Annex 54
Heat Pump Systems with Low GWP Refrigerants

R&D activities about low-GWP refrigerants in Italy within IEA HPT Annex 54

Sergio Bobbo, Stefano Bortolin, Davide Del Col, Laura Fedele, Luca Molinaroli

Activities of Italian team

- The Italian team consists of 3 different research institutes (National Research Council, Polytechnic of Milano, University of Padova) actively involved in numerous research projects about low-GWP refrigerants.

- On a broad-range basis, the activities carried out by the Italian team are related to:
  - Assessment of refrigerant thermophysical properties.
  - Assessment of performance during flow boiling and/or condensation (heat transfer coefficient and pressure drop).
  - Assessment of energy performance (heating capacity and COP) in drop-in application in lab environment.
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At the **Padua headquarters of the CNR ITC**, the main research activity concerns the study and development of **methods, systems, components and materials** aimed at improving energy and technological performance and the environmental sustainability of products in the **air conditioning and refrigeration sectors.**

Main projects on HPs

- **Horizon 2020 GEO4CIVHIC** - Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
- Bilateral project **CNR-NRF/National Research Foundation of Korea**
- **Horizon Europe ECHO** - Efficient Compact Modular Thermal Energy Storage System

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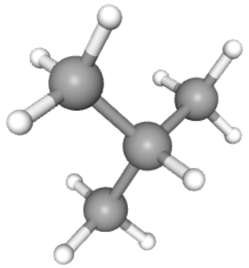
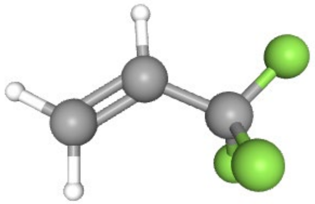
Bilateral project **CNR-NRF/National Research Foundation of Korea**

Experimental evaluation of new low greenhouse effect refrigerants for heat pump applications

The project has the general objective of **identifying** one or more blends of **low GWP refrigerants** as potential substitutes for the current refrigerants, characterized by high GWP, which will have to be abandoned in the next few years. In order to evaluate the energy efficiency of the selected fluid(s), the project involves the execution of **experimental tests** on an instrumented **heat pump**.





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The Department of Industrial Engineering (DII) - University of Padova - participated in Annex 54 activities starting from 2019.
The research activity performed during Annex 54 was part of the Task 2 “Case studies and design guidelines for optimization of components and systems”.

The research activity has been mainly focused on:

- in-tube condensation with low-GWP refrigerants mixtures;
- flow boiling of low-GWP non-azeotropic ternary mixtures;
- experimental and numerical analysis of a CO_2 dual-source heat pump with PVT evaporators for residential heating applications;
- dual source (air/ground) heat pumps.

The activity was performed at the Sustainable Thermal Energy Technologies (STET) research group (prof. Davide Del Col, prof. Stefano Bortolin, dr. Marco Azzolin, dr. Arianna Berto).

