APPLICATION OF THE NOVEL «EMERITUS» AIR COOLED CONDENSER IN GEOTHERMAL ORC

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POLITECNICO MILANO

HEAT REJECTION UNIT FOR ORC

HEAT REJECTION UNIT FOR ORC

Limited efficiency of ORC cycles

+

Increasing of plant dimensions > 1MW

=

Massive thermal power rejection

Remote location of geothermal resources

+

Scarcity of superficial water

=

Use of ambient air for condensation

Configuration

- Direct air cooled condensers
- Indirect heat rejection, using a closed cooling water loop

PROs of closed cooling water loop

- Limited quantity of ORC fluid
- Possibility to use flammable fluids as ORC fluid (often having higher performances and reduced cost compared to refrigerant fluids)
- Minimum pressure can be below atmospheric pressure
- Reduced pressure drops (absence of long headers for fluid distribution)
- Standard HVAC components can be used

INTRODUCTION – Influence of ambient temperature

- The performance of air cooled heat exchangers is strongly influenced by the ambient temperature variations
- The performances of a ORC plant can be significantly penalized by high ambient temperatures
- Additional solutions should be considered to improve global yearly efficiency, considering different off design conditions

HEAT REJECTION UNIT FOR ORC

POSSIBILITY TO USE *HYBRID HEAT EXCHANGER*

Dry

- ✓ Simple and standardized configuration
- ✓ Very low maintenance costs
- ✓ NO "Legionella" Risk
- ✓ No Water circulation system

- ✘ Low performance at high temperature
- ✘ Big footprint

Evaporating tower

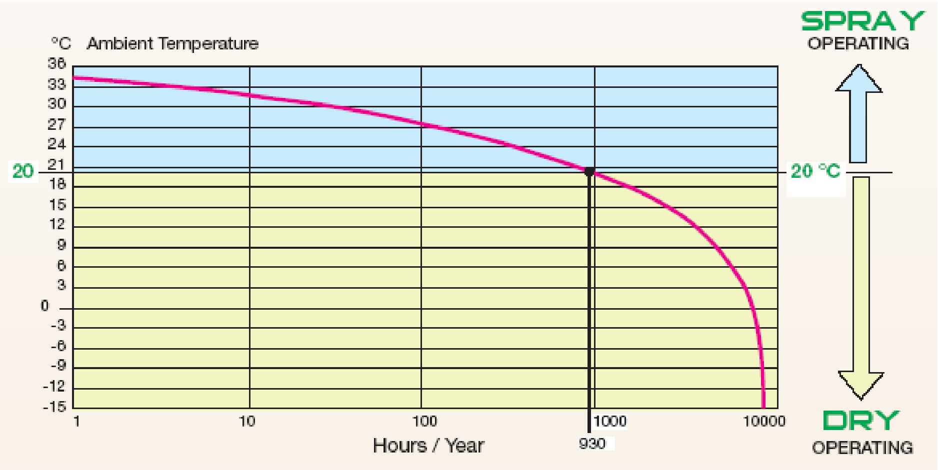
- ✓ Working point near the wet bulb temperature
- ✓ Smaller dimensions

- ✘ High Water consumption
- ✘ Greater maintenance costs
- ✘ Health risk related to: "Legionella"

DRY COOLERS + WATER INJECTION

Water spray condenser

Water spray condenser is fin-and-tube heat exchanger, operating with dry surface when the ambient temperature is lower than a selected design value.

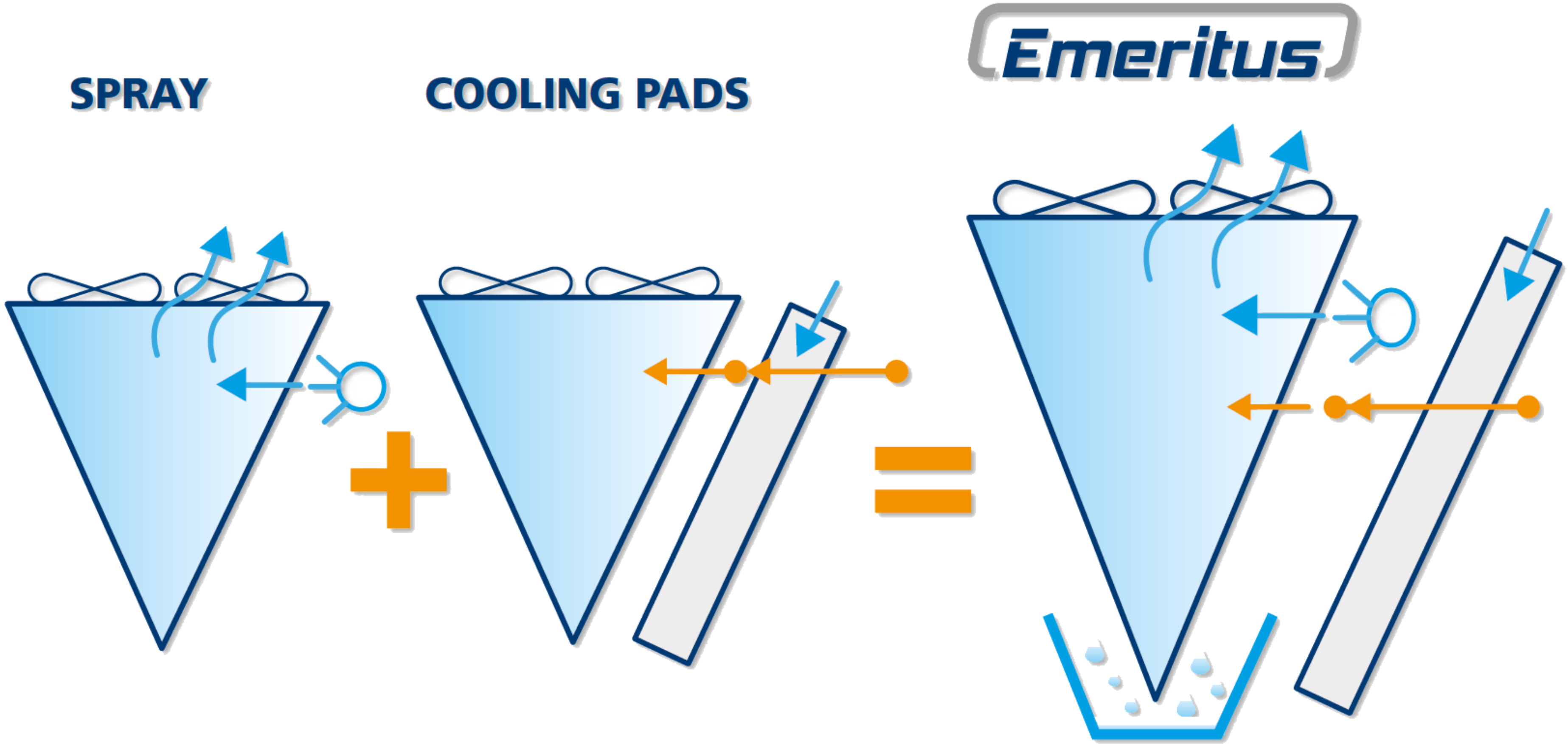


For higher ambient temperatures, the water spray system is activated, allowing significant performance improvements.

