ENGINEERING TOMORROW

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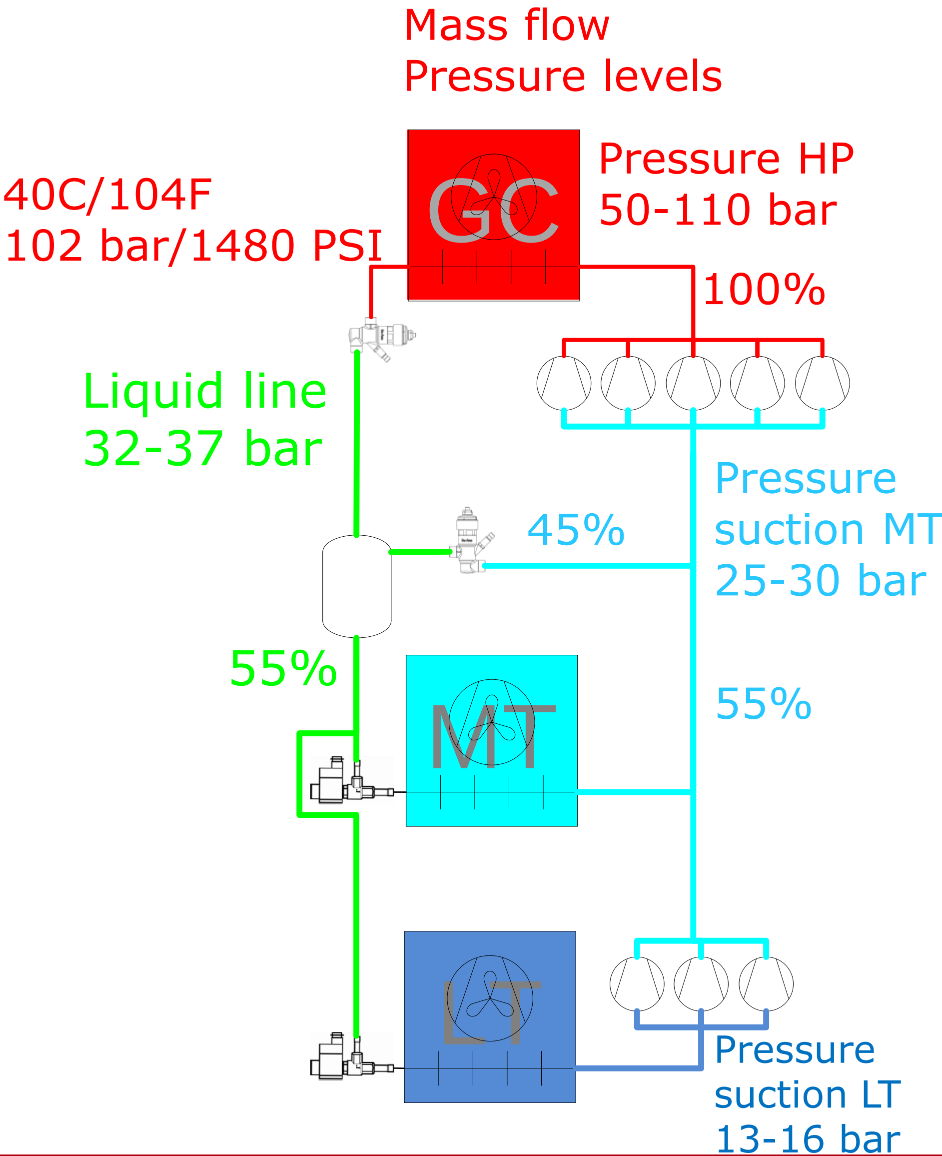
Technology status

Technology allows for world wide adoption of CO_2 only systems

27°C/82°F	38°C/101°F	All ambient	All ambient	All ambient
Booster system (reference)	**Parallel Compression system**	**Ejector system**	**Flooded system**	**Cost reduction simplicity**
+10.000 systems	1000 systems	100 systems	50 systems	3 systems
2007 Commercially Available	2011 Commercially Available	2015 Testing 2017 Commercially Available	2015 Testing 2018 Commercially Available	2015 Early Testing 2018 Extended field trials

1st generation: Booster system

- The transcritical booster system is the most commonly used CO_2 system today.
- The installed base is +10.000 systems with Danfoss components (as of August 2017).
- The market has chosen this as the standard system.



1st generation: Booster system

Pros:

- Long track record with large install base mainly in colder climates.
- Relatively simple compared to most of the other systems on the market.
- In a northern European climate the energy consumption is lower than what we see with R404a.

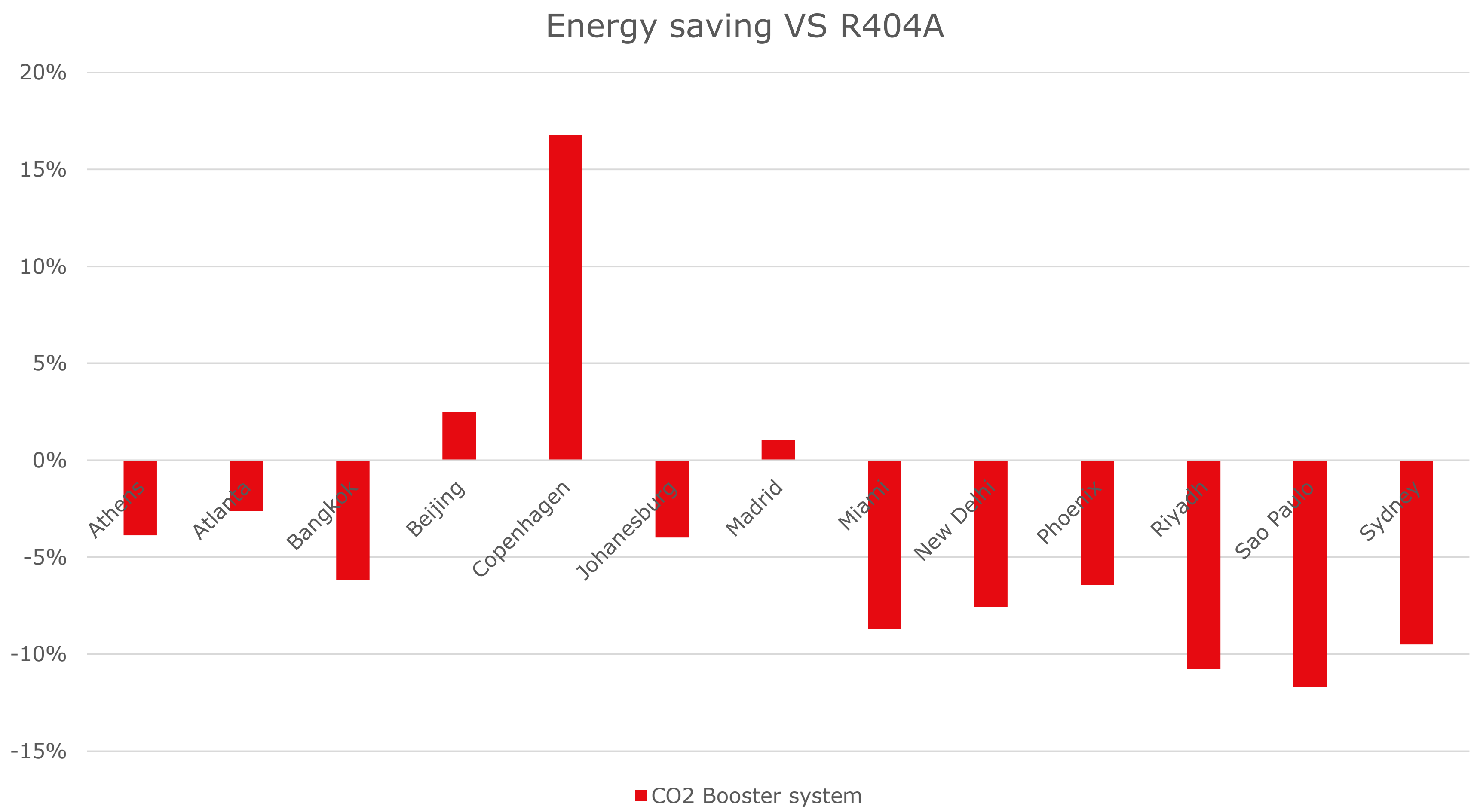
Cons:

- Energy consumption in warm ambient temperature is the main problem.
- Swept volume increases dramatically in warm ambient temperatures.