Heat transfer measurements with low-GWP mixtures

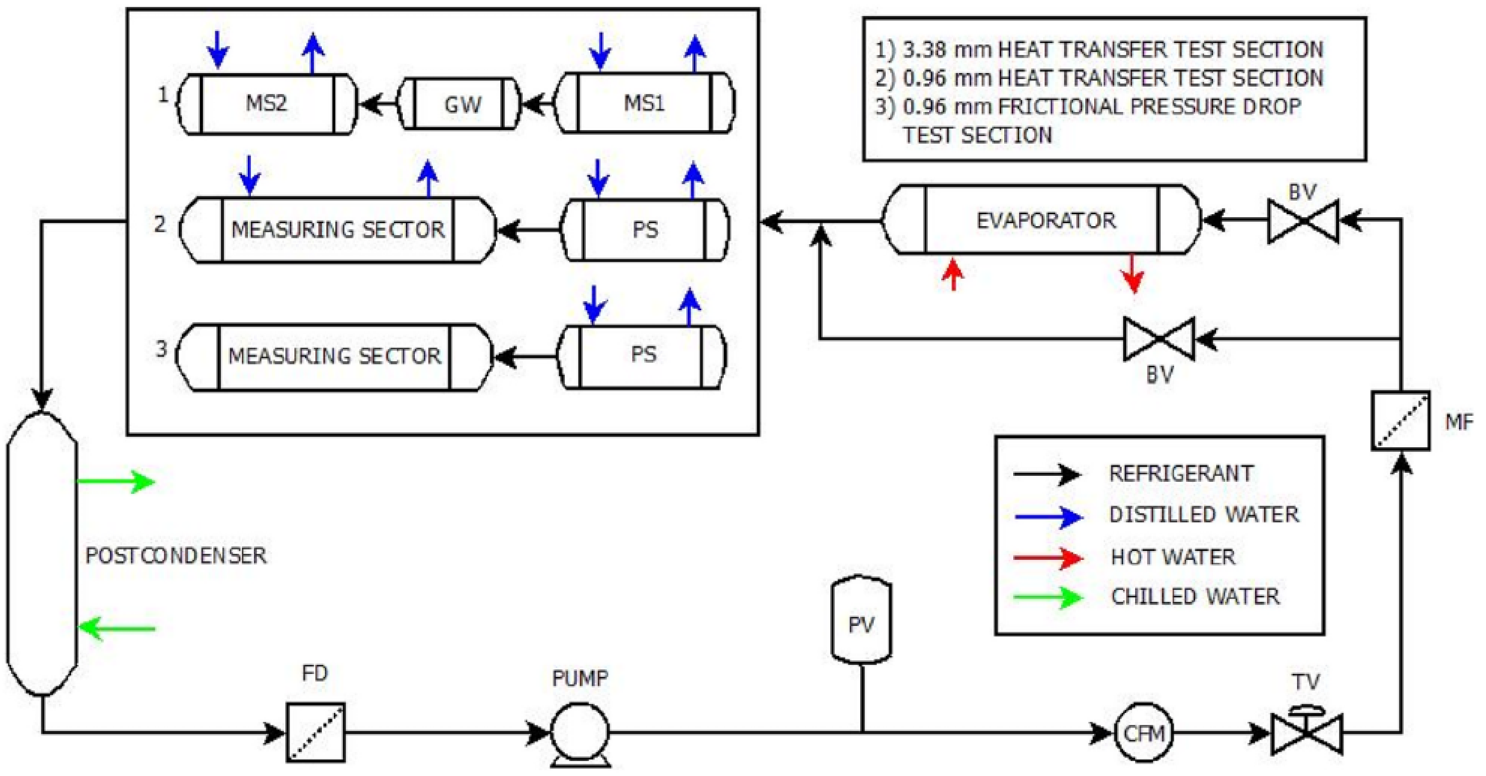
STET research group

- The availability of reliable tools for heat exchangers design is important for the project of heat pumps operating with new low-GWP fluids.
- In some cases, new refrigerants are non-azeotropic mixtures and thus, during phase-change at constant pressure, they present a temperature glide.
- Two experimental test rigs are available for the study of heat transfer during condensation and flow boiling.
- One experimental apparatus is designed for conventional channels (8 mm internal diameter) while the other test rig allows to measure heat transfer coefficients (HTC) inside small diameter channels (from 3 mm down to 1 mm).

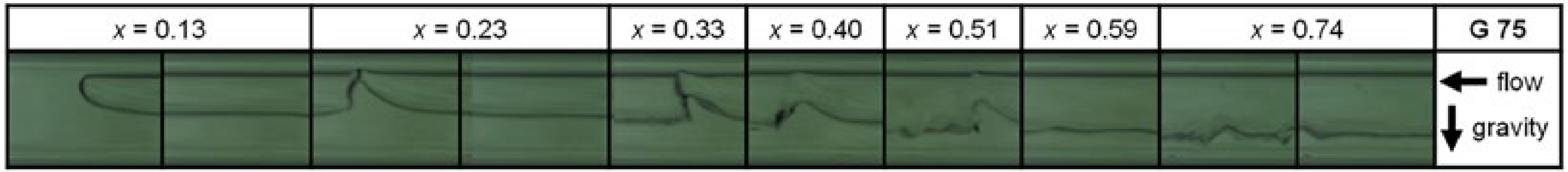
Test rig for HTC measurements in 1 mm and 3 mm diameter channels.

Test rig for HTC measurements in a 8 mm diameter channel.

Heat transfer measurements with low-GWP mixtures



Test rig for HTC measurements in 1 mm and 3 mm diameter channels.



Two-phase flow pattern visualizations of R513A. ***Int. J. Thermal Sciences 189 (2023) 108258***

Condensation with low-GWP refrigerants mixtures

- Condensation heat transfer coefficients, pressure drop and two-phase flow regimes have been investigated with refrigerants blends obtained mixing HFC and HFO fluids.

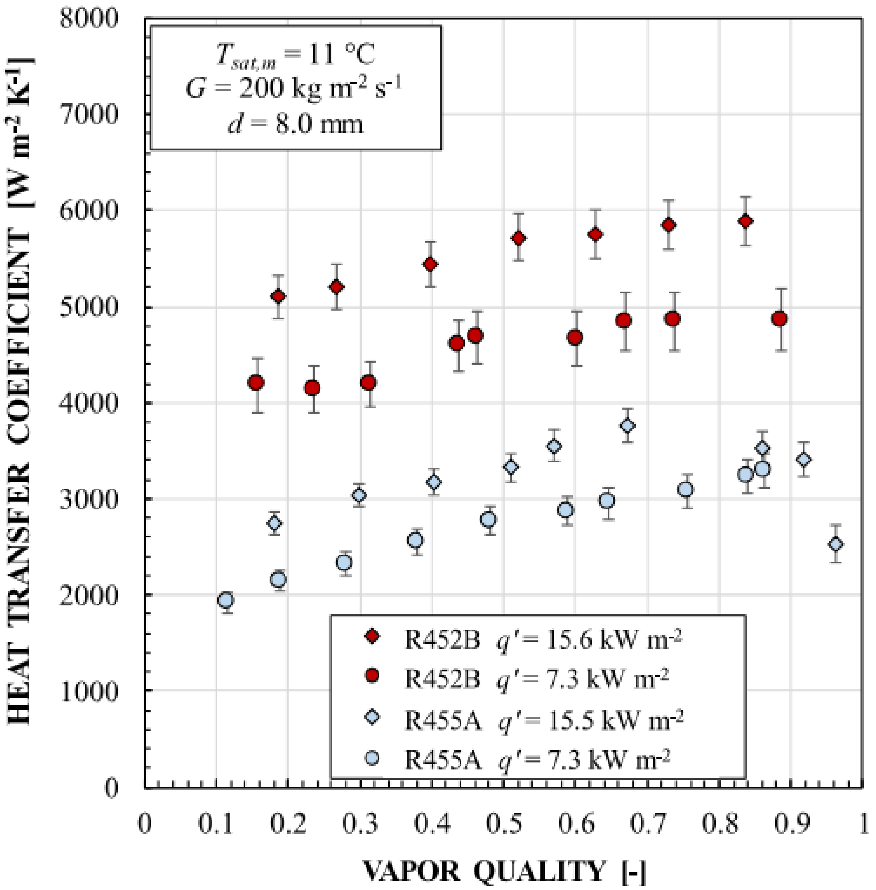
The following mixtures have been considered:

- Zeotropic mixture made of **R32 and R1234ze(E)** (0.748/0.251 by mass composition). A comparison between the condensation performance of the blend and its pure fluids R32 and R1234ze(E) has been done considering exergy losses. Tests have been done inside a 0.96 mm diameter channel.
- Non-flammable binary mixtures **R450A** (R1234ze(E)/R134a at 58.0/42.0% by mass) and **R515B** (R1234ze(E)/ R227ea at 91.1/8.9% by mass) inside two channels (diameter equal to 3.38 mm and 0.96 mm). R515B is an azeotropic mixture whereas R450A is a near-azeotropic blend (temperature glide 0.6 K at 40 °C).
- Azeotropic mixtures **R513A** (R1234yf/R134a 56/44% by mass) and **R516A** (R1234yf/R152a/R134a 77.5/14/8.5% by mass) inside two horizontal channels with 0.96 mm and 3.38 mm internal diameter.

- Correlations for heat transfer coefficients have been validated against the database.

Flow boiling of low-GWP non-azeotropic ternary mixtures

HTCs have been measured during flow boiling of ternary non-azeotropic mixtures inside two horizontal smooth tubes of 8.0 mm and 0.96 mm inner diameter.



Int. J. Refrig.
120 (2020) 271-284

- The following mixtures have been considered:
  - R455A (R32/R1234yf/R744 at 21.5/75.5/3% by mass), temperature glide of about 11 K;
  - R452B (R32/R1234yf/R125 at 67/26/7% by mass), temperature glide of about 1 K.
- The effects of vapour quality, saturation pressure, heat flux, mass velocity and channel diameter have been investigated.
- Models developed for pure fluids must be corrected to take in consideration the additional mass transfer resistance.

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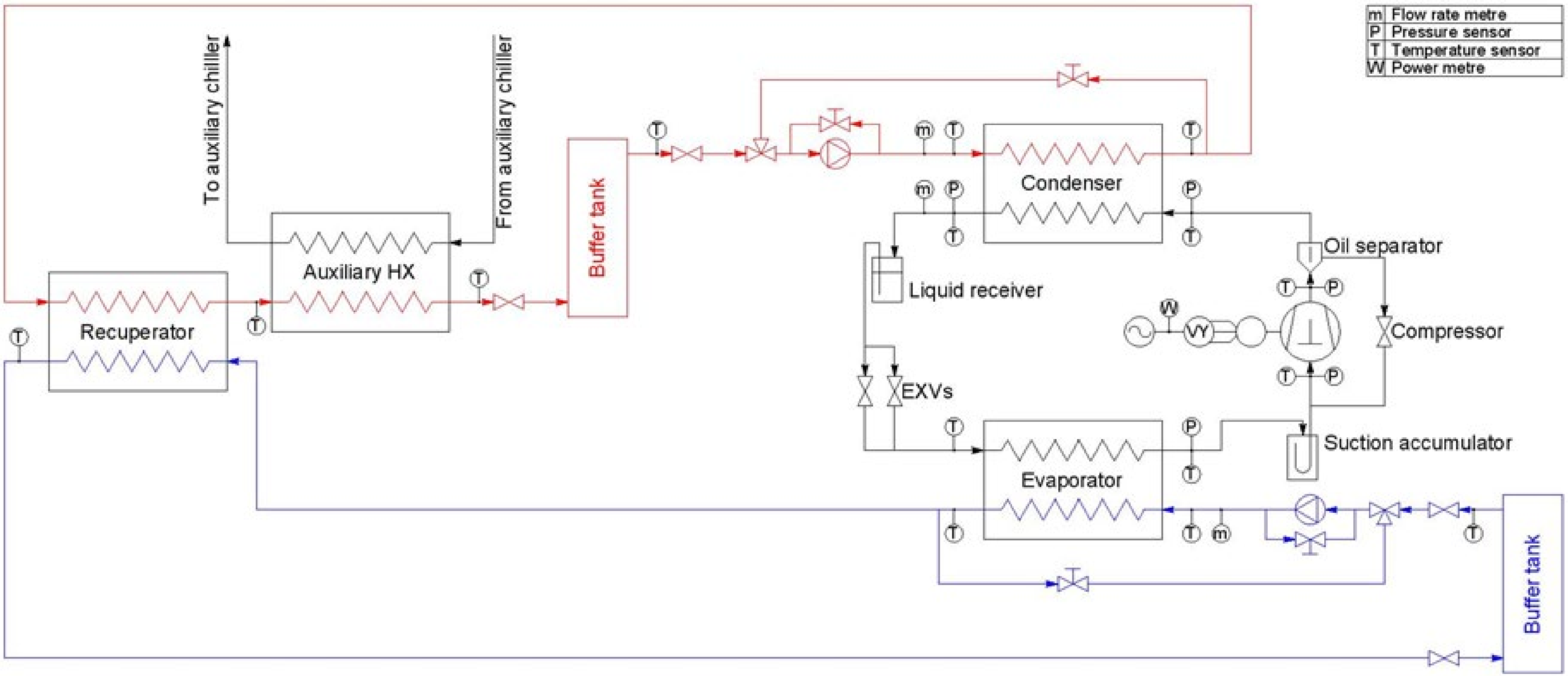
1. Assessment of energy performance (heating capacity and COP) in drop-in application. Tests are carried out setting: (i) the vapour superheating at the evaporator outlet, (ii) the secondary fluids flow rates and (iii) the temperatures of the secondary fluids at heat exchangers outlets. The system finds its own operating point (evaporating and condensing pressures, subcooling at condenser outlet) depending on the refrigerant used.

