Heat pumps integration in the next generation of sustainable buildings

Claudio Zilio
Department of Management and Engineering -University of Padova, Italy

With great contribution of the whole FLEXHEAT Project team

HP_sim&app23 - Carnot User Meeting 2023

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Outline

The European Commission estimates that the energy consumption related to buildings is equal to about **40% of the total energy** consumption in Europe and the sector is responsible for about 36% of European greenhouse gas emission. It is estimated that about **one third of this energy consumption is devoted to space heating in buildings**.

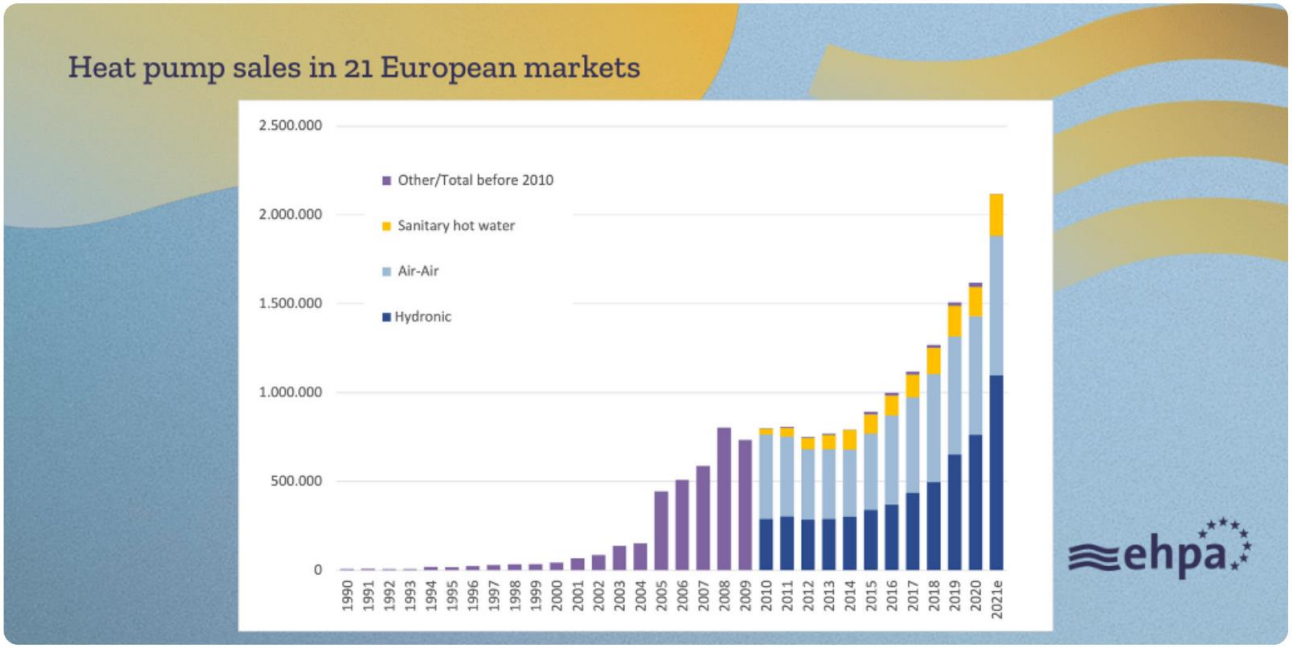
The use of heat pumps (HPs) is universally recognized as an option to promote the use of renewable energy in the air conditioning of buildings.

The advantage of using this technology is its efficiency (e.g., compared to electric or natural gas-based boilers), its ability of using energy coming from renewables and of increasing the use of electricity instead of fossil fuel-based energy for the thermal sector. HPs function appears to be fundamental in order to balance the electricity grids.

Outline

It is fundamental to systematically **develop strategies** for the integration of environmentally friendly heating systems in sustainable buildings.

The keyword if **FLEXibility** and Heat Pumps are key enablers



Partners

FLEXHEAT Project – PRIN 2017 The energy FLEXibility of enhanced HEAT pumps for the next generation of sustainable buildings

Three (4) years project.

- University of Padova (Claudio Zilio)
- University of Bologna (Gian Luca Morini)
- University of Pisa (Daniele Testi)
- University of Trento (Paolo Baggio)
- Polytechnic of Turin (Marco Perino)
- University of Udine (Giovanni Cortella)
- Free University of Bozen (Andrea Gasparella)
- IUAV- Venice (Francesca Cappelletti)

Outline

The study concerns both with the building envelope and the optimization of the fundamental plant's components with emphasis on both air and multisource HPs (air/ground/solar/heat recovery) operating with innovative refrigerants in order to increase efficiency of the whole system and to decrease its environmental impact.

Project synoptic

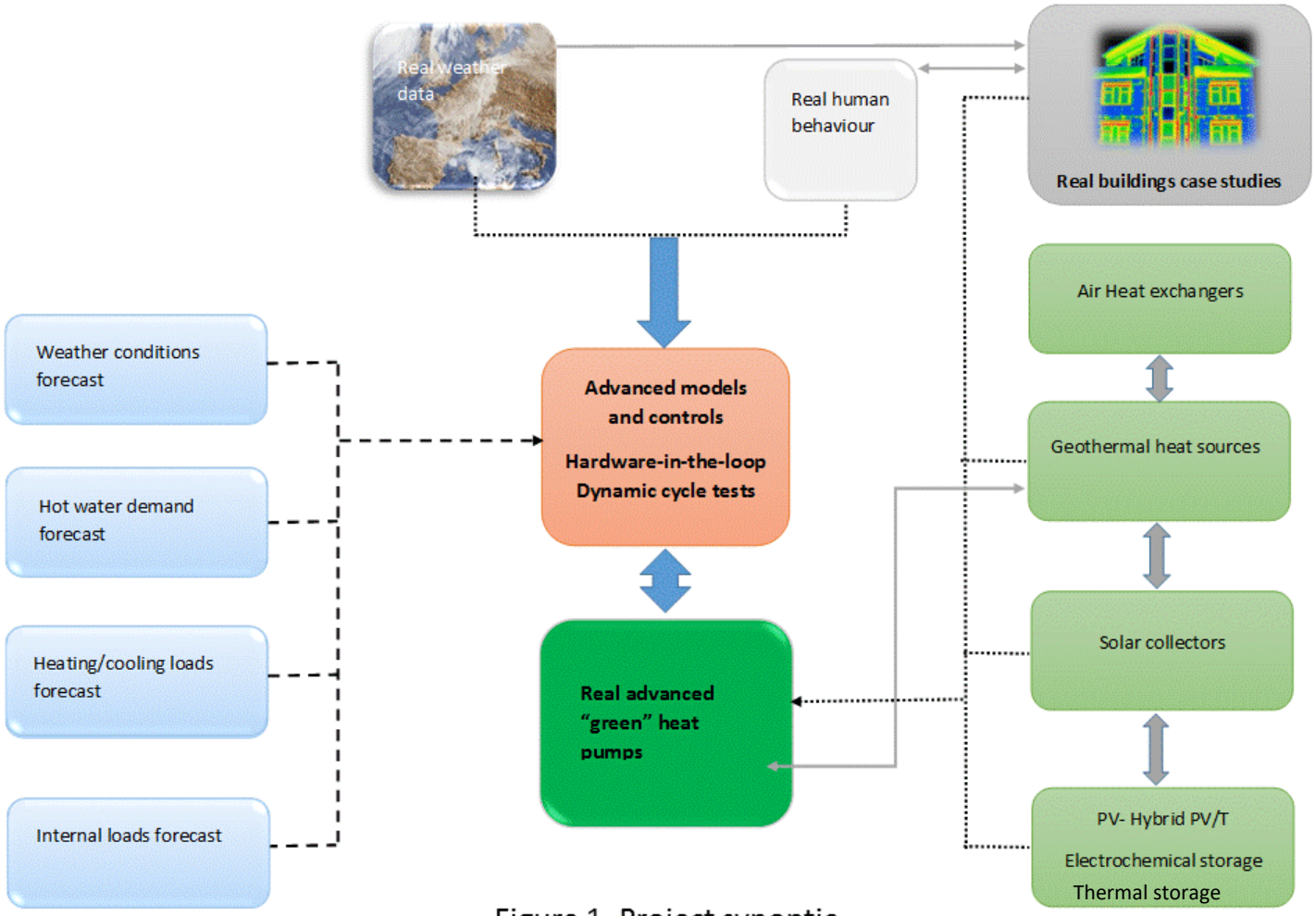
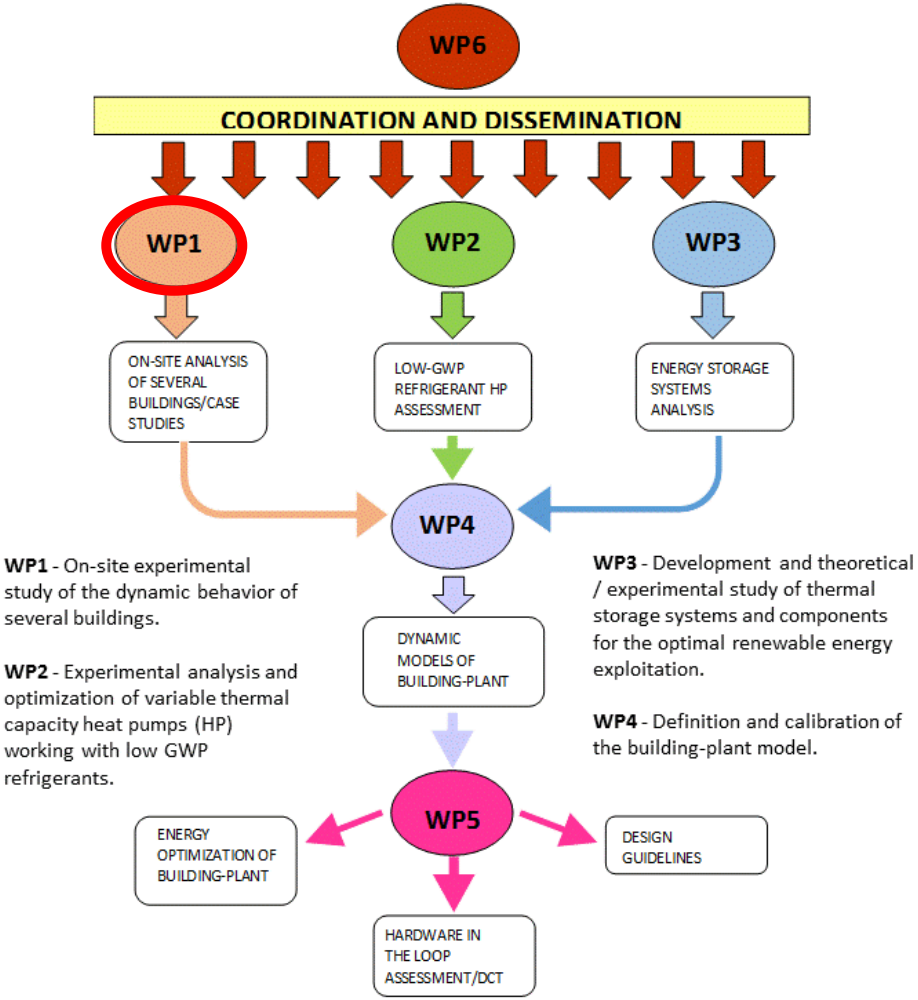