- System already tested with good performance in supercritical R134a ORC plant

Emeritus

The novel LU-VE Emeritus® air cooler introduces adiabatic panels in addition to the spray system and a sophisticated control strategy. The combination of the adiabatic panels and the spray system allows reducing significantly the condensing temperature of the ORC in the hot and intermediate season for a given cooler footprint.



- Union of the two systems in a **combined function:** treated water is sprayed onto the coil and the non-evaporated water is passed through the adiabatic pack
- Greater capacity exchanged and less water consumed

LU-VE exchangers

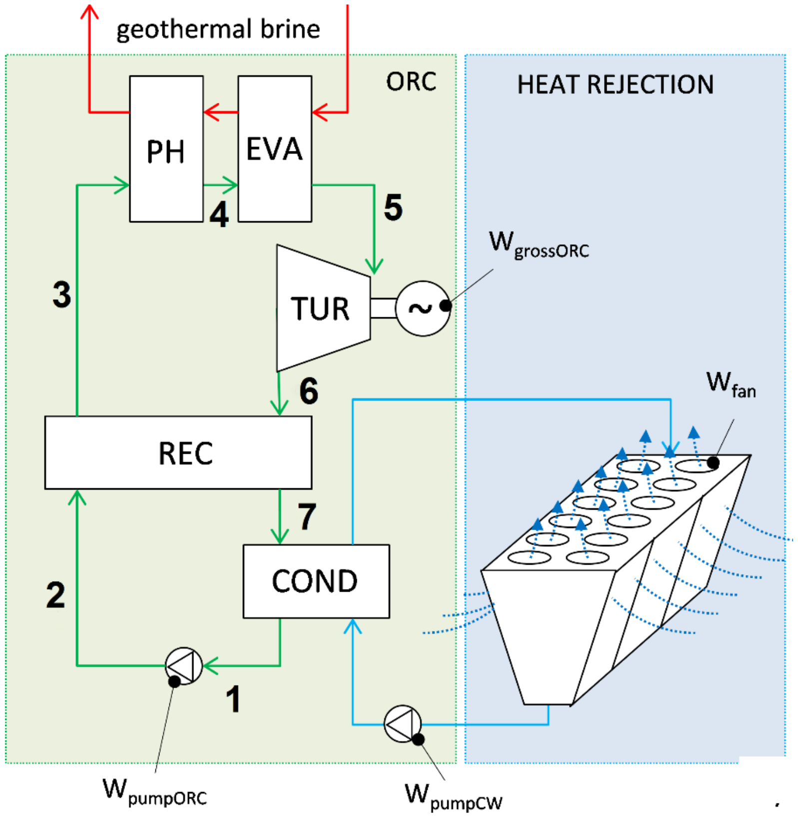
HEAT REJECTION UNIT FOR ORC

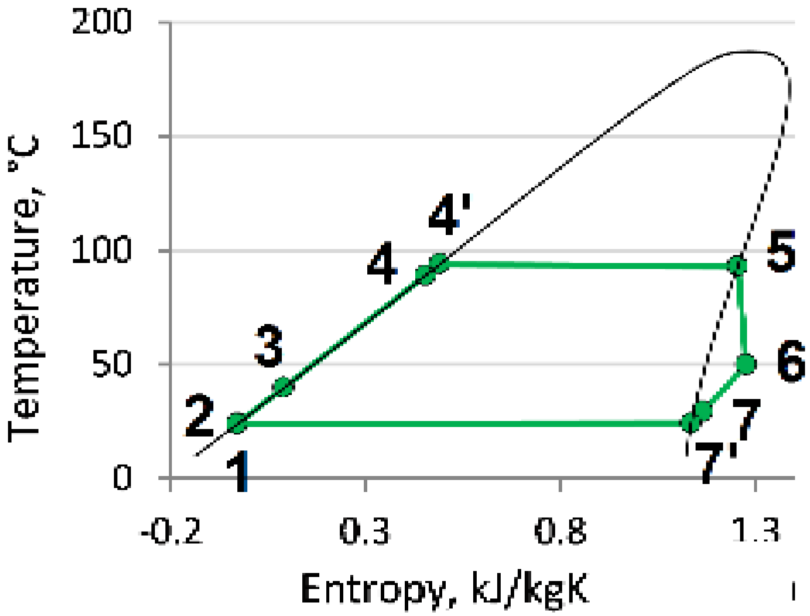
METHODOLOGY: ORC

System fluids:

- Geothermal fluid as hot thermal sources (max 160°C in / min 70°C out)
- Isopentane as working fluid
- Water as cooling fluid
- Ambient air as cold thermal sources

Temperature differences in heat exchangers		Pressure drops in heat exchangers		Component efficiency	
$\Delta T_{pp,EVA}$	5 °C	$\Delta p_{REC(l)}$	0.5 bar	η_{turb}	0.9
$\Delta T_{pp,REC}$	5 °C	$\Delta p_{REC(v)}$	2%	η_{pump}	0.75
ΔT_{sc}	5 °C	Δp_{ECO}	0.5 bar	η_{genm-e}	0.96
$\Delta T_{ap,COND}$	9 °C	ΔT_{EVA}	1 °C	$\eta_{pumpm-e}$	0.95
		ΔT_{COND}	0.3 °C	η_{aux}	0.98



