POLITECNICO MILANO 1863

R&D activities @ HVAC Research Group – Politecnico di Milano

Stefano De Antonellis, Chiara D'Ignazi, Wiliam Ferretto, Luca Marocco, Luca Molinaroli, Rebecca Verlingieri

Pisa, 17TH November 2026

Outline

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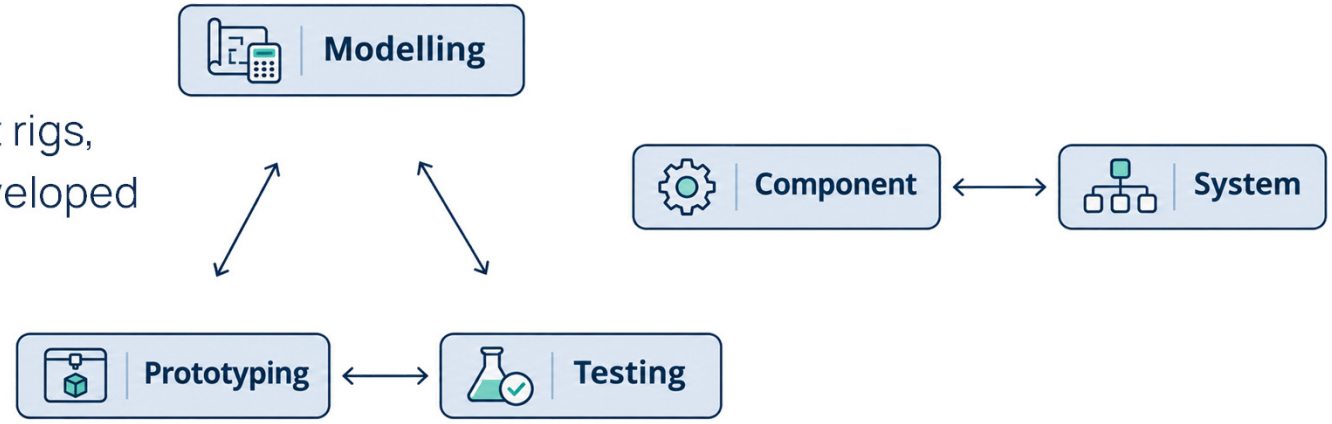
HVAC research group @ PoliMI consists of 5 permanent staff, 1 lab technician, 3 post-docs and 3 PhD students.

Activities are carried out both experimentally, in dedicated test rigs, or numerically, with in-house developed code as well as commercially available CFD tools.



The research activities we are currently carrying out deal with:

1. Carbon dioxide + hydrocarbons mixtures as working fluids for next generation heat pumps
2. Fault Detection and Diagnosis (FDD) techniques for heat pumps
3. Triply Periodic Minimal Surfaces as next generation heat exchanger in heat pumping systems
4. Heat pumping systems for Battery Electric Vehicles (BEV).

Outline

1. **R744+Hydrocarbons mixtures**



Motivation

➢ Regulation (EU F-gas: HFC phase-out by 2050; PFAS restriction on HFOs) is pushing heat pumps towards natural refrigerants.

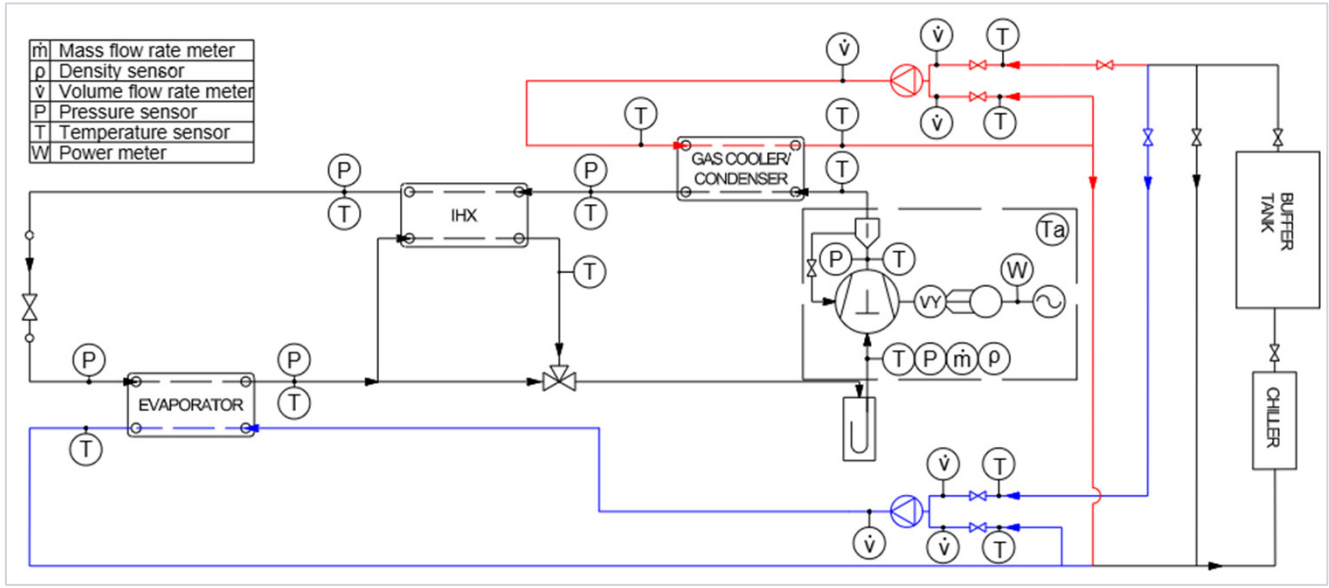
Refrigerants	Pros	Cons
CO_2 (R744)	Natural refrigerant, low GWP Non-flammable	Low critical temperature (30.98 °C) High pressures
Hydrocarbons (R290, R600a)	Natural refrigerant, low GWP High efficiency High economic viability	High flammability
CO_2/HC blends	Lower gas-cooler pressure than pure CO_2 Reduced fire-safety risk vs. pure HCs Zeotropic behaviour: temperature glide	Composition shift in case of leakage Residual flammability

