GEOFIT External Training

Perugia Pilot

(UNIPG)

27/09/22 – Sant’Apollinare PILOT (Italy)

This project has received funding from the H2020
programme under Grant Agreement No. 792210

1. Ex-stable of Sant’Apollinare Fortress

Demo Site – Sant’Apollinare Fortress (Perugia)

The case study **historic building** is represented by an old stable located inside a Benedictine fortress, **Sant’Apollinare Medieval Fortress, situated in Perugia** (Italy).

It is composed by **three different and detached buildings**: the main fortress, the ex-stable (which represents the pilot case study building) and the drying kiln.

Typology	Historic building of cultural value
Use of building	Open-to-the-public for sustainability training programme
Location	Perugia (Italy)
Date of construction	X-XI century
Building area	2 floor of 140 m^2 and a subterranean floor
Climate condition	Humid subtropical climate
Relevant installation	Centralized - biomass
Total energy consumption/year	86.107 kWh in all the fortress (29% in the stable-demo)

GBC HB (Historic Building) Certification

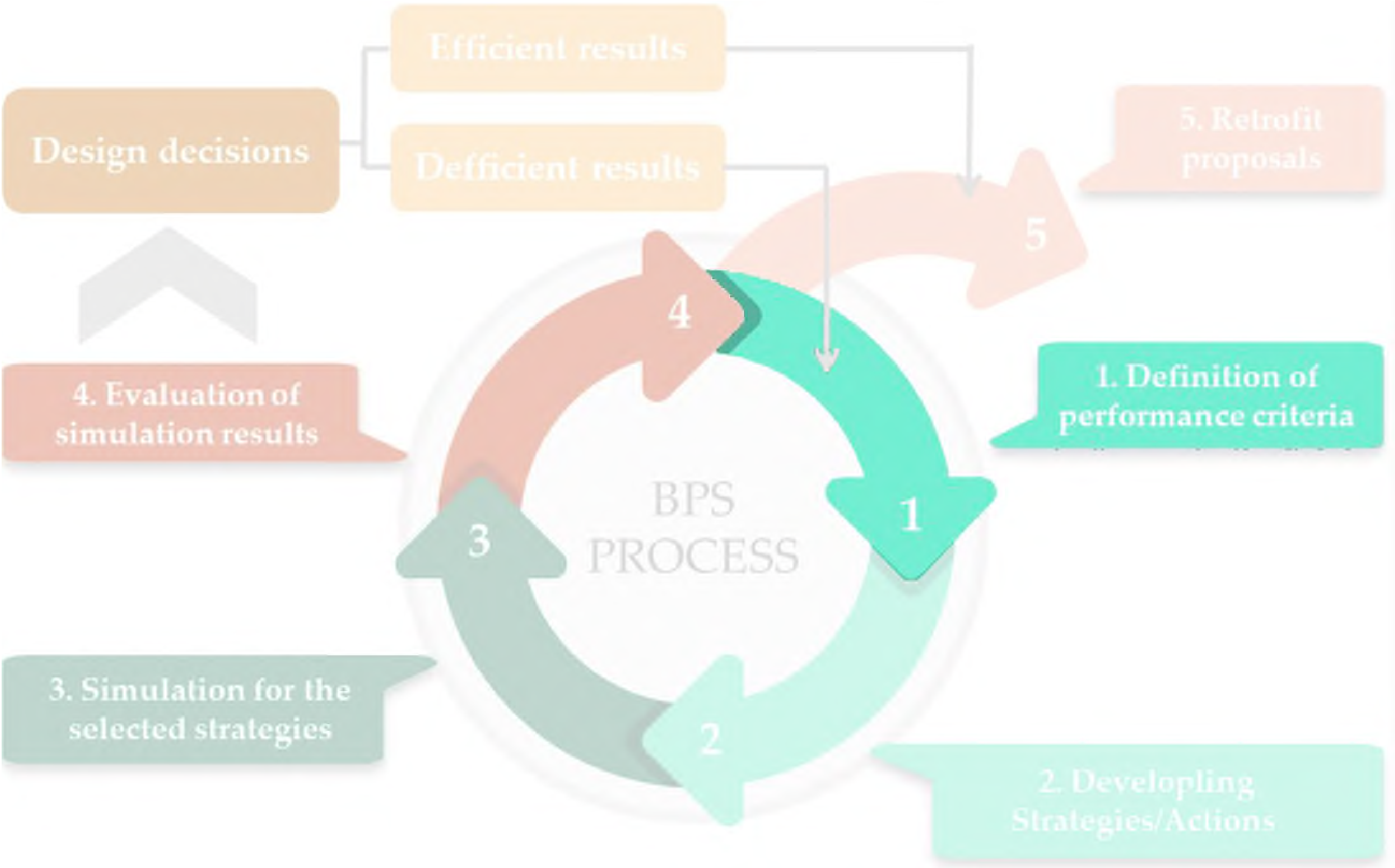
The major renovation interventions concluded are: **high-performance building envelope**, **recycled cork insulation**, **high-albedo materials** for the outdoor areas, **seismic consolidation**, **high efficiency system** (Mechanical Ventilation), ...

The building is the **first worldwide** that received the certification by **GBC Historic Building™** protocol (**Gold Certification**).

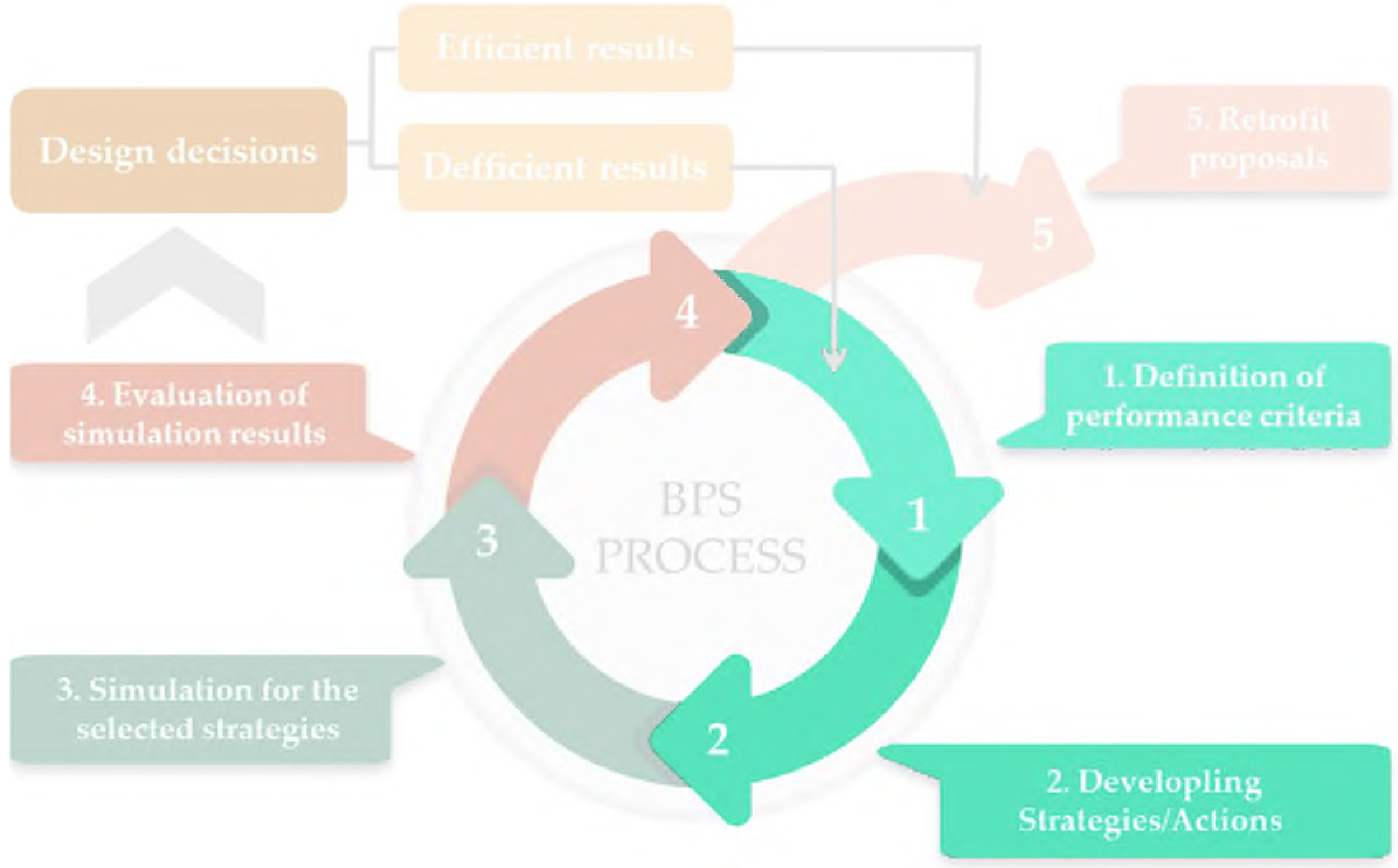
Historical Valence	Achieved score:	3/20
Sustainable Sites	Achieved score:	6/13
Water Efficiency	Achieved score:	7/8
Energy & Atmosphere	Achieved score:	29/29
Materials & Resources	Achieved score:	5/14
Indoor Environmental Quality	Achieved score:	13/16
Innovation & Design	Achieved score:	5/6
Regional Priority	Achieved score:	4/4