2. Yearly simulation of direct and indirect heat pumps that operates with low-GWP refrigerants (R410A vs R290).

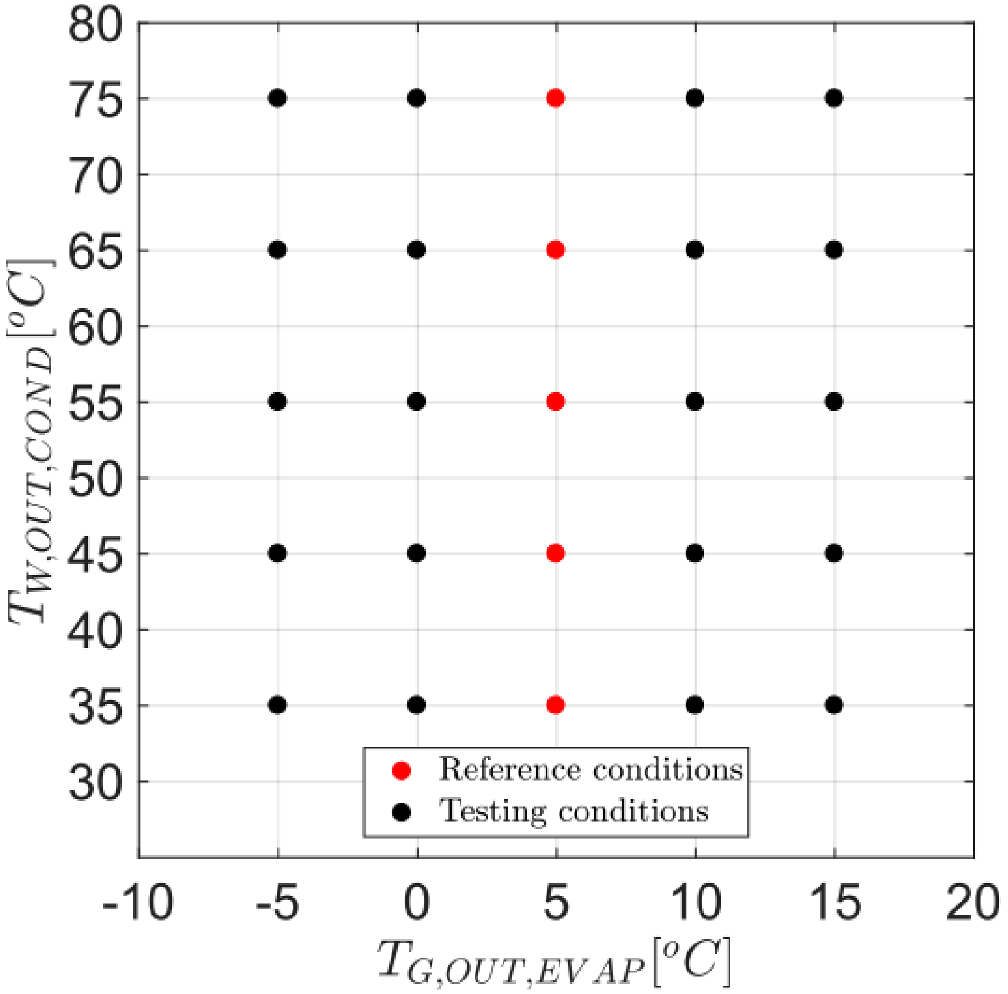
All the activities are performed by the HVAC Research Group