Application:

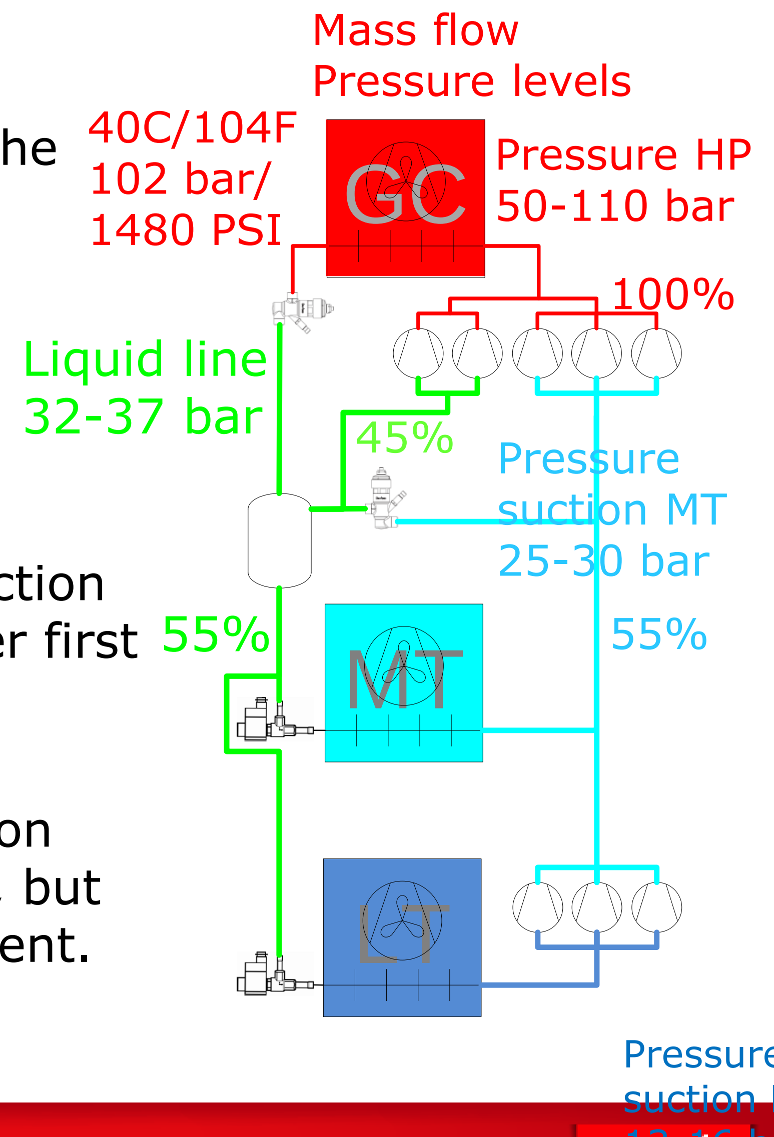
The system covers from small and all the way up to very large systems (CDU, Discounters up to Hypermarkets).
Geographically, the system has a very good foothold in the northern European climate.

Energy savings



2^{nd} generation: Parallel compression

- Parallel compression is the first step into the development towards bringing CO_2 into a warmer climate.
- Parallel compression is giving a significant improvement of COP in warm climates.
- In addition to that, it is also giving a reduction of swept volume of the compressors (lower first cost).
- This reduction of cost can not be realized on systems smaller than approx 100-150 kW, but on larger systems a reduction in cost present.



2nd generation: Parallel compression

Pros

- The system has been on the market for some years and the installations are counted in several hundreds.
- Shows very good energy data in warmer ambient where the energy consumption on annual basis is on the same level or better than R404a
- Compressor sizes are smaller and not as growing as fast in warm ambient
- Integration with AC makes sense

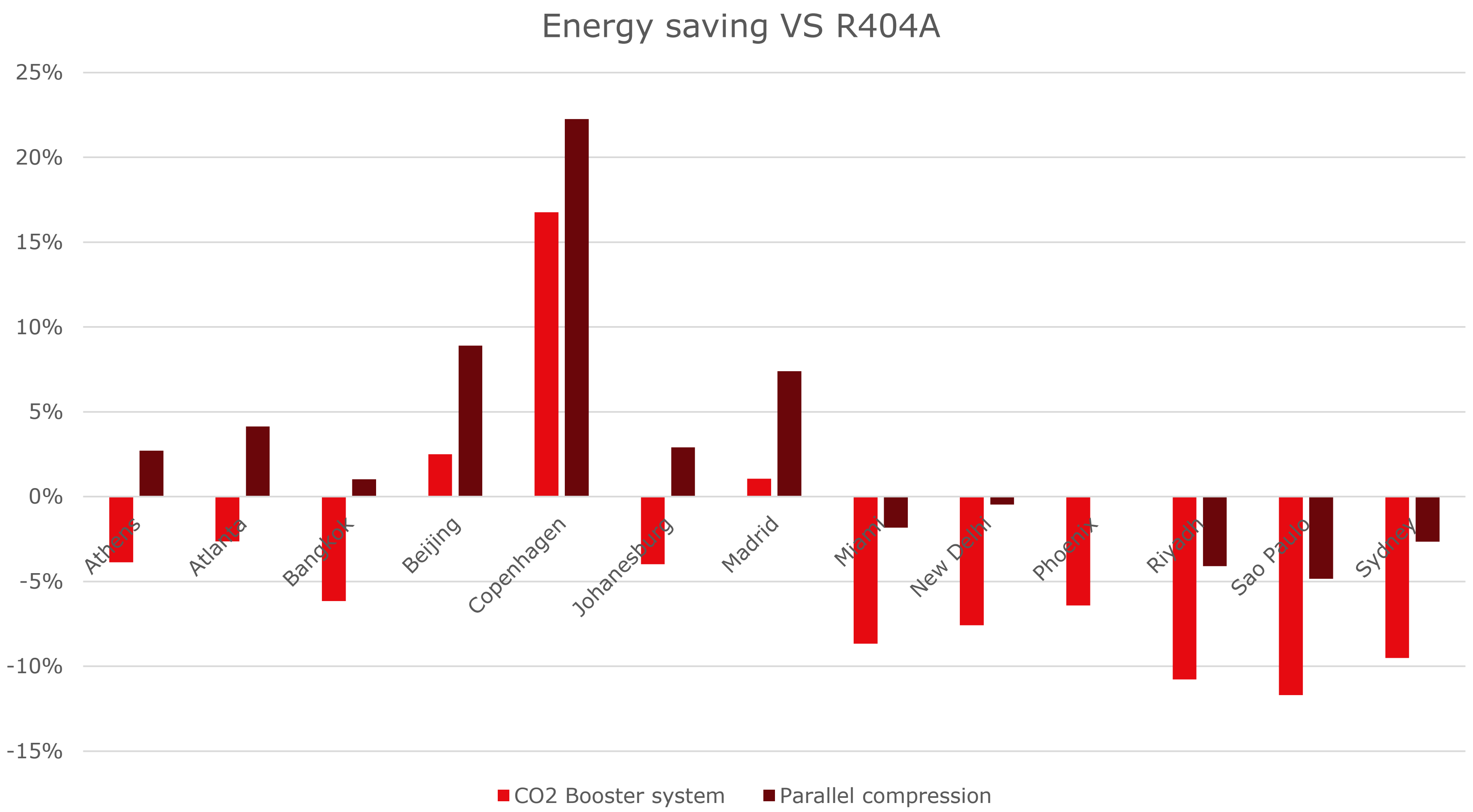
Cons

- The system is more complex than the booster system.
- Small systems are difficult because the compressors are divided in to 2 suction groups

Application:

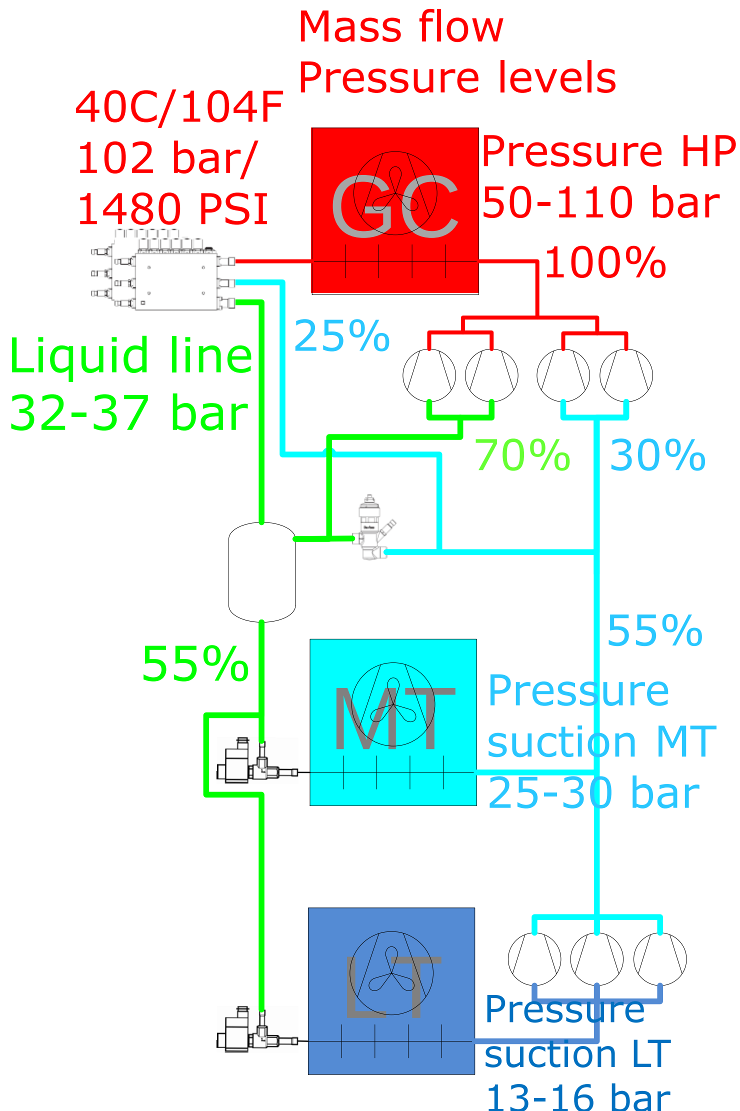
The system fits system sizes from approx. 100-150 kW and up. System can be combined with AC with good results.
Geographically, the system has the largest install base in southern Europe and warmer ambient.

Energy savings



3rd generation: Parallel compression with gas ejector

- First system in opperation with Danfoss Multi Ejector started in January 2015.
- The ejectors are moving gas from MT suction to parallel compressor.
- In some cases, all gas can be moved from MT to parallel compressor (high ambient temperature or 100% heat recovery).



