Project Title:

Innovative compact HYbrid electrical/thermal storage systems for low energy BUILDings

Project Acronym:

HYBUILD

Deliverable Report

Deliverable number:

D3.3

Deliverable title:

Full hybrid storage integrated

Related task:	Task 3.2
Lead beneficiary:	AIT
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Due date:	30th September, 2020

DOCUMENT STATUS HISTORY		
Date	**Description**	**Partners**
2020/09/18	Draft	AIT, CNR-ITAE, NTUA
2020/09/29	Reviewed	AIT, CNR-ITAE, NTUA, UDL, R2M, COMSA
2020/09/30	Accepted	COMSA

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Publishable executive summary

Purpose:

HYBUILD is an EU Horizon 2020-funded project, coordinated by COMSA, which develops two innovative compact hybrid electrical/thermal storage systems for stand-alone and district connected buildings. Deliverable D3.3 "Full hybrid storage integrated" describes the integration phase of the hybrid storages for the Mediterranean and the Continental concept in the laboratories. Special focus was put on the hydraulic and electric integration of the main components. With D3.3, the knowledge about the integration of the specific components of the HYBUILD concepts is passed to the demo sites inside the HYBUILD project, where the technologies will be installed. Furthermore, it may help researchers and developers working on future experiments with the same or similar components. Therefore, potential problems in the system integration can be identified in advance.

Although the thermal and electric storages used in both concepts of HYBUILD are similar, their integration into the two concepts is different. Hence, both concepts are always dealt separately in the following.

For the Mediterranean sub-system, the main purpose of the activity described in D3.3 was the integration of the different components: heat pump with latent storage (RPW-HEX), batteries with DC bus and sorption module and the subsequent integration of all of them together at lab scale.

For the Continental sub-system, the main purposes were: the integration of the heat pump with a DC powered inverter and the latent storage (RPW-HEX) in a first experimental test series (2019) and the integration of the heat pump with a DC powered inverter, the latent storage (RPW-HEX), the decentralized DHW storages and the thermal controller in a second experimental test series (2020). The aim of the second test series was also to demonstrate heating/cooling and DHW-generation operation under realistic test conditions in the lab.

Methodology:

Mediterranean sub-system: At first, the integration of the heat pump and the latent storage was verified by carrying out operational tests at NTUA and CNR (Figure I) in different lab infrastructures. The integration of the DC bus with the batteries was tested at CNR by simulating through a custom software realistic operating conditions and subsequently by connecting the DC bus to the heat pump and the latent storage. The operation of the sorption module by itself integrated in the thermal lab of CNR was verified through tests in operating conditions. Subsequently, the full sub-system integration with a simplified layout was prepared, also considering all the sensors and devices needed for the lab-scale testing of the complete sub-system (to be reported in D3.4).

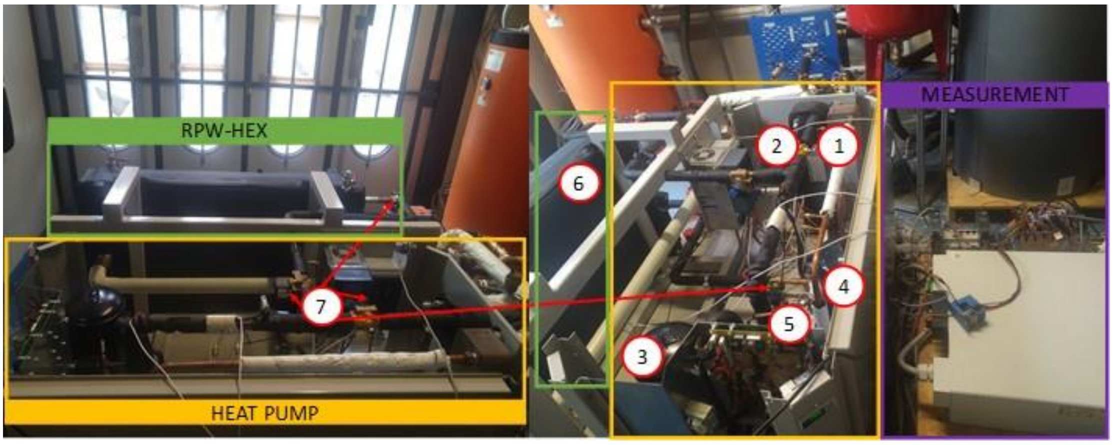


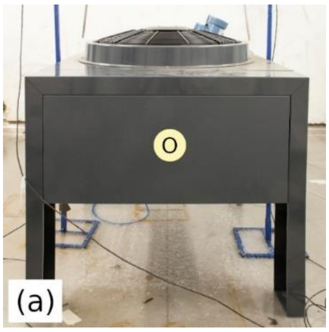
Figure I: integration of the latent thermal storage in the heat pump – focus on refrigerant circuit. 1: condenser, 2: standard evaporator, 3: compressor, 4: liquid receiver, 5: expansion valve, 6: RPW-HEX

Continental sub-system: After testing the OCHSNER heat pump without latent storage (RPW-HEX), the first version of the Continental RPW-HEX manufactured by AKG was tested experimentally together with the OCHSNER heat pump at AIT's thermal lab infrastructure under different operational conditions. With the knowledge gained from this first experimental test series, the RPW-HEX was redesigned by AKG and AIT, the heat pump was retrofitted by OCHSNER and a thermal controller, hydraulic modules and three decentralized DHW storages provided by PINK were further integrated in the adapted experimental setup at AIT (Figure II). Data from more than one hundred sensors were monitored and partly further processed to control the operation of the sub-system. For this purpose, it was necessary to build up a combined data acquisition (DAQ) and control system including the components from OCHSNER (HP controller and HP internal DAQ), PINK (thermal controller and DAQ of DHW storages and hydraulic modules) and AIT (general DAQ of all needed sensors for the experiment and master control).

Key Findings and Conclusions:

Mediterranean sub-system: The integration of the different components was properly designed in order to make it as smooth as possible, considering the relevant number of components which need to be properly integrated from the hydraulic as well as electrical point of view. All the single components were commissioned, proving their proper operation and, once integrated, they will be tested to verify the full sub-system operation. No major issues in the integration phase were highlighted, which makes this phase easy to be performed also at the demo sites level.

Continental sub-system: The experience from the integration of the RPW-HEX in the HP cycle in the first experimental test series helped to improve the RPW-HEX integration in the HP cycle for the second experimental test series. In the second test series, all crucial components except the DC bus controller, which was tested at CNR, were already integrated in the lab and tested. In both experimental test series, many problems that occurred during the integration phase were solved in the lab at AIT and components and control strategies were constantly improved through prompt consultation with the industrial partners AKG, OCHSNER and PINK.



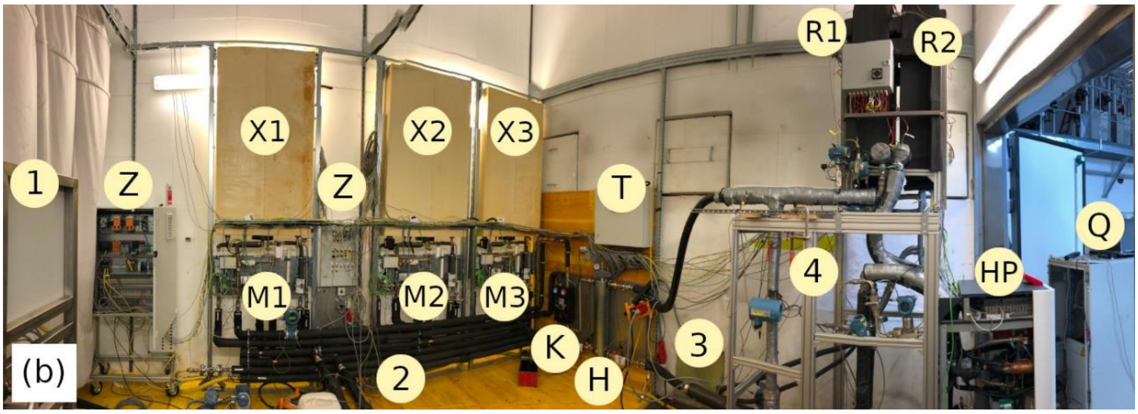


Figure II CONTINENTAL experimental set-up at AIT (2nd test series). **(a)** Outdoor unit (O) including evaporator, fan, expansion valves and sensors located in the outer climatic chamber.
(b) Panorama image of the set-up located in the inner climatic chamber at AIT. (1) hydraulic interface to lab infrastructure, (2) connecting pipes (return- and feed-line of external water cycle connected to (H), return- and feed-line to the heat-sink/source, fresh water and DHW water), (3) refrigerant connections to the outdoor unit located in the adjoining outer climatic chamber, (4) supporting frame for the RPW-HEX and the volume flow sensors, (H) hydraulic separator between HP internal water cycle and external water cycle, (HP) indoor unit of the heat pump, (Q) DC generator, (R1,R1) RPW-HEX modules, (T) Thermal controller, (X1)-(X3) enerboxxes, (Z) B&R DAQ and process control system connected to the thermal controller (T) and the HP controller.

Lessons Learned:

Mediterranean sub-system: Lessons learned for the installation in Mediterranean demo sites are related especially to the de-aeration of hydraulic circuits and the use of the proper mixture of water and glycol-anti-corrosion liquid. Indeed, due to the relevant number of plumbing components and separated circuits, the proper de-aeration components need to be installed to allow a quick and reliable filling of the whole circuit. Similarly, the proper mixture of water and anti-corrosive additive liquid needs to be prepared to fill in all the circuits in which aluminium heat exchangers are operated (i.e. both sorption module and latent RPW-HEX).

Continental sub-system: During the integration phase of the components, many problems were overcome, and several solutions were developed to improve the component and the overall system. Problems with accumulation of oil in the RPW-HEX, unwanted heat bridges and structural issues in the RPW-HEX were solved by redesigning of the RPW-HEX. The HP was retrofitted between the first and second experimental test series and will further be improved before it will be installed on the demo-site. Furthermore, problems with sensors, insulations, or communication interfaces were identified and possible solutions were reported.

Acronyms and Abbreviations

AIT	Austrian Institute of Technology
AKG	AKG Verwaltungsgesellschaft
APROL	Process automation software by Bernecker und Reiner
B&R	Bernecker und Rainer, B&R Industrial Automation GmbH.
CAD	Computer-Aided Design
CANbus	Controller Area Network (CAN) bus
CNR	see ITAE
CSEM	Centre suisse d'électronique et de microtechnique
DAIK	Daikin
DAQ	Data AcQuisition
DC	Direct Current
DHW	Domestic Hot Water
enerboxx	enerboxx® Energy efficient DHW-storage from PINK
FAHRENHEIT	FAHRENHEIT GmbH
HEX	Heat EXchanger
HT, MT, LT	High Temperature, Medium Temperature, Low Temperature
HP	Heat Pump
IO	Input Output Module
CNR-ITAE	Consiglio Nazionale delle Ricerche -
ITAE	(aka CNR-ITAE) The Advanced Energy Technology Institute "Nicola Giordano"
LabView	Automation Software by National Instruments
MIKRO	Mikrometal
NTUA	National Technical University of Athens
OCHSNER	Ochsner Wärmepumpen GmbH
OPC-UA	*Open Platform Communications* - Unified Architecture
PFD	Process Flow Diagram
P&ID	Piping and Instrumentation Diagram
PID	Proportional–Integral–Derivative
PINK	Pink GmbH
RPW-HEX	Refrigerant-PCM-Water HEX (latent storage integrated in the refrigerant cycle of a compression heat pump)
RTU	Modbus RTU (RTU: Remote Terminal Unit)
WP	Work Package

1 Introduction

1.1 Aims and objectives

HYBUILD is an EU Horizon 2020-funded project, led by COMSA Corporación, which will develop two innovative compact hybrid electrical/thermal storage systems for stand-alone and district connected buildings. Deliverable D3.3 "Full hybrid storage integrated" describes the integration phase of the hybrid storages for the Mediterranean and the Continental concept in the laboratories at CNR, NTUA and AIT. Special focus was put on the hydraulic and electric integration of the main components. With D3.3, the knowledge about the integration of the specific components of the HYBUILD project is passed to the demo sites inside the HYBUILD project where the technologies will be installed and furthermore to researchers working on future experiments with the same or similar components. With D3.3, potential problems in system integration can be considered in advance.

1.2 Relations to other activities in the project

Deliverable D3.3 shows how the components of the sub-systems were integrated in the lab. Many practical solutions were developed during the first ever installations of the sub-systems. This information is summarized in D3.3 and will provide valuable information for the installation on the demo-site and therefore to WP6 (Demonstration and evaluation).

Furthermore, the activities described in D3.3 have a direct input to the installations at the demo-sites:

<u>Mediterranean system:</u> CNR will ship all components to Almatret in three separated pallets: 1) the heat pump with RPW-HEX integrated will be shipped to Almatret demo site, 2) the integrated rack with DC bus and batteries, 3) the sorption module

<u>Continental system:</u> Supporting frames designed and manufactured by AIT for the HP and the RPW-HEX, the insulated RPW-HEX version 3 from AKG and the components provided by PINK and OCHSNER (except the HP) were sent to the Continental demo-site at PINK for further usage. The HP was sent back to OCHSNER and a new retrofitted version of the HP will be sent directly to the Continental demo-site at PINK.

1.3 Report structure

This report describes how the individual components of the Mediterranean and the Continental system have been integrated in the lab. Although the thermal and electric storages used in both concepts of HYBUILD are similar, the integration into the two systems is completely different. Hence, both concepts are always dealt separately in the following.

In <u>section 2</u> we present the integration of the components in the Mediterranean sub-system. Besides the description of the overall system in section 2.1, special focus was put on the integration of the RPW-HEX (2.2), the sorption module (2.3) and the electric storage (2.4).

The lessons learned were summarized in section 2.5.

<u>Section 3</u> describes the integration of the components in the Continental sub-system during the first (3.1) and the second (3.2) experimental test series at AIT.

For the first experimental test series, besides a description of the overall setup in section 3.2.1 and a short description about the integration in the lab infrastructure (3.1.3) and the DC integration (3.1.4), the integration of the RPW-HEX version 1 was discussed in detail (3.1.2).

For the second experimental test series the overall setup (3.2.1), the integration of the enerboxx DHW storages (3.2.3), the realisation of the interface between internal HP water cycle and building water cycle (3.2.4), the integration of the RPW-HEX version 3 (3.2.5) were discussed in detail. For the sake of completeness, the hydraulic connection to the lab infrastructure (3.2.2), the integration of the HP outdoor unit (3.2.6), the communication between the individual controllers (3.2.7), and the DC integration (3.2.8) were also described briefly.

The lessons learned were summarized in section 3.3.

Section 4 summarizes the work that was carried out to integrate the components in both concepts.

1.4 Contributions of partners

Mediterranean system (CNR, NTUA, AKG, DAIKIN, FAHRENHEIT):

NTUA and DAIKIN modified the commercial heat pump from DAIKIN, installing the RPW-HEX manufactured by AKG and adapting the supply voltage to DC current. Moreover, NTUA did some preliminary testing of the heat pump. FAHRENHEIT manufactured the sorption module. CNR realised the integration of the heat pump/RPW-HEX with the sorption module and the integration of the electric storage with the DC bus in the lab, was mainly responsible for the development of the Mediterranean concept and wrote section 2 of the report together with NTUA.

Continental sub-system (AIT, AKG, OCHSNER, PINK):

AKG designed all Continental RPW-HEX modules together with AIT and manufactured three different versions of full-scale RPW-HEX modules (about 2.5 kWh latent storage capacity) for the lab tests. OCHSNER developed, adapted and retrofitted the air-source-HP for the tests in the AIT labs, furthermore, they provided the hydraulic separator for the second experimental test series and helped during the installation phase at AIT. PINK provided three enerboxx DHW-storages, three hydraulic modules, a thermal controller and helped during the installation phase at AIT. AIT planned and carried out the integration of each component in the lab, was mainly responsible for the development of the Continental concept and wrote section 3 of the report.