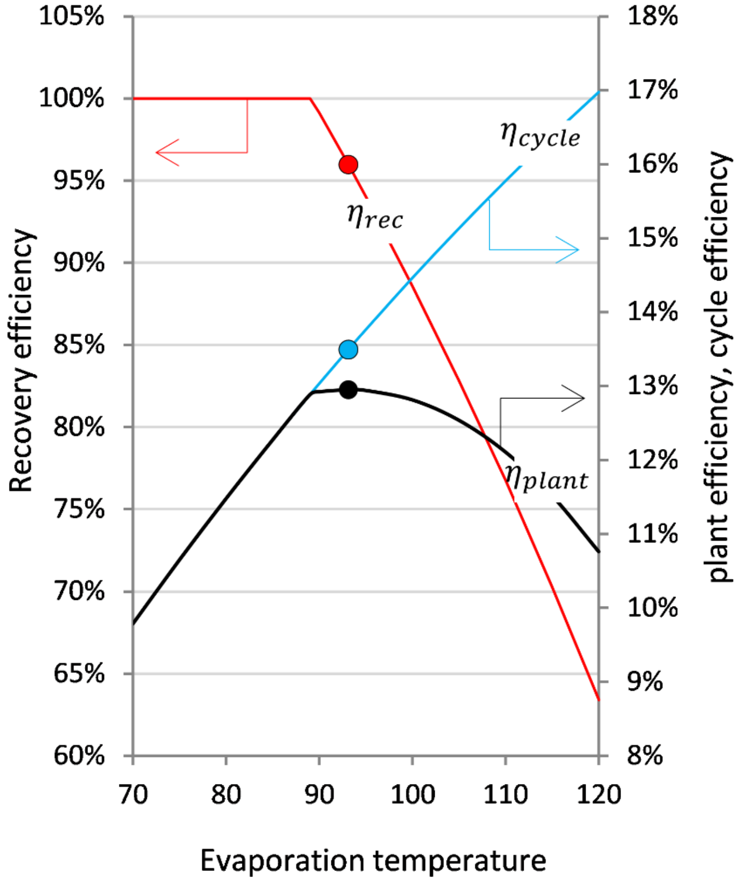


GROSS ELECTRIC POWER = 4.15 MW

$$\eta_{rec} = \frac{Q_{in}}{Q_{max}}; \quad \eta_{plant} = \frac{W_{net}}{Q_{max}}; \quad \eta_{cycle} = \frac{W_{net}}{Q_{in}}$$

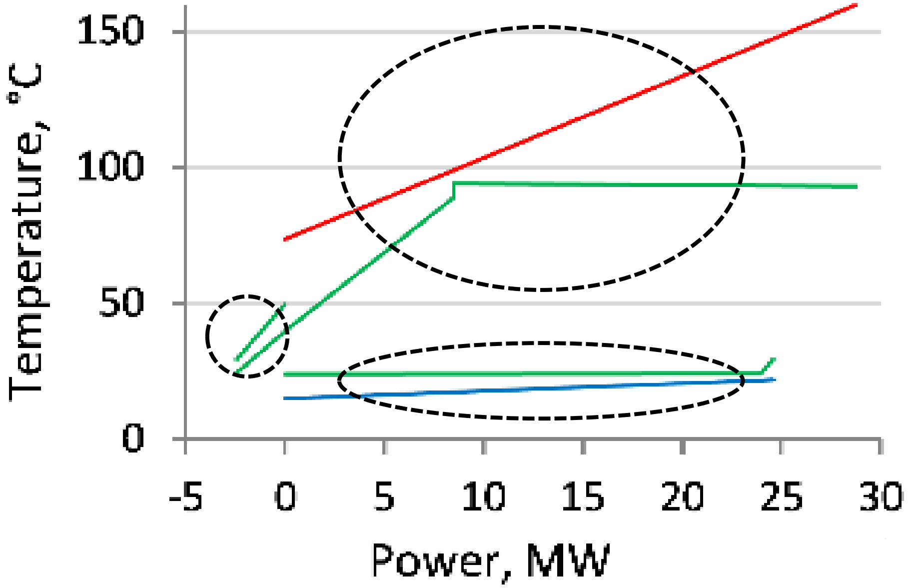
METHODOLOGY: ORC

DESIGN POINT

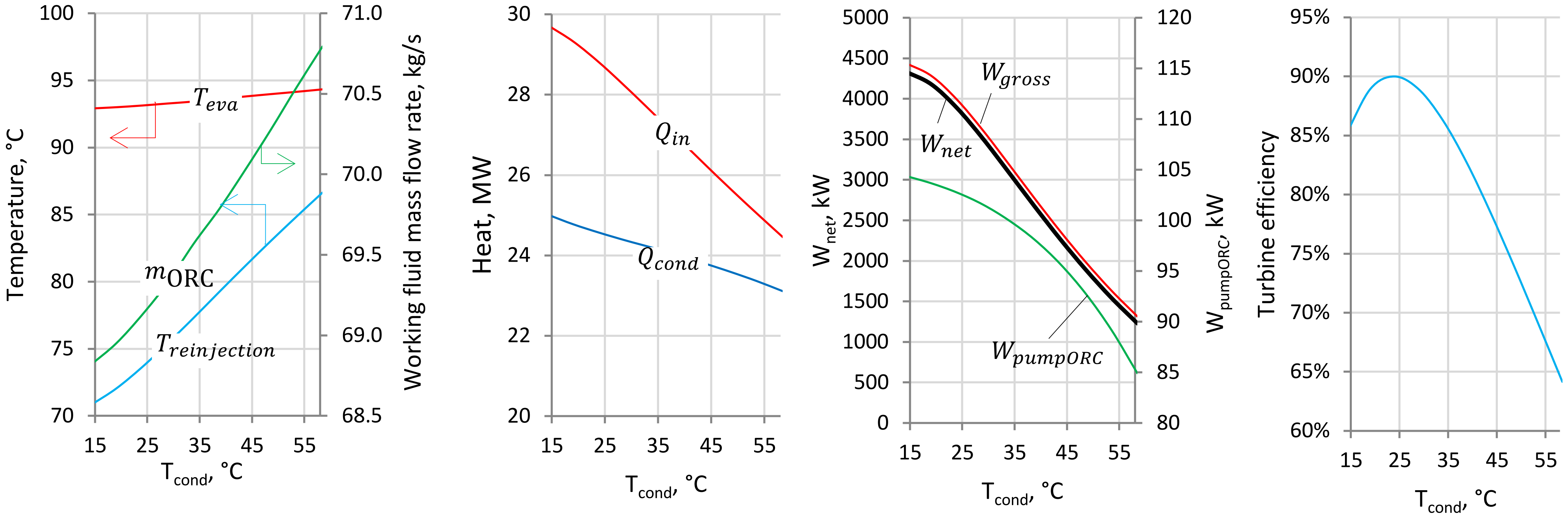


$$\eta_{rec} = \frac{T_{in} - T_{out}}{T_{in} - T_{out\ limit}}$$

- Condensation temperature is set to 24 °C (design)
- Evaporation temperature is optimized with the aim of maximizing the ORC net electric power output and is found equal to 93.1°C
- Gross electric power output is 4.15 MW
- Net electrical power is equal to 3.885 MW, considering the consumption of both the ORC pump (102 kW) and the cooling water pump (88 kW, ΔT=7°C, Δp=1bar)
- Nominal efficiency is 13% with a second law efficiency of 51%



