Investigation of a thermally integrated Carnot battery using a reversible heat pump/organic Rankine cycle

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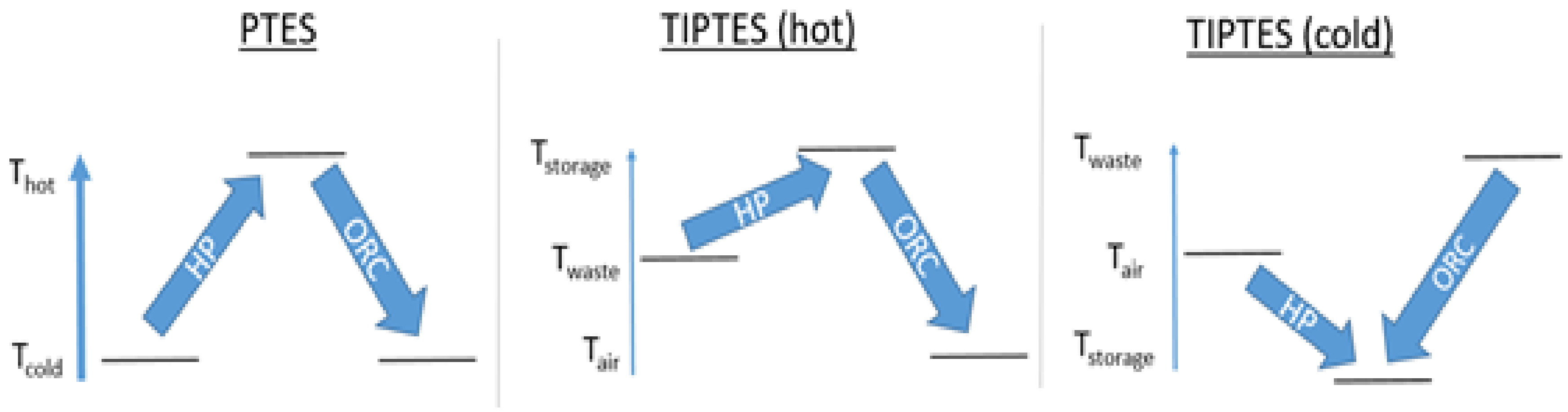
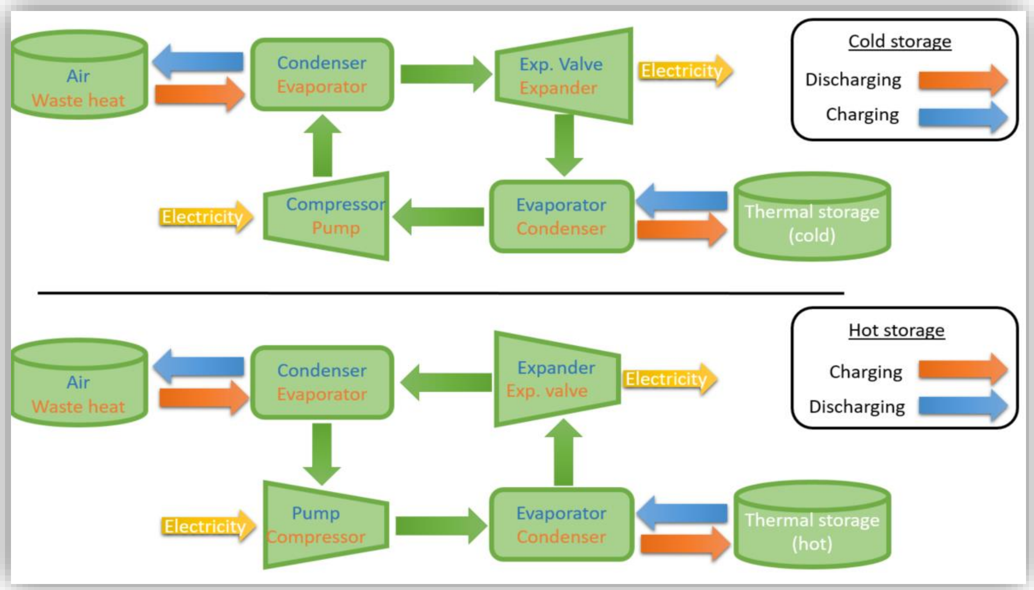
Why Rankine?

- Already available commercial products
- Thermal integration
- Low temperature
- Low costs



Reversible HP/ORC unit

- One unit able to work as HP and as ORC
- Cheap
- Constraints (Reynolds,efficiency)



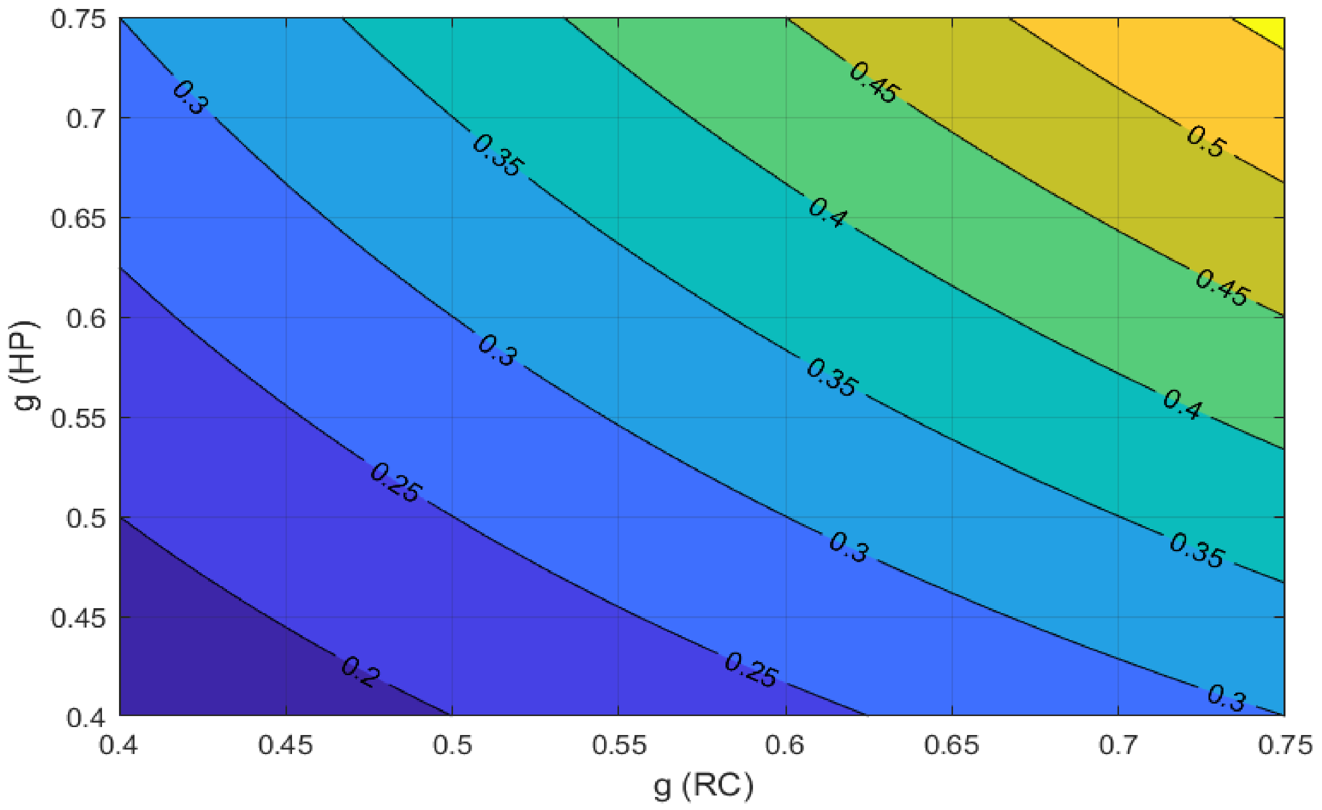
Dumont, O., Quoilin, S., Lemort, V., 2015. Experimental investigation of a reversible heat pump/organic Rankine cycle unit designed to be coupled with a passive house to get a Net Zero Energy Building, Int. J. Refr. 54:190–203.