Figure 1. Project synoptic

Project flow chart



WP1 - On-site experimental study of the dynamic behavior of several buildings.

WP2 - Experimental analysis and optimization of variable thermal capacity heat pumps (HP) working with low GWP refrigerants.

WP3 - Development and theoretical / experimental study of thermal storage systems and components for the optimal renewable energy exploitation.

WP4 - Definition and calibration of the building-plant model.

WP5 - Analysis and optimization of several plant configurations. Scenario analysis.

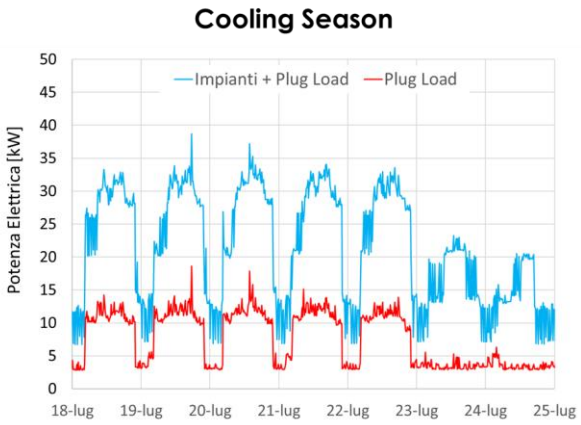
Real buildings monitoring and analysis

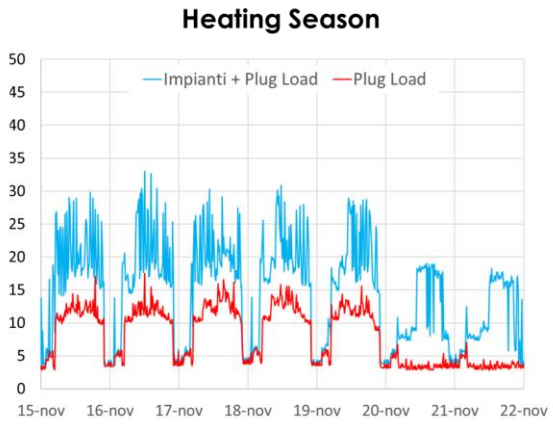
Each RU involved has been responsible for monitoring one or more buildings.

- Monitoring of relevant indoor/outdoor thermal/hygrometric/lighting parameters

- Study of the HP installed in each building. Monitoring of relevant thermodynamic parameters in the HP system

- Analysis of experimental data collected





Real buildings monitoring and analysis

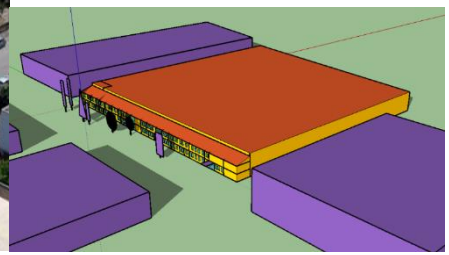
Analysis of the replacement of a conventional gas boiler with an inverter driven Air Heat pump

Bentivoglio (Bologna, IT)

24 offices and open space, 2 floors

Heating Area: 1256 m^2

Heating Volume: 3589 m^3



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New school in Agordo (BL-IT) with ammonia/water multi-source (PVT-ground) heat pumps and AHR

Heating Area: 5680 m^2

Heating Volume: 19,640 m^3

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Real buildings monitoring and analysis

Residential NZEB in Pisa

with GSHP and PV integration






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New Engineering Library @ UniTN

High performance building

High window to wall ratio

Hydronic system with air handling unit

GSHP + ASHP with sequential load distribution


Real buildings monitoring and analysis

Supermarket near Rome

CO_2 refrigeration system for chilled and frozen food

Integration with one R410A HP for DHW

and one R410A HP for HVAC

Ice thermal storage

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New 5 storey hotel, seaside, North Italy

Total floor surface 1600 m^2,

Internal volume 4300 m^3.

High-efficiency envelope.

Two air-water HPs

PV and thermal solar panels.

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Real buildings monitoring and analysis

Museum in Pisa

One room hosting temporary exhibitions

Total floor surface 100 m^2,

Internal volume 500 m^3 , no glazed parts

Use of a multi-purpose heat pump.

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CO_2 heat pump for DHW production in a large multi-family building (8 storeys)

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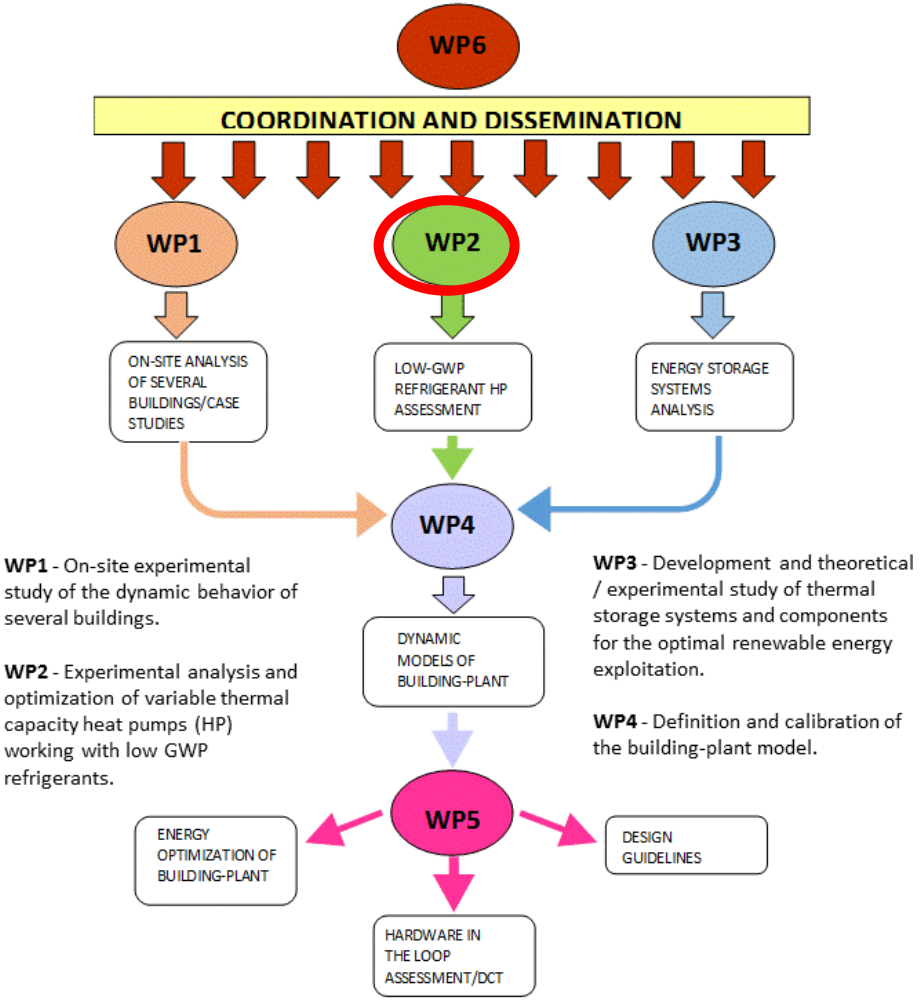
Project flow chart



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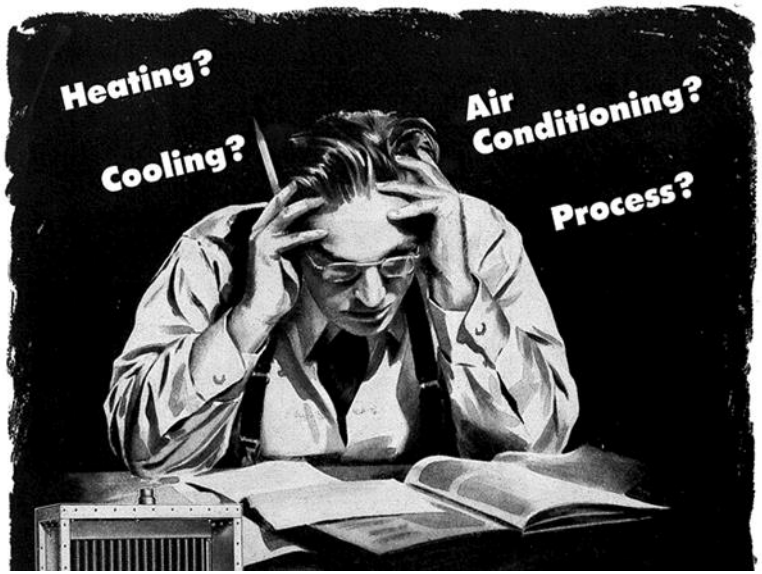
LOW-GWP REFRIGERANTS

GWP

F-GAS



TEWI

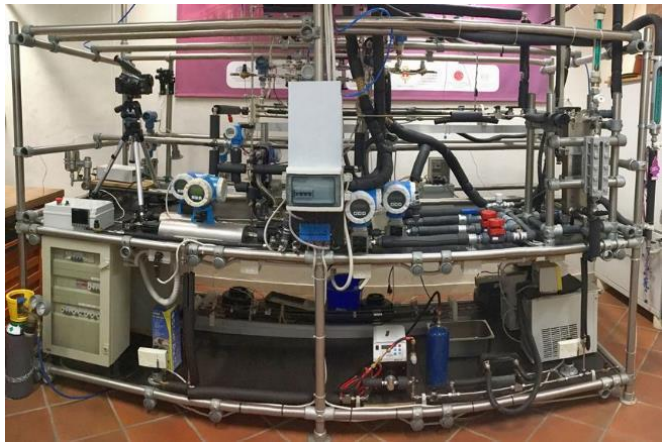
NATURAL REFRIGERANTS

ECODESIGN

Low-GWP refrigerants HP assessment

Performance analysis of the HP working with innovative refrigerants.

