IDEAS

Novel building Integration Designs for increased Efficiencies in Advanced climatically tunable renewable energy Systems

Work Package 3: Heat pump and underfloor heating/cooling

Deliverable 3.4, ITES-MES prototype at small scale

This project Is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 815271

Project Details

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Theme	Building A Low-Carbon, Climate Resilient Future: Secure, Clean and Efficient Energy
Project Title	Novel Building Integration Designs for Increased Efficiencies in Advanced Climatically Tunable Renewable Energy Systems
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Project No.	815271
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Title of Deliverable	D3.4 - ITES-MES prototype at small scale
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Dissemination Level

PU	Public, to be freely disseminated	X
CO	Confidential, only for members of the consortium including the Commission	

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1 Contents

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ITES-MES prototype at small scale

2 Introduction

The prototype is composed of experimental devices which use novel technologies for the exploitation of renewable energies.

A novel CPC-PV/T panel will be installed for power generation and thermal energy; the thermal exchanger will be coupled with phase change materials (PCMs) to smooth the peak temperature and therefore improve the efficiency of the photovoltaic conversion.

A novel horizontal ground heat exchanger will be installed shallow in soil and coupled with PCMs too, to improve the ground thermal energy storage and increase the performance in heat transfer.

Both prototypes will be installed in a circuit in which a water-to-water heat pump is deputed to space heating and cooling of an experimental mock-up (50 m3) by installing a tailored prototype of radiant floor coupled with PCMs to increase the energy storage capability.

A control unit will be then able to switch among all thermal source according to their temperature toward the performance optimisation.

The small-scale prototype fulfils the function of a cheaper test case for checking and eventually calibrating the TRNSYS model implemented in Task 3.3, toward the reliable and affordable design of real cases (WP5).

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3 Mock-up facility

3.1 Selection of the facility devoted to the IDEAS small plant prototype

As originally proposed in the IDEAS project and during the Kick Off meeting held in Dublin (May 2019), UNIFE proposed the use of a small room at the TEKNEHUB laboratory as test facility for the implementation of a scaled IDEA prototype. The room is actually air conditioned by a prototype of dual-source heat pump (DSHP), designed, and tested during the so-called HEGOS project, an EFRD European project carried out from 2016 to 2018. The volume (around 40m^3) was considered suitable for the small test case, as the air conditioning system was coupled with 12m of ground heat exchangers, which the IDEAS project aims to improve with PCMs. However, it was not considered that the main façade is oriented to East and therefore not fully able to maximise the performance of the CPC-PV/T device, which is developing by TCD and UU.

In July 2019, a more suitable location was proposed to the Coordinator and then to the Project Officer, which aimed to improve the installation of the CPC-PV/T device and to provide more freedom for further advancements of the project. Indeed, two experimental mock-ups are available at TekneHub labs. These facilities were built to compare new roof tiles able to enhance the air ventilation in a pitched ventilated roof, and the energy requirement with an equivalent flat roof (LIFE HEROTILE project LIFE14 CCA/IT/000939, 2015-18). All buildings are South-oriented, visibly prominent, air conditioned (air-to-water heat pump), and widely monitored by means of a comprehensive monitoring system. The building's flat roof also seemed fully suitable for the installation of CPC-PV/T on the South façade. Moreover, the use of a whole building, unlike the single room initially proposed, offered a framework more compliant with the goal of the IDEAS project.

The following paragraphs compare the two solutions (the original one: "*original room*"; the new proposal: "*new building*") and highlight the benefit that the proposal could allow if selected.

3.1.1 Description of the two solutions

The two solutions are located in back yard of the TekneHub labs of the University of Ferrara (UNIFE). The following pictures and images characterise the two different solutions in terms of settlement, size, orientation, and structure.

Original room

The "original room" is the solution originally proposed. It is a small warehouse belonging to the TekneHub labs, and comprising of a small building together with a similar room whose envelope is made with bricks, thermal insulation, and inner plaster work. As it was built in 2013, the thermal trasmittance is compliant with the Italian regulations (around 0.2W/mK). The floor finishing is in grey tiles.

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The air conditioning system is an air-to-air heat pump, which was modified in a dual-source heat pump (DSHP) able to switch between air and ground according to which is the better source temperature and to avoid frosting issues. The geothermal closed loop is composed by n.6 Flat-Panels (2,0m x 1,1m x 0,02m each), edgeways buried into a narrow trench, 2.5 m deep in the soil at the base.

As it is an air-to-air HP type, the internal air heat exchanger of the DSHP is not suitable for coupling a heating/cooling floor, since a water-to-water heat pump is needed for the IDEAS project. Moreover, each modification could be constrainted, because as prototype it could be required to remain operating in the same way for some years. This has not been authorised by the Regional office yet.

Finally, the increasing of the floor level which would be required by the installation of a heating/cooling floor (10cm) would form a step at the entrance, which would not be compliant with the functionality of the room.

New building

The “new building” is the new solution proposed. It is an experimental facility, not used for everyday needs, and whose main façade is South-oriented. The building rests on an enbankment 1.6m high above the ground.

The shape is almost a cube. The roof is flat and made of timber (3cm thickness), waterproof membrane and a finishing layer of gravel (8cm thickness). Inside, there are three rooms, two of which are very narrow (60 cm wide) and perform the function of ‘guardian rooms’ to avoid solar gain from East and West direction. The walls are sandwich panels, made of foam 10 cm and metal cladding. During the summer season, the maximum heat flux incoming from the roof may reach around 30 W/m^2, since no insulation is installed. The floor is built with the same sandwich panels and installed on a concrete slab (20 cm). Sizes and configuration permit the installation of a heating/cooling floor.

Three fan coils provide the air conditioning needs of each room, as hydronic terminals of an air-to-water heat pump that also control the pitched building.

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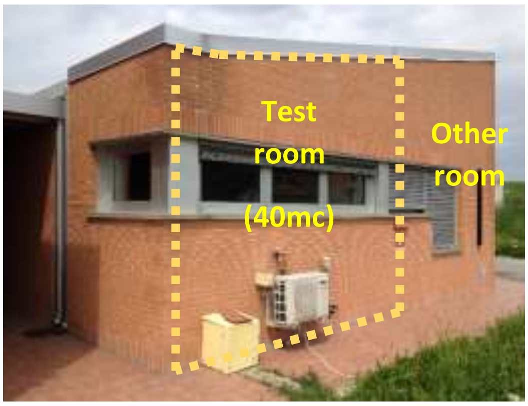

Figure 3.1 - Original demo-building (east façade)

Figure 3.2 - New demo-building, south façade (4.40mx2.60m)

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Figure 3.3 - Original test room design

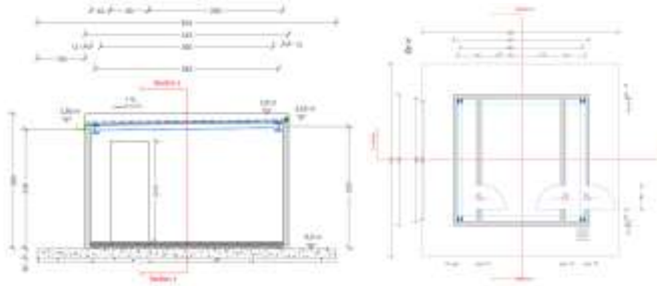

Figure 3.4 - Original test building design

Figure 3.5 - Inner test room

Figure 3.6 - Inner test building

3.1.2 Benefits of the new building

The following table summarises *pro* and *cons* of the new solution (New Building), in comparison to the previous solution (Original Room).

PRO	***CONS***
The new test building has a free façade fully oriented to South direction (4.40m x 2.60m). This is compliant with the PV/T installation, but it could also allow to test the same installation on the other three directions (East, West, North).	The building envelope of the new test building has a lower thermal transmittance than the original one. Therefore, higher thermal energy requirement is foreseen.
The new test building has a flat roof, which could be usefully extend the PV/T installation on the roof with ease.	
The new test building is already fully monitored (deck temperature, ceiling temperature, heat flux at the ceiling, energy meter at the fan coil, …).	
The new test building is not used, and therefore the energy balance is easier to calculate, since no external factors would affect the test.	
The new test building can be modified according to every needs of the project.	
The visibility of the new test building (and therefore of the new devices of IDEAS project for	

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dissemination purposes) is wider than that of the original building, which is covered by an embankment 1.6m high.	
The original test room is air conditioned by mean of a dual-source heat pump coupled with a geothermal closed loop, which is the prototype of the ERDF project HEGOS (2016-18). This system is an air/water-to-air heat pump, which is unable to couple a heating/cooling floor as it is. The new test building is air conditioned by mean of a standard air-to-water heat pump. Therefore, both buildings would need the installation of a new water-to-water heat pump. However, the new installation would warrant a higher reliability than the old prototype of HEGOS project, which was little used for two testing years.	
Since a new closed loop improved with PCMs (or the improvement of the existing loop) is foreseen in the IDEAS project, the same would be installed for the new air-conditioning system of the new building. Therefore, no extra-funds are needed by the new solution.	
Unlike the original room that borders with another room (air conditioned only in summer to control the temperature of the PV inverters), the new building is an independent building, more compliant with the goals of IDEAS.	

In comparison with the initial solution proposed in the project, the new solution provides more interesting benefits and degrees of freedom for the research activities planned in the IDEAS project. Moreover, it does not increase the overall costs as originally foreseen.

The European Project Officer (ing. Charles-André Le Marie, INEA - Innovation and Networks Executive Agency) agreed with the proposed change of site by email on 2019.07.12.

3.2 Site adaptation

The new building is one of two set-up buildings, which were built a few years ago for research purposes.

The first has an 8.00 x 10.00m rectangular plan with a pitched roof, 3.30-meter-high at the ridge line and 2-meter-high at the eaves. The roof-slopes are north and south oriented. The other set up building is located 3 meters NW from the first one. It has an almost square plan of 4.50 x 4.24m and has a 2.80 m high flat roof with a south slope of 1% for rainwater drainage. Both the set-up buildings sit on a reinforced concrete platform on an embankment 1.90 m above ground level. The latter of the afore-mentioned buildings was chosen as the test building for IDEAS project.

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The new test building is divided into three different rooms. The main room is in the central part of the building and is 2.7 by 4.0 m in dimension, while on the east and west sides there are two smaller rooms, just 0.65 m large, called 'guardrooms'. In addition to the difference in size, the rooms differ in the way they are air conditioned: in each room the conditioning is provided by a fan-coil, but in the central room there will be a winter and summer conditioning system created with a radiant floor enhanced with PCMs. Figure 2.7 depicts the mock-up geometry and its conditioning unit.

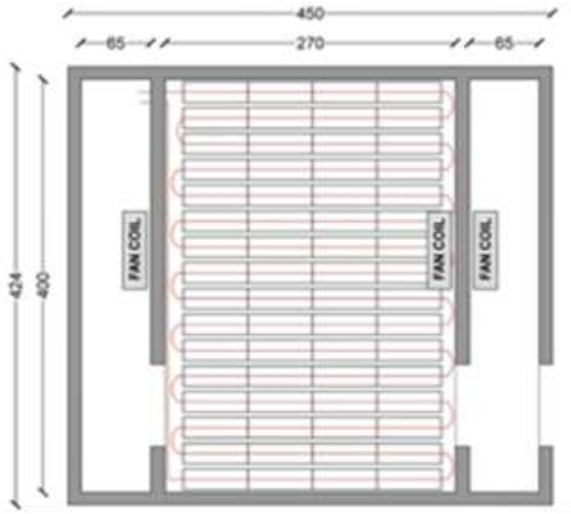

Figure 3.7 – Actual mock-up plan

Figure 3.8 - Additional volume's footprint

In order to carry out the experimental tests, some interventions to adapt the mock-up are planned to satisfy the installation and the safety of prototype. Due to the limited width of the guardrooms, an additional temporary volume was designed in which the heat pump (HP), the air heat exchanger (AHX), the buffer tank and part of the piping can be installed. Moreover, on the southern elevation of the mock-up, a metal frame was designed on which the CPC-PV/T panels can be hung. The geothermal plant can then be realized north-east of the mock-up, below the embankment. Figures 2.8 and 2.9 depict the new interventions.

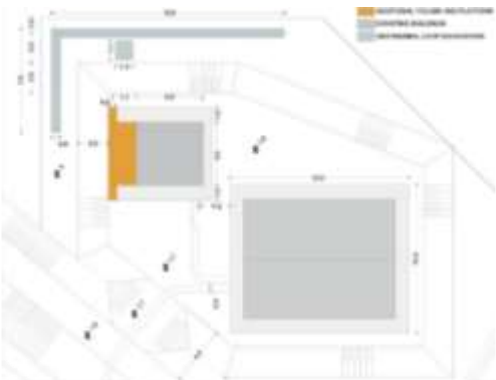

Figure 3.9 - Masterplan of the interventions

Figure 3.10 - Additional volume's plan

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The additional volume is designed to be independent of the existing mock-up, although adjacent on its west side, with a 4.10 x 1.70 m-rectangular plan, a maximum height of 2.60 m at the ridge line close to the mock-up and a minimum one of 2.40 m on the eaves line to the west. The existing reinforced concrete platform is 1.30 m on the west side of the mock-up, so an enlargement can be realized, connected to the existing one and a 0.20 m raised floor on which the plant machinery will be positioned to be sheltered from the weather. The volume designed has a steel frame composed of two HEA120 frames that support the secondary beams, on which a wooden plank and a waterproofing membrane are placed. The façade cladding will be made of perforated metal sheets on all three sides.

The existing mock-up would not have been able to support the weight of the CPC-PV/T panels (> 200 kg each) intended to be installed on the southern elevation. Therefore, a steel structure was required. It would have been realized slightly detached from the southern elevation and the CPC-PV/T panels can be hung there. Three HEA120 pillars, each one 2.10 m-far from the other, would have to support UPN100 profiles on which PV/T panels would be fixed.

Lower down the embankment, NW of the mock-up, the geothermal loop will be installed. An L-shape trench, 7.00+15.00 m-long, 0.40/0.60 m-wide and 2.50 m-deep will be dug and 3 groups of 3 no. flat-panel each will be placed. The trench will be connected to the mock-up through a shallow excavation (<0.50 m) alongside the north side of the embankment slope in which the piping will be layed.

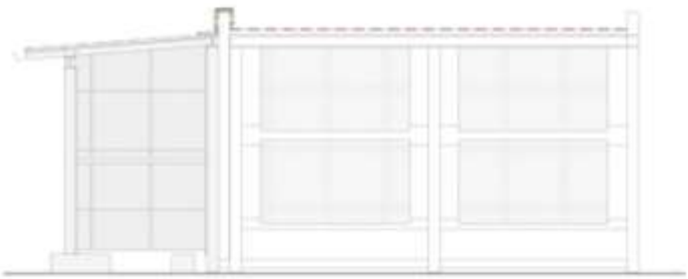

Figure 3.11 - Additional volume's south elevation

The project was submitted to the UNIFE's technical office in November 2019, to obtain the authorisation and to proceed then to the selection of the contractor (building, plumber, …). Unfortunately, the administrative path needed the submission to the local Municipality of a design which formally analysed earthquake stress, as better detailed in Chapter n.6. Furthermore, the design required official undersigning by a designer. This is due to the fact that the local regulation defines this external volume as new volume, even if for a technical, temporary, and experimental structure as the mock up. Similarly, for the frame supporting the CPC-PV/T panels.

To expedite procedures, to warrant the availability of the volume regardless the overcoming issues related to the COVID-19 pandemic, the previous design was translated to an easier

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solution, namely, a simple container, which warranted less problems and a lower cost. The container will be laid on the slab, next to Western wall of the mock-up.

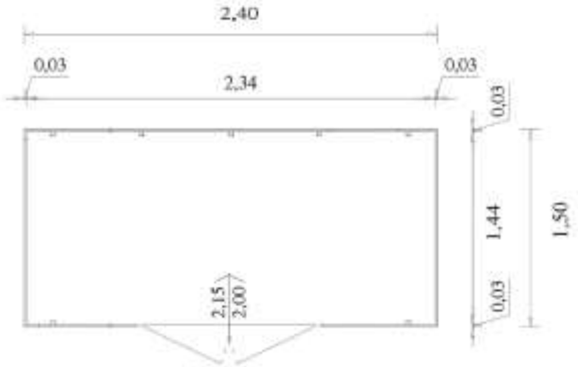

Figure 3.12 – Container for the installation of the IDEAS prototype (source side)

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4 IDEAS prototype

4.1 Description

The design of the IDEAS prototype, as depicted in Fig. 3.1, implements a generalised heat pump system with an invertible heat pump capable or exploiting different thermal source/sink as the sun (CPC-PVT panels, PVT), the air (air heat exchanger, AHX) and the ground (geothermal closed loop, GHX). Therefore, the heat pump (HP) is here selected as a standard water-to-water technology, electrically driven to exploit the PV power, reversible to satisfy both heating and cooling requirements, and integrated with PCMs thermal storage by means of specific technologies foreseen by user-side (heating/cooling floor) and source-side (GHX, PVT).