3rd generation: Parallel compression with gas ejector

Pros:

- System is penetrating the market this years
- Solutions shows better energy consumption in any climate and removes the "CO_2 equator"
- Compressor sizes are smaller and not as grooving as fast
- Combination with AC makes very good sense

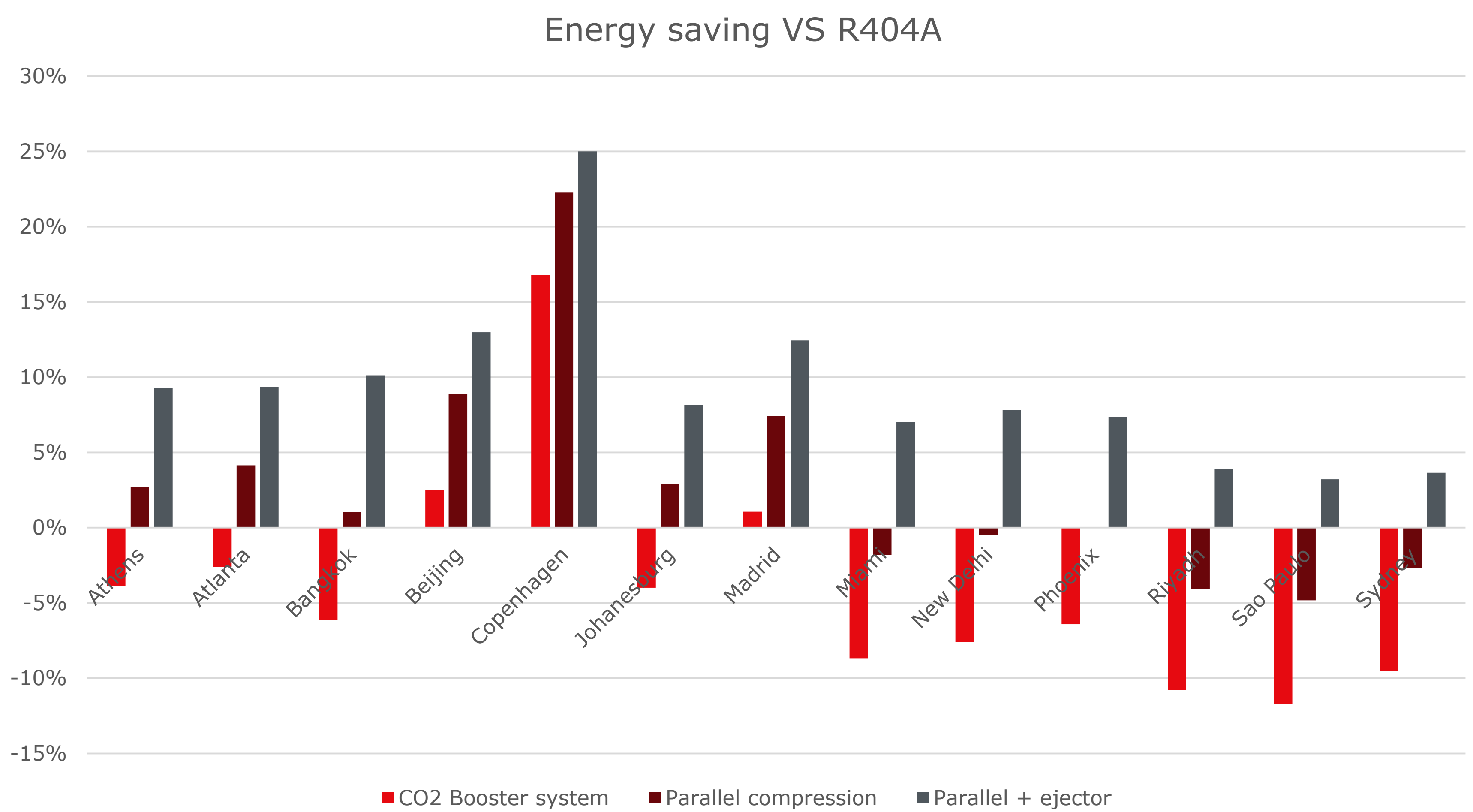
Cons:

- The system is more complex than the booster systems and also parallel compression
- Small systems are difficult because of the compressors divided in to 2 suction groups

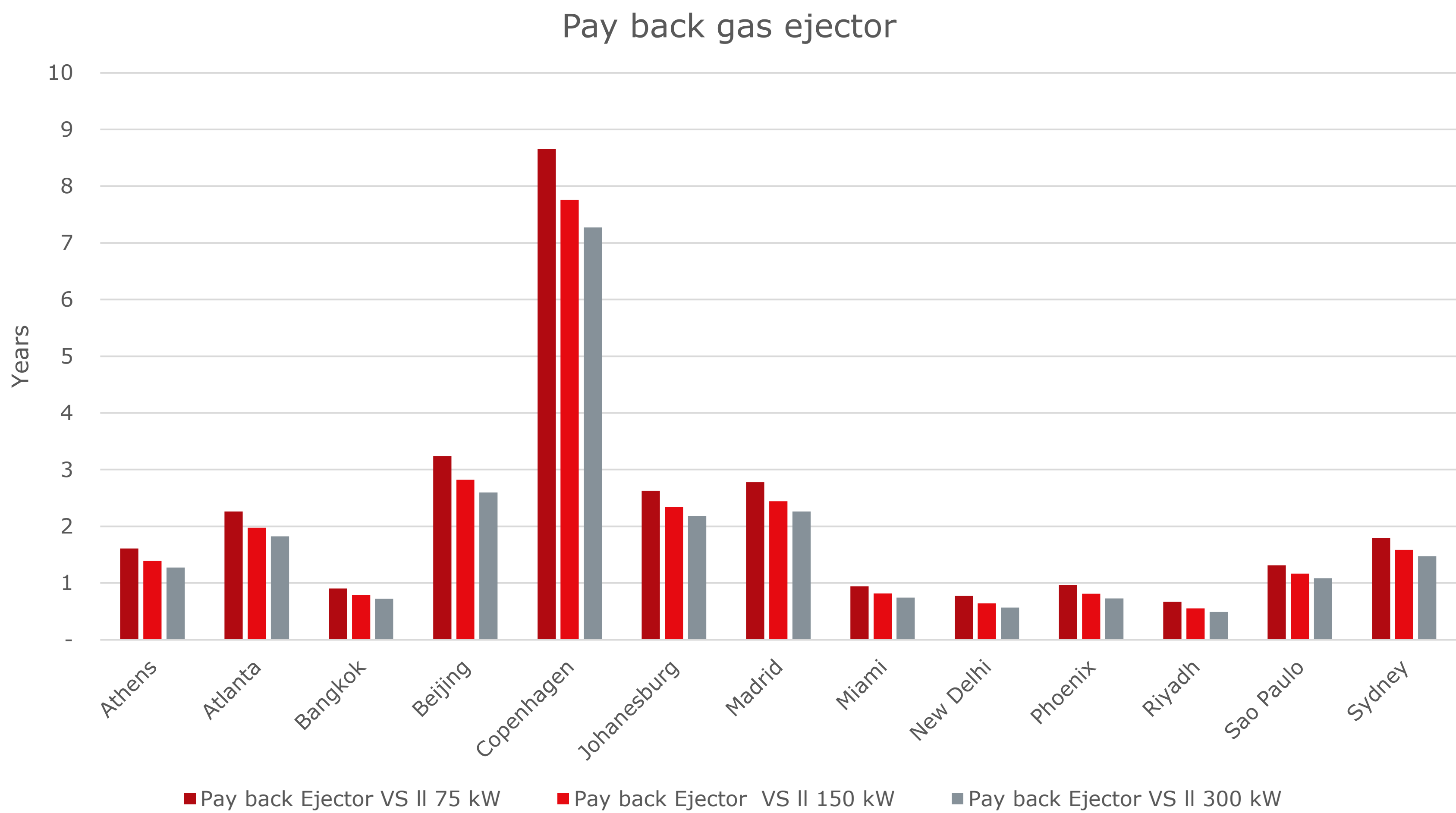
Application:

The system fits system sizes from approx. 100-150 kW and up. System can be combined with AC with very good results.
Geographically the system can be installed in any climate with lower energy consumption than R404a.

