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HYBUILD

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Deliverable Report

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D3.2

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Publishable executive summary

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.

Purpose: The aim of deliverable D3.2 is to provide a comprehensive description of the hard- and software communication interfaces between all actors, sensors, built-in controllers of the components and modules of the hybrid thermal and electrical sub-systems, and the existing automation systems used in the laboratory infrastructure at ITAE, NTUA, CSEM and AIT. D3.2 gives detailed information on their configuration, developed human machine interfaces and interfaces to software for advanced control and simulation.

The established communication and automation is the pre-requisite for the conduction of extensive experimental performance tests of the Mediterranean and Continental sub-systems modules, basic control schemes and their interaction in Task 3.2. The D3.2 documentation is also useful for all activities related to the planning and integration of the automation systems for the sub-systems at the demo sites.

D3.2 provides detailed information, mostly based on lists/tables, textual descriptions and schemes on hardware modules, communication interfaces of on-board Programmable Logical Controllers (PLC) from DAIK, OCHS, FAHR, CSEM, existing and extensions to laboratory process control systems (PCS) from ITAE, NTUA and AIT, additional control systems such as the DC bus maintenance PC, developed graphical user interfaces, and additional sensors and actors used at specific modules, and finally a complete report on all data points, corresponding protocols and parameters for sub-systems automation and data acquisition.

Methodology: The hybrid sub-system for the Mediterranean climate consists of the following modules and control systems

- the sorption storage module manufactured by FAHR, MIK and AKG, equipped with Fahrenheit's internal controller and a Modbus TCP/IP communication interface;
- the vapour compression chiller (DAIK), converter and internal controller with MODBUS/RTU communication interface;
- the low temperature RPW-HEX module manufactured by AKG, equipped with additional sensors and actors connected to Advantech's Input/Output (I/O) modules and interfaced with LabVIEW controller
- the electrical storage module with the DC controller delivered by CSEM and ITAE, and different DC bus components with different communication interfaces, as are the grid converter with CAN interface, the battery converter with CANopen, the power-meters with Modbus RTU, the battery management system (BMS) with Modbus RTU interface.

Communication between all components and modules was established and, if necessary, dedicated converters and gateways were used. Databases are set up or data is fed to existing databases, and graphical user interfaces are developed for sub-system supervision and control. Communications tests with read/write operations were successfully performed with the LabVIEW automation system at CNR-ITAE's and NTUA's thermal laboratory, and a maintenance PC at CSEM's laboratory, see Figure 1 left.

The hybrid sub-system for the Continental climate consists of the following modules and control systems

- the DC powered air-source compression HP from OCHS, an outdoor unit, which is installed in a climate chamber, and equipped with OCHS Siemens controller with a ModBus RTU communication interface;
- the RPW-HEX module (manufactured by AKG), where all additional sensors and actors are directly connected to AIT's PCS system from Bernecker and Rainer;
- the same electrical storage module with the DC controller delivered by CSEM and ITAE as for the Mediterranean climate.

Communication between all components and modules was established using dedicated converters and gateways. Data is fed to existing data bases, and graphical user interfaces were developed and are ready for sub-systems supervision and control. All Communications tests with read/write operations were successfully performed using AIT's thermal lab industrial automation system, i.e. Bernecker und Rainer APROL® software and X20 PLC hardware, see Figure 1 right.

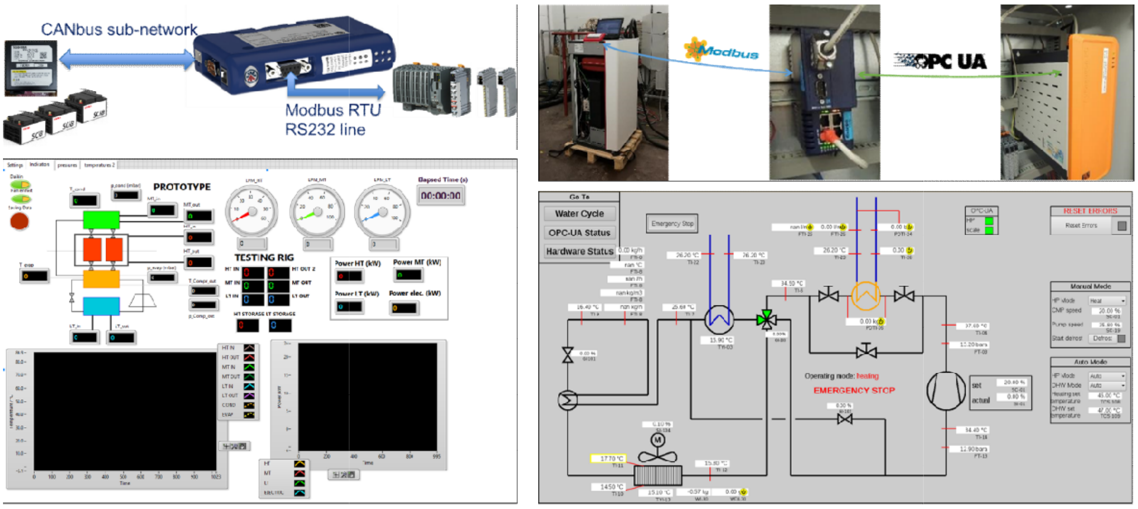


Figure 1: Hardware communication and graphical user interfaces for monitoring and control of the hybrid storage sub-systems installed at CNR-ITAE's (left) and AIT'S (right) thermal laboratory infrastructure.