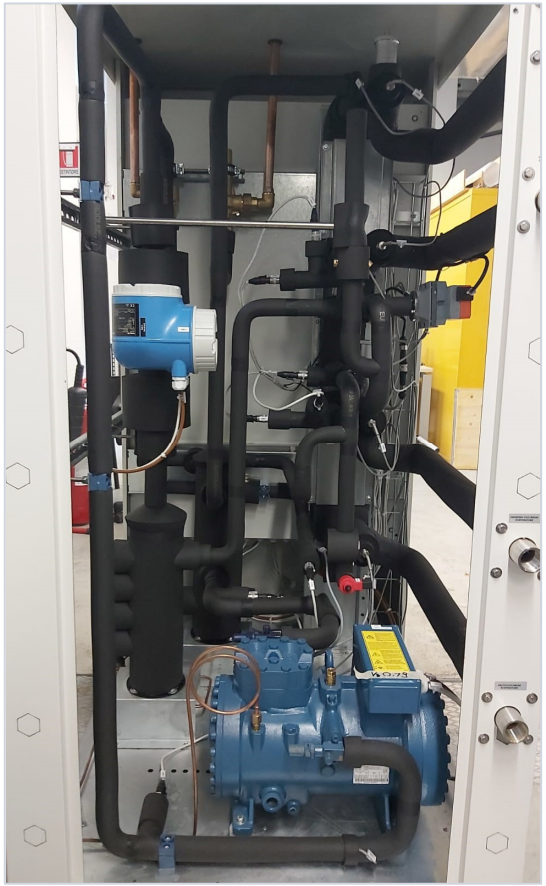
Outline

1. **R744+Hydrocarbons mixtures**



Experimental test rig





- Water-to-water heat pump with a variable-speed semi-hermetic reciprocating compressor (1.89 m³/h @ 50 Hz).
- Brazed plate gas cooler, evaporator and internal heat exchanger (bypassable). Back-pressure EXV sets the gas-cooler pressure in transcritical mode or the superheating in subcritical mode.
- Operating range: max heating capacity: 7 kW; cold side: 5 °C - +35 °C; hot side: range +30 °C - +90 °C.

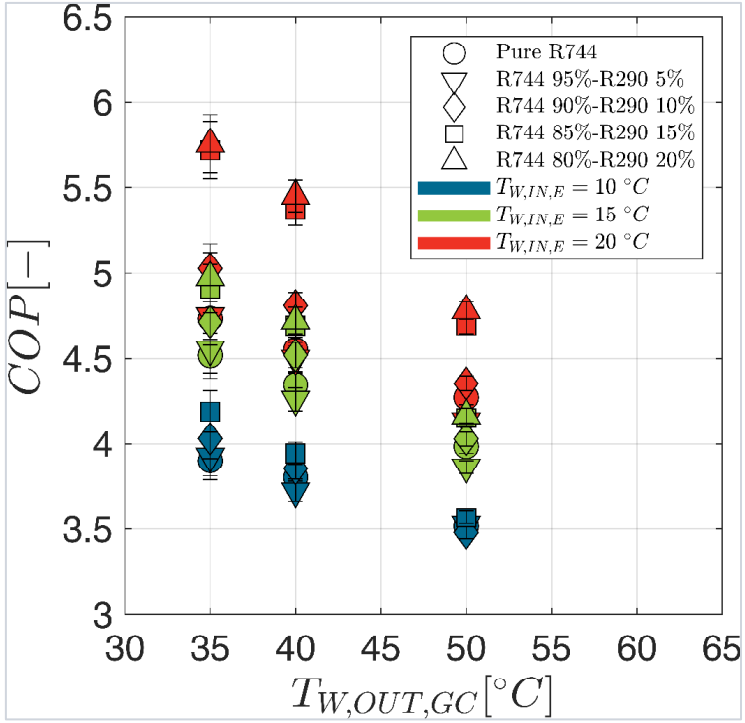
Outline

1. **R744+Hydrocarbons mixtures**



Experimental results

- Steady-state tests at 40 Hz, with the gas-cooler pressure optimised for each condition
- R744/R290 tested in space heating, DHW and industrial conditions.
- Gains from glide matching and subcritical operation, at the cost of heating capacity.



+22%

Max COP gain, space heating ($T_{W,GC}$: 30→35 °C)

+11.8%

Max COP gain, domestic hot water ($T_{W,GC}$: 10→70 °C)

+15%

Max COP gain, industrial conditions ($T_{W,GC}$: 60→80 °C)

-26%

Heating capacity, space heating

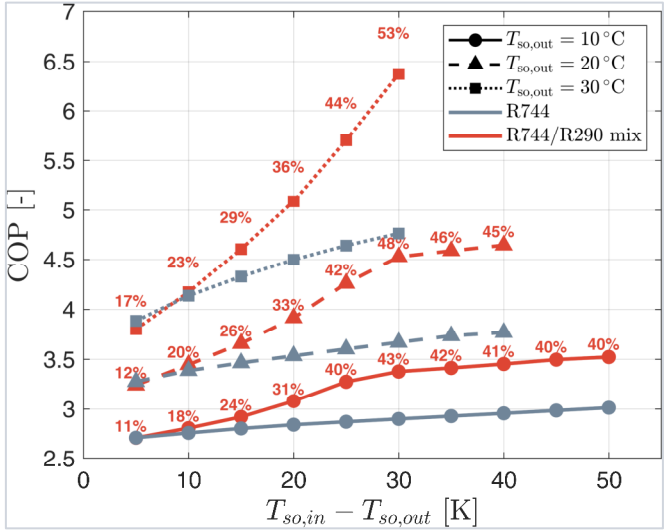
Outline

1. **R744+Hydrocarbons mixtures**

Modelling and case study

Cycle optimisation	Heat-exchanger models	Sizing and charge
Composition and cycle parameters that maximise the COP (Python + REFPROP)	ε-NTU models, validated on test-rig data **MARD gas cooler: 1.3%** **MARD evaporator: 2.6%**	Heat-exchanger areas and refrigerant charge for each optimal cycle

Case study: 250 kW industrial heat pump, sink 30→90 °C, source T_{OUT} = 10, 20, 30 °C with ΔT 5-50 K



Labels: optimal R290 share of the mixture

+34% Max COP gain vs pure R744 ($T_{SO,OUT}$ = 30 °C, ΔT = 30 K)

-50 bar Gas cooler pressure vs pure R744

+258% Max evaporator area increase; total charge comparable or lower at high ΔT



Outline

1. R744+Hydrocarbons mixtures
2. **Fault Detection and Diagnosis**

Motivation

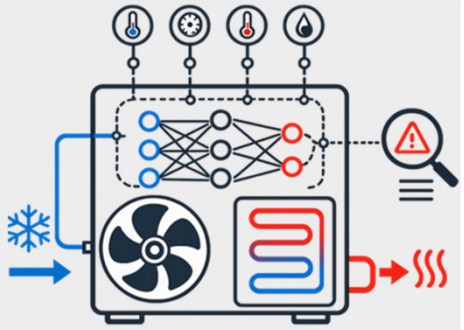
- Decarbonization of the heating sector relies on a massive deployment of heat pumps as a substitute for fossil fuel boilers.
- Compared to boilers, heat pumps can guarantee significant energy and emissions savings. However, being more complex, they are more prone to failure.
- Consequently, Fault Detection and Diagnosis (FDD) techniques are of paramount importance to guarantee the correct and safe operation of heat pumps during the whole lifetime.