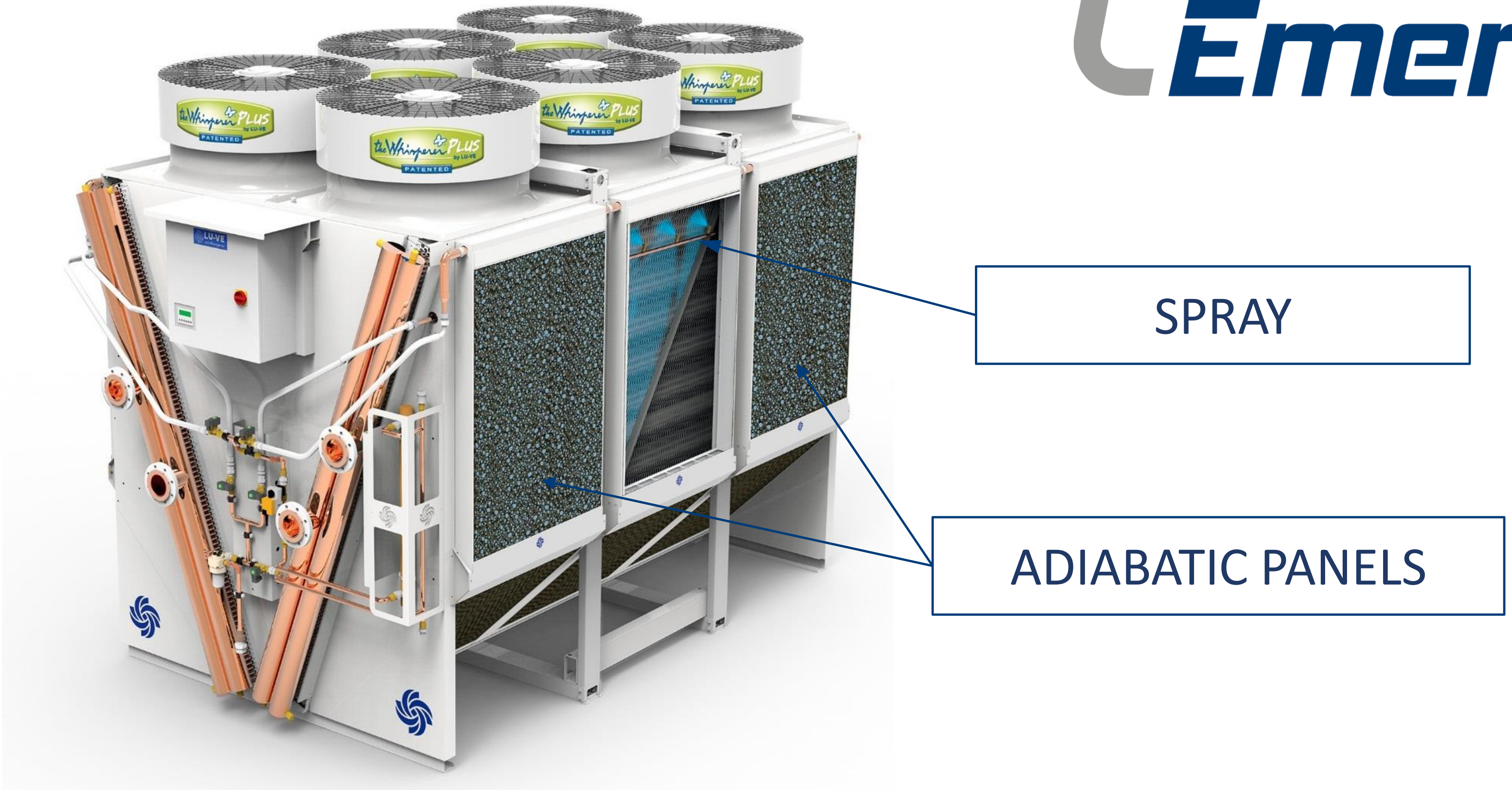
PARAMETERS AS FUNCTION OF T_{COND} — METHODOLOGY: ORC



- By increasing the *condensation temperature*, both the **evaporation** and the brine **reinjection** temperatures increase, leading to a higher working fluid **mass flow rate** and to a lower exploitation of the available heat

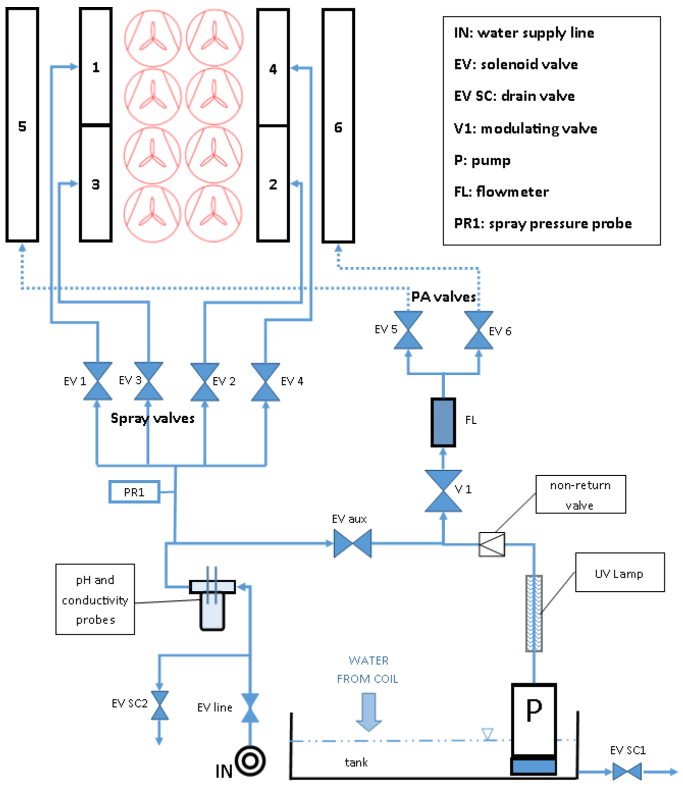
- When *condensation temperature* reduces below the design one, the **ORC power output** increases but with a lower slope, because the thermodynamic benefit of a lower condensation temperature are partly compensated by the reduction of the **turbine efficiency**