Certification level reached: **72/110 GOLD**

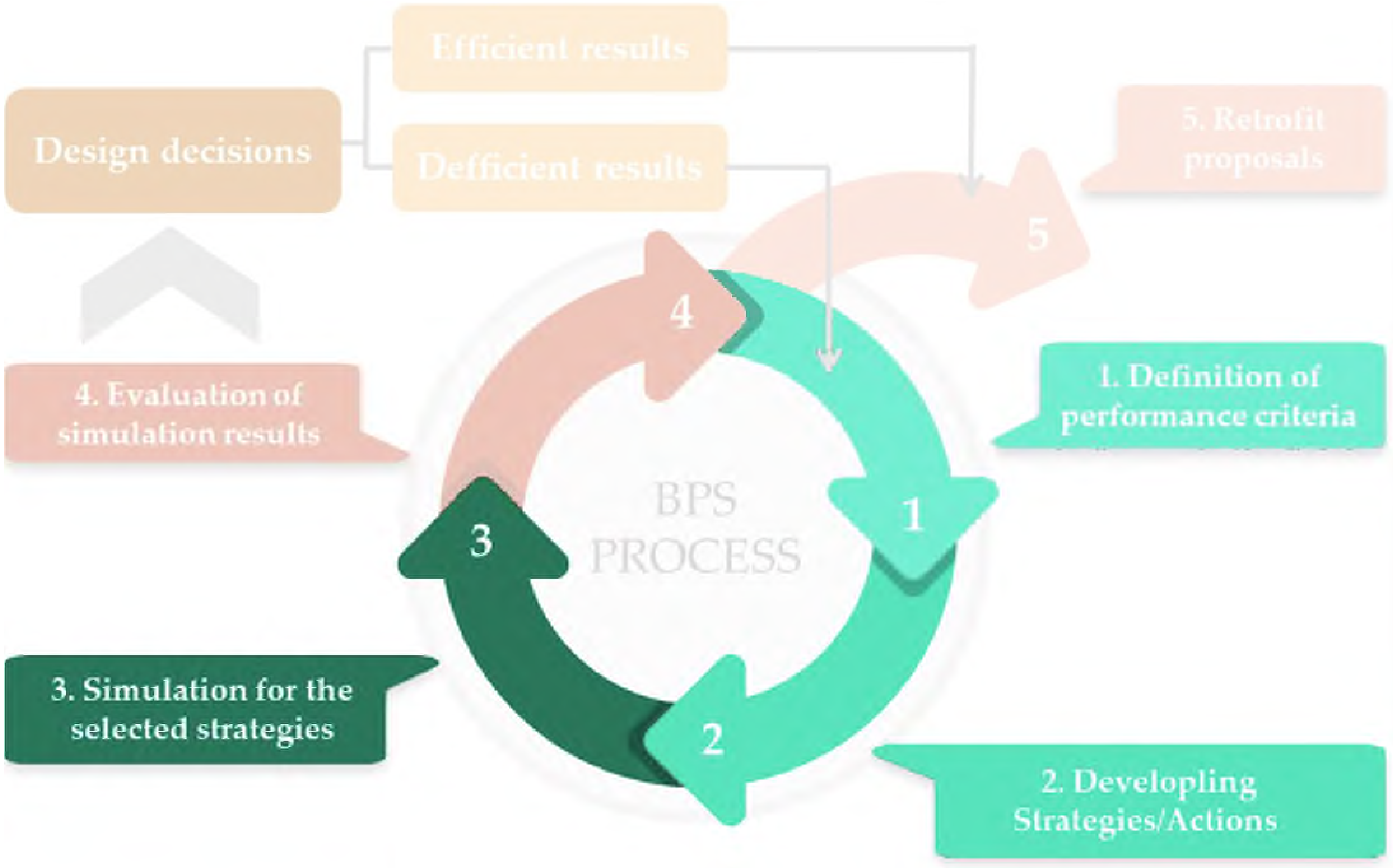
Energy retrofit procedure



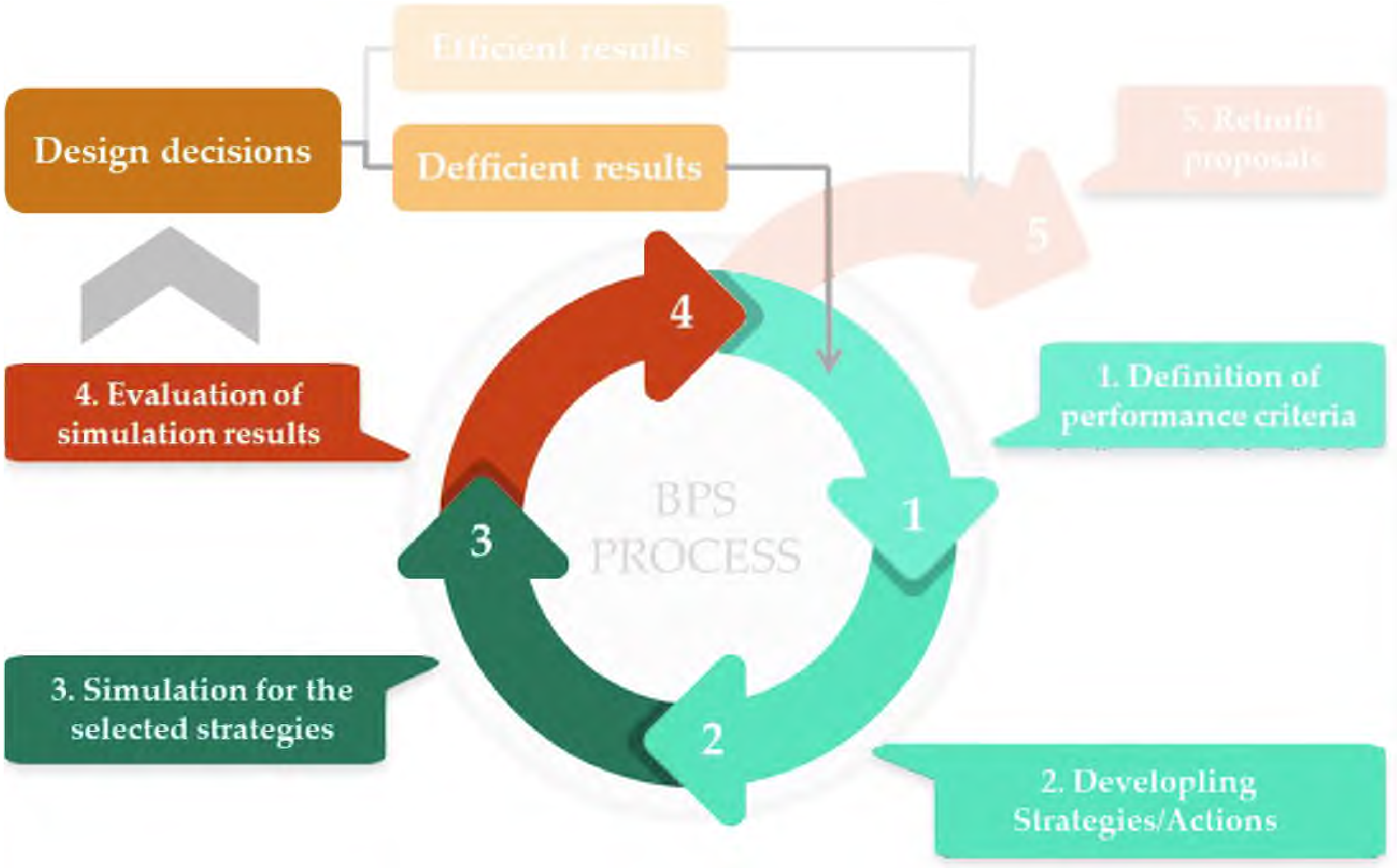
Energy retrofit procedure



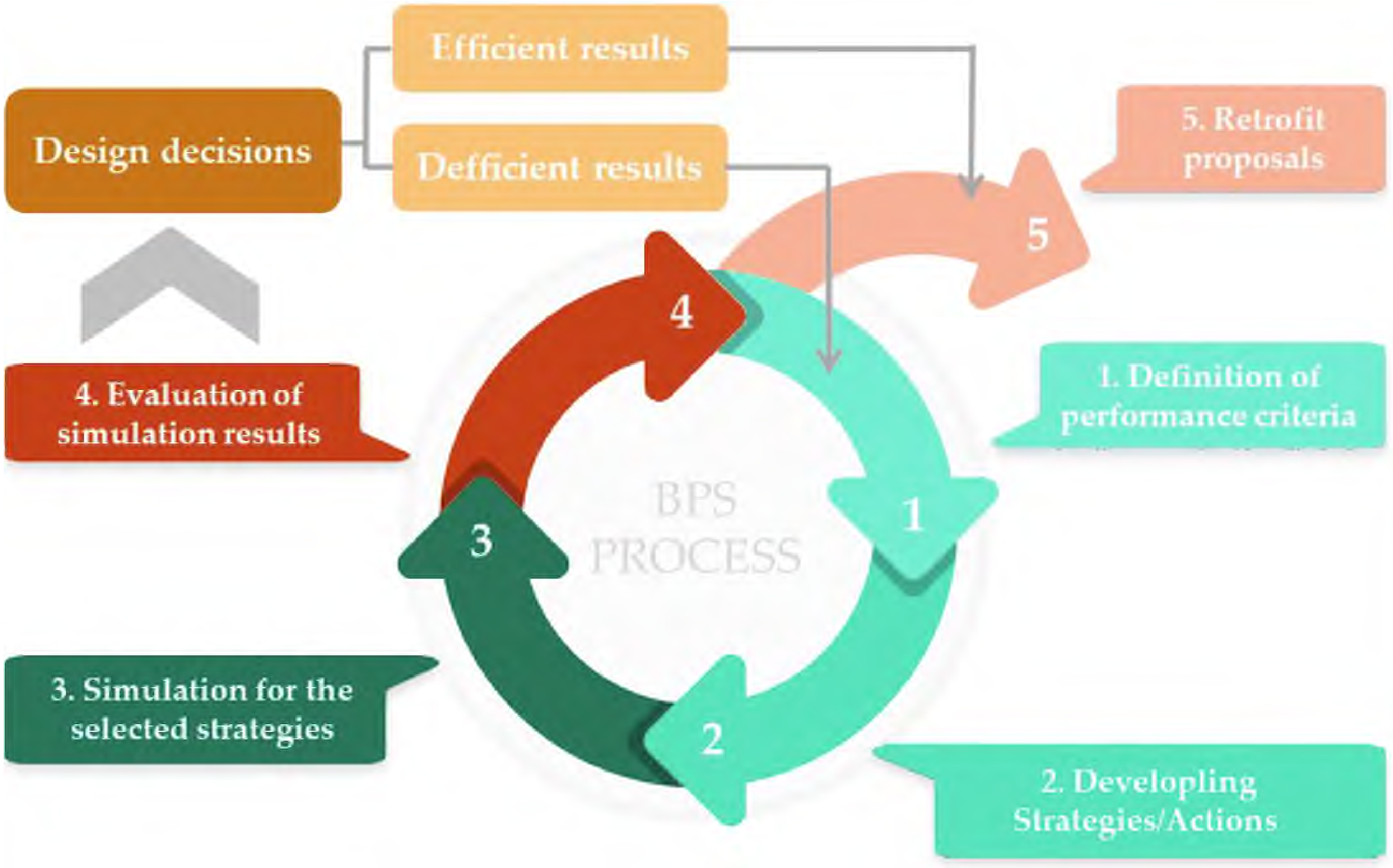
Energy retrofit procedure



Energy retrofit procedure



Energy retrofit procedure



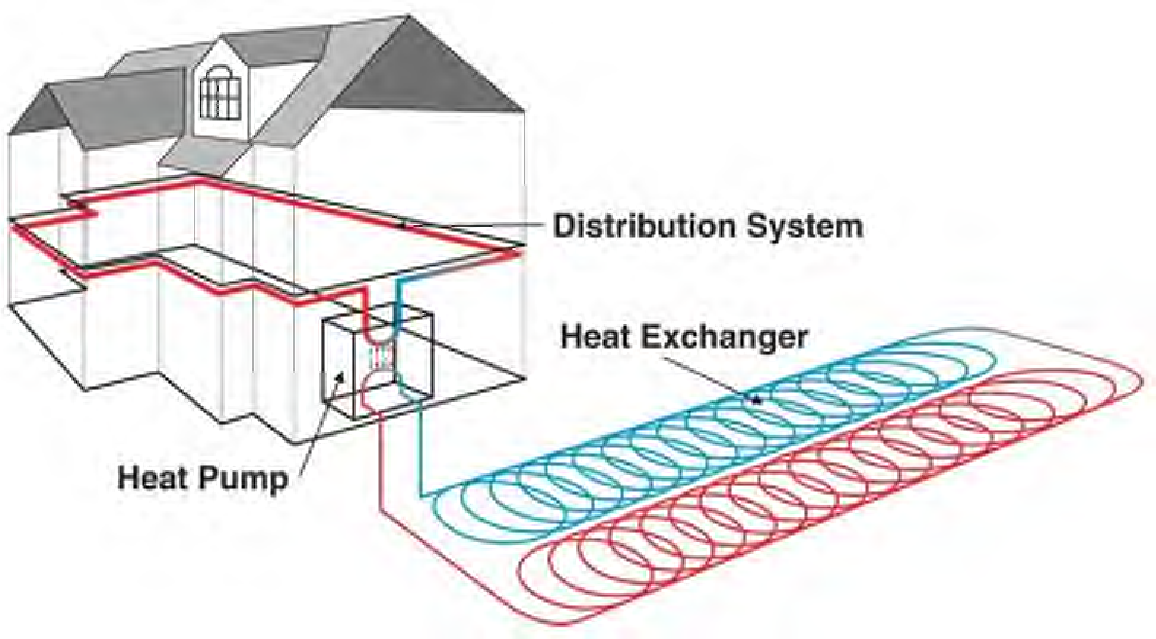
System design

The energy retrofit design process concerned:

1. **Ground Heat Exchangers**

2. **Hybrid Heat Pump**

3. **Interface** between the new and the existing system

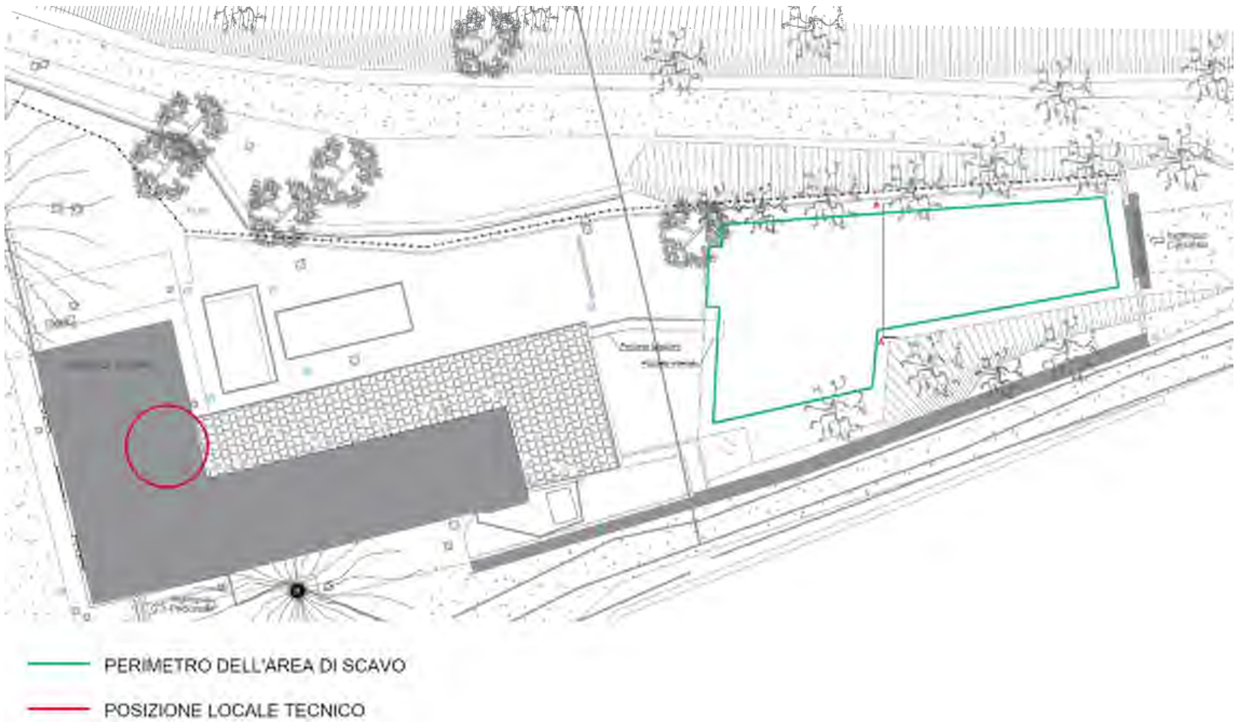


Ground heat exchangers

C**losed-loop GHEX** produced with pipes made of polyethylene **for heating and cooling**.

Design Overview

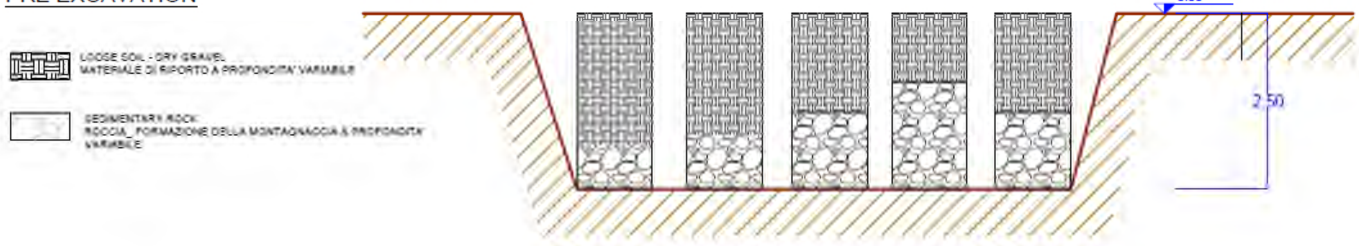
- Based on **simulated load data of 12 kW heating and 6 kW cooling**.
- Estimated **24 hour heating peak load** and **4 hour cooling peak load**.



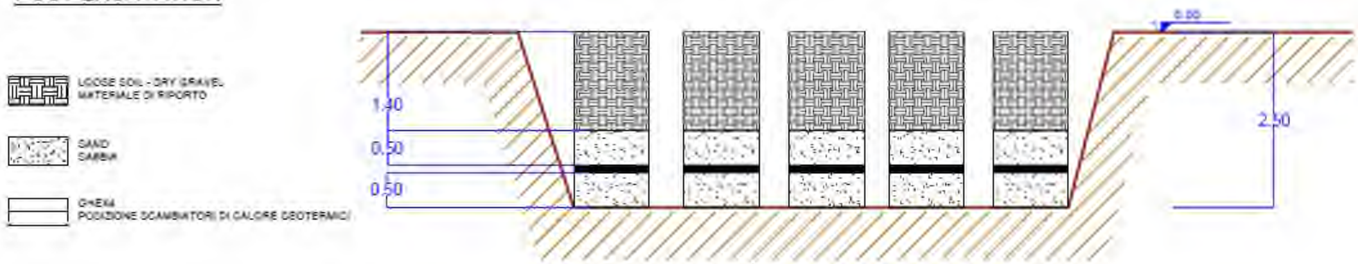
Ground heat exchangers

- **Excavations up to 2.5 m** with **50 cm of sand** above and below the pipelines.
- **Dripping system** introduced to irrigate the ground and locally increase thermal conductivity.
- **The excavated to backfill the area**.

PRE EXCAVATION

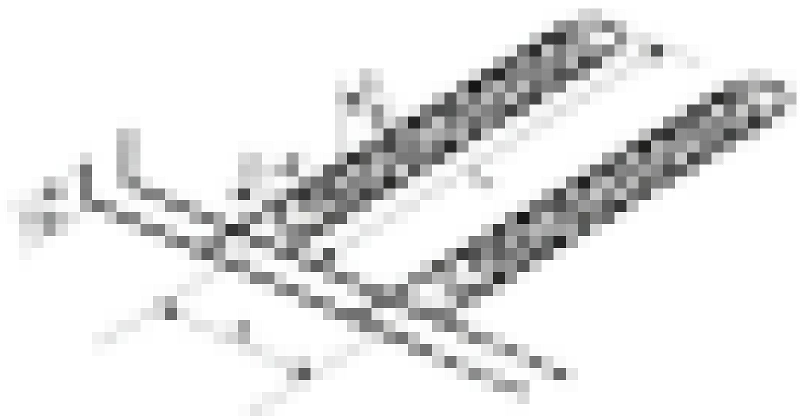


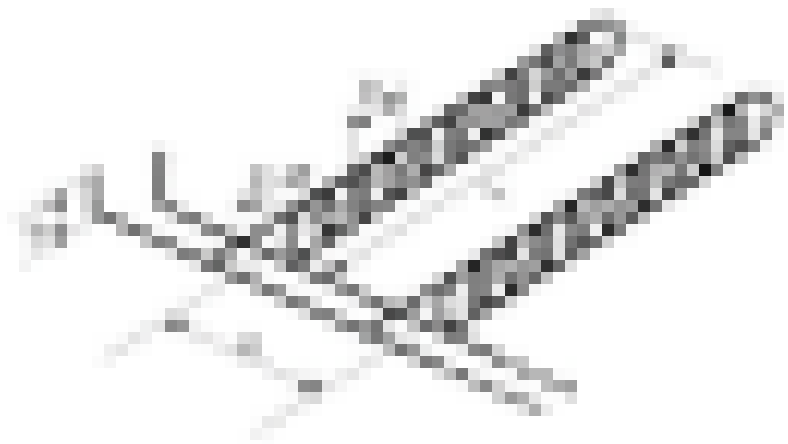
POST EXCAVATION



Ground heat exchangers

- **Shallow excavation** (up to 2.5 m) – SLINKY GHEX (2 m deep)
- **Nr of parallel trenches**: 5;
- **Distance between trenches**: 1.35 m;
- **Average length per trench**: 24 m (covering a total of 123m);
- **Ring diameter**: 1.1 m.

