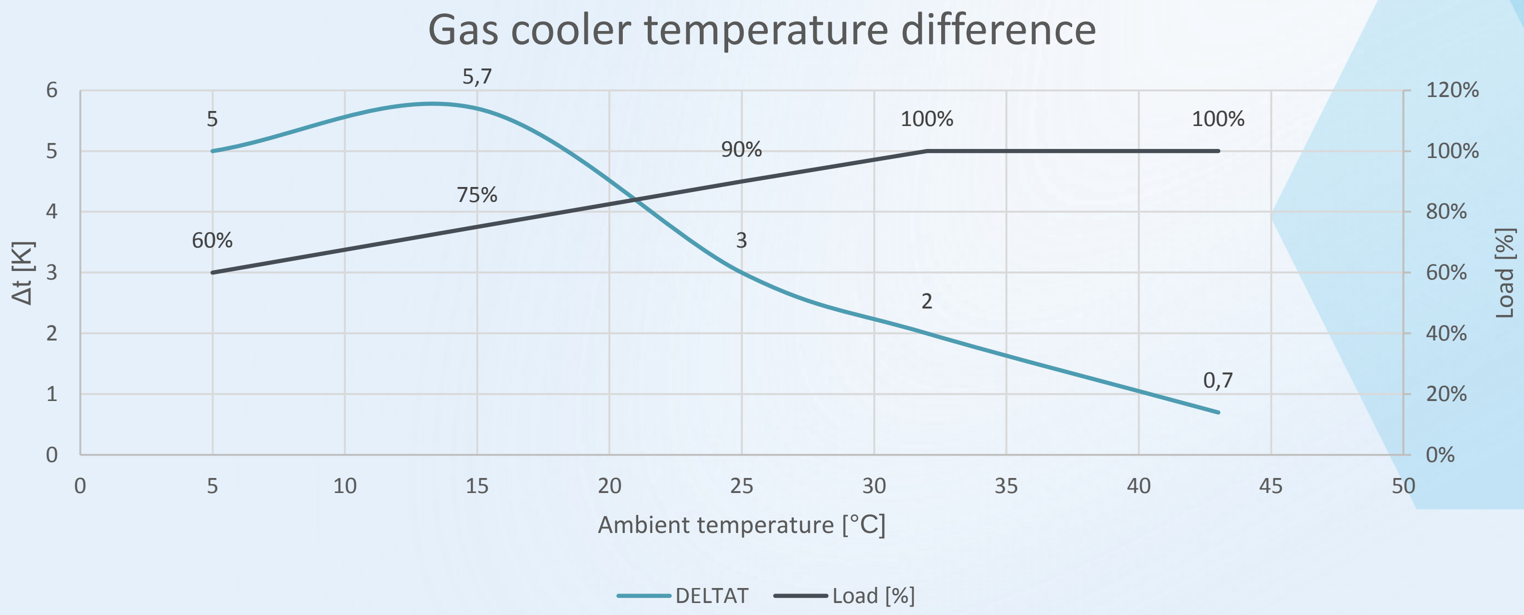
Gas cooler Δt at load profile



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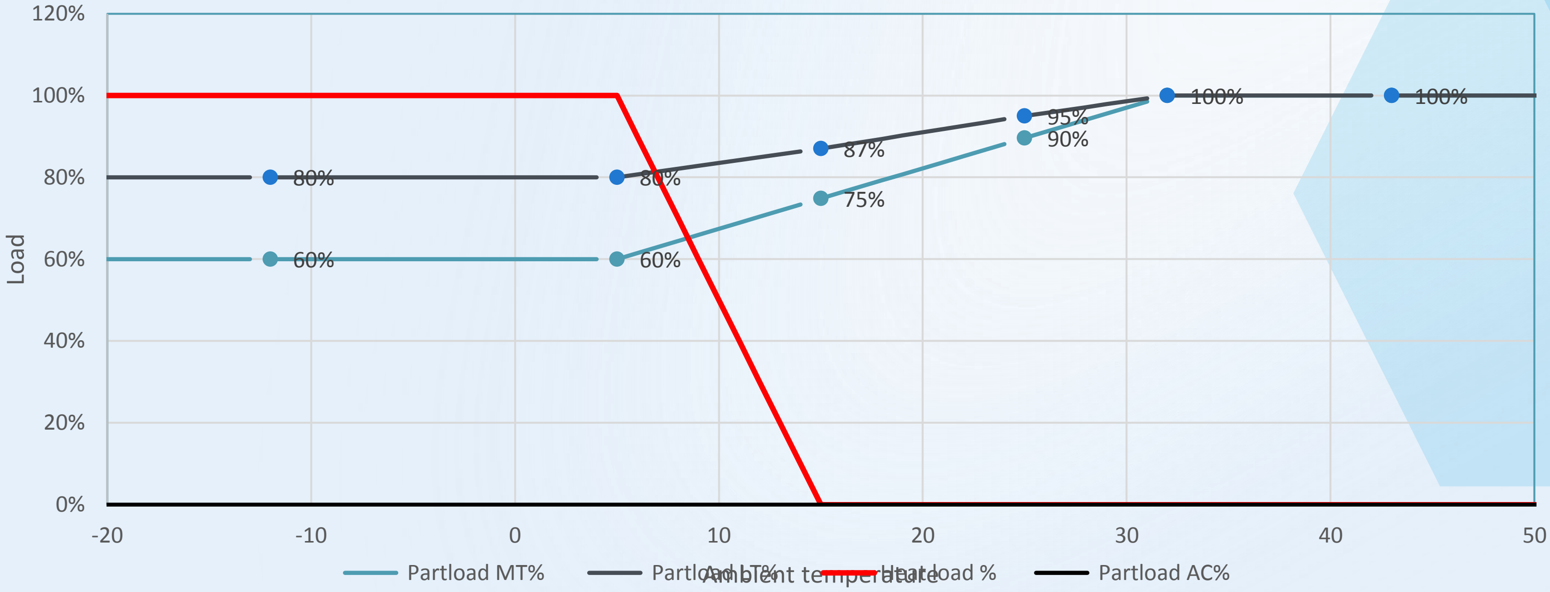
Load profile example



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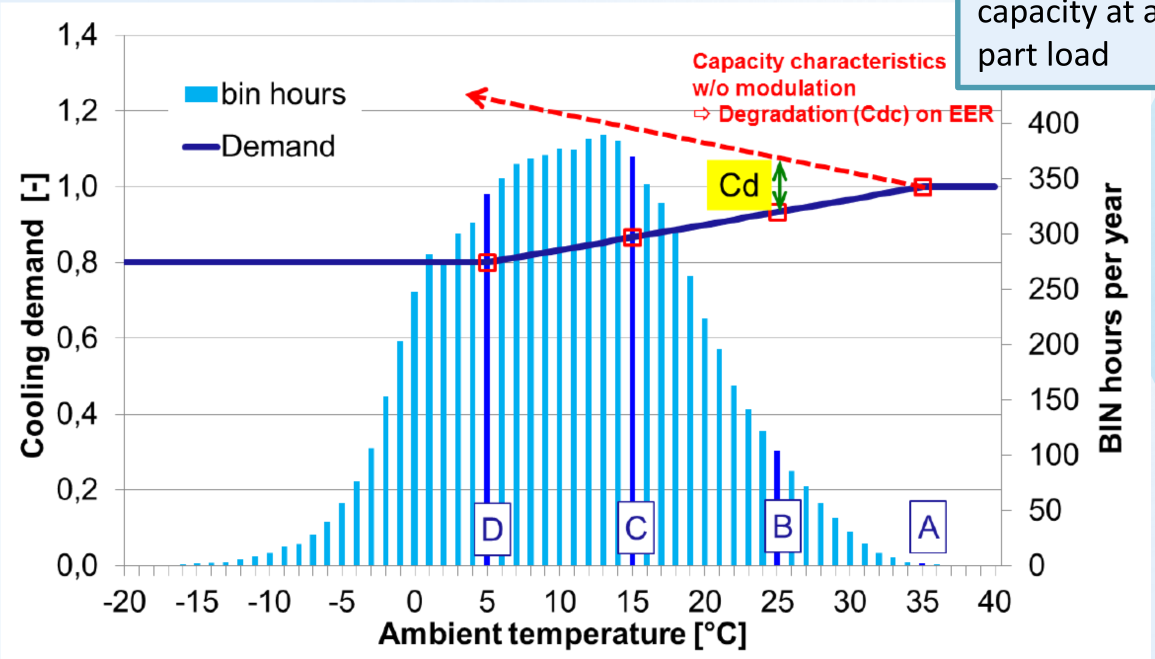
Deviation from standard

We do not use a degradation factor in the calculation because we can match the capacity at all times in part load



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Results

The result is maybe not a realistic number regarding energy consumption, but to benchmark different technologies it gives a very good indication with a minimum effort.

The model is therefor a fast way to reach a pay back time for different technologies.

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PERMANENT MOTOR **COMPRESSORS**

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What is PM motors?

Permanent motors are often build like asynchronous motors, but with a rotor made of a magnetic material.