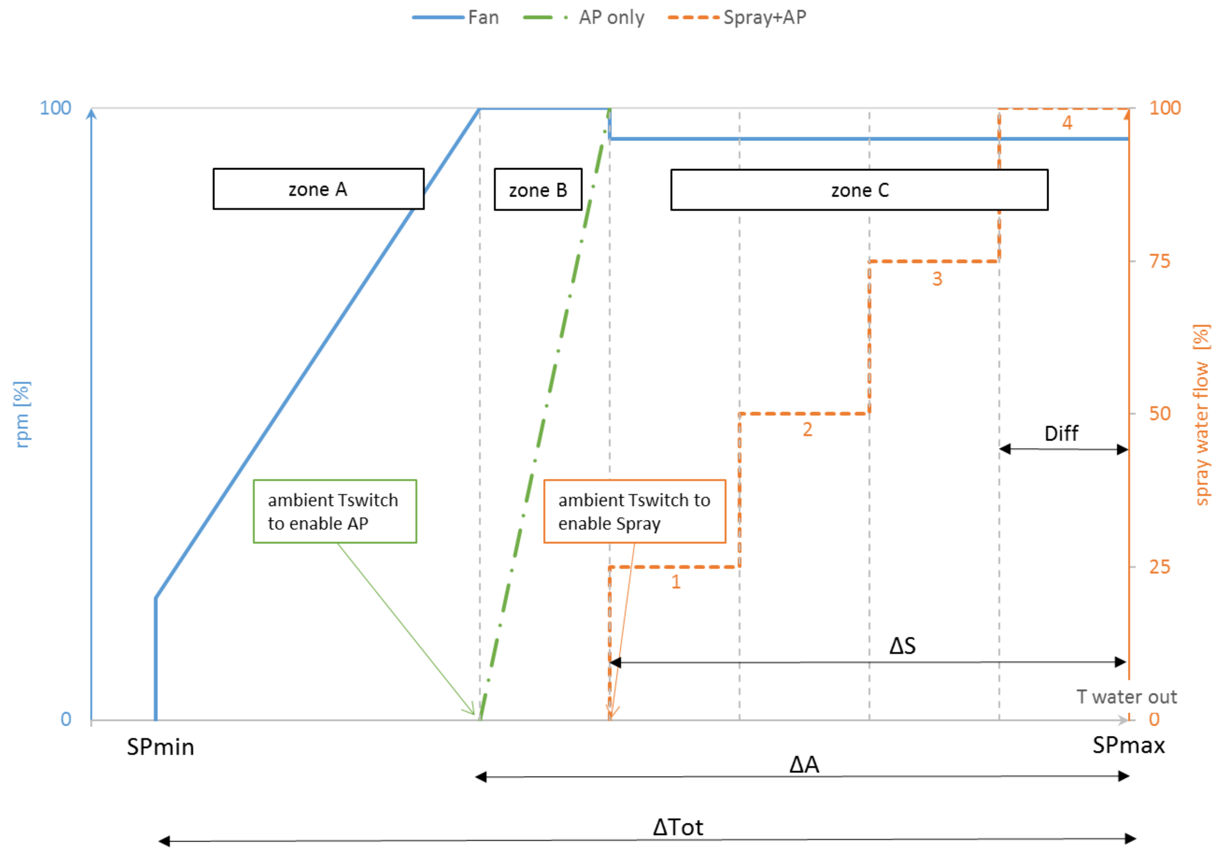
HEAT REJECTION UNIT FOR ORC


the Whisperer PLUS by LU-VE
PATENTED
SPRAY
ADIABATIC PANELS

Emeritus

Example: proportional regulation with fixed set point

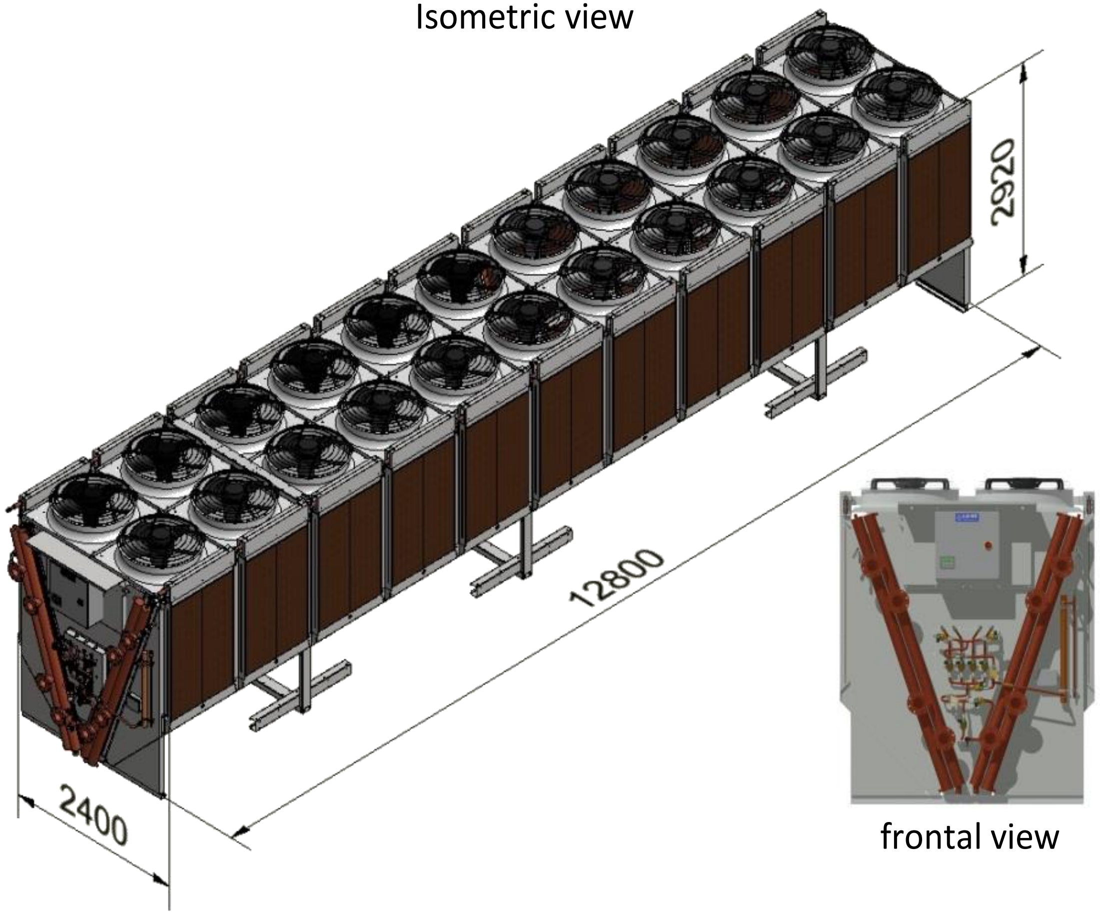




zone	0-A	B	C1	C2	C3	C4
OPEN	-	EVaux,V1, EV5-6	V1, EV1-6	V1, EV1-2-5-6	V1, EV1-2-3-5-6	V1, EV1-2-3-4-5-6
CLOSE	all	EV1-2-3-4	EVaux, EV2-3-4-5	EVaux, EV3-4	EVaux, EV4	EVaux
PUMP	OFF	OFF	ON	ON	ON	ON
FAN	ON PID	ON constant.	ON cost.	ON constant	ON constant	ON constant