2 Integration of the hybrid storage in the Mediterranean system (CNR-ITAE and NTUA)

The heat pump with RPW-HEX was developed by NTUA starting from the commercial heat pump from Daikin. Two sets of modifications were done: on the refrigerant and hydraulic circuit, to allow the installation of the RPW-HEX, and in the electric circuits, to allow the operation with DC current when connected to the DC bus. A detailed description of the modifications is reported in D2.3. It was shipped to CNR and tested in January 2020 to verify the integrated operation of the heat pump with RPW-HEX.

The integration between the electricity storage and the DC bus rack (developed by CSEM) was done at CNR and its operation tested both with simulated parameters and by connecting the DC bus + electricity storage to the heat pump+RPW-HEX.

The sorption module was manufactured by FAHRENHEIT and shipped to CNR in June 2020. The first tests to verify the proper operation of the sorption module by itself were realised in summer 2020.

Due to a problem with the RPW-HEX, i.e. the damaging of the refrigerant passages of the RPW-HEX, a new component was manufactured by AKG and shipped to CNR at the beginning of September 2020. Its installation as a replacement of the old RPW-HEX and subsequent filling with the refrigerant is currently on-going.

The heat pump+RPW-HEX will then be integrated with the sorption module by hydraulically connecting the components.

2.1 Overall setup

The overall Mediterranean subsystem, as integrated in the laboratory of CNR-ITAE is shown in Figure 1 and in Figure 2. The hydraulic integration and installation is shown in Figure 1 and consists of the heat pump, with the integrated hybrid thermal storage, i.e. the sorption module and the latent storage (RPW-HEX). The electric connections for the installation in the lab are shown in Figure 2. It is worth noticing that, after a preliminary test with the heat pump connected to the grid through a DC driver, tests with the integrated heat pump+latent storage+DC bus were done, thus connecting the compressor directly to the bus in the rack with the DC microgrid.

For a detailed description of the components of the heat pump and its operation see section 2.2, whereas for a detailed description of the operation of the sorption module and its main components see section 2.3. The integration of the electric storage, and the management of the electric connections are detailed in section 2.4. The testing facilities and the sensors used for the monitoring and the evaluation of the system performance are described in detail in Deliverable 3.2. The main operation of the system in the lab was controlled by means of a LabVIEW® code specifically realised and intended to replicate the main operating modes of the system under realistic boundaries. Different operating modes will be tested. In particular, at first, the operation of the heat pump with the integrated RPW-HEX will be evaluated, considering the following possible operational modes: (1) operation with standard evaporator, (2) charge of RPW-HEX, (3) discharge of RPW-HEX, (4) parallel charge/discharge of RPW-HEX. Such modes can be selected by changing the position of 4 solenoid valves installed in the refrigerant circuit of the heat pump and by switching the position of a deviating valve installed in the water circuit of the evaporator of the heat pump. Control of the heat pump with RPW-HEX, will be realised at first by electric connection to the grid and, in a second step, by connection to the DC bus included in the rack that integrates also the batteries. Subsequently, the overall setup, as shown in Figure 1 will be installed and tested. In this case, the condenser circuit of the heat pump is hydraulically connected with the Low Temperature (LT) circuit of the sorption module. In this case, the heat source in the testing rig supplies the High Temperature (HT) energy to the sorption module, that cools down the heat pump with RPW-HEX, while dumping the condensation and sorption heat (MT) to a dedicated storage in the testing rig. The condensation heat of the heat pump represents the evaporation source for the sorption module. According to the simulated conditions, electricity needed to drive the heat pump might come from the simulation interface for PV, the batteries or the electric grid. Main focus of the first tests in the lab of CNR-ITAE will be devoted at ensuring the proper operation of the system under the different possible operating modes. Detailed results of the tests will be presented in Deliverable 3.4.

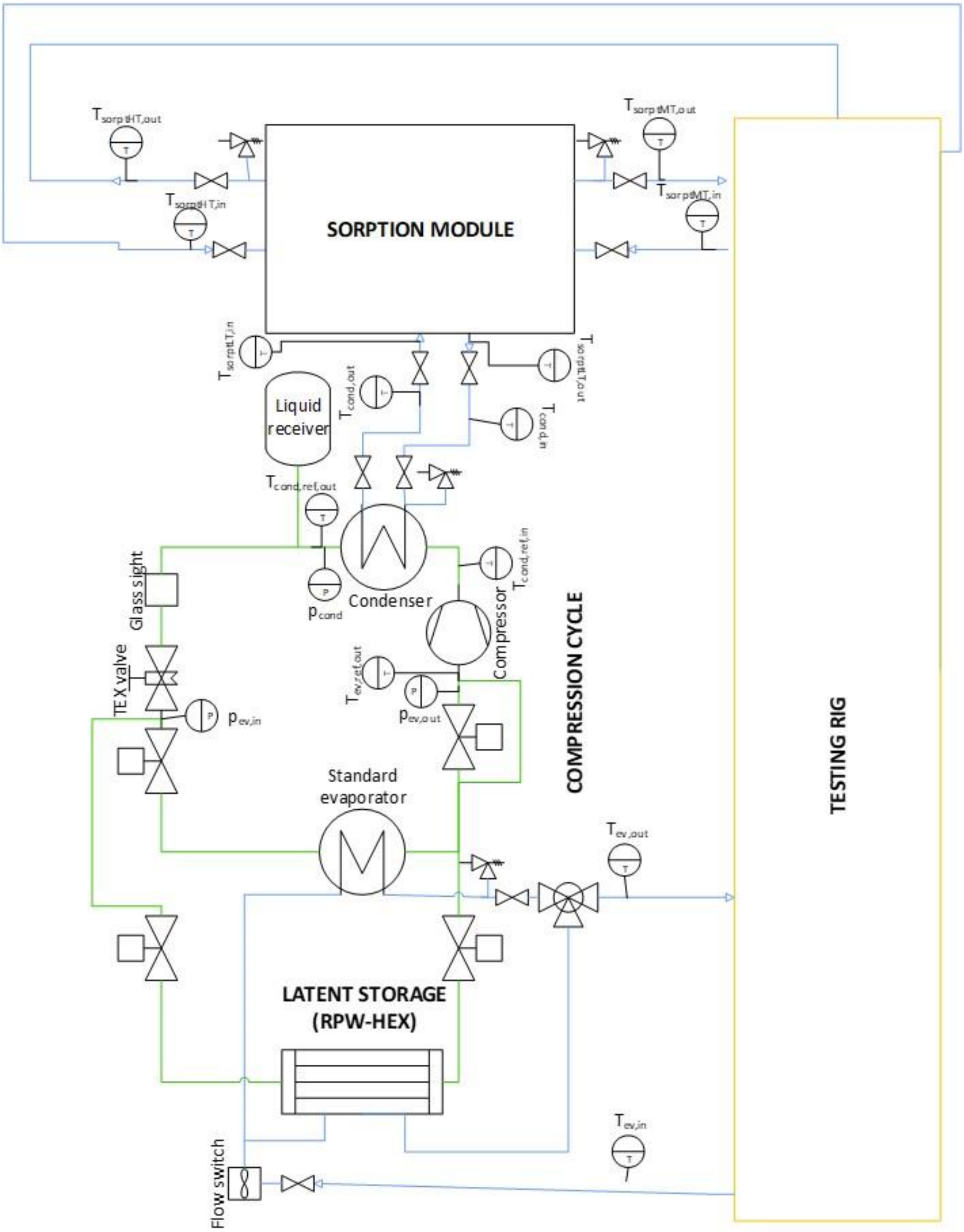


Figure 1: P&ID of Mediterranean subsystem integrated in the lab.

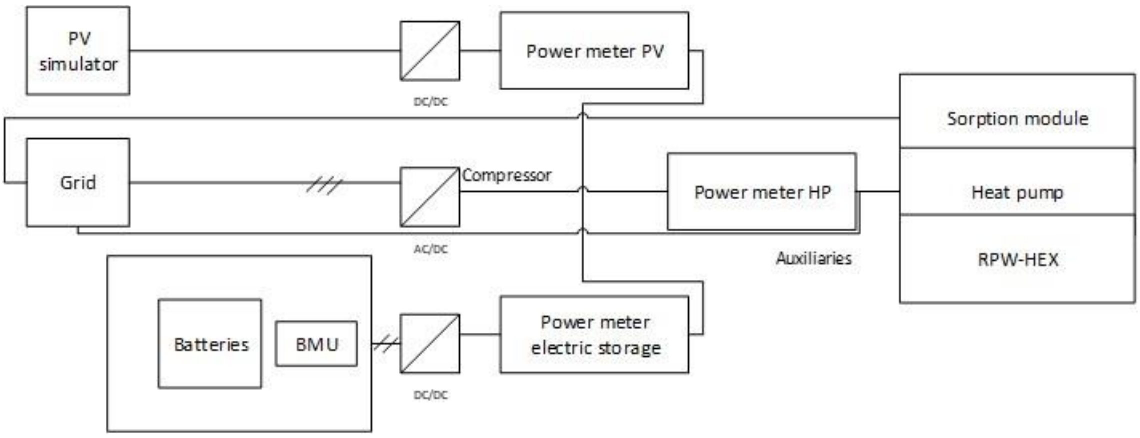


Figure 2: Mediterranean system integrated in the lab - detail of electric connections.

A picture of the complete system installed in the lab is shown in Figure 3.

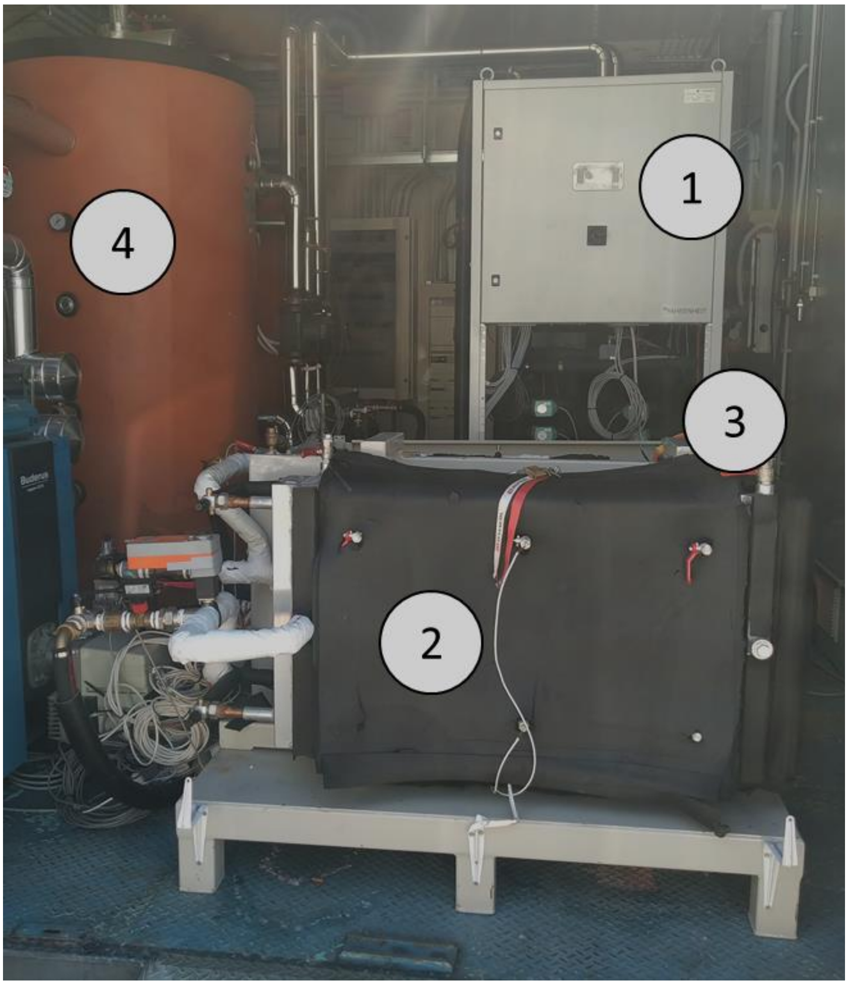
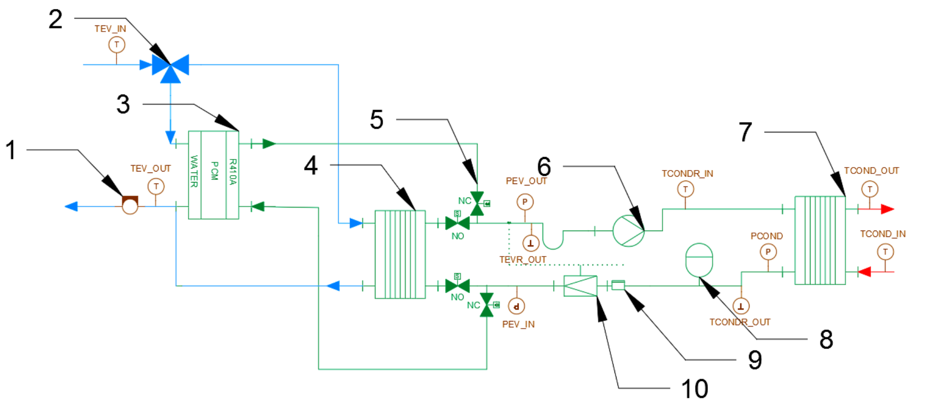


Figure 3: MED sub-system in the lab of ITAE. 1: sorption module; 2: heat pump with RPW-HEX; 3: electric connection to the rack; 4: testing rig.

2.2 Specific integration of the thermal storage (RPW-HEX)

The Mediterranean heat pump unit is of the water/water type providing the option to connect the sorption chiller on top of its condenser. This heat pump unit has been retrofitted with the RPW-HEX and the hydraulic circuit of the evaporator has been filled with glycol-water mixture

(40% v/v) in order to ensure safe operation down to -15°C. A schematic with the components and the installed sensors on the heat pump is depicted in Figure 4. The overall integrated sub-system is shown Figure 5, whereas Figure 6 and Figure 7 are focused on the refrigerant and the hydraulic circuit, respectively.



1	Flow Switch
2	3way HEX bypass valve
3	RPW-HEX
4	Standard Evaporator
5	Solenoid Valves
6	Compressor
7	Condenser
8	Liquid Receiver
9	Sight Glass
10	Thermostatic Expansion Valve

Figure 4: Schematic diagram of the compression heat pump setup in lab for the Mediterranean concept (installed sensors marked in red)

The refrigerant circuit is typical of a conventional water chiller design, consisting of a hermetic scroll compressor (6), a Thermostatic Expansion Valve (10) and two plate heat exchangers, the evaporator (4) and the condenser (7). No 4way valve is installed and thus, if heating is needed, the hydraulic circuits of the evaporator and the condenser need to be swapped by means of 3-way valves. The state of the refrigerant flow after the condenser may be qualitatively determined using the sight glass (9) that can be seen in Figure 8. The RPW-HEX (3) actually replaces the standard evaporator in cooling mode (Figure 9). In order to maintain the option to operate the heat pump with the standard evaporator (essential in heating mode), bypass loops have been implemented in both the refrigerant and the water-glycol circuits. In the hydraulic side, a 3way ball valve (2) connects either the standard evaporator or the RPW-HEX to the water-glycol supply pipeline (Figure 11). The motor of the valve was selected in order to allow fast switching between the two modes in order to prevent evaporator freezing (running time of 45 sec to switch from standard evaporator to RPW-HEX and 24 sec to switch from RPW-HEX to the standard evaporator), while its design permits the switching of the heat exchangers during operation without affecting the Flow Switch (1), which is installed on the outlet of both the heat exchangers. If the charging mode of the RPW-HEX is needed to be tested (thus no water-glycol flow is desired in the heat exchanger), the flow switch can be bypassed from the control unit of the heat pump (Figure 13). On the refrigerant side, four solenoid valves allow the immediate switching between the two heat exchangers. The solenoids connected to the standard evaporator ports are Normally Open (NO), while the ones connected to the RPW-HEX are Normally Closed (NC). Since the 3way valve on the water-glycol side is diverting the flow in the RPW-HEX only when it is electrically connected, the heat pump is reverted to the standard evaporator in case of automation system power loss. Lastly, since a large discrepancy among the refrigerant charge needed among the RPW-HEX and the standard evaporator was identified, a liquid receiver at the exit of the condenser was installed. The retrofitted Mediterranean heat pump has been at first tested in the laboratory of NTUA, described in D3.2 and subsequently shipped to ITAE, where it was integrated in the testing rig described in D3.2.