Objective of the research activity

- Develop and validate a FDD tool based on Artificial Neural Networks (ANNs) to detect and diagnose some soft faults in water-to-water heat pumps.

- Soft fault (Breuker and Braun, 1998): failure that causes a degradation in performance but allows the system to continue operating. It leads to a reduction in energy performance, loss of comfort or premature failure of components. Difficult to detect and diagnose.

  (Hard fault: failure that occurs abruptly and typically forces the system to stop functioning. Easy to detect and diagnose).



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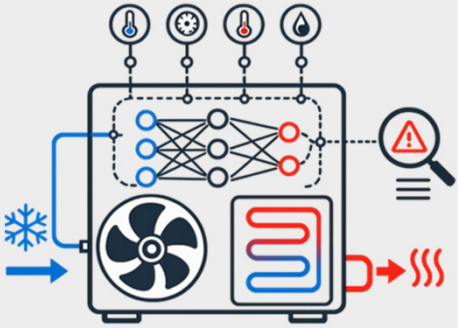
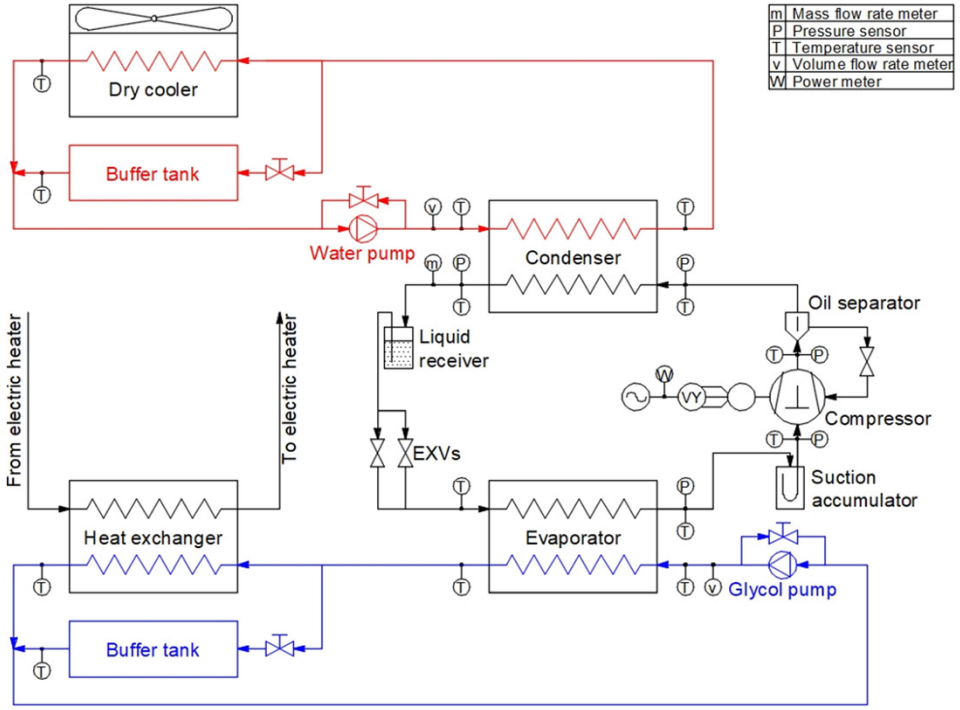
1. R744+Hydrocarbons mixtures
2. **Fault Detection and Diagnosis**



Experimental test rig





- Water-to-water heat pump with a variable-speed semi-hermetic reciprocating compressor (13.15 m³/h @ 50 Hz).
- Brazed plate condenser and evaporator. EXV sets the superheating at evaporator outlet.
- Operating range: max heating capacity: 10 kW; cold side: -10 °C - +25 °C (water+ethylene glycol (25.4%); hot side: range +30 °C - +80 °C.

Outline

1. R744+Hydrocarbons mixtures
2. **Fault Detection and Diagnosis**

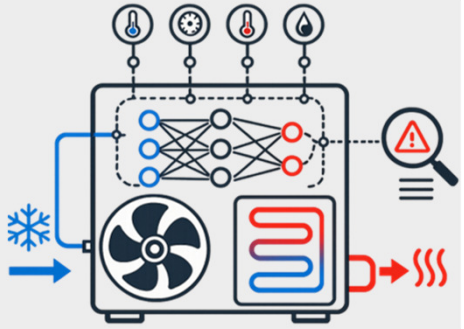
Method – Simulated faults

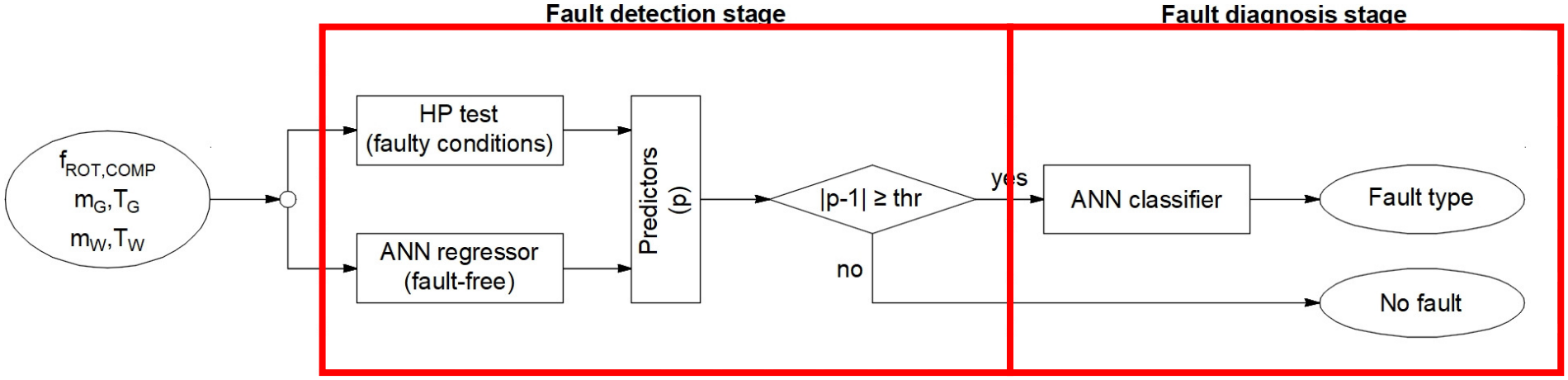
Faults that can be analysed with the experimental setup (in a safe way):