The actual simulation foreseen 25 pieces of Emeritus heat exchanger

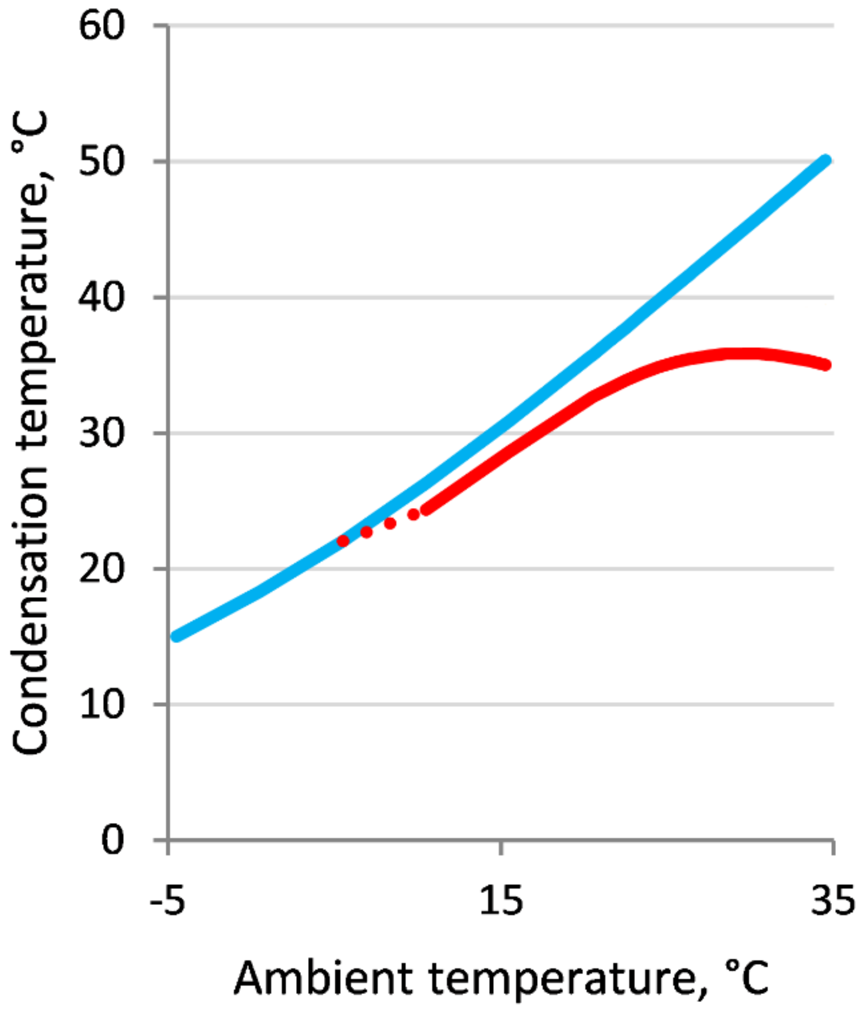
Isometric view



frontal view

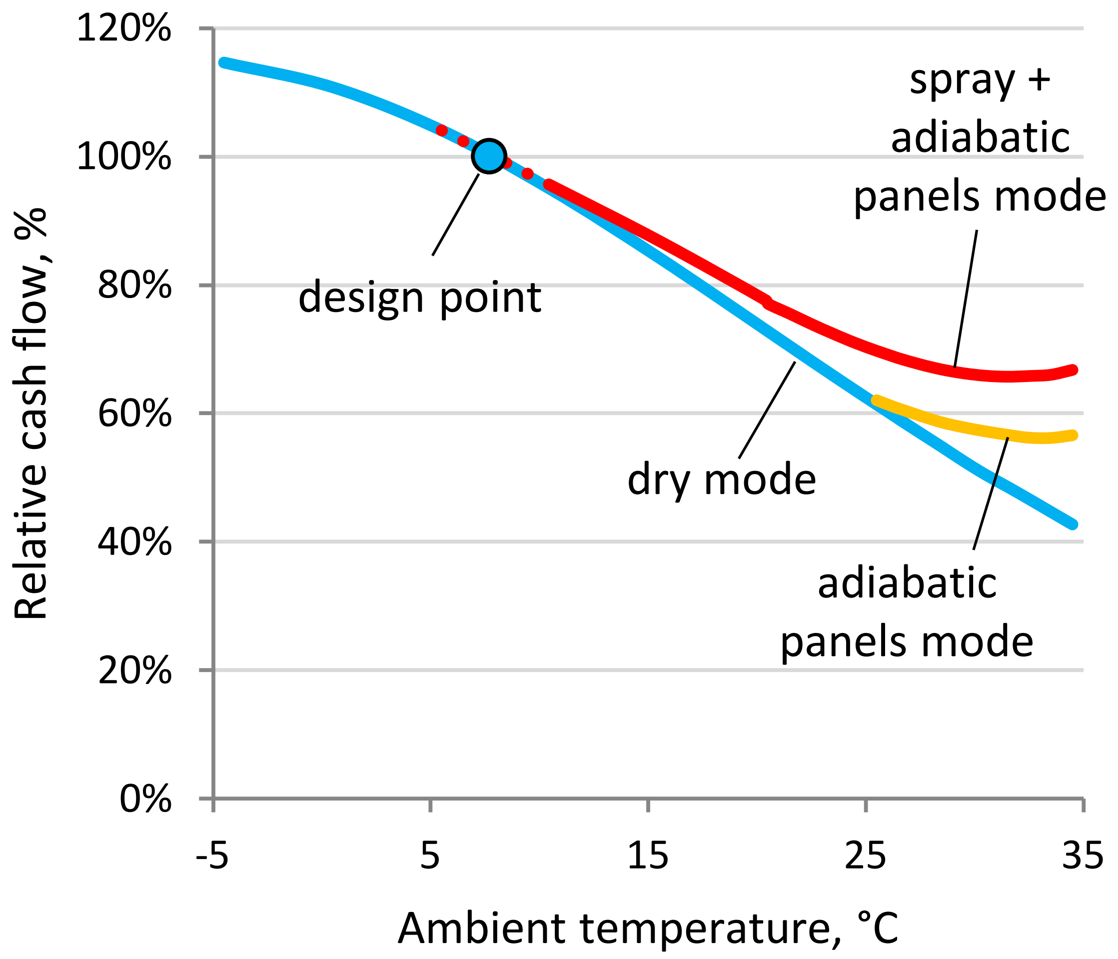
Fin pack	Materials 1340	tubes: Cu fins: painted Al headers: Cu connections: Fe
	external surface	5103 m^2
	int./ext. surface	16,3
	tube int. diameter	9,52 mm
	tube spacing	25 mm
	fin spacing	2 mm
Spray system	Configuration	44 nozzles for each side
	water needed (full load)	3840 kg/h
Ventilation	fan n°	22 – ø 910mm
Adiabatic system	Water needed (full load)	1340 kg/h (totally recovered from sprayed water)

T_{COND} FOR DRY AND WET MODE



Lower condensation temperatures are achievable with a wet solution

ORC OFF DESIGN OPERATION



- N° 25 Emeritus coolers with 22 fans each
- For each temperature, optimal fan speed and flow rate of sprayed water are determined to maximize total cash flow
- Ref. cash flow (100%) at T_{amb} =7,7°C (i.e. T_{cond} =24°C)
- Electricity selling price 200 €/MWh
- Water price 1 €/m^3
- Climatic data from central Italy