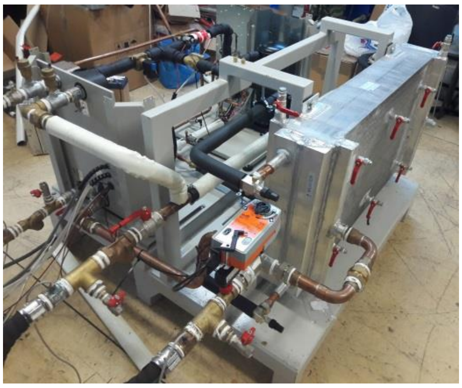


Figure 5 The retrofitted heat pump along with the RPW-HEX

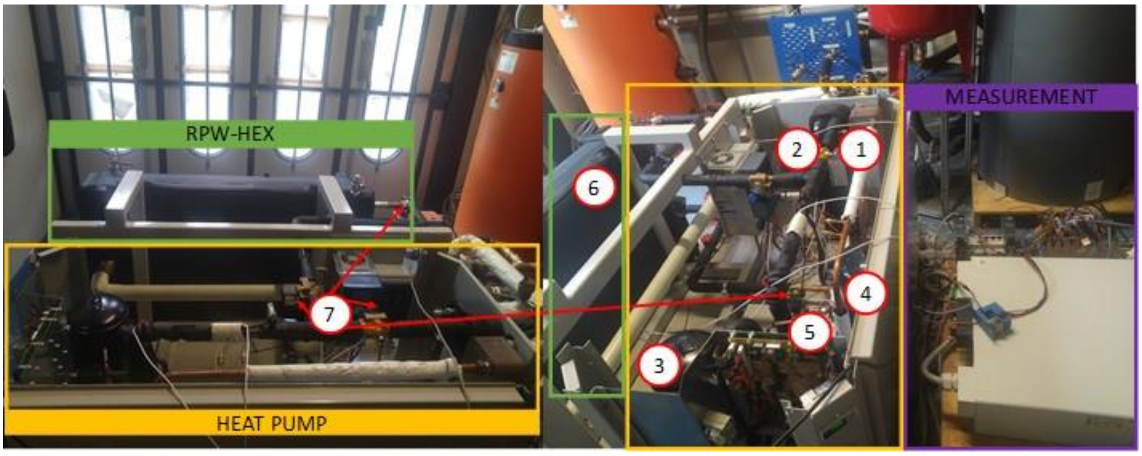


Figure 6: integration of the latent thermal storage in the heat pump – focus on refrigerant circuit. 1: condenser, 2: standard evaporator, 3: compressor, 4: liquid receiver, 5: expansion valve, 6: RPW-HEX

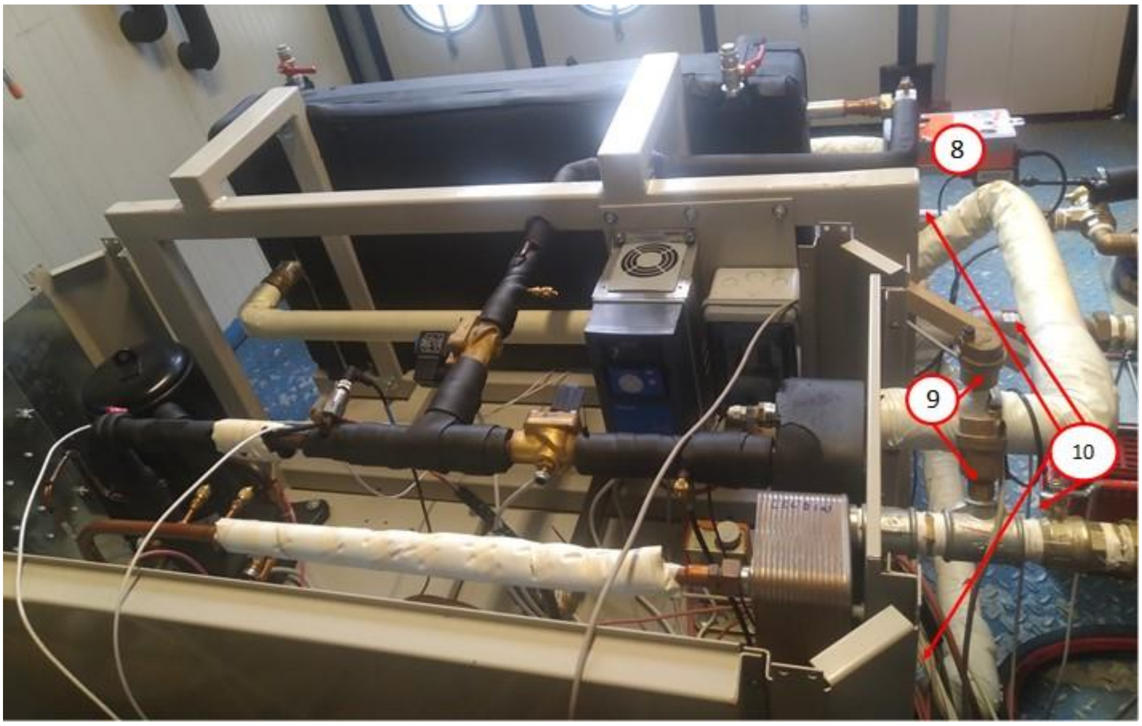


Figure 7: integration of the latent thermal storage in the heat pump – focus on hydraulic circuit. 8: 3-way valve, 9: air traps, 10: manual ball valves.

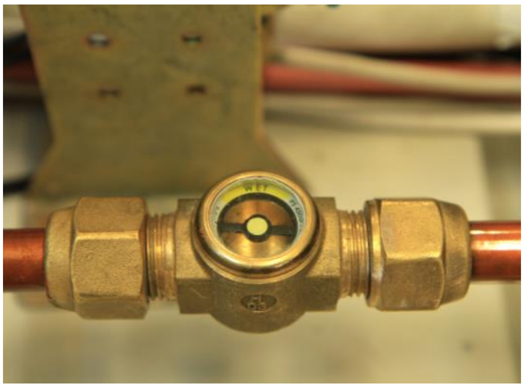


Figure 8 Sight Glass in the refrigerant circuit

Figure 9 The RPW-HEX (insulated)

Figure 10 Pressure and temperature sensors in the refrigerant circuit

Figure 11 The 3-way ball valve in the evaporator circuit

Figure 12 The DC-driven VACON inverter (Variable Speed Drive) of the compressor

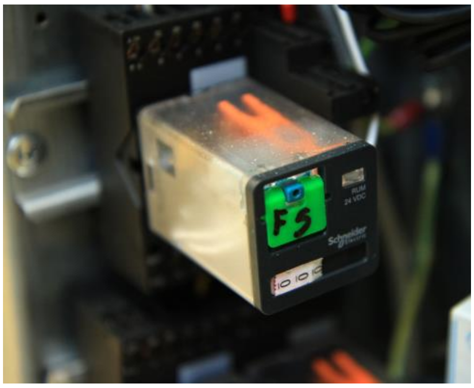


Figure 13 The by-pass relay of the Flow Switch

Finally, Figure 14 shows the detail on the integration of the electric connection. For the connection, there is a dedicated cable suitable for 3-phase connection, to start the auxiliaries of the heat pump. On the main board of the heat pump, some relays allowing the remote control of fixed set-points for the speed of the compressor are installed. In addition, cable (12) is provided, which provides power supply to the compressor. In the overall installation, as shown in Figure 2, it is directly connected to the DC bus inside the electric rack.

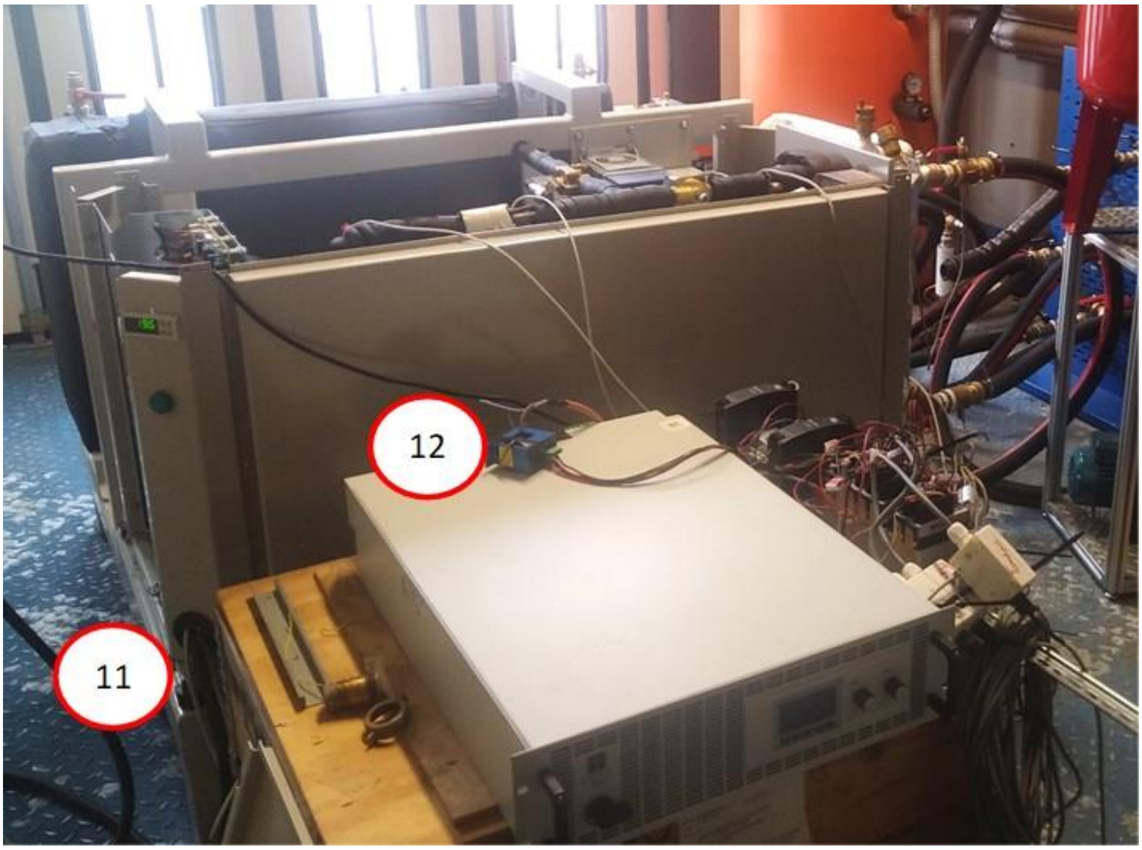


Figure 14: integration of the latent thermal storage in the heat pump – focus on electric connections. 11: cable for DC operation of the heat pump, 12: supply voltage

The heat pump and latent storage were already equipped with all the necessary sensors for measurement (see Figure 1 and Deliverable 3.2), that were connected to the data acquisition system at CNR-ITAE. In particular, the two specific sensors, calibrated Pt100, are installed in the upper and lower part of the thermal storage to measure the temperature of the PCM. In addition, in a first step of the measurement, an additional flow meter, suitable for low flow rates, was installed in case the flow rate when operating the RPW-HEX was significantly lower than expected. However, the operation showed that the optimal operation was from 3 m^3/h to 9 m^3/h, therefore it was not used.

2.3 Specific integration of the sorption module

The integration of the sorption module with the heat pump and with the testing rig is shown in Figure 15.

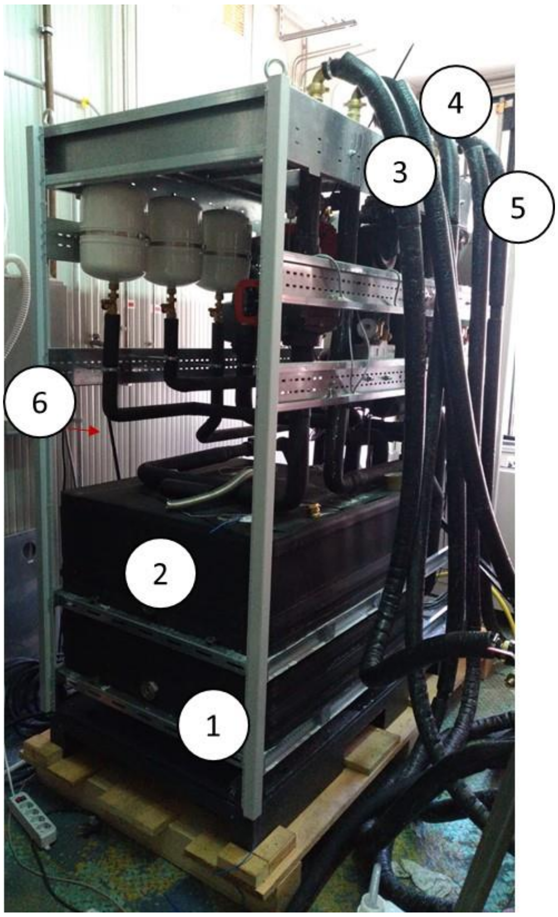


Figure 15: sorption module integrated with heat pump. 1, 2: adsorbers and evaporators/condensers; 3: pipes of LT circuit; 4: pipes of MT circuit; 5: pipes of HT circuit; 6: cable for supply voltage.

6 flexible hoses were used for the installation: 2 hoses were connected to the high temperature storage tank (5 in Figure 15), simulating the heat source; 2 hoses were connected to the medium temperature storage tank (4 in Figure 15), that simulates the ambient heat sink, 2 hoses (3 in Figure 15) were connected at first to the low temperature storage tank of the testing rig, for the characterization of the sorption module, and subsequently to the condenser circuit of the Daikin heat pump to test cascade operation of the components. Manual valves and an air trap for air evacuation from hydraulic circuits were installed on each line.

As for sensing equipment, the sensors already installed inside Fahrenheit chiller were accessed through Modbus TCP and their values acquired during the measurements. They consist of 10 Pt1000 temperature sensors and 3 ultrasonic flow meters, installed as follows:

- Outlet of adsorber 1 temperature;
- Outlet of evaporator/condenser 1 temperature;
- Outlet of adsorber 2 temperature;
- Outlet of evaporator/condenser 2 temperature;
- In/out of HT circuit temperatures;
- In/out of MT circuit temperatures;
- In/out of LT circuit temperatures;
- Flow rate of HT circuit;
- Flow rate of MT circuit;
- Flow rate of LT circuit.

In addition, 6 thermocouple T type were used, which are installed at the inlet/outlet of each circuit of the testing rig and 3 magnetic flow meters, installed in the HT, MT and LT circuit, as shown in Figure 16.

Figure 16: sensors in the testing rig for the sorption module characterization.

