POTENTIAL OF WATER-SPRAYED CONDENSERS IN ORC PLANTS

Stefano Filippini, Umberto Merlo (LU-VE Group)

Matteo C. Romano, Giovanni Lozza (POLITECNICO DI MILANO)

In ORC cycles, 75-90% of inlet heat must be rejected to the environment

Air cooled condenser is often the preferred choice:

→ large condensing surface and footprint

→ high investment cost (about 20% of the ORC module)

→ high auxiliary electric consumption

→ large influence of ambient conditions on ORC performance

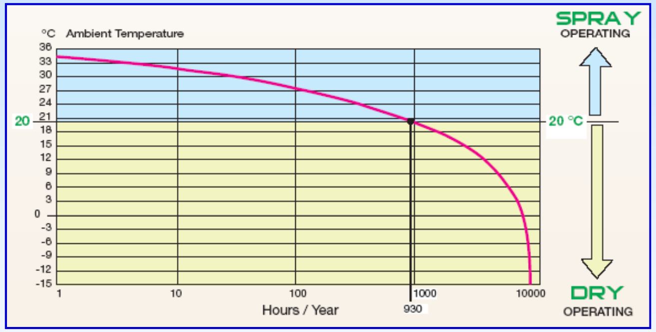
→ Economic optimization of condenser design and operation is important

This presentation illustrates an alternative solution to traditional air cooled condenser able to lower electric consumption and to improve ORC performance and efficiency.

The solution is applied from several years in refrigeration and air conditioning fields showing excellent results

Product description

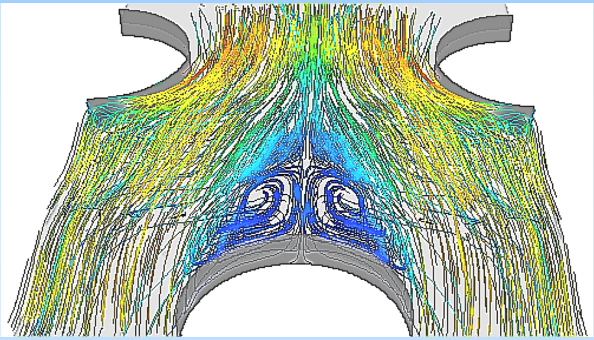
Water spray condenser is a fin-and-tube heat exchanger, operating with dry surface when the ambient temperature is lower than a selected design value.



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

R & D activity – Heat exchanger simulation with CFD – dry mode

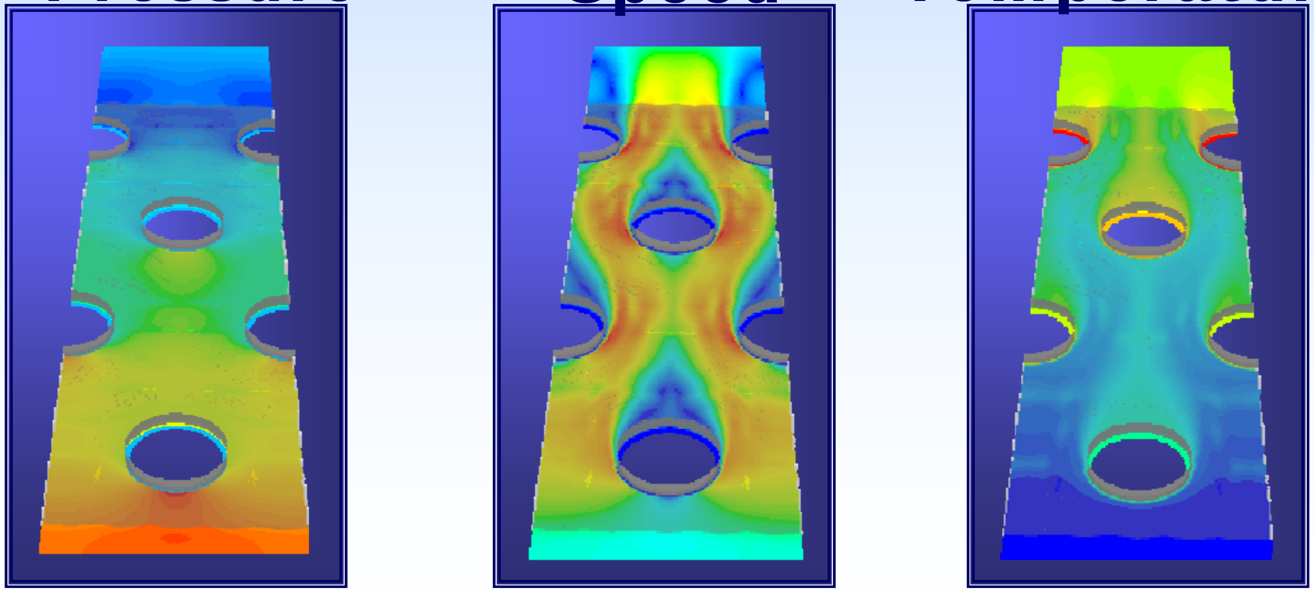
Path lines of wavy fins



Fin design improved by Computational Fluid Dynamics analysis.