Energy saving



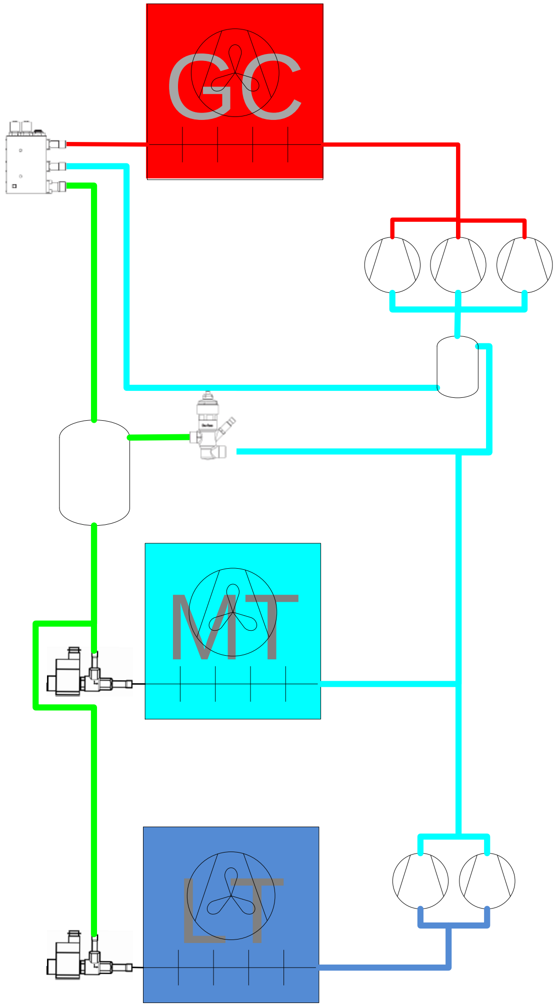
Pay back gas ejector as an add on to parallel compression



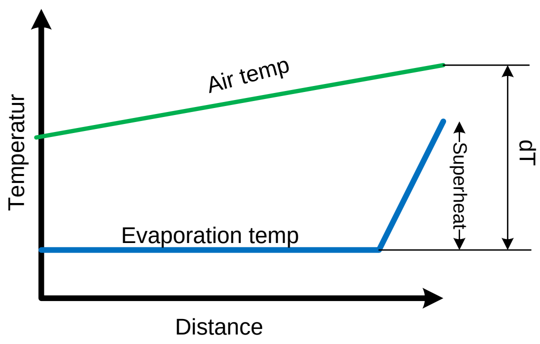
Next generation: Liquid ejector

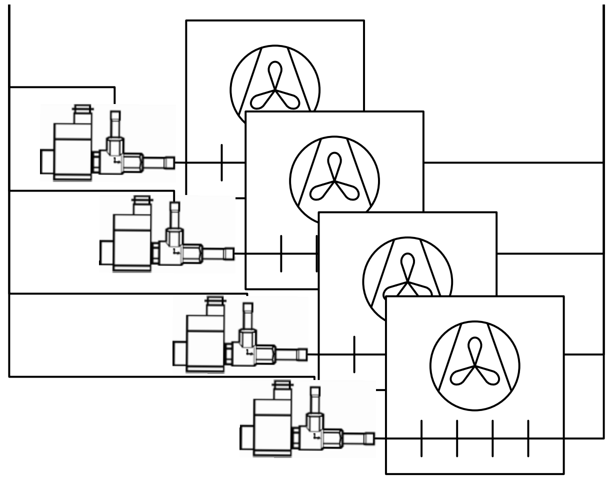
Add on to transcritical systems

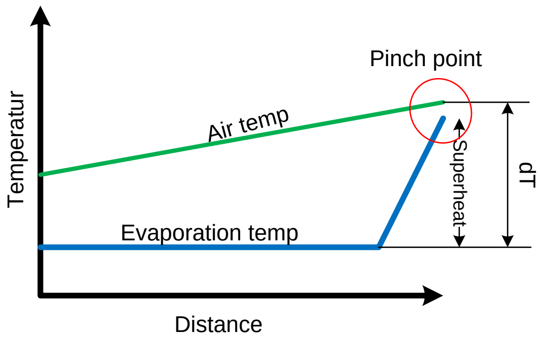
- Liquid ejector systems allow the MT evaporator to be flooded.
- The saving is coming from the higher suction pressure of the compressors.
- Ejector is in this case substituting a pump or other means of removing the liquid from the suction side
- Trials has been running since 2013 with good results. Evaporation temperature is in average raised by 5K.
- Saving is load dependent and dependent on most leaded evaporator



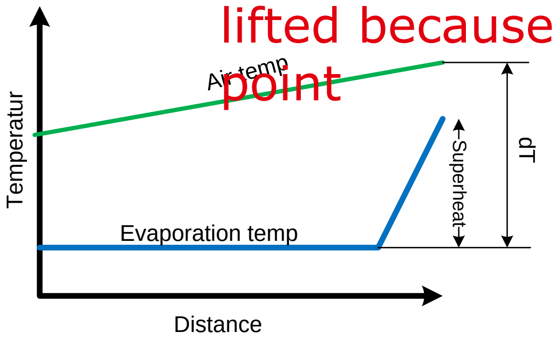
Direct expansion

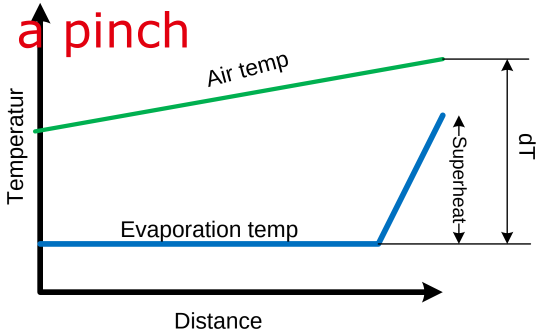




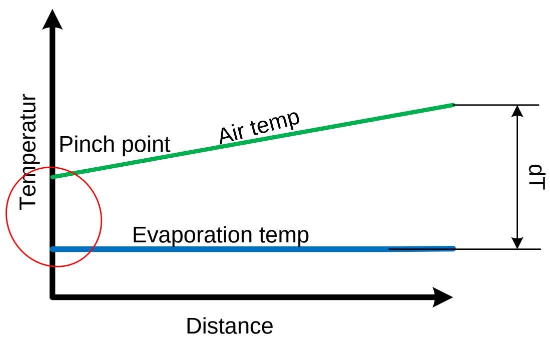


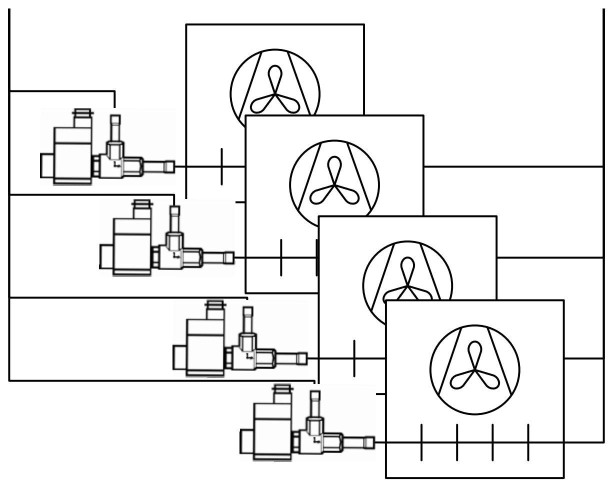
Evaporation temperature can not be lifted because the SH creates a pinch point

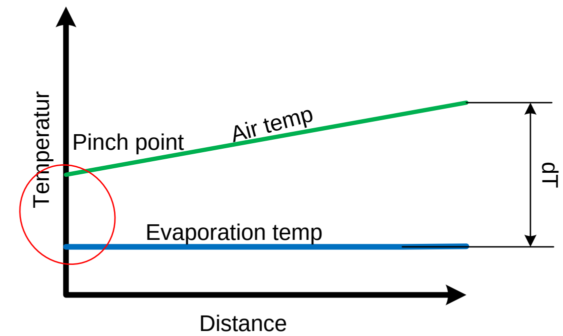




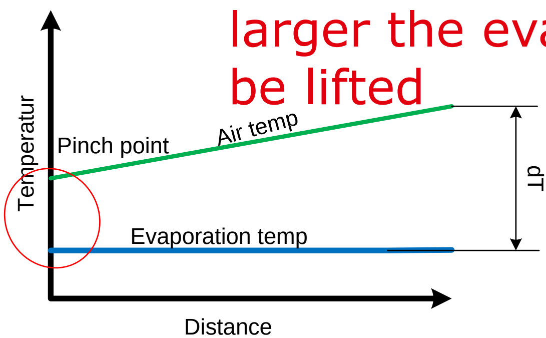
Flooded evaporator without Po optimization

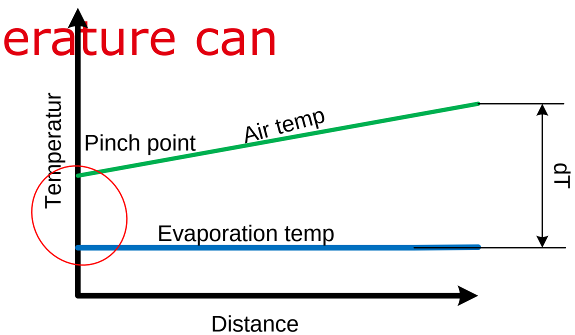




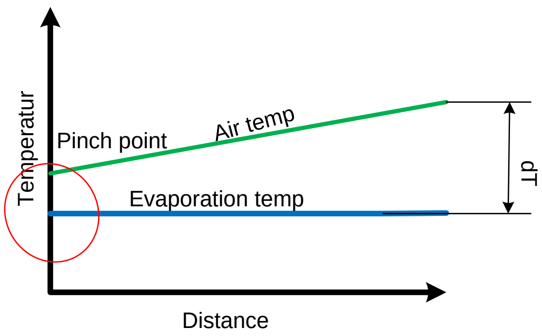


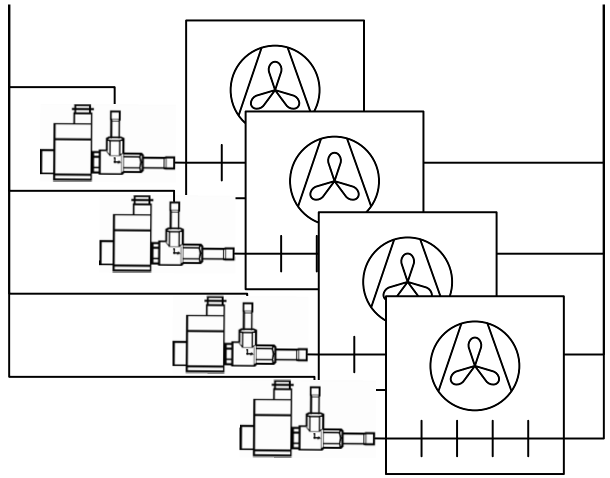
When the pinch point is moved and larger the evaporation temperature can be lifted