All the circuits of the sorption module need to be filled with a water/corrosion inhibitor solution. The corrosion inhibitor[1], supplied by Fahrenheit, is used to prevent corrosion in the HEXs of the sorption module, since the adsorbers are realized in aluminium alloy. A 5% solution of corrosion inhibitor in water is used. Moreover, all the circuits of the testing rig are equipped with plate HEXs for separation purposes.

Electricity consumption of the sorption module was checked by connection of its supply voltage to an electric meter (SINEAX DM5S from Camille Bauer).

2.4 Specific integration of the electric storage (battery, DC converter)

The electric storage was integrated in the main DC bus according to the layout and principles described in D2.3 and D3.2. A picture of the integrated system is shown in Figure 17. The battery pack was installed on the bottom of the rack for weight distribution reasons.

[1] https://www.glysofor.de/en/thermogard-ht/

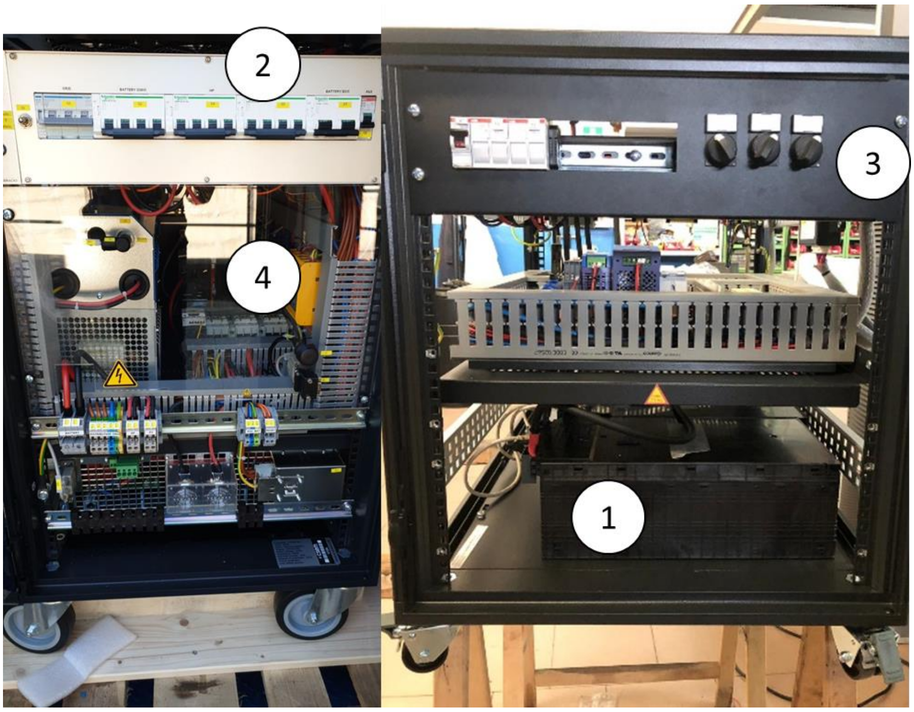


Figure 17: integration of DC bus and electric storage. 1: batteries; 2: main switches; 3: manual switches; 4: main PLC.

The storage control and transcoding devices were installed in a single section of the rack together with the dedicated power supply and terminal block, as shown in Figure 18.

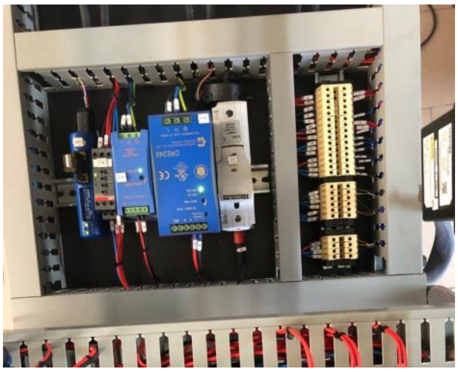


Figure 18: devices for storage control integrated in the rack.

Three power breakers were installed, which are operated according to the BMU internal logic. A dedicated under/over voltage disconnection coil and breaker were used to avoid overdischarge/overcharge even in case of the main controller failure, as shown in Figure 19.

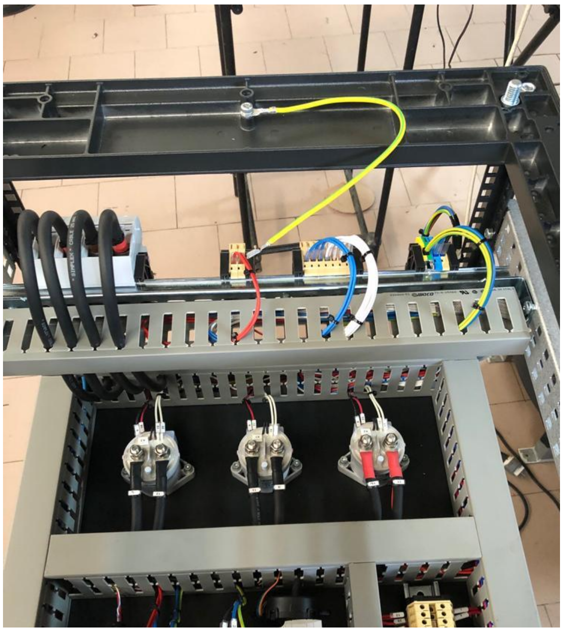


Figure 19: power breakers and safety disconnection coil.

Finally, manual switches were added to let an operator acting safely and effectively in case of maintenance or in a manual startup after a critical failure. The detail of the switches is shown in Figure 20.

Figure 20: detail of the manual switches installed.

The communication interface was tested at first using Modbus RTU protocol level (i.e. simulating the rack PLC controller behavior by a PC with a dedicated software interface developed in LabVIEW environment) to detect any design/programming/configuration errors in the bidirectional communication between the internal BMU and the transcoding device and between the transcoding device and the PLC. Subsequently, a dedicated software application was developed to send commands (and reading the correlated data) to the PLC through the OPC-UA interface provided by CSEM (see Figure 21).

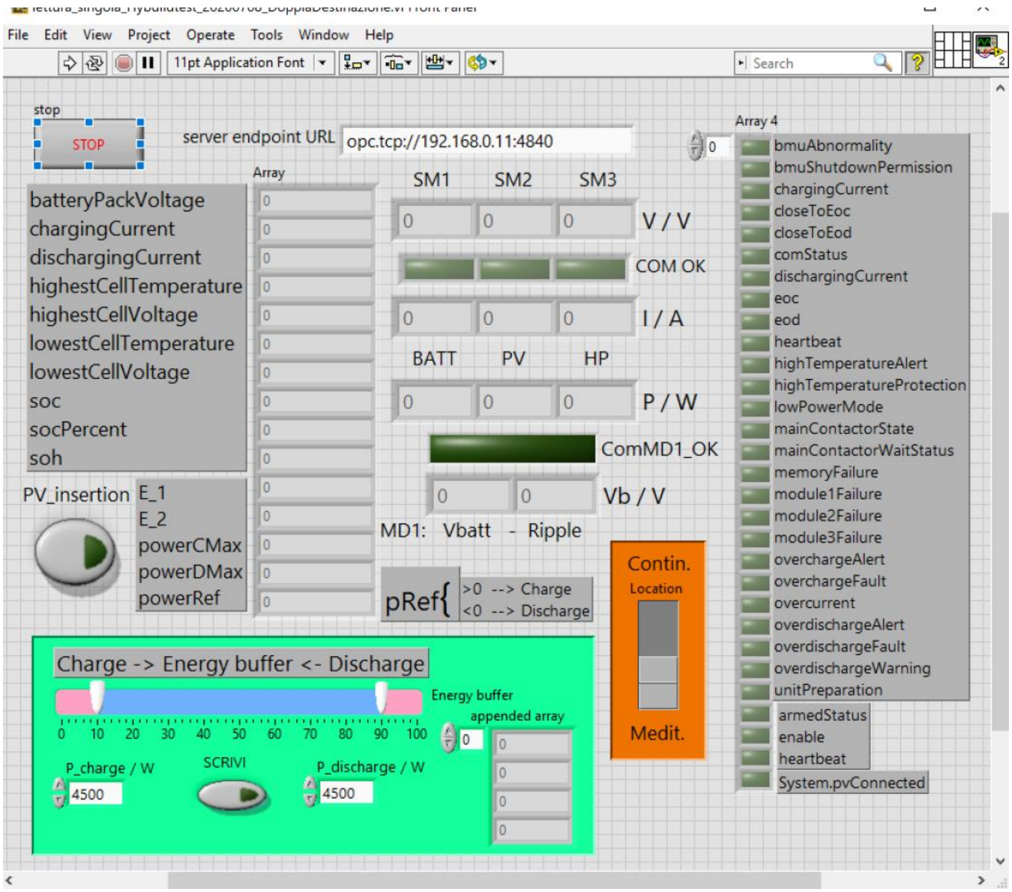


Figure 21: LabVIEW software for testing the OPC-UA communication with the PLC.

The start-up procedure was tested both in debug and in automatic (i.e. normal operating) mode. The former mode was used to test the single components regardless of the control sequence. On the other hand, the automatic mode allowed to verify the correctness of the Finite State Machine model implemented and the detection of warning/alarm conditions with the consequent blocking actions.

All the readouts were coherent with the panel instruments on the front side of the rack, in terms of electric power, voltage and current. Due to the different hardware used for the Continental and Mediterranean implementation, the test application was developed to select the appropriate process variables identifiers (i.e. string identifiers) at runtime. After this first check, the DC/DC converter was forced to charge and discharge the battery by imposing buffer intervals the actual SoC did not belong to. Under this condition, the battery was both charged and discharged and once the SoC was close to the nearest limit of the buffer interval, the power was automatically limited well below the limit value set.

Figure 22: testing of the integrated DC bus and electric storage.

2.5 Lessons learned

2.5.1 Lessons learned for the demo with the RPW-HEX

Regarding the installation in demo sites, the following points were identified as critical:

- Removing air trapped in the circuits, especially the hydraulic circuit of the RPW-HEX is crucial to ensure proper operation and it can take a while.
- A safety condition on the low pressure of the refrigerant has to be implemented in the thermal controller, since there is no low-pressure switch installed.
- During installation, it is important to put attention on the connection of the 3 phases in the main plug since it also supplies the current to the DC driver of the compressor, that does not start unless the rotation sense is correct.
- During RPW-HEX charging operation, it is important to keep a circulation in the hydraulic loop of the RPW-HEX, in order to allow a more homogeneous phase change, and therefore increase the amount of energy that can be stored.
- Charging of the RPW-HEX is not particularly influenced by the speed of the compressor.
- Bypassing the flow switch during discharging is instead necessary to allow the operation of the heat pump.

2.5.2 Lessons learned for the demo with the sorption module

Regarding the installation in demo sites, the following points were identified as critical:

- Removing air trapped in the circuits is crucial to ensure proper operation and it can take a while.
- All the circuits have to be filled with the corrosion inhibitor solution. To do so, the “valve run” mode has to be activated and the solution should be pumped until all the pressure indicators are around 2 bars. However, the MT circuit of the sorption module already includes the separation HEX and has therefore to be filled separately from the others. An external pressure indicator must be installed to check for the correct pressure level.
- It is worth remarking that the supply voltage cable of the sorption module is not connected to the DC bus and that the heat pump has an additional 230 V connection for the auxiliaries (controller and solenoid valves) that should be connected outside the DC bus as well.

3 Integration of the hybrid storage in the Continental system (AIT)

In Task 3.2, two full scale integrated hybrid storage prototypes were tested at AIT during spring/summer 2019 and spring/summer 2020.

The first full scale RPW-HEX prototype from AKG (version 1) was tested together with the heat pump from OCHSNER in 2019. Because the DC bus prototype from CSEM (see 2.4) was used at CNR/ITAE for testing the Mediterranean system together with the battery, the DC feed of the inverter in the HP was tested with a DC generator from AIT (see also Deliverable 3.2). The setup and the integration of this first series of experiments is described in section 3.1.

During the first experimental test series, it was found out that the oil in the refrigerant cycle accumulated in the RPW-HEX, which led to the destruction of the compressor after about 2-4 weeks of operation. After a detailed analysis of this failure, the compressor was replaced, and the experimental procedures – here in particular the start-up procedure – was adapted to account for this design issue. However, the issues faced with the compressor as well as test results made clear that the RPW-HEX had to be redesigned for the demo. The new design must avoid oil traps and unbeneficial heat bridges which were identified as part of the experimental analysis (to be reported in D3.4). Furthermore, it was decided to have the HP retrofitted with an oil separator after the compressor as a secondary safety measure to prevent future failures. Therefore, the experiments with the first RPW-HEX were stopped in autumn 2019. The RPW-HEX design was extensively analysed and adapted in cooperation between AKG and AIT. Furthermore, the HP was retrofitted by OCHSNER to be prepared for the second test series.

The testing of the second RPW-HEX prototype (version 2) manufactured by AKG was planned for November 2019. The test rig at AIT was prepared at this point of time, but unfortunately the RPW-HEX version 2 didn't pass the last safety pressure tests at AKG due to structural issues and unsatisfactory welding. This revealed the need for another design of the RPW-HEX. Among other things, the next version of the RPW-HEX was separated into two smaller versions connected in series. These design adaptions where crucial steps towards the final design but also caused the need for a major adaption of the test rig and the mounting structure. The third version of the full-scale Continental RPW-HEX, together with an adapted test rig for the new RPW-HEX version was finally available at AIT for the tests with the retrofitted HP from OCHSNER in April 2020.

During this second test series (May-August 2020), additionally three decentralized sensible water storages (enerboxxes) from PINK, a thermal controller from PINK and a hydraulic separator provided by OCHSNER to decouple the internal water cycle of the HP from the external water cycle were integrated in the experiment to have the full thermal system tested. To operate at close to demo-site conditions, the inverter of the HP was operated with DC current using the previously mentioned DC generator all the time. The overall setup of these experimental tests is described in section 3.2.

The integration of the sub-components and sub-systems such as the RPW-HEX, the DHW-storages including the hydraulic connections, the hydraulic system, etc. is discussed in detail in the sub-sections of both 3.1 and 3.2.

In section 3.3, the lessons learned during the implementation of the components during the experimental tests in the lab are summarized.

3.1 Experiments with Continental RPW-HEX version 1

3.1.1 Overall set-up

Figure 23 shows the integration of the RPW-HEX version 1 and the vapour compression HP in the AIT Lab infrastructure.