- Heat transfer during condensation and boiling of the new refrigerants (R134a, R410A, R32, R152a, R236fa, R290, R1270, R600a, R1234yf, R1234ze(E), R1234ze(Z), R1233zd(E), R1224yd(Z))



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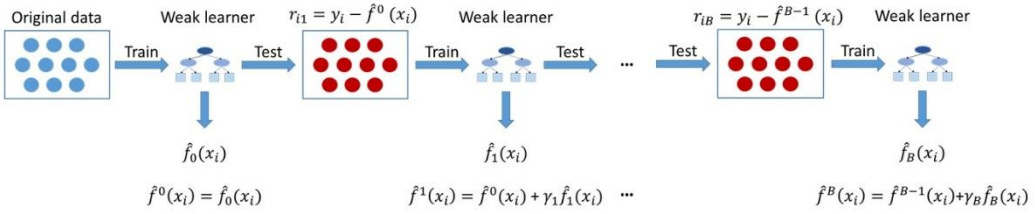
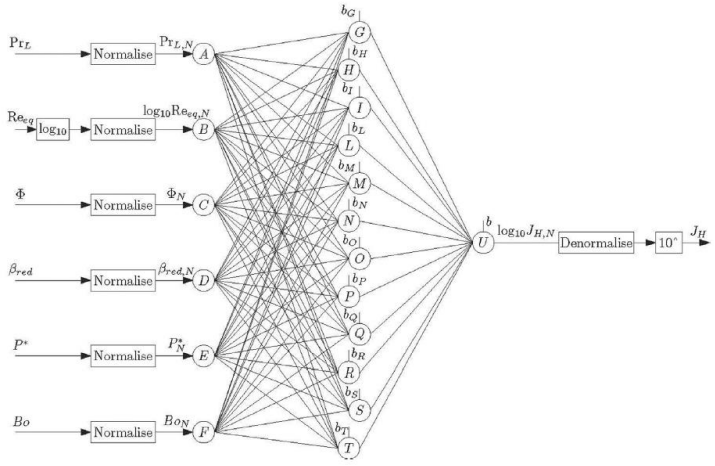
- Implementation of correlations of heat transfer coefficients and pressure drops (incl. ANN and ML)

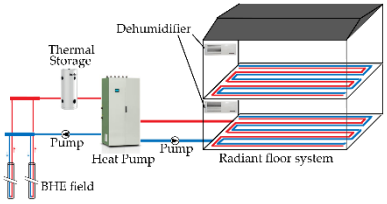


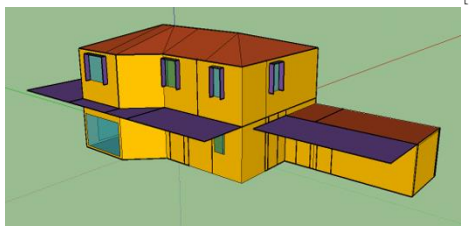


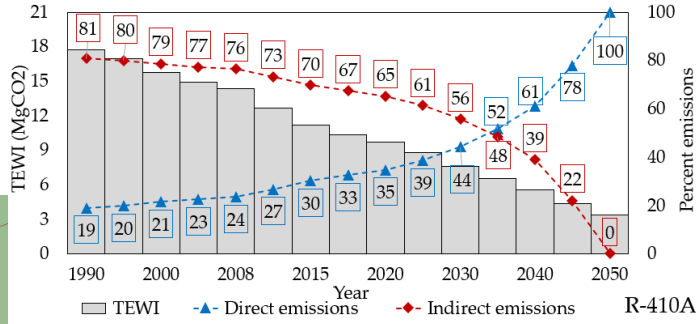
Low-GWP refrigerants HP assessment

Energy and environmental performance of HP systems working with **alternative refrigerants**

- Seasonal performance comparison of **R410A** and **R454B**
- **Comparable annual performance factor** between two refrigerants
- **TEWI** value **decreases of 26%** with R454B







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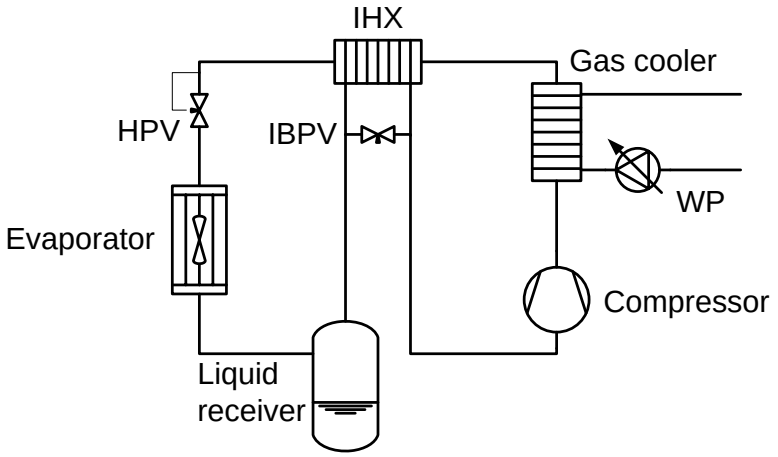
CO_2 heat pump with IHX for hot water production

Control rules at partial load conditions, with high return water temperature, to preserve efficiency while reducing discharge temperature through gas cooler pressure control.



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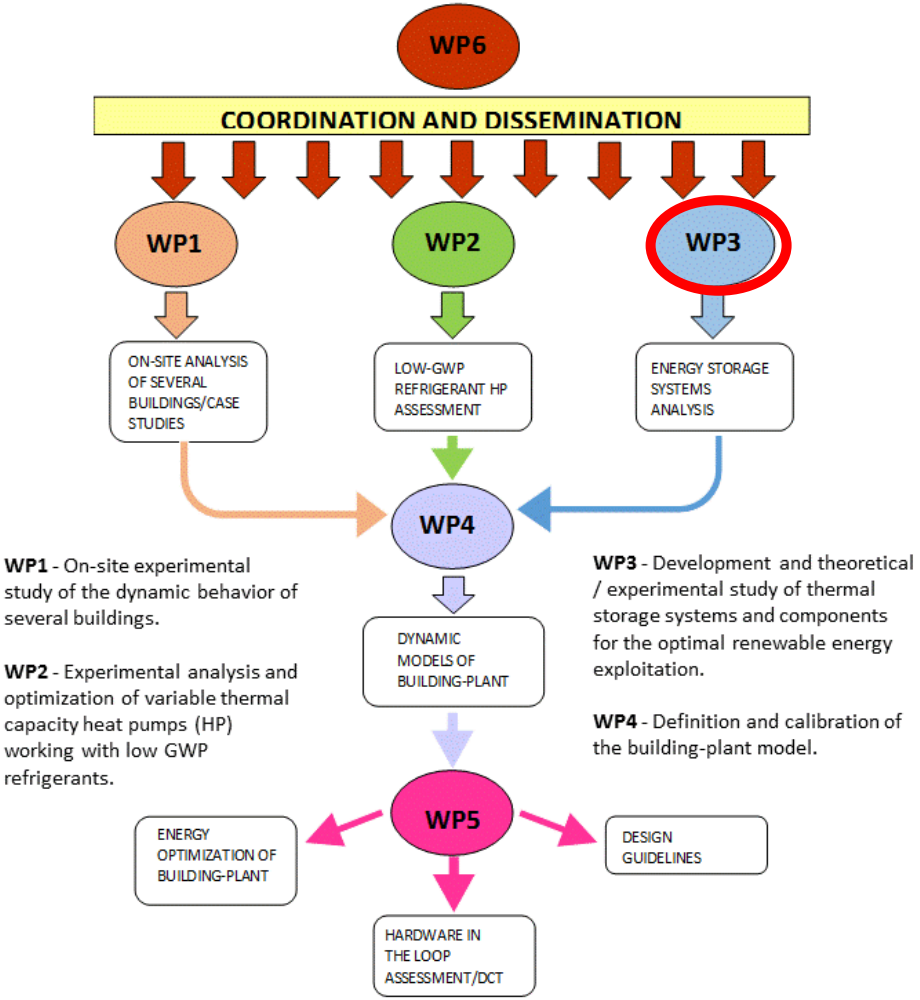
Project flow chart



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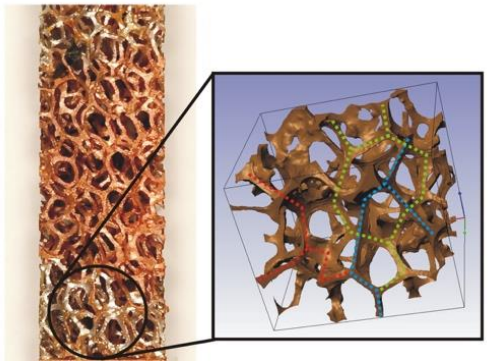
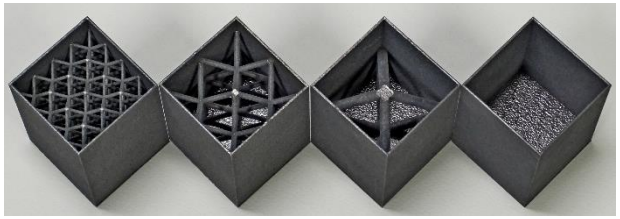
Energy storage systems analysis

