Numerical comparison of the yearly performance of an indirect vapour compression system working with R290 with R410A systems

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Background

- Due to regulations that reduce the emissions from fluorinated greenhouse gases, a significant increase in the use of natural refrigerants is expected in the next years.

- Among them, R290 is gaining popularity in the residential heat pumps sector.

- To improve safety, refrigerant charge has to be reduced as much as possible.

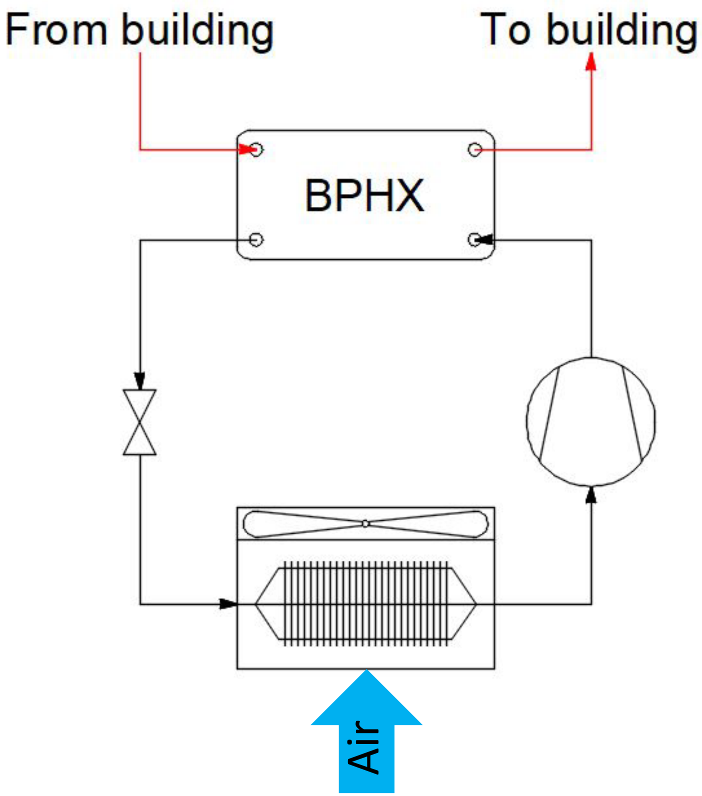
Objective

- Analyse the performance of an indirect expansion, brine-to-water heat pump working with R290 (low charge heat pump).

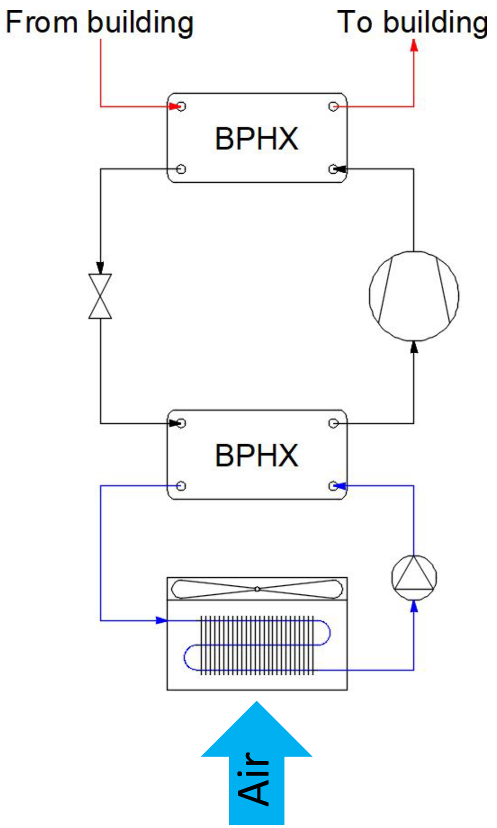
- Benchmark (reference technology): air-to-water heat pump working with R410A.
- Benchmark (congruent technology): indirect expansion, brine-to-water heat pump working with R410A.