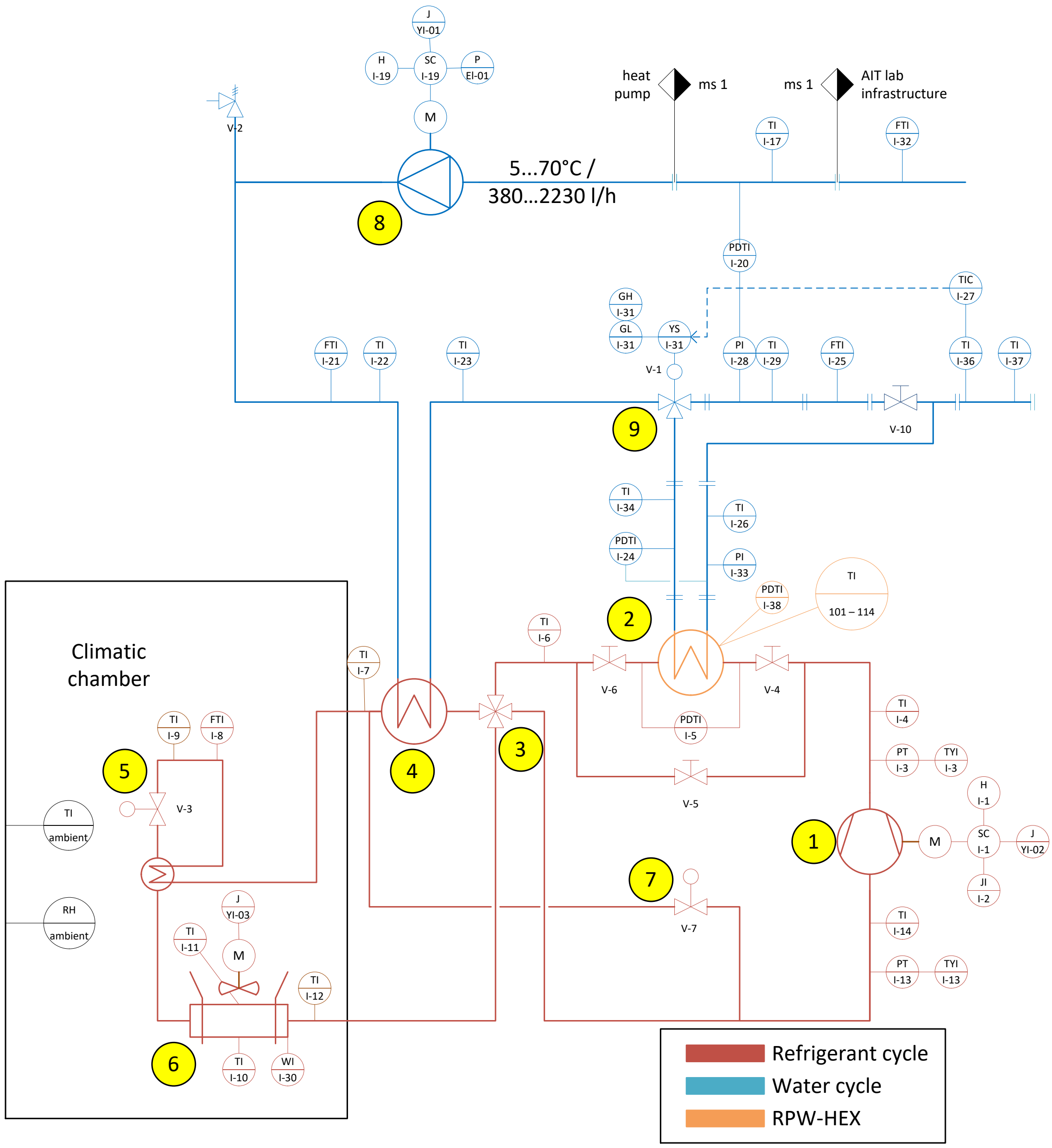


Figure 23: P&ID of the experimental setup to perform tests with RPW-HEX Version 1. ① Compressor, ② thermal storage (RPW-HEX), ③ 4-way-valve, ④ Condenser, ⑤ Expansion valve, ⑥ Evaporator, ⑦ Liquid injection valve, ⑧ water pump, ⑨ 3-way-valve. (TI) Temperature sensors, (PT) Pressure sensors, (FTI) mass flow sensors, (SCI) speed monitoring, (JI) electric power measurement, (WI) scale.

During heating operation, the refrigerant is compressed by the compressor ① and the hot gas leaving the compressor charges the RPW-HEX ②. Please note, that valves V-4 to V-6 can be used to bypass the RPW-HEX as it was the case during the benchmark tests of the heat pump without RPW-HEX (winter/spring 2019). After the refrigerant has transferred sensible energy to the PCM in the RPW-HEX, the refrigerant leaves the RPW-HEX with a colder temperature than at the inlet and enters the four-way valve ③. The four-way valve is used to reverse the heat pump cycle during defrosting or cooling operation. In heating mode, the refrigerant flows to the condenser ④ where it condensates and transfers heat to the water flowing on the secondary side of the condenser. To guarantee a liquid state of the refrigerant at the inlet of the expansion valve ⑤, the refrigerant is further cooled down by the outlet flow of the expansion valve with the aid of a HEX. The same HEX warms up the liquid refrigerant after the expansion valve. After having passed the evaporator ⑥, the superheated refrigerant flows back to the compressor. If the hot-gas exceeds 105°C, the liquid injection valve ⑦ opens (controlled by an internal PI-controller) and liquid refrigerant is bypassed from the high-pressure side to the entrance of the compressor to cool down the inlet and therefore the outlet temperature of the compressor. The compressor can handle the refrigerant in a two-phase state as long as the liquid share is relatively small.

In cooling and defrosting mode, the refrigerant cycle is being reversed by the four-way valve ③. The superheated refrigerant leaving the compressor ① still transfers heat to the RPW-HEX ② but now the four-way valve ③ directs the hot refrigerant into the evaporator located in the outdoor unit ⑥. Thus, the evaporator becomes the condenser. Then, the refrigerant flows through the expansion valve ⑤ and evaporates in the former condenser ④. Subsequently, the refrigerant flows back to the compressor via the four-way valve. In cooling and defrost operation the liquid injection valve ⑦ is closed all the time.

On the water side, the process water is connected to the AIT-lab infrastructure which acts as a controllable heat-sink or -source, respectively. At the water inlet (TI-17) the water is provided with a constant set-temperature independent of the outlet temperature (TI-36). The HP-internal water pump ⑧ pumps the water through the secondary side of the condenser ④. In heating or cooling mode, the three-way valve ⑨ is completely closed and therefore, the water bypasses the RPW-HEX. In DHW generation mode, the three-way valve is either fully opened or controlled to have a part of the water flowing through the RPW-HEX ② and therefore discharging the RPW-HEX. The valve V-10 is a manual valve which is used for hydraulic balancing. The temperature sensor TI-36 at the mixing point of the bypass and the RPW-HEX path, was used to regulate the three-way valve during DHW generation mode. For this purpose, a software controller was implemented in AITs control system (B&R).

Please note that during some tests the inverter of the heat pump was powered with a DC generator (not shown in Figure 23).

All the sensors which are visualised in Figure 23 were either sensors which were originally installed in the HP by OCHSNER or were additionally attached by AIT. Temperature sensors which have been installed by OCHNSER were PT 1000, class B sensors (TI-22, TI-23, TI-4, T-06, TI-12, TI-9, TI-7, TI-6, PTI-13, PTI-3, TI-36). Sensors provided by AIT were calibrated PT 100, 1/3 class B sensors (TI-17, TI-34, TI-26, TI-29, TI-37, TI-101 – TI-114).

3.1.2 Integration of the thermal storage (RPW-HEX version 1)

Figure 24 shows the RPW-HEX version 1 manufactured by AKG. It had a total mass of 155 kg whereby the aluminium accounted for 115 kg and the PCM for 40 kg. The PCM used in this thermal storage was RT64 HC from Rubitherm, which has a melting peak at 64°C and two solidification peaks between 64°C and 61°C.

Figure 25 shows how the RPW-HEX is integrated into the test rig. The storage was mounted in a frame which allows to raise and lower one side of the RPW-HEX. This allowed the RPW-HEX to be tilted from a horizontal position to a 45° diagonal position during operation (Figure 26) to allow the oil, accumulated in the RPW-HEX, to return to the refrigerant cycle. Hence, flexible hoses were used instead of pipes to connect the RPW-HEX with the HP. The water in- and outlet was realized with hoses and pipes whereby special attention was paid to guarantee sufficient long inlet sections for the sensors (pressure, temperature, mass flow).

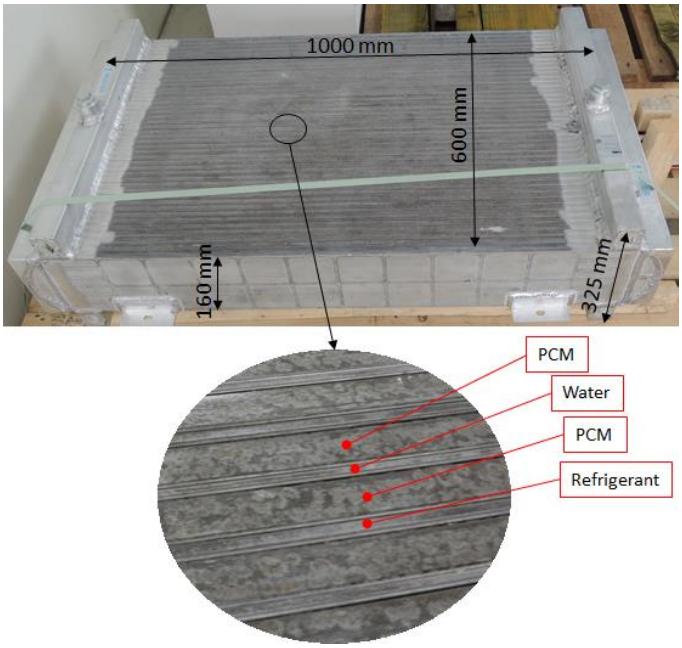


Figure 24: Picture of the RPW-HEX with external dimensions and detailed view of the micro channels.

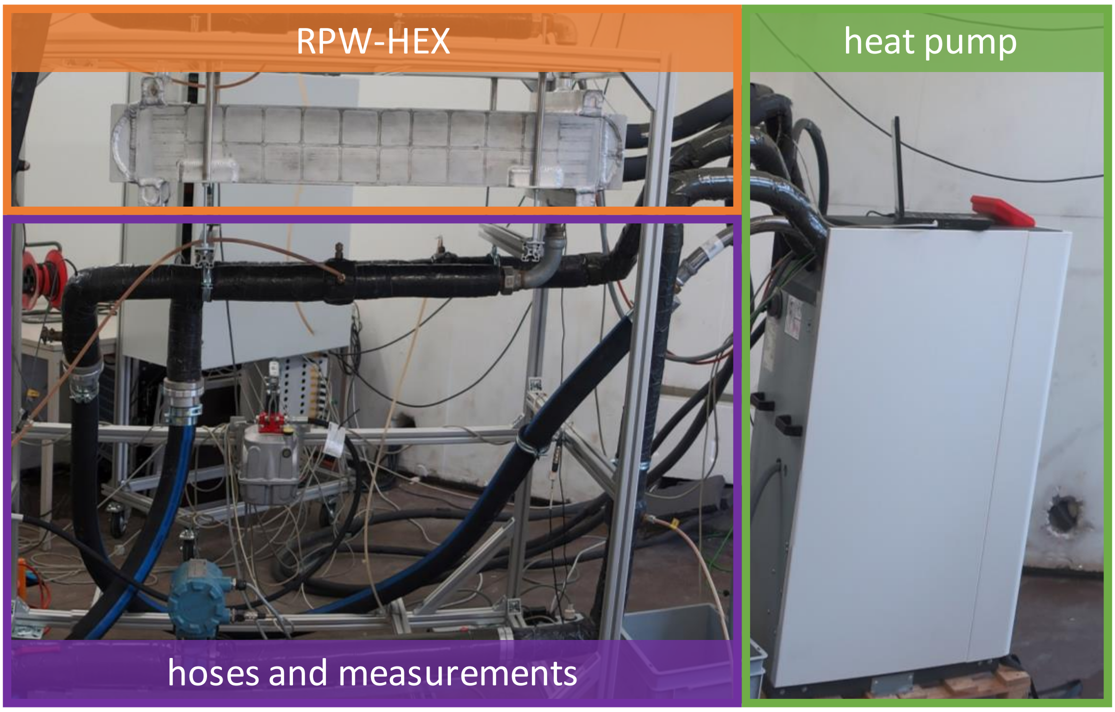


Figure 25: Experimental setup showing the heat pump indoor-unit (green), the RPW-HEX (orange) and hoses and flow measurement sensors (violet).

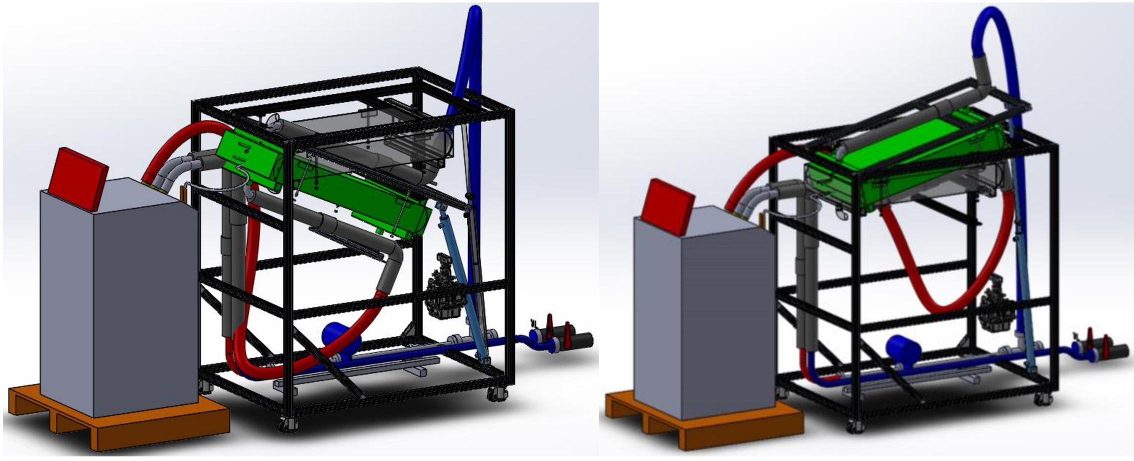


Figure 26: Isometric of the HP with the RPW-HEX mounted onto the special scaffolding. Left: RPW-HEX is tilted down. Right: RPW-HEX is tilted up.

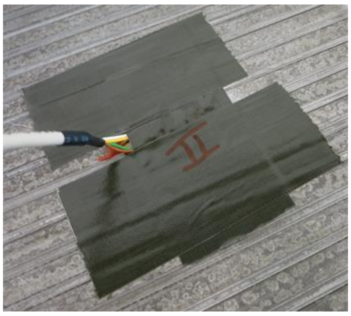
The RPW-HEX was equipped with 14 temperature sensors (thin-film calibrated class A PT-100 temperature sensors) mounted on the aluminium surface above the PCM channels (see Figure 27). To ensure proper application of the sensors, the surface was first cleaned (Figure 27 (a)). After that, a heat-conducting paste was applied (Figure 27 (b)) and the sensor was fixed with Kapton tape (Figure 27 (c)). To ensure good attachment, additionally, the sensor was fixed with a duct tape (Tesa extra power Universal, 50mm) (Figure 27 (d)). After all surface temperature sensors were applied, the whole storage was insulated using 32 mm Armaflex (Figure 27 (e)). The cables from the temperature sensors were routed through the insulation (Figure 27 (f)) to the DAQ system.

(a)

(c)

(e)

(b)



(d)

(f)

Figure 27: Mounting of the surface temperature sensors on the RPW-HEX. (a) The surface was sanded smooth and cleaned. (b) Heat conduction paste was applied onto the surface. (c) The temperature sensor was attached to the surface with Kapton® tape. (d) Duct tape was used to ensure good fixation. (e) The entire RPW-HEX was insulated with Armaflex (3.2 cm) (f) The RPW-HEX is completely insulated, cables from the temperature sensors were routed through the insulation.

Furthermore, a pressure sensor was attached to the PCM section to measure the pressure above the PCM (for details see deliverable D2.2).

3.1.3 Integration in the lab infrastructure

The temperature and air humidity of the climatic chamber is recorded with a *LabView* program at AIT. Data from all the other sensors (temperature, mass flow, and pressure as well as electric consumption and valve positions) are being constantly monitored with a process control system from B&R. The visualization was carried out with the APROL DISPLAY CENTER (Figure 28).

The heat pump and additional valves were controlled by AITs process control system (B&R). The communication with the OCHSNER heat pump was established via Modbus, whereas valves of the subsystem (e.g. ⑨) were directly controlled with B&R.

A detailed description on control hardware and interfaces is given in Deliverable 3.2.