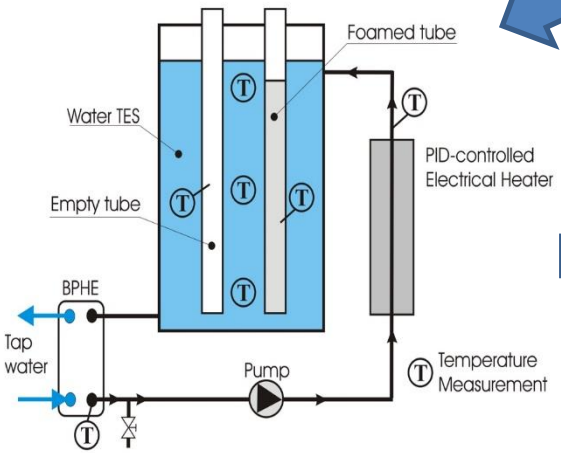
Given the high volatility of the renewable energy sources, a proper integration of the HP systems with suitable energy (thermal and electrical) is mandatory in order to optimize energy use and increase overall system efficiency while considering part-load operation of the HPs

Several types of PCM (incl. ice).

Several types of enhanced surfaces.







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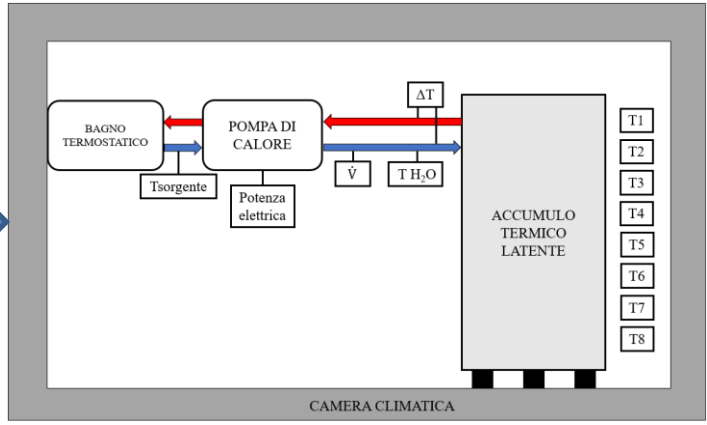
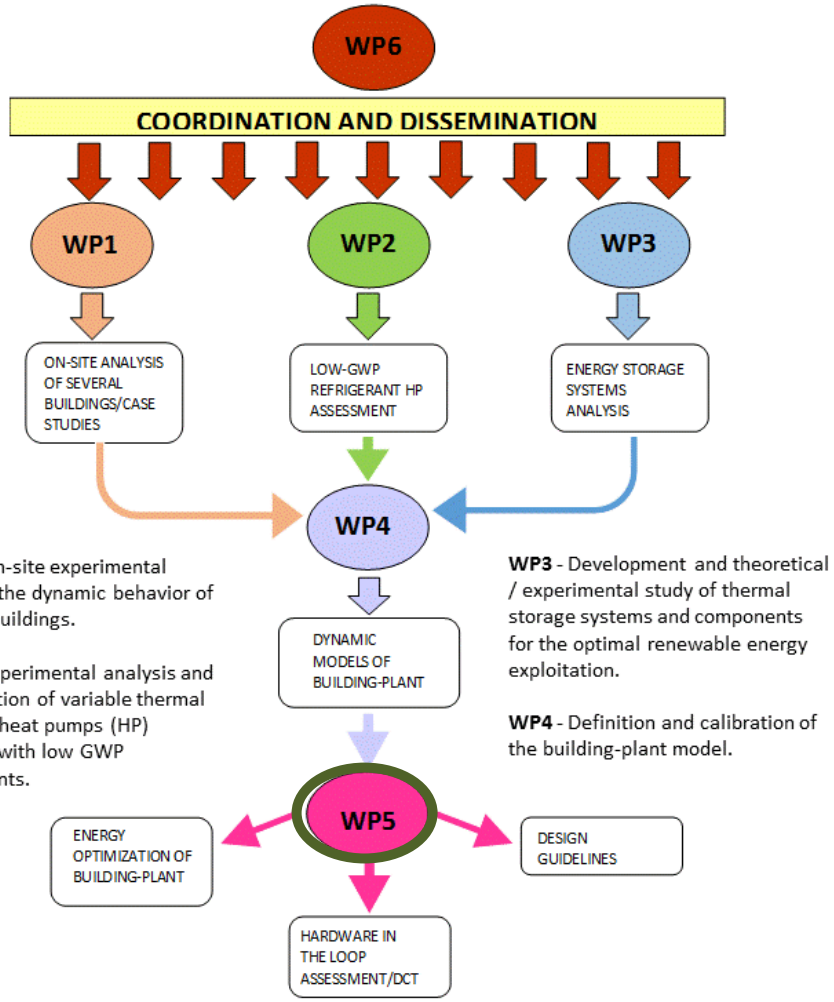


Project flow chart



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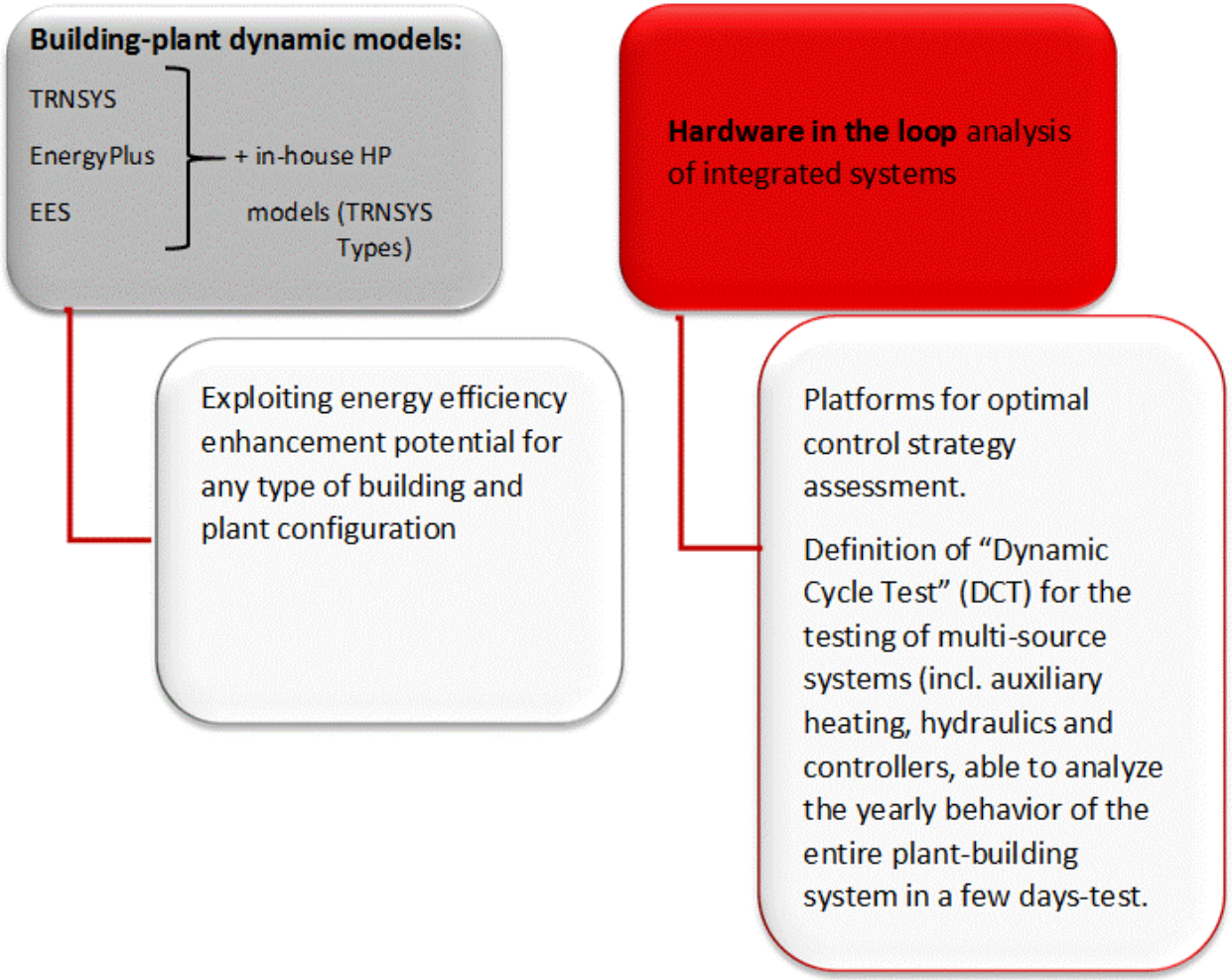
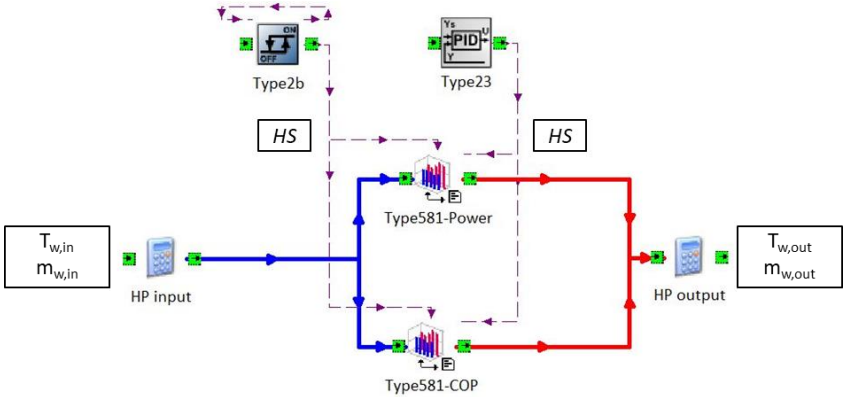
Dynamic models: general approaches