Compared to the full IDEAS plant system preliminarily foreseen in the deliverable D3.2 and dedicated to the experimental test at real scale (WP5), the small-scale system that will be installed at the TekneHub laboratory will be equipped with two storage tanks, named BF1 and BF2, and a plate exchanger that allows an immediate PVT panel cooling by supplying heat to the user-side. This layout was discussed and agreed during the IDEAS consortium meeting held in Belfast, November 2019.

The system is mainly composed of three loops:

1. **PVT loop** (-5/+80°C), whose heat source is the PVT device, which stores heat in the buffer tank n.1 (BF1)
2. **Air-ground loop** (-5/+50°C), in which air and ground can be alternatively source or sink for the HP system, operating through the buffer tank n.1 of the PVT loop (BF1). When the HP is off, this loop may be used to control the temperature of the PVT device, or stores energy in the ground for subsequent exploitation
3. **User loop** (+10/+50°C), which warms up (or cools down) the buffer tank n.2 of the radiant floor or the fan coil systems (BF2).

The two tanks are used as buffer tanks in order to control the thermal inertia of the system and to hydraulically separate the heat pump operating without problems when it is turned on (see Fig. 3.1), because of the presence of a primary and a secondary loop. In Figure 3.1 the two sides of the heat pumps are underlined with different colours: the source side and the user side, as well as the HP group.

With reference to the seasonal conditions, the thermal source for the HP evaporator (HX1) is the buffer tank n.1 (BF1), which can be recharged by air, ground, and solar source, or by their mixing according to weather conditions or other boundary conditions. Therefore, BF1 temperature should be assumed as main source reference temperature for the HP model. HP condenser (HX2) can provide heating for the buffer tank n.2 (BF2) which is devoted to heating of the radiant floor (and/or fan coils). Since the heating of the main room by means of radiant floor system has the priority over the fan coil system in normal conditions, the setting of valve V7 considers that the flow rate should firstly flow through the radiant floor and if necessary, through the fan coil. Meanwhile the fan coil system heats the guardrooms.

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BF2 and PCMs in the radiant floor can compensate for the absence of direct heating (HP off). Temperature in BF2 (radiant floor) should be assumed as sink reference temperature for the HP model, according to the set point determined by the user.

The temperature in the BF1 can be raised via the PVT and GHX and/or/ the AHX. Which is selected depends on the temperature of the outdoor air, the ground temperature, the weather forecast, and the energy requirement. If the air temperature drops below a certain temperature (e.g. 5-7°C) the GHX can supply or substitute the heating, because the ground temperature should be higher than the outdoor air temperature and so the heat pump's COP can be increased.

The operation of the heat pump will be managed by proportional three-way diverting valves, which will permit the exploitation of one of the sources rather than another (soil, air, solar radiation) and to use an air conditioning system rather than the other (radiant floor, fan coils).

A control unit will manage the heat pump and proportional valves (WP4).

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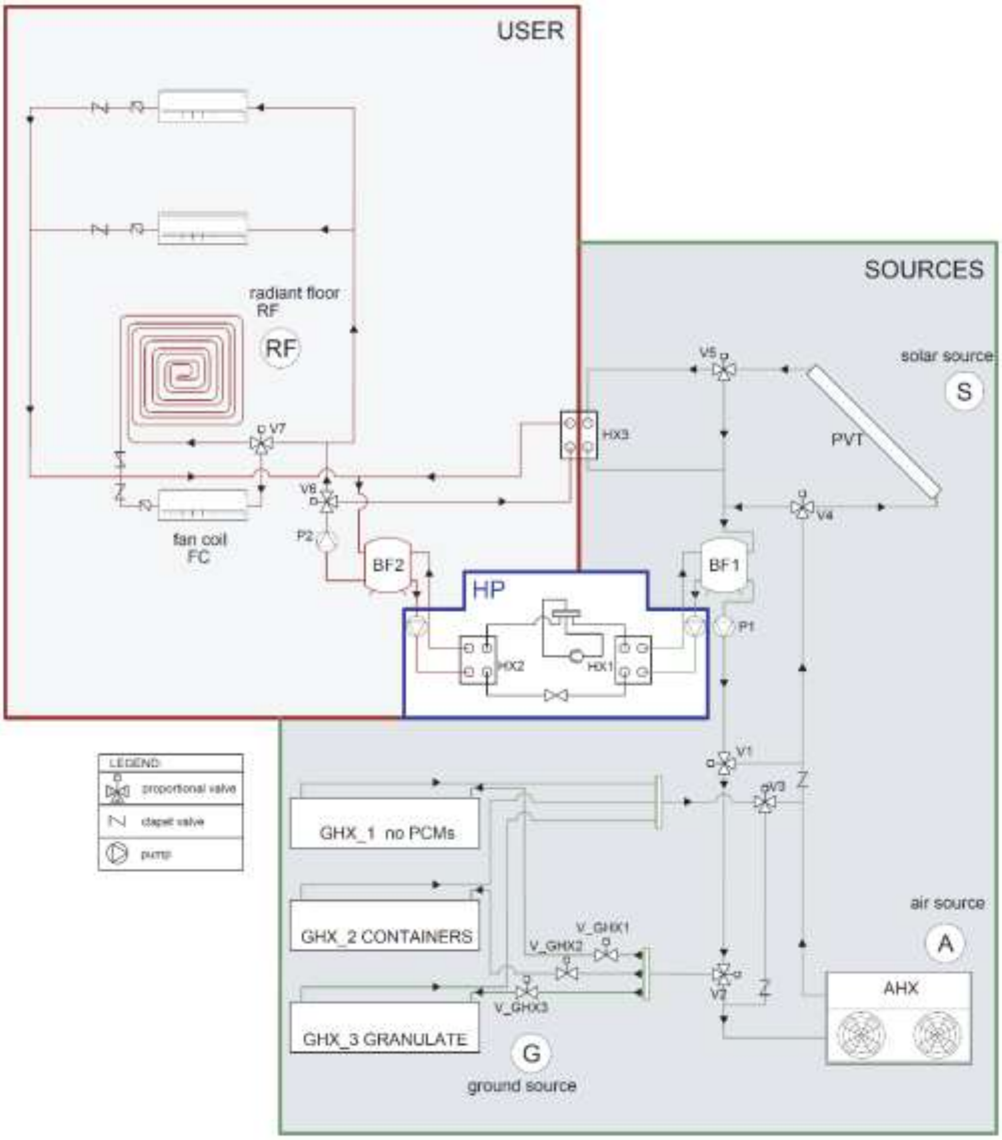

Figure 4.1 – HP system layout

The test construction to which the volume in question rests is equipped with a 40 cm wide channel under the track, obtained in the thickness of the sandwich panel placed to cover the floor (13 cm), connected to the other experimental mock-up in which the flow and return pipes are housed in the fan coil units, the condensate drain pipe, the line cable and the electric cables.

To connect the machines housed in the additional volume, the channel under track and its piping will be extended.

As for the hydraulic system, a sectioning of the pipes entering the mock-up will be carried out to make the system independent of the other test construction, while for the electrical system an additional connection to the other mock-up will be necessary, given the increase in the energy demand of the new equipment.

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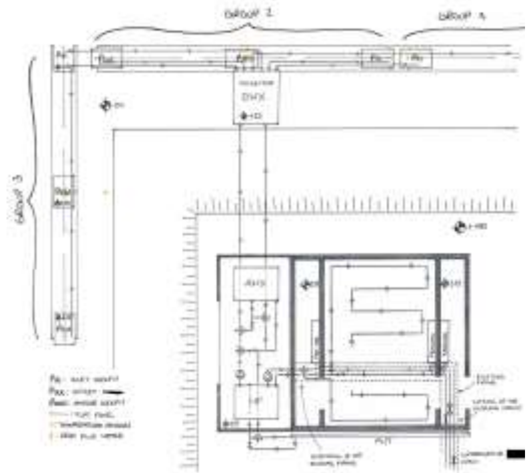

Figure 4.2 - Sketch of the small-scale IDEAS prototype

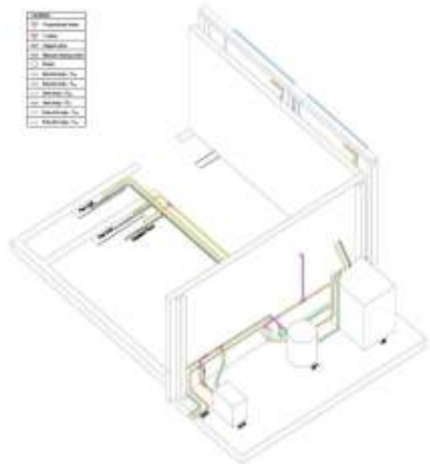

Figure 4.3 - 3D isometric view of the system, (North-West facades)

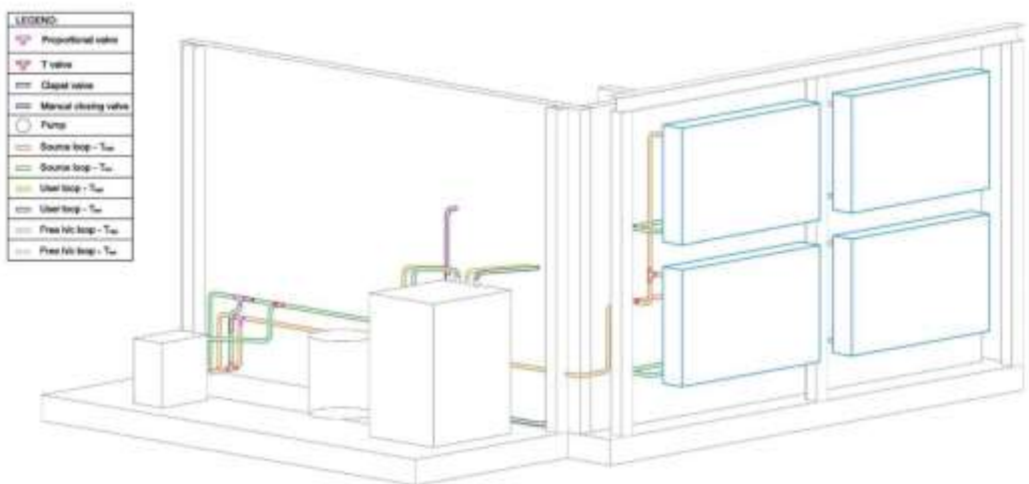

Figure 4.4 - 3D isometric view of the system, (South-West facades)

4.2 Geothermal closed loop (GHX)

Basically, the geothermal closed loop of the small-scale test at the TekneHub labs will be comprised by three groups each consisting of three Flat-Panels (GHXs), for a total number of 9 panels, in which the working fluid (water & glycol) flows as pumped by an INVERTER pump unit (P1).

The installation will be carried out in a narrow trench 2.5 m depth and 40-60 cm wide to reduce the excavation costs. In the first group, sand will be used as backfilling material: this will be the benchmark case. The other two groups will integrate PCMs through two specific application technologies discussed below.

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Figure 4.5 – Trench of the HEGOS geothermal closed loop and location of the new geothermal loop of IDEAS project

The flat panels used are 2.0 x 1.1 x 0.015 m in size. They will be connected in groups of three panels through DN25 HDPE connections and positioned at a depth of 2.4 m, where the ground conditions are more stable than they are on the surface.

To install the flat-panels, an excavation with an obligatory section will be carried out along the property boundary for a total length of about 22 meters. In correspondence with the panels, the trench will be filled with sand, including 10 cm sand bedding material and as much above. A 20 cm thick layer of washed gravel will then be placed on top of which will be placed a micro-cracked corrugated drainage pipe DN110 HDPE which will be used to "flood the trench" in order to increase the heat exchange. To prevent impurities from entering the drain pipe, the washed gravel layer will be surrounded by 200 g/m2 nonwoven fabric.

Each group of panels will be connected with piping made of insulated DN32 HDPE pipes and placed within corrugated DN90. The groups of panels can work individually or in parallel, never in series, and a collector will be installed to separate the flows of each group.

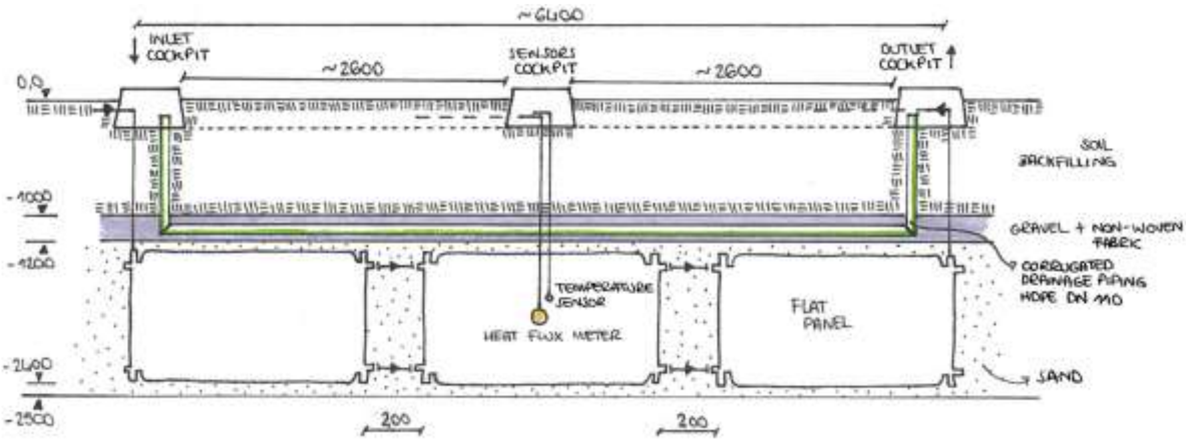

Figure 4.6 – Installation of a flat-panels group

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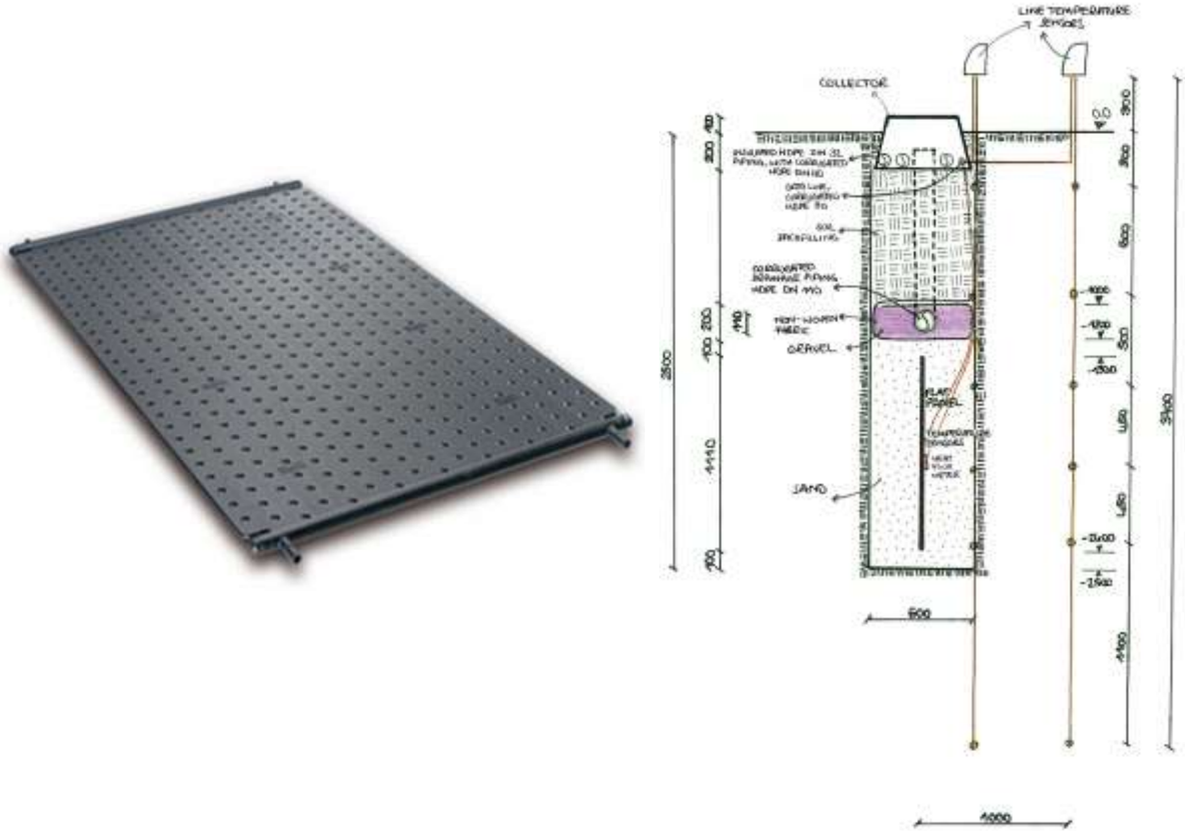