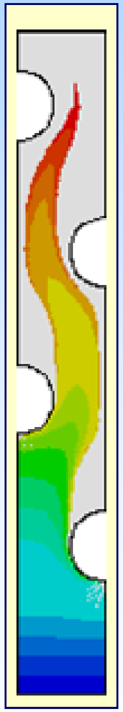
Distributions of

Pressure Speed Temperature

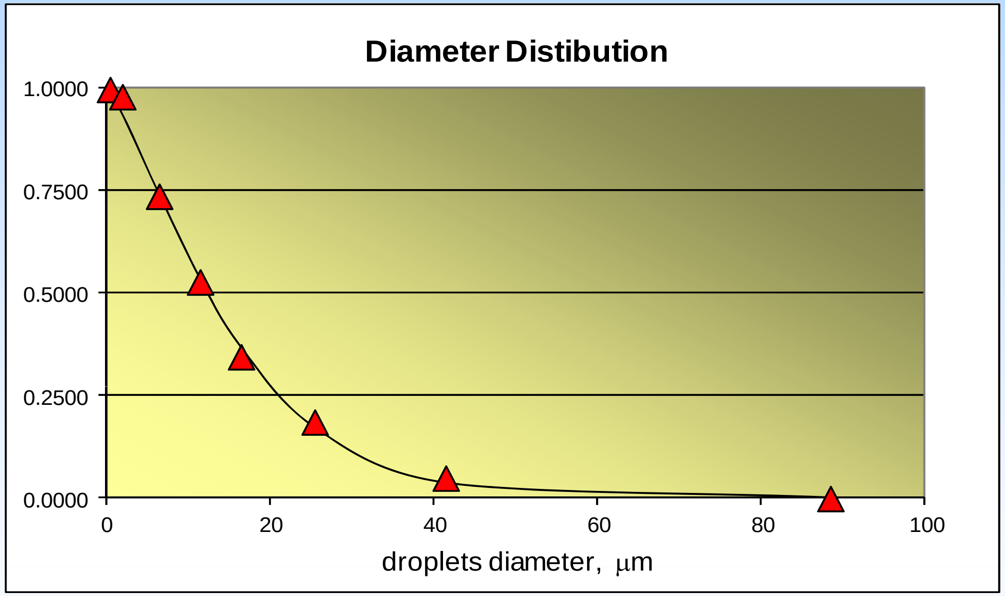


Application of COMPUTATIONAL FLUID DYNAMICS ANALYSIS on a sprayed fin: "WET" application.

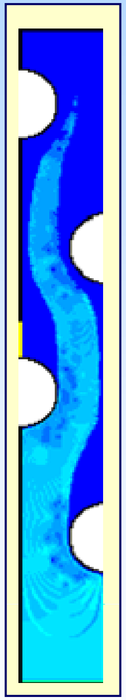
Water droplets distribution



Flow of the evaporated water



- min diameter 3.5 μm
- max diameter 87.5 μm
- avg. diameter 17.5 μm
- distribution field 1.25