HVAC ADVANCED TECHNOLOGIES FOR ENVIRONMENTAL CONDITIONING

Activity 1 - Experimental set-up layout



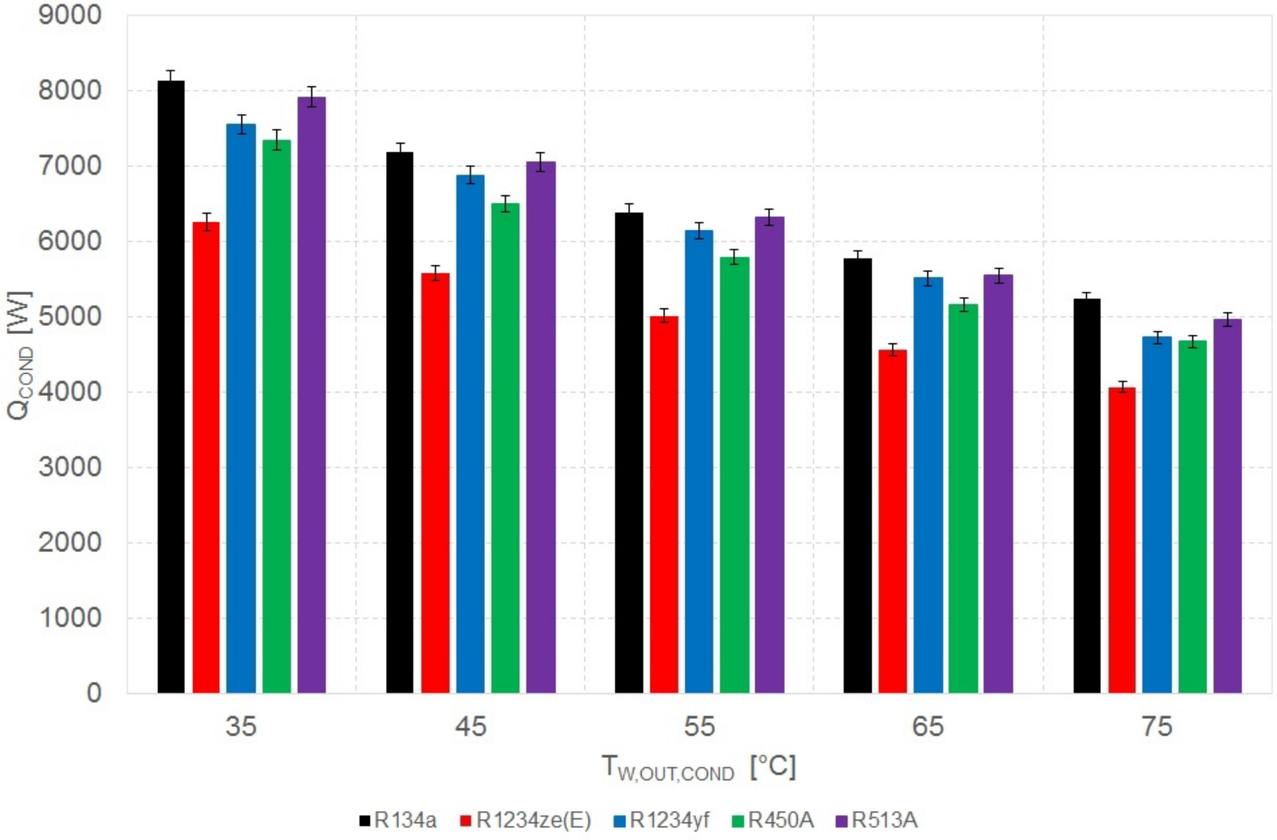
Activity 1 - Experimental conditions

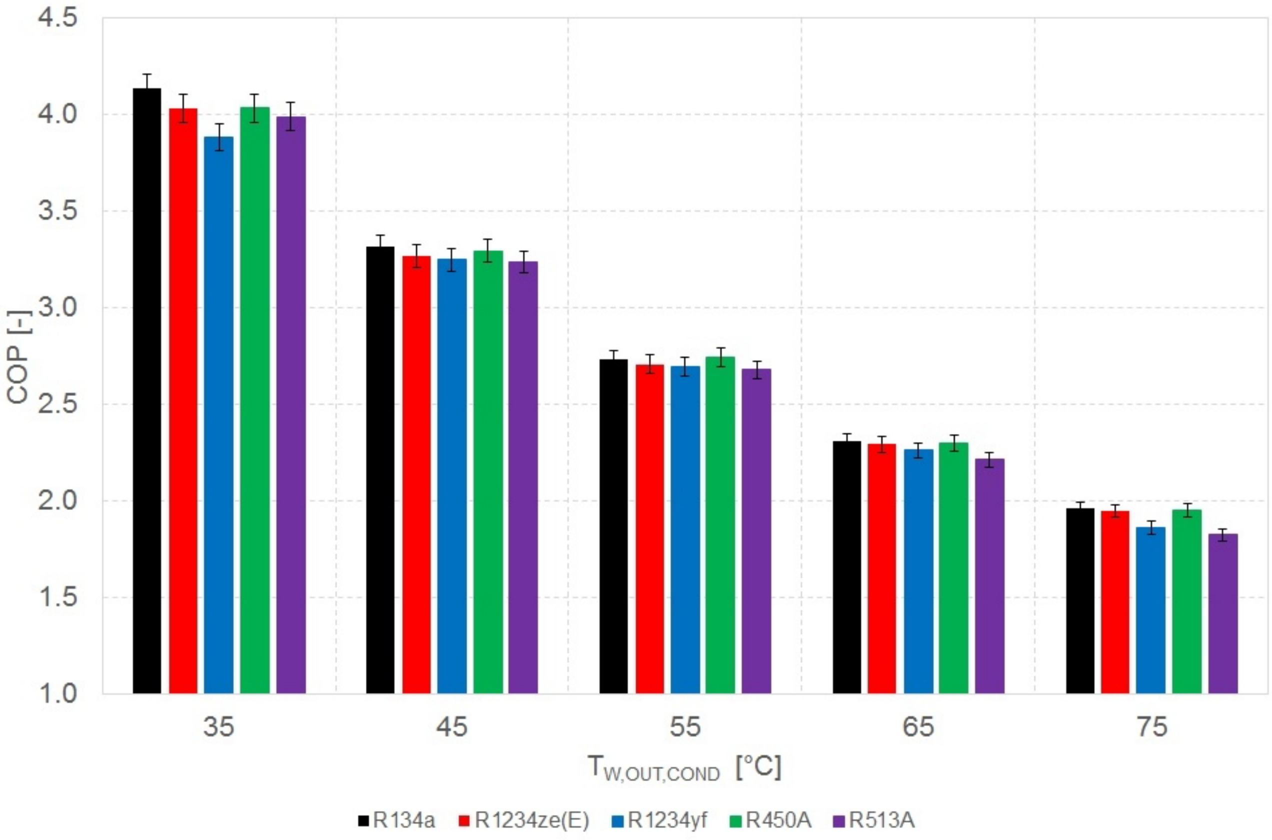


Reference conditions: conditions used to identify secondary fluid mass flow rates. ΔT across heat exchanger fixed to 5 °C.

Testing conditions: the mass flow rate and the outlet temperature are kept constant.

Activity 1 – Example of results





Water-glycol temperature at evaporator outlet equal to 5 °C.

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Most easy, efficient and low cost geothermal systems for retrofitting civil and historical buildings GEO4CIVHIC

www.geo4civhic.eu
Topic LCE-17-2017 (Horizon2020)
Start date 01/04/2018
Duration 68 months
Coordinator CNR – ISAC, Adriana Bernardi