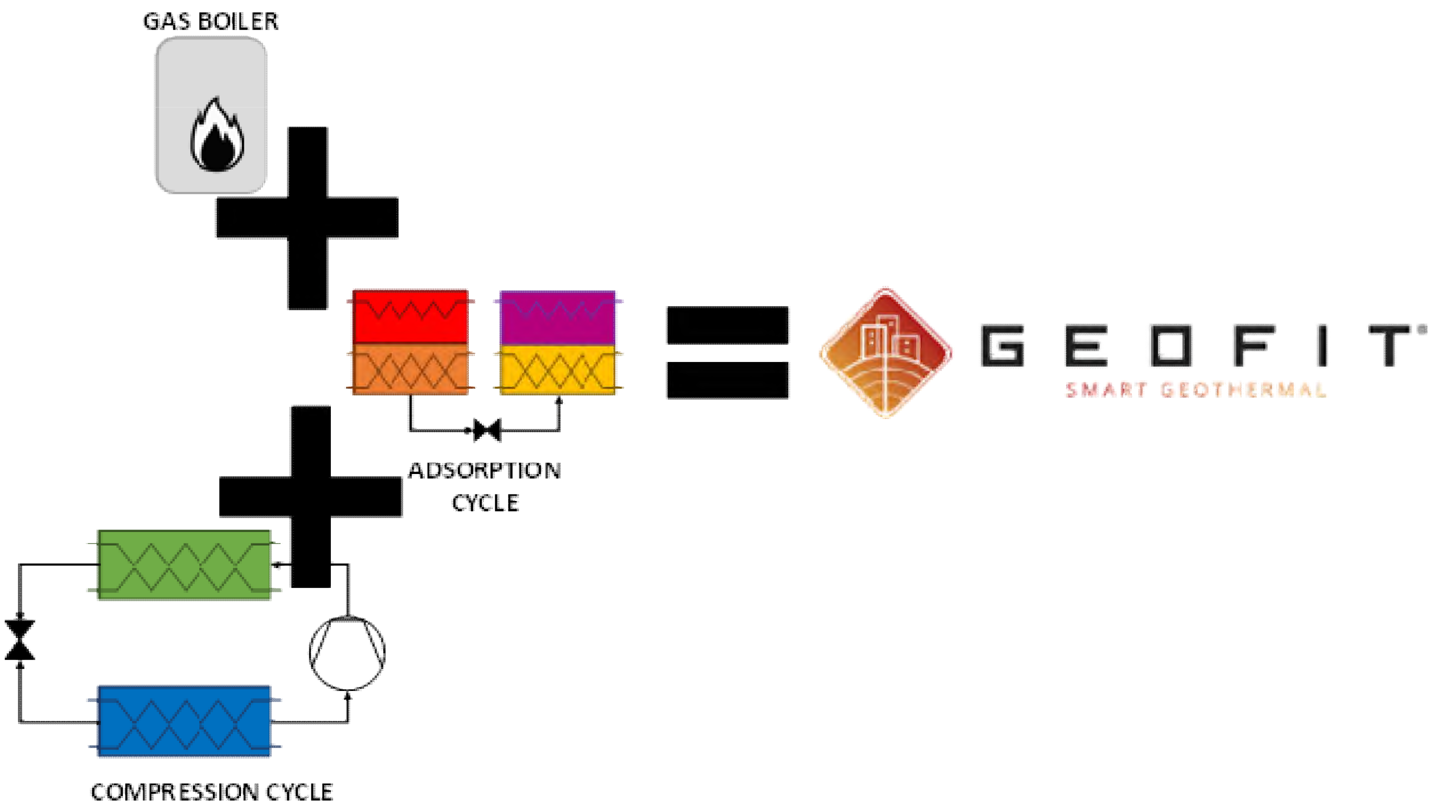




Hybrid Heat Pump

Consists of three main components:

1. **Gas boiler;**
2. **Adsorption unit;**
3. **Vapor compression unit.**

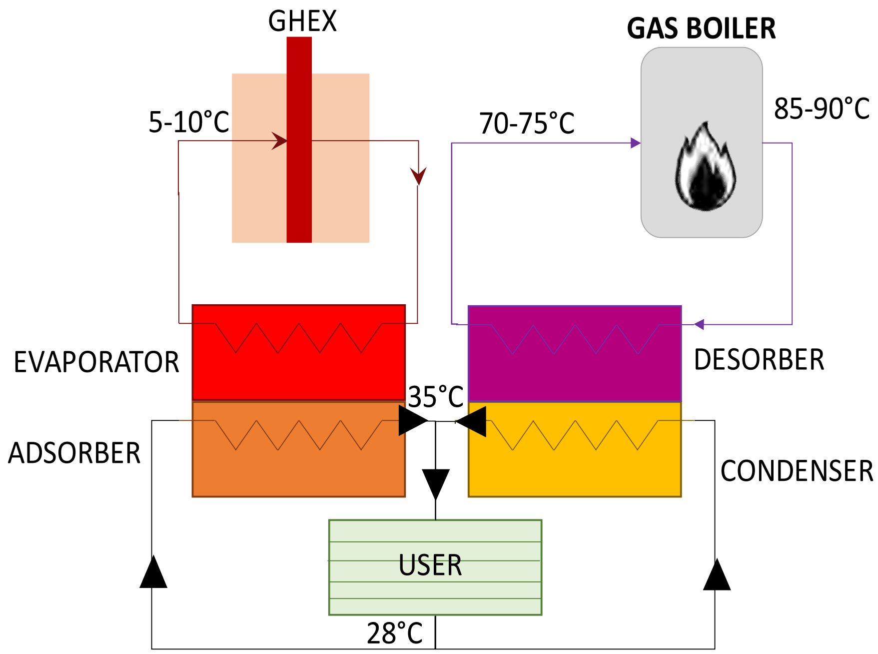


Hybrid Heat Pump

The gas boiler is operated **as heat source** to **drive the adsorption cycle**.

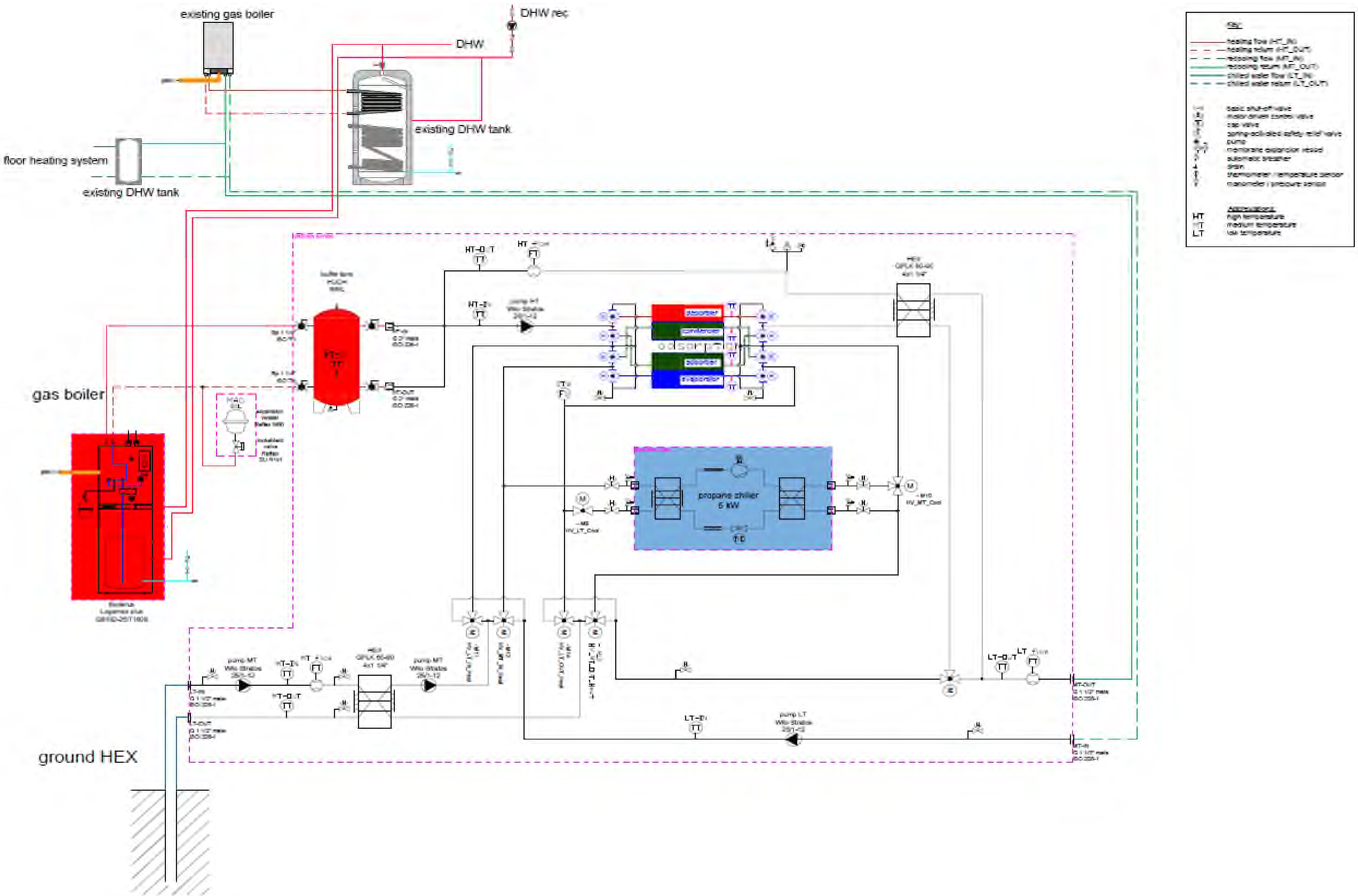
The gas-driven heat pump is **coupled to the compression cycle**, which is mainly employed to **provide space cooling**.

Ground source heat exchanger represents the **heat source/sink** for the operation of the overall system in winter and summer.

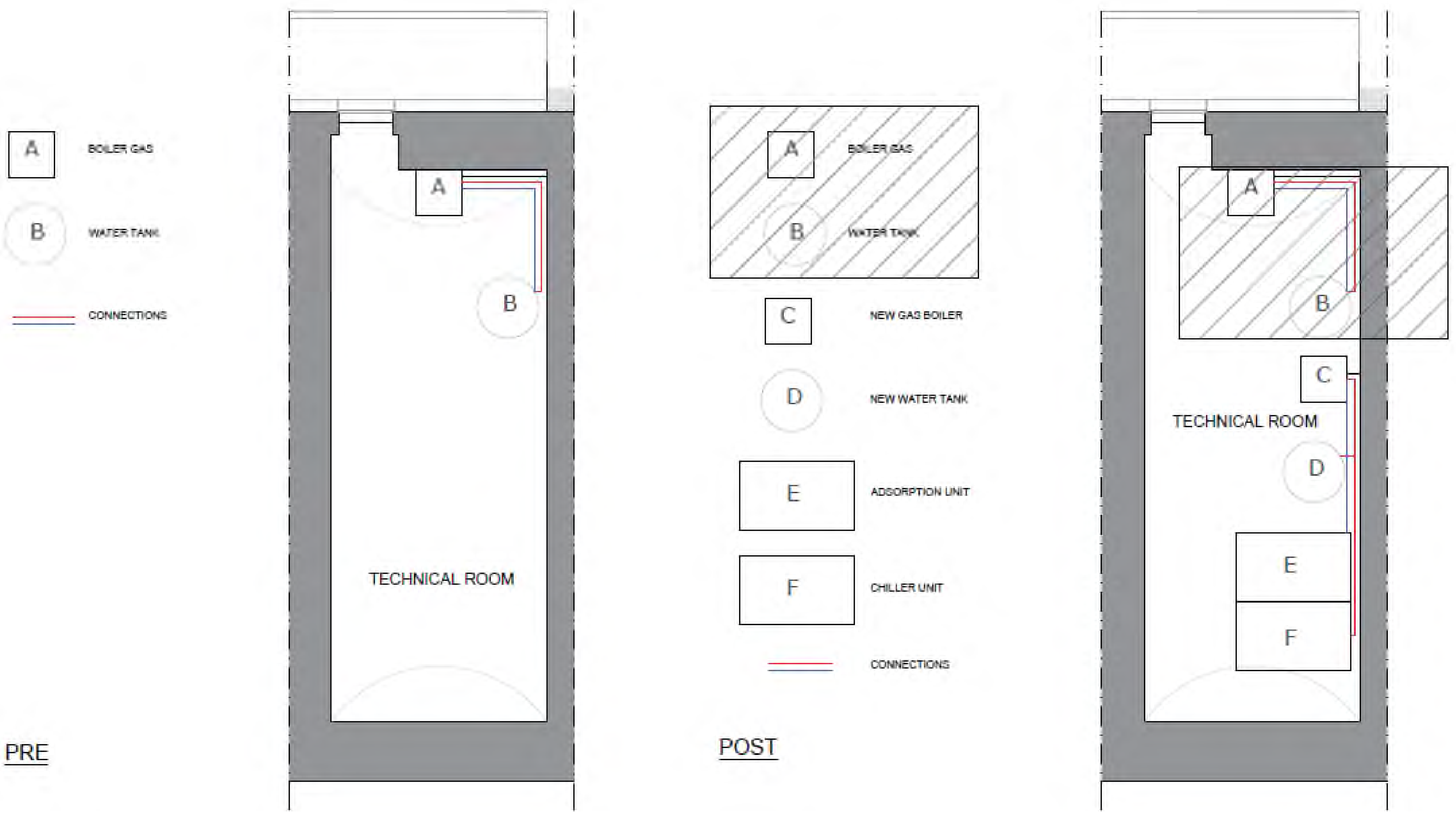


Compared to electric-driven systems, **the thermally-driven heat pump requires a lower amount of heat at the evaporator**, thus allowing the installation of a **smaller geothermal field**, which is a beneficial feature when evaluating retrofitting solutions.