Methods – Systems under comparison

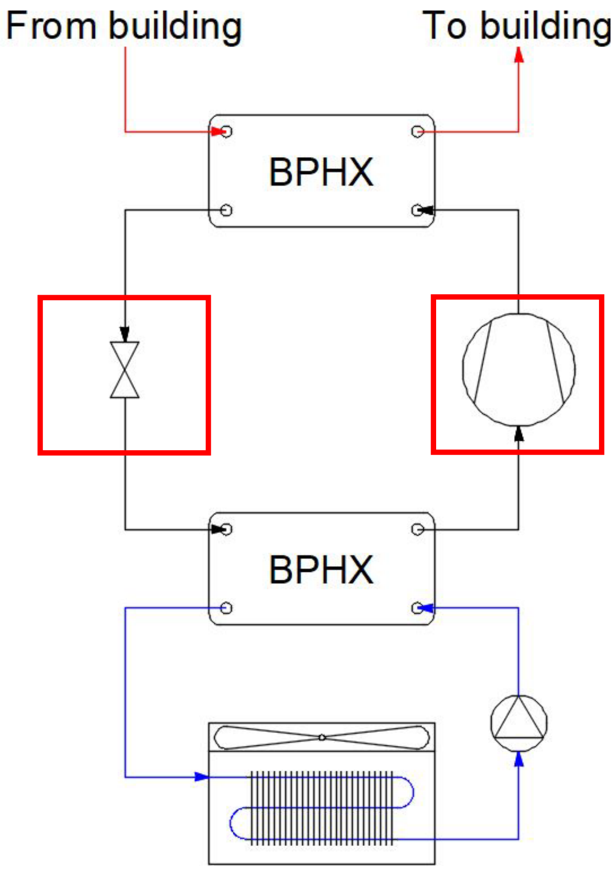
Direct expansion system



Indirect expansion system

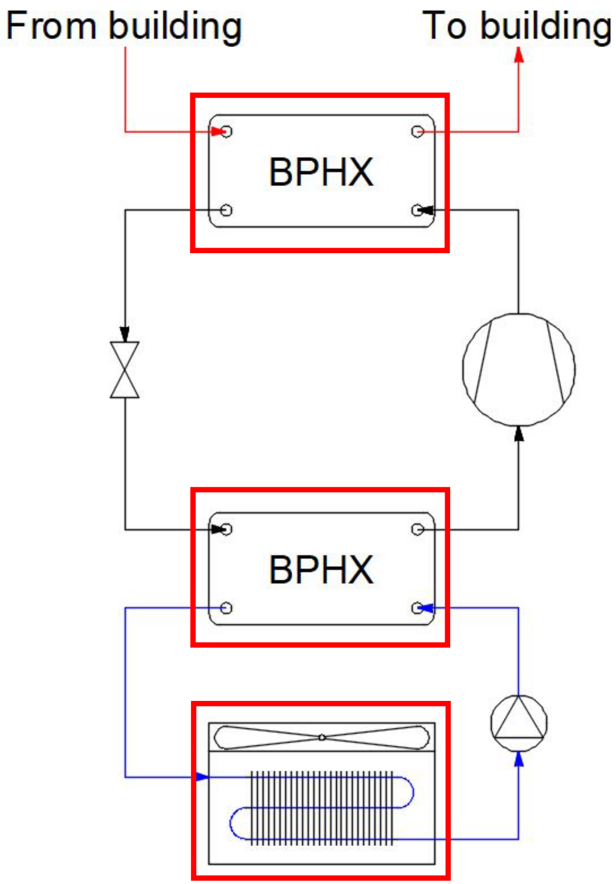


Methods – Heat pump modelling (1/3)



- Model built with a bottom-up approach, i.e. connecting the sub-models of each component of the heat pump.
- Refrigerant → Properties calculated using Refprop 10.
- Compressor → Hermetical, variable speed scroll compressors modelled through the ten coefficients polynomial curves.
- Expansion valve → Isenthalpic process and constant superheating at the evaporator outlet in any operating conditions.