The permanent magnet helps improving the motor and compressor efficiency by lowering the losses in the motor and the difference is quite significant

Some motor types require a drive to run the motor where other types does not require that (Bitzer LSPM)

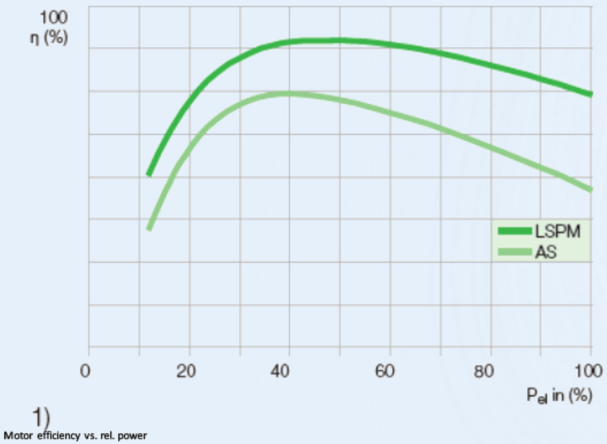
The permanent magnet also offers synchronies speed on the compressor and therefore the capacity of the motor is also increased by approx. 3-4%

Currently Bitzer is the only one offering this type of motor on semi hermetic compressors where the hermetic more or less all of them comes with PM motors

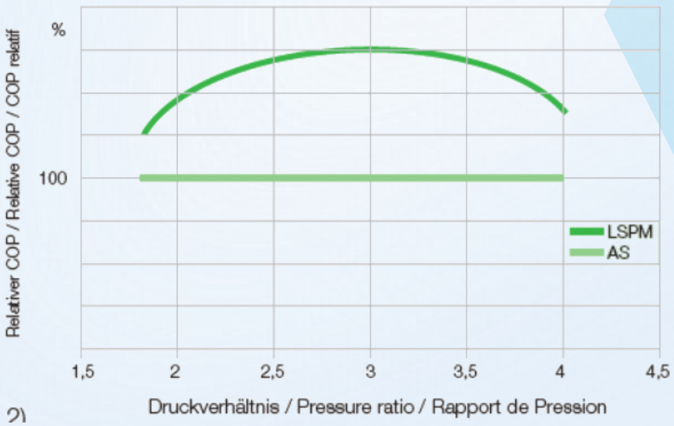
PM COMPRESSORS

Advantages:

- Higher Efficiency as Standard TC compressors
- Less technology complexity
- Synchronus opperation – no slip – more capacity



Motor efficiency vs. rel. power



COP improvement LSPM vs. AS (@cond. Te)

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Pay back PM compressors

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/4,91 (5%)	4,4
Strasbourg	3,93/4,18 (6%)	2,6
Lisbon	3,25/3,50 (8%)	1,6

100 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

Pay back PM compressors

	SEPR MT only [-]	Pay back [years]
Oslo	2,21/2,43 (10%)	1,0
Strasbourg	2,45/2,69 (10%)	1,1
Lisbon	2,92/3,17 (9%)	1,3

100 kW MT, -10 C evaporation, 2K gas cooler, **with HR**

With HR the energy consumption is higher and therefore the saving is of a larger amount of energy. Secondly the LSPM motor is most efficient in the higher load condition so therefore this also adds to the saving.

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CAPACITY CONTROL OF COMPRESSORS

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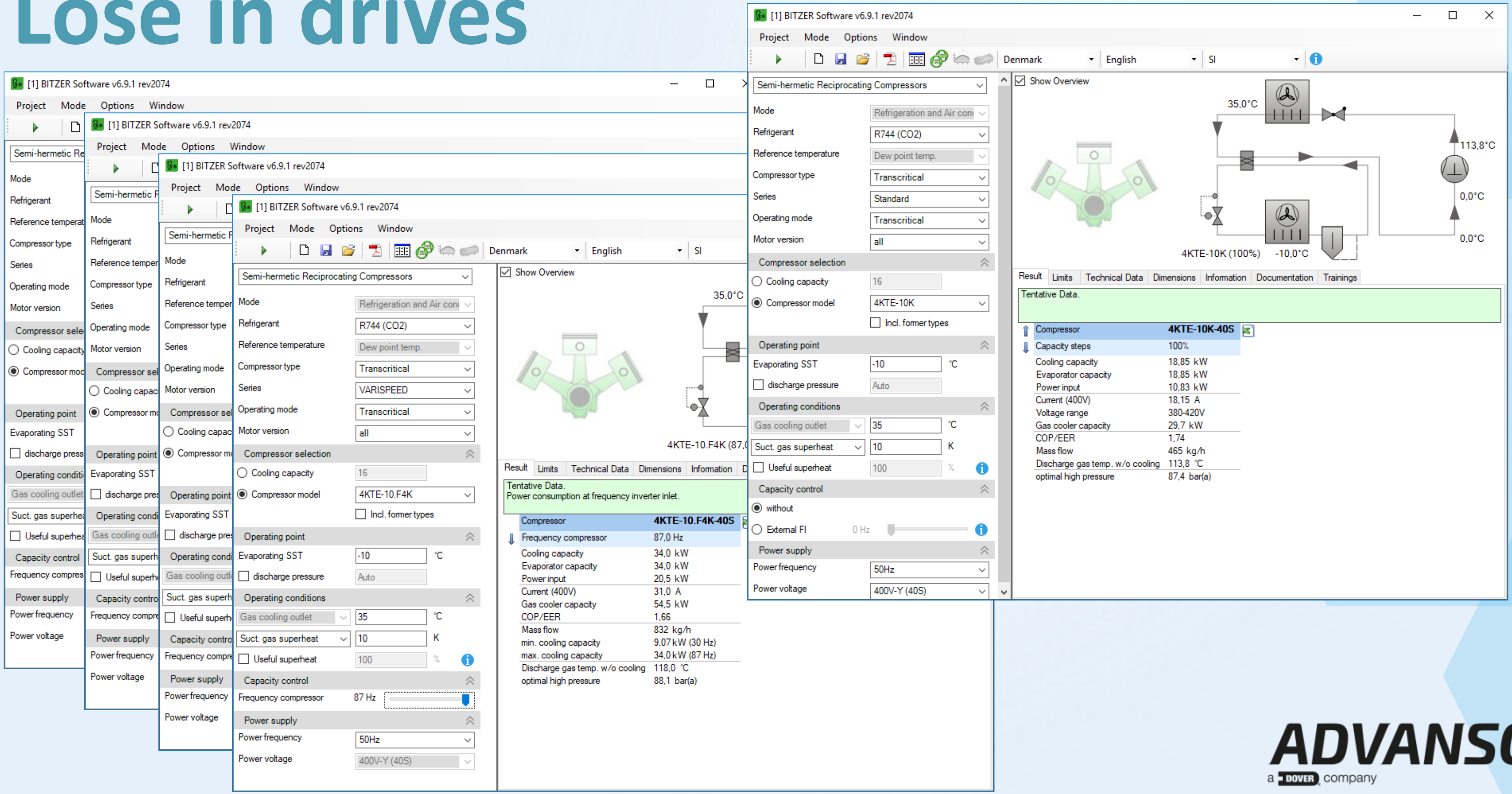
Lose in drives



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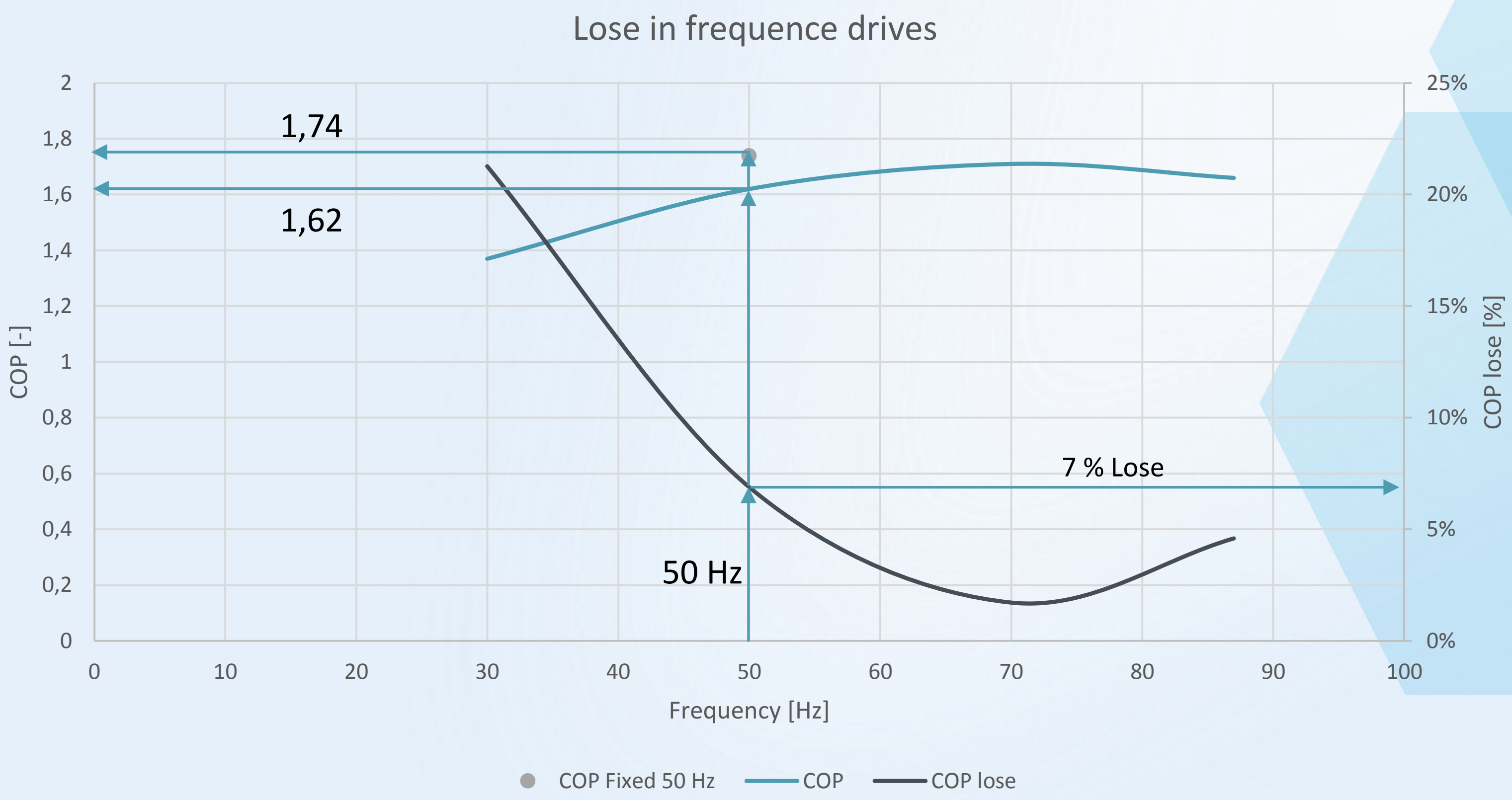

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COMPARISON DRIVE VS UNLOADER

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Comparison

Unloaders has for years been seen as an inefficient way of doing capacity control of compressors and frequency inverters has been seen as I high efficient way of doing this.

It is of cause true that there are losses in unloader systems because of friction and pressure drop in the open valve, but for some reason the losses in the operation with frequency drives has not been very high on the agenda.