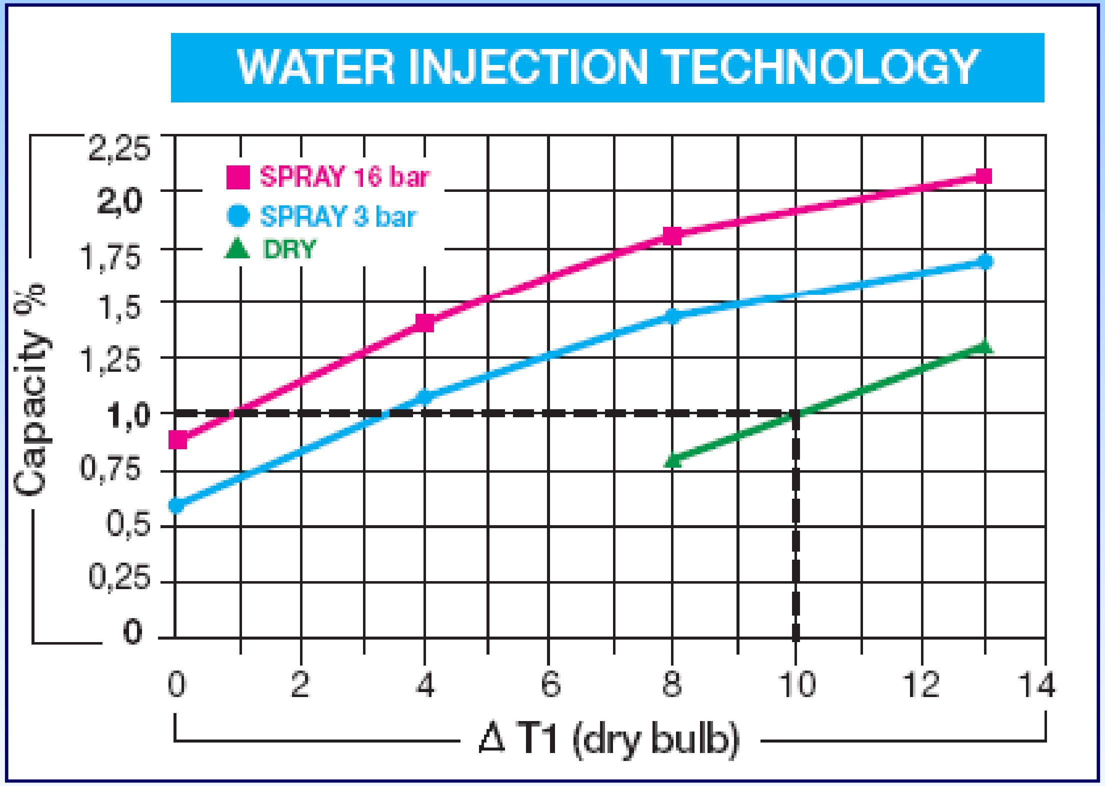


Quantity distribution of the evaporated water

R & D activity – Heat exchanger testing activity

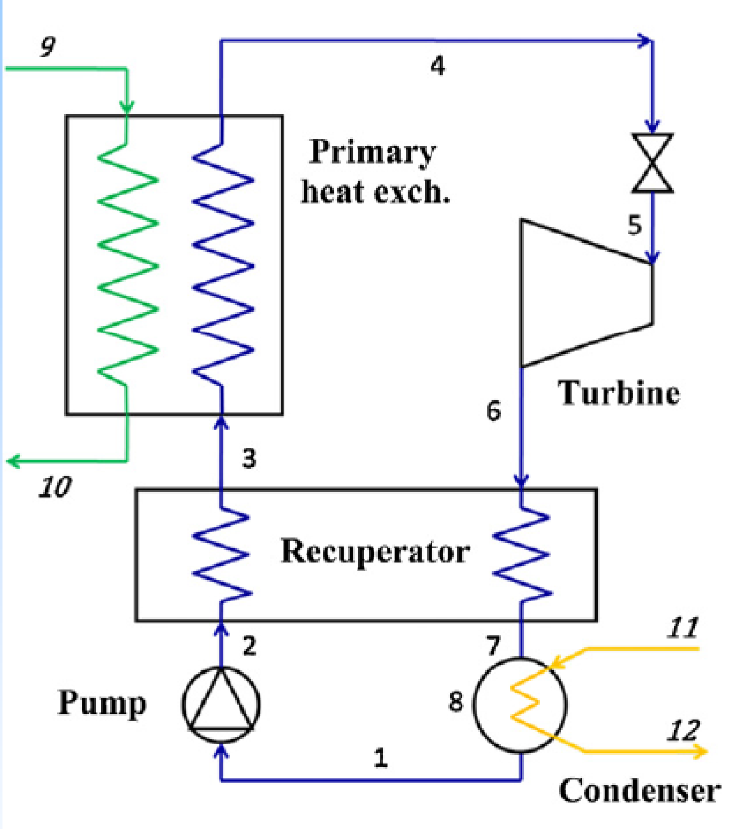
LU-VE- Testing station

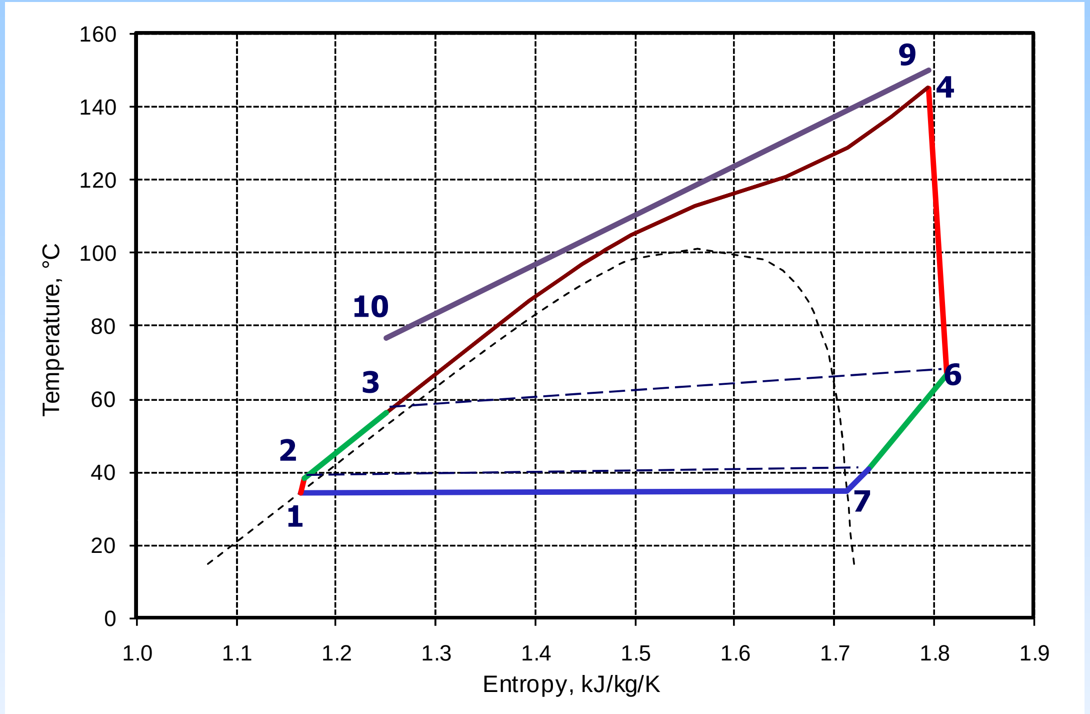
DRY and SPRAY - Performance



Performance of DRY and SPRAY related to EHLD1S range, with 30% Ethylene Glycol and ΔTw=5K

Case study: R134a recuperative supercritical ORC cycle for geothermal application





Design conditions

- T_w=150°C
- $T_{reinj-min}$=70°C
- T_{amb}=23,5°C
- T_{cond}=35°C

Performance

$\eta_{cyc,gross}$=16.4%

$\eta_{heatr\ rec}$ =91.7%

η_{net}=11.6%

Q_{cond}=85.6% of Q_{in-ORC}

Calculation model

Given the cycle operating conditions at design point, off-design performance are estimated considering constraints imposed by components design:

- **Main heat exchanger heat transfer surface**
- **Recuperator heat transfer surface**
- **Turbine nozzle critical section**
- **Condenser design: tube and fin geometry + fan characteristic curve**

Dependent variables used to respect the given constraints:

- **Turbine inlet temperature**
- **Recuperator effectiveness**
- **Turbine inlet pressure**
- **Condensing temperature**

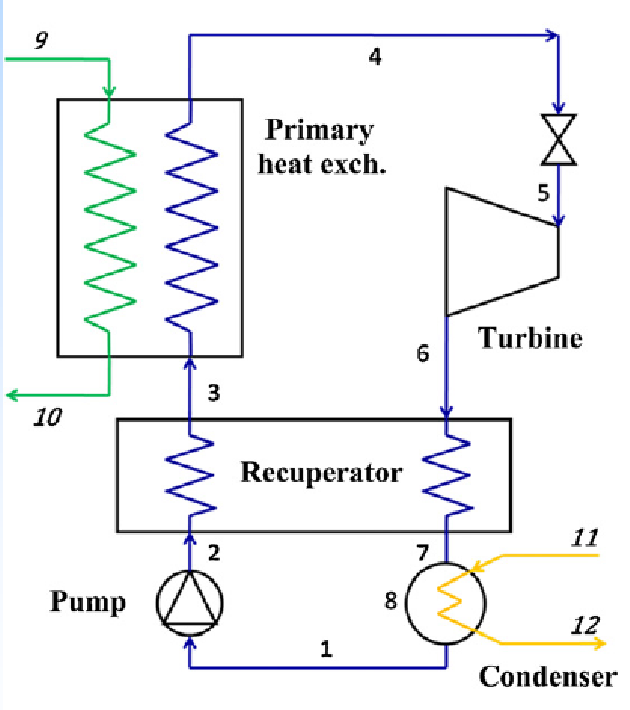
Turbine efficiency corrected by taking into account the isentropic enthalpy drop and outlet volume flow rate.