2. Energy and comfort



Existing system will be maintained as backup and maintenance reasons. Considering the use of the building, different systems could be showed during training and students' visit.



Pre-intervention monitoring

Energy Monitoring

- Electricity consumption
  → (whole building)
- Heat consumption
  → (whole building)
- Gas consumption
  → (whole building)

Microclimate Monitoring

- Indoor temperature
- Indoor CO_2
- Indoor relative humidity
- Noise level
- Outdoor temperature
- Outdoor relative humidity
- Pressure
- Wind gauge

Structural monitoring

- Comfort analysis
- Structural damages
- Ambient vibration tests

Microclimate and energy pre-intervention monitoring

Nr	Source/Type	Parameter (units)	Data acquisition	Measurement point (By UNIPG - iLECO)
1	**Electricity meter**	Electricity power (W) Electricity consumption (kWh)	15 min 60 min	General electric panel (underground floor) (maximum power registered every 15min)
2	**Heat meter**	Heating consumption (kWh)	15 min	Near the existing boiler (technical room)
3	**Gas meter**	Gas consumption (m3)	Progressive	Connection point to the authority line (near the outdoor access)
4	**Climate station (main station) Netatmo**	Indoor T (°C) Indoor RH (%) Noise level (dB) Indoor CO_2 (ppm)	15 min	Office (ground floor)
5	**Climate station (outdoor module) Netatmo**	Outdoor T (°C) Outdoor RH (%)	15 min	North-West façade
6	**Climate station (wind meter) Netatmo**	Wind speed (km/h) Wind direction (°N)	15 min	North-West façade
7	**Indoor microclimate station UNIPG**	Indoor T and RH (°C) (%) Indoor CO_2 (ppm) VOC (ppm) MRT (°C) Air speed (m/s) Turbulence (%)	10 min	Office (ground floor)

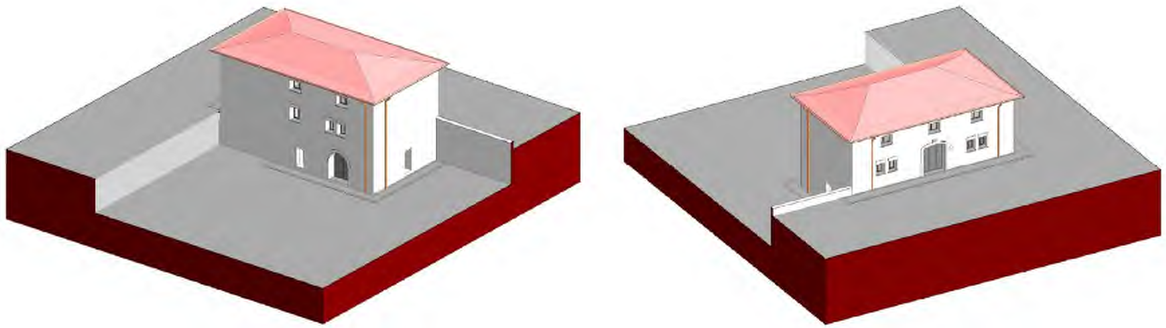
Microclimate and energy pre-intervention monitoring

Nr	Source/Type	Parameter (units)	Data acquisition	Measurement point (By UNIPG - iLECO)
8	**Climate station (outdoor) UNIPG**	Outdoor T (°C) Indoor RH (%) Wind speed (m/s) Wind direction (°N) Pressure (hPa) Global radiation (W/m^2) Direct radiation (W/m^2) Outdoor CO_2 (ppm) Precipitation (mm)	10 min	North-West (next to the gate)



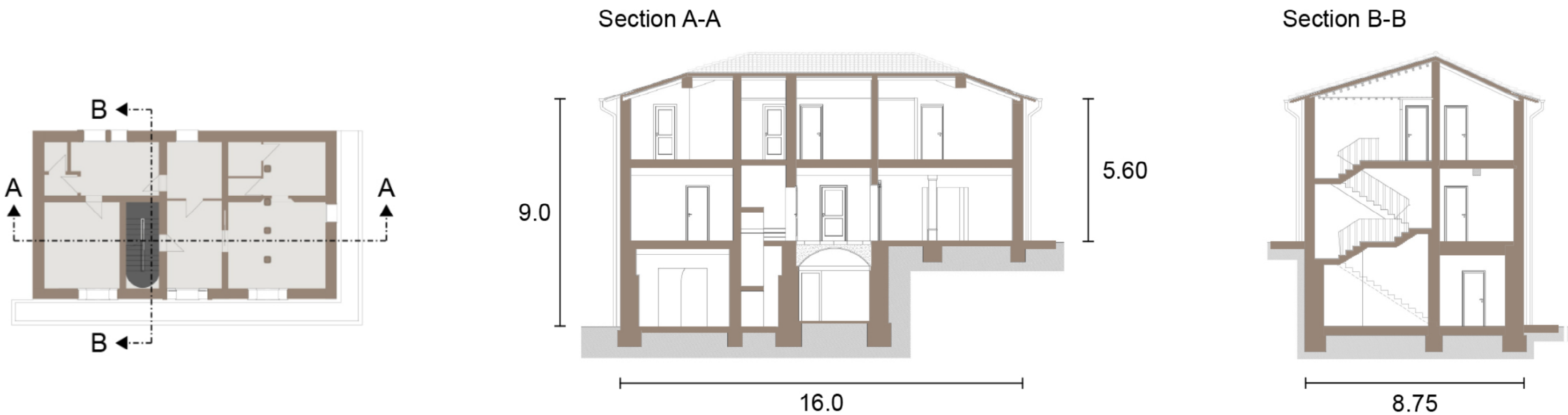



HBIM model

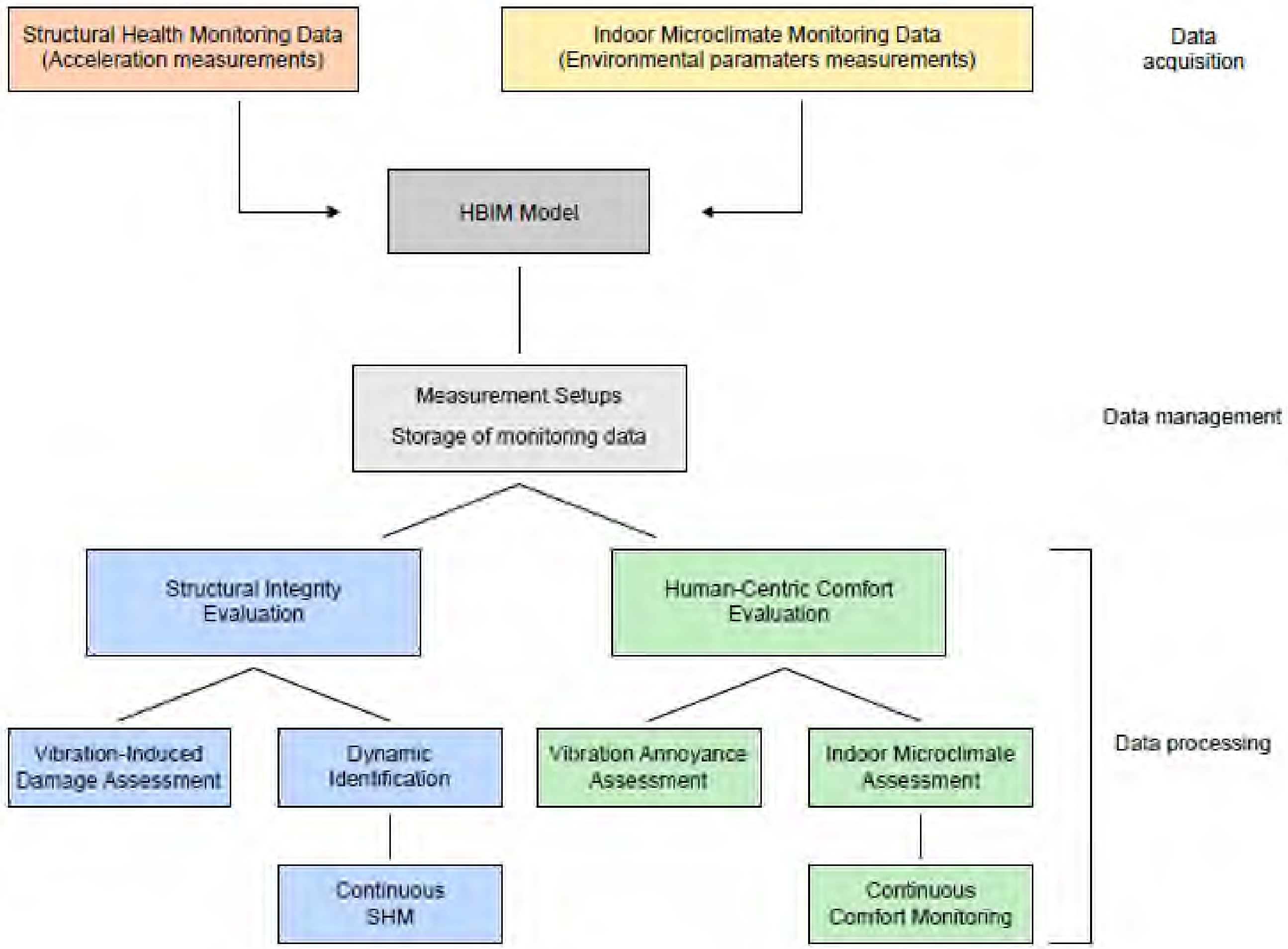


Building model: simplified Revit model using **HBIM** (Historical Building Information Modeling).

The same HBIM model is **used both for structural and microclimate monitoring**.