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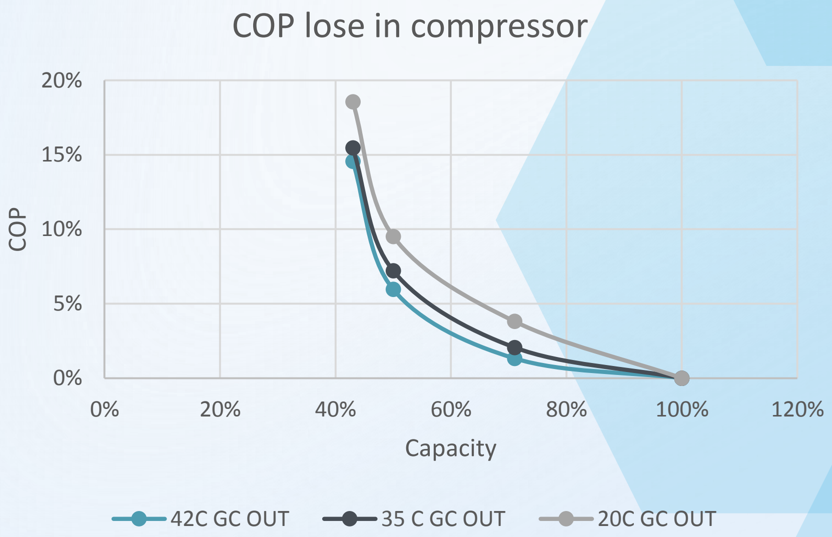
Lose in compressors with variable speed

- If the lose in the compressor alone is calculated using the Bitzer software with ext. FI the results shows that the compressor has the highest COP at full load and at high discharge pressures.
- On reason for this is that some of loses are fixed and therefor takes up more at low load and speed.



COP lose in the compressor alone can be as much as 19% in part load

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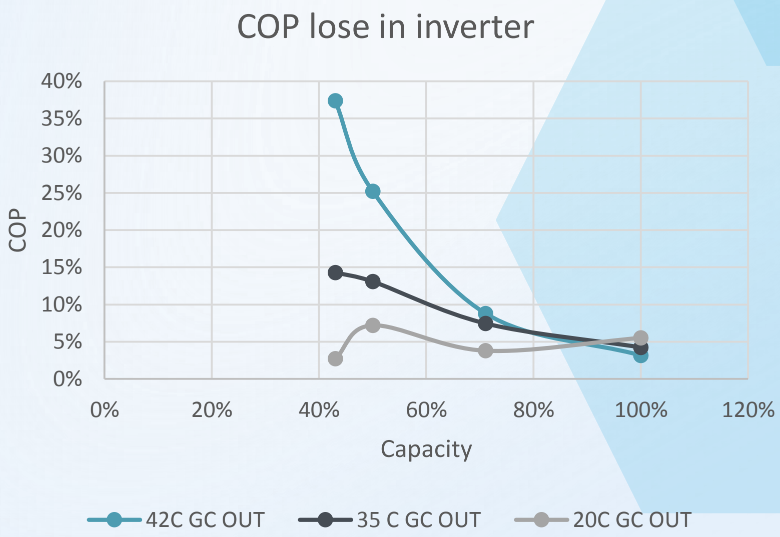
Lose in inverter

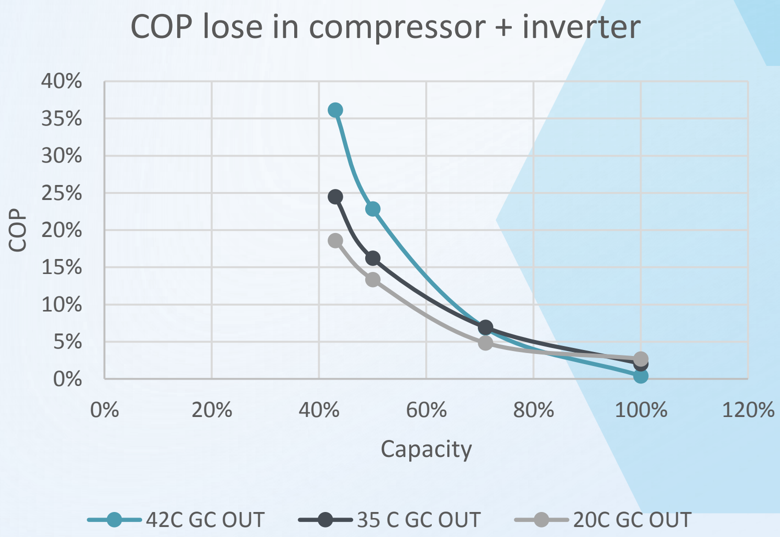
- The lose in the inverter is calculated using the Bitzer software
- Similar calculation are made with Varispeed compressor (integrated inverter) and with ext. inv. The difference in COP is the lose in drive
- The lose is highest at high pressures and low load/frequency



Lose in drive can account for as much as 37% lose in COP

Lose in inverter and compressor

- The total lose in inverter and compressor combined is not to be neglected at low speed
- At maximum speed the inverter is actually giving a lift in efficiency of approx. 1,5% compared to net frequency



The total lose in drive and compressor combined can be up to 36%

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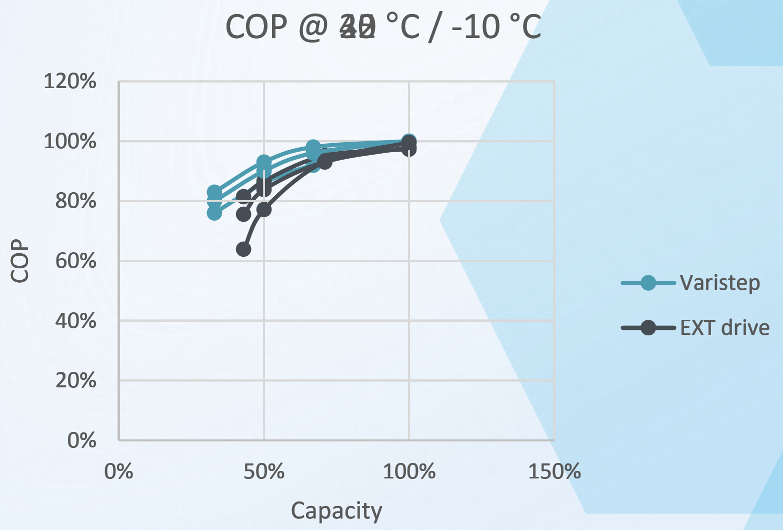
Comparison

- At 20°C there in no significant difference in COP comparing unloader technology with inverter
- At 35 °C the difference starts to show at low capacities
- At 42 °C the difference is quite significan. The difference can be as much as 25 %



Capacity unloading offers better COP in low load and very high degree of capacity control (down to 10% on 4 cyl comp and 33% on 6 cyl)

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Unloading new perspectives

- Cylinder unloading offers a very competitive energy consumption comparing with inverters
- At the same time it opens for very low part load capacity comparing to inverter
- This opens up for a completely new way of designing systems
- The low part load allows us to select larger compressors for compressor no 1 and still being able to have a very good part load. An example is a system with two identical compressors (4 cyl). This would be able to go to 5% of max load as the systems minimum part load.
  Therefore it opens for:
  - Systems with less compressors equal to lower price
  - More flexibility since the match of compressors does not need to fit 100%
- Parallel compression systems will also get a lift in efficiency because we can use larger compressors and get still get a part load that is lower than what we get today. This gives more running hours at the lower ambient and also possibility to take all the flash gas even at full load at the warmest day!
- If there is a saving in energy on not is not easy to say. Bitzer claims it is the same, but it will give lower first cost!

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ULTRA LOW **SUPERHEAT**

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Ultra low superheat

Ultra low superheat means that the superheat reference is so low that some of the evaporators return liquid to the rack.

It is not all evaporators that return liquid, but the ones that are the most loaded will return liquid.
In general the liquid return rate is never above 3% on mass base.
It is not a flooded system with high circulation ratios.

The returned liquid can be removed from the suction line in different ways:

- It can be pumped with a mechanical pump
- It can be pumped with an ejector
- It can be removed by evaporation in heat exchangers

All technologies will have more or less the same effect on the system, but all have pros and cons.
Advansor has build systems with all the different technologies and therefore has the experience of when to apply what technology.

We offer ultra low superheat solutions on both low, medium and aircon temperature levels.

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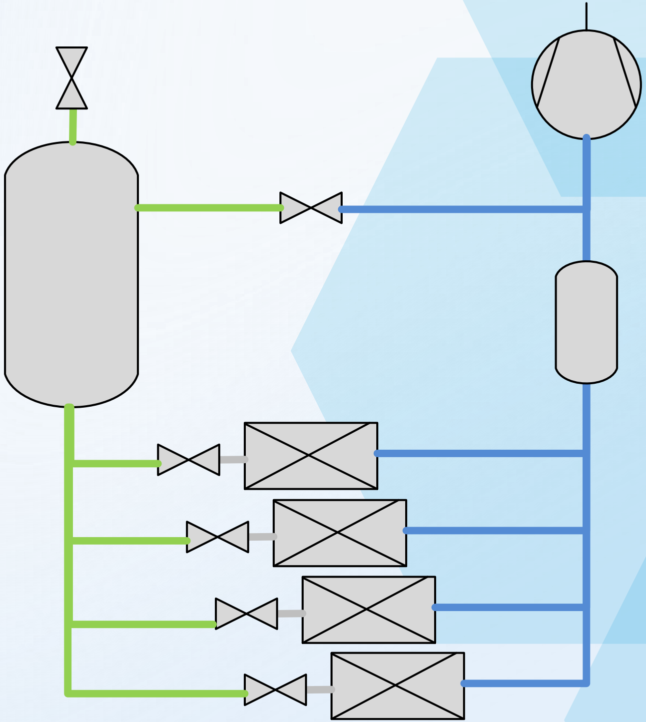
System design

- System contains of multiple evaporators and the controls always include:
    - Modulating thermostat
    - Low superheat
    - Po optimization
- There must always be a suction accumulator before the compressors to handle larger amounts of liquid in short periods
- The liquid can be removed by Liquid ejector or by evaporation in a heat exchanger.