Mapping of performance

$$\varepsilon_{rt,hot} = \left(\frac{COP_{HP,hot}}{Q_{cd,HP}}\right).(\eta_{RC,hot}Q_{ev,RC}) \;= COP_{HP,hot}.\eta_{RC,hot}$$

$$COP_{HP} = \frac{Q_{cd}}{E_{el}} = g_{HP}\frac{T_{hot}}{T_{hot} - T_{cold}}$$

$$\eta_{RC} = \frac{E_{el}}{Q_{ev}} = g_{RC}(1 - \frac{T_{cold}}{T_{hot}})$$



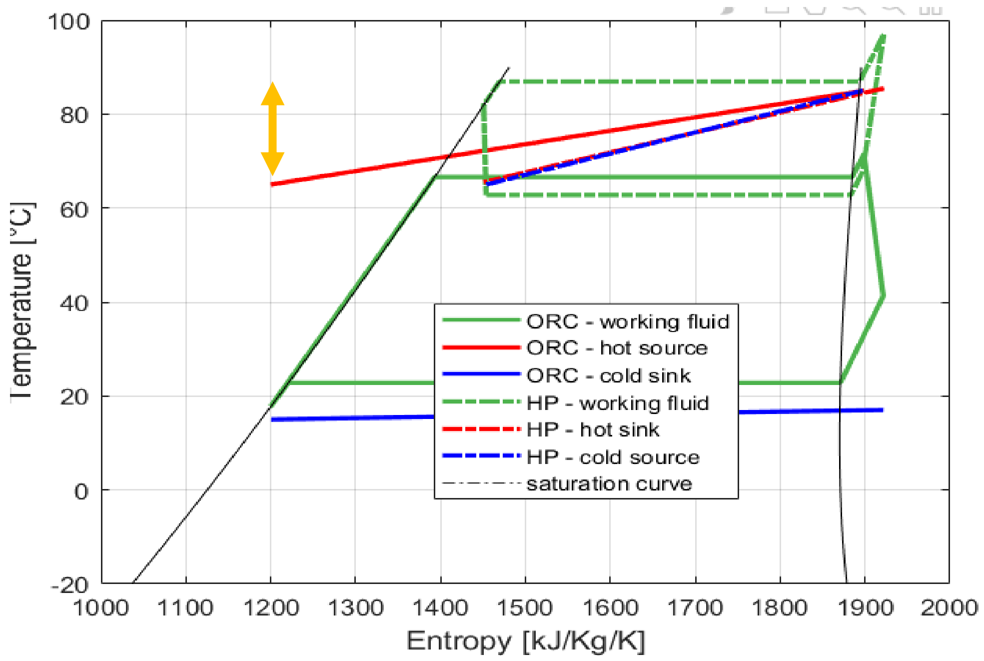
Thermal integration

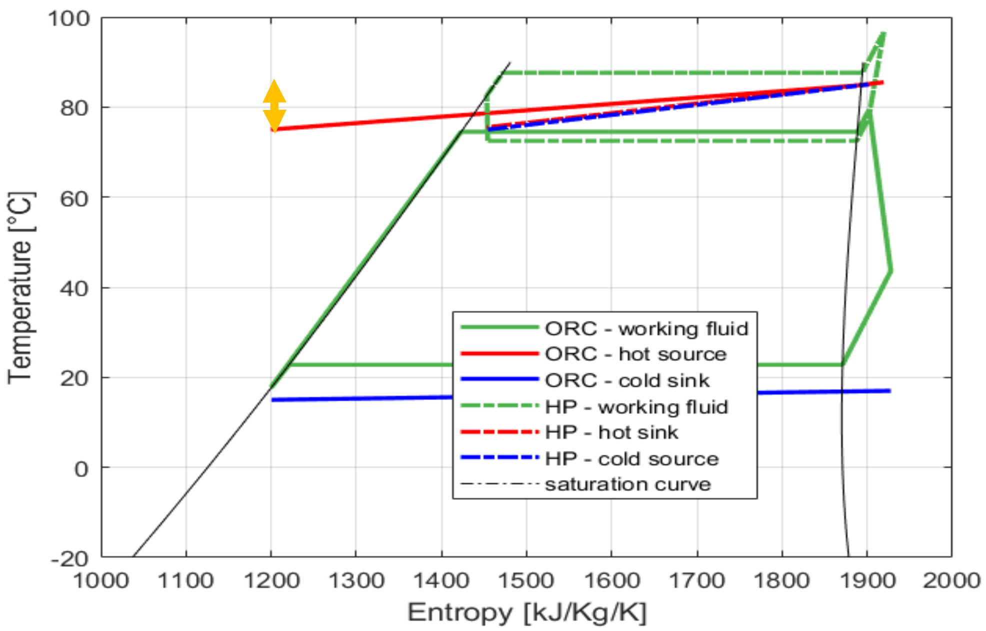
High lift

- High compactness
- High waste heat energy use

Low lift

- High roundtrip efficiency

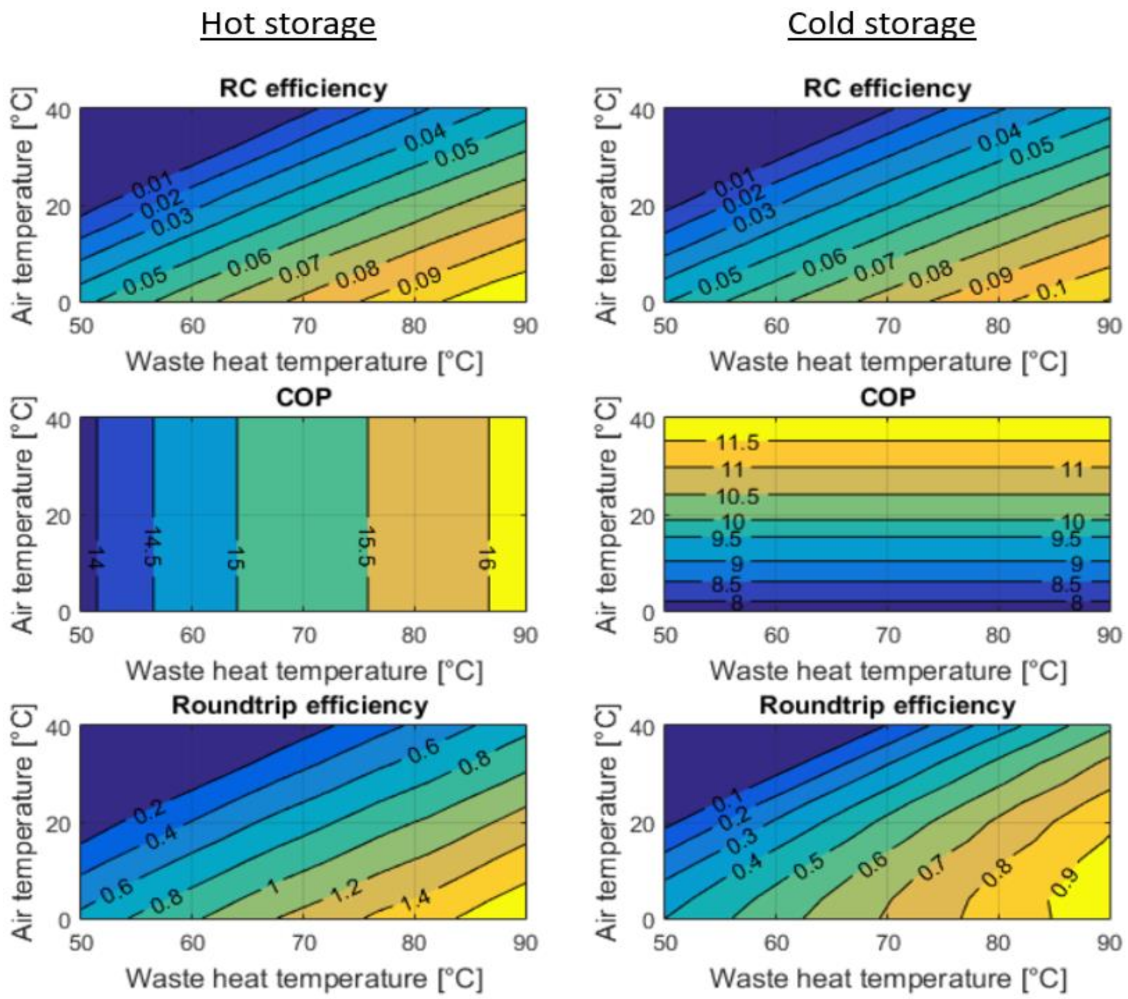




[] Frate Guido Francesco, Antonelli M, Desideri U. A novel Pumped Thermal Electricity Storage (PTES) system with thermal integration. Appl Therm Eng 2017;121:1051–8.

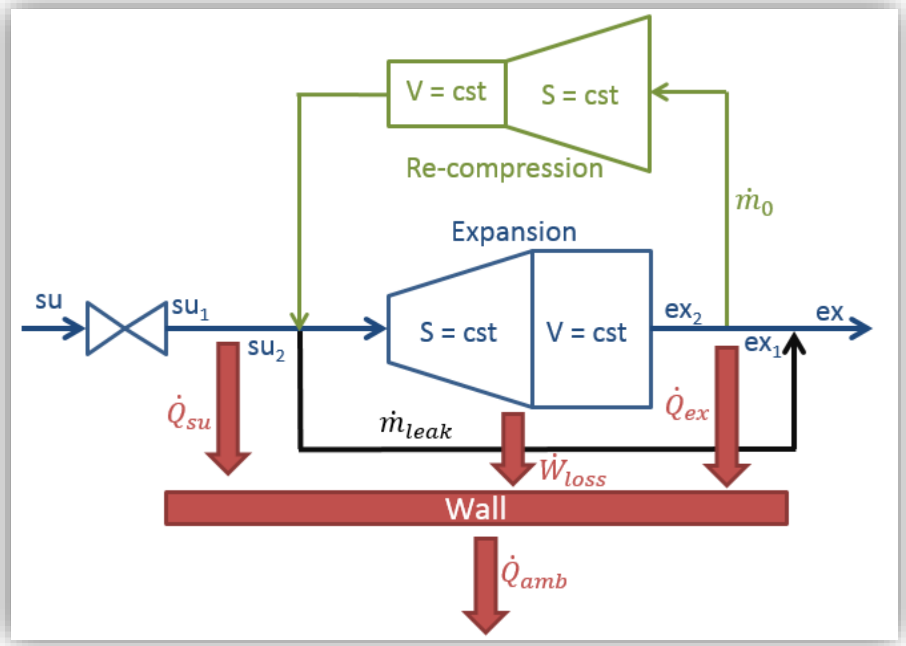
[] Dumont, O., Lemort, V., 2020. Mapping of performance of pumped thermal energy storage (Carnot battery) using waste heat recovery, energy, in press

Mapping of performance (thermally integrated)



Modeling

- Ideal storage
- Compressor/expander semi empirical modeling [1]
- Heat exchangers – Constant pinch point of 2K (conservative)
- Pump part load model [2]
- Pressure drop - Proportionnal to the quare of the mass flow rate
- Auxiliary pump efficiency 50%