Methods – Heat pump modelling (2/3)



- Plate heat exchanger → 1D elemental volume approach with ε-NTU method for the calculation of the heat transfer rate.
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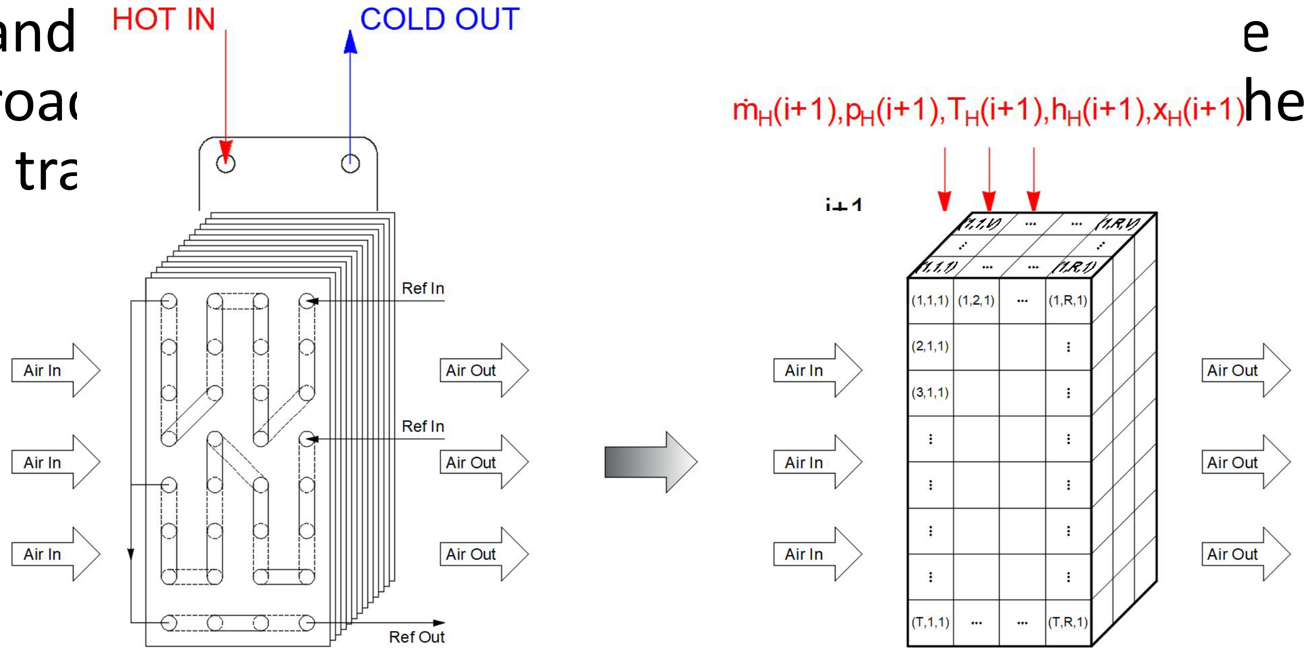
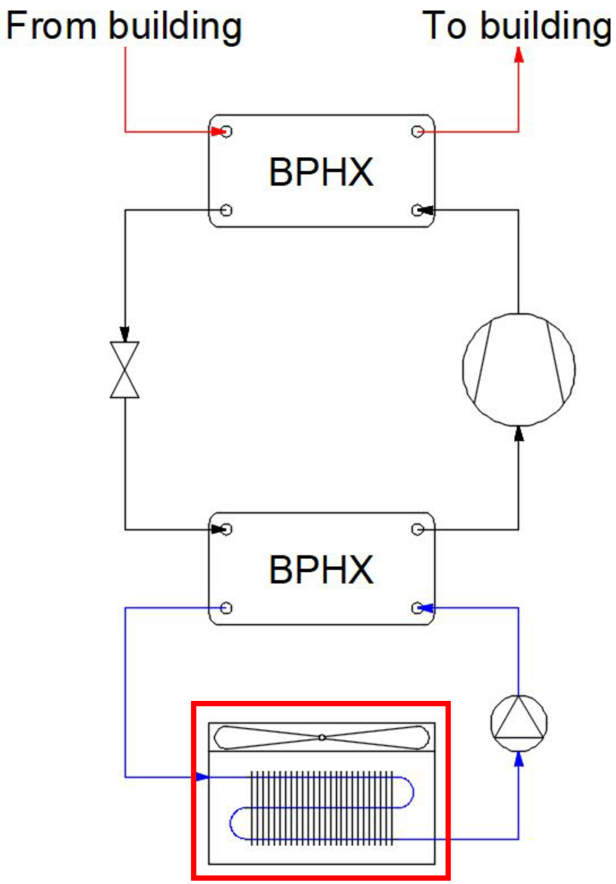