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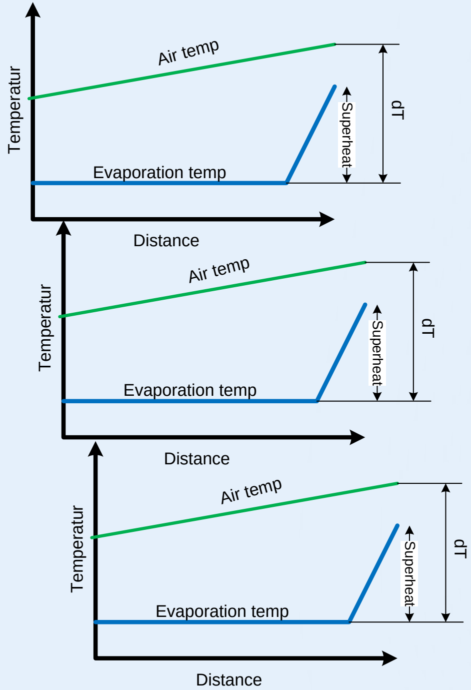
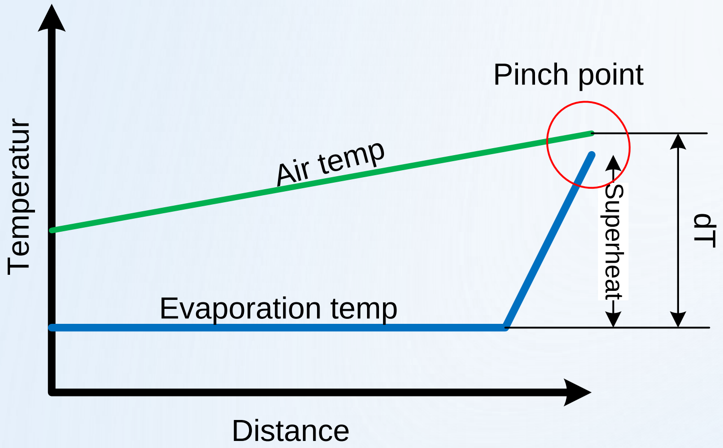
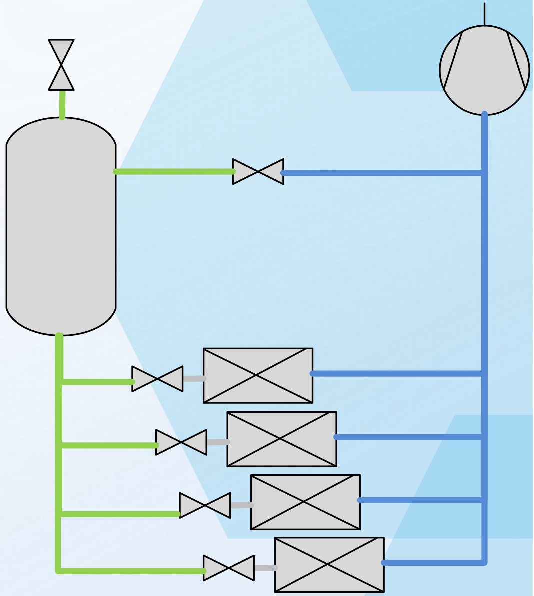
Direct expansion







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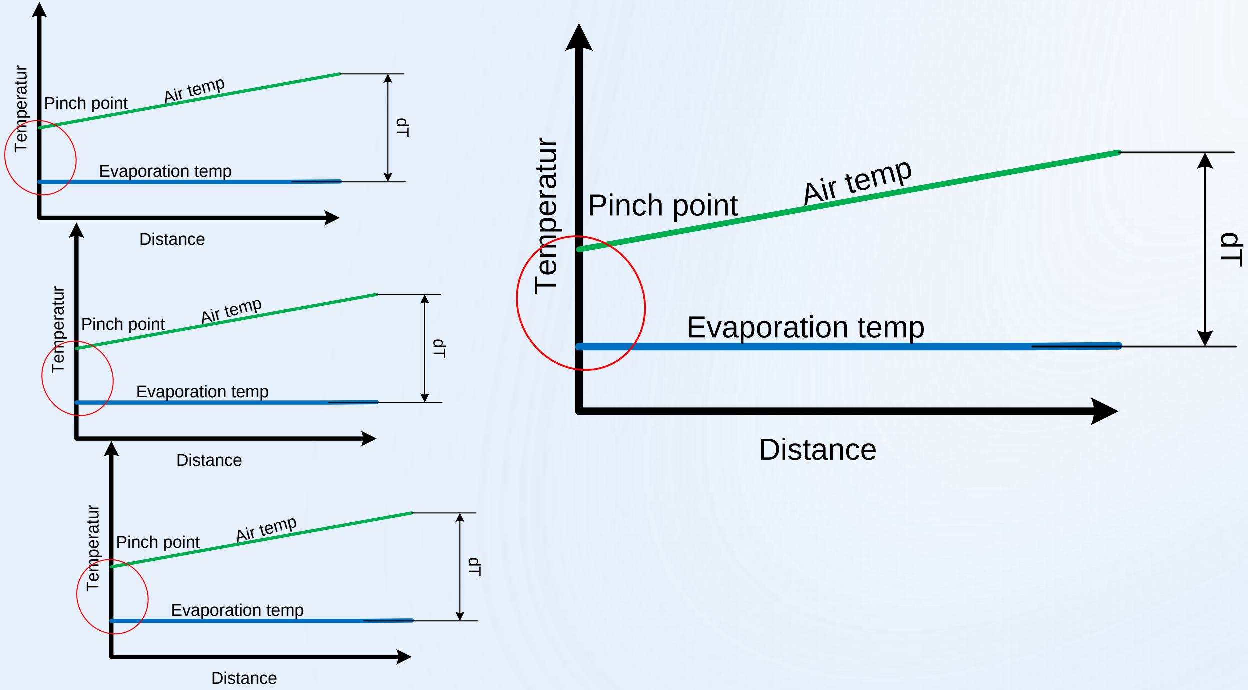
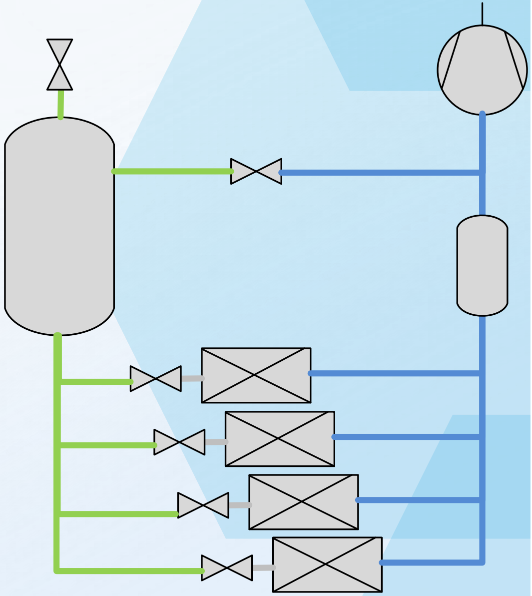
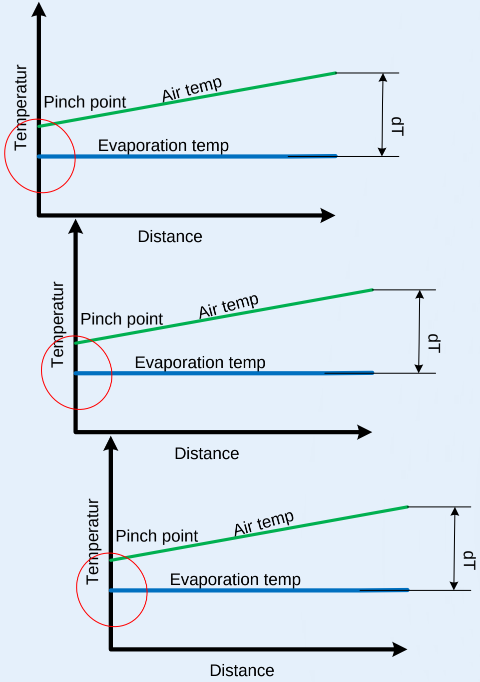
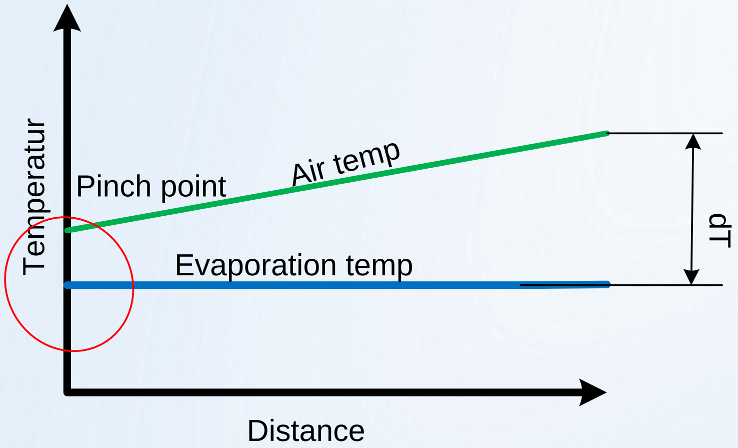
ULSH evaporator without Po optimization

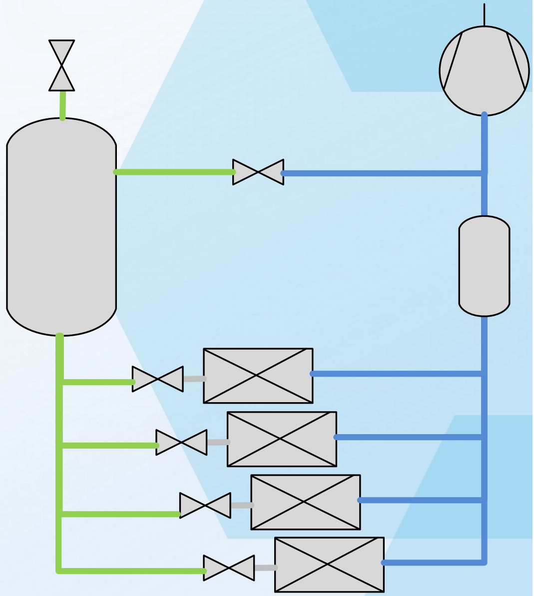




ULSH and Po optimization







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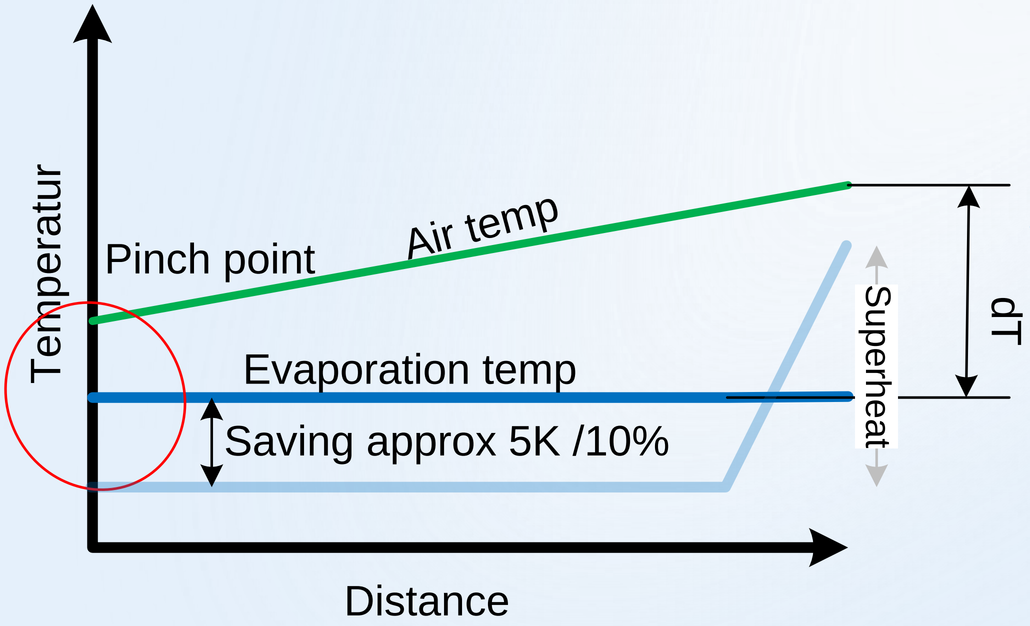
Effect of ULSH