ORC OFF DESIGN OPERATION

Dry

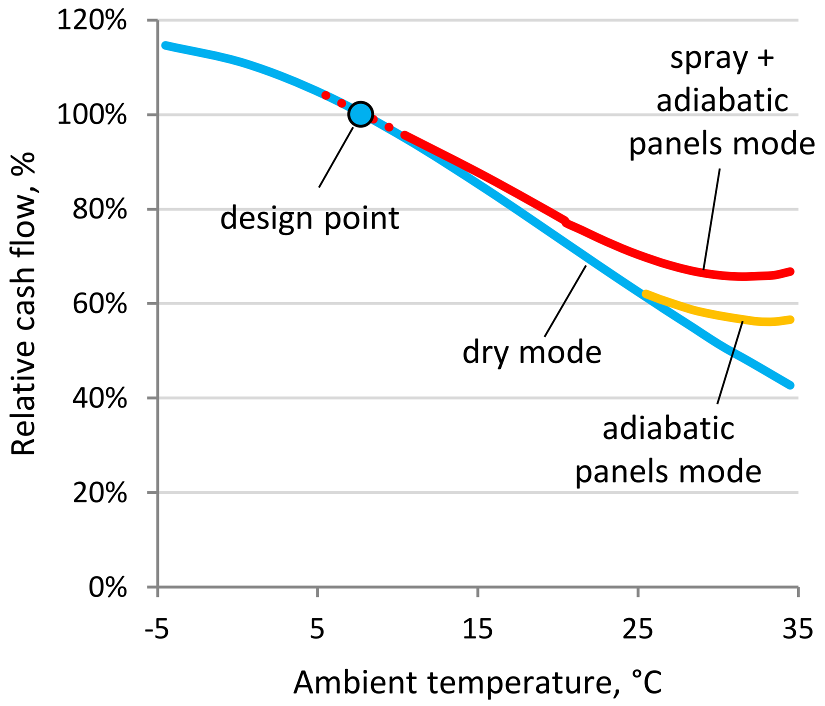
- At 30 °C CF is 50% of the ref
- Increasing condensing temperature
- Increased consumption of the fans

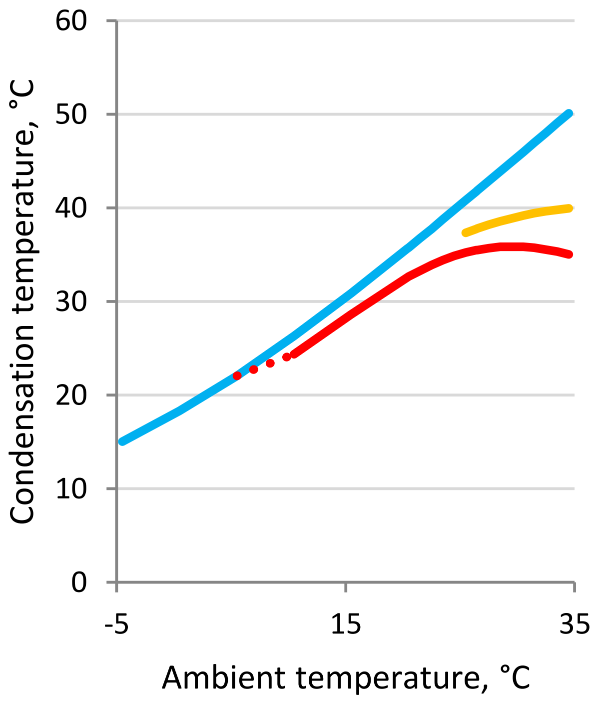
Adiabatic panels

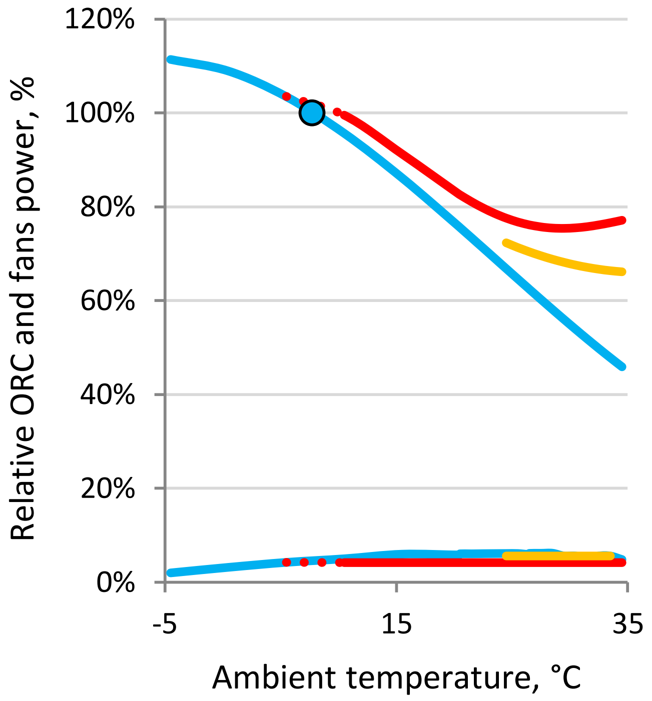
- After 25°C the use of the adiabatic panels is convenient
- At 35°C CF 27% higher than DRY mode