- Refrigerant undercharge or overcharge. Non-condensable gas.
- Expansion valve incorrect opening or blockage.
- Sensors' loss of precision
- Evaporator and/or condenser fouling (secondary fluid side).

Method – FDD tool

- 2-stages tool (Fault Detection stage + Fault Diagnosis stage) based on ANNs.
- Compressor rotational frequency + heat sink and heat source signals as input of the tool, refrigerant p and T as internal feature.





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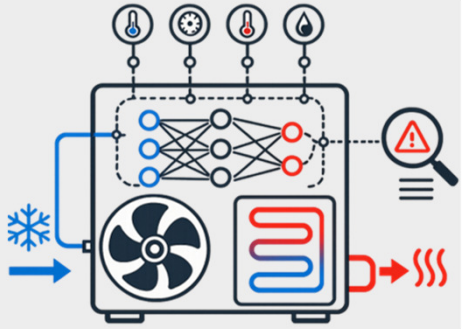
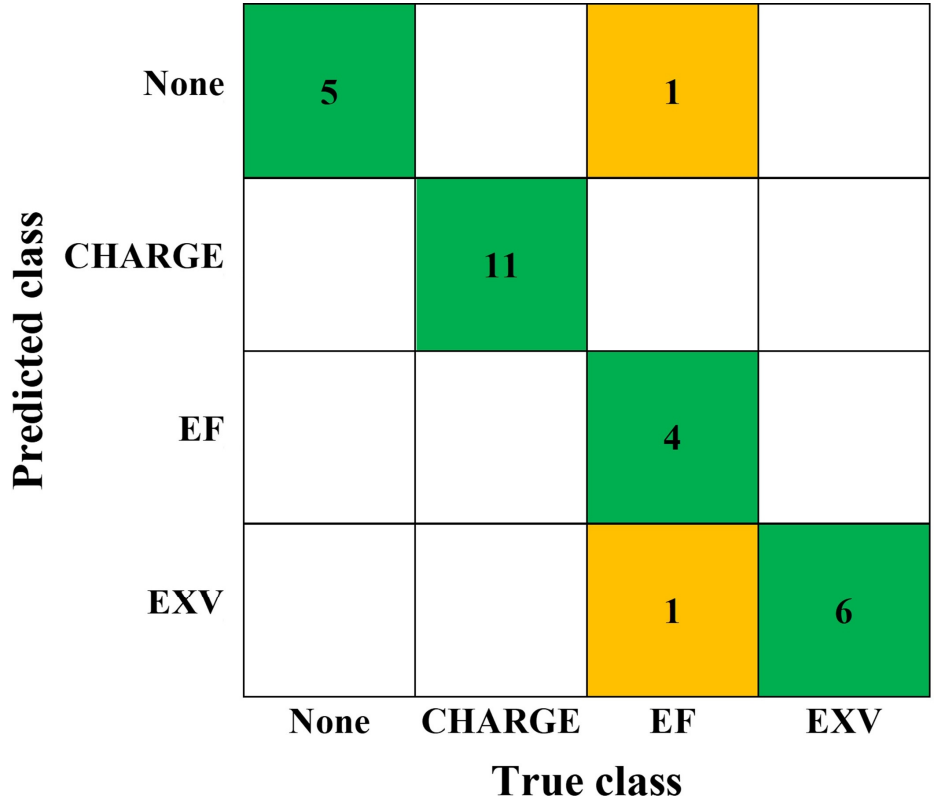
1. R744+Hydrocarbons mixtures
2. **Fault Detection and Diagnosis**



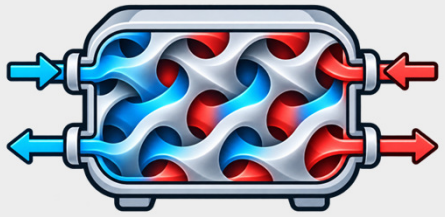
Results

- Only single soft faults analysed so far. Soft faults considered: evaporator fouling (EF), expansion valve blockage (EXV) and refrigerant undercharge/overcharge (CHARGE).
- Confusion matrix on the 28 (5 fault free + 23 faulty) testing conditions: 26 (out of 28) conditions correctly diagnosed, 2 EF misinterpreted as fault-free or EXV.
- Overall, 96% accuracy in fault detection and 93% accuracy in fault diagnosis.



