Experimental Validation of a Heat Pump Model for B-Segment Electric Vehicles at Component Level

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Context

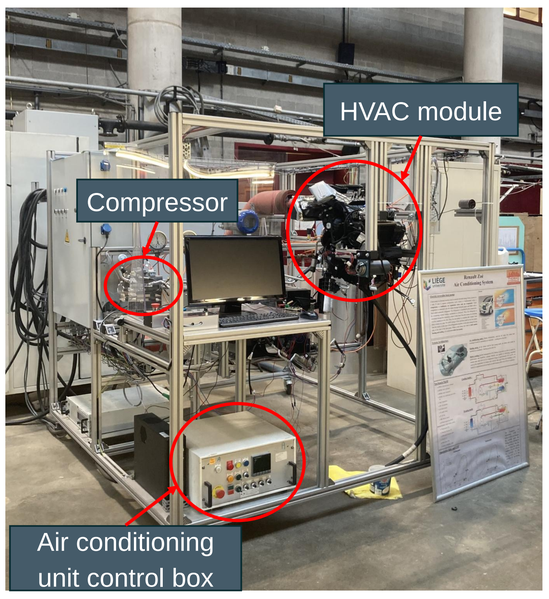
- **Domestic transportation** remains the **largest source of GHG emissions** in the EU, highlighting the need for further decarbonization [1]
- **Electric vehicles** (EVs) **deployment** is accelerating as part of Europe's energy transition towards **low-carbon solutions**, while land transport offers a strong potential for rapid transformation due to its **shorter operational lifetime** compared with other energy systems [2]
- **Thermal management** is a **key challenge** in EVs, impacting driving range, efficiency, and component lifetime [3]
- **Air conditioning** significantly affects **EV autonomy**, making efficient HVAC systems essential [4]
- **Reversible heat pumps** provide both heating and cooling with **higher efficiency** than conventional resistive heating systems

Dual objective

Research
- Develop component-level models of an EV reversible heat pump
- Develop validated models enabling the identification of system operating limits

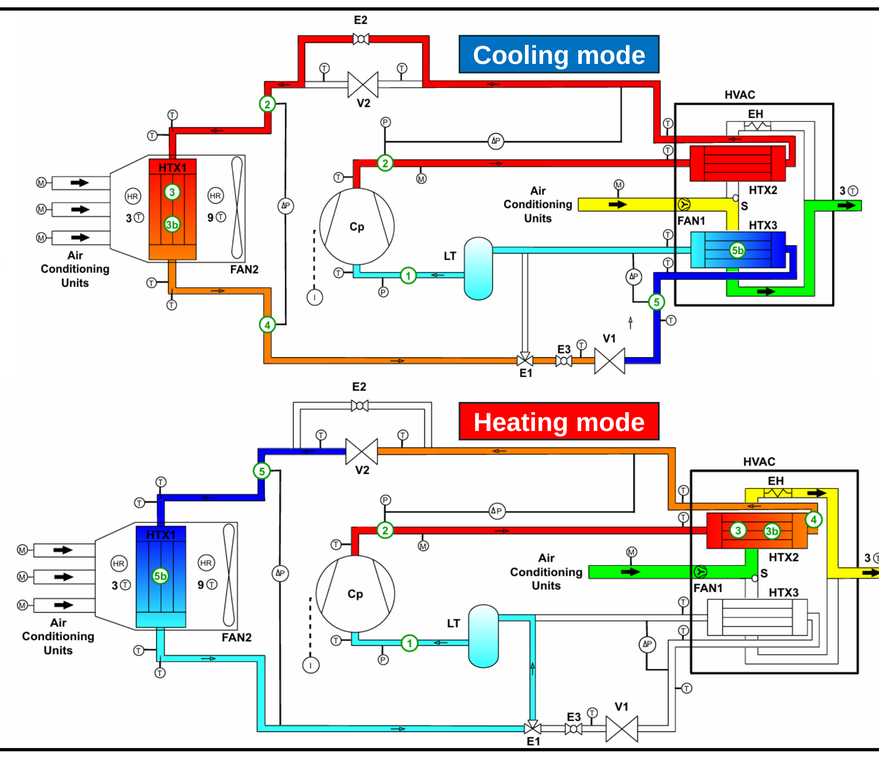
Education
- Implement a Project-Based Learning framework for thermal systems education
- Provide interactive laboratory sessions promoting active and hands-on learning