Figure 4.7 Flat-Panel and cross section of the installation trench

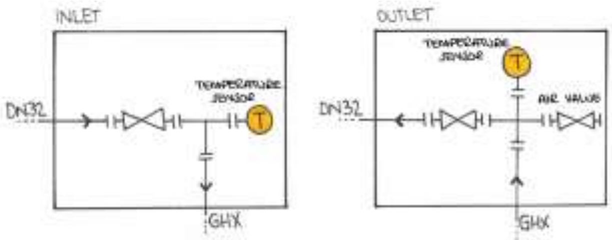

Figure 4.8 - Inlet and outlet manhole of each flat-panels group

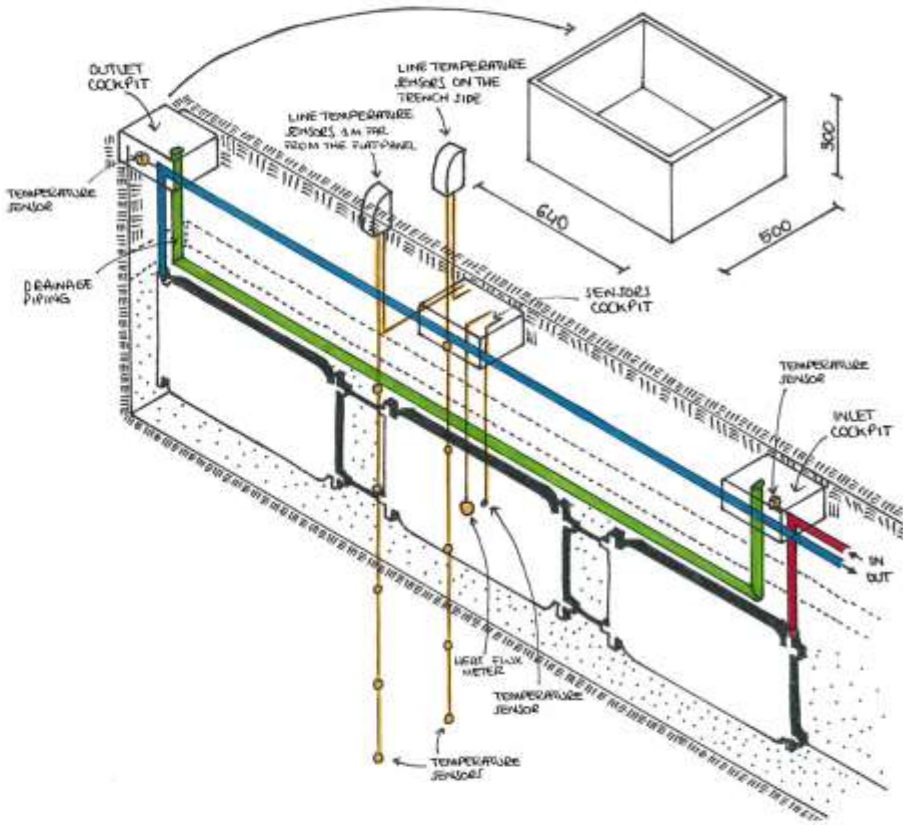

Figure 4.9 - Isometric sketch of a flat-panels group and probes

As thoroughly studied and described in Deliverable 3.1 and Annex to the present Deliverable 3.4, the application technologies of interest for the geothermal system are as follows:

1. TubeICE plastic containers (cylindrical geometry, HDPE) containing hydrated salts, positioned in the sand close to the GHXs surface
2. granules with adsorbed paraffins directly mixed with sand and then backfilling the GHX into the trench.

Since the trench will be soaked to increase the thermal conductivity, containers are needed to avoid the direct contact of hydrated salts with sand and water, whilst granules are selected to avoid the paraffin mobility due to its complete insolubility and a lower density of the organic material with respect to water.

The PCMs characteristics were discussed during the IDEAS consortium meeting held in Belfast (November 2019) and then thoroughly studied by means of numerical models (Annex to the present Deliverable 3.4). Quantities and technologies are summarised in Tables 3.1 and 3.2.

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Table 4.1 - TubeICE supplies (hydrated salts)

	Heating	*Cooling*
Melting Point	8	27
PCM	S8	S27
Product	TubeICE	TubeICE
Num. of Containers	112	56
PCM mass	241 kg	120 kg
UTES	31.3 MJ	22.3MJ

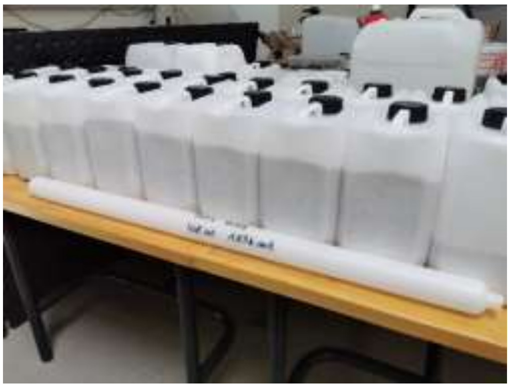

Table 4.2 – Granule supplies (paraffins)

	Heating	*Cooling*
Melting Point	8	27
PCM	A8	A27
Product	granule*	granule*
PCM mass	174 kg	89 kg
Product mass	348 kg	178 kg
UTES	31.3 MJ	22.3 MJ

** granules are supposed having 50% in mass of paraffin (PCM Products Ltd.)*

4.3 Air source heat exchanger (AHX)

As air source heat exchanger, a standard tube and fins fan heater has been selected by CFR by means of a public tender. According to all offers, the best solution was offered by GALLETTI Spa: AREO12M0ECC0.

AREO12M0ECC0 is equipped with an electric motor in permanent magnets (brushless) which, controlled by an inverter, allows the continuous variation of the number of revolutions of the fan. The great advantage of brushless motors is the significant reduction of electrical absorption, which during instantaneous operation reaches up to 2/3 compared with the absorption of conventional motors and in integrated operation it stabilises at approximately 50%. DC Inverter technology allows the continuous adjustment of the air flow to the actual needs of the room thereby greatly reducing the temperature fluctuations typical of interval adjustments (Fig. 3.10). An electronic device can be controlled via MODBUS protocol from the PLC to follow all needs by saving energy.

The AHX thermal power is more than 11 kW (water), therefore able to cover the full thermal power of the heat pump in summer season, and additionally extra power from PVT panels. The exchanger can operate also as evaporator. A solution of water and glycol must be calibrated according to the minimum temperature predictable for the working fluid. Since the design minimum temperature of outdoor air is -5°C in Ferrara, in order to avoid icing

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with a temperature decreasing below -5°C at the HP evaporator, the percentage of propylenic glycol should be around 25-30% (-12°C icing temperature).

Once the AHX is available, it will be tested to monitor its performance for compiling the performance map reference for the TRNSYS type, in order to specifically calibrate this device.

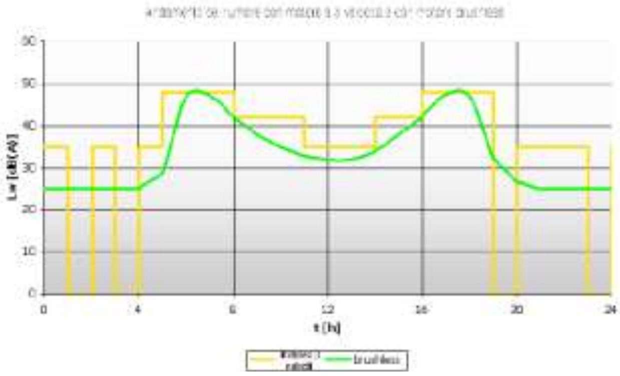

Figure 4.10 – Air heat exchanger AREO12M0ECC0 (AHX)

Model	Engine Features	Power Supply	VROT	Q_a	P_w 15-85/75 °C	DPW_H	H max @100% speed	L max @100% speed	Sound Power	Sound pressure	Power Consumption	Weight	Water Content Battery
		V-ph-Hz	% del max	m^3/h	kW	kPa	m	m	dB A	dB A	kW	kg	dm^3
AREO 12 EC	1F	230-1-50	100%	1626	11,2	37	4	7	68	63	80	19	0,88

Figure 4.11 - AREO12M0ECC0 performance

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4.4 CPC-PV/T panels (PVT)

4.4.1 Prototypes delivered

The prototypes of CPC-PV/T modules were assembled in February 2020 at Trinity College Dublin (TCD) and they were delivered to Italy the 25th of February via courier. Because of the COVID-19 virus outbreak there were some concerns from the courier about entering Italian territory. We were told the courier could not deliver the containers to Ferrara. To overcome this contingency, UNIFE and CFR personnel (Michele Bottarelli and Donato Vincenzi) arranged the collection of the containers at the Italian-Austrian border. The transfer from courier's truck to UNIFE's passed without difficulties and the return to Ferrara happened the same day because of a snow storm on the Alps.

The number of prototypes delivered to Italy was 4. A reference module with no optical concentrator was also shipped together with the 4 modules. The front glasses of the modules were stored in a separate box. These were to be installed and sealed by TCD personnel in Ferrara. Desiccant bags were also to be installed inside the modules just prior to the installation of the front glass.

Heat exchangers were to be mounted on the back of the module and thermally coupled to the aluminium backplate of the prototypes. During a conference call between UNIFE, CFR, TCD, and UU, it was communicated that just two of the four modules are to be equipped with heat exchanged with PCM, one will be provided with heat exchanged and no PCM, while one module will not be equipped with heat exchanger. The availability of heat exchanges is expected in the month of June 2020, so comparative tests will be started once those components are delivered.

Since part of the assembling was still to be completed, UNIFE was asked to keep the module in horizontal position and to wait until TCD personnel completed the assembling process. Unfortunately, the COVID-19 virus outbreak became even more widespread and Northern Italy appeared to be one of the regions where the pandemic had the greatest impact. Research centres were closed and very few people had access to the laboratories, so the research activity turned out to be severely delayed.

Since there is still no clear forecast of when international travel will be possible, UNIFE and CFR asked TCD for permission to proceed with the opening of the boxes and the preliminary tests of the modules.

The unboxing of the modules revealed some features will have to be taken into account during the test phase.

1. Wavy surface of the CPC reflector. The deviation of the reflecting surface from the ideal profile should have minimal impact on the short circuit current of the module but may cause local variation of the illumination profile over the single cells and cause a reduction in the fill factor. As a consequence, we will run a comparison of

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the modules showing different effects of this phenomenon in order to assess its influence on the electrical performance of the module

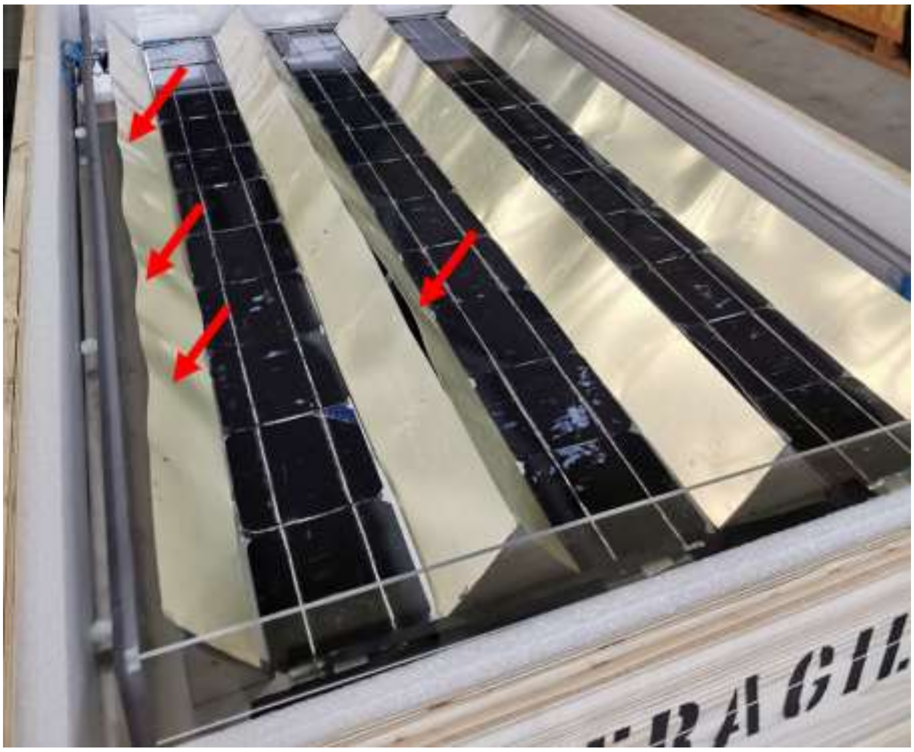

Figure 4.12 - Wavy surface of the CPC reflector

2. Inhomogeneous coating of the surface of the solar cells. The modules equipped with solar cells coated with downshifting layer show, in some cases, inhomogeneous coating (Figure 3.13 left) or portions of the PV devices with no coating (Figure 3.13 right). This phenomenon could be ascribed to the presence in solar cells of surface features like electrical contacts (bus-bar and fingers) which jeopardize the spreading of the coating liquid on the surface during spin on deposition. At present it is not possible to forecast the impact of this phenomenon on the electrical performance of the cells. Different reflectivity and thermal resistance of the coating may turn into uneven temperature profile of the cells. This phenomenon will be studied with the aid of a thermal camera both in dark (flowing a current equal to the one in ISC condition) and under solar illumination using multispectral imaging. This test will be carried out using a FLIR SC640 camera.

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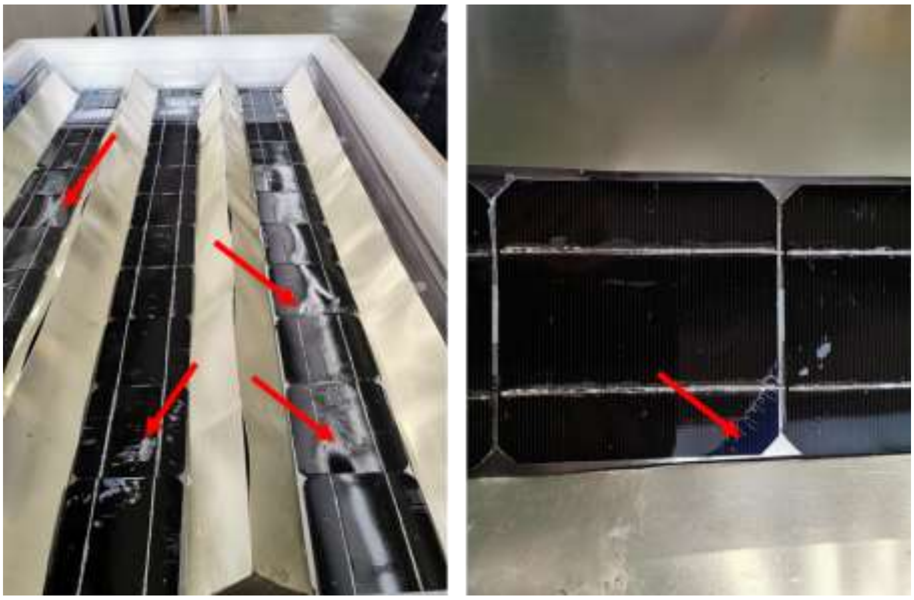

Figure 4.13: Inhomogeneous coating of the PV devices with down-shifting layer.

3. Cracks on some solar cells. Some of the solar cells present cracks which will limit the current fed by that specific cell and, being connected in series, of the whole module. Fortunately, this defect is present in very few cells. While the modules are open, CFR will run specific IV curves for the single solar cell devices which will show effects of this defect in order to assess the performance loss of the device and of the module.

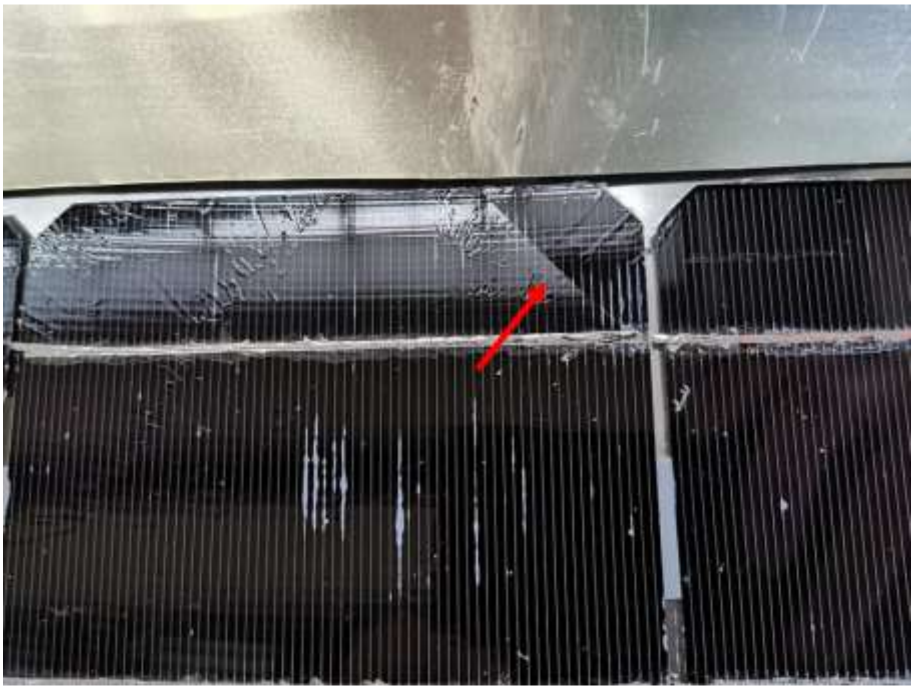

Figure 4.14: Cracks of the edge of a solar cell

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4. Air gap between the PV devices and the backplate; in some cases, the visual inspection of the solar cell devices showed a thin air gap between the back contact of the solar cell and the compound used to stick the solar cells to the backplate. This phenomenon may cause local heating of the PV devices leading to a decrease in the Voc of that device and eventually to a light increase of the short circuit current. Temperature maps will be recorded making use of the FLIR camera and compared with PV devices not showing air gaps to the backplate.