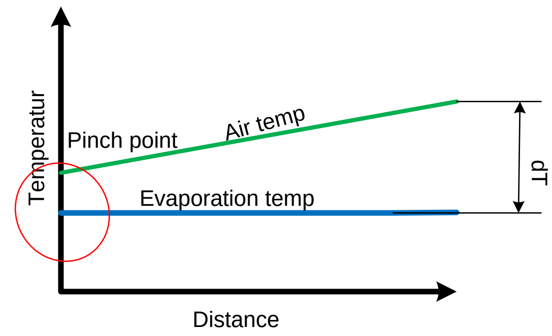




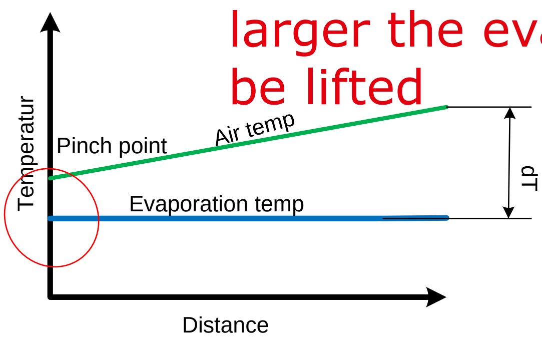
Flooded evaporator and Po optimization

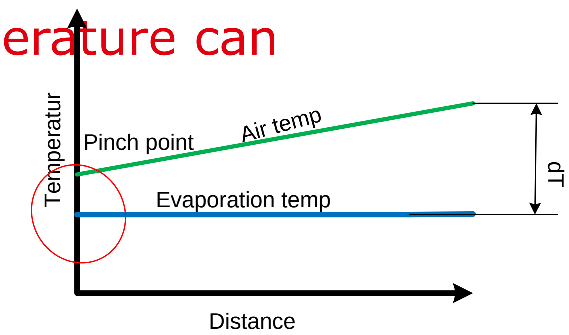




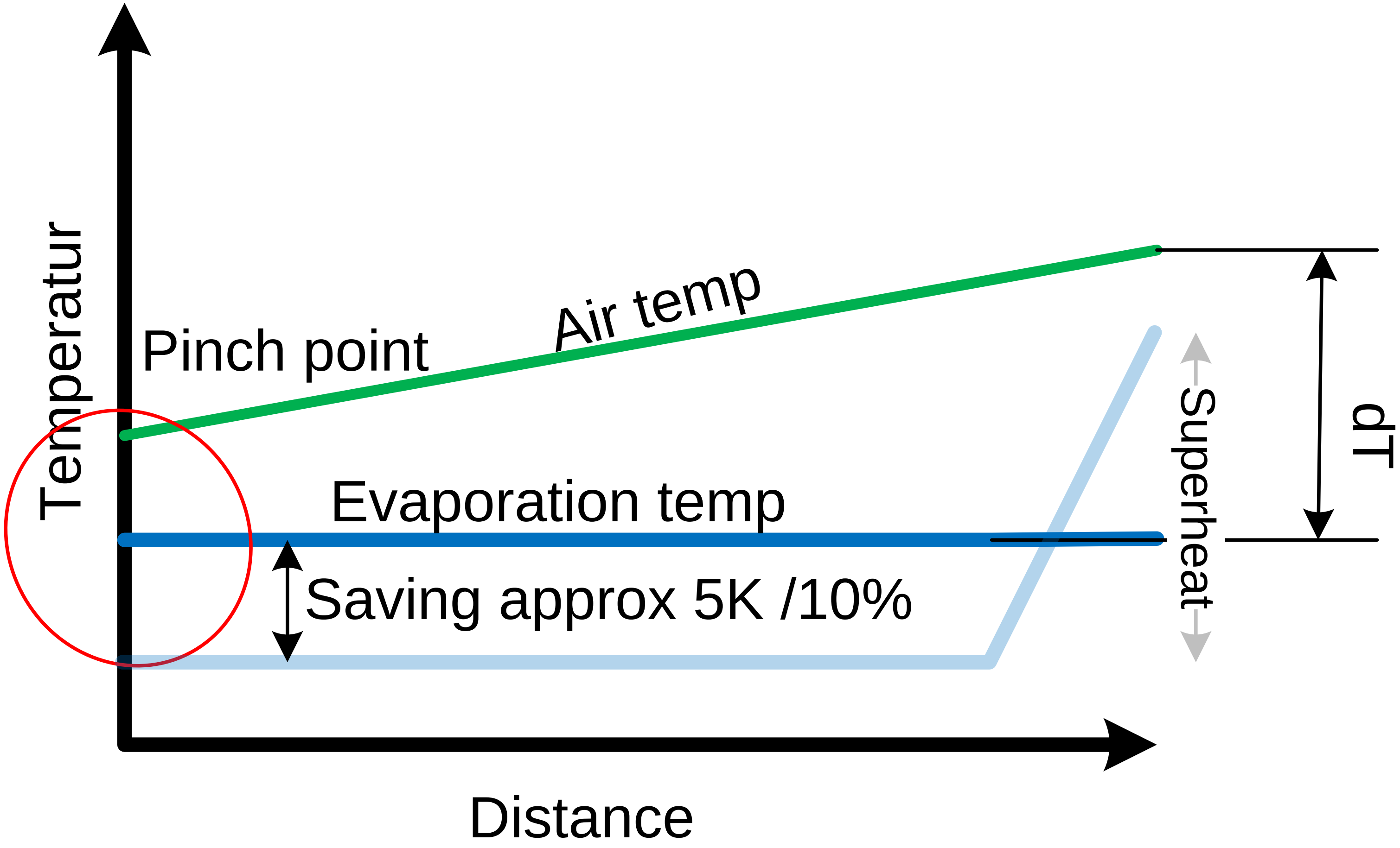


When the pinch point is moved and larger the evaporation temperature can be lifted





Effect of flooded evaporators and PO optimization



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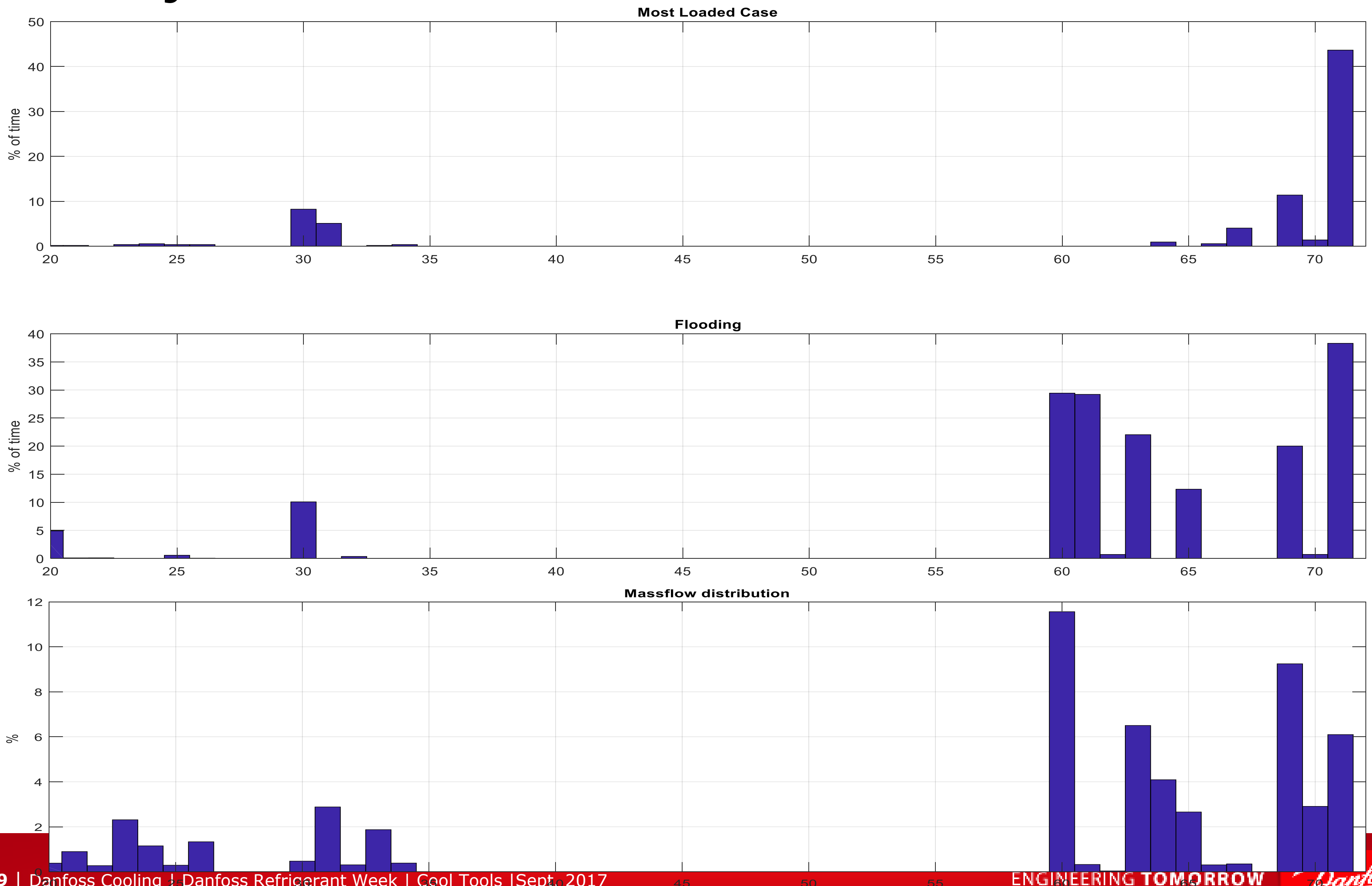
Data from supermarkets