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Test results

- Cash and carry market in central Germany
- 220 kW MT load
- ULSH on MT only
- ULSH in operation since July 2017

- Test from 12th of June 2017
- Test matrix
    - One week with ULSH
    - One week with 3K superheat
    - One week with 6K superheat
    - Repeat 3 times

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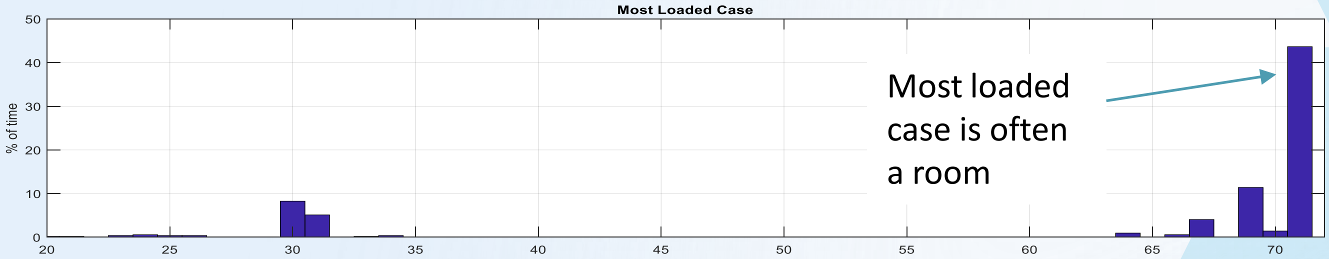
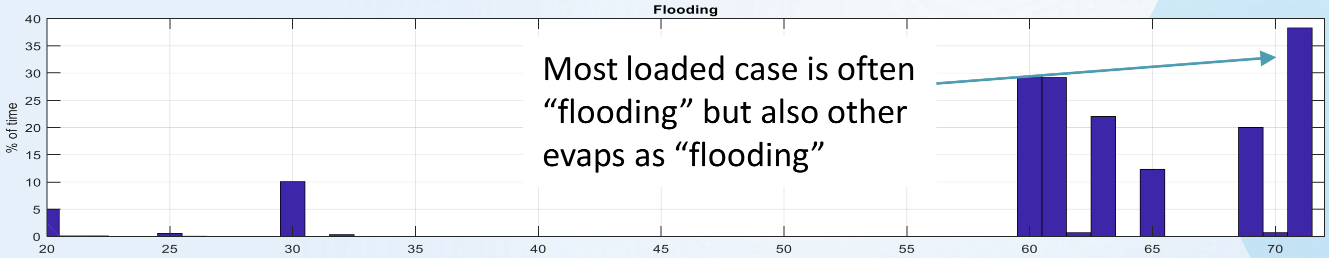
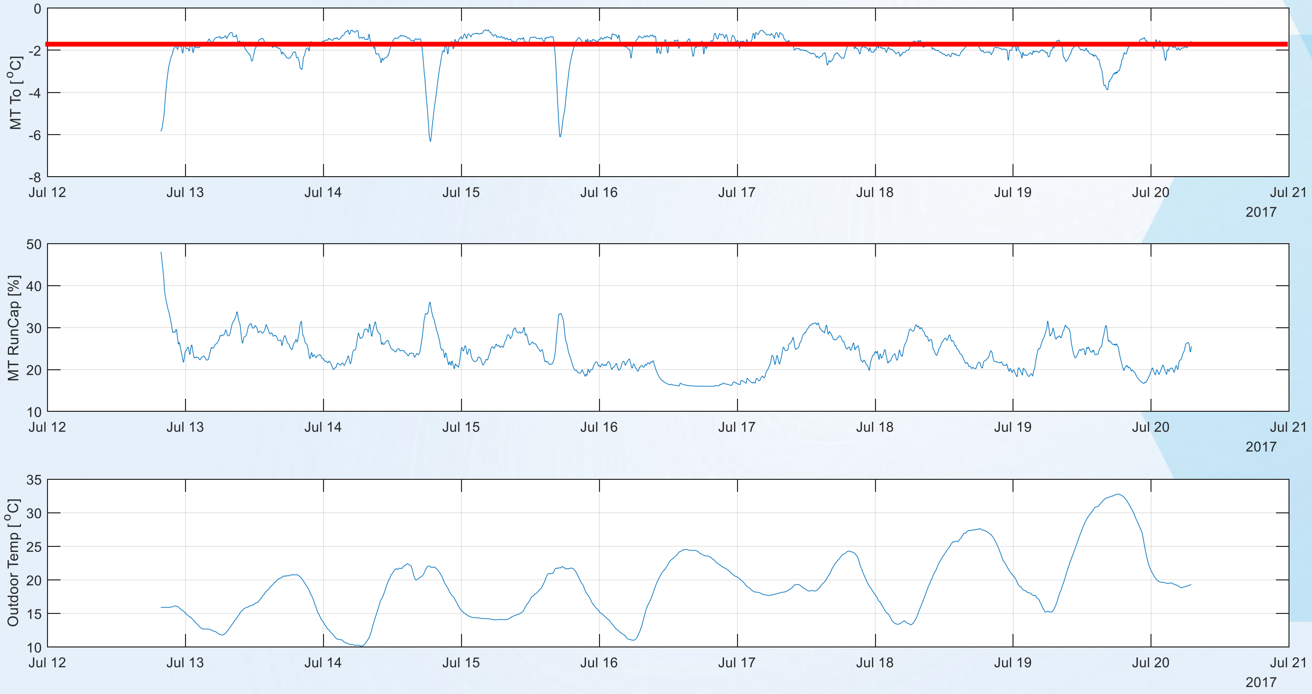
ULSH operation 12-20jul





ULSH operation 12-20jul



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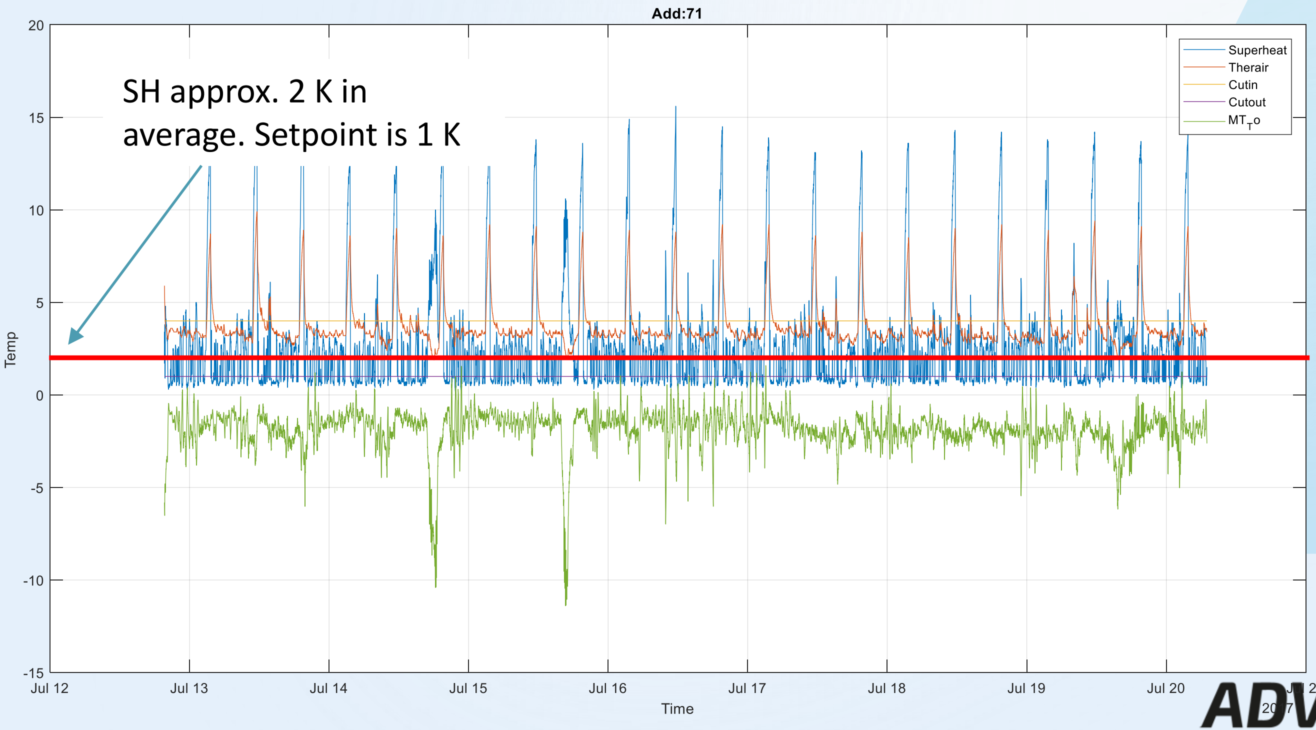
Moste loaded evap ULSH operation 12-20jul