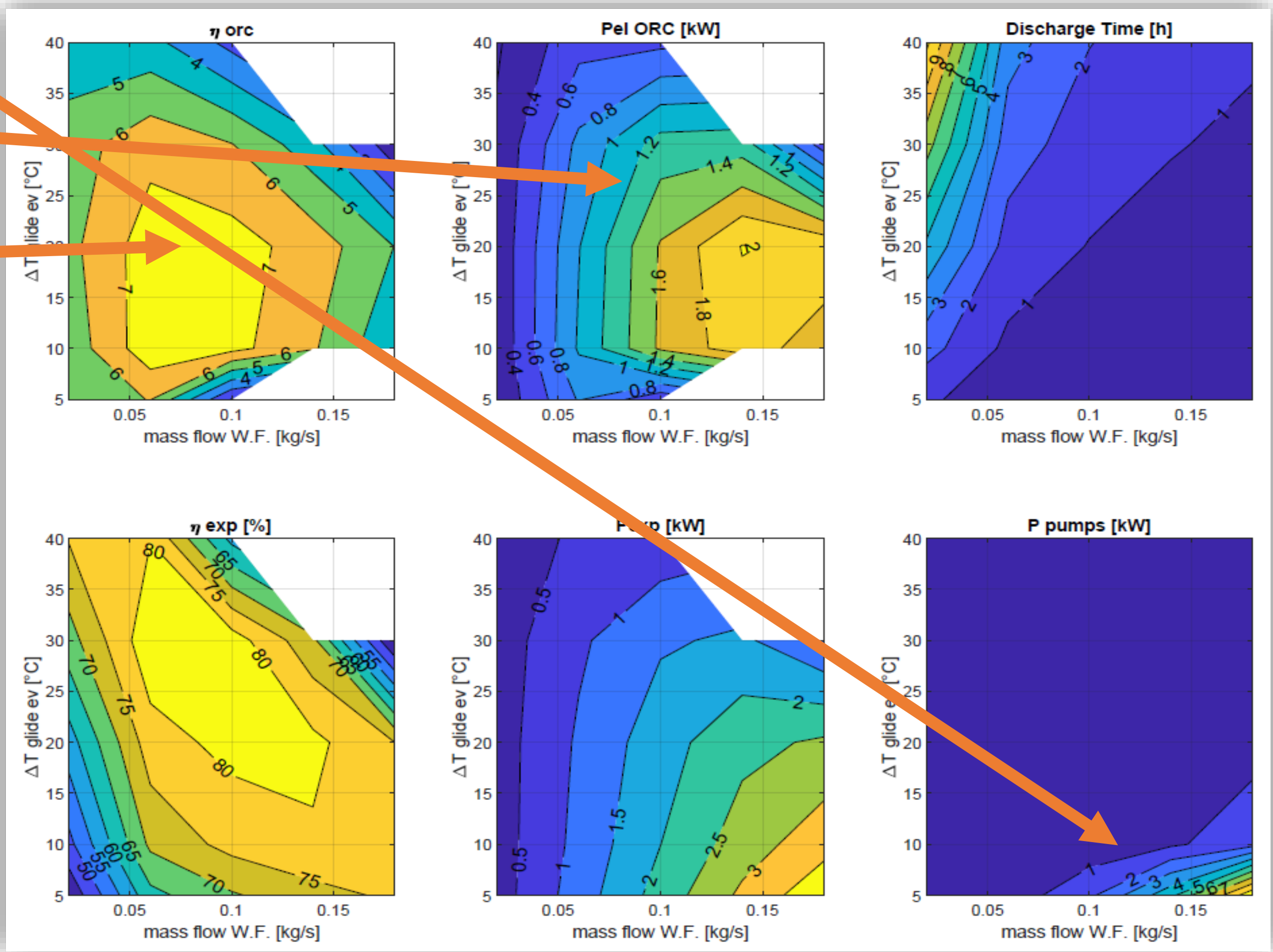


[1] Landelle, A., Tauveron, N., Revellin, R., Haberschill, P., Colasson, S., Roussel, V., 2017. Performance investigation of reciprocating pump running with organic fluid for organic Rankine cycle, Applied Thermal Engineering 113 (2017) 962–969

[2] Lemort, V., 2008. PhD thesis, Contribution to the characterization of scroll machines in compressor and expander modes, (Liege).

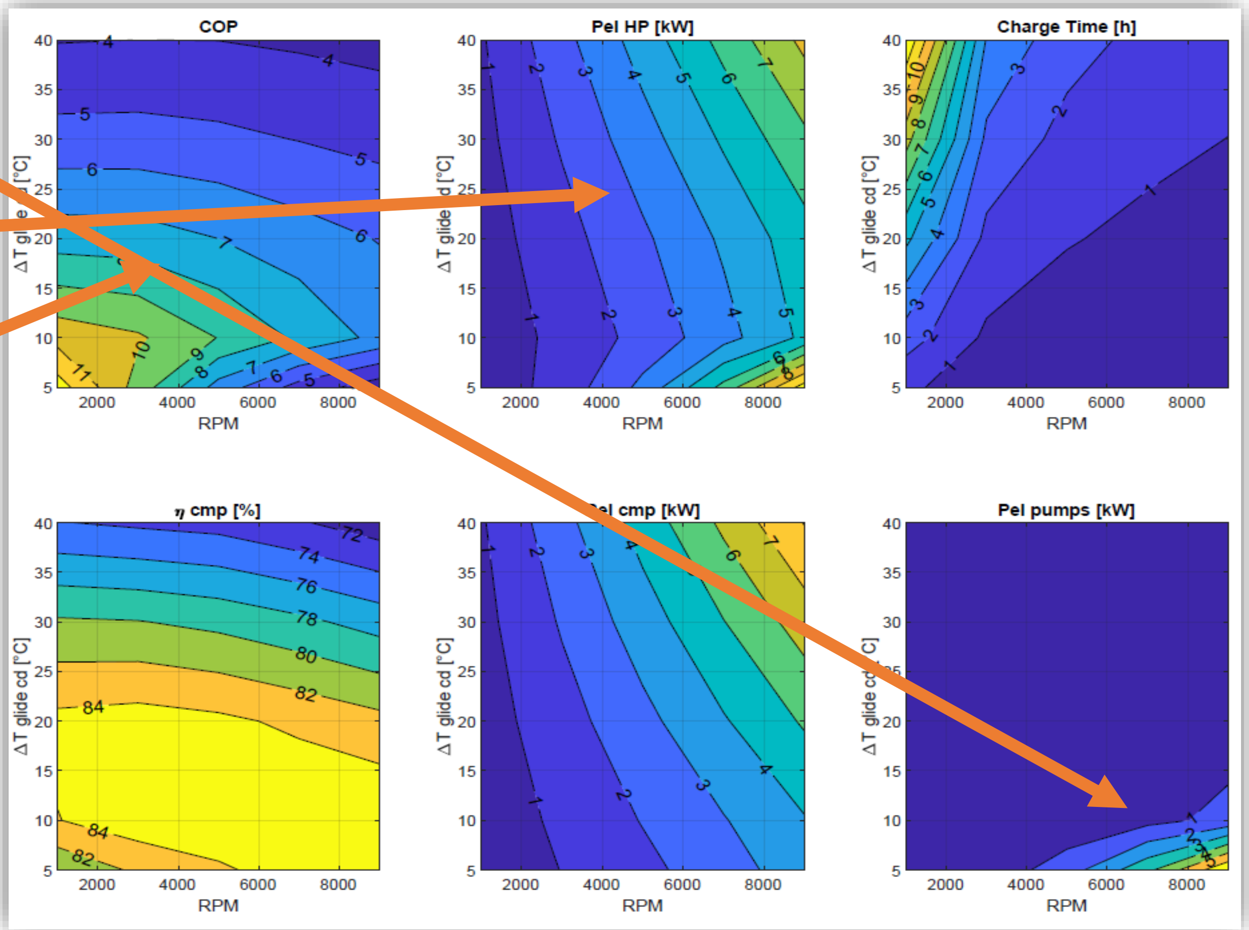
ORC Mappings

- For to temperature levels:
- Possibly strong influence of auxiliary pumps
- Optimization of the evaporator glide
- Necessary optimization of the mass flow rate