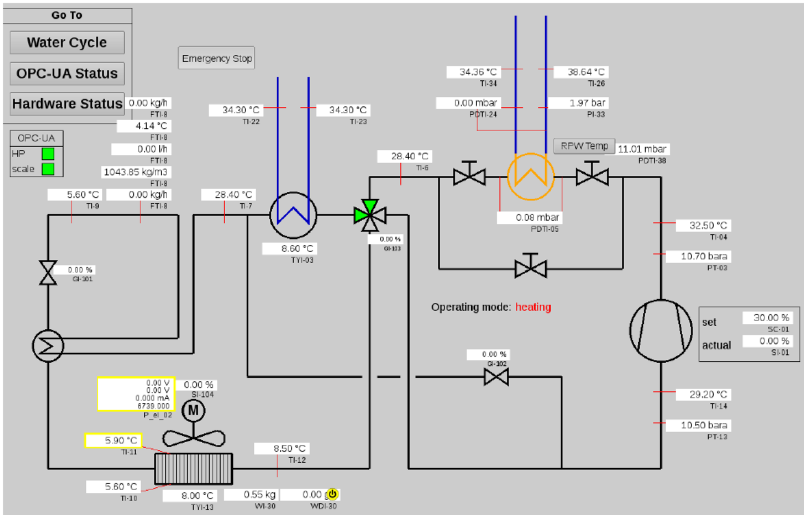


Figure 28: Screenshot of the APROL DISPLAY CENTER showing all the sensors and their current values in the refrigerant cycle.

3.1.4 DC integration

The compressor of the HP was equipped with an inverter that can be fed directly with DC to omit the conversion from AC to DC in the first stage of the inverter. The DC operation was tested during the experiments. Details are given in Deliverable 2.3.

3.2 Experiments with the Continental RPW-HEX version 3

3.2.1 Overall setup

Figure 29 shows the Process Flow Diagram (PFD) scheme of the experimental tests with the RPW-HEX version 3. Contrary to the previous tests with the RPW-HEX version 1 (see sub-section 3.1.1) additionally, a hydraulic group for decoupling the HP internal and the building water cycle (K,H,U), three decentralized DHW storages including hydraulic modules (X1-3,M1-3), and the thermal controller from PINK (not shown in Figure 29) were integrated in the overall setup.

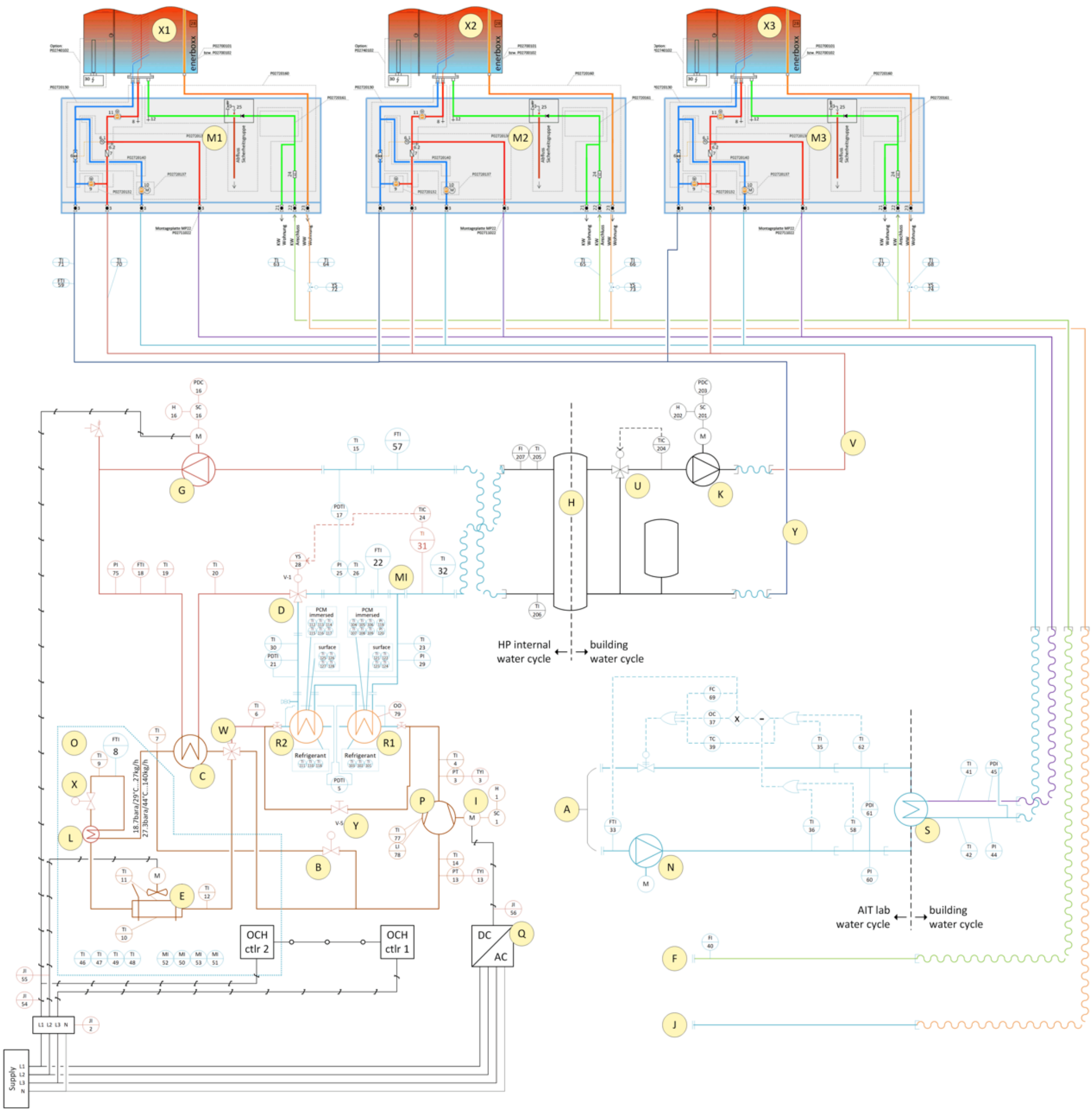


Figure 29: PFD scheme of the experimental setup to perform tests with RPW-HEX version 3. (A) interface to AIT lab infrastructure (heat-source and -sink), (B) liquid injection valve, (C) condenser, (D) three-way valve to control the water outlet temperature during DHW charging (RPW-HEX discharging), (E) evaporator and fan, (F) fresh water inlet, (G) internal water pump of the heat pump, (H) hydraulic separator between HP internal water cycle and building water cycle, (I) inverter, (J) DHW outlet, (K) water pump of building water cycle, (L) HEX for additional subcooling, (M1-M3) hydraulic modules of enerboxxes to switch between DHW charging, heating/cooling and bypassing the enerboxxes, (MI) mixing point for DHW generation, (N) water pump of building water cycle, (O) outdoor unit including (E), (L) and (X), (P) compressor, (Q) DC generator, (R1 and R2) RPW-HEX modules, (S) Heat exchanger working as heat-sink or -source for the building water cycle, (U) three-way valve to control the building water cycle temperature, (V) process water feed line, (W) four-way valve for switching between regular and reverse heat pump cycle (i.e. between heating and cooling/defrost), (X1-X3) enerboxx DHW storages, (Y) process water return line

The HP/RPW-HEX cycle on the refrigerant and water side was similar to the first test series except for a few exceptions:

- The RPW-HEX version 3 consisted of two equally sized RPW-HEX modules connected in series (R1 and R2).
- The RPW-HEX had, besides the surface temperature sensors (TI121-TI128), also temperature sensors directly immersed into the PCM (TI104-TI109 and TI112-117).
- Each RPW-HEX was equipped with three temperature sensors to measure refrigerant temperature.
- An additional pressure sensor (PI120) was used to measure the pressure directly in the PCM in (R1).
- The three-way valve (D) was controlled by the OCHSNER controller with the aid of TI31 and not any more by AITs B&R system.
- During all tests, the inverter of the heat pump (I) was powered with DC voltage provided by a DC generator.
- An oil separator was included after the compressor (not shown in Figure 29) to ensure good oil recirculation in the refrigerant cycle.
- The hot gas temperature of the refrigerant was limited to 110°C instead of 105°C

A detailed description of the refrigerant cycle can be found in section 3.1.1.

Contrary to the first test series, the water in- and outlet of the HP/RPW-HEX cycle was not directly connected to the AIT infrastructure but was connected via a hydraulic separator (H) to a building water cycle (feed (V) and return line (Y)). The building water cycle was connected to the hydraulic modules (M1-M3). Depending on the operation mode - heating/cooling of the building, DHW charging or bypassing the enerboxx - the feed and return line of the building water cycle were connected to: the plate-type heat exchanger (S), the heat exchanger inside the DHW storage (X1-X3), or were just bypassed by (M1-M3).

The return temperature of (Y) was controlled via the inlet temperature (TI58) of the heat exchanger (S) on the AIT-lab infrastructure side.

Furthermore, fresh water (F) and DHW (J) lines were connected to the enerboxxes and temperatures were measured at the in- and outlet. At the DHW outlet of each enerboxx, magnetic valves (YS72-YS74) controlled by the B&R system were used to simulate typically tap water usage over a day. The DHW mass flow was measured at the inlet of the common fresh water line (FI40) using a Coriolis mass flow sensor. Because the tap water was never drawn simultaneously from the enerboxxes, one mass flow sensor in the common line was enough to determine the DHW consumption.

All the sensors shown in Figure 29 were sensors which were originally installed in the HP by OCHSNER. In the enerboxxes and the hydraulic modules, additional sensors installed by PINK (not shown in Figure 29) were available and were used for monitoring, especially the DHW tank temperature. Temperature sensors which have been installed by OCHNSER were PT 1000, class B sensors. Temperature sensors installed by AIT were PT100 1/3 class B sensors, except for the thin film sensors mounted on the RPW-HEX which were PT100 class A. The temperature sensors installed by PINK were PT1000 class B sensors.

Figure 30 shows the overall setup located in the climatic chambers at AIT. The outdoor unit of the HP (O) was located inside the outdoor chamber and the rest of the experimental setup was located in the indoor chamber next to it. Figure 30 (b) shows a panoramic photo taken from the central point of the indoor chamber.

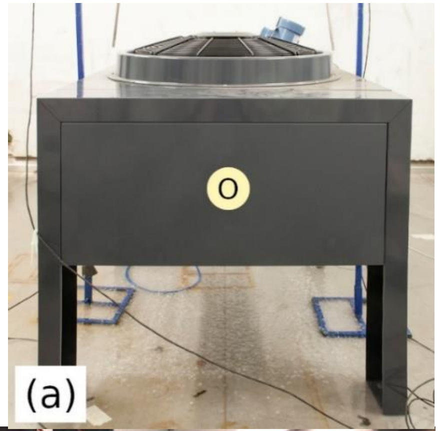
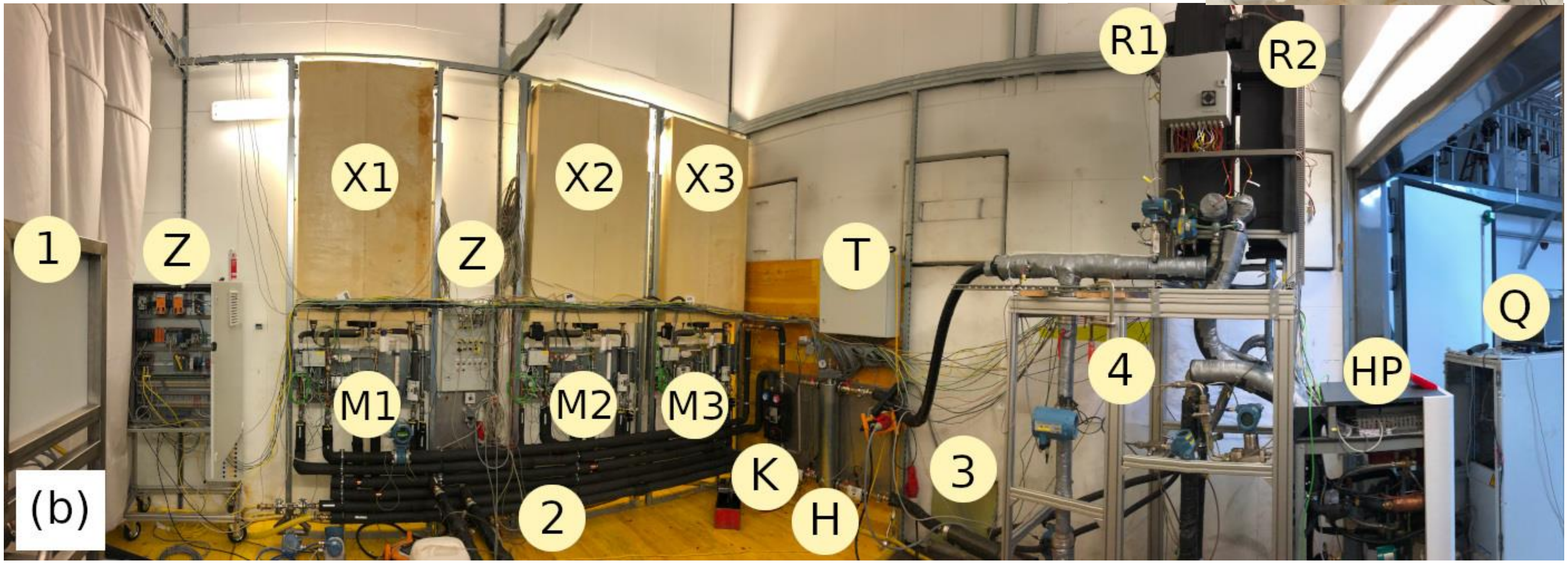


Figure 30: Photos of the experimental set-up.
(a) Outdoor unit (O) including evaporator, fan, expansion valves and sensors located in the outer climatic chamber.
(b) Panorama image of the set-up located in the inner climatic chamber of AITs laboratory. (1) hydraulic interface to lab infrastructure, (2) connecting pipes (return- and feed-line of external water cycle connected to (H), return- and feed-line to the heat-sink/source (S in Figure 14), fresh water and DHW water), (3) refrigerant connections to the outdoor unit located in the adjoining outer climatic chamber, (4) supporting frame for the RPW-HEX and the volume flow sensors, (H) hydraulic separator between HP internal water cycle and external water cycle, (HP) indoor unit of the heat pump, (Q) DC generator, (R1) RPW-HEX module connected to the compressor and R2 on the refrigerant side, (R2) RPW-HEX module connected to R1 and the four way valve on the refrigerant side, (T) Thermal controller, (X1)-(X3) enerboxxes, (Z) B&R DAQ and process control system connected to the thermal controller (T) and the HP controller.



In front of the left wall, the hydraulic interface between experimental setup and the lab infrastructure (1) was positioned. The B&R components for DAQ and controlling the entire system (Z), the enerboxx - DHW storages (X1)-(X3), the hydraulic modules (M1)-(M3) and the connecting pipes (2) were installed in front of the rear wall. The hydraulic separator (H), the external water pump (K) and the thermal controller (T) were positioned next to the right wall in the corner. The RPW-HEX modules (R1) and (R2), the volume flow sensors (4) and the HP indoor unit (HP) were located next to the right wall which separates the indoor and the outdoor chamber. Therefore, the refrigerant is routed through the wall (3) to the outdoor unit. The DC-generator (Q) was placed just outside the chamber, because there was not enough space inside the room left.

In the following, the integration of the several parts of the experiment will be discussed in detail.

3.2.2 The hydraulic interface between the building- and the lab-water cycle

The heat generated during heating operation by the heat pump was removed from the building water cycle with the aid of a cold-water chiller integrated in the lab infrastructure. A plate-type heat exchanger (S in Figure 29 and Figure 31) acted as a thermal heat sink/source for the building water cycle.