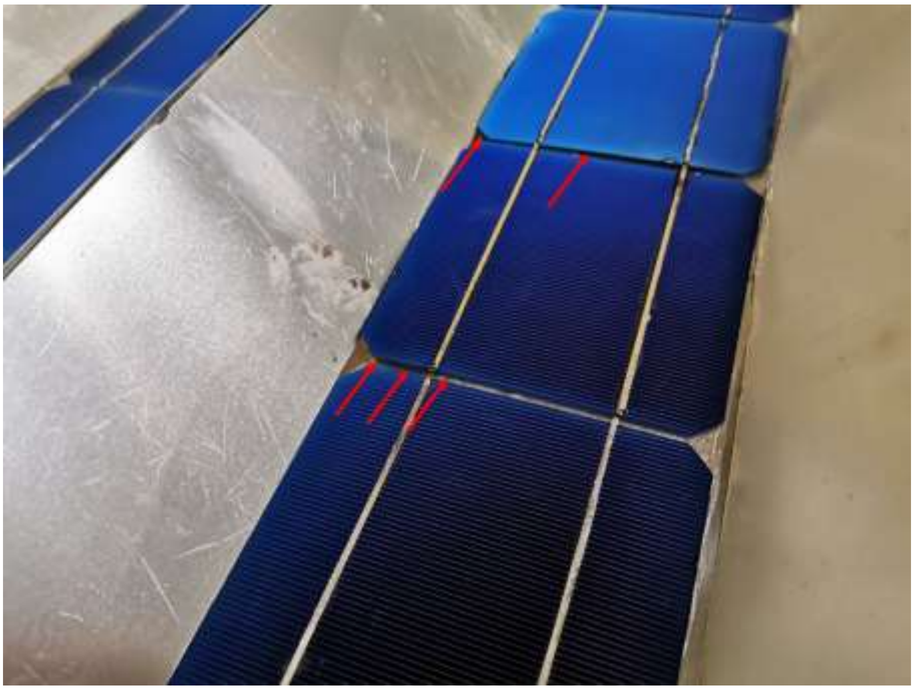

Figure 4.15: Thin air gap between the solar cell devices and the back panel.

The assembling of the frame structure to support the modules under test at CFR has been completed during W17 and starting from W18 the modules will undergo the preliminary electrical test in dark and under illumination. The CPC-PV/T modules will be individually tester

4.4.2 Definition of the test methodology and design of the test setup

As addressed in the previous section, CPC-PV/T modules under test at CFR/UNIFE laboratory show different features in order to run a number of comparison among them. The differences can be listed as:

- some modules have a downshifting layer applied on the surface of the PV cells, while one of the modules does not
- two modules will be equipped with heat exchanger + PCM, one module will be equipped with heat exchanger and no PCM and another module will not be equipped with heat exchanger.

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The modules will undergo routine electrical tests and the power and electrical energy produced by the PV/T façade will be continuously monitored.

The electrical tests which will be carried out at the UNIFE test facility will be:

1. Dark I-V curve: this test will allow the assessment of series and parallel resistance, inverse saturation current and its dependence on temperature.
2. I-V curve under illumination: this test will allow the measurement of the peak power produced by the module, the open circuit voltage, the short circuit current and the fill factor. The dependence of these parameters on the temperature will also be monitored thanks by a thermocouple installed on the backplate of the module.
3. AC energy produced on an hourly base: AC meters connected downstream with respect to the DC/AC inverter will provide an accurate monitoring of the energy fed into the sub-network of the UNIFE mock-up.

In Figure 4.16 we show the electrical schematic of the PV testing facility which will be used in WP3 to test the CPC-PV/T modules.

The I-V characterization will be carried out with a DC electronic load Elektro-Automatik EA-3200-25B with LAN interface. The PC supervisor uses a LabView software to trigger the I-V voltage sweep and to record the current data. During the I-V characterization of each single module a 4-contact deviator (Schneider Electric RPM42BD Power plug-in relay) will disconnect the module from the series connection and will connect it to the DC electronic load.

The voltage sweep takes less than 5 seconds, and we can expect the I-V test to be carried out at the equilibrium temperature the module would have under MPP operation.

A further 4-contact deviator driven by the PC supervisor disconnects the module from the inverter and connects the remaining modules in series. The same relay provides a clean contact for the PLC managing the heat pump and the valves to communicate that the system is under test and part of the power produced by the PV plant may not be available.

In normal operation mode the four modules are connected in series and provide an open circuit voltage higher than 60V. Since the open circuit voltage of flat PV modules has steadily increased over the past years, there are very few grid-connected inverters having the MPPT voltage range lower than 100 V.

In this case a Stecagrid 300 inverter will be used since it has an MPPT range which can ensure the three remaining modules will work under MPP condition during the I-V test of one module (Fig. 3.16).

The power produced by the four CPC-PV/T modules is likely not enough to power the heat pump, the water circulators and all the users connected to the UNIFE mock-up, so part of the energy needed has to be drained from the distribution network.

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The metering of the energy drained by the network and produced by the modules will be carried out by two AC meters. In the normal operation of the heat pump there might be moments in which the unit is switched off and the power produced by the module is higher than the power drained from the users of the subnetwork.

Italian regulations for experimental power plants forbid the supply of energy into the electrical network without permission.

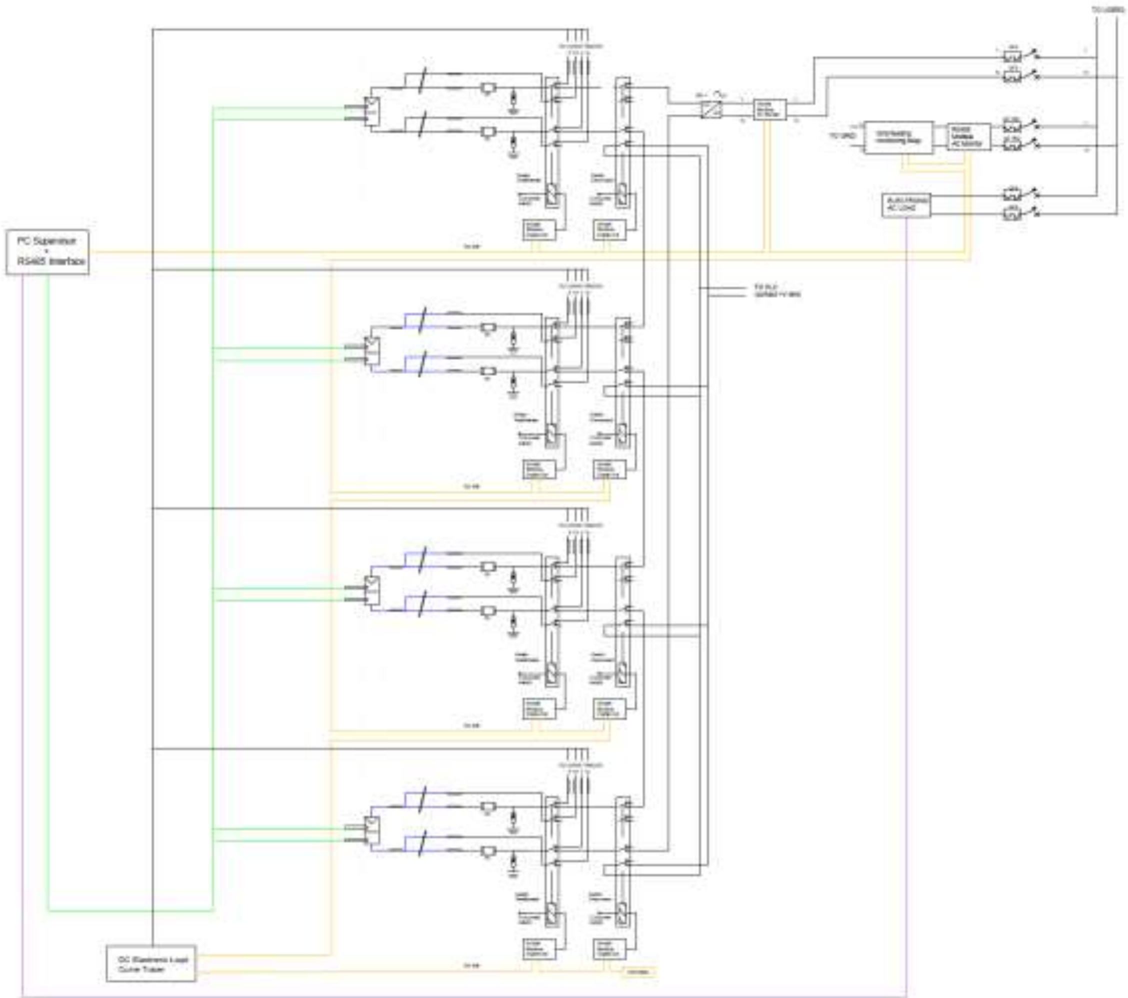

Figure 4.16: Schematic of the testing setup for CPC-PV/T modules (WP3)

Since the procedure to register this experimental power plant can take quite a long time, we prefer to make sure that no power is fed into the network by providing an AC electronic load connected downstream of the PV inverter.

This solution allows the inverter to drain the maximum power from the PV modules they can provide, while the programmable AC electronic LOAD (ADAPTIVE Power Systems 34M0) will dissipate the eventual excess power into heat. The PC supervisor will provide the energy balancing of this small network and will ensure that no power is fed into the network even in case of disconnection of the heat pump.

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	StecaGrid 300 UK	StecaGrid 500 UK
DC input side (PV-generator)		
Maximum start voltage	100 V	170 V
Maximum input voltage	135 V	230 V
Minimum input voltage	45 V	75 V
Minimum input voltage for rated output	64 V	106 V
MPP voltage	45 V ... 100 V	75 V ... 170 V
Maximum input current	5 A	
Maximum input power	320 W	530 W
Maximum recommended PV power	375 Wp	625 Wp
Derating / limiting	automatic when - input power is higher - the device is not cooled sufficiently - input currents > 5 A (higher currents are limited by the equipment and therefore will not damage the inverter)	

Figure 4.17: DC-side electrical parameters of Stecagrid 300 and 500

Italian law requires an interface protection device to be installed upstream with respect to all the sub-network components. The interface device should be compliant with the CEI-0-21 regulation. The testing facility will use a Bytronic BY2537 Voltage and Frequency relay. This interface monitors the voltage and frequency of the AC voltage and disconnect the sub-network from the distribution network in case the voltages and frequencies of the two differs by a programmable amount. The interface device logic diagram is reported in Figure 4.18.

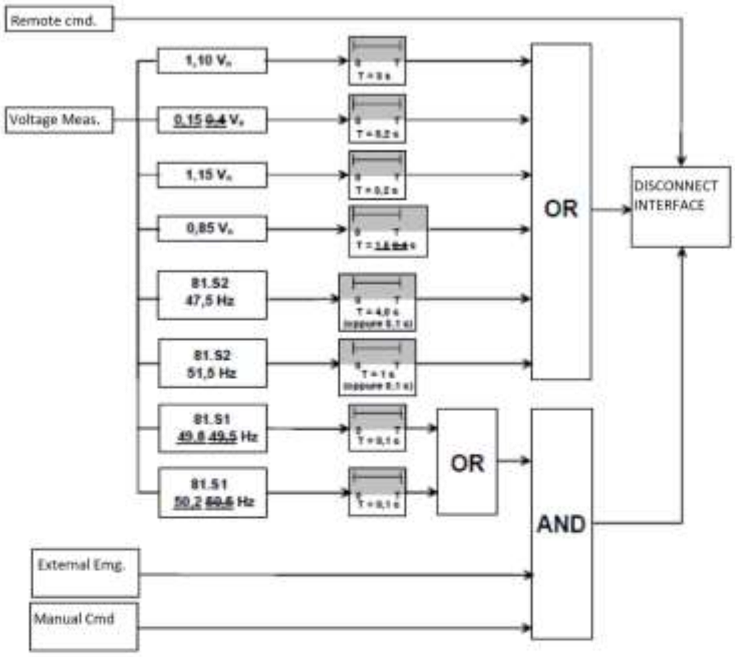

Figure 4.18: Interface protection device logic diagram

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4.4.2.1 Standards followed for testing procedures

- IEC 62108 ed. 2: Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval
- IEC 60904-1 (2006-09) I-V Characterisation
- IEC 60904-2 (2008-04) Requirements for reference solar devices
- IEC 60904-3 (2008-04) Tabulated Solar Spectrum
- IEC 60904-5 (2011-02) Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
- IEC 60904-7 (2008-11) Computation of Spectral Mismatch
- IEC 61724 (1998-04) Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange, and Analysis
- IEC 61829 (1995-03) On-Site Measurement of I-V Characteristics

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4.5 Radiant floor (RF)

The new radiant floor prototype composing the user loop (around 1.5 kW) will provide space heating and cooling using water as working fluid and will be integrated with PCMs as illustrated in the following section.

4.5.1 Selected PCMs

The selection of PCMs melting temperatures for heating and cooling purposes was conducted on the basis of the results obtained from a large number of numerical analyses which were then validated by experimental tests, as thoroughly reported in Annex to the present Deliverable 3.4.

The issue was initially faced with the assessment of the mock-up energy demand, experimentally and by means of the standard regulation. It was found that heating energy demand was met with a heat flux of 30 W/m^2 for 50% of the heating period. This value was assumed as the reference value for the selection of the PCM melting point. Then, the software COMSOL Multiphysics® 5.3a (COMSOL, 2019) was implemented to analyse supply water temperature, heat flux and floor surface temperature under different PCM melting points. Hydrated salts provided by PCM Products Ltd. (PCM Products Ltd., 2018) were considered.

As for space heating, simulations were carried out taking into consideration PCMs S32 and S27. Results showed that the selection of S27 for heating purposes is better and more justified. Furthermore, a supply water temperature of 35°C is suggested to obtain the best thermal efficiency, as reported by Mohammadzadeh & Kavgic (2019), and ensure a floor surface temperature of nearly 29°C, which is the maximum value allowed by regulation in typically occupied areas with a setpoint temperature of 20°C (EN 1264-2, 2008). As regards space cooling, numerical analysis was conducted for PCMs S19, S20 and S21. The latter was identified as the most suitable and reasonable choice, as already found by other studies in the literature (Barreneche et al., 2014; Cabeza et al., 2011; Lazaro et al., 2009). Thermal properties of the selected PCMs are reported in the following table.

Table 4.3 – Thermal properties of the selected PCMs (PCM Products Ltd., 2018)

	S21	*S27*
Melting temperature [°C]	21	27
Latent heat [kJ/kg]	220	185
Density [kg/m^3]	1530	1530
Specific heat [J/(kgK)]	2200	2200
Thermal conductivity [W/(mK)]	0.54	0.54

Afterwards, a series of experimental tests were carried out for space heating in a laboratory scale in TekneHub lab of the University of Ferrara. The aim was to validate the results obtained from numerical analysis and to evaluate the energy performance of the radiant floor system under different floor configurations. Specifically, two radiant floor setups were

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investigated – PCM containers installed above and under heating pipes, as illustrated in Figures 3.19-3.21. – in dry and wet sand conditions of the sand layer under the floor finishing, to understand the behaviour of the system with low/high thermal conductivity. The case with piping below the containers solves the issue of a very thin mortar installation (of a few centimetres), whilst that with piping upper the container represents a standard installation (around 10 cm).

Supply water temperatures of 32-35-40°C were adopted during the tests. Sand is the medium considered as it permits the substitution or modification of the configuration of the radiant floor.