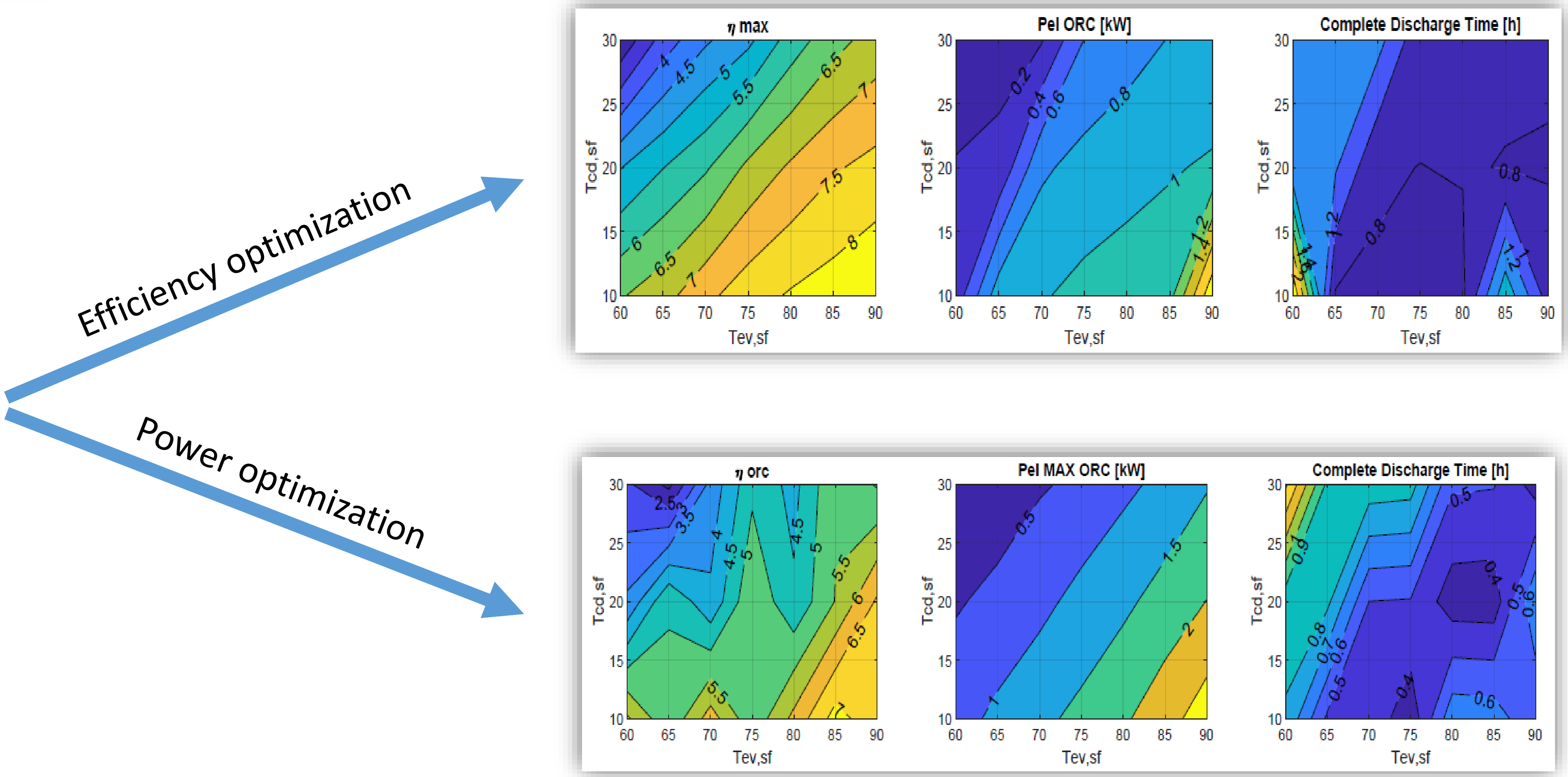


HP mappings

- For to temperature levels:
- Possibly strong influence of auxiliary pumps
- Increase of the thermal power with the RPM and with the glide (opposite for COP)
- Necessary optimization of the scroll speed