Test bench description



Key features:
- Air-to-air reversible heat pump
- B-segment EV heat pump components (except compressor)
- Refrigerant: **R1234yf**
- Scroll compressor
- 3 heat exchangers
  → 2 internal (HTX2-3)
  → 1 external (HTX1)

Controlled parameters:
- Compressor speed
- Outdoor air temperature
- Airflow rates (through HTX1 and HVAC module)

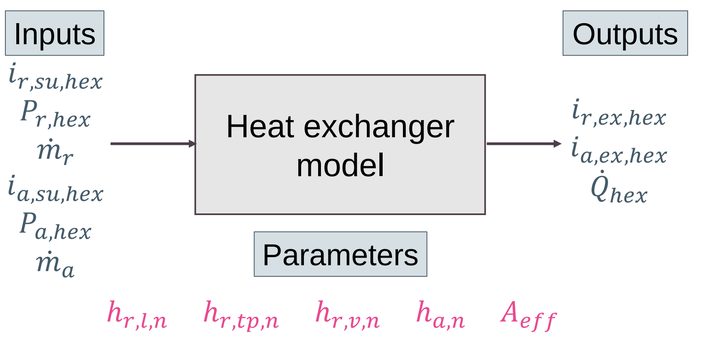


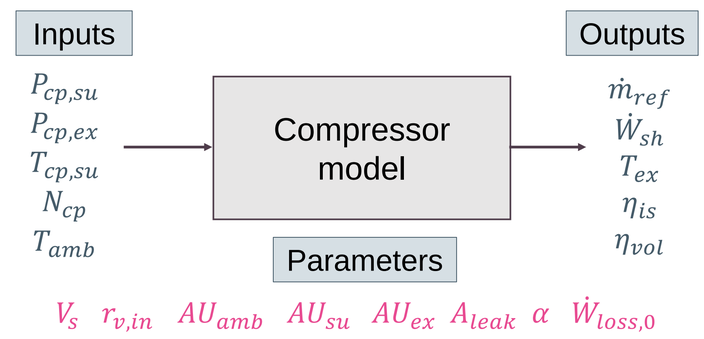
Components:
COMP = **Comp**ressor
EXP = **Exp**ander
HX = **H**eat **E**xchanger
EV = **E**xpansion **V**alve
LR = **L**iquid **R**eceiver
PP1 = Refrigerant **P**um**p**
PP2/**PP**3 = Water **P**um**p**

Sensors:
T = Temperature
P = Pressure
M = Flowmeter
W = Wattmeter

Methodology and Modelling

Experimental measurements → Component-level models → Parameters calibration → Models Validation

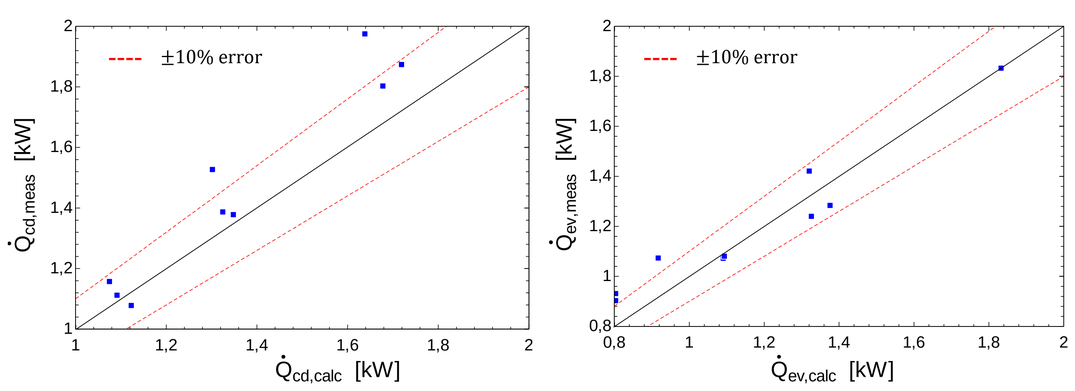




- **Heat exchangers**: three-zone **moving-boundary** approach
- **Compressor**: **semi-empirical** approach
- Model complexity reduced to enable student implementation during laboratory sessions
- Model parameters identified by minimizing the deviation between simulations and experimental measurements