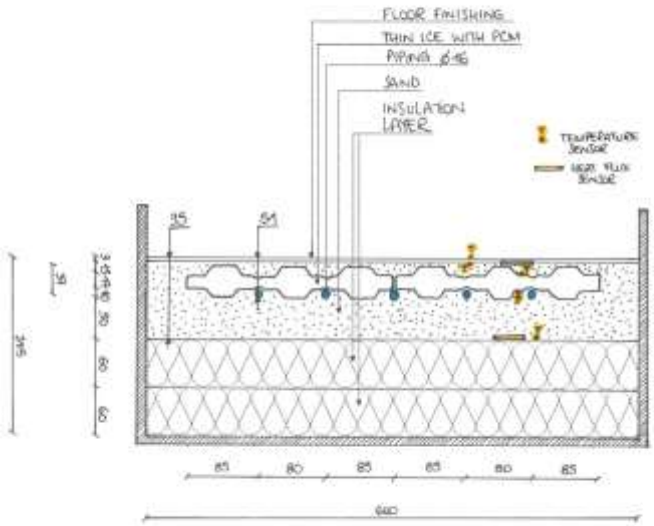

Figure 4.19 - Experimental setup with PCM containers above heating pipes

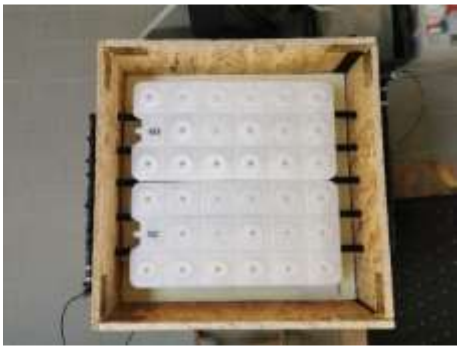

Figure 4.20 - Top view of the setup with PCM containers above heating pipes (thin mortar)

Figure 4.21 - Top view of the setup with PCM containers under heating pipes (standard mortar)

High-density polyethylene (HDPE) containers so called ThinICE (Figure 3.22) filled with PCM S27, provided by PCM Products Ltd. (PCM Products Ltd.), were considered. Results shown that the use of high thermal conduction in sand increases the overall performance of the radiant floor system much more rapidly. Mean floor surface temperature in steady state and wet sand conditions was found to be about 26.5°C and 28.5°C for PCM containers installed above and under heating pipes respectively.

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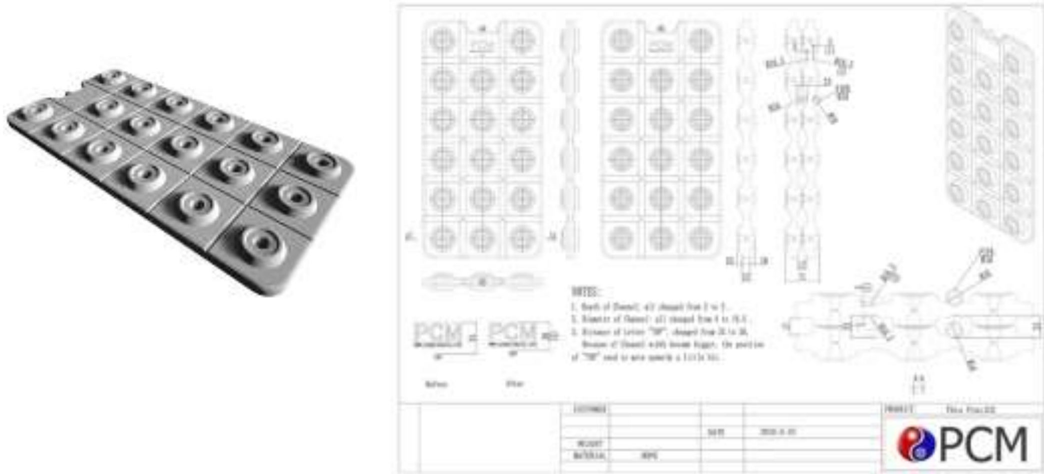

Figure 4.22 – PCM containers ThinICE (PCM Products Ltd.)

4.5.2 Radiant floor structure of IDEAS prototype

The PCM integrated radiant floor will be installed in the main room – floor surface equal to about 11 m^2 (= 4.0x2.7m) – of the new test building (mock-up), as shown in Figure 3.2. The structure of the system consists of a few different layers as illustrated in Fig. 3.23: thin laminate layer as floor finishing, wet sand as filling material with low-density polyethylene (LDPE) pipes (external diameter of 16 mm and wall thickness 2 mm) integrated inside, PCM layer, dry sand. Two nylon sheets, one under the floor finishing and one above the existing insulation layer, were used to avoid evaporation.

The radiant floor system will be installed over the existing floor structure of the mock-up, composed of 20 cm concrete slab and 12 cm sandwich panel. Layers are reported in Table 3.4.

Table 4.4 – Material and thickness of the layers composing the radiant floor

Layer number	***Material***
1	Laminate floor finishing
2	Nylon sheet
3	Wet sand
4	PCM in HDPE containers
5	Dry sand
6	Nylon sheet

Table 4.5 – Material and thickness of the layers composing the radiant floor

ThinICE	***Heating***	***Cooling***
PCM product	S27	S21
Melting Point	27	21
Number of containers	100	50

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Figure 4.23 - Radiant floor configuration (layer thickness expressed in mm)

4.6 Automatic valves

In order to manage all thermal sources (GHX, AHX, PVT) and the user needs, seven 3-way valves are needed, as depicted in the layout of the system (Fig. 3.1). All valves are automatic and proportional and are controlled via MODBUS by the control unit. Since the metal piping is DN25, all valves are DN20, as is usual they are a step smaller than the main circuit. The proportional opening will be calculated in real time by the control unit, according to the rules which are undergoing design.

The geothermal loop is split in three sub loops (GHX_1 without PCMs, GHX_2 with TubeICE, GHX_3 with granules). To differently manage all sub-loops, three 2-way automatic valves will be installed at the inlet of each sub-loop. All valves are of simple on/off operation. Since a volume flow rate is installed close to each valve, to avoid dramatic turbulence affecting the monitoring, their diameter has been selected similar to that of the piping, and therefore as DN25.

Figure 4.24 – Automatic 3-way valves (proportional)

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Type	DN []	Rp ["]	FS [l/s]	Δp [kPa]	PN []
FM015R-SZ	15	1/2	0.42	13	16
FM020R-SZ	20	3/4	0.78	13	16
FM025R-SZ	25	1	1.38	9	16
FM032R-SZ	32	1 1/4	2.16	7	16
FM040R-SZ	40	1 1/2	3.00	7	16
FM050R-SZ	50	2	5.76	16	16

Figure 4.25 – Automatic 2-way valves (on/off)

4.7 Heat pump

The heat pump is a water-to-water reversible type, which will be coupled with:

- Three fan coils (already installed, 1.5kW each) and a new radiant floor (PCMs enhanced, around 1.5 kW) for space heating and cooling (user side)
- CPC-PV/T panels group for power production and heating supply (sources side, PVT)
- geothermal closed loop (<3 kW_{peak}) for heating and cooling supply and thermal energy storage (sources side, GHX)
- tube and fins air heat exchanger (<10kW_{peak}) for heating and cooling supply (sources side, AHX)

According to the analysis carried out to assess the building energy requirement and presented in Annex to the present Deliverable 3.4, the average thermal power for heating needs of the whole mock-up is less than 3 kW, with peaks around 5 kW. Similar values are compliant with the smallest standard water-to-water heat pumps on the market, that are not with INVERTER compressor; therefore, the heat pump operates in standard on/off mode.

The equipment purchase was carried out by CFR by mean of a public tender. The best solution (price, performance and willingness) was offered by CLIMAVENETA (c/o MITSUBISHI) for the model BWR MTD2 0011, which is reported in the following figures. The heat pump has already two circulators on board that will operate to control the temperature of the working fluid on both buffer tanks (BF1 side source, BF2 user source), by means of their primary loops. An electronic device installed in the heat pump will allow the direct connection with the IDEAS control system via MODBUS protocol, making it able to modify several parameters in real time, such as setpoints, temperature differences, etc.

While the product has the possibility for DHW production by installing a further device, this has not been purchased since that functionality was not foreseen for the small prototype at TekneHub labs. However, this option would not be overly complicated to carry out subsequently.

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As soon as the heat pump is installed, it will be tested to monitor its performance for compiling the performance map reference for the TRNSYS type, in order to specifically represent this heat pump.

Figure 4.26 - BWR MTD2 - 0011

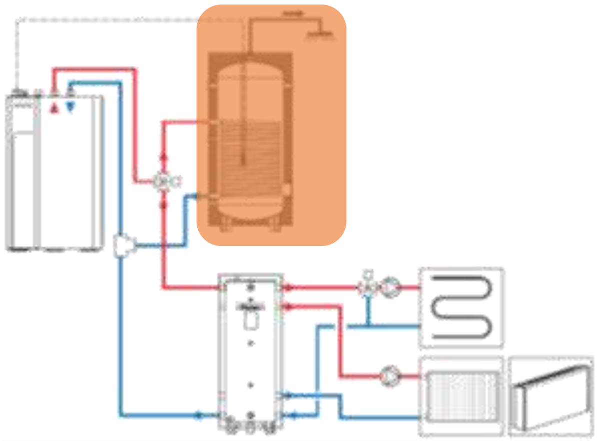

Figure 4.27 - Layout

Tcd	25	30	32	35	40	42	25	30	32	35	40	42	25	30	32	35	40	42
Tev	7						9						12					
Pf	5,73	5,47	5,35	5,17	4,86	4,72	6,11	5,83	5,71	5,52	5,19	5,05	6,69	6,39	6,26	6,05	5,70	5,55
Pat	1,20	1,36	1,43	1,55	1,75	1,84	1,20	1,37	1,44	1,55	1,76	1,84	1,21	1,37	1,45	1,56	1,76	1,84
Qev	0,987	0,941	0,921	0,891	0,836	0,813	1,05	1,00	0,984	0,951	0,894	0,870	1,15	1,10	1,08	1,04	0,982	0,956
Dpev	9,13	8,30	7,96	7,44	6,55	6,19	10,4	9,46	9,07	8,49	7,49	7,09	12,5	11,4	10,9	10,2	9,04	8,57
Pt	6,93	6,83	6,79	6,72	6,60	6,56	7,32	7,20	7,15	7,08	6,95	6,89	7,90	7,76	7,70	7,61	7,46	7,39
Qcd	1,18	1,17	1,16	1,15	1,13	1,12	1,25	1,23	1,22	1,21	1,19	1,18	1,35	1,33	1,32	1,30	1,28	1,26
Dpcd	13,2	12,8	12,6	12,4	11,9	11,7	14,7	14,2	14,0	13,7	13,2	13,0	17,1	16,5	16,3	15,9	15,2	15,0
Tev	13						15						18					
Pf	6,89	6,57	6,44	6,23	5,87	5,71	7,28	6,95	6,81	6,59	6,21	6,05	7,88	7,52	7,37	7,14	6,73	6,57
Pat	1,21	1,38	1,45	1,56	1,76	1,84	1,21	1,38	1,45	1,56	1,76	1,84	1,21	1,37	1,44	1,55	1,75	1,83
Qev	1,19	1,13	1,11	1,07	1,01	0,985	1,26	1,20	1,17	1,14	1,07	1,04	1,36	1,30	1,27	1,23	1,16	1,13
Dpev	13,2	12,0	11,6	10,8	9,59	9,10	14,8	13,5	12,9	12,1	10,8	10,2	17,3	15,8	15,2	14,2	12,7	12,0
Pt	8,10	7,95	7,89	7,79	7,63	7,56	8,49	8,32	8,26	8,15	7,97	7,89	9,08	8,89	8,81	8,69	8,48	8,40
Qcd	1,39	1,36	1,35	1,33	1,30	1,29	1,45	1,43	1,41	1,40	1,36	1,35	1,56	1,52	1,51	1,49	1,45	1,44
Dpcd	18,0	17,4	17,1	16,7	16,0	15,7	19,8	19,0	18,7	18,3	17,4	17,1	22,7	21,8	21,4	20,8	19,8	19,4

Figure 4.28 - Performance in cooling mode

Tev	-5	0	5	7	10	15	-5	0	5	7	10	15	-5	0	5	7	10	15
Tcd	30						35						40					
Pt	5,13	6,25	7,41	7,88	8,60	9,82	5,03	6,12	7,23	7,68	8,37	9,53	4,94	5,97	7,04	7,47	8,12	9,23
Qcd	0,887	1,08	1,28	1,36	1,49	1,70	0,871	1,06	1,25	1,33	1,45	1,65	0,856	1,04	1,22	1,30	1,41	1,60
Pcd	7,38	11,0	15,4	17,4	20,7	27,0	7,12	10,5	14,7	16,6	19,7	25,5	6,87	10,1	14,0	15,7	18,6	24,0
Pat	1,15	1,17	1,19	1,19	1,19	1,19	1,30	1,33	1,35	1,36	1,36	1,35	1,47	1,51	1,53	1,54	1,54	1,53
Pf	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17	5,17
Qev	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891	0,891
Dpev	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44	7,44
Tev	-5	0	5	7	10	15	-5	0	5	7	10	15	-5	0	5	7	10	15
Tcd	45						50						55					
Pt	4,84	5,83	6,83	7,24	7,86	8,91	-	5,67	6,62	7,01	7,59	8,58	-	-	6,40	6,76	7,30	8,24
Qcd	0,841	1,01	1,19	1,26	1,37	1,55	-	0,988	1,15	1,22	1,32	1,49	-	-	1,12	1,18	1,27	1,44
Pcd	6,64	9,61	13,2	14,8	17,5	22,5	-	9,15	12,5	13,9	16,4	20,9	-	-	11,7	13,0	15,2	19,4
Pat	1,67	1,71	1,73	1,74	1,74	1,72	-	1,94	1,95	1,96	1,95	1,92	-	-	2,19	2,19	2,18	2,15
Pf	5,17	5,17	5,17	5,17	5,17	5,17	-	5,17	5,17	5,17	5,17	5,17	-	-	5,17	5,17	5,17	5,17
Qev	0,891	0,891	0,891	0,891	0,891	0,891	-	0,891	0,891	0,891	0,891	0,891	-	-	0,891	0,891	0,891	0,891
Dpev	7,44	7,44	7,44	7,44	7,44	7,44	-	7,44	7,44	7,44	7,44	7,44	-	-	7,44	7,44	7,44	7,44

Figure 4.29 - Performance in heating mode

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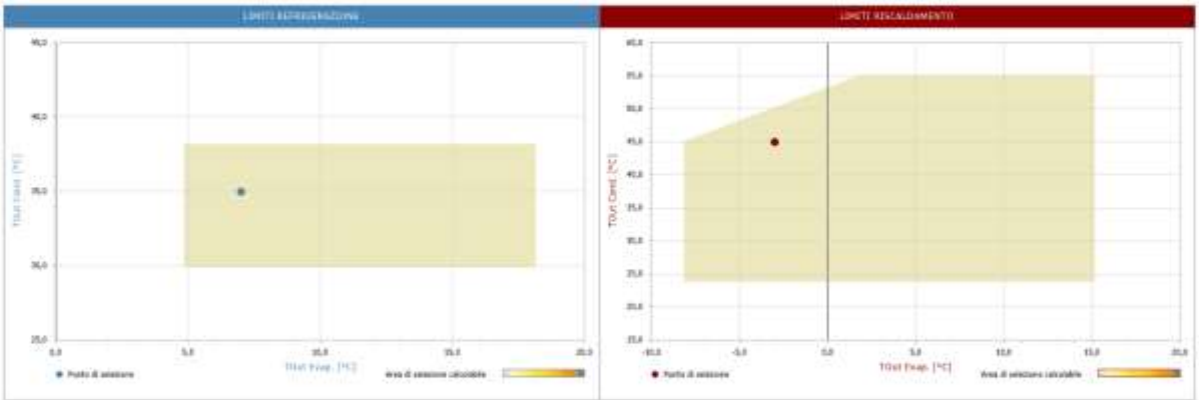

Figure 4.30 - Working frame

4.8 Piping and pumps

4.8.1 Hydraulic head losses

Pressure head loss in a piping system can be caused by fluid rising in elevation, friction, shaft work (e.g., from a turbine) and turbulence due to sudden changes in direction or cross-sectional area. In addition to pressure head losses due to pipe surface friction, the local losses are the pressure head loss occurring at flow appurtenances, such as valves, bends, and other fittings, when the fluid flows through these appurtenances. The local head losses are surface fiction, direction change of flow path, obstructions in flow path or gradual changes in the cross section and shape of the flow path.

With the aim of minimizing pressure drops in the system, a prototype installation of the system has been studied. This prototype takes into account all the listed kind of head losses and tries to avoid them as possible.

The circulation pump placed on the source side should supply all the pressure head loss to guarantee the plant system working properly. The total pressure head losses can be estimated by using the Eq. (1), where the first component indicates the distributed head losses and the second the local ones.

$$\Delta H_{tot} = \sum_i \frac{\lambda_i}{D_i} \cdot \frac{u_i^2}{2g} \cdot L_i + \sum_j \xi_j \frac{u_j^2}{2g} \qquad \text{Eq. (1)}$$

In order to express the total head losses as function of the flow rate, Eq. (1) become:

$$\Delta H_{tot} = kQ^2 \qquad \text{Eq. (2)}$$

This report aims to evaluate the maximum heat loss of the system considering the single use of the three thermal sources, from the worst case where the losses are the highest, to the best case where the losses are the lowest.