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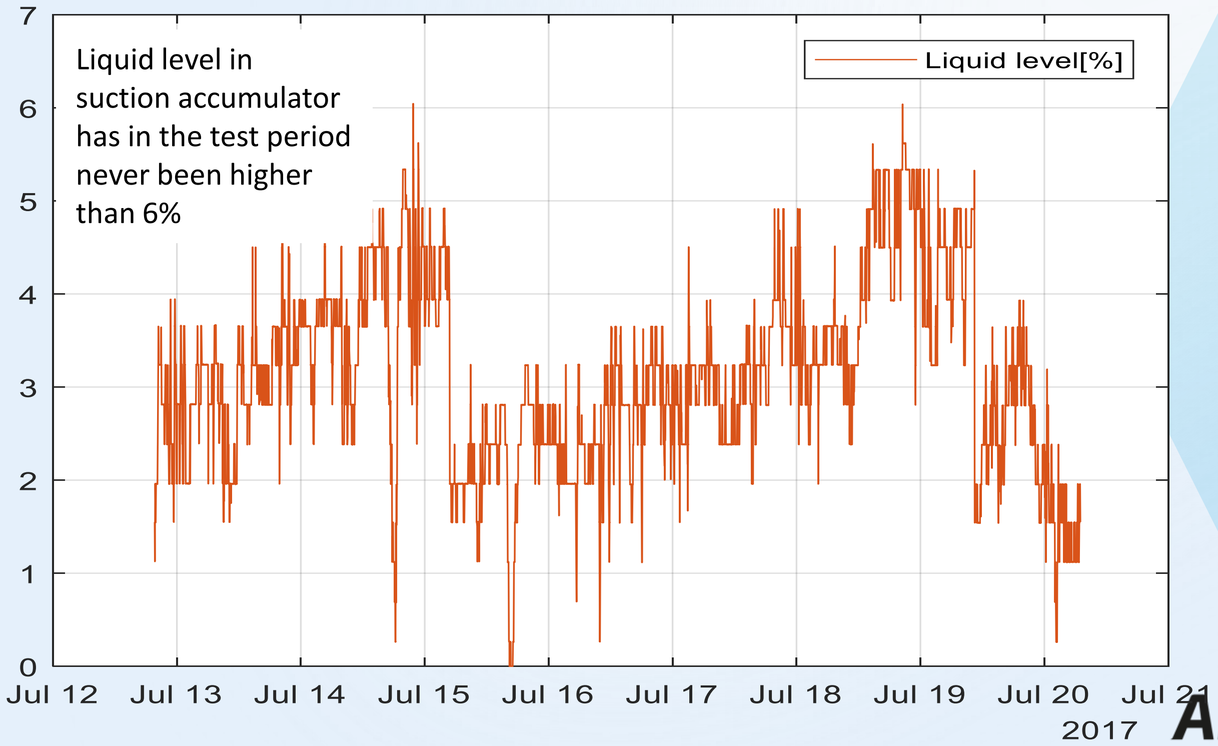
ULSH 12-20jul



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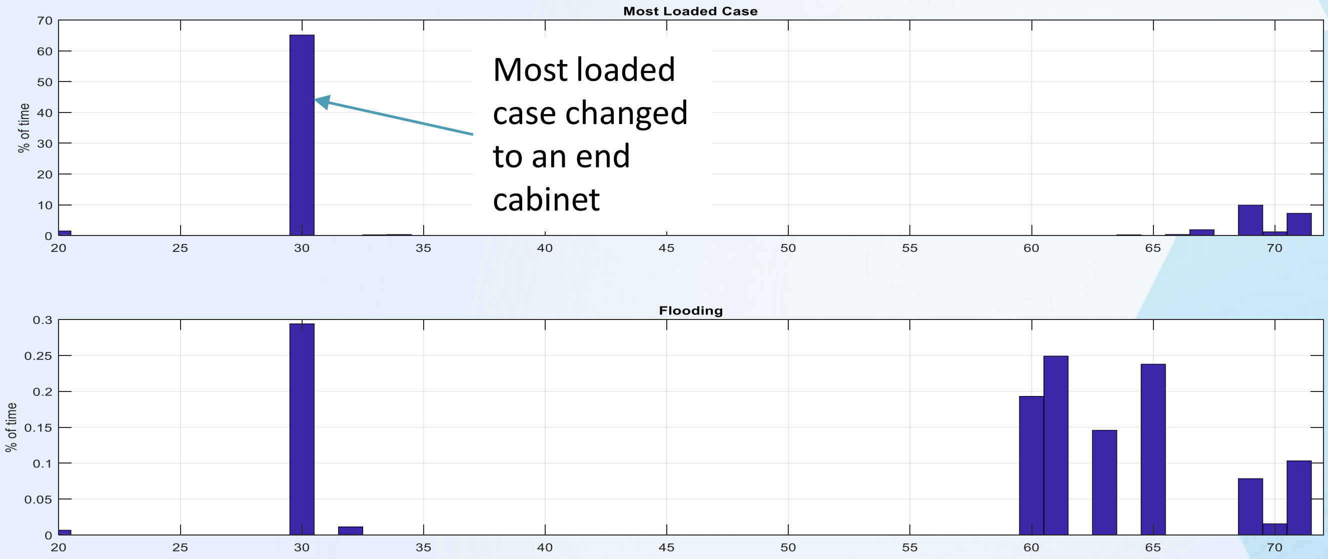
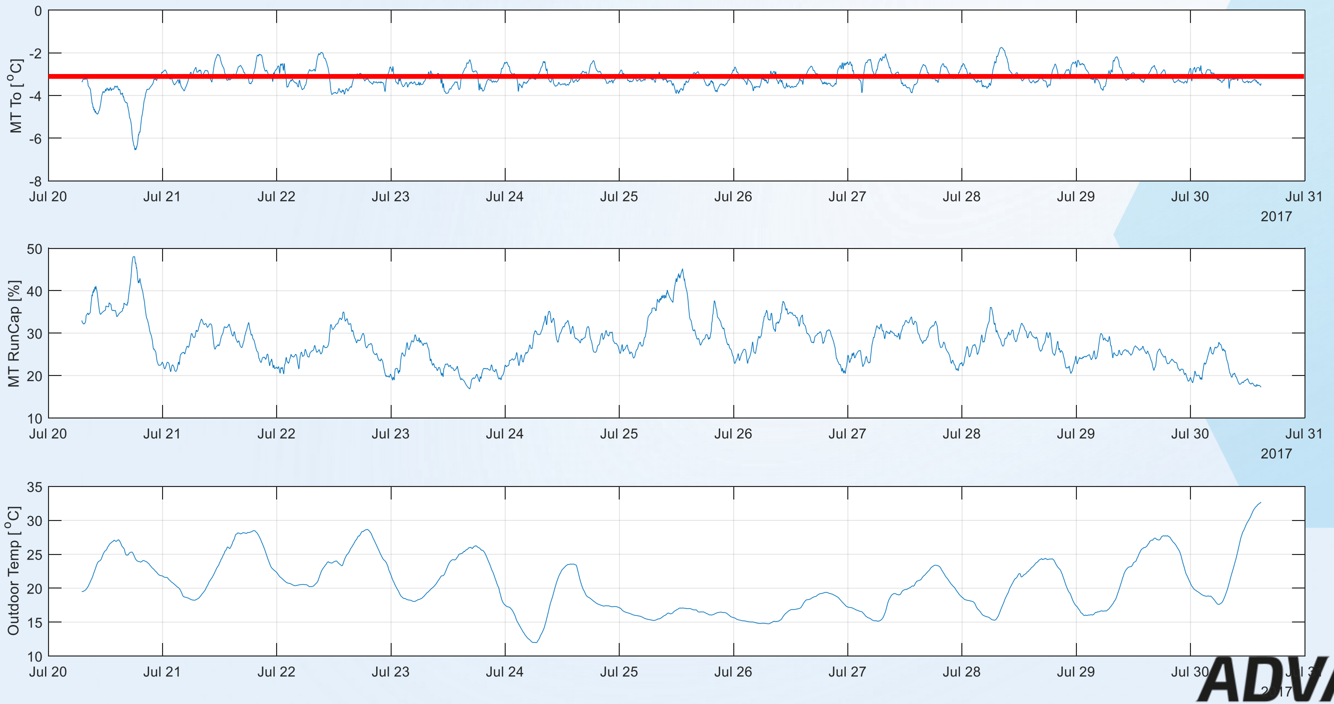
3 K SH 20-31 jul



3K SH 20-31 jul



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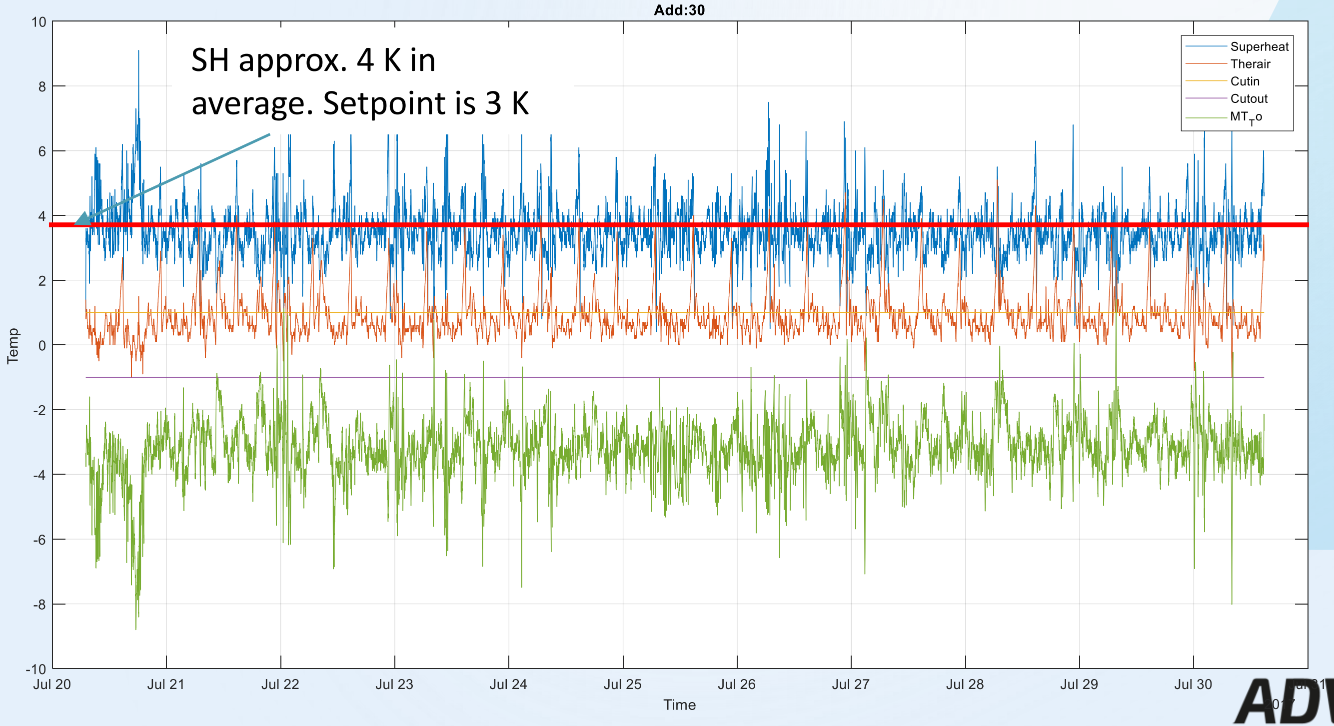
Most loaded evap 3K SH operation 20-31 jul