Flooded operation

12-20jul



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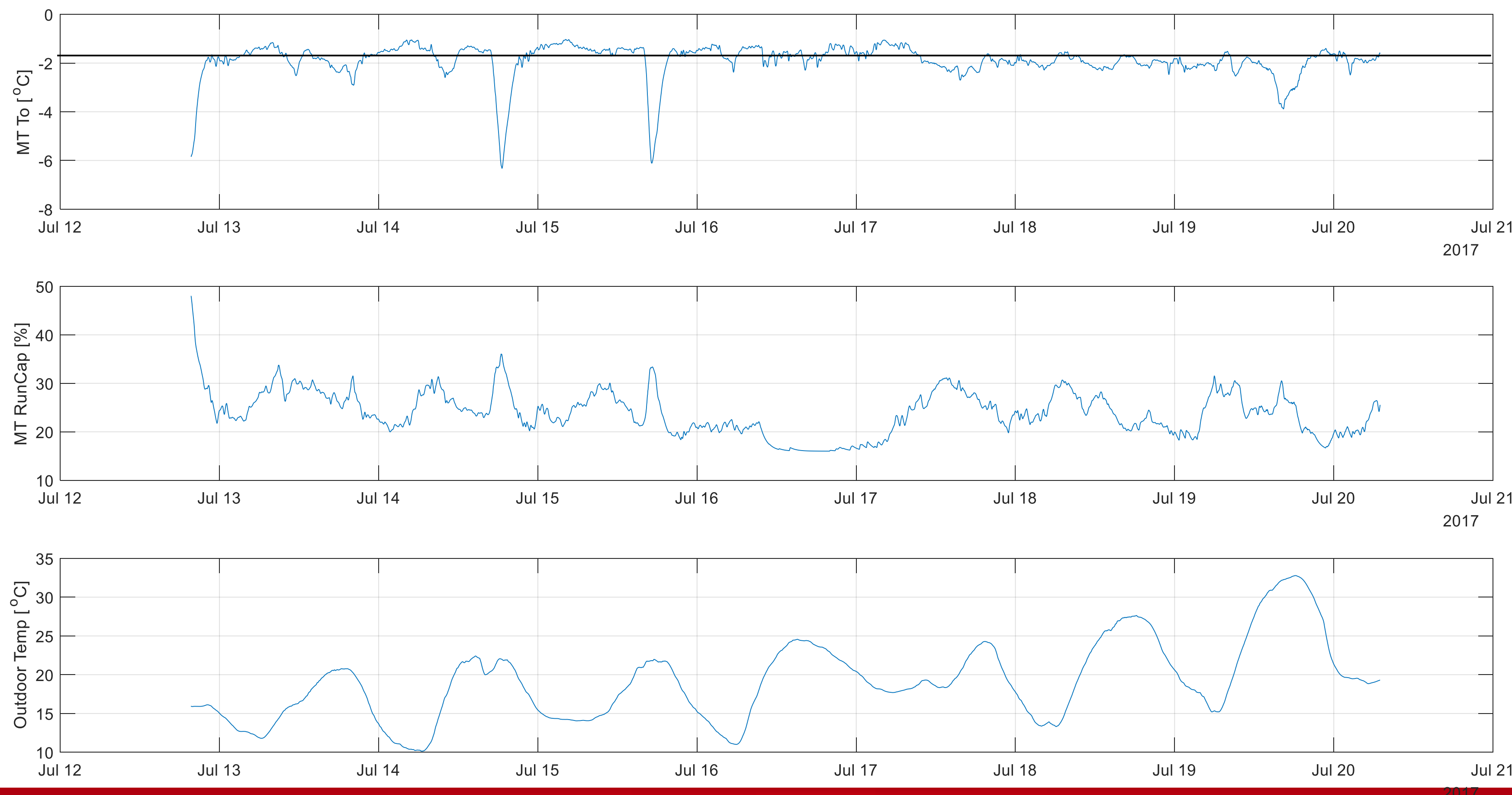
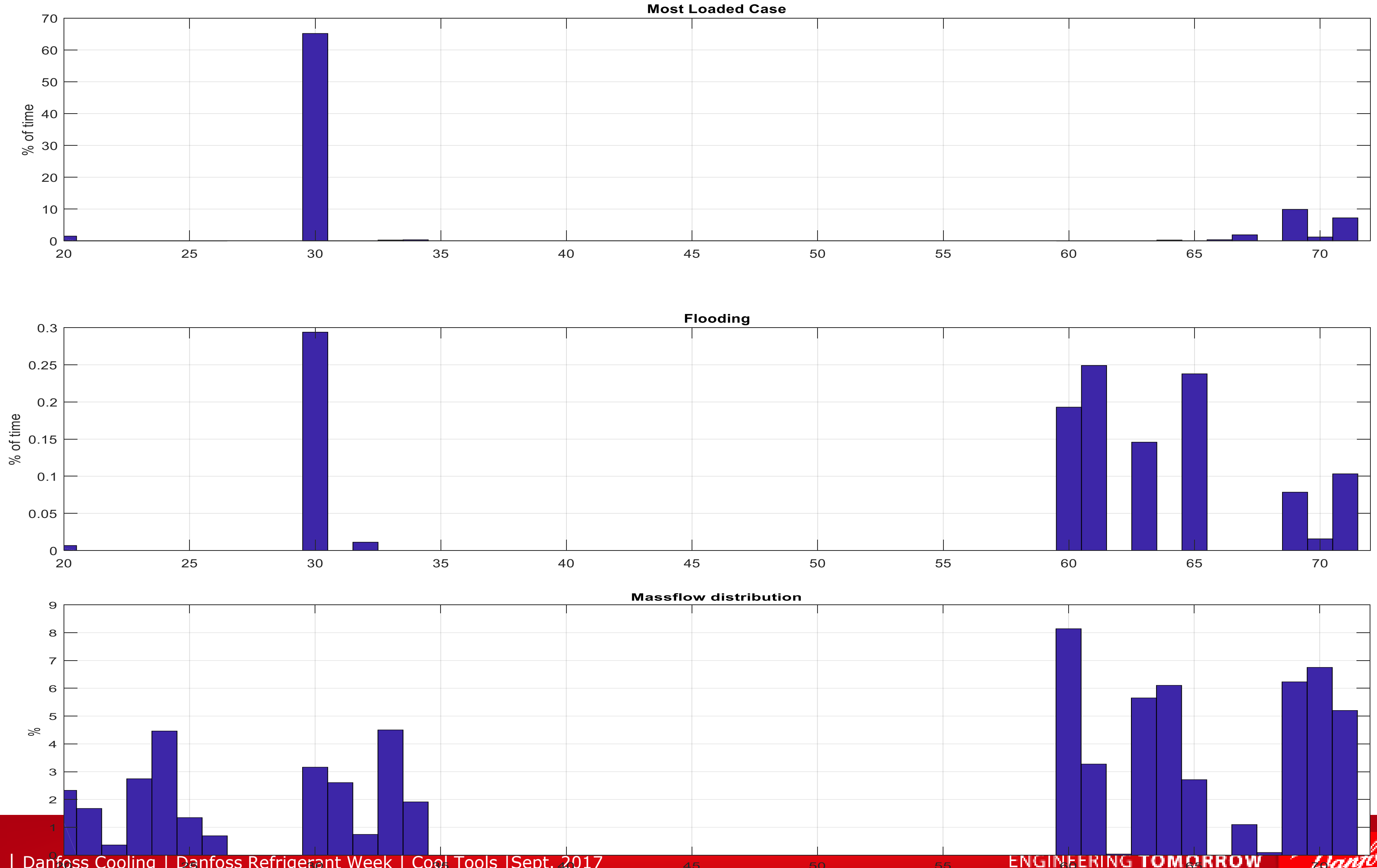
Flooded operation