It worth noting that the piping system will be realised in steel DN25 (inner diameter around 25 mm) for the pipes places inside the technical room, whereas the diameter and the material of the pipes will change for the ground installation. This means that pipes in steel

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DN25 will compose the PVT loop and the AHX loop, while the GHX loop will be realised for the first meters in steel DN25 and for its majority in HDPE DN32 PN10 (inner diameter around 26 mm).

Allowing for the mass flow rate flowing in the piping, it is necessary checking that the chosen piping permits to the working fluid to keep its flow rate under a maximum value. This value was taken as a precautionary measure, and it comes from the following considerations.

The heat pump to be installed in the system can supply a thermal power equal to 5 kW, whereas the maximum power supplied by the aerothermal machine is approximately 10 kW. Under the hypothesis of considering the average temperature difference reachable by the aerothermal, so a ΔT of 7 K, is possible to calculate the mass flow rates delivered. This calculation takes into account that the working fluid flowing in the circuit is not water, but is water integrated with Glycol at 30%, therefore the specific heat of the working fluid drops from 4.2 kJ/(kgK) to 3.8 kJ/(kgK).

Table 4.6 - AHX thermal power

	Thermal Power [kW]	ΔT [K]	m [kg/s]
AHX	10	7	0.41

For this calculation, a specific heat of 3.5 kJ/(kgK) was considered for the glycol in order to obtain a higher mass flow rate in favour of safety. The resulting velocity into the DN25 steel piping is around 0.83 m/s.

If a single geothermal group were used in order to fully support the HP thermal power (5 kW), the resulting velocity into the HDPE DN32 would be approximately 0.90 m/s, by assuming an average temperature difference of 3 K.

Consequently, the maximum flow rate admitted for this type of plants is up to 1 m/s, so all calculations have been made using this limit flow rate value, as a precautionary measure.

4.8.1.1 Geothermal loop

In order to estimate the pressure losses of the geothermal loop, just one group of flat panels will be considered: that which is placed furthest from the geothermal inspection well. The total length of the longest circuit is equal to 60 meters: measured from the buffer tank installed in the source side up to the furthest flat panel group and back.

The piping is also characterised by a change of its material and its diameter while leaving the Mock-up: until the piping installation is inside the technical room it will be in steel. When the piping reaches the ground in order to connect the heat exchangers with the heat pump, a piping in HDPE has been chosen. This change of material is fundamental to avoid corrosion problems. The loop has the hydraulic characteristics listed in Table 3.4, where are also

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presented the local losses that affect the circuit. It worth noting that Local Head Loss Coefficient ξ were taken from literature.

The parameters used to evaluate the total heat losses are reported in the Table 3.5, so as the final value of pressure drop.

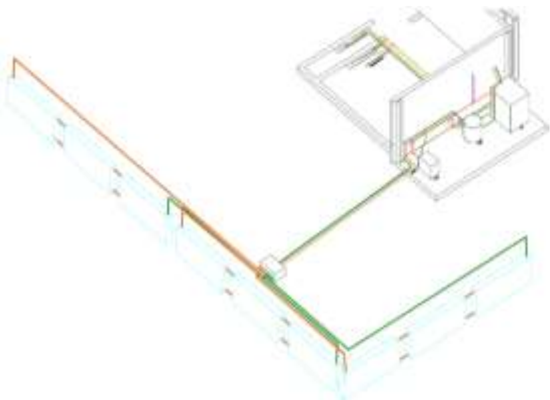

Figure 4.31 – Plant system with focus on the GHX loop

Table 4.7 – Loop details

		Φint [mm]	Area [m²]	Roughness [mm]
Φ in Steel	DN25	25	4.91E-04	0.04
Φ in HDPE	DN32	26	5.31E-04	0.04

		Local Head Loss Coefficient ξ	Σξ	Total Local Head Losses
Number of Φ increase	1	0.0057	0.0057	54.01
Number of Φ reduction	1	0.0009	0.0009	
Number of Valves	6	5.00	30.00	
Number of T Pieces	6	1.50	9.00	
Number of Curve Pieces	15	1.00	15.00	

Table 4.8 – Total Heat Loss calculation

Pipe Lenght in Steel	m	15
Pipe Lenght in HDPE	m	45
Φ in Steel	m	0.025
Φ in HDPE	m	0.026
ε in Steel	mm	0.04
ε in HDPE	mm	0.04
Σξ		54.007
λ in Steel		0.0221
λ in HDPE		0.0219

Local Head Loss	m	2.8
Distributed Head Loss	m	2.6
Total Head Loss	**m**	**5.4**

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4.8.1.2 Aerothermal loop

The aerothermal loop is installed inside the technical room, so its piping is realised in steel DN20. The total length considered from the buffer tank to the machine and back is approximately 5 m. The loop has the following hydraulic characteristics (Table 3.6). The different types of local losses that affect the loop are also listed in the same table. Local Head Loss Coefficient ξ were taken from literature.

The parameters used to evaluate the total heat losses are reported in the Table 3.7, so as the final value of pressure drop.

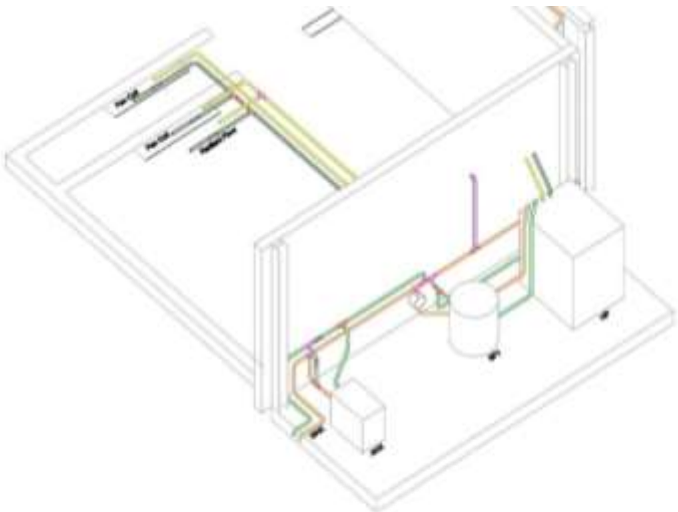

Figure 4.32 – Plant system with focus on the AHX loop

Table 4.9 – Loop details

		Φint [mm]	Area [m²]	Roughness [mm]
Φ in Steel	DN25	25.000	4.91E-04	0.04

		Local Head Loss Coeff. ξ	Σξ	Total Local Head Losses
Number of Valves	3	5.000	15	25.5
Number of T Pieces	3	1.500	4.5	
Number of Curve Pieces	6	1.000	6	

Table 4.10 – Total Heat Loss calculation

Pipe Length in Steel	m	5.000
Φ in Steel	m	0.025
ε in Steel	mm	0.040
Σξ		25.500
λ in Steel		0.022
Local Head Loss	m	1.30
Distributed Head Loss	m	0.23
Total Head Loss	**m**	**1.52**

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4.8.1.3 PVT loop

The piping of the PVT loop is of steel DN25. The total length of the circuit is approximately 16 m. The loop has the hydraulic characteristics reported in Table 3.1, which shows the kind of local losses that affect the loop. Local Head Loss Coefficient ξ were taken from literature.

The parameters used to evaluate the total heat losses are reported in the Table 3.2, so as the final value of pressure drop.

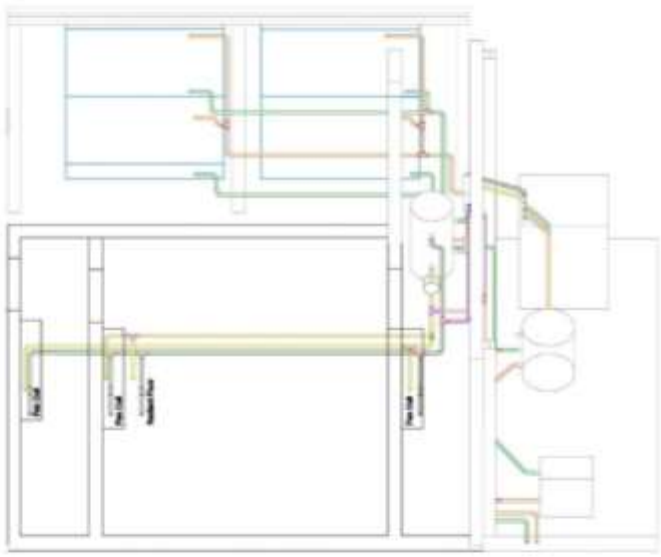

Figure 4.33 – Plant system with focus on the PV/T loop

Table 4.11 – Loop details

		Φint [mm]	Area [m²]	Roughness [mm]
Φ in Steel	DN25	25	4.91E-04	0.04

		Local Head Loss Coeff. ξ	Σξ	Total Local Head Losses
Number of Valves	2	5	10	
Number of T Pieces	6	1.5	9	34
Number of Curve Pieces	15	1	15	

Table 4.12 – Total Heat Loss calculation

Pipe Length in Steel	m	16
Φ in Steel	m	0.025
ε in Steel	mm	0.04
Σξ		34
λ in Steel		0.0221

Local Head Loss	m	1.73
Distributed Head Loss	m	0.72

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Total Head Loss	**m**	**2.45**

4.8.2 Pump selection

Considering the single use of the three sources, the results show that:

- the worst case is the geothermal loop, where the prevalence demand is 5.4 m
- the best case is represented by the aerothermal loop, whose prevalence demand is equal to 1.52 m
- The PVT loop needs a total head of 2.45 meters

With reference to Equation (2), where the total pressure drop is a quadratic function of the flow rate by means of the constant K. Table 4.3 reports the K-values.

Table 4.13 – K values

GHX	K local	5.44E+06	***K tot***	1.51E+07
	K dist	9.64E+06		
AHX	K local	5.39E+06	***K tot***	6.33E+06
	K dist	9.34E+05		
PV/T	K local	7.19E+06	**K tot**	1.02E+07
	K dist	2.99E+06		

According to the previous analysis and assuming more precautionary values, the main pump of the secondary source loop (P1) has been selected to provide a volume flow rate around 2 m3/h with a hydraulic head not lower than 6-8 m of water column.

Other main characteristics considered for the selection are as follows:

- INVERTER engine
- MODBUS protocol
- Compactness
- For cooling and heating working fluid, therefore also for brine or water-glycol mixture
- Possibility to a direct interfacing with the producer
- Best value for money criteria

The DAB EvoPlus Small 110/180 model has been selected, as depicted in the following figures.

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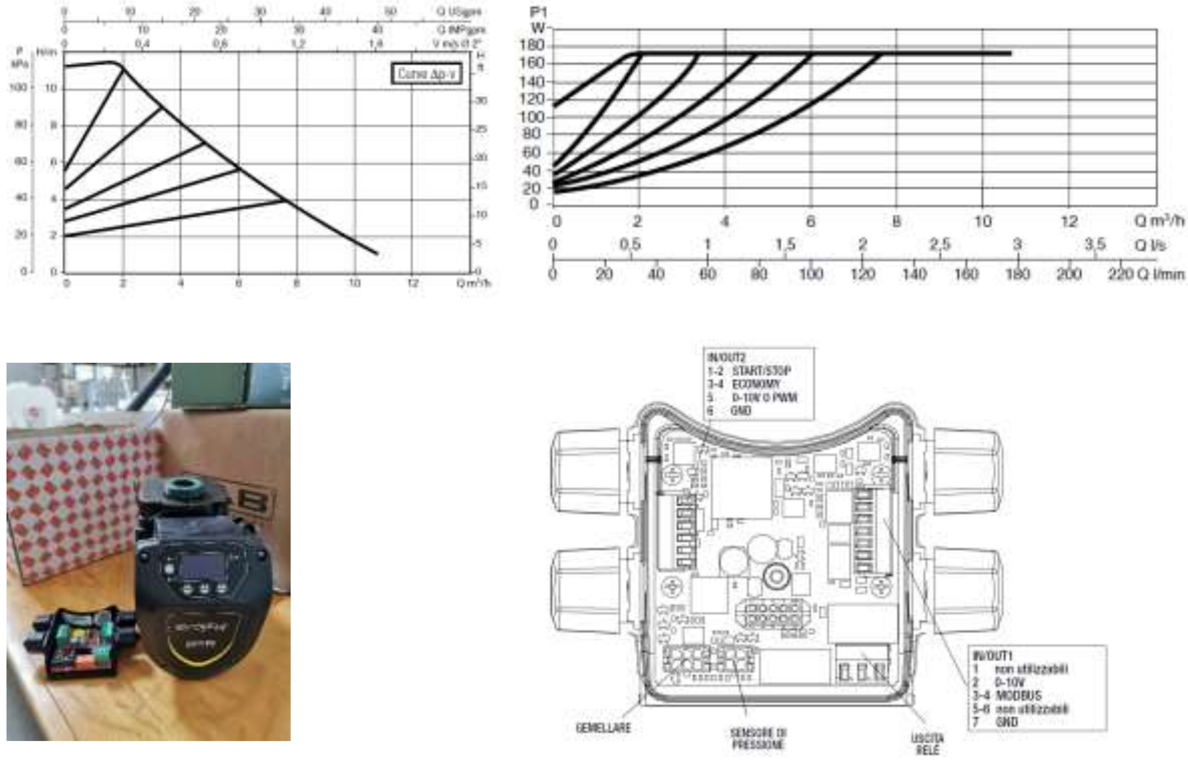

Figure 4.34 – Hydraulic pump of the secondary loop (source side)

At the user side, the needs for supplying a radiant floor and fan coils have not been considered so advanced as to justify such a sophisticated pump, and thus a standard circulator has been suggested to the contractor.

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4.9 Wiring and automation

From an electrical point of view the equipment will be located in two different cabinets, one dedicated to the PLC (with its power supply unit, its terminal blocks to connect all the sensors and the bus wires) and one dedicated to the other electrical devices and interfaces, with all the protective circuit breakers, the AC-DC power supply and the 24Vac transformer.

The main line is a standard single phase 230VAC, 50Hz.

The two cabinets will be located in an existing small research building, already equipped with electrical services and data connection, but due to the fact that the new equipment will require much more power than before (in the new plant there are a heat pump, a dry cooler, many electrical valves etc) the electrical plant has to be redesigned.

Both the new main line and the data connection (Ethernet CAT6 cable) will be derived from the existing ones located in another and larger building, situated near the small research building.

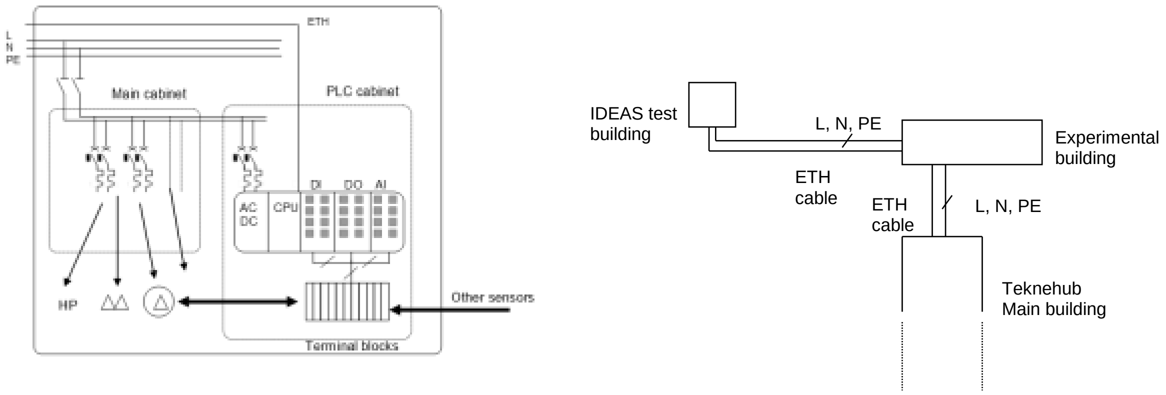

Figure 4.35 - Overall system

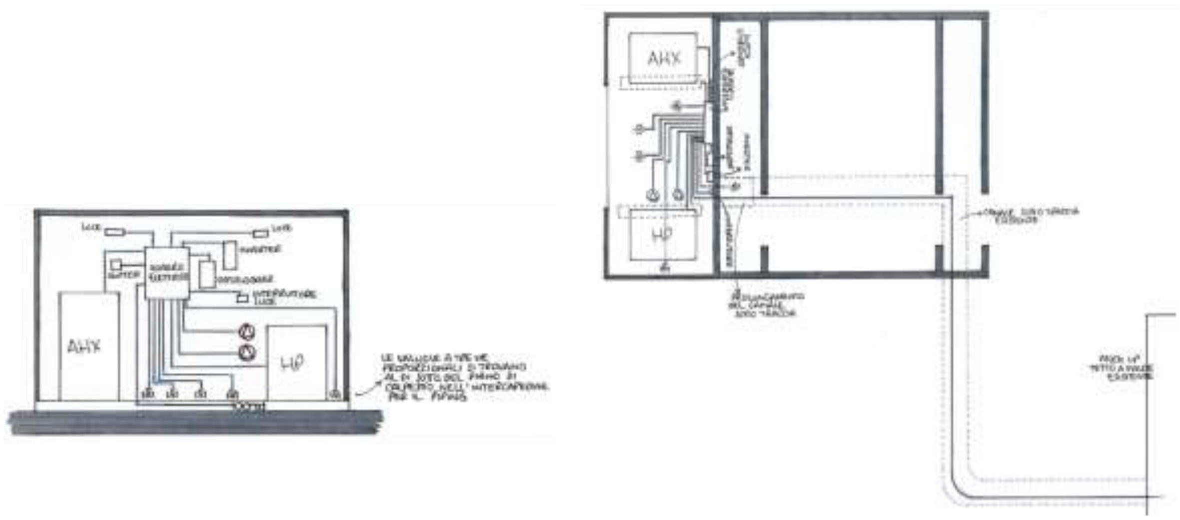

Figure 4.36 – Sketch of the preliminary wiring

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The plant will be controlled by means of a PLC (programmable logic controller), and data will be collected and recorded using both the PLC and different datalogging systems.