Dynamic models: hp

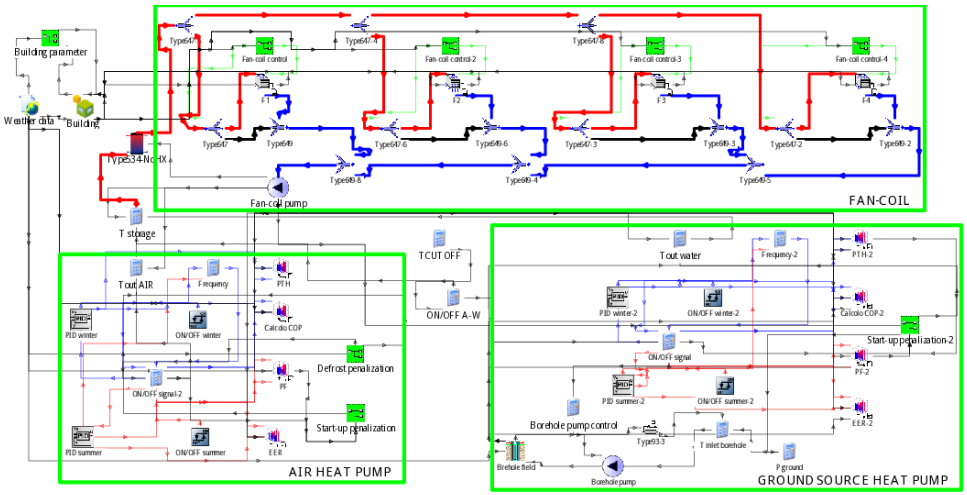
Numerical models of inverter-driven and dual-source heat pumps developed in TRNSYS



$$u(t) = K_p\left[DT(t) + \frac{1}{T_i}\int_0^t DT(t)d\tau + T_d\frac{dDT(t)}{dt}\right]$$

Type223-pompa di calore dual source completa

- **Models not available in standard libraries**
- **HP performance** as a function of **heat source temperature** and **frequency**
- Implementation of dedicated **control strategies**



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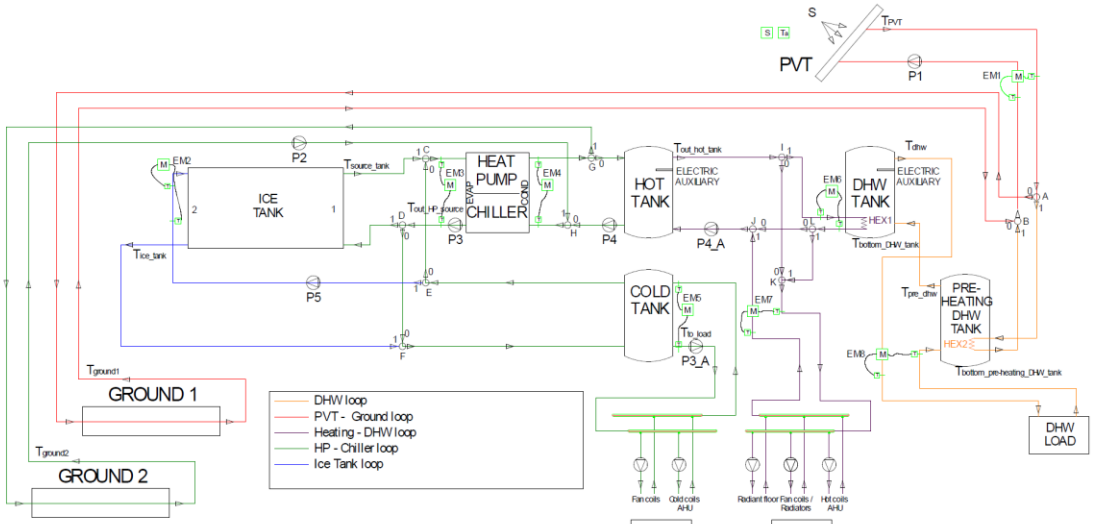
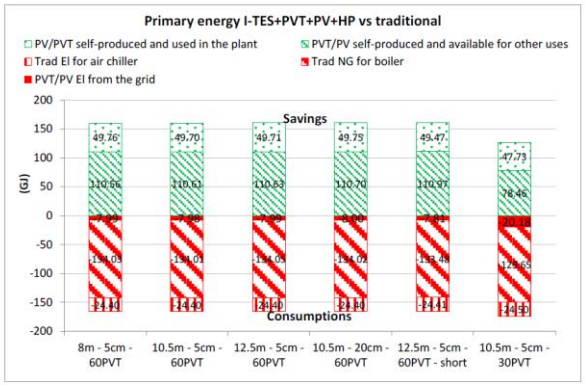
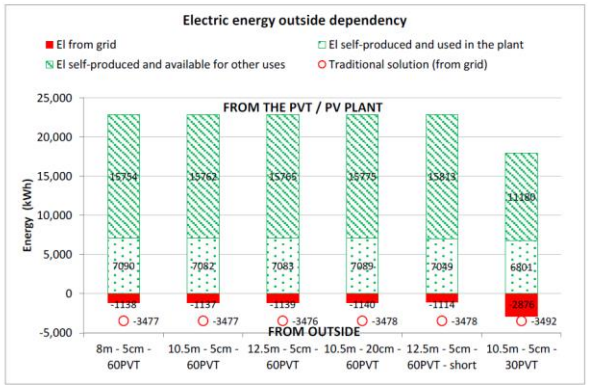
Dynamic models: systems

Numerical models of Heat Pump Coupled with Ground, Ice Storage and Photovoltaic/Thermal Modules developed in TRNSYS







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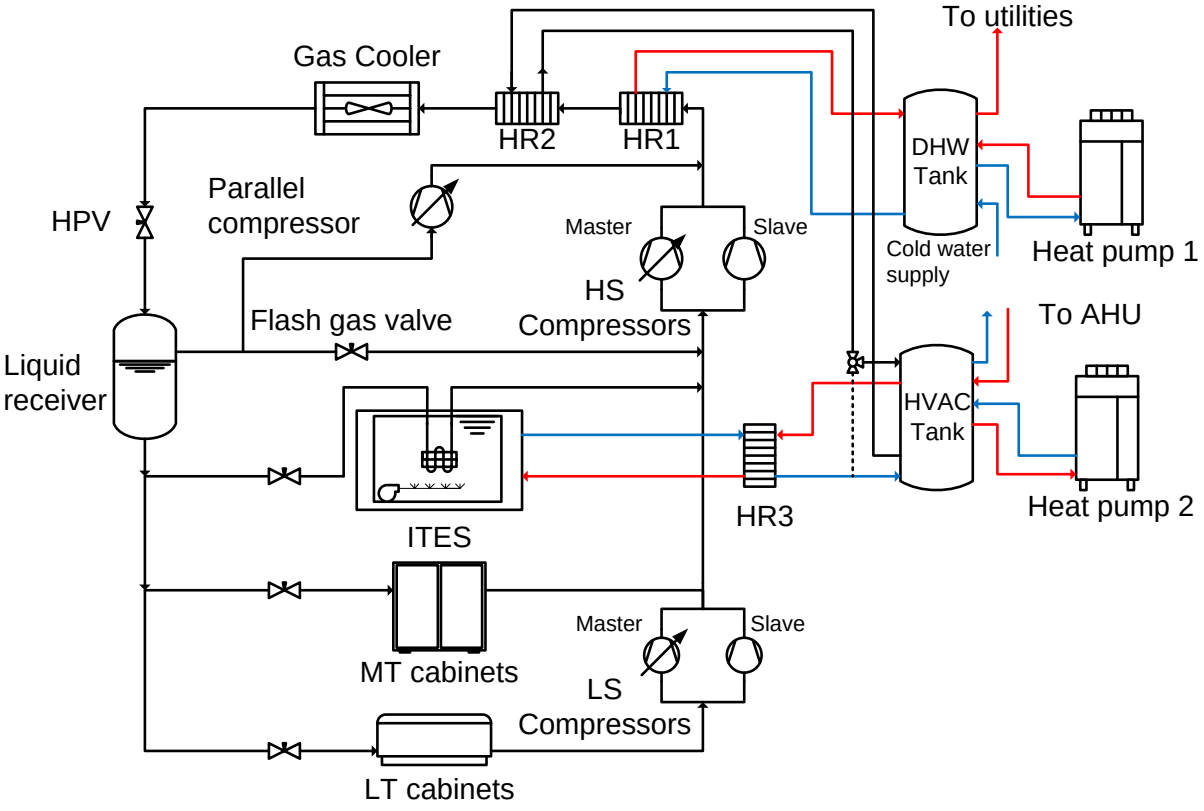
Dynamic models: systems

Supermarket with integrated CO_2 system for refrigeration, heating, cooling and hot water production.

Ice thermal energy storage.