12-20jul

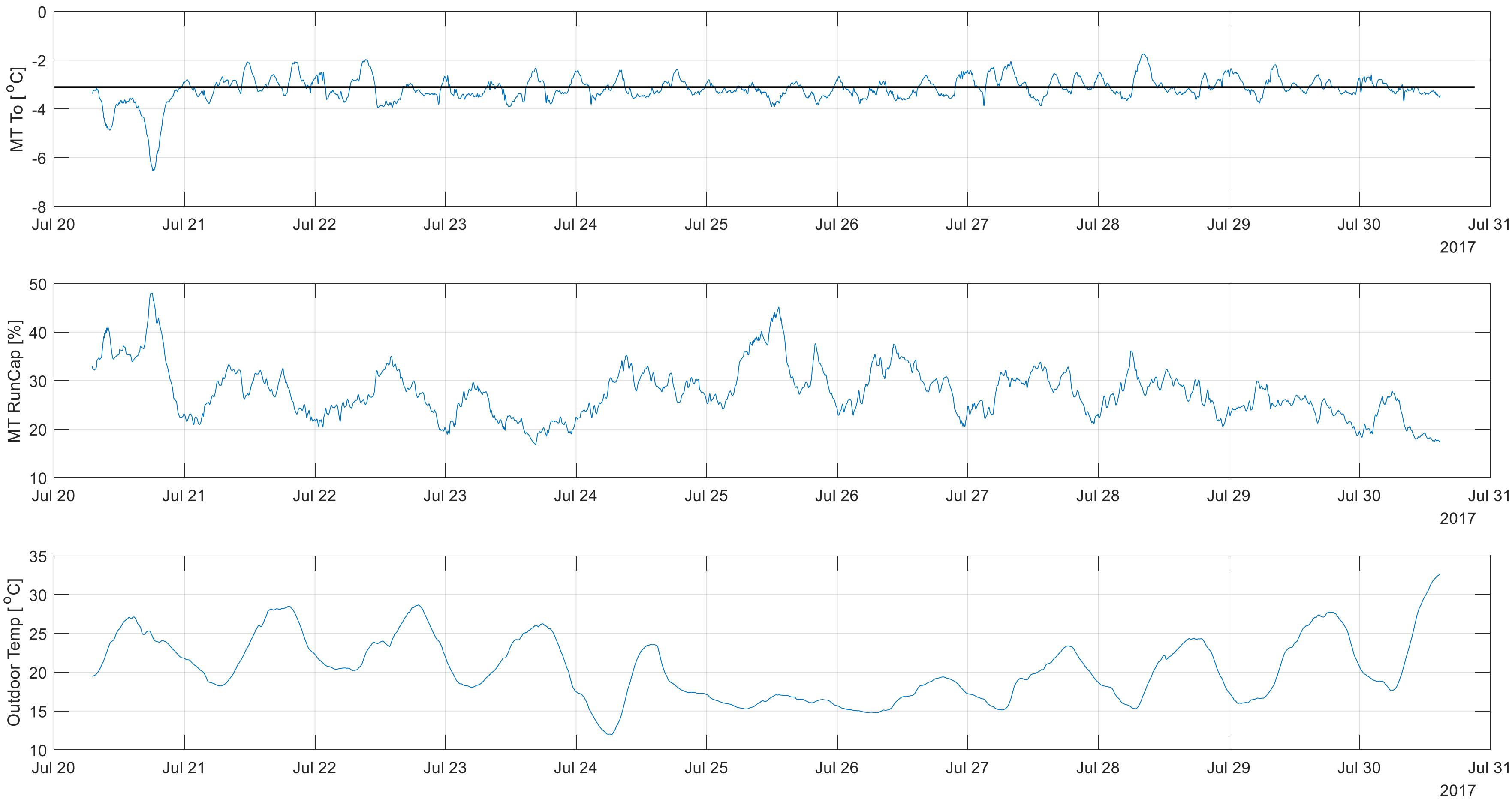


Dry expansion
20-31 jul

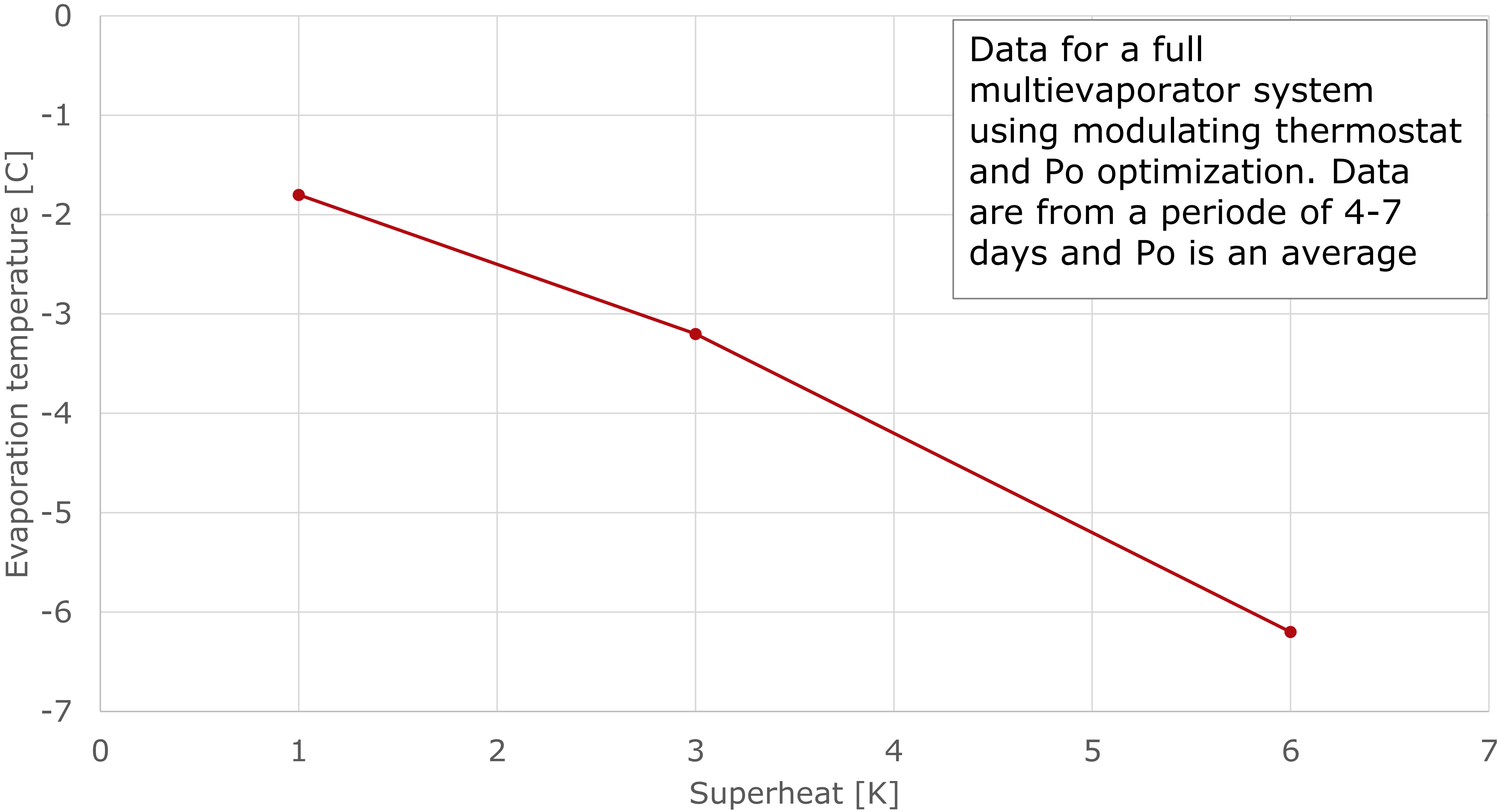


Dry expansion

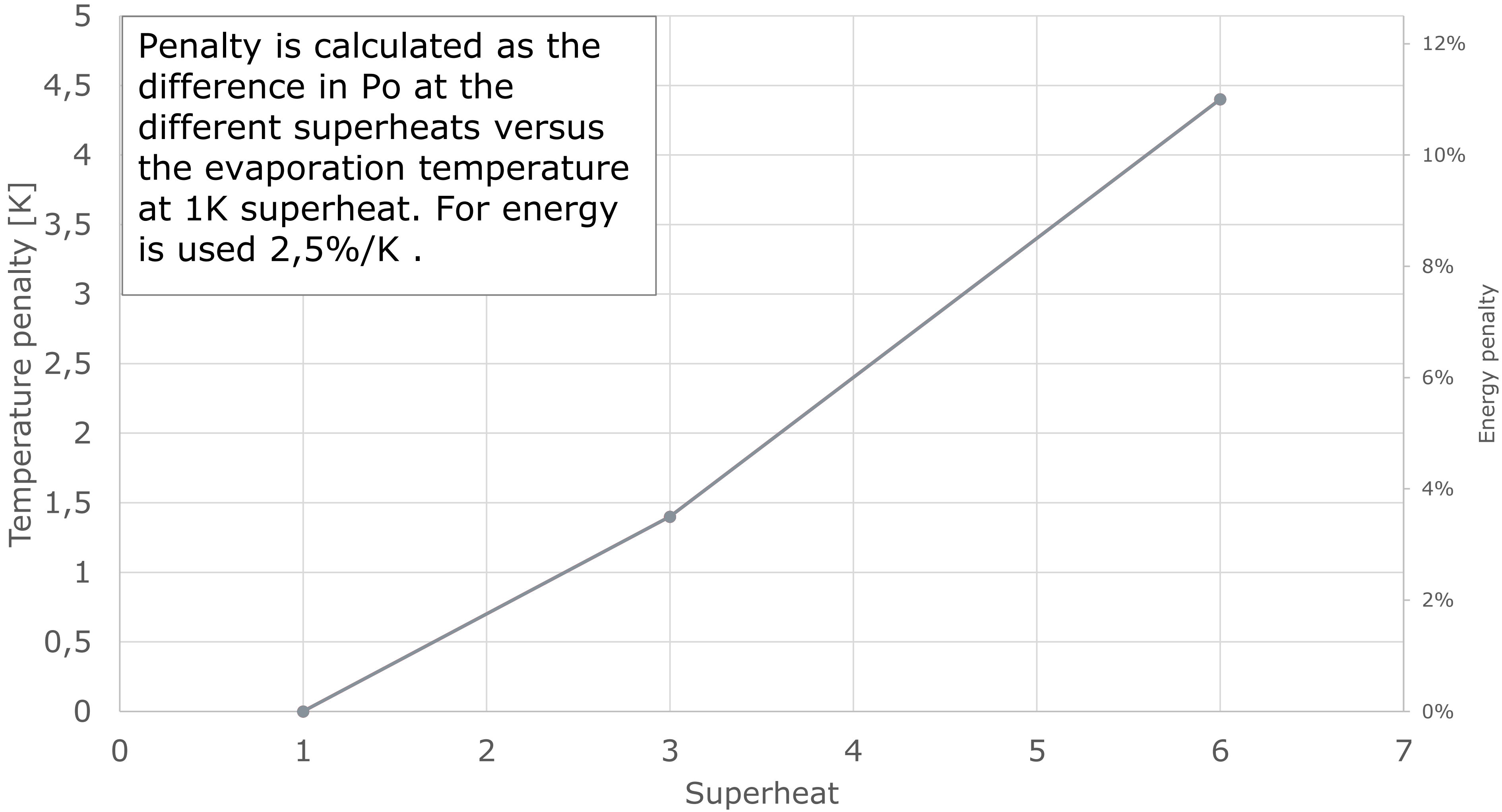
20-31 jul



Evaporation temperature as a function of superheat



Evaporation temperature penalty VS superheat



Next generation: Liquid ejector

Pros:

- Very promising results from the tests running
- Relatively simple system where the complexity is in the controllers and not in the lay out.
- Commercially available Q2 2018

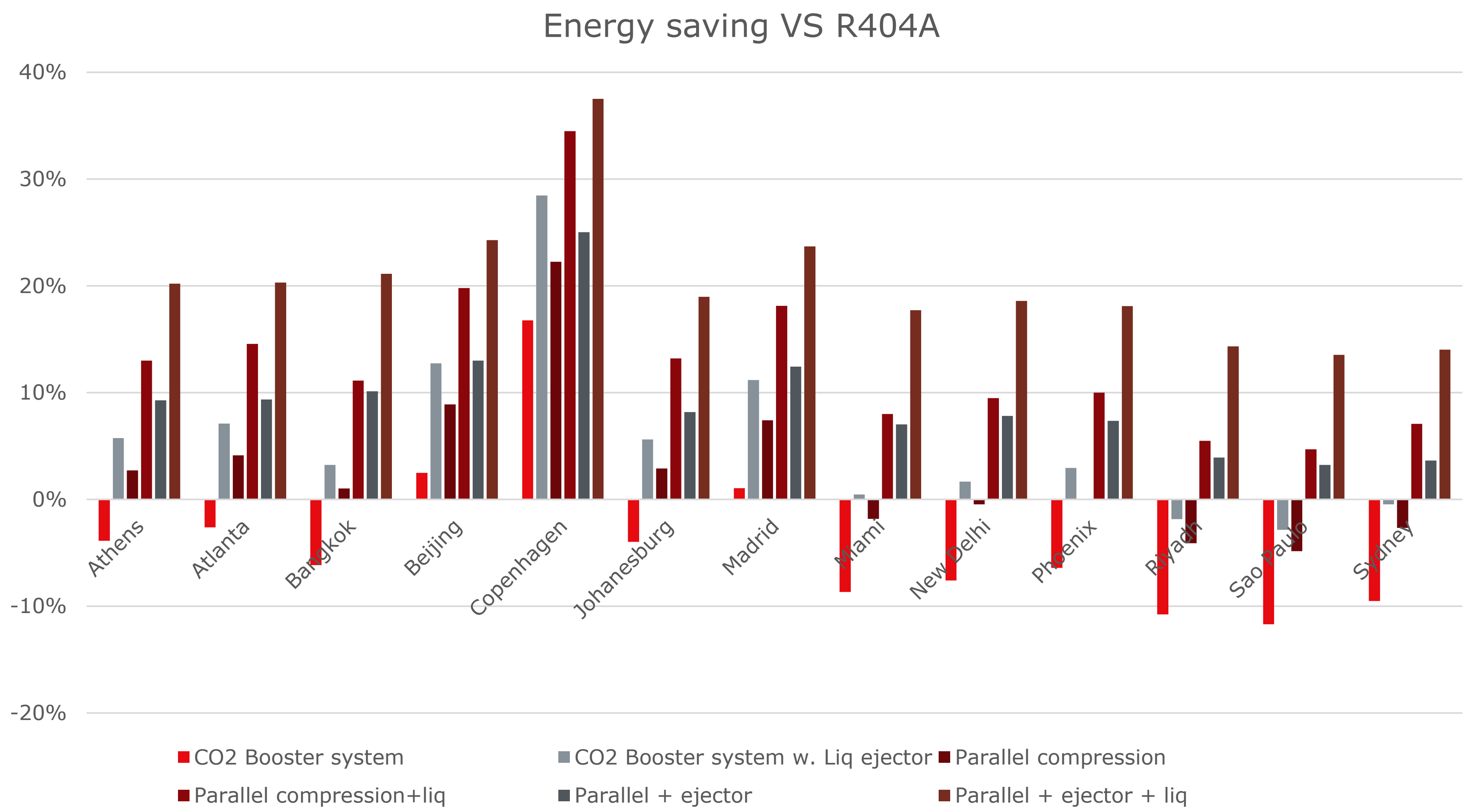
Cons:

- Increases complexity slightly of the systems and controls
- Reducing superheat will give some of the same effects

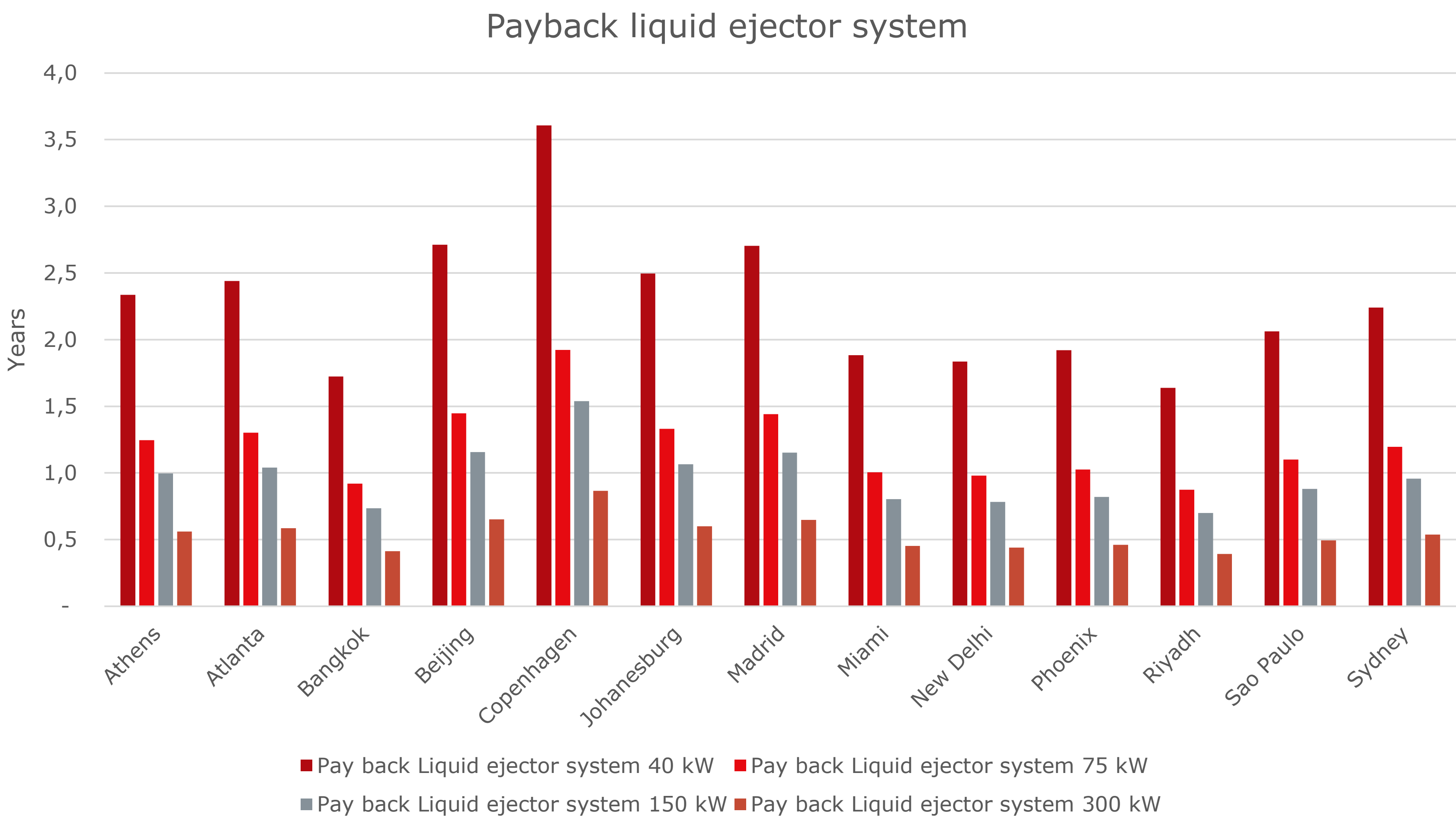
Application:

The system covers from small and all the way up to very large systems (CDU, Discounters up to Hypermarkets).
Geographically the system will provide the saving in any climate.

Energy saving



Pay back liquid ejector as an add on to any system



Conclusion

- 10 years ago transcritical CO_2 was only for cold climates in Scandinavia
- 5 years ago parallel compression shows promising results in southern Europa
- With ejector technology installed on 4 continents in approx. 200 installations transcritical CO_2 shows energy savings and good performance world wide.
- The journey does not stop here. To make CO_2 a solution in all regions we need to make Transcritical CO_2 simple and easy to use.
- The biggest hurdle we are facing is education and training

Questions?

Questions and feedback

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