Methodology Architecture



Flowchart representing the methodology proposed to evaluate the structural performance of historic buildings and the human-centric comfort of their occupants in HBIM.

1 Human-centric Comfort

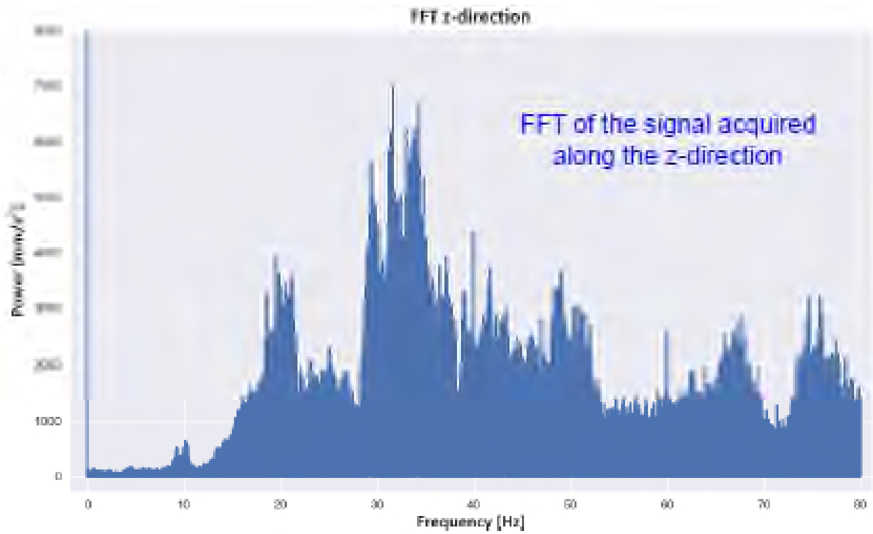
<u>Vibration Annoyance Assessment</u>:

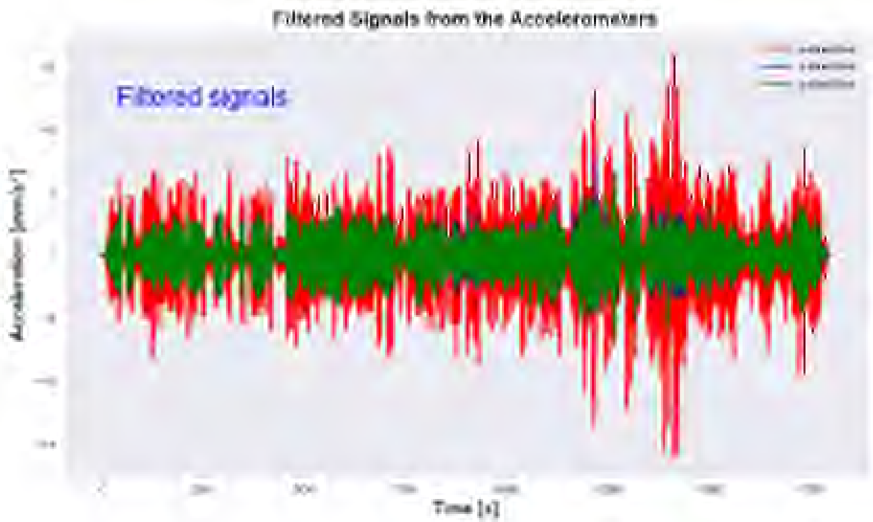
Vibration annoyance assessment for the occupants of historic buildings according to the prescriptions provided by the Italian Technical Standard UNI 9614.

A study of vibrations is carried out in order to assess **their influence on the comfort of people in the building**, considering acceleration data and environmental parameters.
Its application includes **vibrations produced by sources that are both internal and external to the monitored structure**, yet excluding those of seismic nature.

Results: within the regulatory limits.

The vibrations induced by the excavation phases have not affected the comfort of the people.

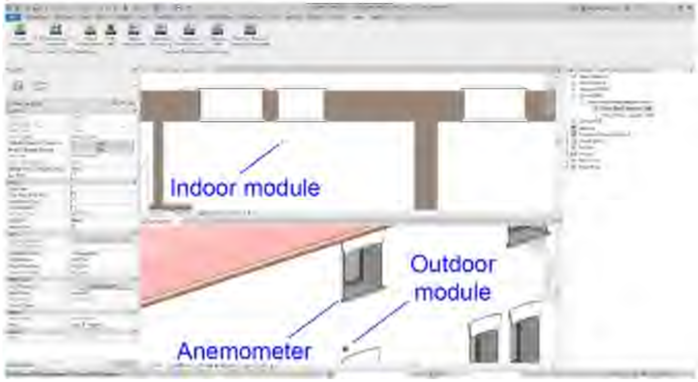


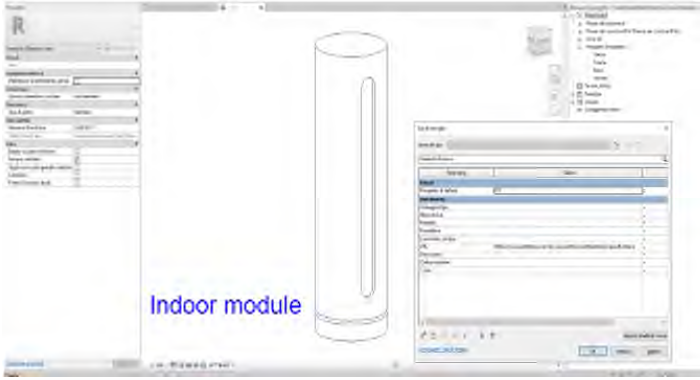


1 Human-centric Comfort

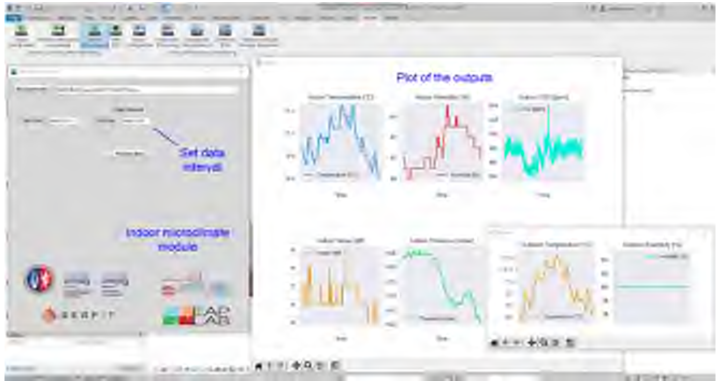
Indoor Microclimate:

Shows the **measurements made by dedicated microclimate monitoring sensors**, both inside and outside the building in a selected time interval.





Measurement setup adopted to perform indoor and outdoor microclimate monitoring with details of the designed Revit family for the indoor module



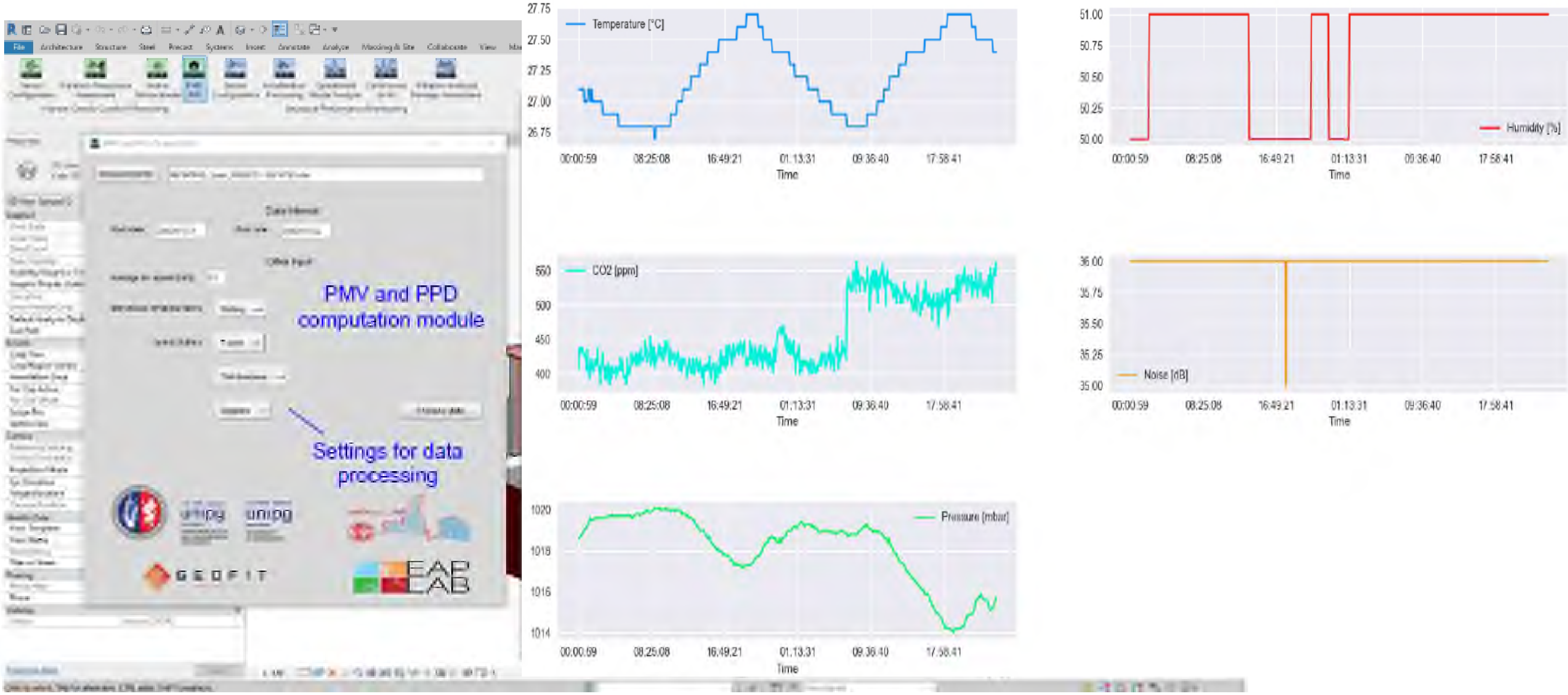
Screenshots from the Indoor microclimate module used to process and visualize the microclimate measurements acquired from the sensors.

1 Human-centric Comfort

Predicted Mean Vote and Predicted Percentage of Dissatisfied Computation:

To assess the human-centric thermal comfort conditions under the prescriptions provided by the Technical Standard EN ISO 7730.

This application processes the data that potentially are continuously monitored in terms of indoor and outdoor microclimate conditions.