The photovoltaic part of the plant will have a dedicated data logging, also used to characterize the panels I/V behaviour.

The same applies to data collected by means of thermal resistances located at different depths near the geothermal flat panels. These sensors will not be managed by the PLC but communicate with a standalone data logging system.

The other devices and sensors will be connected to the PLC or to a central datalogging equipment, called Datataker, readable by the PLC.

PLC will manage data by means of different standards and protocols: the majority of devices (heat pump, dry cooler, pump inverter, 2-ways valves, 3-ways valves, weather station, energy meters) communicates by means of Modbus RTU, the Datataker uses Modbus TCP/IP, the heating meters use M-bus and the flow mass meters use a simple 0 – 10 V signal to communicate data.

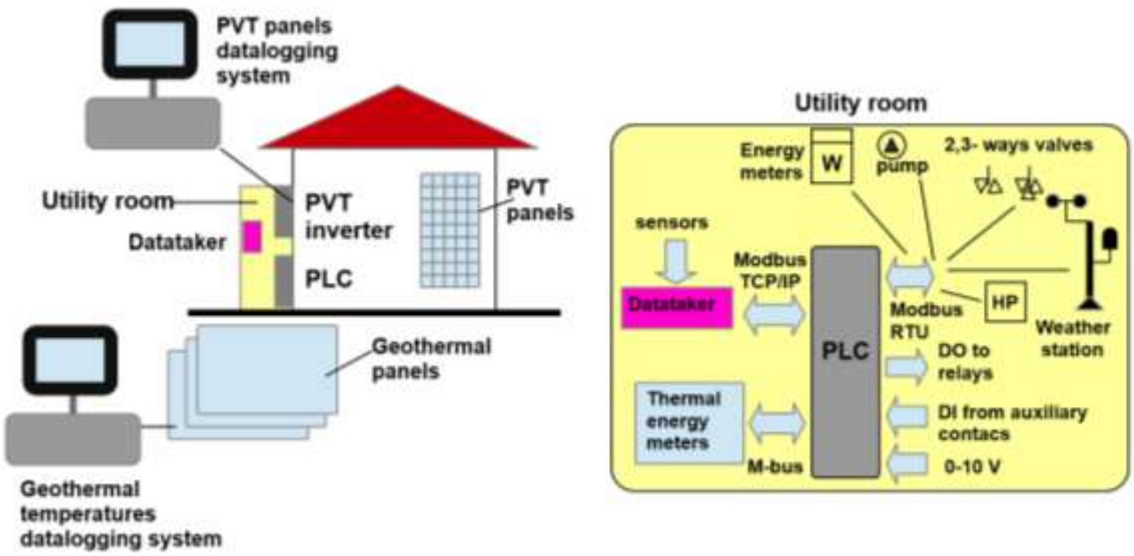

Figure 4.37 -System layout

Connection with heating meters, energy meters, flow mass meters and weather station will be one-way, from the devices to the PLC, which will read the energy consumption of every device, the mass flow rate in specific points to the piping, many different temperatures (from the heating meters) and weather data.

Connection with heat pump, pump inverter, and two and three-way valves will be bidirectional. The PLC will control the opening of the valves, some thresholds and parameters of the heat pump, the speed of the pump inverter.

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The PLC will also have many digital inputs related to the state of the protection devices (magneto-thermal circuit breakers) and will control relays coils, being able to connect/disconnect every single device from the powerline.

The software that will run on the PLC will thus collect data from many parts of the plant and decide which behaviour to adopt, by means of different control laws. These control laws will be designed taking into account user needs, availability of energy of the different sources, weather conditions and weather forecast.

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5 Monitoring system

The control system of the IDEAS prototype will fully be implemented in WP4 according to different operating states of the HP and rules for the thermal sources optimisation, as first introduced in Deliverable D3.3 and advanced in Section 6 below. In the main, the methodology is based on the knowledge of the thermodynamic state of all system components, and therefore great relevance has the monitoring system, which is here reported as designed at the present step to identify probes for operating control needs and overall behaviour of the system.

The state of the art (SoA) of the monitoring system is depicted in Fig. 4.1, in which all probes are set in specific plant sections to collect the thermodynamic state of all parts of the IDEAS system (HP, valves, GHX, AHX, PVT, RF, BF1, BF2, etc.). In relation to the hydraulic system therefore, the working fluid at side-user and side-sources, temperatures will be measured by PT100 4 wires and/or by mean of energy meters. These will be distributed in the whole system, i.e., the temperature will be monitored at inlets and outlets of the ground heat exchangers (GHX), air heat exchanger (AHX), and hybrid photovoltaic panels (PVT). The average tanks temperature will be monitored for BF1 as well as for BF2. During the taking of these measurements the mass flow rate of working fluid will also be monitored using flow meters to characterise all thermal sources (air, ground, sun), user needs (fan coils, radiant floor) and primary loops (HP, HX1, HX2). In particular, the ground source, the volumetric flow rate will be separately collected for the three geothermal groups (GHX_1, GHX_2, GH_3) also, as well as the heat flux and wall temperature at the central panel, so as to evaluate the different behaviour of PCMs containers and granules. In order to monitor the performance of the heat pump, the temperature at the inlets and outlets of the exchangers HX1 and HX2 will be measured (4 probes in total). Room temperature and humidity will be controlled as reference for the knowledge of the setpoint, as well as the radiant floor and the weather conditions. Moreover, electricity supplied to the compressor and the circulation pumps (P1, P2) will be monitored, as well as at the power production of PVT panels and therefore at the inverter.

Probes working with MODBUS protocol will be directly connected to the control unit, whilst all other sensors (mainly analogic sensors as Pt100, humidity, heat flux, etc.) will be collected by a datalogger (DataTaker 85 S4) and data will be stored via FTP in a storage unit. The control unit will be then connected with the datalogger via MODBUS. All data will be available and accessible to all partners. According to the project Coordinator and Energy Co-operatives Ireland (leader of WP8), the performance will be summarised for dissemination purposes.

The SoA of probes is presented and described in Table 4.1 below.

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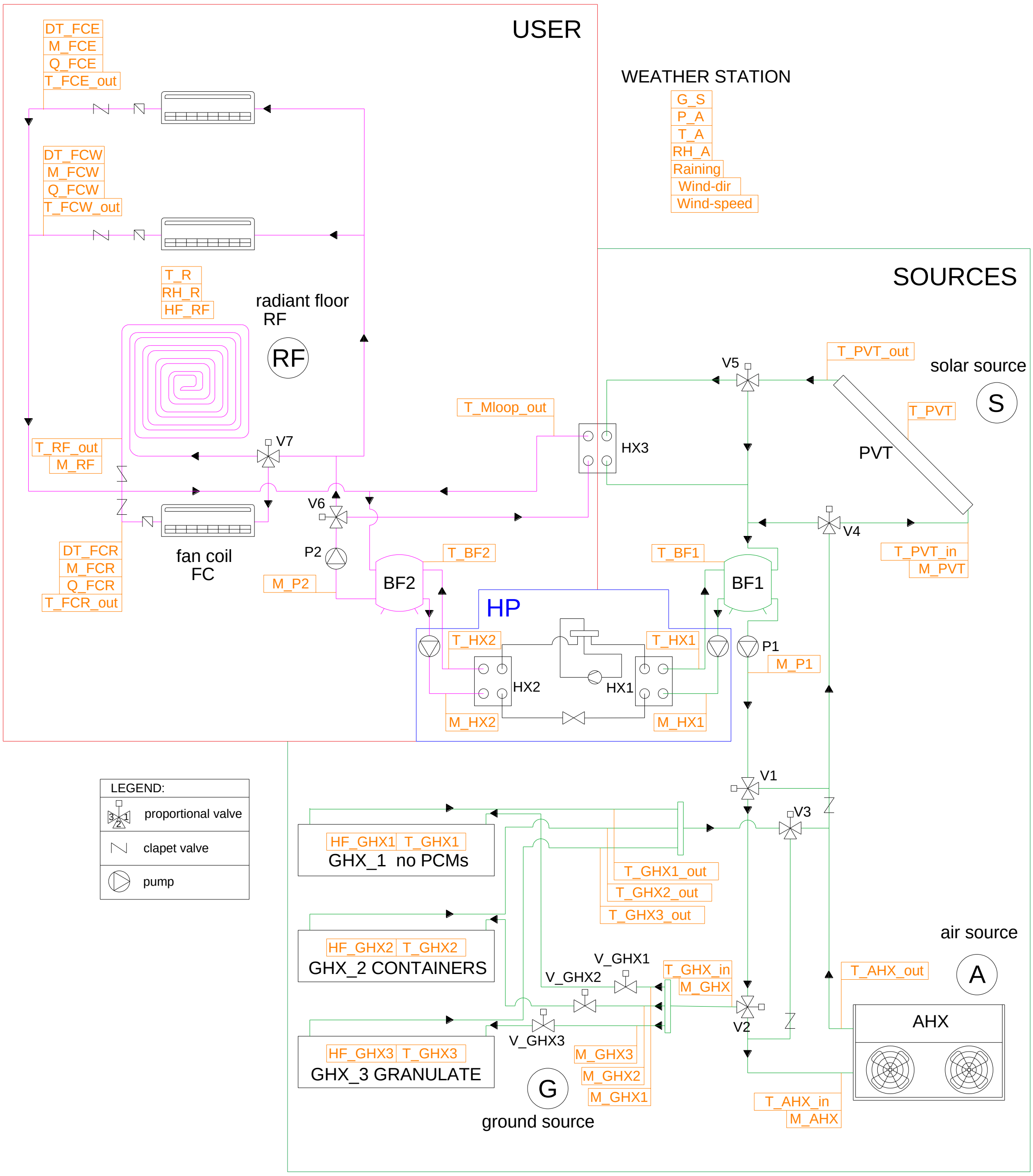

Figure 5.1 – Probes location

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Table 5.1 – Probes (M)

SOURCE	*NAME*	*UNIT*	*DESCRIPTION*	*MODBUS*[1]	*LAB*[2]
air source	M_AHX	kg/h	Mass flow rate of the working fluid into AHX (wfs)		
air source	P_AHX	We	AHX power		
air source	T_AHX_in	°C	Inlet temperature of the working fluid entering AHX (wfs)		
air source	T_AHX_out	°C	Outlet temperature of the working fluid leaving AHX (wfs)		
ground source	HF_GHX1	W/m2	Heat flux at the GHX_1 external wall		
ground source	HF_GHX2	W/m2	Heat flux at the GHX_2 external wall		
ground source	HF_GHX3	W/m2	Heat flux at the GHX_3 external wall		
ground source	M_GHX	kg/h	Mass flow rate into geothermal loop		
ground source	M_GHX1	kg/h	Mass flow rate into geothermal loop (GHX1)		
ground source	M_GHX2	kg/h	Mass flow rate into geothermal loop (GHX2)		
ground source	M_GHX3	kg/h	Mass flow rate into geothermal loop (GHX3)		
ground source	T_GHX1	°C	External wall temperature of the flat-panel group GHX_1		
ground source	T_GHX1_out	°C	Outlet temperature from GHX_1 (wfs)		
ground source	T_GHX2	°C	External wall temperature of the flat-panel group GHX_2		
ground source	T_GHX2_out	°C	Outlet temperature from GHX_2 (wfs)		
ground source	T_GHX3	°C	External wall temperature of the flat-panel group GHX_3		
ground source	T_GHX3_out	°C	Outlet temperature from GHX_3 (wfs)		
ground source	T_GHX_in	°C	Inlet temperature at the the geothermal loop		
ground source	T_GHX_out	°C	Outlet temperature at the the geothermal loop		
heat pump	M_HX1	kg/h	Mass flow rate into HX1 exchanger (wfs) - primary loop source side		
heat pump	M_HX2	kg/h	Mass flow rate into HX2 exchanger (wfu) - primary loop user side		
heat pump	M_P1	kg/h	Mass flow rate into P1 (wfs) - secondary loop source side		
heat pump	M_P2	kg/h	Mass flow rate into P2 (wfu) - secondary loop user side		
heat pump	P_HP	We	HP power		
heat pump	P_P1	We	P1 power		
heat pump	P_P2	We	P2 power		
heat pump	T_BF1	°C	BF1 tank temperature (inlet temperature at HX1)		
heat pump	T_BF2	°C	BF2 tank temperature (inlet temperature at HX2)		
heat pump	T_BF1_back	°C	Back temperature secondary loop source-side (wfs)		
heat pump	T_BF2_back	°C	Back temperature secondary loop user-side (wfu)		
heat pump	T_HX1	°C	Outlet temperature at HX1 exchanger		
heat pump	T_HX2	°C	Outlet temperature at HX2 exchanger		
room - main	DT_FCR	°C	I/O temperature difference at fan coil of main room (wfu)		
room - main	HF_RF	W/m2	Radiant floor heat flux		
room - main	M_FCR	kg/h	Mass flow rate into fan coil of main room (wfu)		
room - main	M_RF	kg/h	Mass flow rate into the radiant floor (wfu)		
room - main	Q_FCR	°C	Thermal power at of fan coil of main room (wfu)		
room - main	RH_R	%	Relative humidity of indoor air (room)		
room - main	T_FCR_out	°C	Outlet temperature at fan coil of main room (wfu)		
room - main	T_RF_out	°C	Outlet temperature of the working fluid leaving the radiant floor		
room - main	T_R	°C	Room temperature		
room - east guard	DT_FCE	°C	I/O temperature difference at fan coil of east guard room (wfu)		
room - east guard	M_FCE	kg/h	Mass flow rate into fan coil of east guard room (wfu)		
room - east guard	Q_FCE	°C	Thermal power at of fan coil of east guard room (wfu)		
room - east guard	T_FCE_out	°C	Outlet temperature at fan coil of east guard room (wfu)		
room - west guard	DT_FCW	°C	I/O temperature difference at fan coil of west guard room (wfu)		
room - west guard	M_FCW	kg/h	Mass flow rate into fan coil of west guard room (wfu)		
room - west guard	Q_FCW	°C	Thermal power at of fan coil of west guard room (wfu)		
room - west guard	T_FCW_out	°C	Outlet temperature at fan coil of west guard room (wfu)		
solar source	M_PVT	kg/h	Mass flow rate into PVT (wfs)		
solar source	P_PVTr	We	Real PVT power		
solar source	T_Mloop_out	°C	Outlet temperature from the "Mloop"		
solar source	T_PVT	°C	PVT temperature		
solar source	T_PVT_in	°C	Inlet temperature of the working fluid entering PVT		

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solar source	T_PVT_out	°C	Outlet temperature of the working fluid leaving PVT		
weather	G_S	W/m2	Solar radiation		
weather	P_A	mBar	Air pressure		
weather	RH_A	%	Relative humidity of outdoor air at the AHX		
weather	T_A	°C	Outdoor air temperature at the AHX		
weather	Wind_dir	DEG	Wind direction		
weather	Wind_speed	m/s	Wind speed		
weather	Raining	mm/h	Rain intensity		

[1] *Communication protocol*

[2] *Sensor or probe already available in lab*

A further monitoring system dedicated to the survey of the ground thermal filed is already available in the laboratory and therefore will be installed to details the behaviour of the three geothermal groups. As detailed in deliverable D3.2, two probes will be installed in the ground at the middle panel of each group: the first one at the trench wall around 25 cm far from the GHX, the second one at 1 m distance for the GHX. Each probe has n.5 digital sensors of the temperature, which are connected to a multiplex device and then with a local computer via RS485. This sub-system has not been considered relevant for the unit control of the IDEAS system, but important to survey the performance of the different technologies selected for coupling PCMs and GHXs.

Figure 5.2 - Multiplex reader

Figure 5.3 – Probe for ground installation

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6 Control system methodology

The preliminary methodology to control the IDEAS prototype was presented in Deliverable D3.3 and was discussed with Institute Mihailo Pupin (IMP) during the meeting held in Ferrara, February 2020. Here, a preview is presented, as following some amendments. It should be noted that control rules are foreseen in the IDEAS project's GANNT around M24. However, their current development work aims to better support the operating of the small-scale prototype.