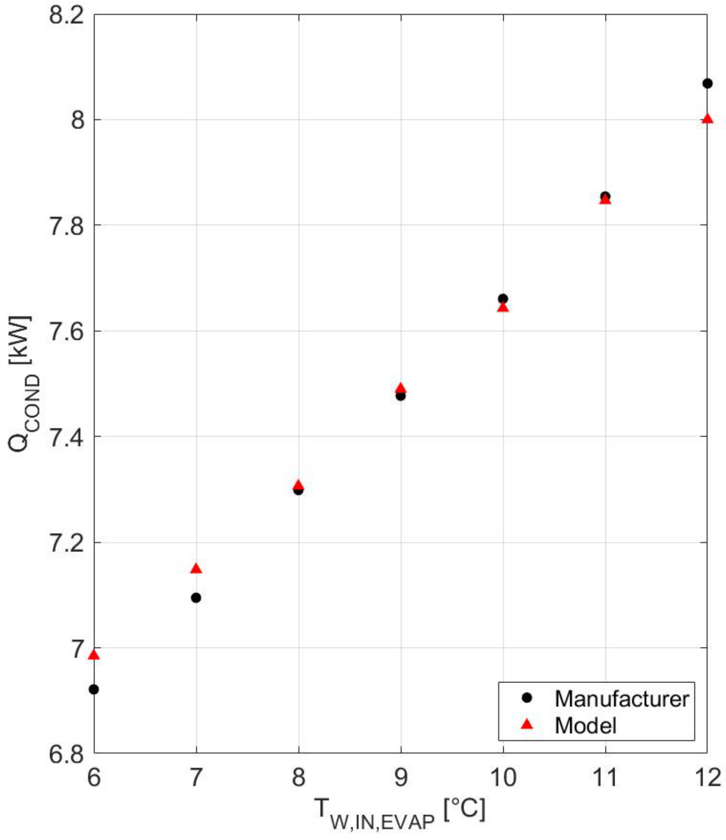
Methods – Heat pump modelling (3/3)