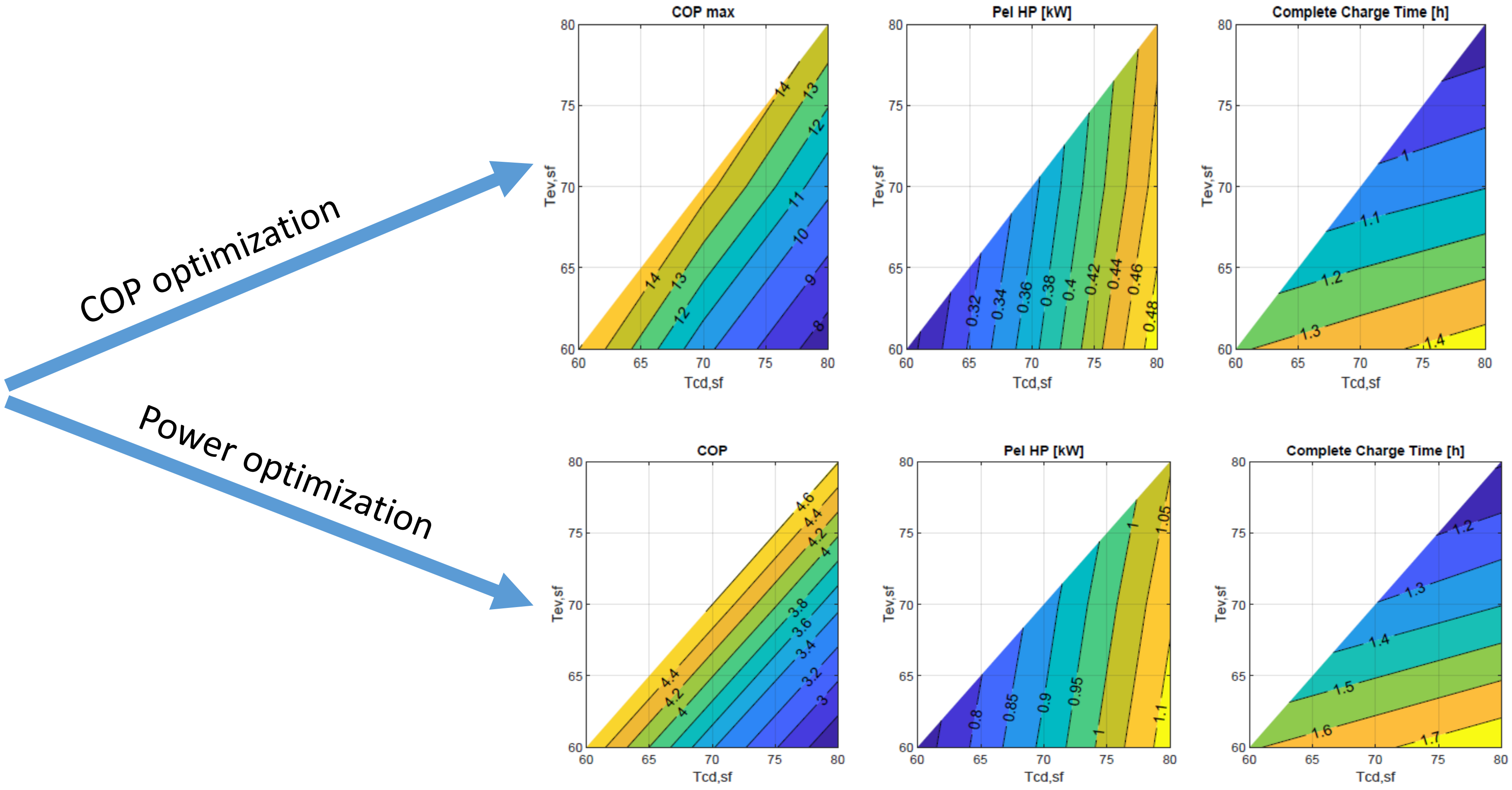


Optimization of ORC performance



➔ Power increased with glides and mass flow rate

Optimization of heat pump performance



- Power increased with glides and mass flow rate
- Strong influence on COP

Experimental setup

Heat Pump

- Cold source= Waste heat (75°C)
- Hot sink = storage (85°C)
- COP = 14

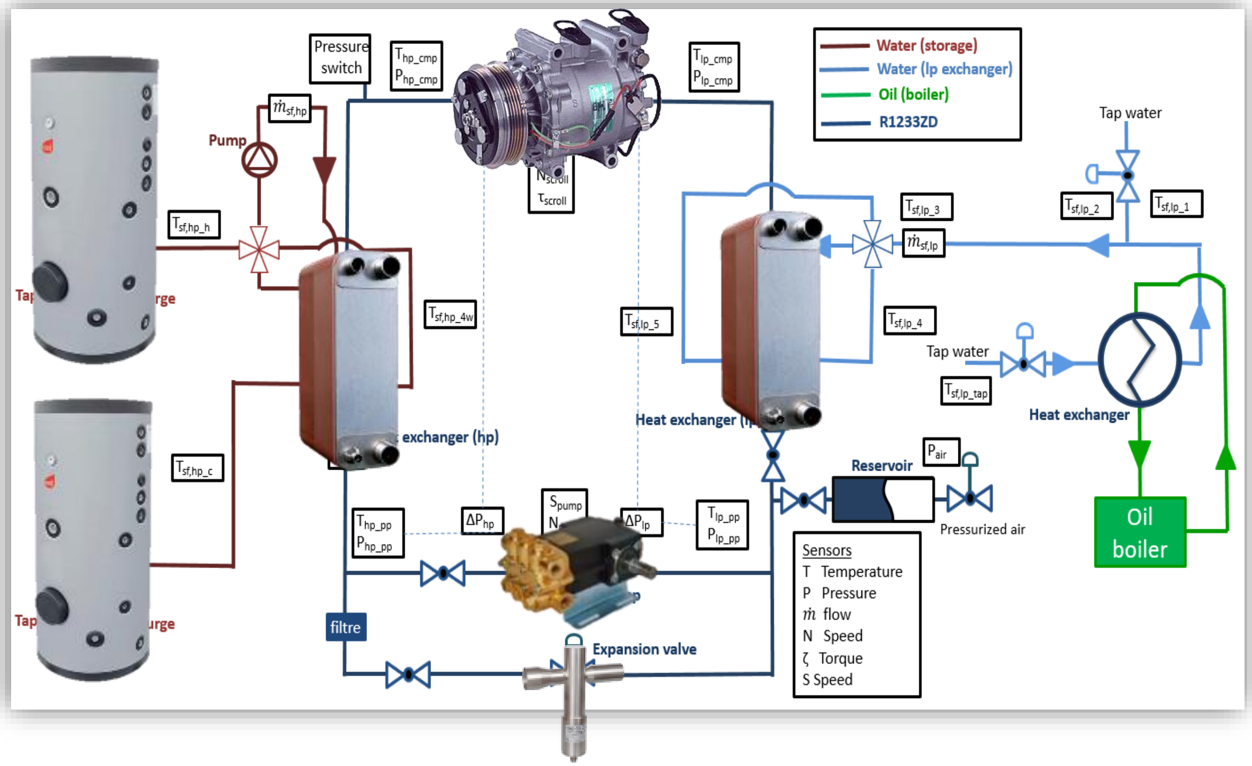
ORC

- Hot source = Storage (85°C)
- Cold sink = Air (15°C)
- Efficiency = 7%

➔ Energy to energy ratio ~ 100%

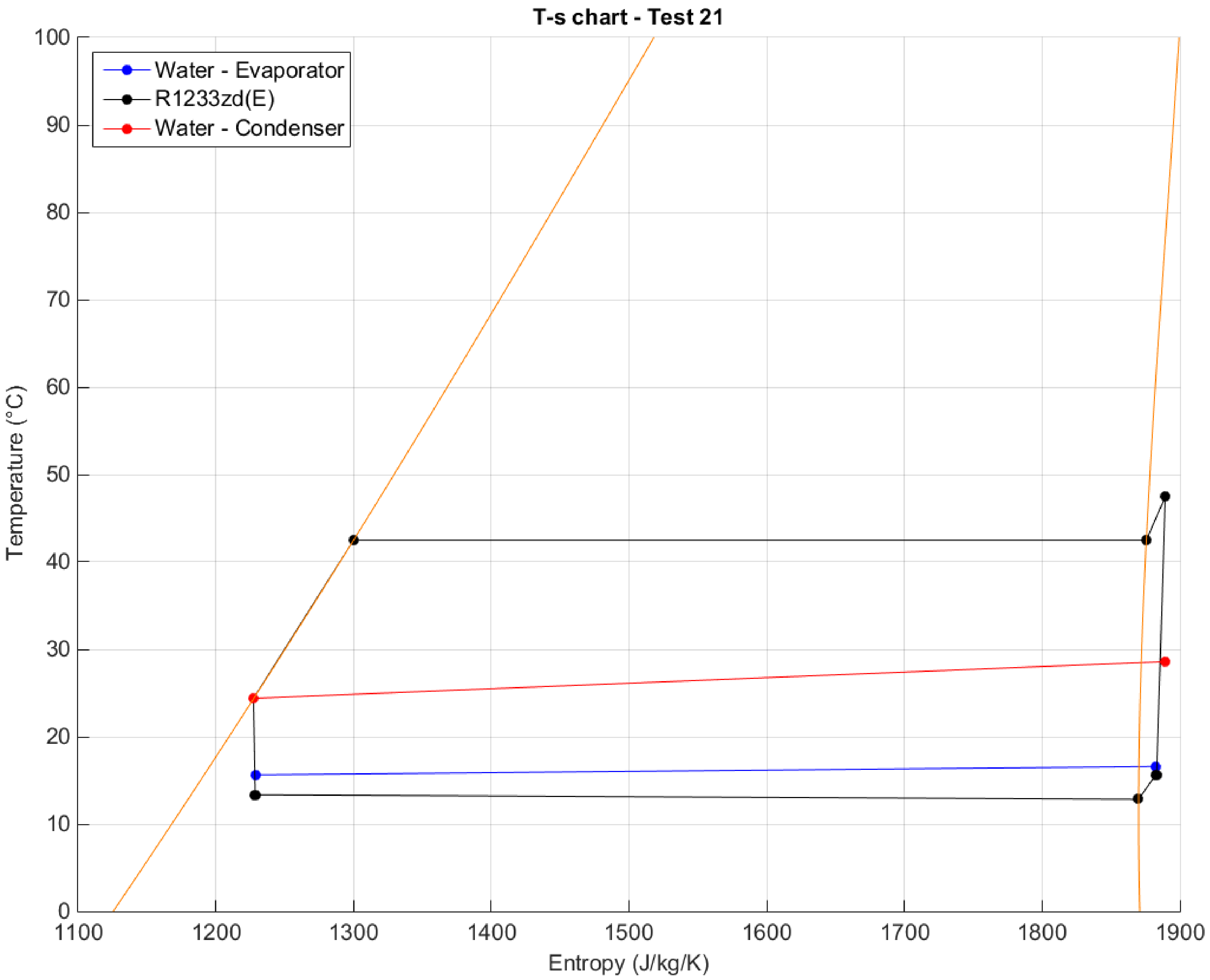
		ORC	HP
Parameters	Sub-cooling [K]	5	5
	Exchangers pinch points [K]	2	2
	Evaporator secondary fluid glide [K]	10	10
	Condenser secondary fluid glide [K]	2	10
	Compressor volume ratio [-]	2.2	
	Compressor maximum efficiency [-]	0.75	
	Condenser secondary fluid temperature [°C]	15	85
	Evaporator secondary fluid temperature [°C]	80	75
Outputs	COP/eff [-]	0.076	12.9
	Condenser thermal power [W]	20985	24110
	Evaporator thermal power [W]	22844	21720
	Compressor power [W]	1942	1865
	Condenser pressure [bar]	1.25	8.27
	Evaporator pressure [bar]	5.45	5.17
	Working fluid flow rate [kg/s]	0.096	0.14
	Compressor speed [RPM]	5000	8000
	Auxiliary pump consumption	129	29
	Compressor efficiency [-]	0.70	0.72
	Volume ratio [-]	2.26	0.57
	Compressor swept volume [m^3]	$3e^{-5}$	
	P2P [-]	1.01	
	Reynolds ratio [-]	0.76	
	Electrical ratio [-]	1.04	