Outline

1. R744+Hydrocarbons mixtures
2. Fault Detection and Diagnosis
3. **Triply Periodic Minimal Surfaces**

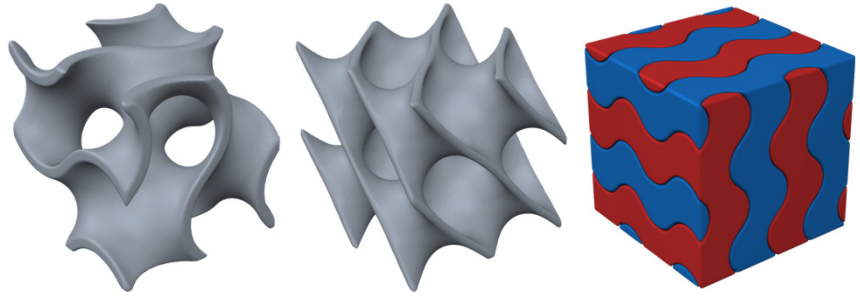


Motivation

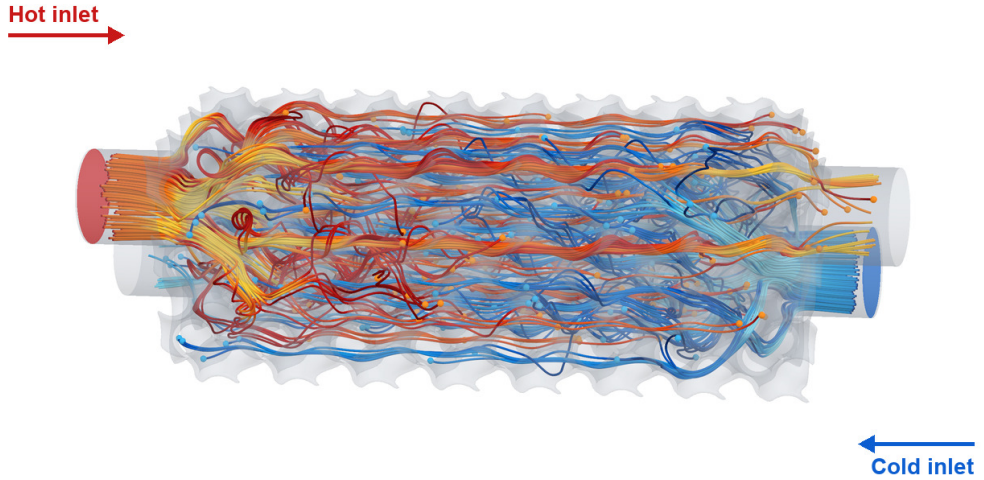
- Reduction in $\Delta T_{APPROACH}$ and refrigerant charge held in heat exchanger is beneficial for heat pump performance and capacity.

Objective of the research activity

- Triply Periodic Minimal Surfaces (TPMS) are 3D-printed lattices that keep two fluids separate, offering high surface-to-volume ratio and strong mixing: a route to compact heat exchangers.
- We are currently investigating their use in power production applications but we want to extend it to heat pumping application is on-going.



Gyroid cell | Diamond cell | Two fluid domains



OpenFOAM streamlines from the inlets, coloured by velocity

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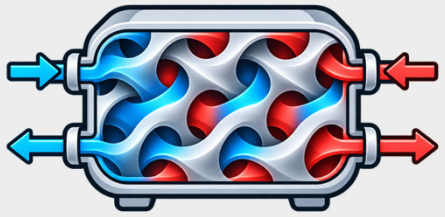
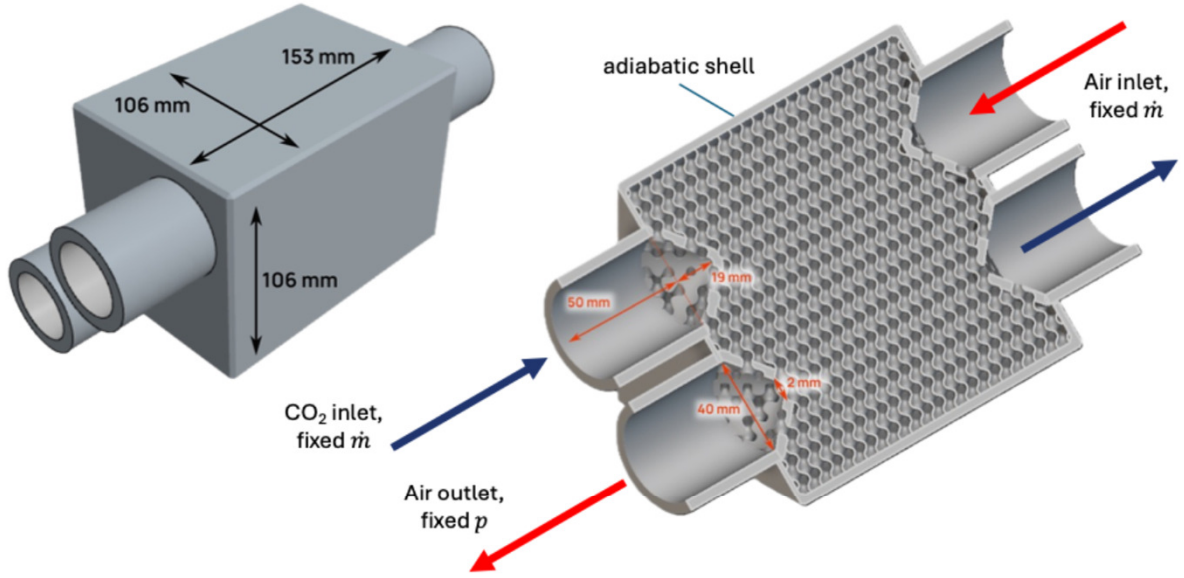
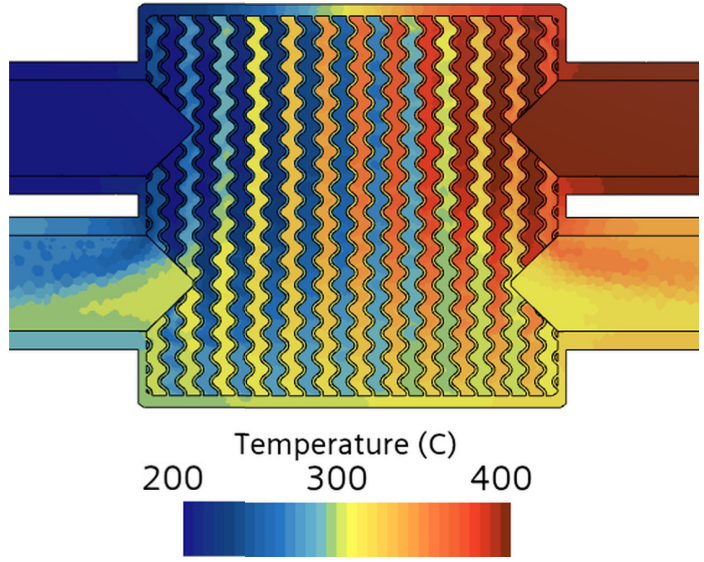
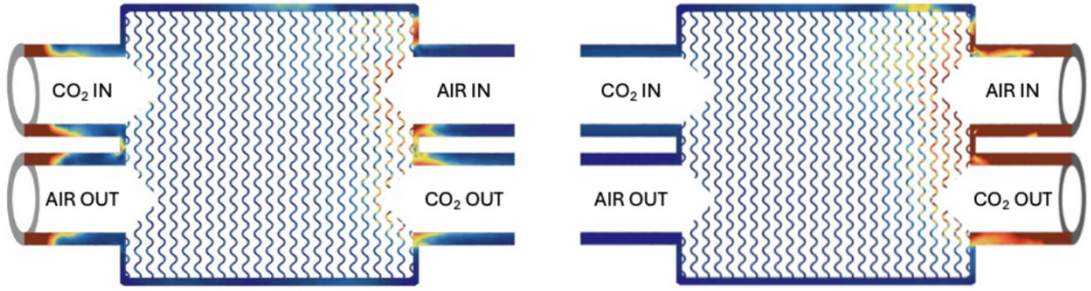


Method - Modelling with CFD

- CFD of TPMS heat exchangers, from periodic cell arrays to the complete component.
- Thermo-mechanical analyses based on the CFD temperature field, to assess stress.