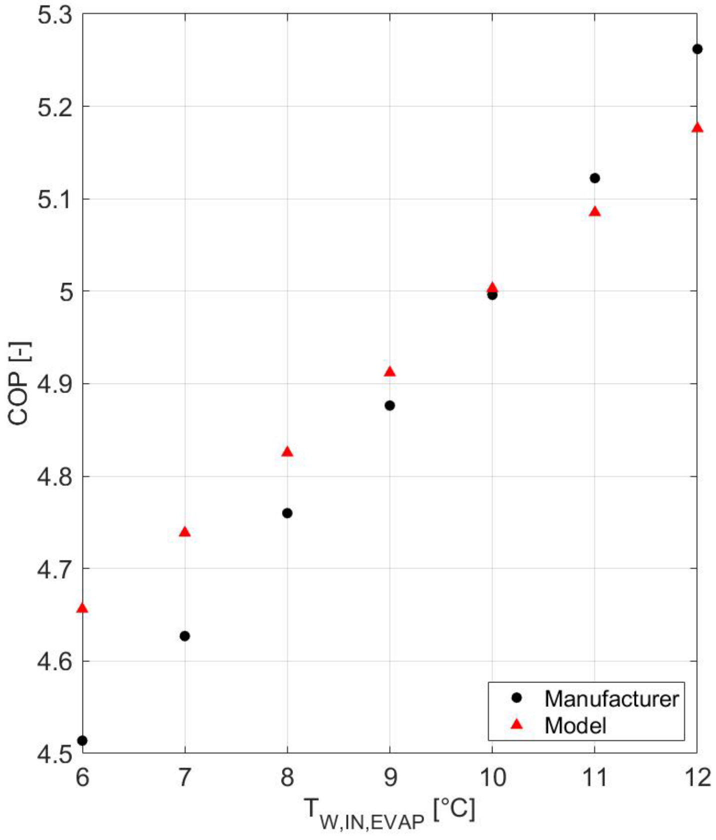


- Fin-and-tube heat exchanger → 3D elemental volume approach with ε-NTU method for the calculation of the heat transfer rate.
- Three different operating conditions:
  - Dry mode.
  - Wet mode → McQuinston et al. (2004) model for the convective heat transfer coefficient and the fin efficiency change.
  - Frost mode → Qiao et al. (2017) model for frost formation and accumulation. Defrosting cycle begins when the increase in the air-side pressure drop exceeds a threshold value.

Methods – Heat pump model validation

- Validation against commercially available water-to-water R410A heat pump.