2 Structural Performance

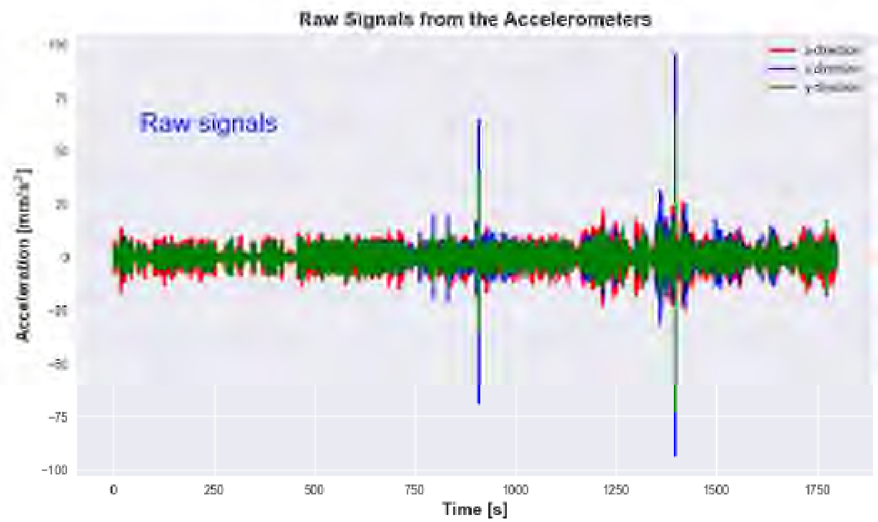
Vibration-Induced Damage Assessment:

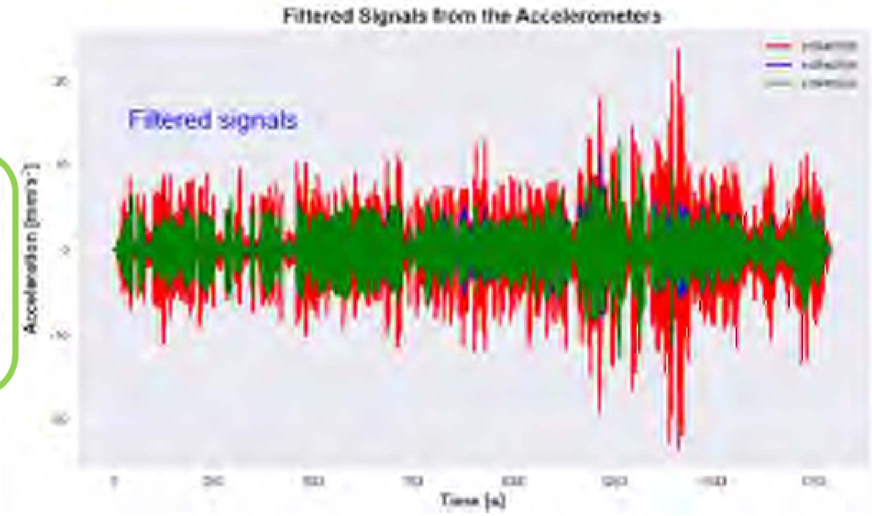
Assessment of **vibration-induced structural damages** under the prescriptions provided by the Italian Technical Standard UNI 9916.

Accordingly, its application includes **vibrations produced by sources that are both internal and external to the monitored structure**, such as those induced by explosions, tracks, and construction sites, yet excluding vibrations of seismic nature.

Results:

Excavation operations produced peak velocity values that were within the regulatory limits, therefore not capable of inducing structural damages.





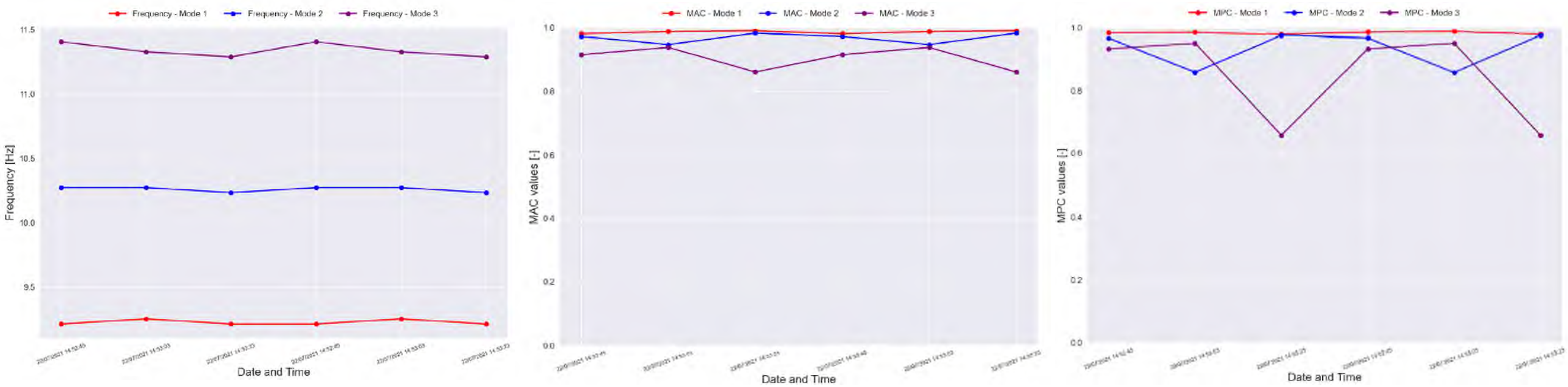
2 Structural Performance

Operational Modal Analysis:

Assessment of the **dynamic response of a structure under ambient vibrations** by means of the retrievement of its modal features. Also in this case, the **vibrations induced by the excavation operations did not lead to structural changes in the building**.

Continuous SHM:

Once the **baseline natural frequencies** of a structure are identified, **this module allows their tracking over time**, which can be used for **damage detection** via statistical pattern recognition approaches **in long-term monitoring** applications by using control charts.

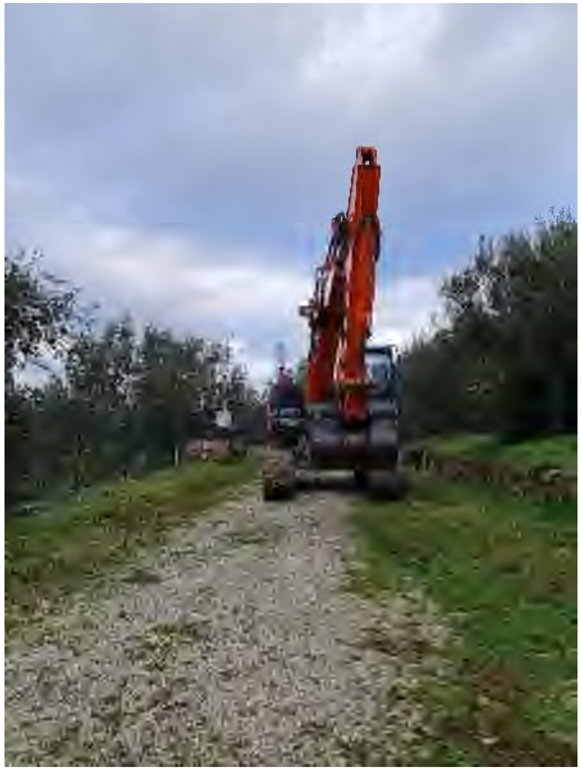


(a) (b) (c)

Continuous SHM module: (a) Tracking of the main natural frequencies of the case study building; (b) Tracking of the MAC values of the tracked mode shapes; (c) Tracking of the MPC values of the tracked mode shapes.

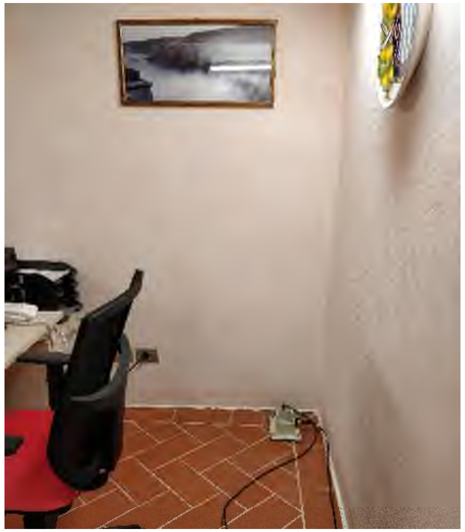
Installation steps

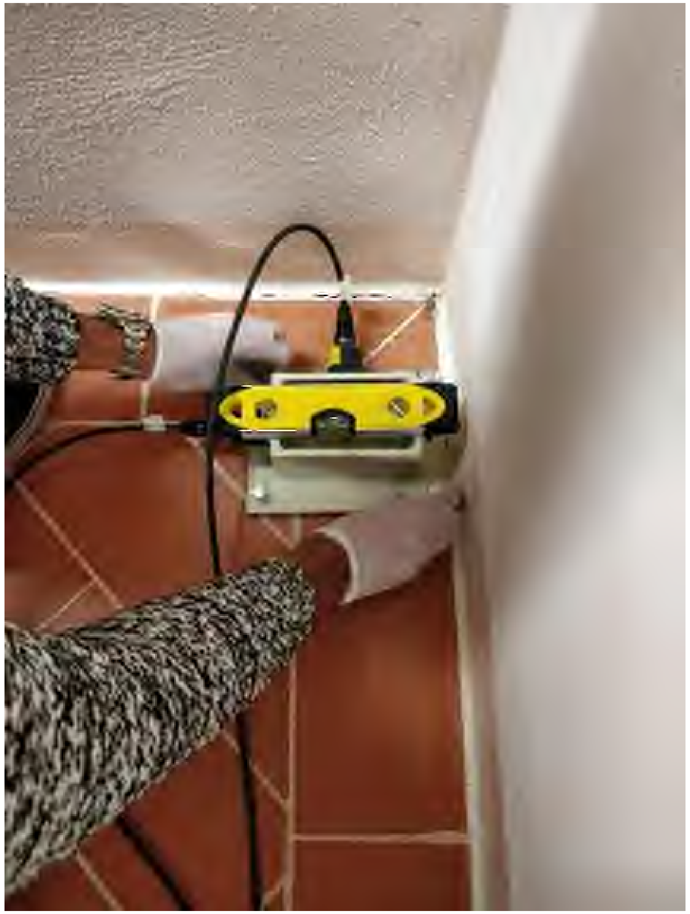
- On **December 3rd, 2020** civil works started in Perugia Pilot with the support of the partners IDSGEORADAR for performing a Ground Penetrating Radar measurements survey and R2M for performing UAV flights with and without thermal camera.



- The day before, the HP with the new gas boiler and the water thank were delivered in the pilot thanks to FAHR.

UNIPG completed the **Structural Health Monitoring** (SHM) before, during, and after the drilling phase (All the conditions were satisfied without any displacement).





3. Installation of the system

3. Installation of the system

- After one week, shallow excavations up to 2.5 m deep were completed and the area was ready to put 50 cm of sand bed to increase the **conductivity** on the ground.



- To be able to install the **GHEXs** considering the exactly design geometry, GROEN advised the use of metal grid that helped the company to respect all the design dimensions.