Results

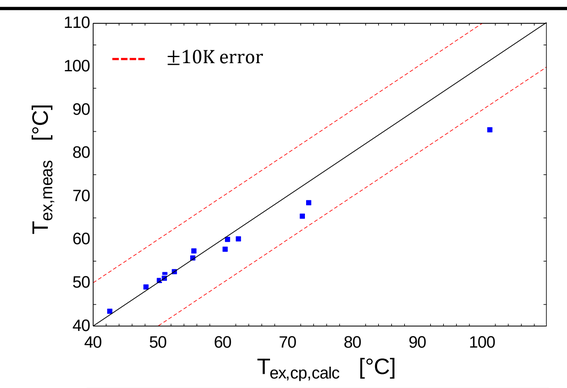
Heat exchanger model

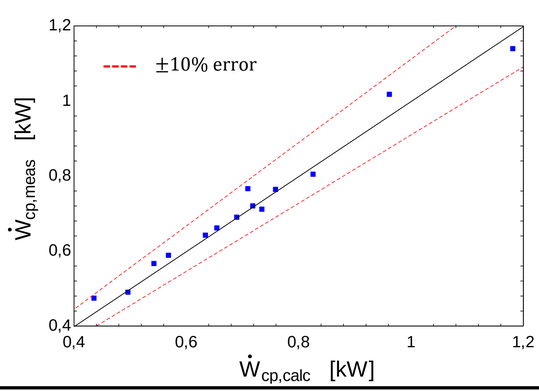


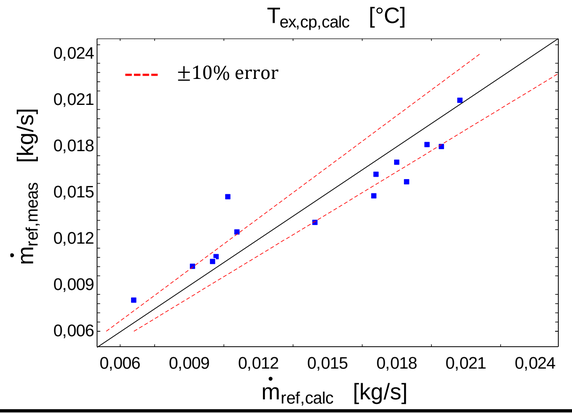
- Overall heat transfer trends correctly reproduced
- Slight underestimation:
  → Condenser (HTX2): high thermal loads
  → Evaporator (HTX1): low thermal loads
- ✓ Most points within ±10% deviation

Compressor model

- Compressor power and discharge temperature accurately predicted
- Refrigerant mass flow rate shows larger deviations

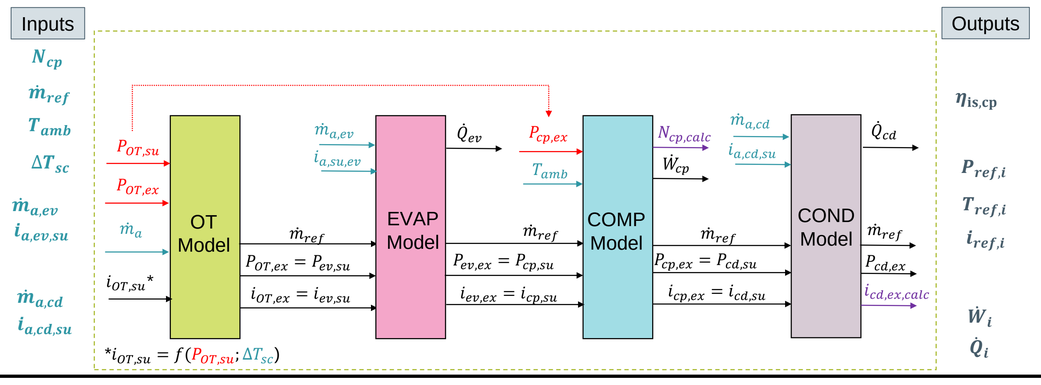






Future work

- Integration of validated component models into a complete EV heat pump system model
- Python implementation using LaboThApPy [5] for full-cycle simulations and educational applications



Conclusion

- ✓ Component-level models successfully developed and calibrated
- ✓ Experimental validation confirms the ability of models to reproduce system trends
- ✓ Project-Based Learning approach links thermal-system theory with real experimental applications

References

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[2] S. Kalweit, E. Zeyen, and M. Victoria, 'Endogenous transformation of land transport in Europe for different climate targets', Energy Convers. Manag., vol. 344, p. 120203, Nov. 2025, doi: 10.1016/j.enconman.2025.120203.

[3] M. Kılıç and M. Ö. Korukçu, 'The Effect of Energy Management in Heating–Cooling Systems of Electric Vehicles on Charging and Range', Appl. Sci., vol. 14, no. 15, p. 6406, Jan. 2024, doi: 10.3390/app14156406.

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