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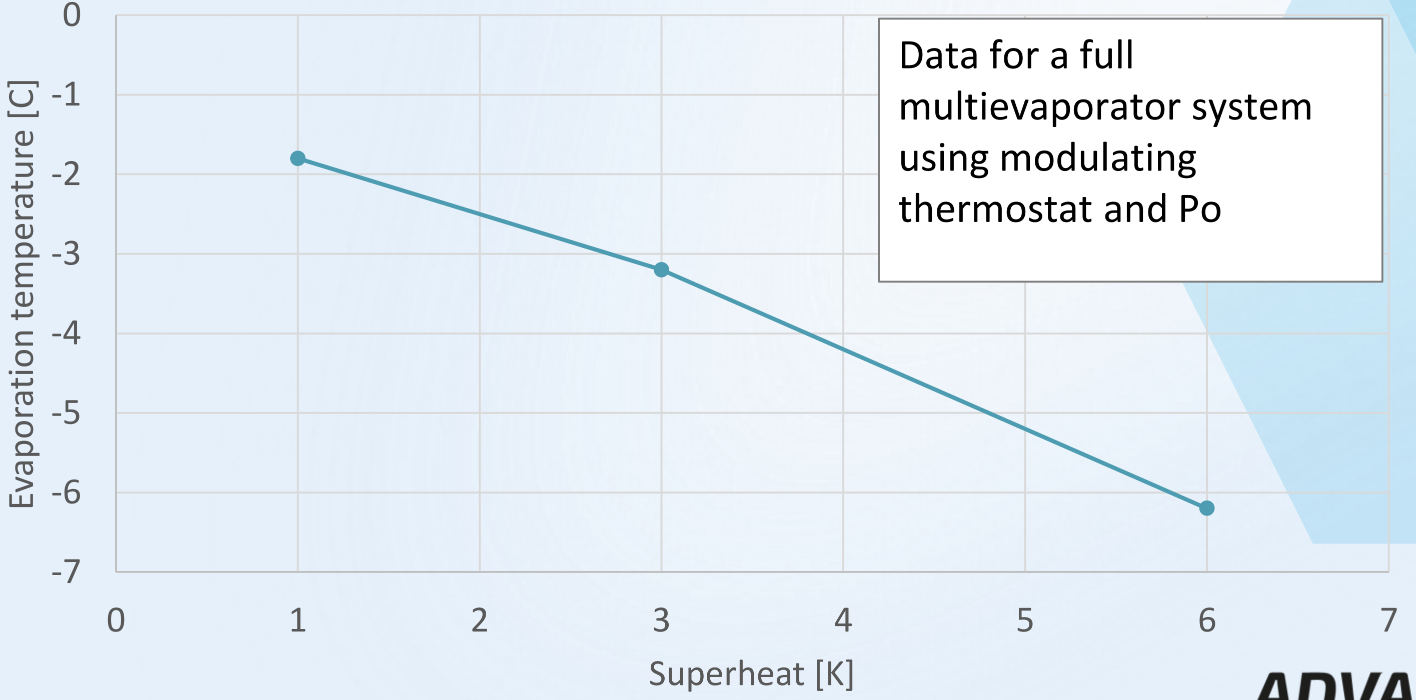
Evaporation temperature as a function of superheat



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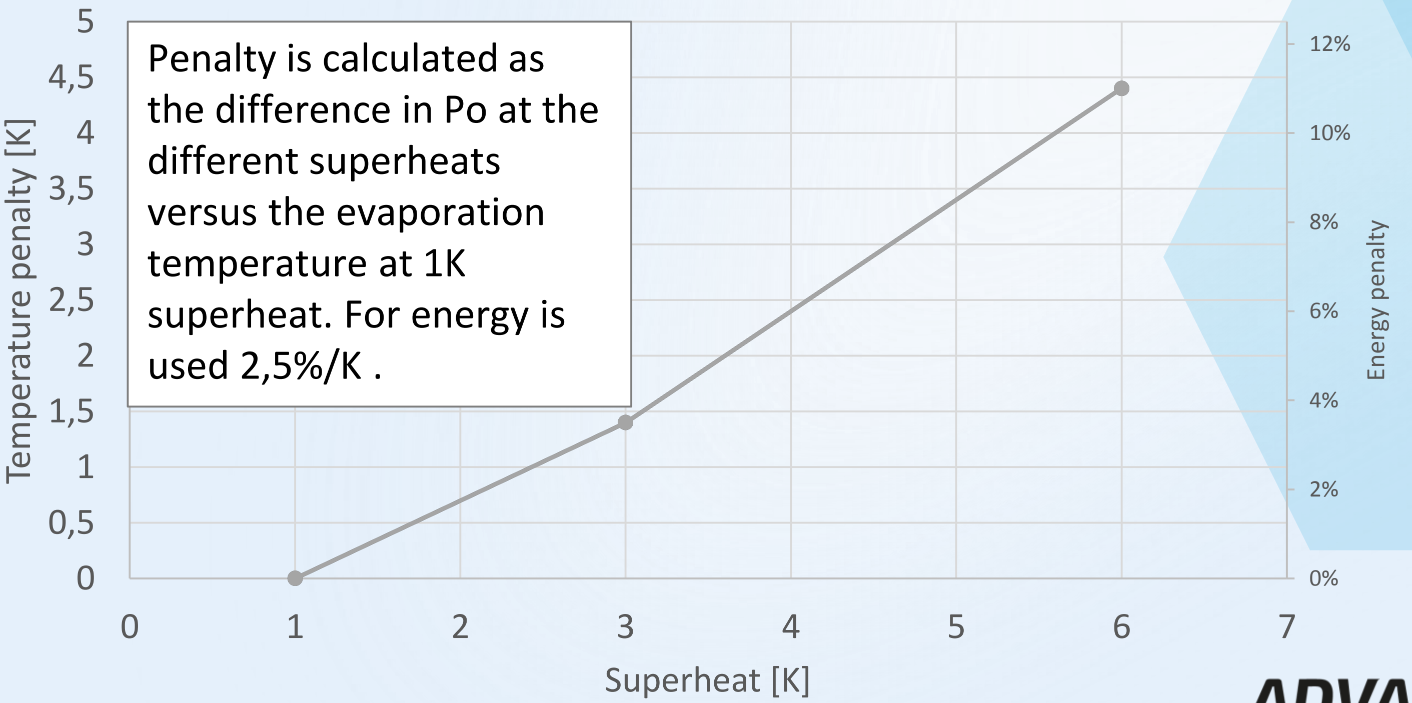
Evaporation temperature penalty VS superheat



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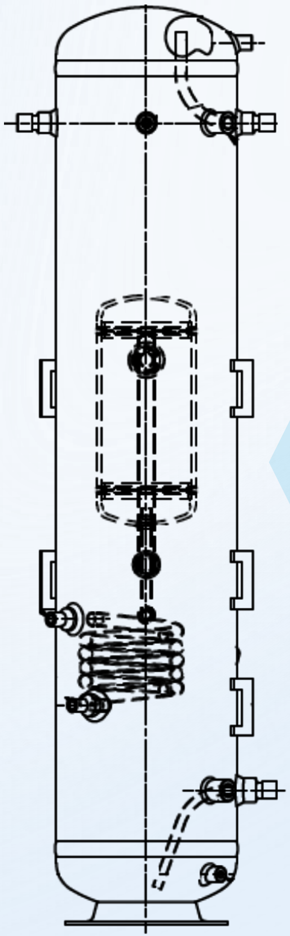
Conclusion test

- Effect of superheat clearly documented
- Going from 6K superheat to ULSH gives approx. 11% energy saving but going from 6 to 3K SH releases most of the potential saving and the risk is lower if the system is made with out liquid ejectors but is based on evaporation of the liquid.
- ULSH also has a positive effect on evaporators that are difficult to control
- The ability to remove liquid using a Danfoss liquid ejector has newer been a problem in the test period
- Test results is very much in line with results from other investigations

ULSH ValuePack

- ValuePack comes with integrated Suction accumulator and Superheater coil integrated in the design
- This makes the construction very robust and suitable for Low superheat applications.
- Results from Norway show -25 °C average suction on LT and -0,4°C average suction pressure on MT recorded over a full week. This is obtained with a standard configuration on a ValuePack.
- Coil is applied on LT at -30 °C and +2 °C receiver pressure the coil can evaporate approx. 9 kW liquid
- Suction accumulator together with LT discharge can also handle long periods with high liquid return rates because the receiver in receiver design works as suction accumulator and suction line heat exchanger at the same time.



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Pay back ULSH

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/5,16 (10%)	0*
Strasbourg	3,93/4,32 (10%)	0*
Lisbon	3,25/3,57 (10%)	0*

70 kW MT, -10 C evaporation, 2K gas cooler, **no HR**
*With VP receiver design and proper adjustment of evaporator controllers

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Pay back ULSH

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/5,16 (10%)	3,8
Strasbourg	3,93/4,32 (10%)	3,0
Lisbon	3,25/3,57 (10%)	2,3

200 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

EJECTORS
SYSTEMS

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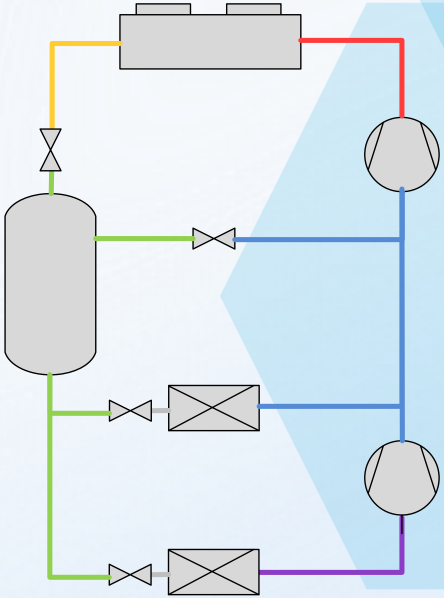
Booster system

- Booster system is the reference for all systems
- By fare the most common system
- Standard since 2007
- Good in cold climates



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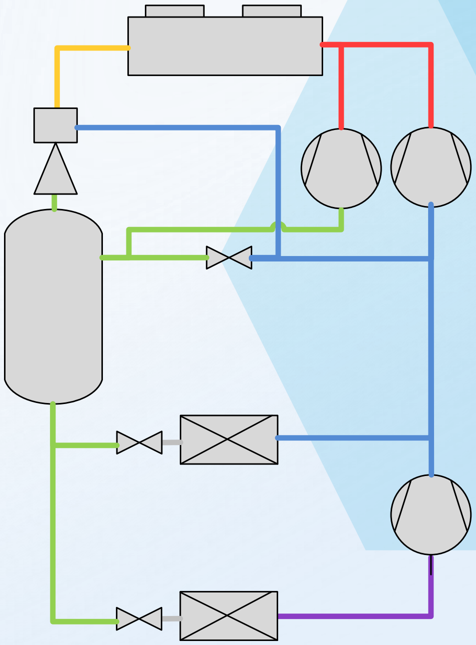
High pressure lift application