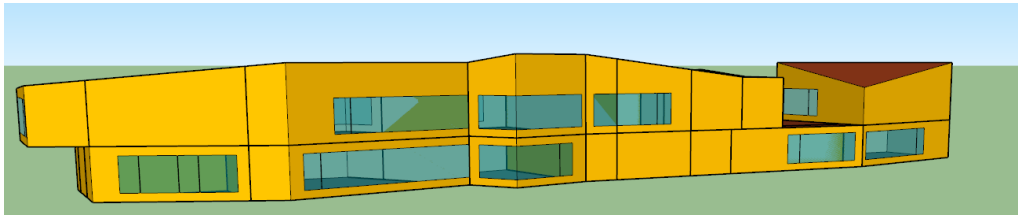
Control rules to shave peaks in electrical power use or to increase daily efficiency

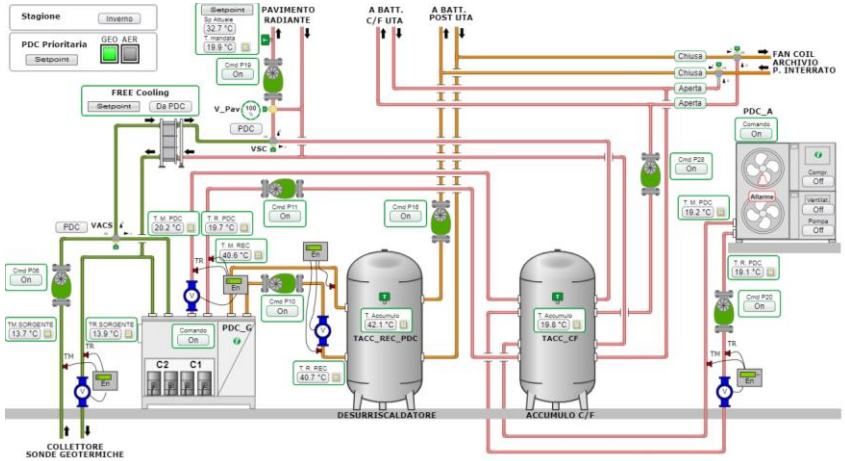


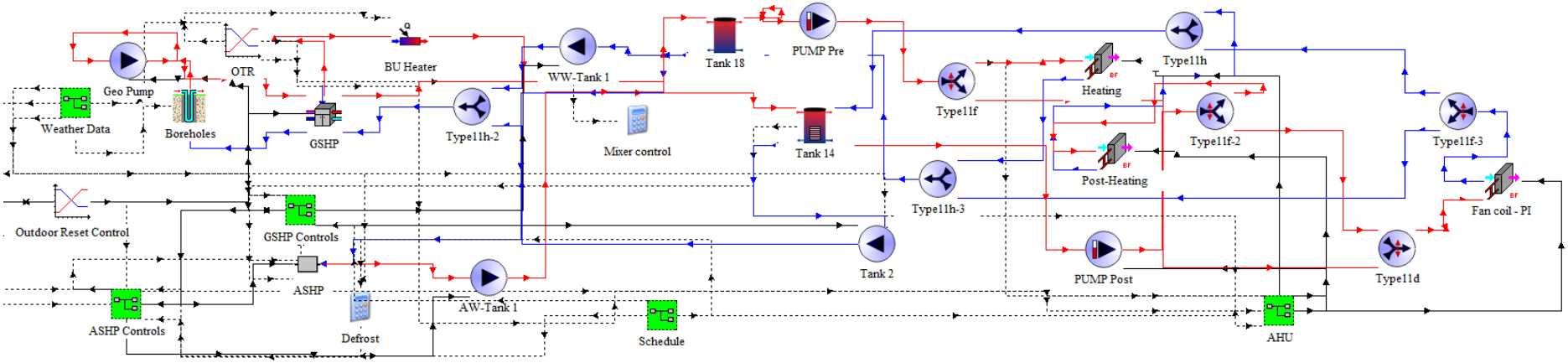
Dynamic models: building-plants

UNITN library building and HVAC systems models developed in TRNSYS

GSHP-ASHP + hydronic system

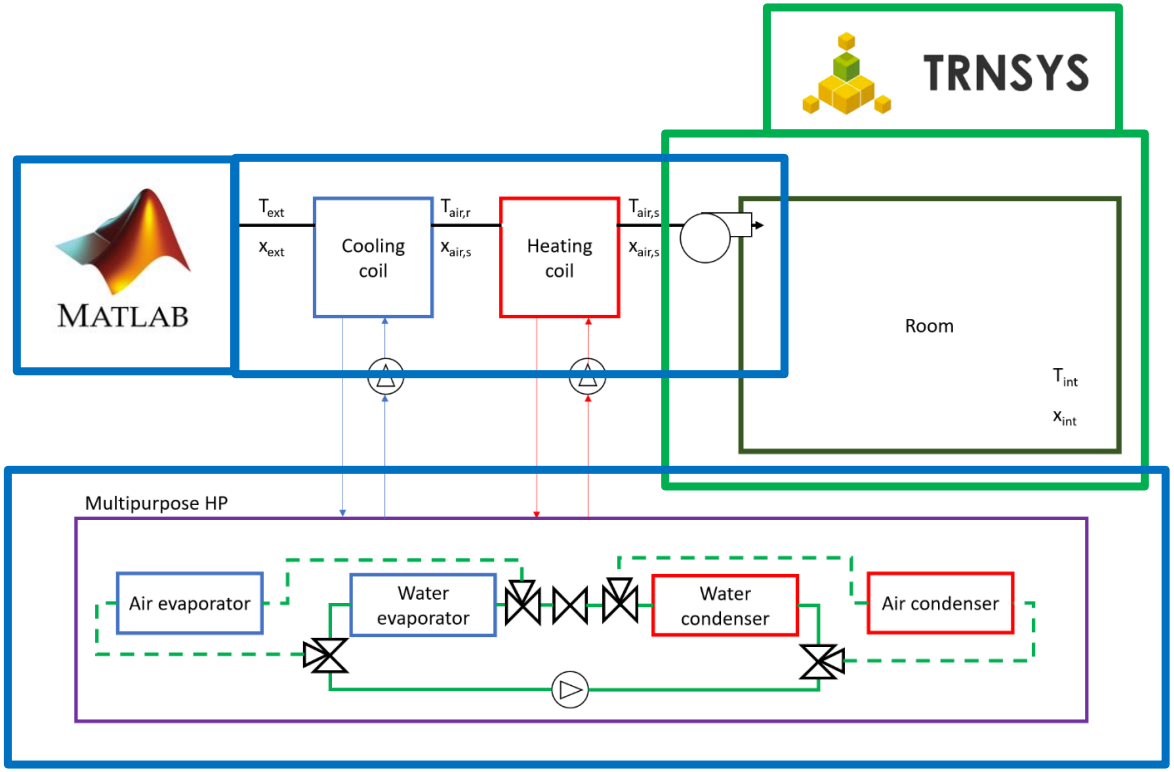






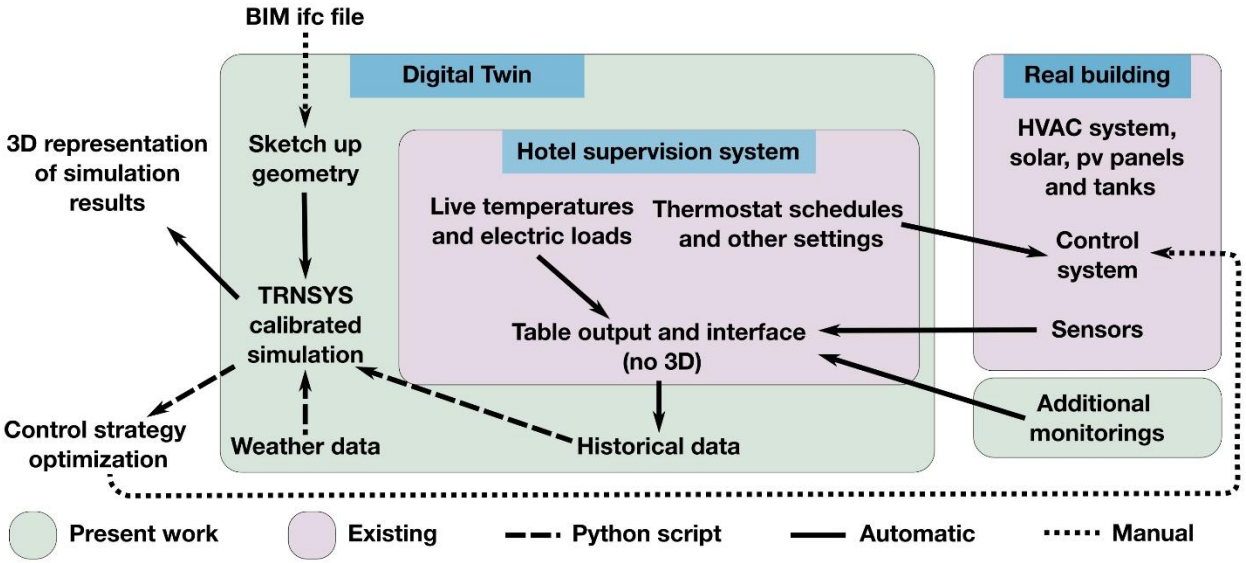
Dynamic models: building-plants

Multi-purpose HP integrated with museum rooms in Pisa systems models



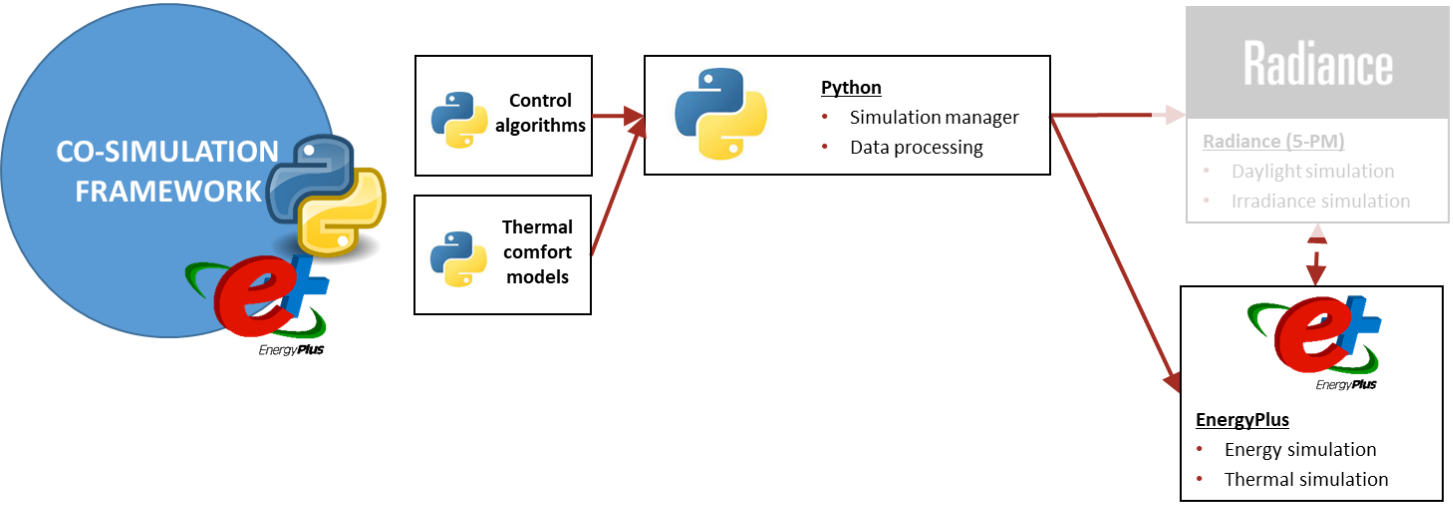
Dynamic models: building-plants

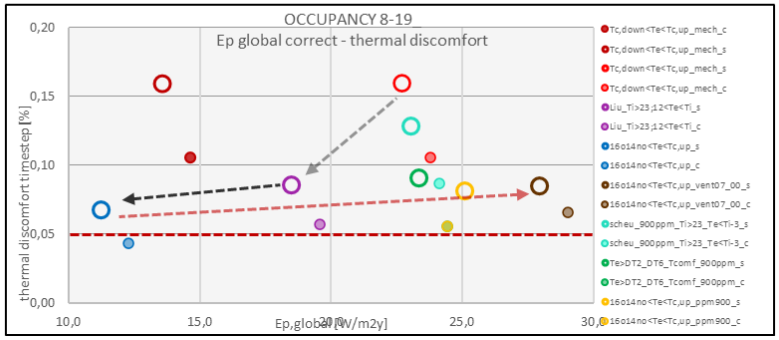
Development of an energy digital twin from a hotel supervision system using building energy modelling

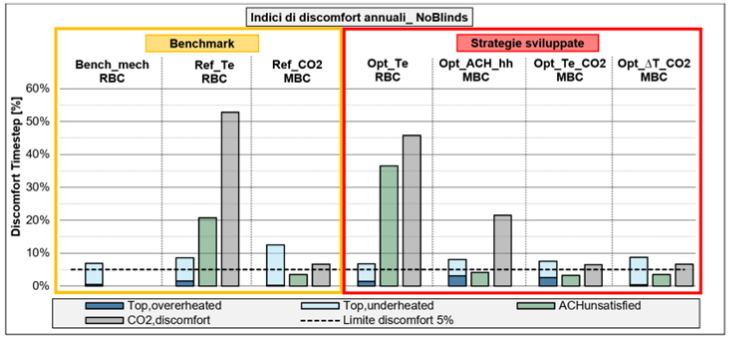


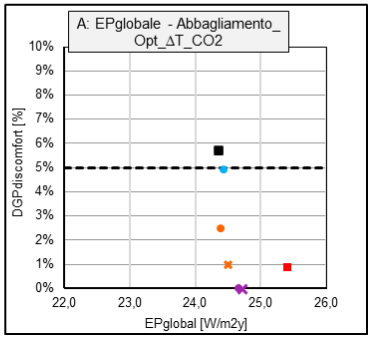