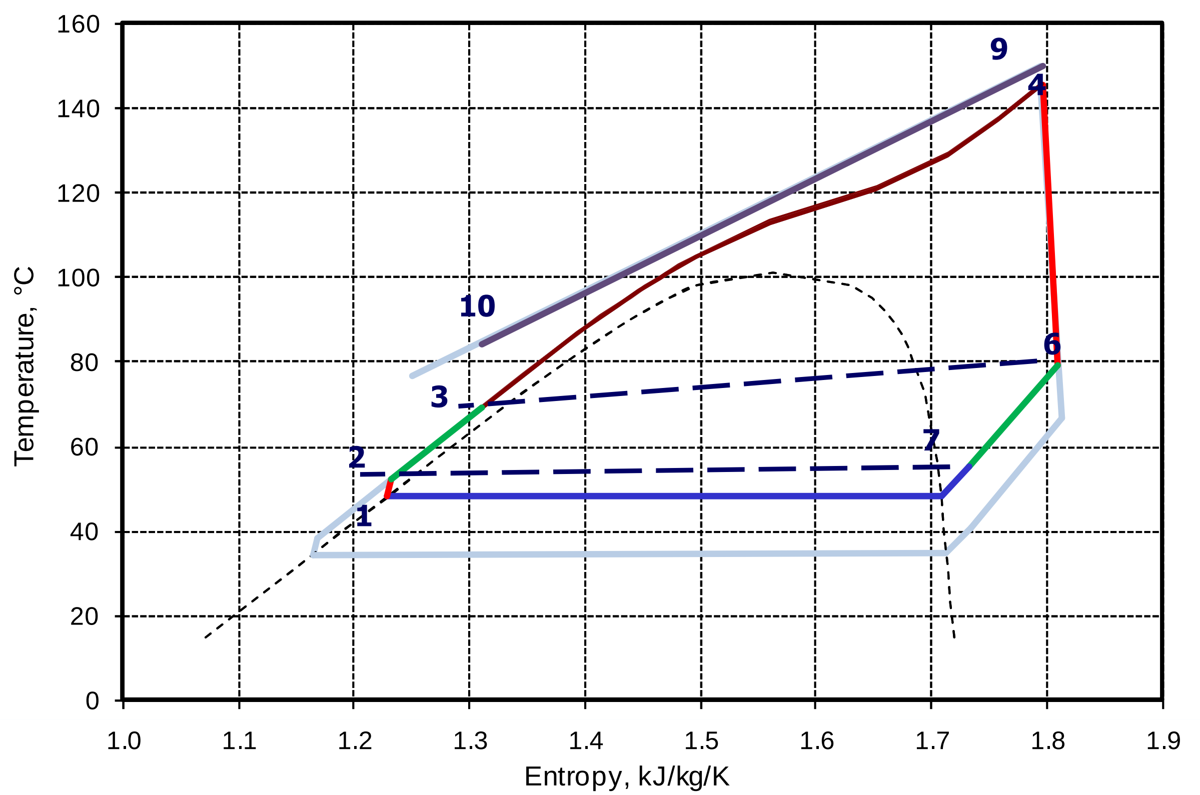
Influence of ambient temperature

T_{amb}=35.6°C, fans speed at design value (670 RPM):

→ **increased condensing temperature**

→ **reduced heat recovery efficiency** (recup. cycle)