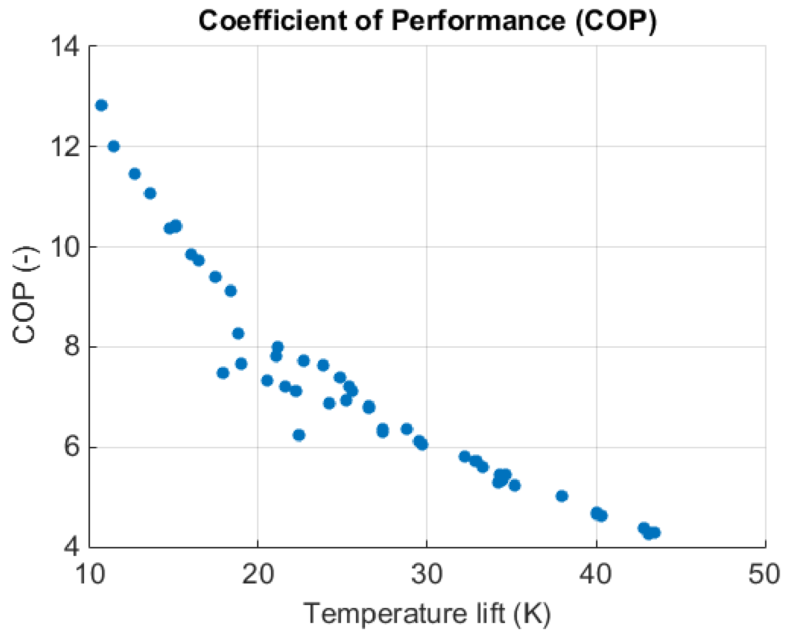
Layout/components

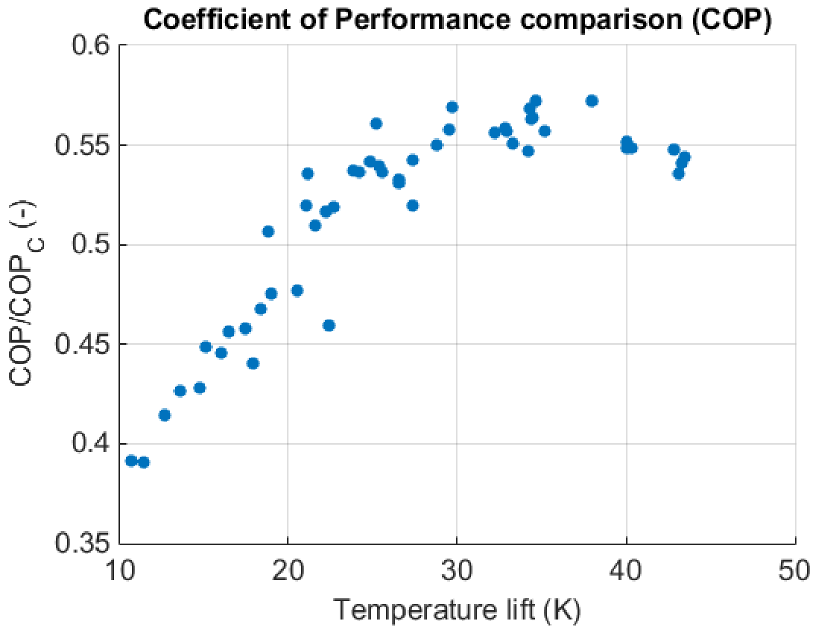


- Mechanical scroll
  - Variable speed
  - VR=2.2
  - Swept volume = 121 cm^3
- Plate heat exchangers
  - 25 kW
- Hot and cold water storage
  - Perfect stratification
  - 2X900 L
- Plunger pump
  - 70 g/s
- Manual expansion valve

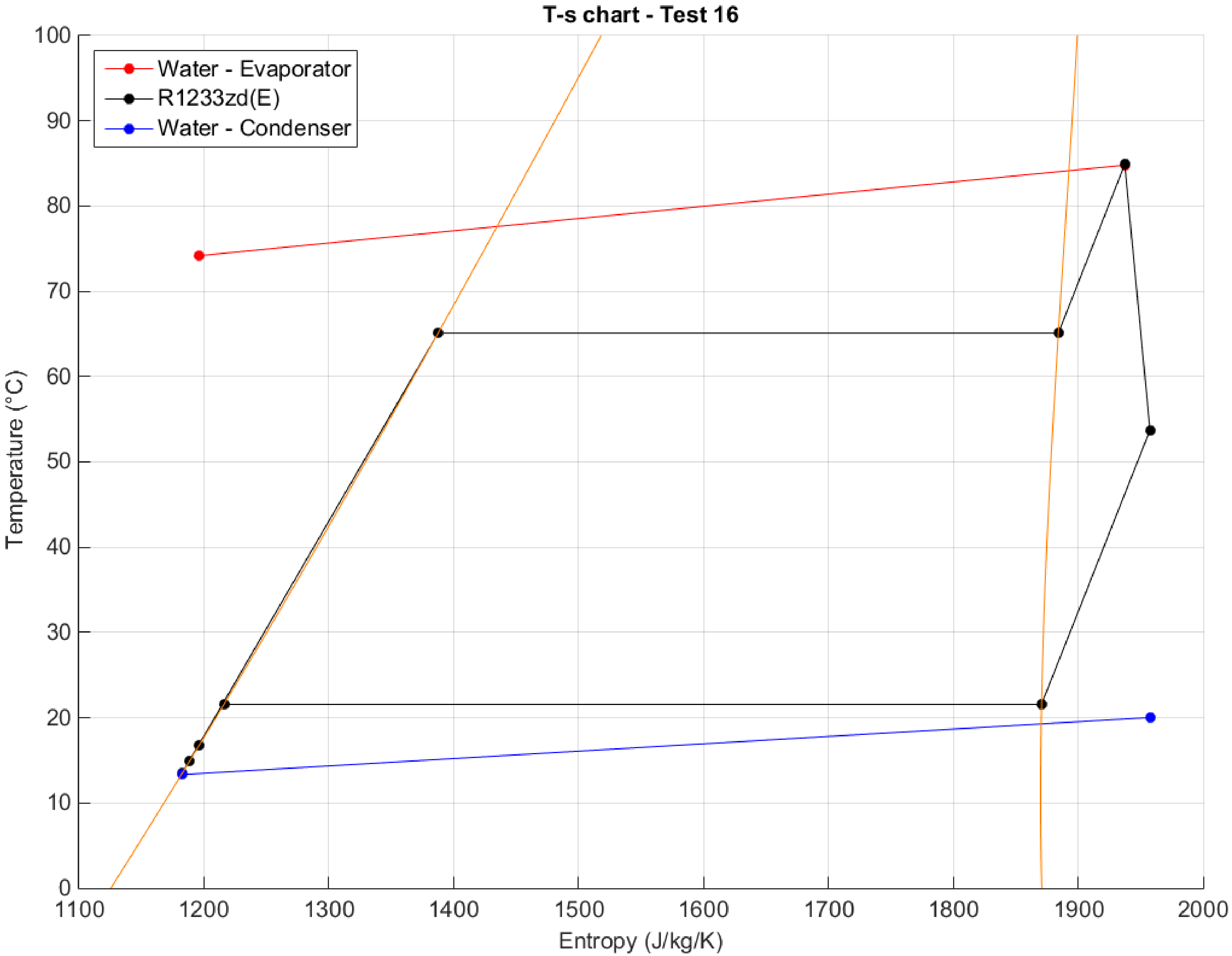
Heat pump mode – Global performance (1)