GEO4CIVHIC project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 792355

Main **objective** of GEO4CIVHIC is to develop **easier to install and more efficient geothermal heat pumps**, using compact, innovative and tailor-made **drilling machines** and developing or adapting heat pumps or other hybrid solutions in combination with **renewable energies**, to the **renovation of buildings**

GEO4CIVHIC wants to accelerate the implementation of **shallow geothermal systems** for heating and cooling in the **retrofitting** of existing and historic **buildings**. It is based on innovative solutions studied by a group of international experts from companies and research centres.

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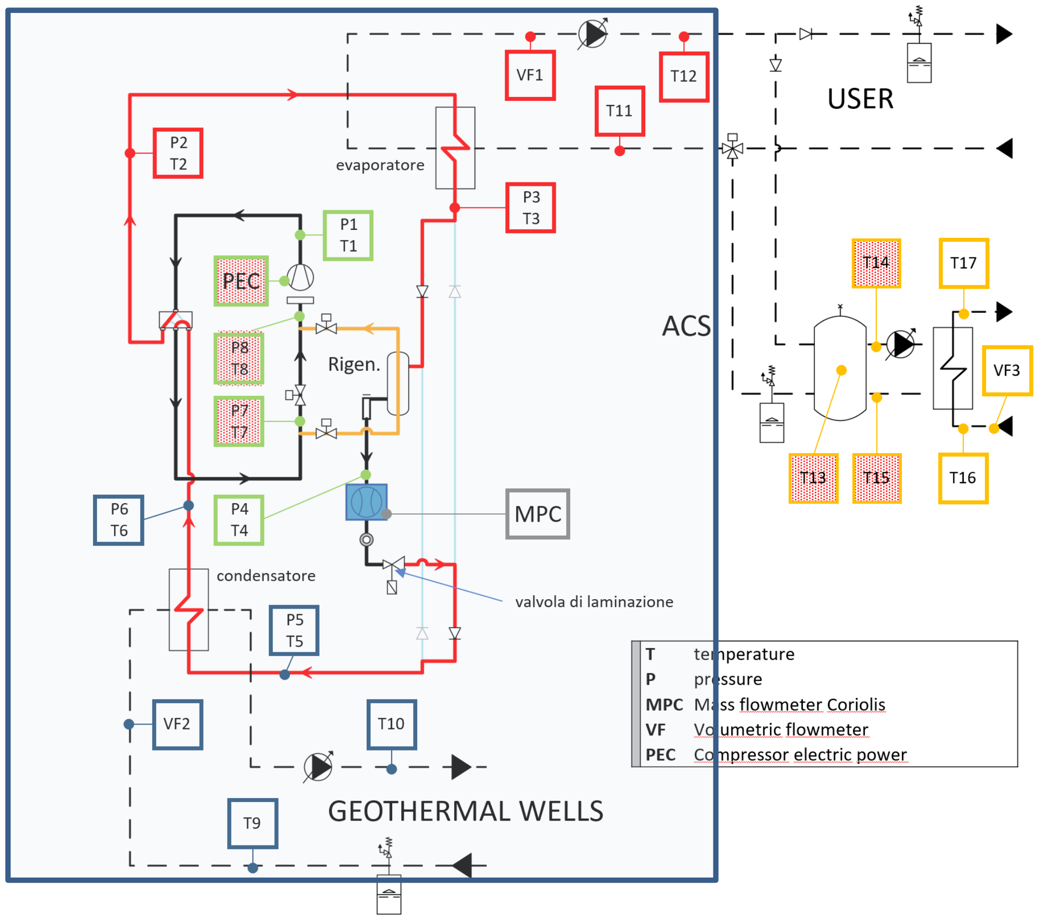
GEO4CIVHIC