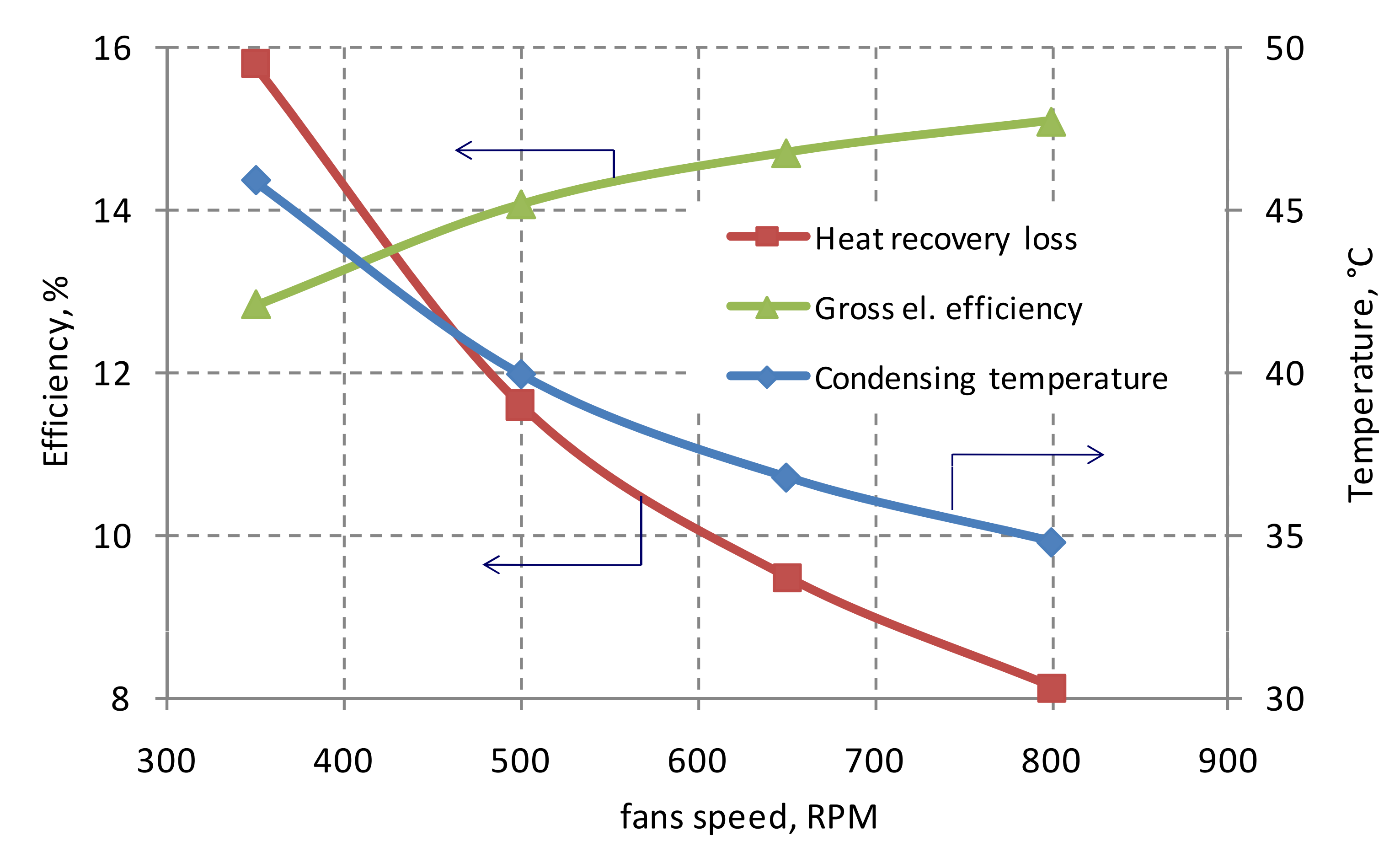




Influence of ambient temperature – dry operation

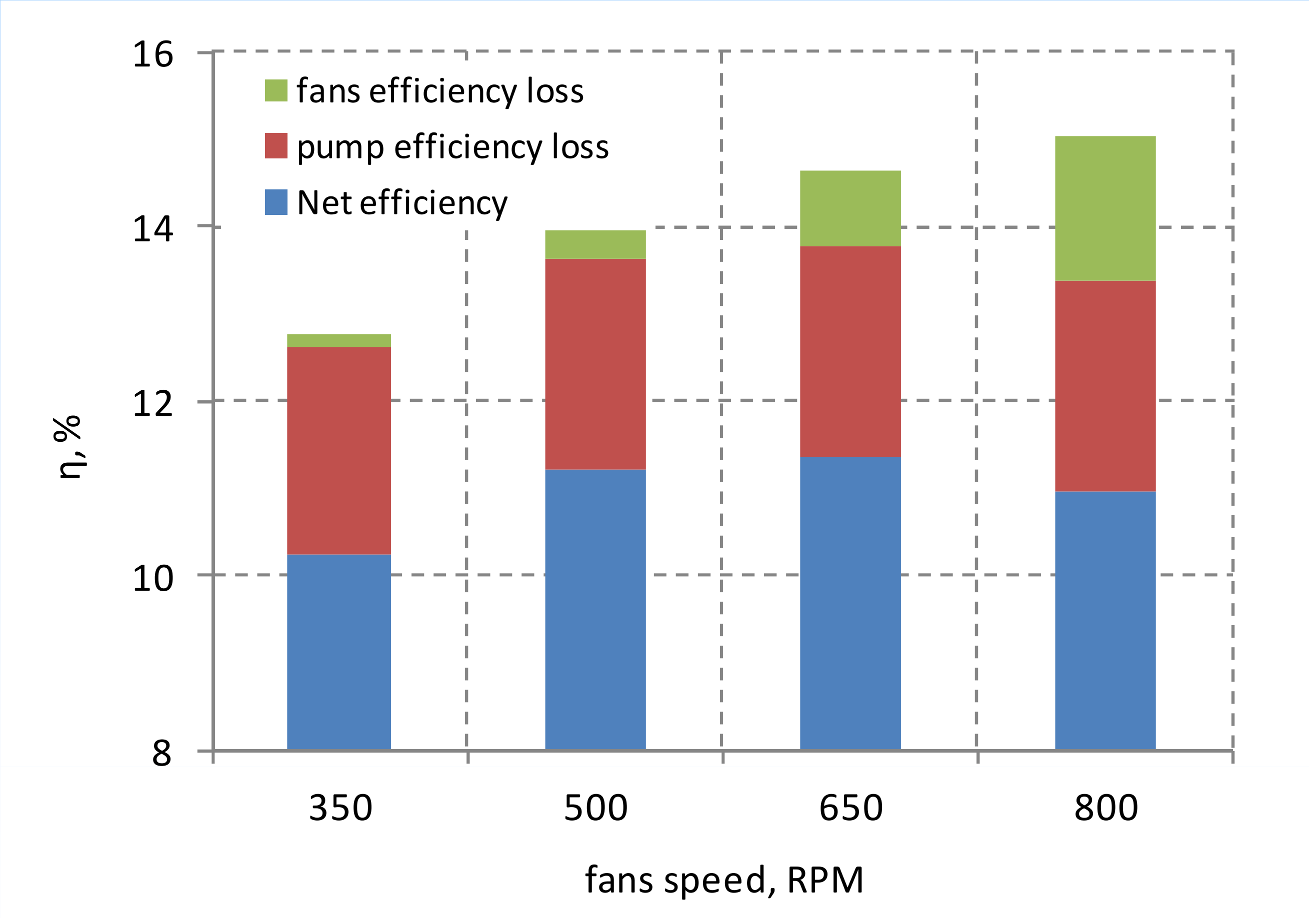
Effect of fans speed:

ambient temperature = 23.5°C



Influence of ambient temperature – dry operation

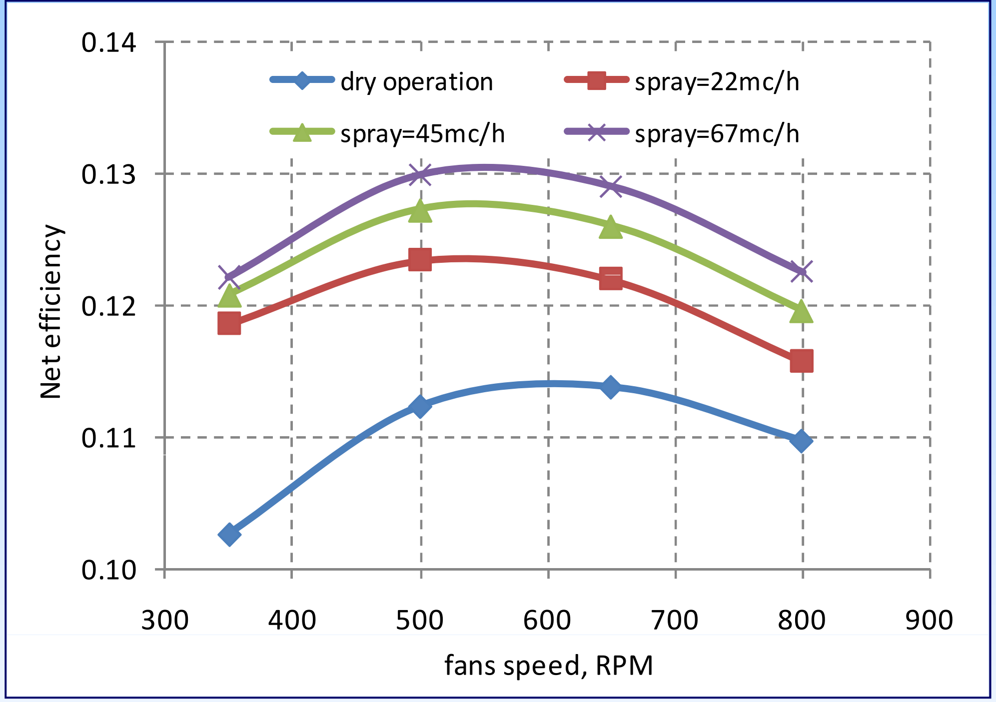
Efficiency decay at ambient temperature = 23.5°C



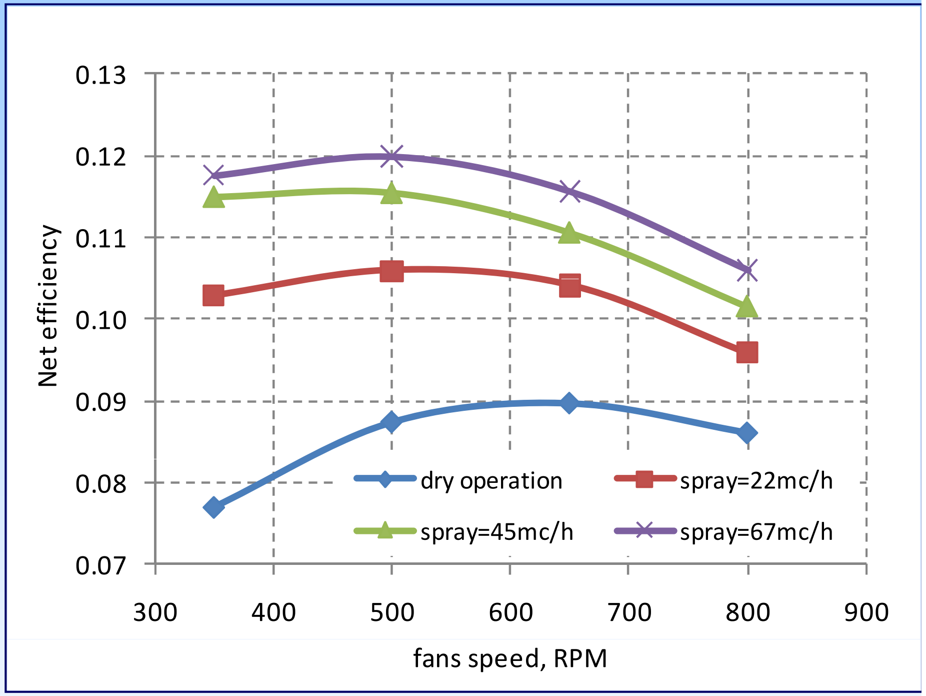
An optimal fan speed maximizing net efficiency can be found

Influence of ambient conditions – wet operation

T_{amb}= 23.5°C; RH=68%



T_{amb}= 35.6°C; RH=31% (summer peak)