Firstly, operating configurations are proposed at the user-side (combinations of different terminals for cooling/heating) and sources-side (combinations of different thermal sources), to define different system states for the logic control of all devices (HP, GHX, AHX, PVT, valves, etc). Then, some control rules to control some proportional valves are proposed.

Further parameters and functions however must be defined to complete the framework. Therefore, in the following tables the main default values for setting the overall system (setpoint, etc) and preliminary functions are reported. These last are mainly dependent variables calculated by mean of simplified equations and based on parameters and collected data (independent variables).

Table 6.1 – Parameters (default values)

SOURCE	*NAME*	*VAL*	*UNIT*	*DESCRIPTION*
ground source	DT_AG_span_S	5	K	Min temp. difference between outdoor air and ground temp. for ground exploitation in summer
ground source	DT_AG_span_W	3	K	Min temp. difference between outdoor air and ground temp. for ground exploitation in winter
ground source	T_AG_gsave_S	30	°C	Min outdoor air temperature to avoid ground exploitation in summer
ground source	T_AG_gsave_W	8	°C	Min outdoor air temperature to avoid ground exploitation in winter
heat pump	c_wfs	4.2	kJ/(kg*K)	Specific heat of the working fluid in source loop
heat pump	c_wfu	4.2	kJ/(kg*K)	Specific heat of the working fluid in user loop
heat pump	DT_BF2_S	2	K	Hysteresis for turning on/off in summer
heat pump	DT_BF2_W	2	K	Hysteresis for turning on/off in winter
room - main	DT_R_down_S	1	K	Hysteresis for turning off in summer
room - main	DT_R_down_W	1	K	Hysteresis for turning off in winter
room - main	DT_R_up_S	1	K	Hysteresis for turning on in summer
room - main	DT_R_up_W	1	K	Hysteresis for turning on in winter
room - main	T_R_target_S	27	°C	Setpoint for room temperature in summer
room - main	T_R_target_W	21	°C	Setpoint for room temperature in winter
solar source	eta_PVT_e	0.15	%	Electrical efficiency of PVT
solar source	eta_PVT_t	0.70	%	Thermal efficiency of PVT
solar source	Q_PVT_min	50	W/m2	Min solar power for PVT thermal exploitation
solar source	r_PVT	0.1	%	Solar reflectance of PVT panel
solar source	T_PVT_limit	80	°C	Max PVT temperature
solar source	Mloop	0		Flag for PVT cooling (0=no)
solar source	T_Mloop_max	50	°C	Max Mloop temperature

Table 6.2 – Functions (F)

SOURCE	*NAME*	*UNIT*	*DESCRIPTION*
air source	M_AHX_air	kg/h	Mass flow rate of outdoor air through AHX (air)
air source	Q_AHX	W	Thermal power of AHX exchanger
ground source	Q_GHX	W	Thermal power of geothermal loop
ground source	T_GHX	°C	Ground average temperature of sole working groups
heat pump	Q_U_S	W	Thermal power requirement in cooling mode
heat pump	Q_U_W	W	Thermal power requirement in heating mode

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heat pump	T_BF2_S	°C	BF2 tank target temperature in summer (inlet temperature at HX2)
heat pump	T_BF2_W	°C	BF2 tank target temperature in winter (inlet temperature at HX2)
solar source	P_PVT	We	PVT power calculated
solar source	Q_PVT	W	Thermal power of PVT panel
2-way valve	V_GHX1	logic	Opening of GHX1 valve
2-way valve	V_GHX2	logic	Opening of GHX2 valve
2-way valve	V_GHX3	logic	Opening of GHX3 valve
weather	BURIAN	logic	Forecast for very cold weather within X days (1=save UTES)
weather	SAHARA	logic	Forecast for very hot weather within X days (1=save UTES)

6.1 Proportional diverting valves codification

In order to facilitate the interpretation of all diverting valves settings, it was decided to identify each inlet/outlet of the V valves with a number. So, the nomenclature of the valves will be Vi.j, where the "i" indicate the number of the valve, and the "j" indicates the considered inlet/outlet.

The in/out section numbering follows the clockwise direction: a graphical representation is shown in Fig. 5.1.

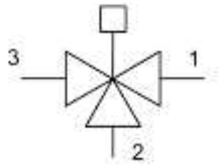

Figure 6.1 - V valves section legend

Table 6.3 – Rules (R)

3-way valve	V1	%	Proportionality of valve 1 (sources)
3-way valve	V2	%	Proportionality of valve 2 (sources)
3-way valve	V3	%	Proportionality of valve 3 (sources)
3-way valve	V4	%	Proportionality of valve 4 (sources)
3-way valve	V5	%	Proportionality of valve 5 (sources)
3-way valve	V6	%	Proportionality of valve 6 (user)
3-way valve	V7	%	Proportionality of valve 7 (user)

6.2 System states configurations at user-side

At user-side, the heating or cooling requirement is controlled by a standard room temperature sensor which turns on/off the pump P2 (secondary loop). As required during the meeting held in Belfast, a further option is the possibility for cooling the PVT to improve its efficiency. Therefore, only a system state is at user-side, and the HP is only turned on according to the temperature in the buffer tank BF2 (primary loop).

Since the room temperature could be far from the setpoint and the high thermal inertia of the radiant floor could affect the time for achieving the room setpoint, valve n.7 is proposed proportionally controlled (R) to maximise/minimise the fan coil usage according to the difference between the room temperature and the target temperature; within a default interval, the fan coil is then no longer used.

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If the PVT leaving temperature is higher than a fixed threshold (T_Mloop_max), AHX is not available for free cooling service and a specific option is selected (Mloop=1), the extra cooling capacity (space cooling is primary) can be used for improve the efficiency of the PVT, and therefore the valve V6 has to be proportionally set.

This state of the system is called U1, as depicted in Tab. 5.4, and the system configuration is reported in Tab. 5.5, in which is stated that for heating/cooling:

- HP is turned on (according to T_BF2)
- P2 is turned on
- V7.1 is full open (inlet)
- V7.2 is proportionally controlled (R_7, first outlet)
- V7.3 follows the proportional control of V7.2 (1-R_7, second outlet)
- V6.1 follows the proportional control of V6.2 (1-R_6, second outlet)
- V6.2 is proportionally controlled (R_6, first outlet)
- V6.3 is full open (inlet)

Table. 5.6 presents two preliminary rules for the control of the two proportional valves V6 and V7.

Table 6.4 – Cases and system states

CASES	ACRONYM	STATE	EXCHANGERS
Heating/Cooling	RF_FC_Mloop	U1	RF + FC + HX3

Table 6.5 – System states configurations – USER SIDE

CASE	U1
	RF & FC & Mloop
HP	X
P2	X
V6.1	R
V6.2	R
V6.3	I
V7.1	I
V7.2	R
V7.3	R

I, inlet
O, outlet
R, outlet proportionally controlled
"", not relevant

Table 6.6 – Preliminary rules for valve V7 in winter or summer season

NAME	RULES	CONDITIONS
R_7	MAX(ABS(Tr_target_W-Tr); DTr_up_W) / DTr_up_W	always

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	OR MAX(ABS(Tr_target_W-Tr); DTr_up_S) / DTr_up_S	
R_6	M_P2/M_HX2*(T_R_back-T_BF2)/(T_BF2-T_HX2)	IF Mloop=1 AND T_a>=T_Mloop_max AND Q_U_S<=Q_HP_S

6.3 System states configurations at sources-side

Table 5.7 lists all possible thermal sources combinations and modality in which the system can operate. These system states are mainly related to the corresponding heat exchangers and the on/off of the heat pump. For example, the acronym "G" is for the sole exploitation of the ground as thermal source, it is necessary to set the group valves in a way that is suitable to use the sole GHX exchanger.

The all system states configuration does not change between winter and summer, but their setting follows the energy requirements that are not only related to the HP operating for heating or cooling (primary function), but also for cooling the PVT, underground thermal energy storage, free cooling or heating.

Table 6.7 – Cases and system states

CASES	*ACRONYM*	*STATE*	*LOOP*	*HP*	*AIM*
Solar source	S	S1	PVT	On	Use of PVT for heating
Ground source	G	S2	GHX	On	Use of GHX for heating/cooling
Air source	A	S3	AHX	On	Use of AHX for heating/cooling
Ground + Air source	GA	S4	GHX + AHX	On	Use of GHX & AHX for heating/cooling
Solar + Air source	SA	S5	AHX + PVT	On	Use of AHX & PVT for heating
Solar + Ground source	SG	S6	GHX + PVT	On	Use of GHX & PVT for heating
Solar + Ground + Air source	SGA	S7	GHX + AHX + PVT	On	Use of GHX, AHX & PVT for heating
Free Heating	FREE_H	S8	PVT	Off	Use of PVT for direct heating
Free Cooling	FREE_C	S9	GHX + AHX	Off	Use of GHX & AHX for direct cooling
Underground heating storage	UHS	S10	GHX + AHX + PVT	Off	Use of AHX & PVT for ground heating storage
Underground cooling storage	UCS	S11	GHX + AHX + PVT	Off	Use of AHX & PVT for ground cooling storage
PVT cooling	PVT	S12	GHX + AHX + PVT	Off	Use of GHX & AHX for PVT cooling

In Table 5.8 all configuration states of the system are shown in terms of states of group valves, HP and P1 circulator. Following for simplicity the previous state S4 (GA):

- HP is operating, as well as the circulator P1
- Valve n.1 is open at side 1 and 3
- Valve n.2 is open at side 3 and proportionally at sides 1 and 2, to control the mass flow rate toward GHX and AHX

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- Valve n.3 is open at side 3 and proportionally at sides 1 and 2, to modulate the operating in parallel or series
- Valve n.4 is open at side 2 and 3, closed at side 1 (no PVT)

Table 6.8 – System states configurations – SOURCE SIDE

CASE	***S1***	***S2***	***S3***	***S4***	***S5***	***S6***	***S7***	***S8***	***S9***	***S10***	***S11***	***S12***
	S	***G***	***A***	***GA***	***SA***	***SG***	***SGA***	***FREE_H***	***FREE_C***	***UHS***	***UCS***	***PVT***
HP	on	on	on	on	on	on	on	off	off	off	off	off
P1	on	on	on	on	on	on	on	on	on	on	on	on
V1.1	I	I	I	I	I	I	I	I	I	I	I	I
V1.2	O							O				
V1.3		O	O	O	O	O	O		O	O	O	O
V2.1			O	R	O		R		R			O
V2.2		O		R		O	R		R	O	O	
V2.3		I	I	I	I	I	I		I	I	I	I
V3.1		O		R		O				R		
V3.2				R			O		O	R	O	
V3.3		I		I		I	I		I	I	I	
V4.1	R				R	R	R	R		R		O
V4.2	I	I	I	I	I	I	I	I	I	I	I	I
V4.3	R	O	O	O	R	R	R	R	O	R	O	
V5.1	I				I	I	I	I				
V5.2	O				O	O	O					
V5.3								O				

I, inlet
O, outlet
R, outlet proportionally controlled
"", not relevant

According to the list of parameters described in Table 4.1, the conditions that address all specific system states configurations are reported in Table 5.9 for the winter season, and in Table 5.10 for the summer season. Both tables are still preliminary and not completed yet. They will probably be enhanced during the implementation of the control unit and the experimental test.

The state S4 is here described for a better understanding.
The configuration for ground and air thermal exploitation (state S4, acronym GA) in winter season (heating) has to be selected if the following conditions are respected:

- air temperature has to be lower than a specific threshold (Ta_gsave_W), which preserves the thermal energy in the ground

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- air temperature has to be higher than the ground temperature
- the difference between air and ground temperature has to be higher than a specific value (DTag_span_W)
- PVT temperature has to be lower than the ground temperature
- the thermal power of the PVT panel has to be lower than a specific threshold (Qs_min)
- HP has to be turned on
- No adverse weather conditions are expected in the coming days.

Table 6.9 - States conditions in winter season

STATE	NAME	Ta	Tg	Ts	Qs	HP	BURIAN
S1	S	<Ta_gsave_W	<Ta+DTag_span_W	> Ta	> Qs_min	on	
S2	G	<Ta_gsave_W	>Ta+DTag_span_W	< Tg	< Qs_min	on	FALSE
S3	A	>Ta_gsave_W	< Ta+DTag_span_W	< Ta	< Qs_min	on	
S4	G+A	<Ta_gsave_W AND >Tg	>Ta+DTag_span_W	< Tg	< Qs_min	on	FALSE
S5	A+S	>Ta_gsave_W	< Ta+DTag_span_W	> Ta	> Qs_min	on	
S6	G+S	<Ta_gsave_W	>Ta+DTag_span_W	> Tg	> Qs_min	on	FALSE
S7	G+A+S	< a_gsave_W AND >Tg	>Ta+DTag_span_W	> Ta	> Qs_min	on	FALSE
S8	FREE_H			> T_BF2	> Qu_W and > Qs_min	off	
S9	FREE_C	*not analysed or relevant*					
S10	UTHS		< T_BF1		> Qu_W and > Qs_min	off	
S11	UTCS	*not analysed or relevant*					
S12	PVT	*not analysed or relevant*					

Table 6.10 - States conditions in summer season

STATE	NAME	Ta	Tg	Ts	Tr	Qs	HP	SAHARA
S1	S							
S2	G	>Ta_gsave_S	<Ta-DTag_span_S				on	FALSE
S3	A	<Ta_gsave_S					on	
S4	G+A	*not analysed or relevant*						
S5	A+S	*not analysed or relevant*						
S6	G+S	*not analysed or relevant*						
S7	G+A+S	*not analysed or relevant*						
S8	FREE_H			>Ts_limit AND >Ta	<Tr_target_S		off	
S9	FREE_C	<TBF2-DTr_down	<TBF2-DTr_down				off	
S10	UTHS	*not analysed or relevant*						

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S11	***UTCS***	<Tg		<Ta			off	
S12	***PVT***			>Ta			off	

Finally, Table 5.11 shows the sole rule to control the proportionality of valve n.2, as follows from the energy balance between valve n.1 and n.3. By multiplying the reported ratio for the overall mass flow rate flowing at HX1, the share to the AHX is estimated and that to the GHX follows as difference. In addition in this case, only a preliminary proposal is reported here, since the operating rules will be compiled during the installation of the small scale prototype.

Table 6.11 – Preliminary rules

NAME	***FUNCTION***
R_V1	*to be defined*
R_V2	(T_HX1-Tg_out)/(Ta_AHX_out-Tg_out)
R_V3	*to be defined*
R_V4	*to be defined*

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7 COVID-19 pandemic impact on building the small-scale prototype

WP3 plays a quite complex role because it couples UNIFE's prototype (GHX) with other prototypes from WP1 (CPC-PV), WP2 (/T, PCMs) and WP4 (AI) for prototyping the first IDEAS system, as proposed for the small-scale installation. The main goal is to operate with a cost effective system to drive the large-scale installation (WP5) better, and to anticipate preliminary rules and strategies for the next finer control with an AI (WP4).

The installation of the small prototype was scheduled for February and then completed later in March. The operating check was therefore scheduled in April and the first run due to start in May. Due to some administrative issues and the COVID-19 pandemic lockdown, the planned deadlines can no longer be met, because of delays in building authorisation, hiring contractors, and several supplies from companies, warehouses, and consortium partners also, who have similar problems.

In the following Tab.6.1, the comparison between the original Action Plan and the State of the Art is presented together with an optimistic rescheduling.

Table 7.1 - Original action plan, SoA and new scheduling

Activity / Supply	*Action Plan*	*State of the Art*
Design of small-scale prototype installation (HP, piping, wiring, monitoring system, …)	M10 – 28/02/2020	Completed in November 2020
Acquisition of all permits and authorizations for installation	M10 – 28/02/2020	Municipality protocol acquired on 20/04/2020
Delivery of CPC-PV/T and PCM coupling technology (>300W_e)	M10 – 28/02/2020	Unassembled PV panels delivered without thermal exchangers and PCMs (Brennero, 27/02/2020) Thermal exchangers delivery foreseen in June/July (UU)
Delivery of GHE and PCM coupling technology (12m)	M10 – 28/02/2020	PCMs delivery foreseen in mid-May (PCMP)
Delivery of radiant floor and PCM coupling technology (20m^2)	M10 – 28/02/2020	Radiant floor is in charge of the contractor PCMs delivery foreseen in mid-May (PCMP)
Delivery of PCMs for PV/T, GHEs and underfloor	M10 – 28/02/2020	PCMs delivery foreseen in mid-May (PCMP)
Commission of company for installation of small-scale prototype	M10 – 28/02/2020	Contractor hired on 17.03.2020
Installation of small-scale prototype	M11 – 30/03/2020	30/06/2020 (*predicted*)
Checking of all system functionalities	M12 – 30/04/2020	30/07/2020 (*predicted*)

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