Dynamic models: building-plants

Co-Simulation framework for advanced building components









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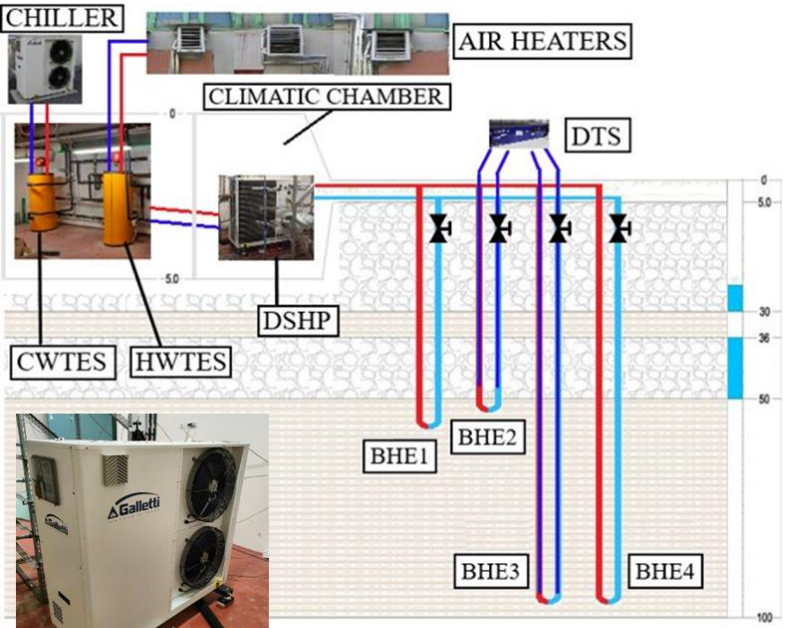
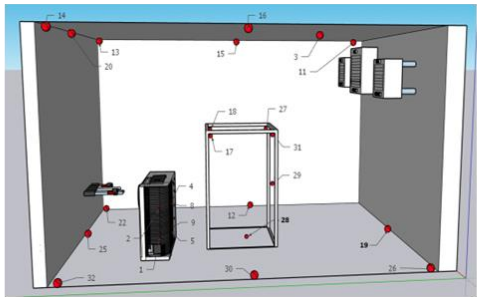
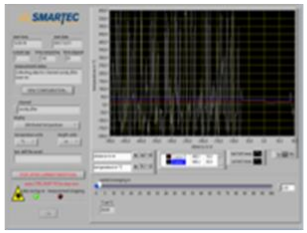
Hardware-In-the-Loop - HIL

Facility for experimental tests on air-source, ground-coupled and dual-source HPs

Test facility based on the Hardware-in-the-Loop approach to perform dynamic experimental runs



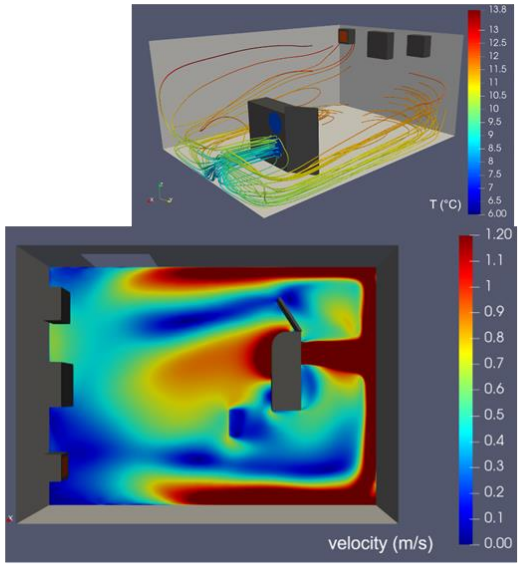




Monitoring and **control** system in **Labview**

Distributed Temperature Sensing system for **vertical BHE field**

CFD model of the climate chamber **validated with experimental data**



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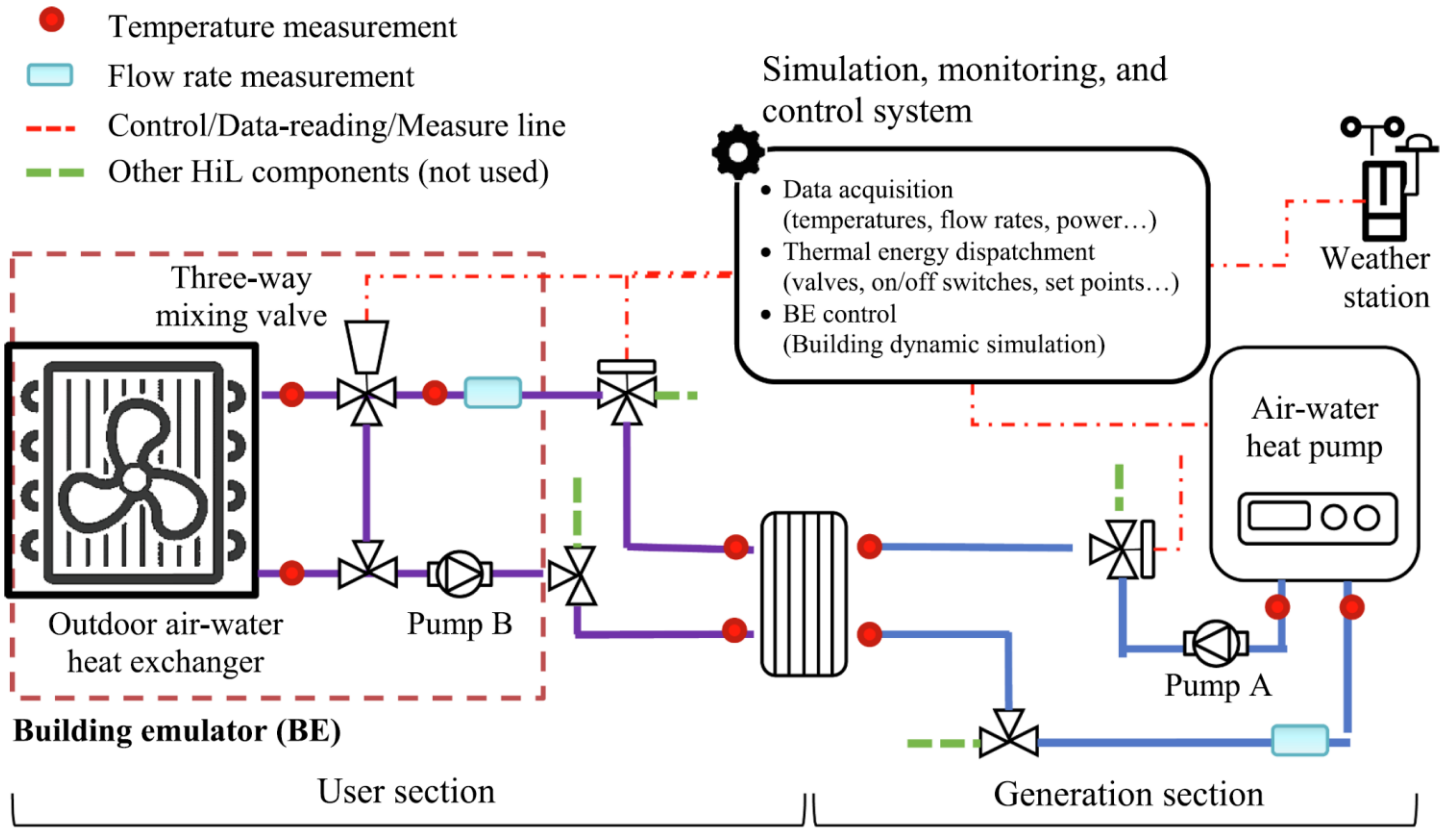
Hardware-In-the-Loop - HIL