Methods – Building and simulation

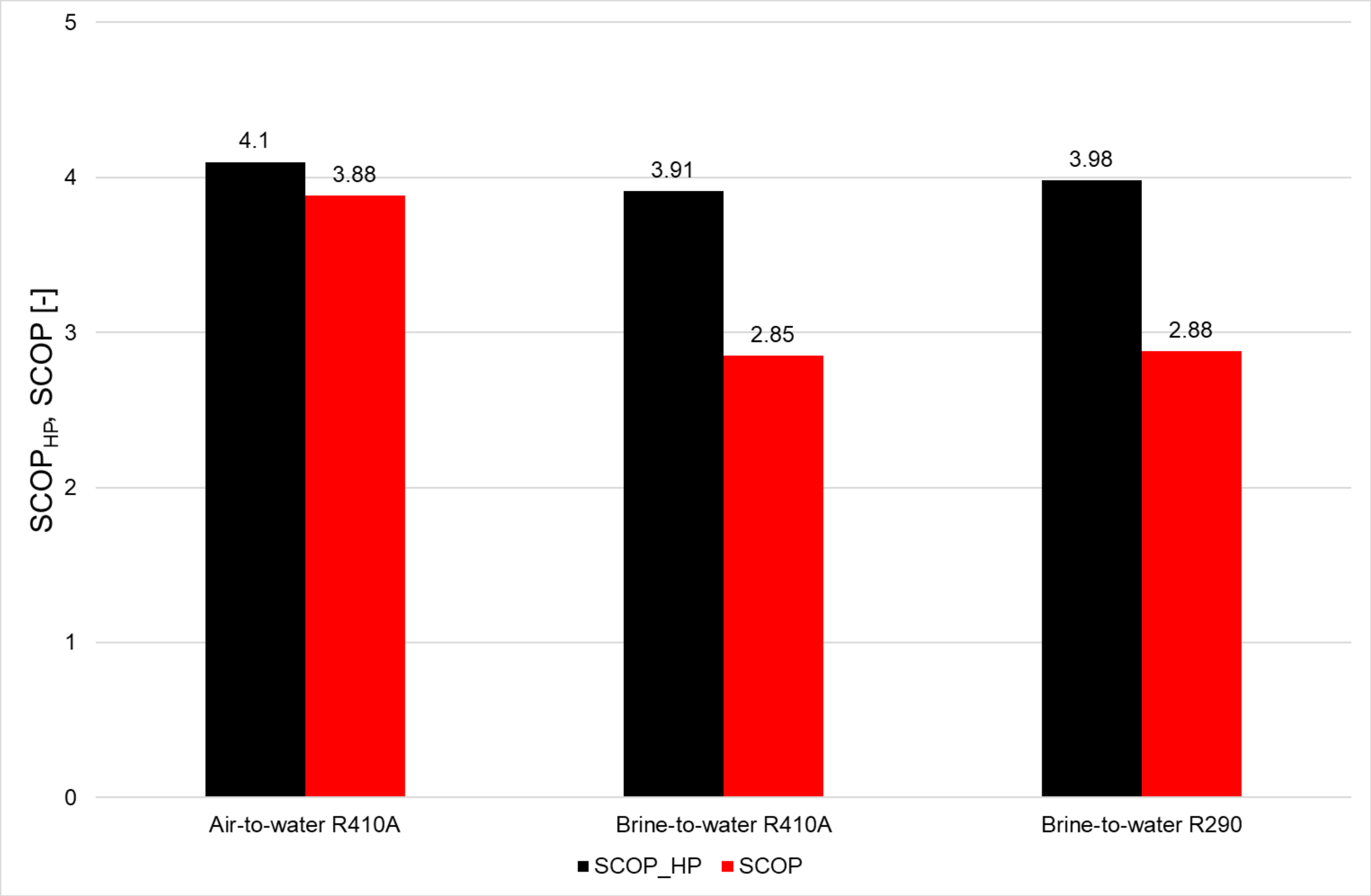
- TRNSYS environment. Single-family house with 2 floors, 70 m^2 each. Radiant floor is the emitting system. DHW not considered for simplicity.
- Maximum heating load Q_{BLD} = 6340 W @ T_{AIR} = -12 °C. Duration of heating season = 2822 h. Nominal capacity of the heat pump Q_{HP} = 7000 W (oversizing ≈ 10%).
- Sequence of steady-state operating conditions. Time step Δt = 3600 s in normal operation, Δt = 300 s if frost formation occurs.

Results – Charge

System	Charge
Air-to-water R410A	3561 g
Brine-to-water R410A	899 g
Brine-to-water R290	467 g