GSHP monitoring system scheme – Refrigerant R454B

Heating mode



SCOPE

identify the most suitable **alternatives** to the present high GWP refrigerants used in geothermal heat pumps

METHOD

Monitoring of the ground source heat pump (GSHP) **performance** by measuring the main thermodynamic parameters (temperatures, pressures, mass flowrate) on the **refrigerant side**

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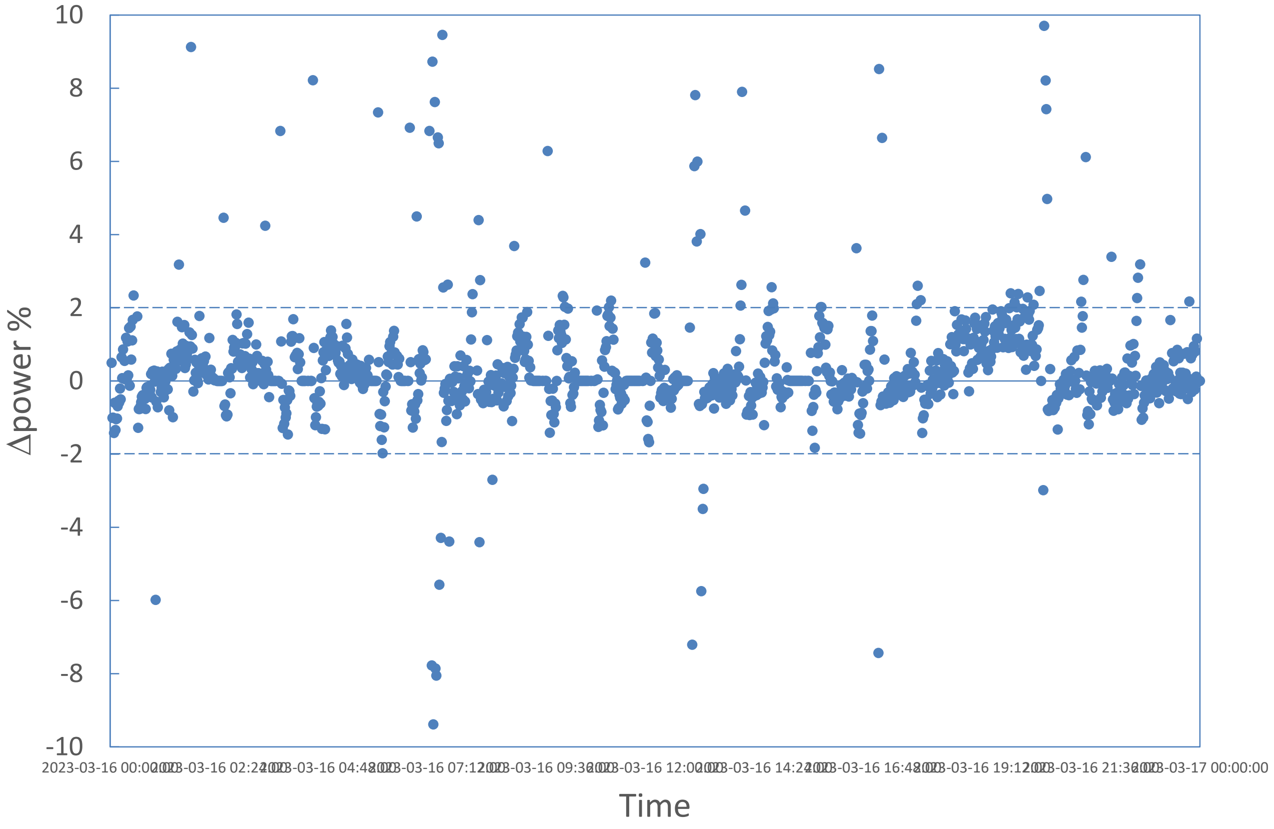
First principle energy balance refrigerant side

$$\Delta power\% = P_{condenser} - \left(P_{evaporator} + P_{compressor}\right)$$