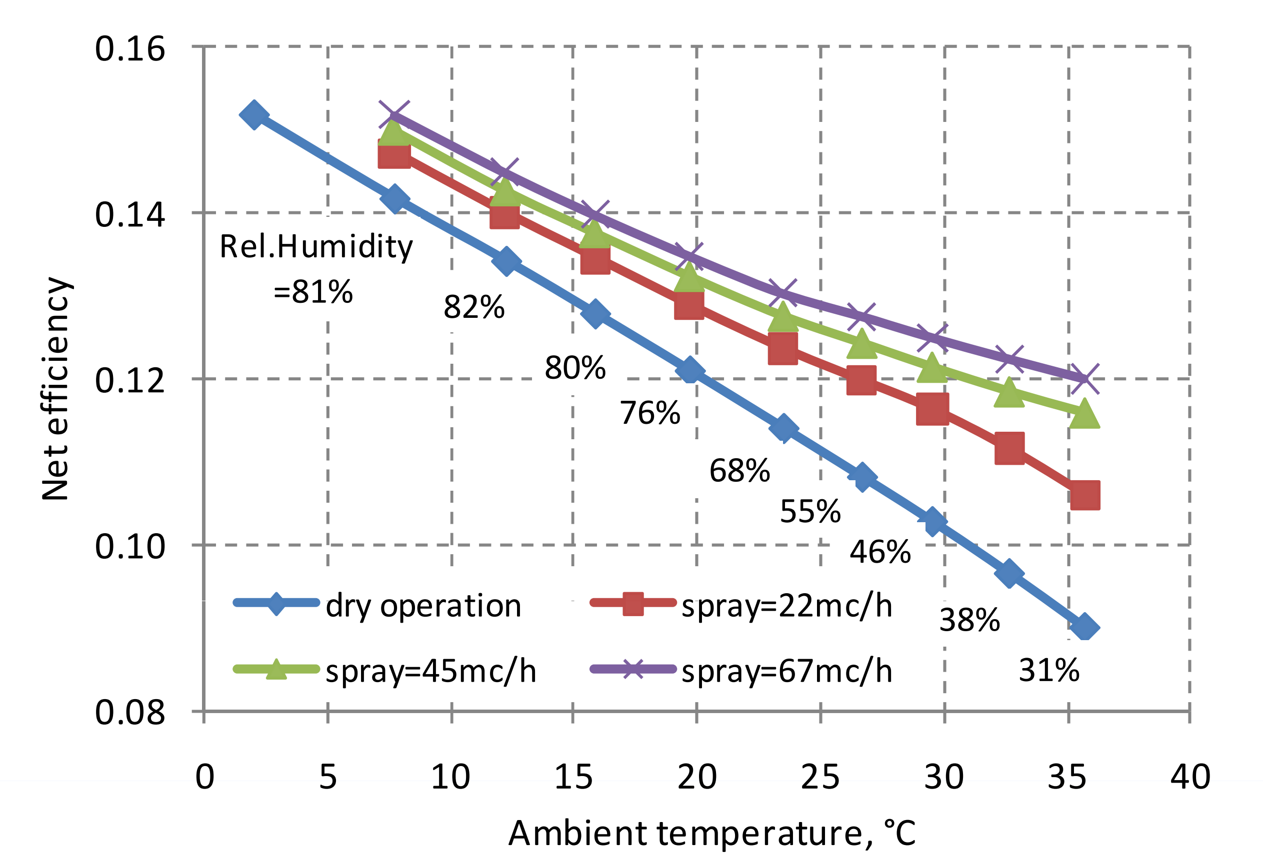


Thanks to wet operating net efficiency increases by 13% (T_{amb} 23,5°C) and by 33% (T_{amb} 35,6°C).

Also in these cases there is an optimal fan speed maximizing net efficiency

Influence of ambient conditions – wet operation

Net electric efficiency vs. ambient conditions at optimal fan speed



Water spray injection improves the net efficiency by 7 ÷ 33%, according to ambient temperature

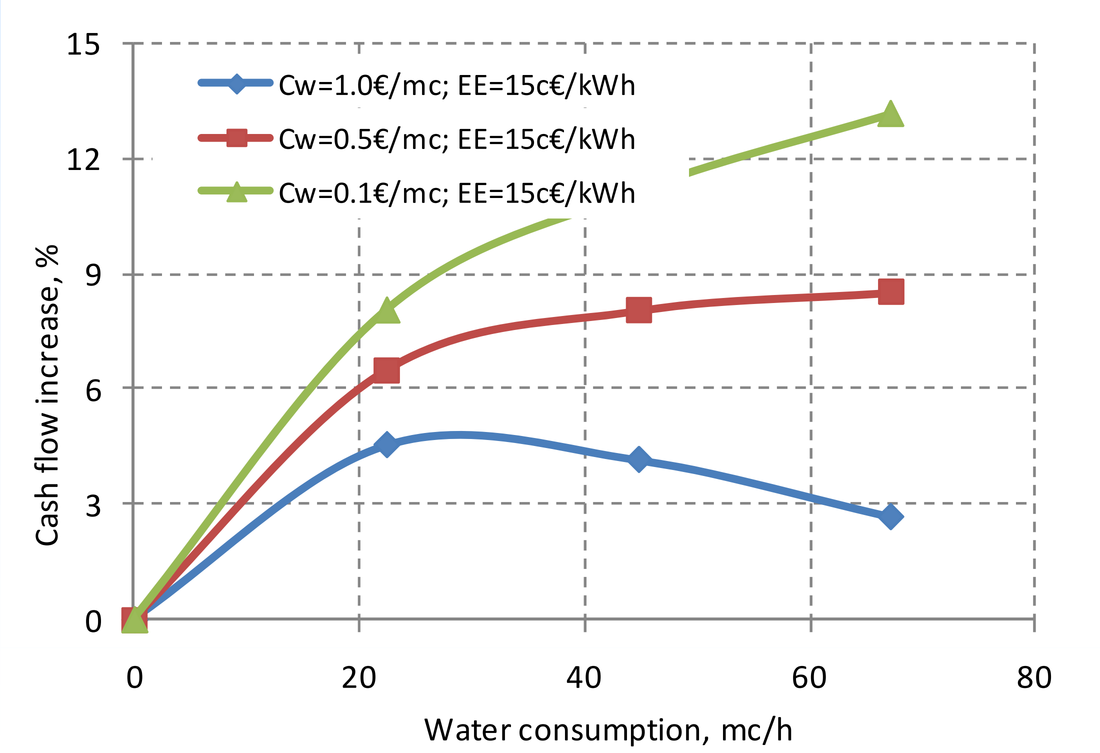
Economic calculation

Increase of water injection always enhances net electric efficiency

Optimal operations should be optimized to maximize cash flow

The trade-off between water cost and price of electricity is very dependent on site conditions and local costs