- High pressure lift ejectors are always used in systems with parallel compression.
- Enhance the energy consumption with up to 9% (on anualy basis) in warm climates compared to parallel compression and up to 17% compared to booster system.
- A saving on swept volume of up to 15-35% is also possible (largest in warm climates)
- Cost of the system can be reduced, but mainly on larger systems. On smaller systems the cost is not lowered due to ammount of components needed.
- System target size 100-150 kw and up



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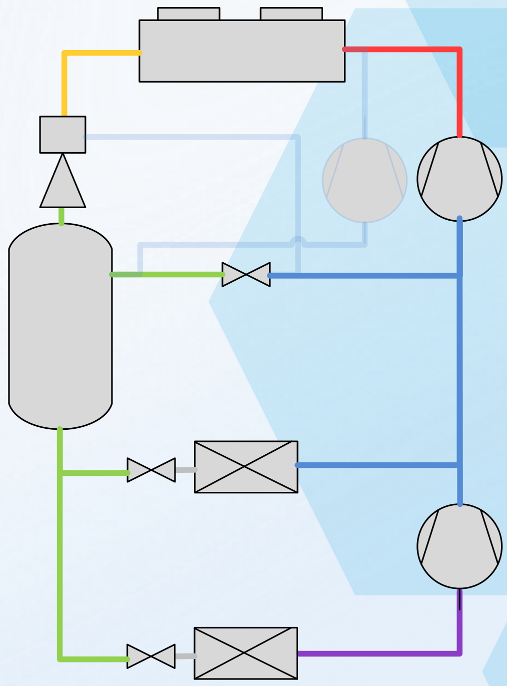
Cycle explanation HP ejector system: Winter mode

The high pressure ejector system is in winter mode is operating like a booster system.

The gas bypass valve is taking the flash gas from the receiver and putting the gas to the MT compressors.

The gas from the gas by pass valve is mixed with gas from MT evaporators and from the LT compressors and compressed with the MT compressors that needs to be able to compress enough gas to handle the capacity in this situation.

The ejector will in this mode just work as a high pressure valve and adjust the high pressure according to the normal algorithm.



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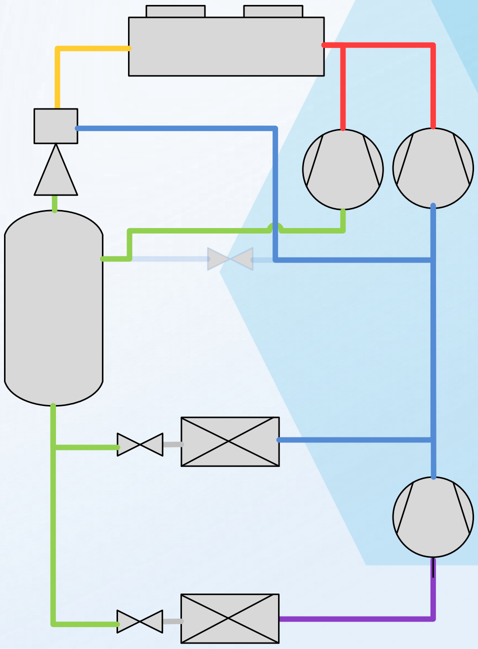
Cycle explanation HP ejector system: Summer mode

When the temperature out of gas cooler warmer the ejector starts to pump.

The gas from MT is pumped through the ejector and is lifted to the receiver where it is separated with the gas from the expansion.

The liquid flows to the evaporators and the gas is moved to the parallel compressors where it is compressed.

The parallel compressor will do approx. 75% of the total flow and the MT compressors will do the remaining 25%.



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Pay back HP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/4,95 (5%)	20
Strasbourg	3,93/4,31 (10%)	9
Lisbon	3,25/3,68 (13%)	5,2

70 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

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Pay back HP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	2,21/2,65 (20%)	3,0
Strasbourg	2,45/2,90 (18%)	3,3
Lisbon	2,92/3,36 (15%)	4,2

70 kW MT, -10 C evaporation, 2K gas cooler, **with HR**

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Pay back HP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/4,95 (5%)	7,1
Strasbourg	3,93/4,31 (10%)	3,3
Lisbon	3,25/3,68 (13%)	1,8

200 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

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Pay back HP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	2,21/2,65 (20%)	1,0
Strasbourg	2,45/2,90 (18%)	1,2
Lisbon	2,92/3,36 (15%)	1,5

200 kW MT, -10 C evaporation, 2K gas cooler, **with HR**

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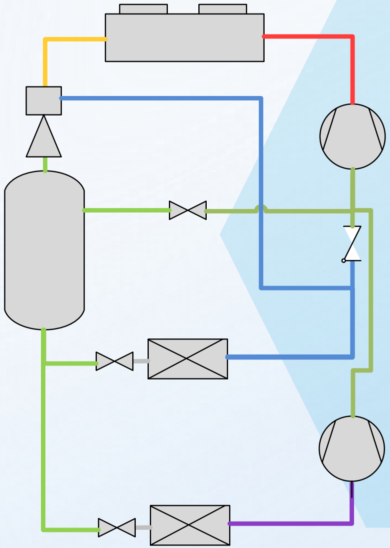
Low pressure lift application

- Low pressure lift application is used in systems with out parallel compression
- Energy data indicates energy savings 15% lower than booster systems and up to 34% compared to R404A
- Due to the high suction pressure on the compressors (7 bar higher at 32 °C amb) the required swept volume will be approx. 75% of what a booster system would need.
- First cost will be slightly higher than a booster system due to the extra cost of the ejector.
- System target size 20- 150 kW



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Cycle explanation LP ejector system: Winter mode

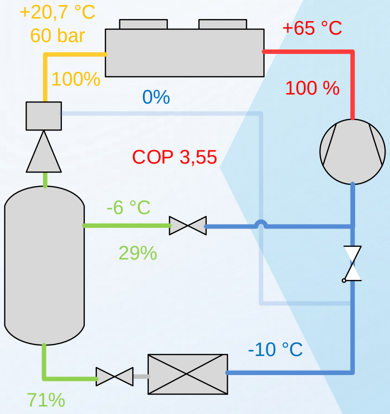
In winter mode the gas coming from LT compressor and MT evaporators is sucked through the NRV in the suction line and mixed with gas from gas by pass valve. The ejector is not capable of lifting the gas from evaporators (maybe a smaller part that will flow back through the gas by pass valve).

The Mt compressors is then compressing the gas that flows through the gas cooler to the high pressure side of the ejector.

In winter mode the ejector is simply controlling the high pressure as a high pressure valve would have done.

The flow from the ejector will flow to the receiver where liquid and gas from expansion is separated and the gas flows through the gas by pass valve to the MT compressors and the liquid is expanded to the evaporators.

<u>In winter mode the system operates like a normal booster system.</u>



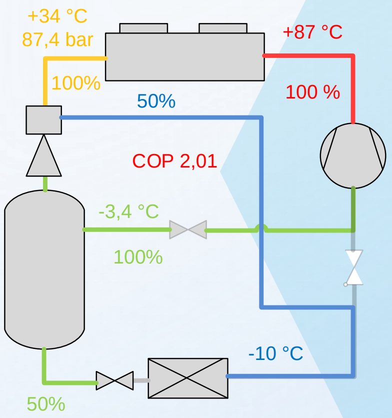
Cycle explanation LP ejector system: Summer mode

In summer mode the temperature out of the gas cooler is so high that the ejector is capable of lifting all the gas from evaporators through the ejector and to the receiver (check valve in suction line between compressors and evaporators is closed due to pressure difference).

Inside the ejector the gas from the evaporators is mixed with the gas/liquid flow from the gas cooler and flows to the receiver.

In the receiver the gas and liquid is separated and the liquid is expanded in the evaporators and the gas flows through the gas by pass valve, which is fully open and has a very low pressure difference.

The compressors is sucking the gas directly from the receiver and compressing to the high pressure. The flow is then cooled in the gas cooler and expanded in the ejector.



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Pay back LP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/4,83 (3%)	8
Strasbourg	3,93/4,12 (5%)	3,9
Lisbon	3,25/3,46 (7%)	2,2

70 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

Pay back LP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	2,21/2,45 (11%)	1,1
Strasbourg	2,45/2,69 (10%)	1,3
Lisbon	2,92/3,15 (8%)	1,7

70 kW MT, -10 C evaporation, 2K gas cooler, **with HR**

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Pay back LP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	4,69/4,83 (3%)	5,6
Strasbourg	3,93/4,12 (5%)	2,7
Lisbon	3,25/3,46 (7%)	1,5

200 kW MT, -10 C evaporation, 2K gas cooler, **no HR**

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Pay back LP ejector system

	SEPR MT only [-]	Pay back [years]
Oslo	2,21/2,45 (11%)	0,8
Strasbourg	2,45/2,69 (10%)	0,9
Lisbon	2,92/3,15 (8%)	1,2

200 kW MT, -10 C evaporation, 2K gas cooler, **with HR**

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HP VS. LP ejectors conclusions

- HP ejectors are generally for larger systems (+100 kW) and for warm climates
- LP ejectors are generally for smaller systems (20-150 kW) and for warm climates
- In general if systems are used for refrigeration only ejector systems has an attractive payback from south of Germany and further south
- If systems are with heat recovery ejectors can be a benefit even in colder climates because the ejector is working in wintertime.
- LP systems looks to have a lower payback than HP ejector systems even for larger systems, but keep in mind that the saving is larger on HP systems, and so is the investment, but after the system is payed the revenue is much larger for HP systems.
- Payback for HP systems will also change in the future due to better possibilities for switching compressors from MT to parallel.

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Conclusion

- Significant savings for CO2 refrigeration systems can be obtained.

- Some of the savings can be harvested at the same time because it is different mechanisms we use. HP and LP ejectors can not be combined with each other, but permanent magnet motors, ULSH and one of the ejector types can in principal be combined wit good effect and the savings can be added.

- Eksample could 200 kW system in Norway with heat recovery:

LSPM	10%	1,0 year
HP ejector	10%	1,0 year
ULSH	10%	3,8 years
Total	30%	Total expected pay back time 1,4 years

Savings are based on calculations and pay back and savings needs to be verified case by case