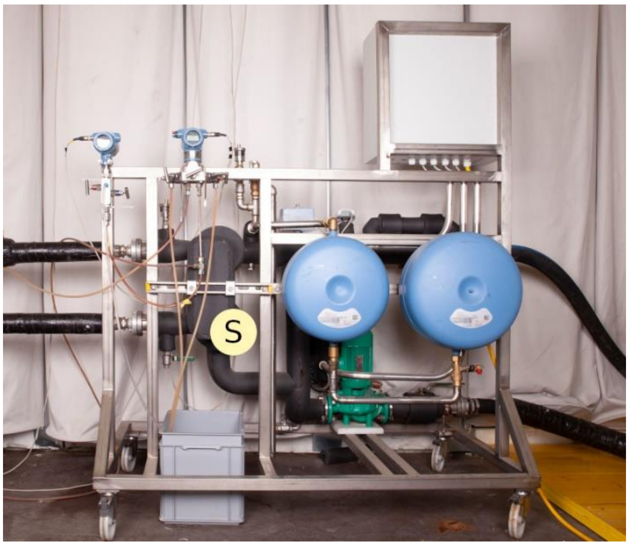


Figure 31: Interface to the AIT lab infrastructure. (S) Plate type heat exchanger working as a heat- sink/source for the building water cycle. The other components on the test rig (pumps, controllers, etc.) were not used during the experiments.

With the aid of (S) also a physical decoupling between the lab infrastructure water cycle and the building water cycle was possible.

3.2.3 Integration of the enerboxx storages (DHW storages)

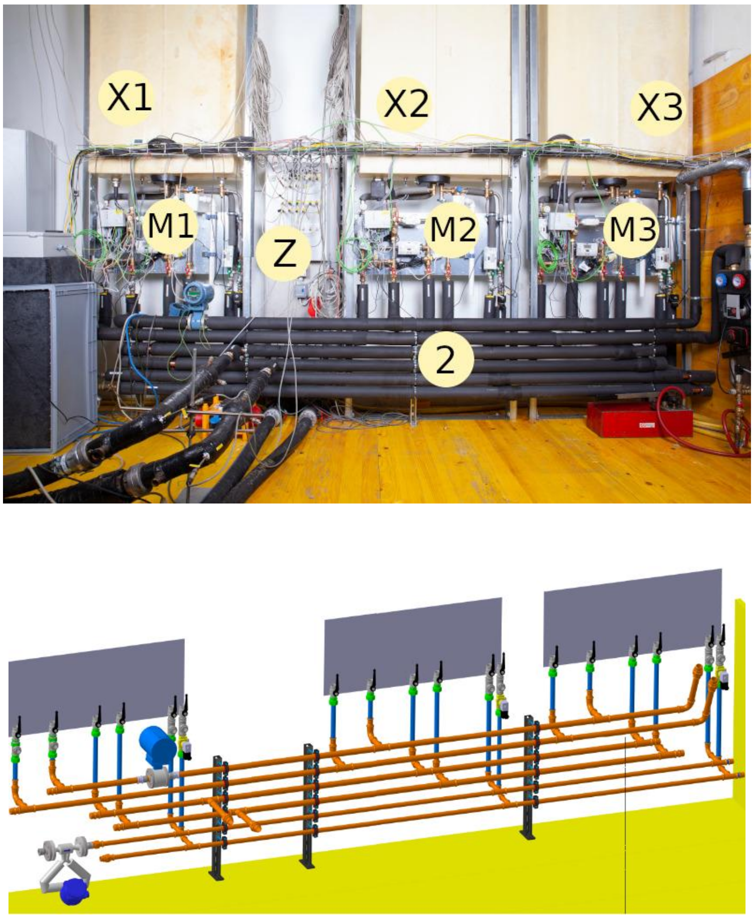
3.2.3.1 Piping and assembling

Figure 32a shows a photo how the enerboxx DHW-storages were integrated in the lab. The enerboxx storages (X1-X3) and the hydraulic modules (M1-M3), both provided by PINK, were mounted on a supporting frame which was fixed on the floor (silver shining frame around the enerboxxes). In order not to destroy the floor, timber formwork was laid on the floor of the climatic chamber (yellow plates on the floor). Mapress cooper pipes from Geberit were mainly used for connections in the building water cycle. Close to the enerboxxes, the water pipes were fixed with three stands mounted on the floor (see Figure 32b).

The following feed and return lines were mounted on these stands (from top to bottom in the Figure 32a and b):

i. Feed line from the hydraulic separator to the hydraulic modules ((V) in Figure 29)
ii. Return line from the hydraulic modules to the hydraulic separator ((Y) in Figure 29)
iii. Return line from the heat- sink/source (S in Figure 29) to the hydraulic modules
iv. Feed-line from the hydraulic modules to the heat-sink/source (S in Figure 29)
v. Fresh water feed to the hydraulic modules ((F) in Figure 29)
vi. DHW water from the hydraulic modules to the sink ((J) in Figure 30).

The pipes were all insulated with at least 13 mm Armaflex.



(a)
(b)

Figure 32: Connections and piping. (a) Photo of the hydraulic connections. (M1)-(M3) hydraulic modules, (X1)-(X3) 140 liter DHW enerboxx storages, (Z) B&R DAQ, (2) connecting pipes. (b) CAD drawing of the piping

To avoid corrosion in the RPW-HEX, the process water in the pipes (i to iv) consisted of 10 V% Glysacoor® G93 (Inhibitor) and 90 V% distilled water.

3.2.3.2 The hydraulic modules

The hydraulic modules (Figure 33) were mounted below the enerboxx storages. In order to fulfil their task to connect the feed- and return-line from the hydraulic separator either to the DHW storages (DHW charging mode) or to the heat- sink/source (heating/cooling mode), three volume control valves (1-3) were installed. The volume control valves were able to switch between closed and open, whereby the volume flow in the open state could be set manually at the valve. The required volume flow rates were set during the installation phase with the aid of the volume flow sensor integrated in the energy meter (EM). Although, the volume flow should be kept constant by the valve, it had to be readjusted a few times during the experimental tests.

In DHW charging mode, valve (1) was opened and valve (2) and (3) were closed. Hence, the feed- and return-line from the hydraulic separator was connected to the heat exchanger in the DHW storage and the HP/RPW-HEX heated the DHW inside the storage. In heating/cooling-mode, valve (1) and (3) were closed and valve (2) was open. Therefore, the feed- and return-line from the hydraulic separator was connected to the heat sink/source. Valve (2), which acts as a bypass for the module, was used during switching between the two modes in order to preheat the piping without affecting the DHW storage (e.g. by pumping cold water through the hot DHW storage).

The energy meters (EM), the valves (1-3) and the temperature sensors inside the enerboxx DHW storages (not shown in Figure 33) were connected to the thermal controller (T in Figure 30b) via a CAN-bus node (4). The magnetic valves in the DHW line were controlled by AITs B&R system to emulate tap water consumption.

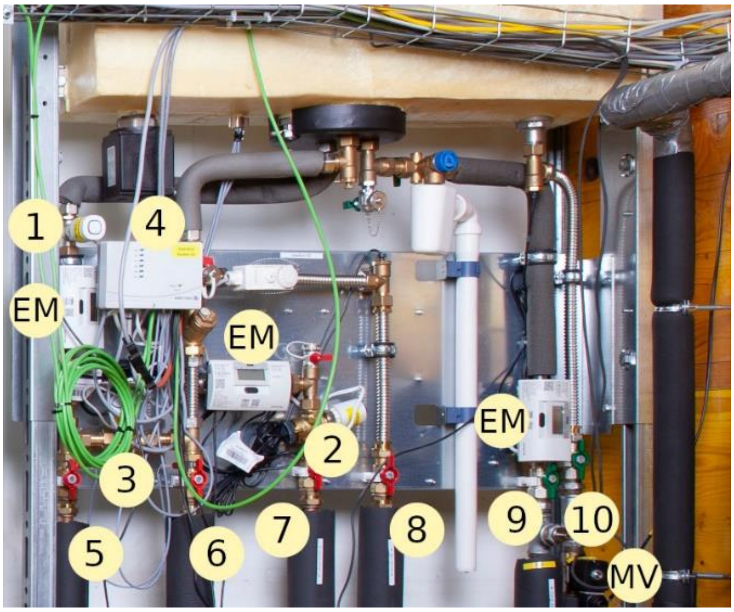


Figure 33: Hydraulic module (M3) connected to enerboxx (X3). (1-3) volume flow controller, (4) CAN-Bus node, (5) connection to the hydraulic separator – return line ((Y) in Figure 29) in, (6) connection to the hydraulic separator – feed line ((V) in Figure 29), (7) connection to heat sink/source ((S) in Figure 29) – return line, (8) connection to heat sink/source – feed line, (9) connection to fresh water ((F) in Figure 29), (10) connection to DHW water sink ((J) in Figure 29), (EM) energy meter, (MV) magnetic valve to simulate tap water usage (not part of the hydraulic module from PINK)

3.2.4 The hydraulic interface between HP internal and building water cycle

Figure 34 shows the interface between HP internal and the building water cycle. The two cycles were separated with a hydraulic separator (H in Figure 34) provided by OCHNSER. The hydraulic separator was insulated with 10 cm mineral wool. The hydraulic separator is needed to decouple the HP internal water cycle from the building water cycle and therefore to avoid possible failures or damages on both sides (e.g. to allow the HP to turn off the water flow if the temperature falls below a critical limit independent of the status of the water pump in the building water cycle (K in Figure 23) and the thermal (master) controller).

The water pump for the building water cycle was integrated in a compact box (1) (provided by PINK) together with the three-way valve (U in Figure 23) and additional temperature sensors. The pumps speed was set to a value that was high enough to achieve the desired volume flow rates at the hydraulic modules (see also 3.2.3.2).

Furthermore, the energy meters (attached at the in- and outlets of the hydraulic separator), the pump control (on/off) and the three-way valve were directly connected to the thermal controller (T, Technische Alternative UVR controller) provided by PINK. The thermal controller was furthermore connected to AITs B&R DAQ and process control system via Modbus RTU.

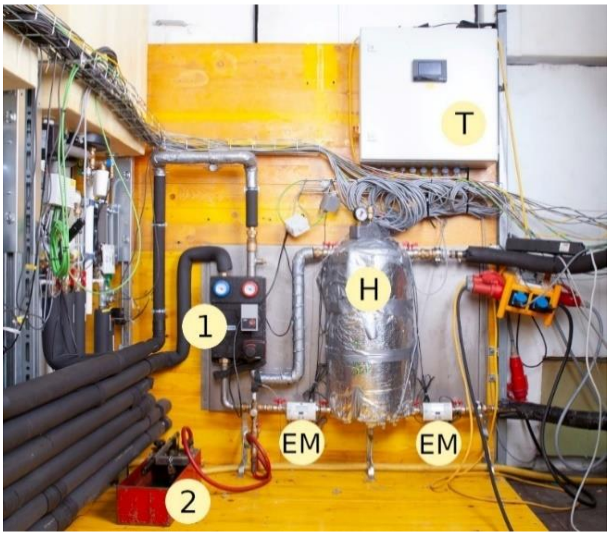


Figure 34: Interface between HP internal and building water cycle. (1) water pump (K in Figure 23), three-way valve (U in Figure 23) and temperature sensors integrated in a compact box, (2) filling station for the process water, (EM) energy meters, (H) hydraulic separator (Please note that the uninsulated hydraulic separator can also be seen in Figure 30b), (T) thermal controller.

3.2.5 Specific integration of the thermal storage (RPW-HEX)

The RPW-HEX modules were mounted above the indoor unit of the heat pump so that oil can drain from the RPW-HEX and flow back to the compressor. To mount the RPW-HEX safely, a mobile supporting framework using aluminium strut profiles was designed. The support frame contained besides the RPW-HEX, the indoor unit of the HP, the volume flow sensors, and water temperature and pressure sensors. Figure 35 shows the 3D design drawing and Figure 36 shows the final assembled frame at AIT.

Water connections were carried out with standard hydraulic fittings and pipes and the joints between the refrigerant pipes were brazed.

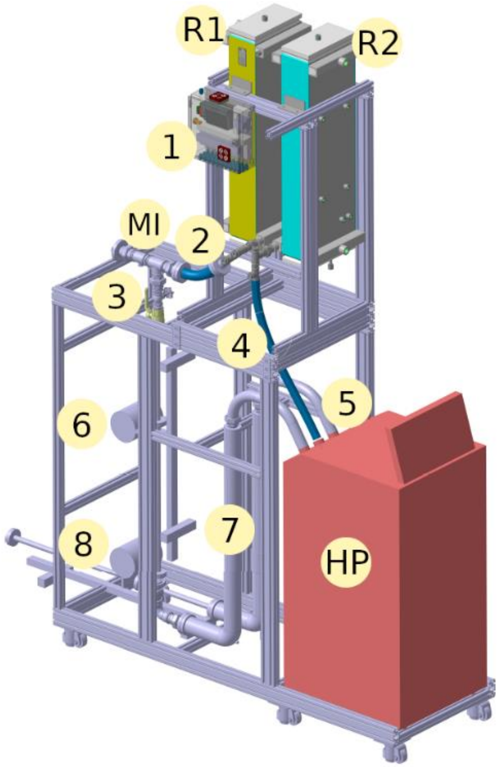


Figure 35: 3D CAD drawing of the support frame for the two RPW-HEX modules, the indoor unit of the HP and the volume flow sensors including the piping. (1) Remote I/O system for DAQ, (2) water connection between (R1) and mixing point (MI), (3) valve for hydraulic balancing, (4) water connection between three-way-valve ((D) in Figure 29) and (R2), (5) water feed line from the HP to the hydraulic separator, (6) volume flow meter (FTI22, Emerson 8711/30F) in water bypass to RPW-HEX, (7) water bypass of RPW-HEX, (8) volume flow meter (FTI57, Emerson 8711/30F) in water return line to the HP.

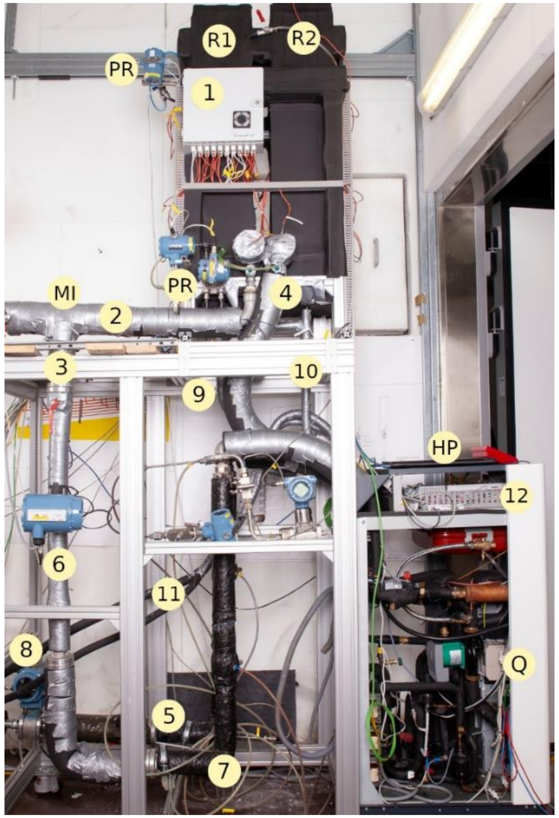


Figure 36: RPW-HEX modules, volume flow sensors and indoor unit of the HP in the climate chamber at AIT. (1) Remote I/O system for DAQ, (2) water connection between (R1) and mixing point (MI), (3) valve for hydraulic balancing (hidden behind aluminium profile), (4) water connection between three-way-valve ((D) in Figure 29) and (R2), (5) water feed line from the HP to the hydraulic separator, (6) volume flow meter (FTI22, Emerson 8711/30F) in water bypass to RPW-HEX, (7) water bypass of RPW-HEX, (8) volume flow meter (FTI57, Emerson 8711/30F) in water return line from the hydraulic separator to the HP, (9) refrigerant connection from the compressor to the RPW-HEX (partly hidden behind the water pipe), (10) refrigerant connection between RPW-HEX and four-way valve, (11) refrigerant connections to the outdoor unit, (12) HP controller, (Q) DC powered inverter.