A design methodology for thermal storages in heat pump systems to reduce partial-load losses



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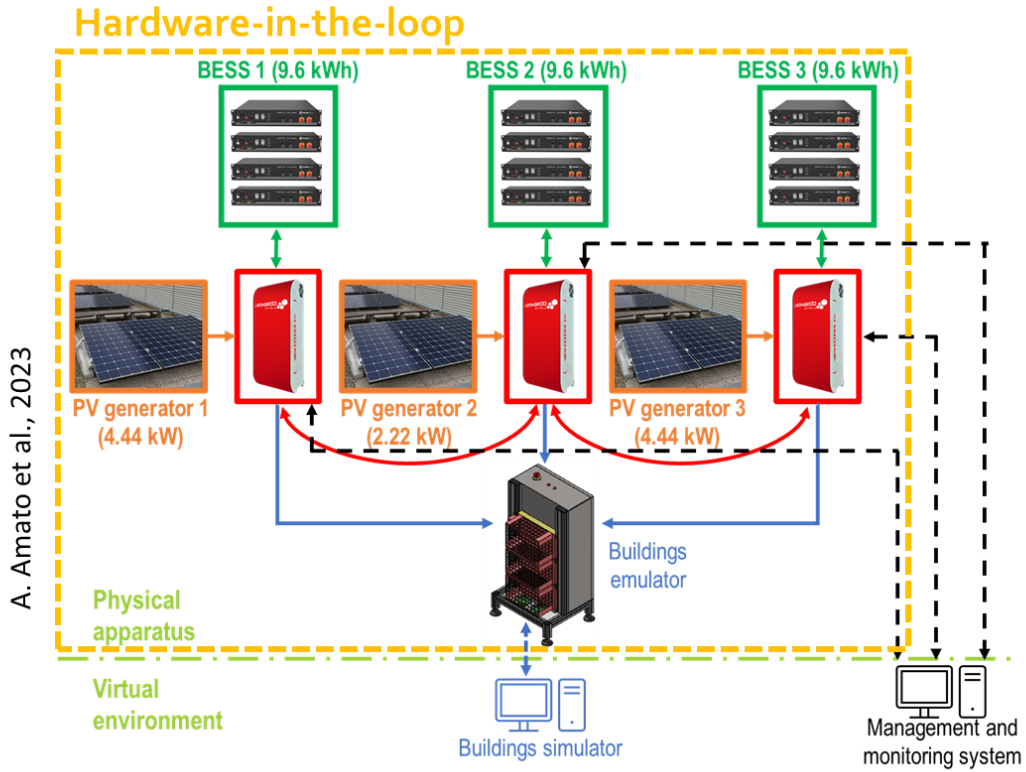
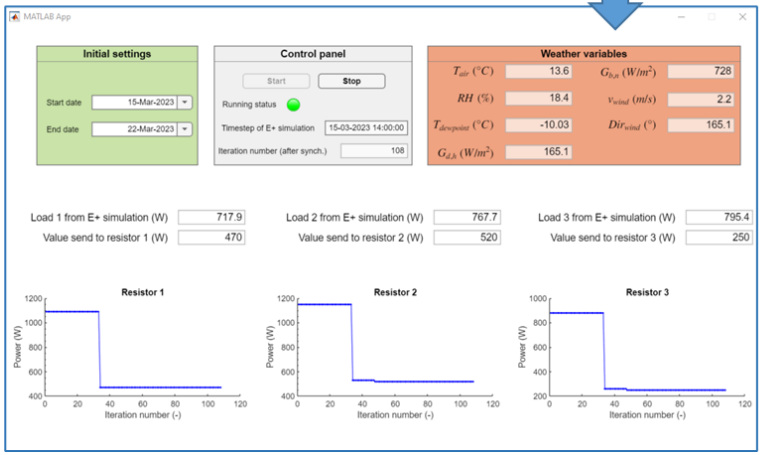
Hardware-In-the-Loop - HIL

A **Hardware-in-the-Loop Lab** for simulating different types of energy users and testing energy exchange algorithms within a virtual REC (Renewable Energy Community)





More info on https://pvzen.polito.it/

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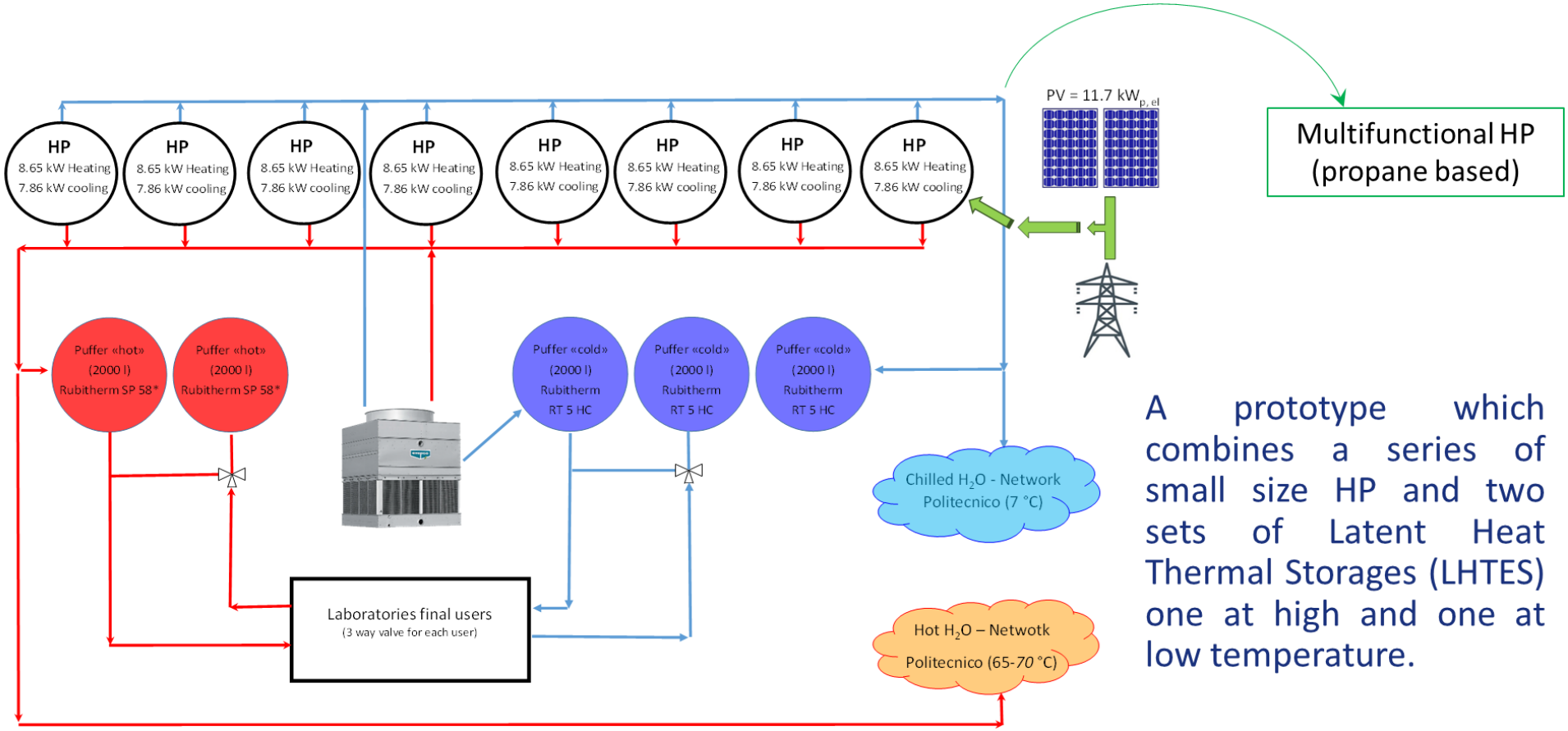
New labs

Design of a full-scale experimental facility to test, develop and optimize measures to foster the **energy flexibility in buildings**.



A prototype which combines a series of small size HP and two sets of Latent Heat Thermal Storages (LHTES) one at high and one at low temperature.

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Lessons learnt and conclusions

- The dynamic simulation models of numerous buildings-plant combinations, validated on a thoroughly database recovered for several types of buildings, eventually supplemented with HIL approaches, enables the implementation of robust optimization algorithms.
- The numerical tools could be used for the designers in order to reduce primary energy consumptions in the buildings sector in Europe, including residential, commercial and educational or service buildings.
- The choice of the refrigerant has a major impact on the heat transfer behaviour and accordingly on the HP performance.
- The design of the thermal storage has a direct impact on the HP efficiency and suitable control laws should be implement.
- The use of electrical storage integrated with HPs requires suitable dynamic control of the integrated system.
- Depending on the HP control characteristics and on a proper integration with electrical and thermal storages and with building components, remarkable energy savings can be obtained with a consistent step forward for carbon neutrality.

Many thanks!

Claudio Zilio

claudio.zilio@unipd.it