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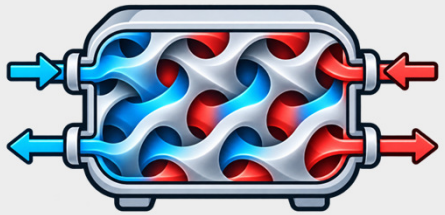
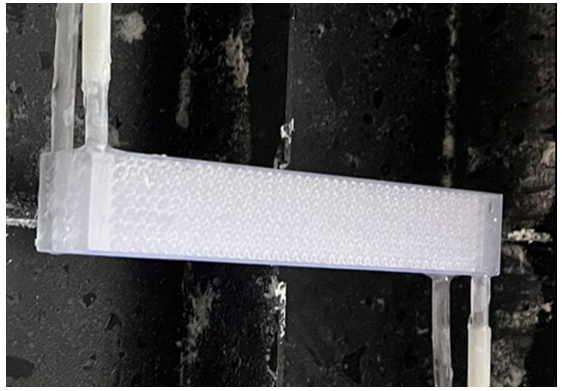


Method - In-house 3D printing and experimental analysis

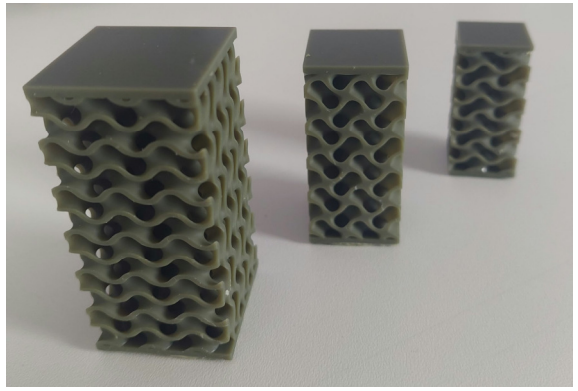
➢ TPMS heat exchangers are typically first printed in-house to explore how well the performances of different TPMS geometries are predicted by CFD (polymer heat exchanger).