Figure 37 shows the two RPW-HEX version 3 modules at different stages of the integration. Figure 37a shows the modules as delivered from AKG in April 2020. The size of each module without insulation is about 100 cm x 32 cm x 16 cm and the weight including 20 kg PCM (RT64HC from Rubitherm) is 115 kg each. The temperature sensors (PT100 class 1/3 DIN B) emerged into the PCM as well as in the refrigerant section, were mounted with the aid of metal compression fittings (Figure 37b). In the PCM sections the tip of the temperature sensor was positioned to measure the temperature in the centre between front and back surface. The surface temperature sensors were mounted exactly on the same position of the sensors immersed in the PCM but on the opposite surface (not shown in the figure). They were mounted in the same way as for the RPW-HEX version 1 (see also Figure 27). The entire RPW-HEX was insulated with 3.6 cm Armaflex HT (Figure 37c) first and additionally with an additional layer of 10 cm mineral wool at a later point of time (Figure 37d).

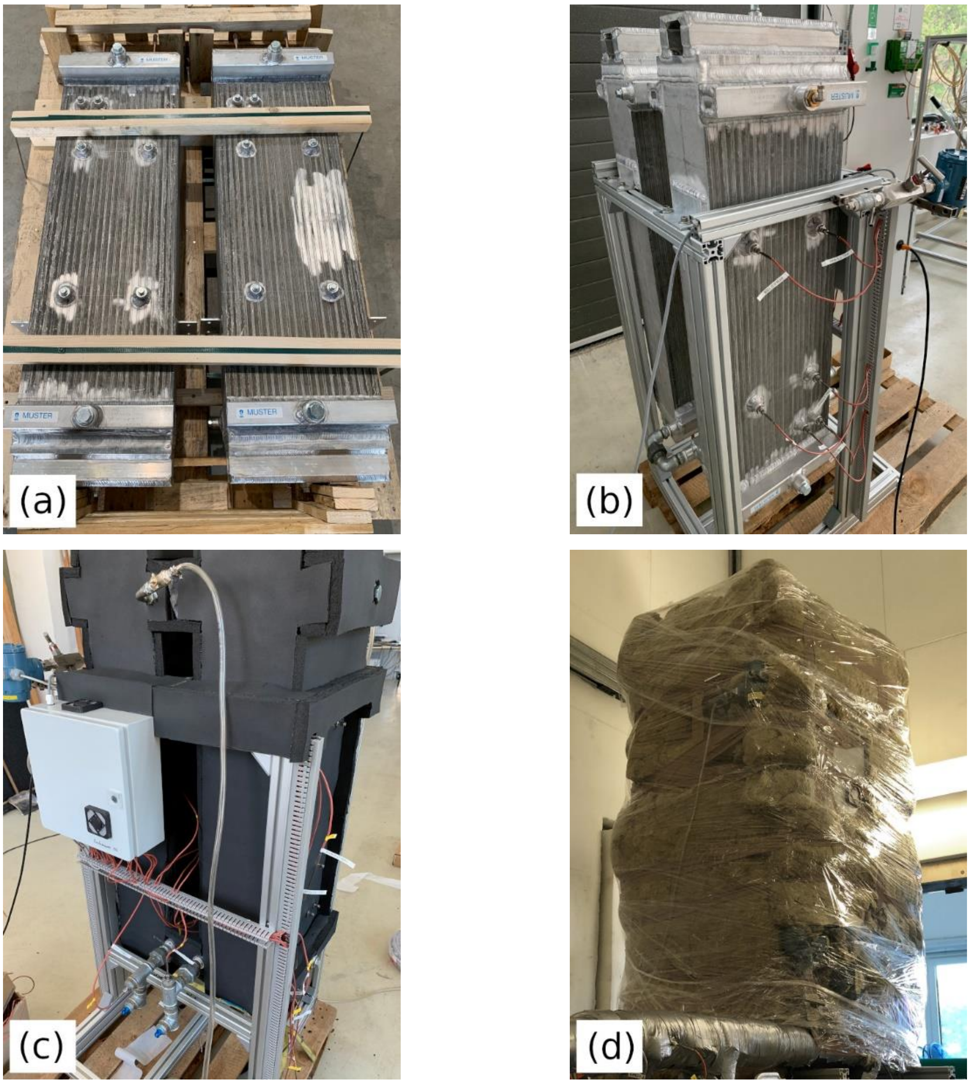


Figure 37: (a) RPW-HEX without insulation and sensors, (b) RPW-HEX equipped with sensors and assembled to the upper part of the supporting frame, (c) RPW-HEX insulated with 3.6 cm Armaflex HT, (d) RPW-HEX integrated in the full set up and insulated with further 10 cm mineral wool.

3.2.6 The outdoor unit

The outdoor unit of the HP was positioned in the outdoor climatic chamber to allow for controlled climatic conditions (Figure 38).

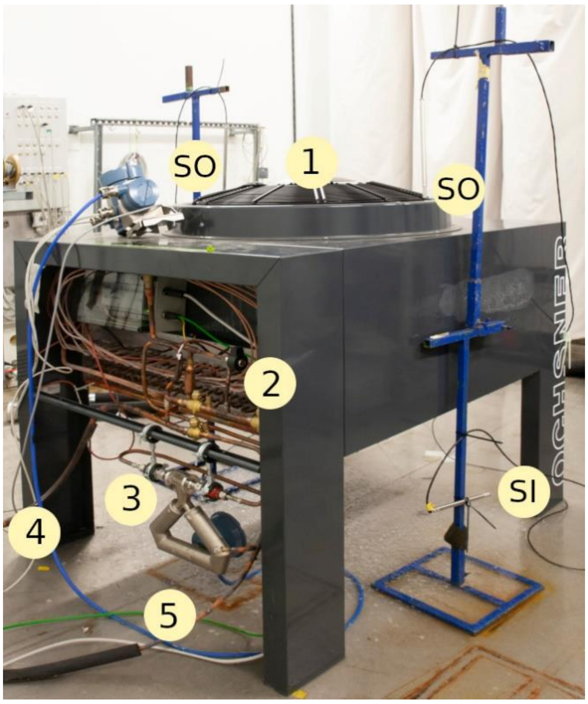


Figure 38: Outdoor unit of the air-source heat pump located in the outdoor climatic chamber. (1) fan, (2) evaporator mounted horizontally below the fan, (3) Coriolis mass flow meter (FTI8), (4) and (5) refrigerant line from and to the indoor unit, respectively, (SI) and (SO) temperature and moisture sensors close to the air inlet and outlet, respectively.

A Coriolis mass flow sensor (3, FTI40, Emerson CMF010) was integrated in the refrigerant line before the expansion valve. The refrigerant lines from the indoor unit (4) and (5) were brazed at their joints. Two temperature and moisture sensors were positioned close to the air inlet (SI) and outlet (SO). The average values of the air inlet sensors (SI) were used to control the temperature and the moisture in the climatic chamber.

3.2.7 Communication between the individual controllers

The communication between the heat pump, the PINK controller and the AIT lab control system was setup up via a ModBus RTU network. An interface converter was used to convert from OPC-UA (AIT lab control system) to ModBus RTU. For flexible testing of the system, the interface converter in the ModBus RTU network was set as master with the AIT lab control system having priority control over the interface converter. Communication between the heat pump and the PINK controller was established via the AIT lab control system as an intermediate forwarding request with adjustable priority. This allowed for manual operation, where the AIT lab control system controlled both the operation of the heat pump and the enerboxx setup by setting temperatures, flows and drive speeds. Furthermore, an auto-operation mode was possible, in which the PINK controller was responsible to setting the operation of the heat pump.

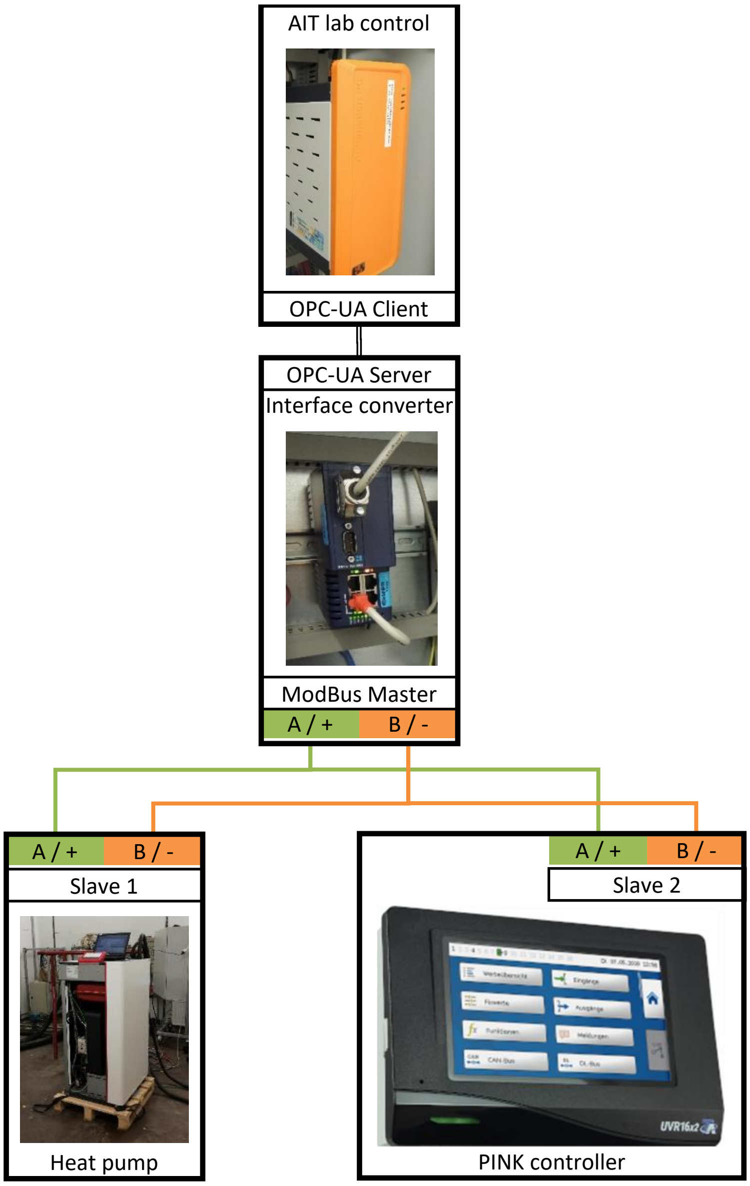


Figure 39: Schema of the connection between the individual controllers

3.2.8 DC integration

The indoor unit of the HP was equipped with an inverter that can be fed directly with DC and therefore, the conversion from AC to DC can be omitted. To test the operation with DC supply, the inverter was always connected to the DC-generator. Details are given in Deliverable 2.3.

3.3 Lessons learned

In the following, the lessons learned from the integration of the components during the experimental tests with both RPW-HEX versions are summarized:

- Temperature sensors were directly mounted in the RPW-HEX with the aid of metal compression fittings in the refrigerant path of the RPW-HEX. To withstand the temperature and pressure – up to 120°C and 43 bar can be obtained – high performance fittings are needed. Metal compression fittings made of stainless-steel are capable to seal effectively at such and more extreme conditions and have therefore been used. However, mounting of these turned out to be difficult due to the significantly different strength of the stainless-steel fitting and the aluminium RPW-HEX body. For this reason, at two temperature measurement positions the aluminium thread was damaged and had to be repaired using HELICOIL® repair threads. It is therefore advisable to limit the number of inversive measurement to a minimum and to balance between mechanical integrity and measurement accuracy. Attachment of temperature sensors using conductive material to the surface of the pipes slightly before or after the RPW-HEX is one suitable solution.

- Pressure sensors in the RPW-HEX were mounted with standard thread fittings, as the pressure in the PCM passages of the RPW-HEX should not reach values above a few bars. Nevertheless, we have observed small leakages of PCM after the installations requiring to re-tighten the connections several times (see Figure 40). Leakage detection was very difficult, because it may accumulate inside of the insulation of the RPW-HEX. It was also observed that the leaking PCM left the insulation at a different position than the actual leakages occurred due to the very low viscosity of the PCM which finds its way through the insulation. Hence, we strongly recommend checking all openings of the RPW-HEX on a regular basis to ensure that no PCM escapes.
- During tests with the RPW-HEX version 1, oil traps in the refrigerant part of the RPW-HEX lead to a lack of oil in the compressor and finally damaged it. Redesigning the RPW-HEX and additionally adding an oil separator after the compressor in the refrigerant cycle seemed to have solved the problem as the problems didn’t occur during the tests with the RPW-HEX version 3.
- The mounting brackets of the RPW-HEX shall be improved as their limited size made attachment of the thermal insulation difficult.
- Once set, the volume flow should be kept constant with the aid of the volume control valves in the hydraulic modules ((1-3) in Figure 33). Nevertheless, it was observed that the volume flow changed slightly over time. Hence, the set-point of the valves had to be readjusted a few times during the experimental tests. Furthermore, a small leakage flow in one of the valves (10-15 l/h) was observed.
- Due to the geometry and the multiple sensor ports of the RPW-HEX, insulating the RPW-HEX was very time consuming and difficult. Since a proper insulation is crucial for the performance of the system, this should be considered in future designs.

Figure 40: Accumulation of PCM below a leaking connection

4 Conclusions

The individual components of the Mediterranean and the Continental sub-systems were successfully integrated on different levels in the laboratories at CNR, NTUA and AIT.

The integration of the Mediterranean sub-system was realised in four steps:

- Integration of the RPW-HEX in the DC-driven heat pumps (NTUA);
- Integration of the batteries in the DC bus rack (CNR);
- Integration of the sorption module with the heat pump and the RPW-HEX;
- Integration of all components.

The integration involved both the hydraulic and electric connections and allows the operation under different modes. During the installation, the main lessons learned for demo sites were noted and reported. In particular, for the Mediterranean system, critical issues were the removal of air in all the hydraulic circuits and the use of water/glycol and corrosion inhibitor solution to avoid corrosion problems to the aluminium heat exchangers in the adsorbers and the latent storage.

The integration of the Continental sub-system was realised in two experimental test series:

- Integration of the RPW-HEX version 1 in the DC powered heat pump cycle (AIT, 2019)
- Integration of the RPW-HEX version 3, in the sub-system with: the DC-powered retrofitted heat pump, three decentralized enerboxx DHW storages, three hydraulic modules, and the thermal controller (AIT, 2020).

The integration at the AIT labs allowed to operate the RPW-HEX under constant boundary conditions during the first test series and to operate the system under “real-life” dynamic conditions with simulated tap water consumption and energy-controlled heating and cooling consumptions during the second test series. Between the two test series, RPW-HEX and HP were redesigned and retrofitted, respectively, with the aid of the results from the first test series.

During the integration phase of both sub-systems in the lab, valuable experiences have been gained, which will help implementing the systems on the demo sites and improving future components.

5 References

Eurostat. (2015). Retrieved 11 2017, 9, from http://ec.europa.eu/eurostat/statistics-explained/images/9/9c/Final_energy_consumption_in_the_residential_sector_by_type_of_end-use%2C_EU-28%2C_2015.png