In theory, on the base of the **first principle of thermodynamics** applied to the heat pump, the **Δpower%** should be equal to **0**

From the measurements, an average **unbalance of ±2%** has been observed, confirming that the **measurements performed are satisfactory**

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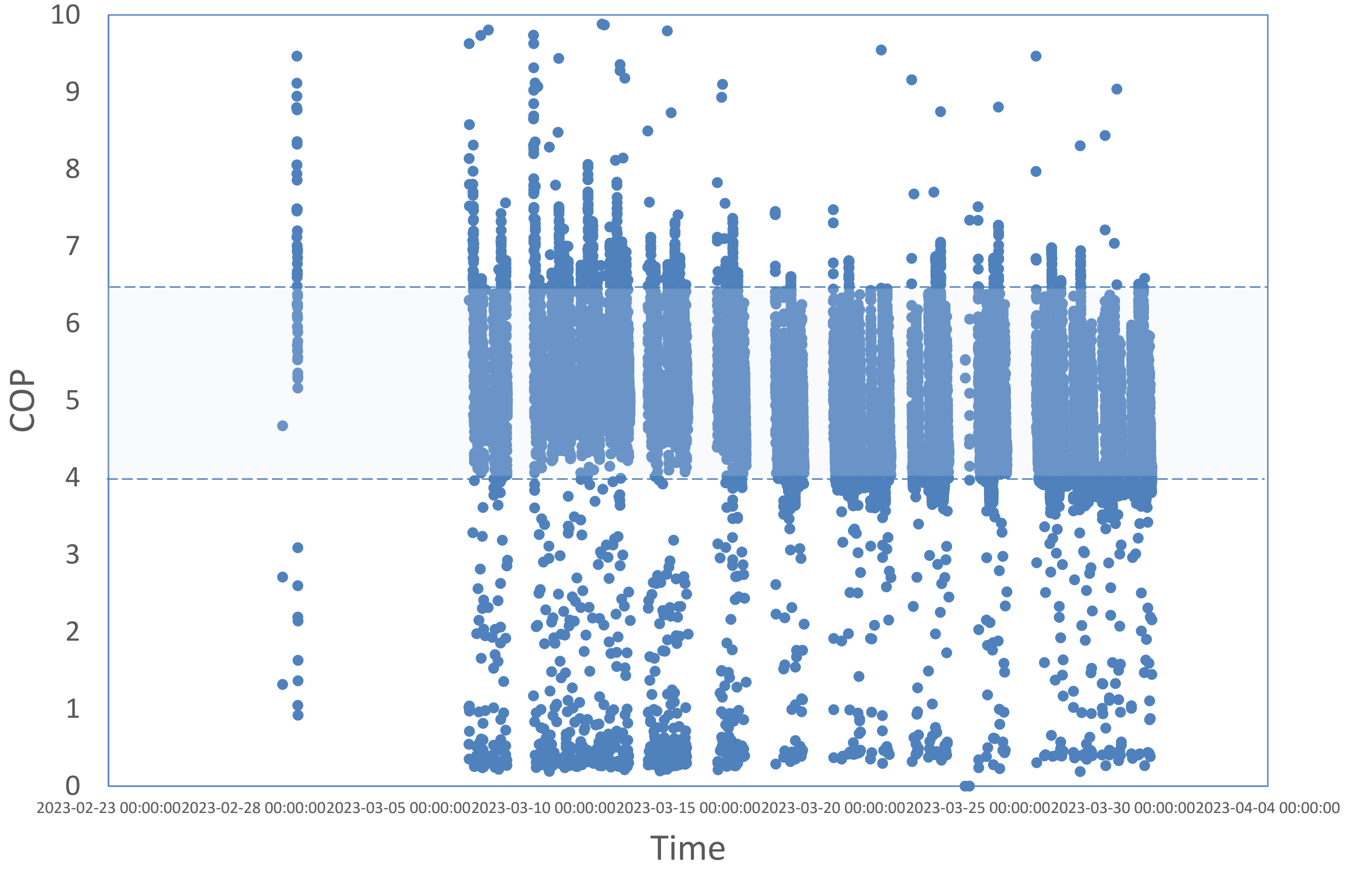
COP heating mode – month MARCH 2023



The **measured COP** ranged **between 4 and 6.5**, depending on the heat pump regime and the heat demand.

The results are **satisfactory** and will be **compared** with those that will be measured for a **prototype** under development **working with R600a**, considered as a long term low GWP alternative

Conclusions

- Both basic and applied research carried out during the 5 years journey.
- Several low-GWP refrigerants have been investigated/are currently under investigation.
- All-in-all, whatever the traditional, old, high-GWP refrigerant is considered, it is hard to find a one-to-one low-GWP alternative. Rather, more than one options are available and, therefore, the final choice should consider not only thermodynamic features but also safety aspect, environmental metric (TEWI or LCA), cost etc…

Thank you for your kind attention!!!

Sergio Bobbo, bobbo@itc.cnr.it

Stefano Bortolin, stefano.bortolin@unipd.it

Davide Del Col, davide.delcol@unipd.it

Laura Fedele, fedele@itc.cnr.it

Luca Molinaroli, luca.molinaroli@polimi.it