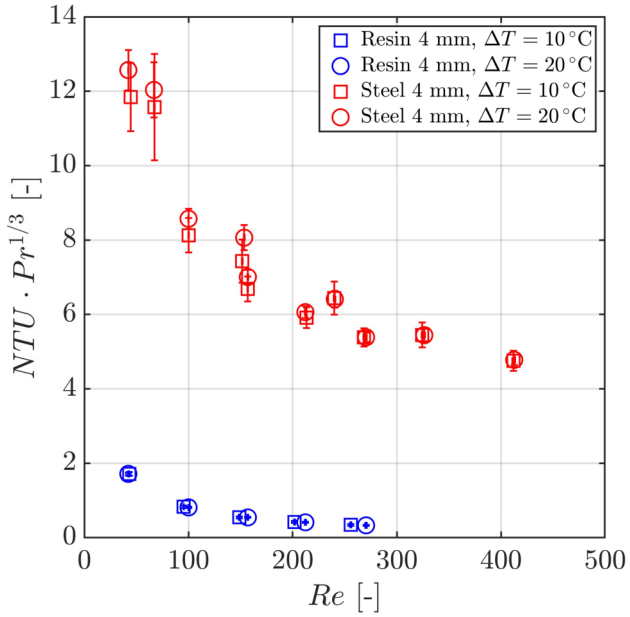
Transparent resin printing



Resin TPMS heat exchanger



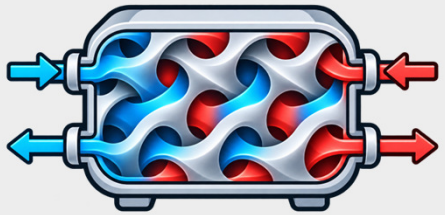
Printed TPMS samples



Stainless steel vs. resin

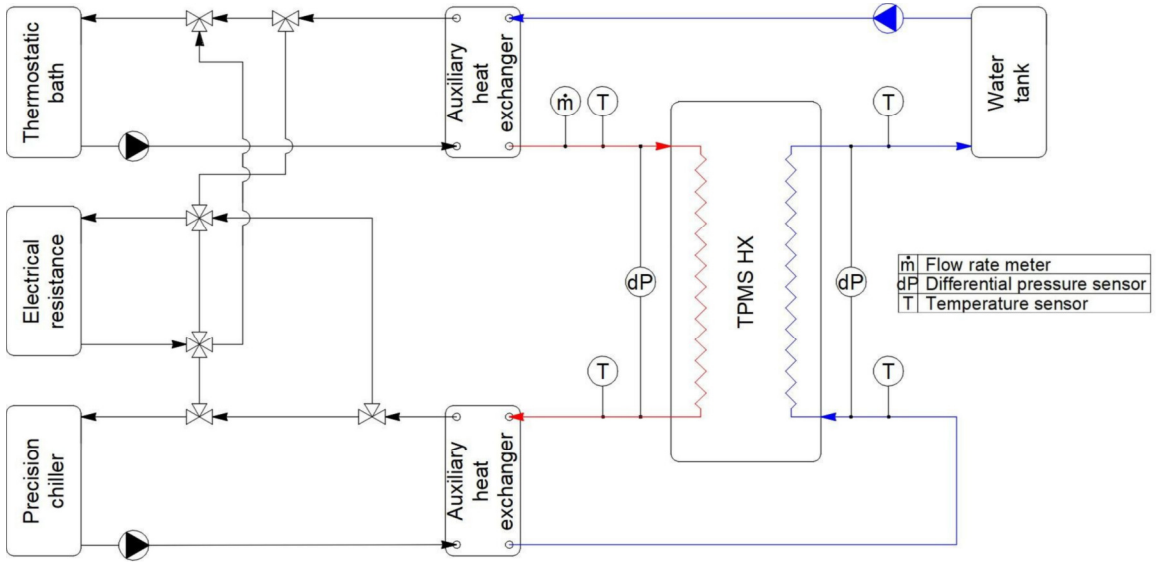
Outline

1. R744+Hydrocarbons mixtures
2. Fault Detection and Diagnosis
3. **Triply Periodic Minimal Surfaces**

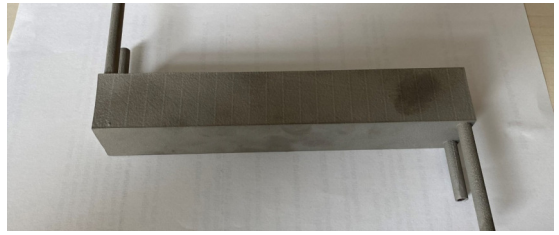


Method - Experimental activity on final sample

- Dedicated test bench to assess the thermal and hydraulic performance of a 3D-printed AISI 316L TPMS heat exchanger.
- Benchmark against a brazed plate heat exchanger for the same heat load: the TPMS is much more compact, at the cost of a higher pressure drop.



Test bench



AISI 316L TPMS



Brazed plate

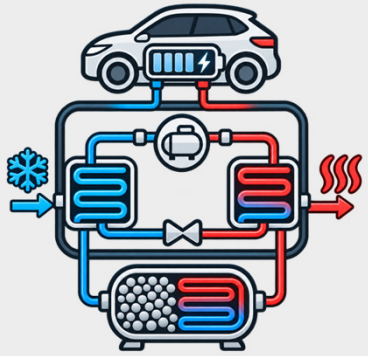
TPMS vs. plate	Difference
Total volume	–42%
Specific area	+56%
Weight	+16%
Pressure drop	up to +279%

Outline

1. R744+Hydrocarbons mixtures
2. Fault Detection and Diagnosis
3. Triply Periodic Minimal Surfaces
4. **Battery Electric Vehicles**

Motivation

- Battery Electric Vehicles (BEV) experience a significant drop in the driving range under extreme weather conditions.
- PTC heater are largely used for cabin heating.



EVEREST Project: Energy-efficient VEhicle Range Enhancement through Smart Thermal design and user-centric solutions

- Road Battery Electric Vehicles (BEV) optimised user-centric solutions for energy efficiency design and consistent range throughout weather conditions (2ZERO Partnership)
- Topic identifier: HORIZON-CL5-2025-04-D5-05
- Objectives:
  - Develop and demonstrate **innovative, user-centric, and cost-effective thermal and energy management solutions** for **battery-electric LDVs** and **LCVs**
  - Maintain **driving range under extreme weather conditions** ensuring personalized thermal comfort
  - **Reduce** climate-related **range loss by at least 30%** compared to the state of the art
  - **Improve overall energy efficiency by 10%** through intelligent, predictive, and AI-based control strategies.



EVEREST Project: Energy-efficient VEhicle Range Enhancement through Smart Thermal design and user-centric solutions

Project overview

- Technology bricks:
  - **AREA I:** Thermal management technologies
  - **AREA II:** Virtual demonstrators and control strategy
  - **AREA III:** Real-world demonstrators and evaluation

- Heat pump and related technologies:
  - **Innovative CO2-hydrocarbons AC system**
  - **Thermal Energy Storage System**



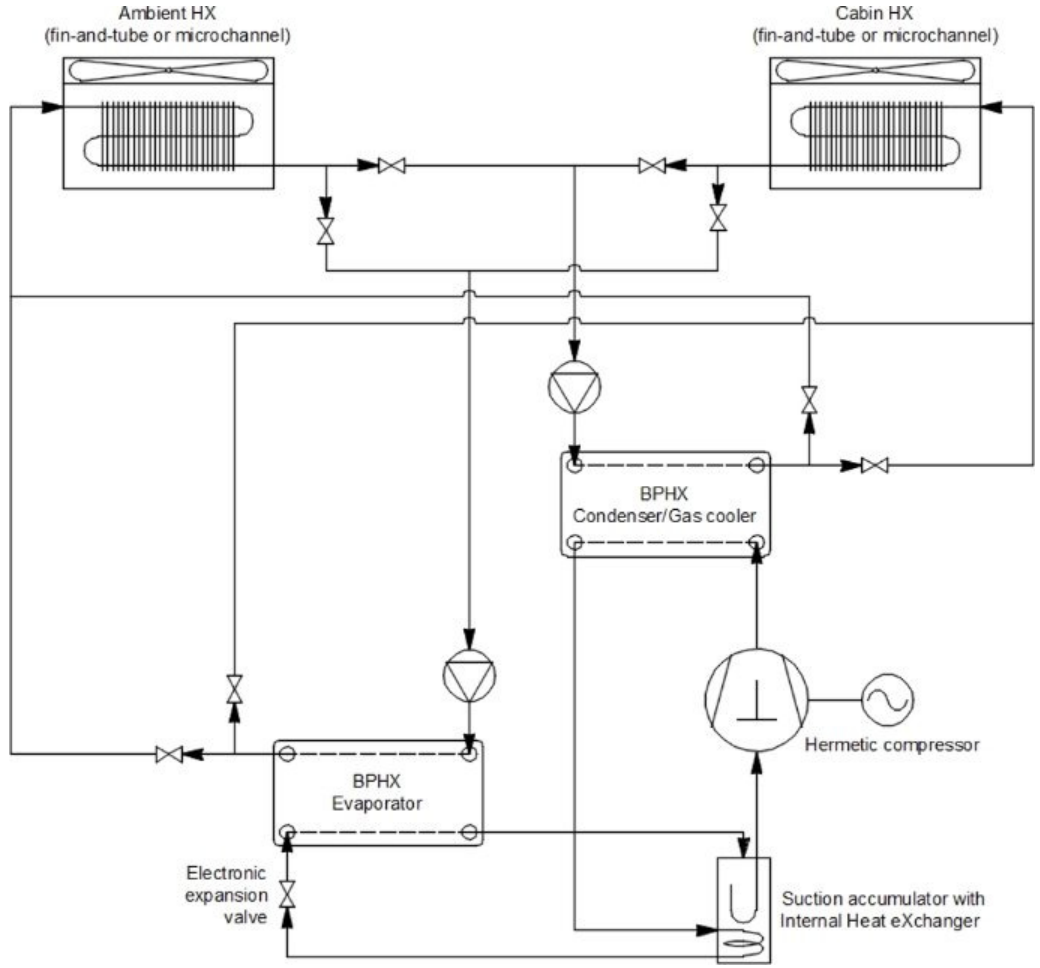
EVEREST Project: Energy-efficient VEhicle Range Enhancement through Smart Thermal design and user-centric solutions