T_{amb}= 23.5°C; RH=68%



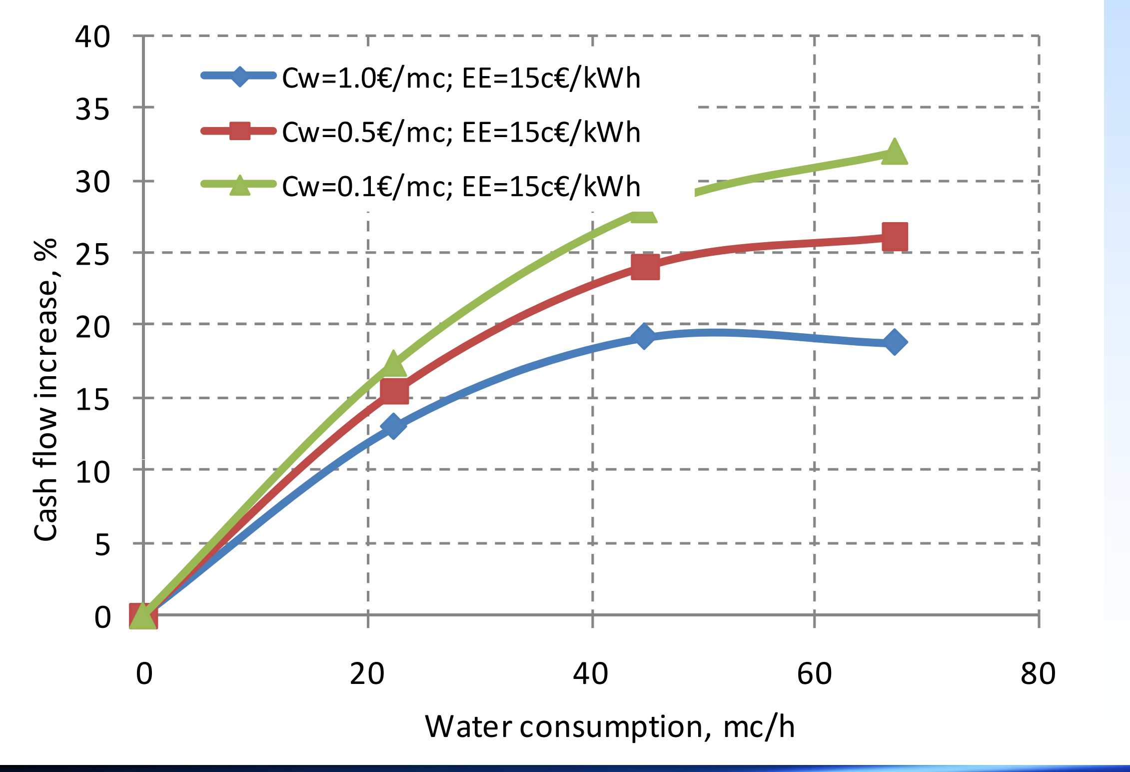
Economic calculation

Increase of water injection always enhances net electric efficiency

Optimal operations should be optimized to maximize cash flow

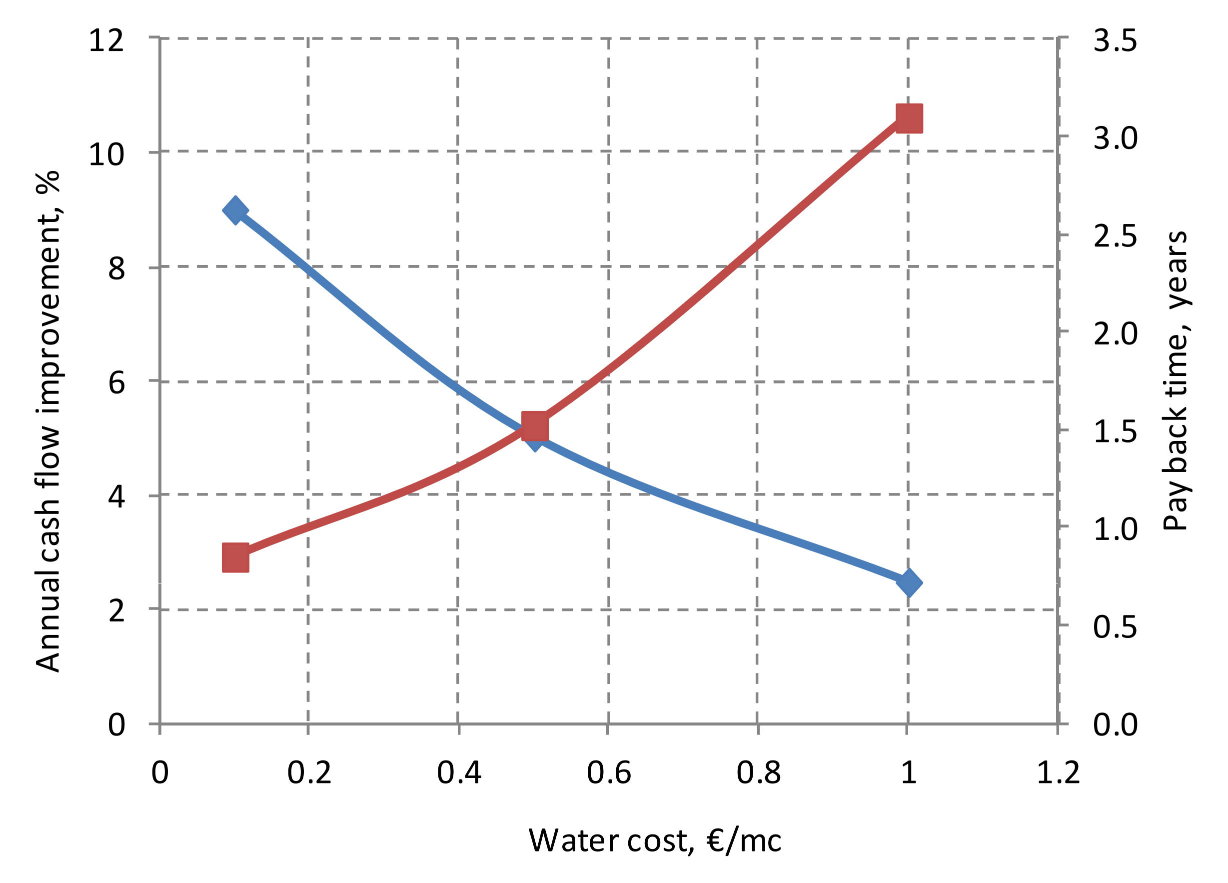
The trade-off between water cost and price of electricity is very dependent on site conditions and local costs

T_{amb}= 35.6°C; RH=31%



Economic calculation

By considering an annual temperature distribution (Central Italy case), an annual calculation can be undertaken at optimized (maximum cash flow) working conditions, for different costs of water



Conclusions

- Dry & spray technology can be an effective system to improve power output and profitability of ORC plants
- Actual performance should be evaluated on a annual basis and are strongly dependent on the installation site (climate, water cost and electricity price)
- In a comprehensive optimization process, effects of the investment costs should also be considered, defining the proper condenser size considering the water spray option
- Dry & spray technology will be more convenient in solar power generation plants, where production is concentrated during the hot hours of the day