Spray

- In principle convenient after 10°C
- At 35°C CF is 70% higher than DRY mode







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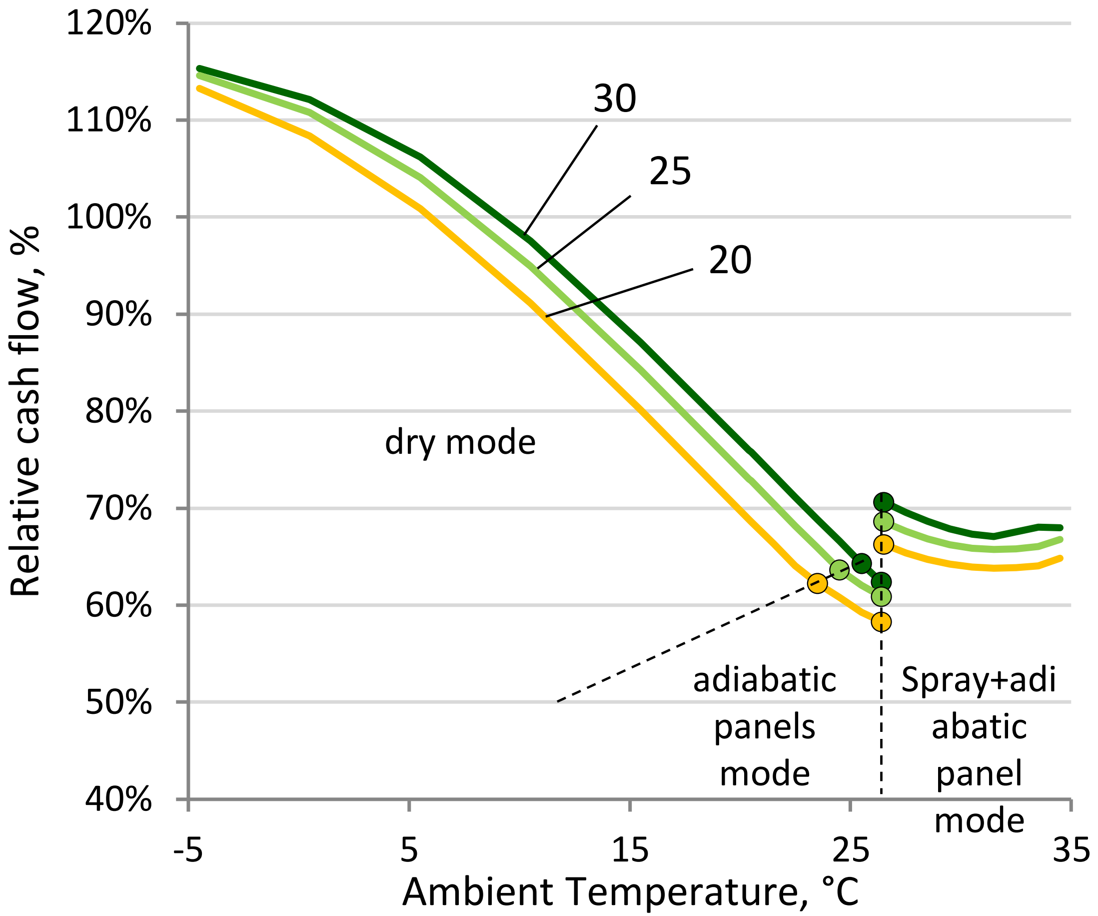
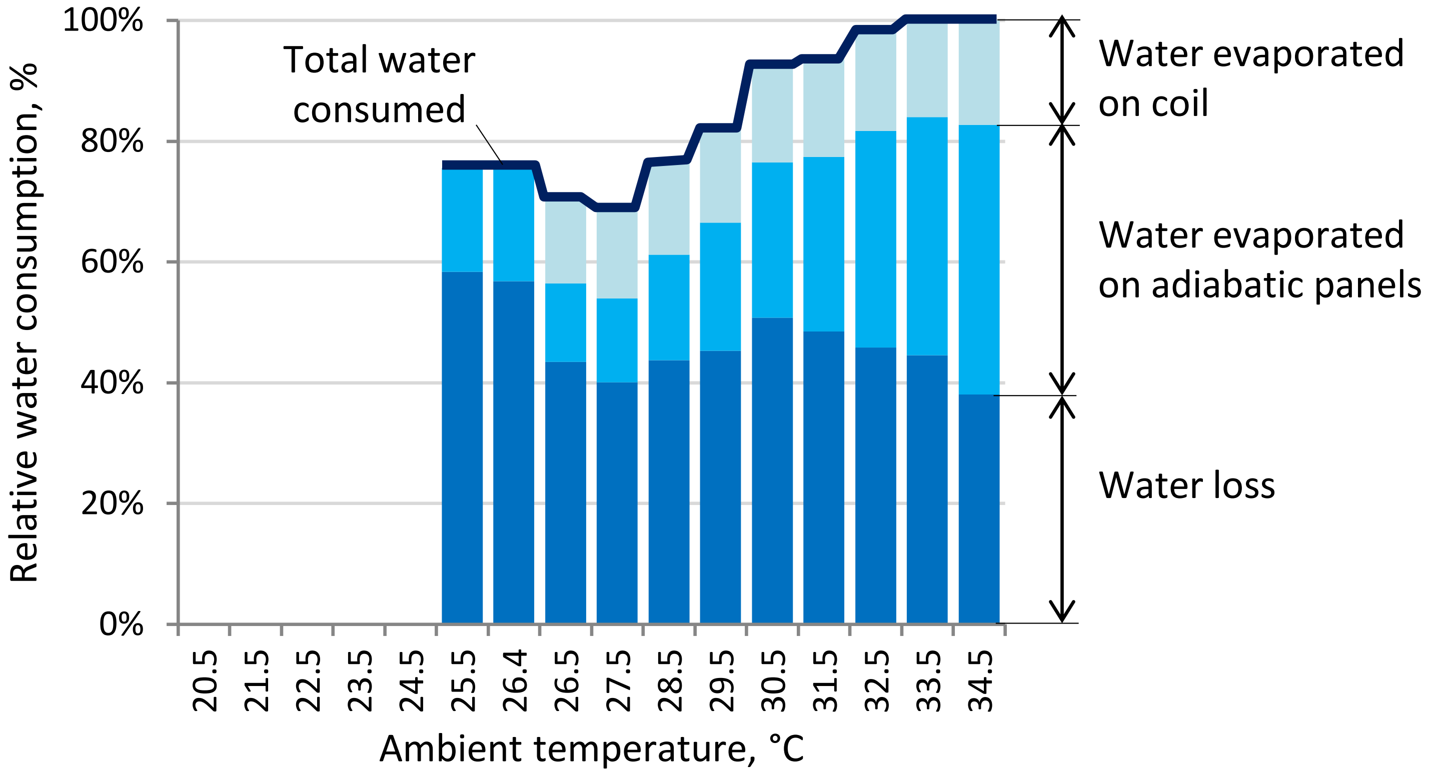
Three sizes of the Emeritus heat rejection system



- Between 5 and 23 °C the CF is 5-10% higher with 30 Emeritus than 20
- 26,5°C is the spray switch temperature, defined in order to not exceed 500 h/y of spraying time
- The switch temperature for the adiabatic panels is found from an economical point of view and it increase with the number of units:
  - 23,5°C with 20 Emeritus
  - 25,5°C with 30 Emeritus

DIMENSIONLESS WATER CONSUMPTION



- The water is used only over a certain ambient temperature (25°C)
- As soon as the water is used, both on adiabatic panels and sprayed on finned surface, the water efficiency increases
- Compared to traditional cooling tower the water consumption on yearly basis is much lower
- The water lost from the adiabatic panels is not recirculating, aiming to prevent risk of bacteria contamination

HEAT REJECTION UNIT FOR ORC

1. Introduction
2. Advantages in using wet & dry configuration
3. Reference case: geothermal power plant
4. Techno-economical optimization for the off-designed operation
5. Conclusion

- The operation of a ORC plant in off design mode has been calculated, considering variable ambient temperature.

- The new air heat exchanger allows to combine dry operation and wet operation, reducing significantly the condensing temperature at warm ambient temperatures and increasing the overall efficiency and the cash flow (50k€ yearly additional revenues).

- The Emeritus configuration allows to reduce strongly the yearly water consumption compared to a traditional cooling tower system

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Emeritus