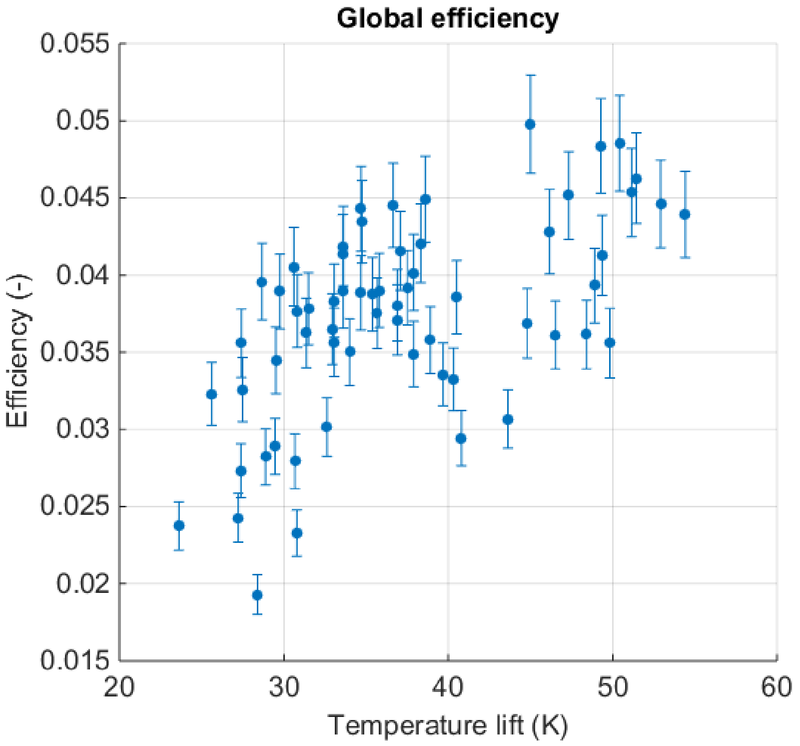




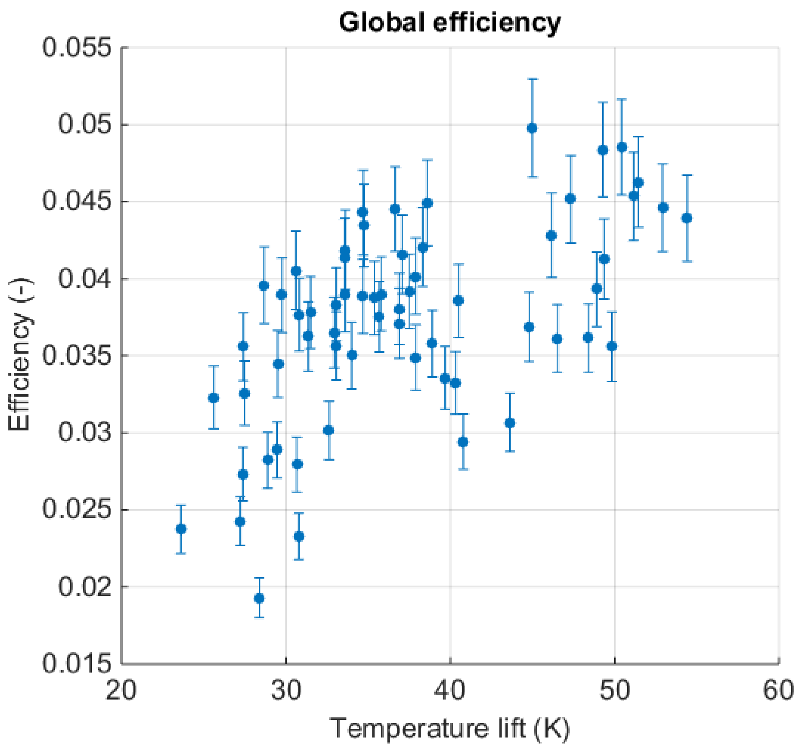


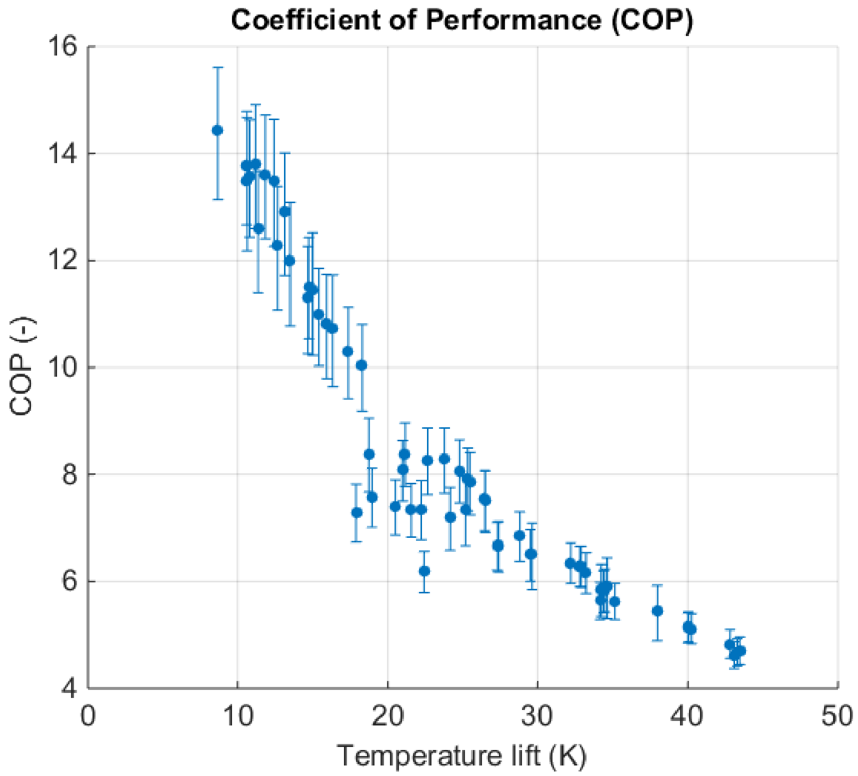
ORC mode – Global performance





First tests





- No optimal control (scroll speed, sub-cooling, over-heating)
- No optimization of the volumetric machine

Thank you!

Perspectives

- Control optimization
- Cycle optimization
- Business model

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