3. Installation of the system

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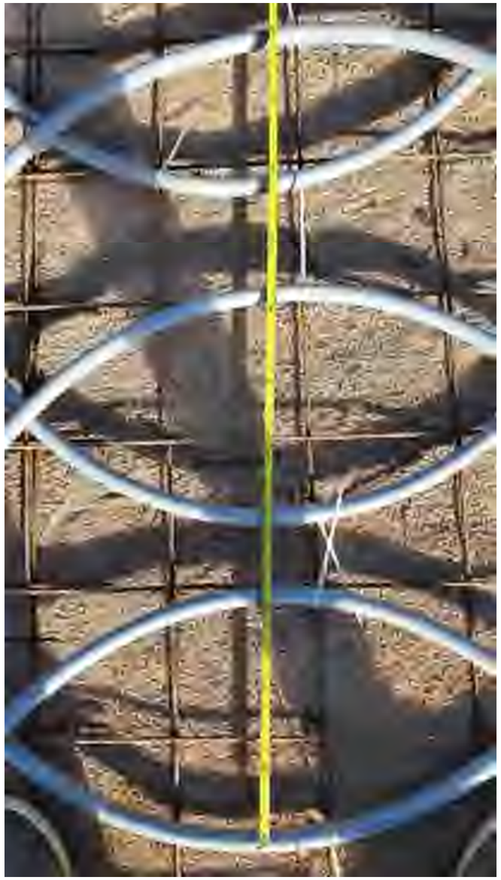
- On **January 11th, 2021** the company in charge of the whole field work started the installation of slinky GHEXs (2 m deep) considering 5 parallel trenches, with 1.35 m mutual distance, 24 m average trench length, and 50 rings for each trench.



3. Installation of the system

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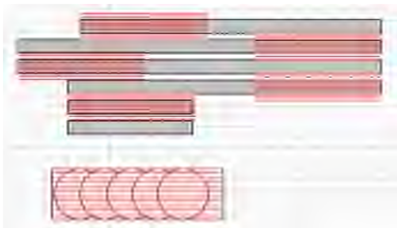
- After the GHEXs installation, on **January 18th**, GROENHOLLAND came at Perugia Pilot to install the FOC monitoring with a particular approach that allows to check remotely the performance of the new system, while matting underground temperature.



3. Installation of the system

- To increase the innovative aspects and the scientific relevance, UNIPG decided to install two parallel tubes of a **drip plant** (on the first two trenches) to carry out experimental evaluations and comparison considering different boundary conditions and configurations, such as with varying ground hydration content.

- Civil works were completed on January 28th with all the excavated area backfilled with other 50 cm of sand and the ground excavated material that was reused on site.

3. Installation of the system

3. Installation of the system

- All the heating/cooling system components (**heat pump, boiler, tank, chiller**) were installed at UNIPG pilot and connected to the existing system.



3. Installation of the system

- On **April 21st, 2021** UNIPG with CNR on site and FAHR from remote connection moved forward with the **commissioning of the GeoFit system**.

3. Installation of the system

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4. GEOFIT system - overview

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Microclimate and energy post-intervention monitoring

Nr	Source/Type	Parameter (units)	Data acquisition	Measurement point (By UNIPG - iLECO)
1	Electricity meter Electrex	Electricity power (W) Electricity consumption (kWh)	15 min 60 min	General electric panel (underground floor) (maximum power registered every 15min)
2	**Electricity meter Gavazzi EM210**	System electricity consumption (kWh)	15 min	System electric panel (technical room)
3	**Heat meter AR-Therm Excelsius M-Bus**	Heating and cooling consumption (kWh)	Progressive (15 min with BMS)	Near the existing boiler (technical room)
4	Gas meter Domusnext G4 M-Bus	Gas consumption (m3)	Progressive	Connection point to the authority line (near the outdoor access)
5	**BMS monitoring XWeb**	Room T (°C) Room RH (%) …	15 min	Building/each conditioned room
6	Climate station (main station) Netatmo	Indoor T (°C) Indoor RH (%) Noise level (dB) Indoor CO_2 (ppm)	15 min	Office (ground floor)
7	Climate station (outdoor module) Netatmo	Outdoor T (°C) Outdoor RH (%)	15 min	North-West façade
8	Climate station (wind meter) Netatmo	Wind speed (km/h) Wind direction (°N)	15 min	North-West façade

Microclimate and energy post-intervention monitoring

Nr	Source/Type	Parameter (units)	Data acquisition	Measurement point (By UNIPG - iLECO)
9	Indoor microclimate station UNIPG	Indoor T and RH (°C) (%) Indoor CO_2 (ppm) VOC (ppm) MRT (°C) Air speed (m/s) Turbulence (%)	10 min	Office (ground floor)
10	Climate station (outdoor) UNIPG	Outdoor T (°C) Indoor RH (%) Wind speed (m/s) Wind direction (°N) Pressure (hPa) Global radiation (W/m^2) Direct radiation (W/m^2) Outdoor CO_2 (ppm) Precipitation (mm)	10 min	North-West (next to the gate)

Post-intervention monitoring

Energy Monitoring

- Electricity consumption
  → (whole building)
- Heat consumption
  → (whole building)
- Gas consumption

Structural monitoring

- Ambient vibration tests

Microclimate Monitoring

- Indoor temperature
- Indoor CO_2
- Indoor relative humidity
- Noise level
- Outdoor temperature
- Outdoor relative humidity
- Pressure
- Wind gauge

Additional monitoring

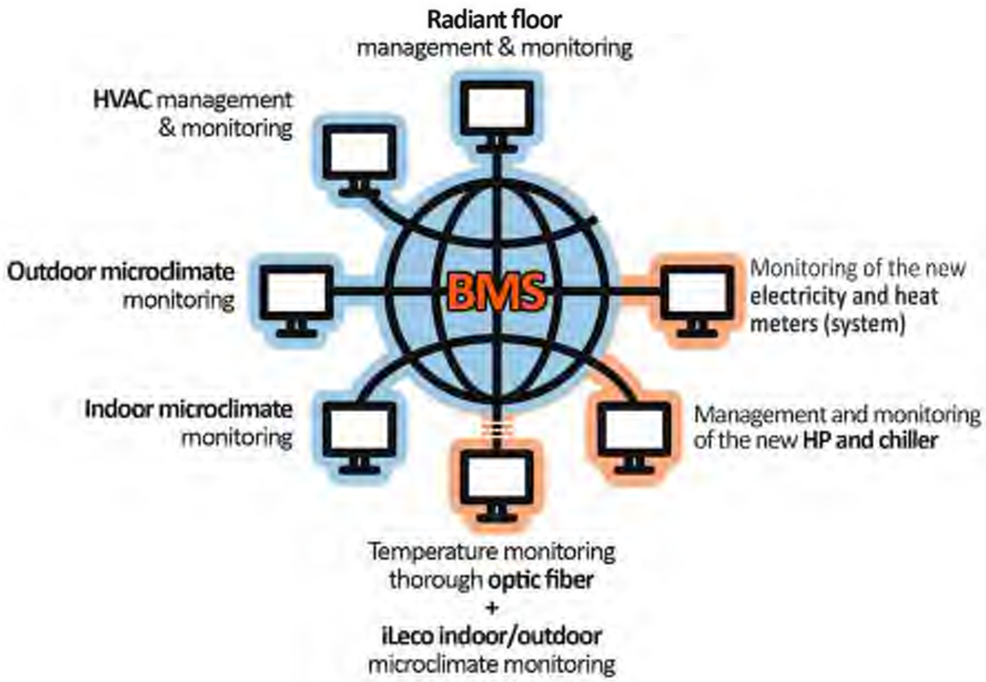
- Temperature fiber optic monitoring
- Internal monitoring of the heat pump and chiller
- System heat production
- System energy consumption
- Temperature and pressure monitoring of the circuits
- Water consumption from the drip irrigation system

<u>Results from the on-site monitoring will be used **to calculate the GEOFIT saving**</u>:

- monitored energy **consumption of the GeoFit system**;
- monitored **COP of the hybrid HP**.

Structure of the new monitoring/managing system

UNIPG is currently **updating the existing monitoring/managing system of the Demo Site** for implementing the new Geofit equipment and the related probes.
The system uses a MODBUS RS485 routine and reads the following inputs:



Parameter	Unit	Time step
T_air (for each room)	°C	15 min
RH_air (for each room)	%	
T_ext	°C	
T_out radiant floor	°C	

Parameter	Unit	Time step
T SET	°C	15 min
Setpoint Burner	°C	
Setpoint Heating	°C	
T HT IN	°C	
T HT OUT	°C	
T MT IN	°C	
T MT OUT	°C	
T LT IN	°C	
T LT OUT	°C	
T LT OUT intern	°C	
T HT SP	°C	
Volume flow HT circuit	L/h	
Volume flow MT circuit	L/h	
Volume flow LT circuit	L/h	
Power consumption	Wh	
T LT IN CC	°C	
T LT OUT CC	°C	
T MT IN CC	°C	
T MT OUT CC	°C	

New layout of the monitoring/managing system webpage

Economy Temperature:
the minimum temperature in the building when no-one is present.
Time bands: from 7 p.m. to 7 a.m.
For public holidays.

Comfort Temperature:
the minimum temperature that must be on the floor when the building is occupied by people.
Time bands: from 7 a.m. to 7 p.m.
For weekdays.

These parameters vary depending on the **summer or winter season**.

New layout of the monitoring/managing system webpage

What went well

	Main tips for future applications
The partners were able to design and install a **geothermal system** on a **historic building** for **energy retrofit.**	Geothermal applications **very well fit existing buildings with constraints!**

What went well

	Main tips for future applications
The partners were able to design and install a **geothermal system** on a **historic building** for **energy retrofit.**	Geothermal applications **very well fit existing buildings with constraints!**
The partners were able to develop and use in the specific demo site a holistic and novel approach to **geothermal retrofitting**, making use of different kinds of analysis, most of which were integrated in **BIM** (Building Information Modeling)	**BIM integration** allows to produce a **multipurpose smart design tool!**

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What went well

	Main tips for future applications
We were able to design and install a **geothermal system** on a **historic building** for **energy retrofit.**	Geothermal applications **very well fit existing buildings with constraints!**
We developed and used a holistic and novel approach to **geothermal retrofitting**, making use of different kinds of analysis, most of which were integrated in **BIM** (Building Information Modeling).	**BIM integration** allows to produce a **multipurpose smart design tool!**
We were able to **integrate the new system controls and monitoring platform on the existing BMS** for producing a general management and monitoring system.	The integration of the **new components and monitoring should be designed carefully** to fit the existing system!

What went wrong

	Main tips for future applications
The project was rather complex as it foresaw the integration of **several technologies and systems**. It was difficult to design the final setup comprehensive of controls and monitoring plan.	Always design a **general plan to integrate all features before starting with the installation**!

What went wrong

	Main tips for future applications
The project was rather complex as it foresaw the integration of **several technologies and systems**. It was difficult to design the final setup comprehensive of controls and monitoring plan.	Always design a **general plan to integrate all features before starting with the installation**!
It was particularly difficult to obtain the **permits from the municipality**.	Before designing a geothermal retrofit for a historic building, always **"test the ground" in terms of needed permission, limitations, and timing!**

What went wrong

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Given the **pandemic** and the large occupation of local professionals due to the **extended amount of economic incentives provided at a central level for building energy retrofit**, it was very difficult to interact with the local professionals and bring them to complete the works.	Although pandemic and extreme events cannot be expected, it could be useful to **define a backup plan in terms of professionals involved**!

Thank you for your attention

GEOFIT

SMART GEOTHERMAL

UNIPG team