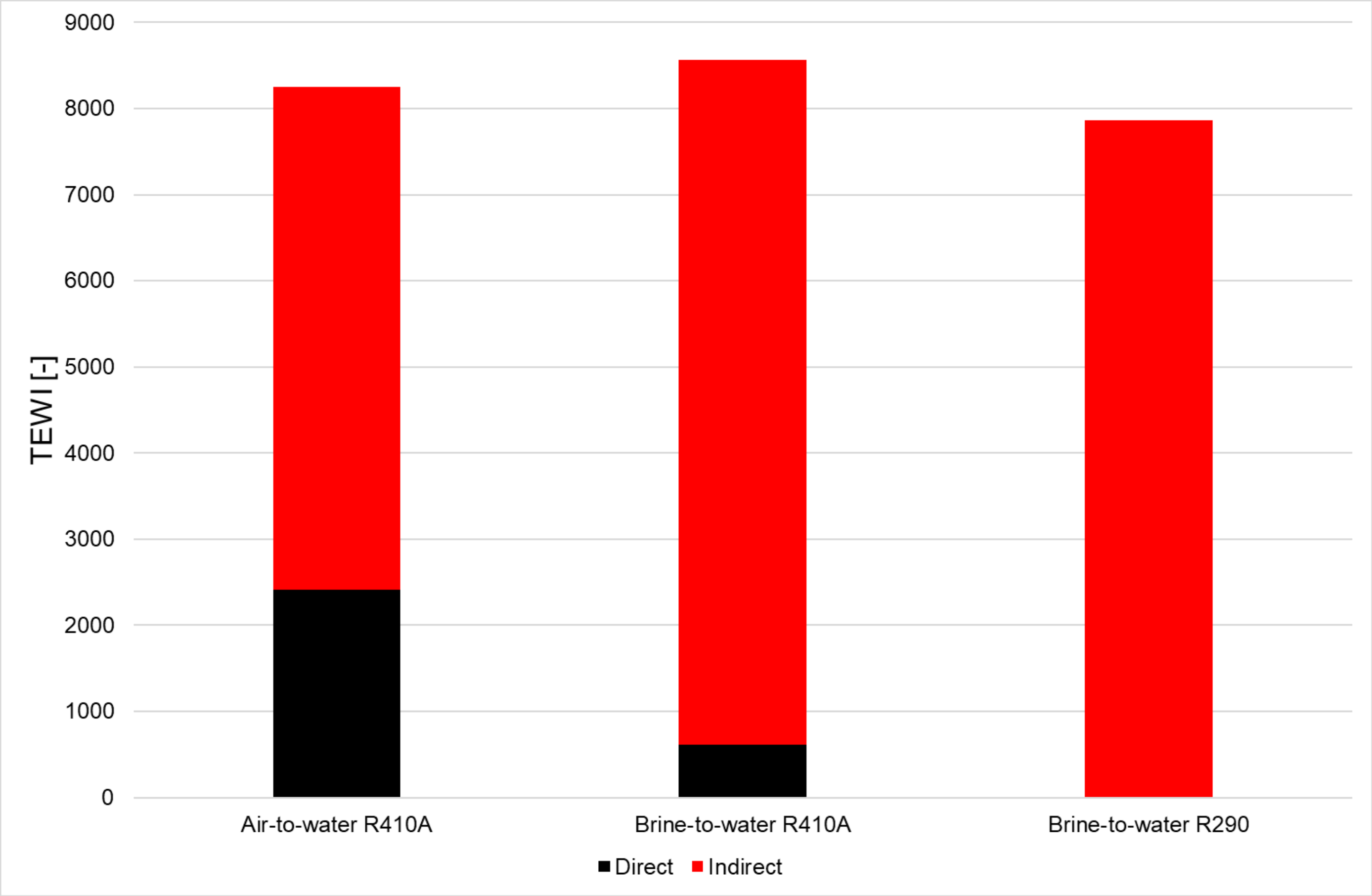
- Indirect system shows a lower charge since the fin-and-tube evaporator is replaced with plate heat exchanger.
- R290 heat pump benefits from a lower density refrigerant.

Results – $SCOP_{HP}$ and SCOP



- Very similar $SCOP_{HP}$.
- In indirect systems, R290-based heat pump performs slightly better than the R410A-based.
- Significant drop in SCOP of the indirect systems due to the consumption of the auxiliaries.

Results – TEWI



- The lower charge of indirect systems leads to a lower direct impact.
- Conversely, indirect systems suffer from an increased consumption of the auxiliaries.
- Despite its lower energy performance, the system using R290 largely benefits from the low-GWP of this refrigerant.

Conclusions

In the present study, the performance of an indirect expansion heat pump working with R290 is compared with that of R410A heat pumping systems. We found that:

- SCOP of the indirect systems are around 25% lower than that of the direct system, mainly because of the consumption of the auxiliaries.
- Indirect systems significantly reduce the charge (R410A: -75%, R290: -87%).
- TEWI is positively affected by the charge reduction, but negatively affected by the increase in the consumption of the auxiliaries (R410A: +4%). Despite this, R290 outperforms fluorinated refrigerant R410A (R290: -5%).

Future work

- Include R290 air-to-water heat pump (and R32 units).
- Add DHW production.
- Optimize the control of the auxiliaries in indirect systems.

THANK YOU FOR YOUR KIND ATTENTION!