Heat pump and related technologies

Design, prototyping and testing of innovative CO_2-hydrocarbons AC system base on blend of carbon dioxide and hydrocarbons

Key points:

- Vapour compression system (VCS) design and assembly
- Baseline design with pure CO_2 (R744) components, keeping in mind blends peculiarity
- Requirements aligned with vehicle partners
- Detailed AC system testing



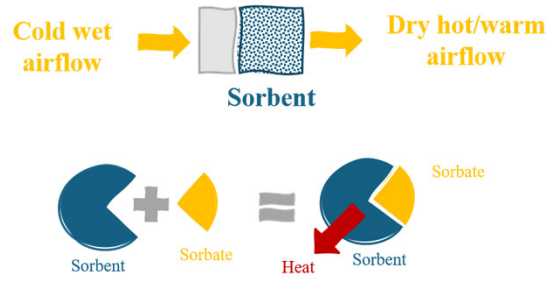
EVEREST Project: Energy-efficient VEhicle Range Enhancement through Smart Thermal design and user-centric solutions

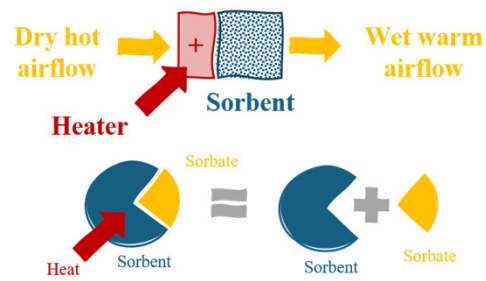
Heat pump and related technologies

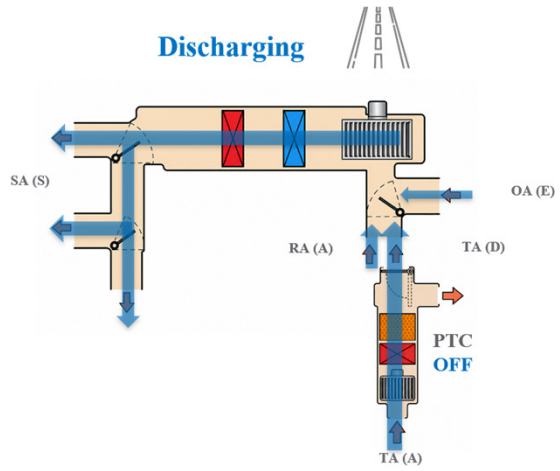
Design, prototyping and testing of innovative sorption based Thermal Energy Storage System (TESS) allowing energy to be stored and provide heating and dehumidification on demand

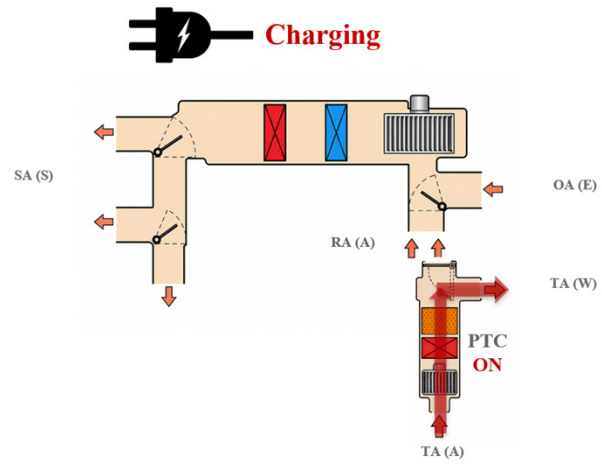
Key points:

- Design of the adsorbent bed, PTC heater, flaps and fan
- Winter operation is the primary design case
- Compatible with the vehicle HVAC architecture
- Detailed AC system testing, integration in mock-up vehicle in in real demonstrators





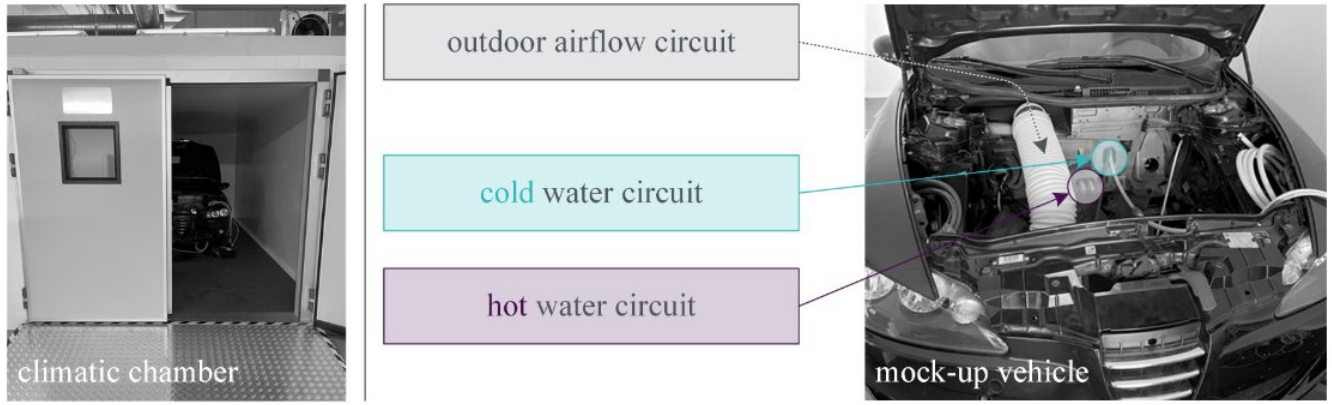




EVEREST Project: Energy-efficient VEhicle Range Enhancement through Smart Thermal design and user-centric solutions

Heat pump and related technologies

- Testing of system and components in dedicated experimental setup and Mock-up Vehicle @ Polimi



- Testing of system and components in real demonstrators @ OEMs facilities



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Thank you for your kind attention!

Luca Molinaroli
Dipartimento di Energia – Politecnico di Milano
Via Raffaele Lambruschini 4/A, 20156, Milano (MI)
+39-02 2399 3872
luca.molinaroli@polimi.it
www.polimi.it