Key Findings and Conclusions: We successfully managed to set up, configure and test the communication between all electrical and thermal modules of the Mediterranean and Continental sub-systems. Moreover, tools for automation, supervision, control and data acquisition were developed. Based on these results during the next month extensive experimental tests will be conducted to evaluate the integrated sub-systems, their performance and basic control schemes in Task 3.2.

In addition, the D3.2 documentation details on data points, access levels and communication protocols will streamline the coordination and planning of the automation systems at the demo sites.

Acronyms and Abbreviations

AIT	Austrian Institute of Technology
AKG	AKG Verwaltungsgesellschaft
APROL	Process automation software by Bernecker und Reiner
Aux	Auxilary
B&R	Bernecker und Rainer
BMS	Battery Management System
BMU	Battery Management Unit
CANbus	Controller Area Network (CAN) bus
DAIK	Daikin
DC	Direct Current
DCS	Distributed Control System
DHW	Domestic Hot Water
HEX	Heat EXchanger
HT, MT, LT	High Temperature, Medium Temperature, Low Temperature
HP	Heat Pump
ID	Identification number
IO	Input Output Module
CNR-ITAE **ITAE**	Consiglio Nazionale delle Ricerche - (aka CNR-ITAE) The Advanced Energy Technology Institute “Nicola Giordano”
LabView	Automation Software by National Instruments
LSB	Least Significant Byte
MIKRO	Mikrometal
MSB	Most Significant Byte
NI	National Instruments
NTUA	National Technical University of Athens
OPC-UA	Open Platform Communications - Unified Architecture
PCS	Process Control System
PID	Proportional–Integral–Derivative
PLC	Programmable Logical Controller
RHC lab	Renewable Heating and Cooling laboratories at AIT
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)
SoC	State of Charge
SoH	State of Health
SOR	Sortech
TCP/IP	Transmission Control Protocol/ Internet Protocol
UDL	Universidad de Lleida / University of Lleida
WP	Work Package

1 Introduction

1.1 Aims and objectives

The aim of deliverable D3.2 is to provide a comprehensive description of the hard- and software communication interfaces between all actors, sensors, built-in controllers of the components and modules of the hybrid thermal and electrical sub-systems, and the existing automation systems used in the laboratory infrastructure at ITAE, NTUA, CSEM and AIT. D3.2 gives detailed information on their configuration, developed human machine interfaces and interfaces to software for advanced control and simulation.

The established communication and automation is the pre-requisite for carrying out extensive experimental performance tests on the Mediterranean and Continental sub-systems modules, basic control schemes and their interaction in Task 3.2. The D3.2 documentation is also useful for all activities related to the planning and integration of the automation systems for the sub-systems at the demo sites.

D3.2 provides detailed information, mostly based on lists/tables, textual descriptions and schemes on hardware modules, communication interfaces of on-board Programmable Logical Controllers (PLC) from DAIK, OCHS, FAHR, CSEM, existing and extensions to laboratory process control systems (PCS) from ITAE, NTUA and AIT, additional control systems such as the DC bus maintenance PC, developed graphical user interfaces, and additional sensors and actors used at specific modules, e.g. the RPW-HEX, and finally a complete report on all data points, corresponding protocols and parameters for sub-systems automation and data acquisition.

1.2 Relations to other activities in the project

Deliverable D3.2 presents the hardware and software tools necessary for the conduction of experimental tests on the performance of full-scale hybrid storage modules under realistic operating scenarios (Task 3.2). The generated data will be used for validation of design decisions (WP2 and Task 3.1), models (WP2 and Task 3.1, 4.1) and basic control schemes (Task 3.2).

The successfully tested hard- and software communication interfaces also provide useful information for the activities in WP4, related to the planning of the conceptual low- and high level communication and automation framework for the integration of the sub-systems at the demo-sites, and by this to provide practical insights for the demonstration in WP6 (Task 6.1-6.3).

1.3 Report structure

This report is organized as follows:

Section 2 gives information on the installations in the Mediterranean sub-system. Section 2.1 starts with a brief overview about ITAE's existing thermal lab infrastructure. The concept for integration of the Mediterranean sub-system is explained in section 2.2. Finally, section 2.3 gives details on communication protocols and data points relevant for each component and module.

Section 3 gives information on the installations in the Continental sub-system (it is structured in the same way as Section 2). Section 3.1 starts with a brief overview about AIT's existing thermal lab infrastructure. The concept for integration of the Continental sub-system is explained in section 3.2. Finally, section 3.3 gives details on communication protocols and data points relevant for each component and module.

1.4 Contributions of partners

As work package leader of WP3, AIT is the editor of this report. Besides AIT, CSEM, Fahrenheit , ITAE, NTUA, OCHS, SOR, and AKG gave detailed inputs on all points related to hard-, and software components, interfaces, protocols, layouts, data points for the laboratory infrastructure and sub-systems components and modules. Hence, they have written different sub-sections of section 2 and 3 in this report. The reader can recognize who is mainly responsible for each contribution by the institution name following the title of a sub-section in parentheses.

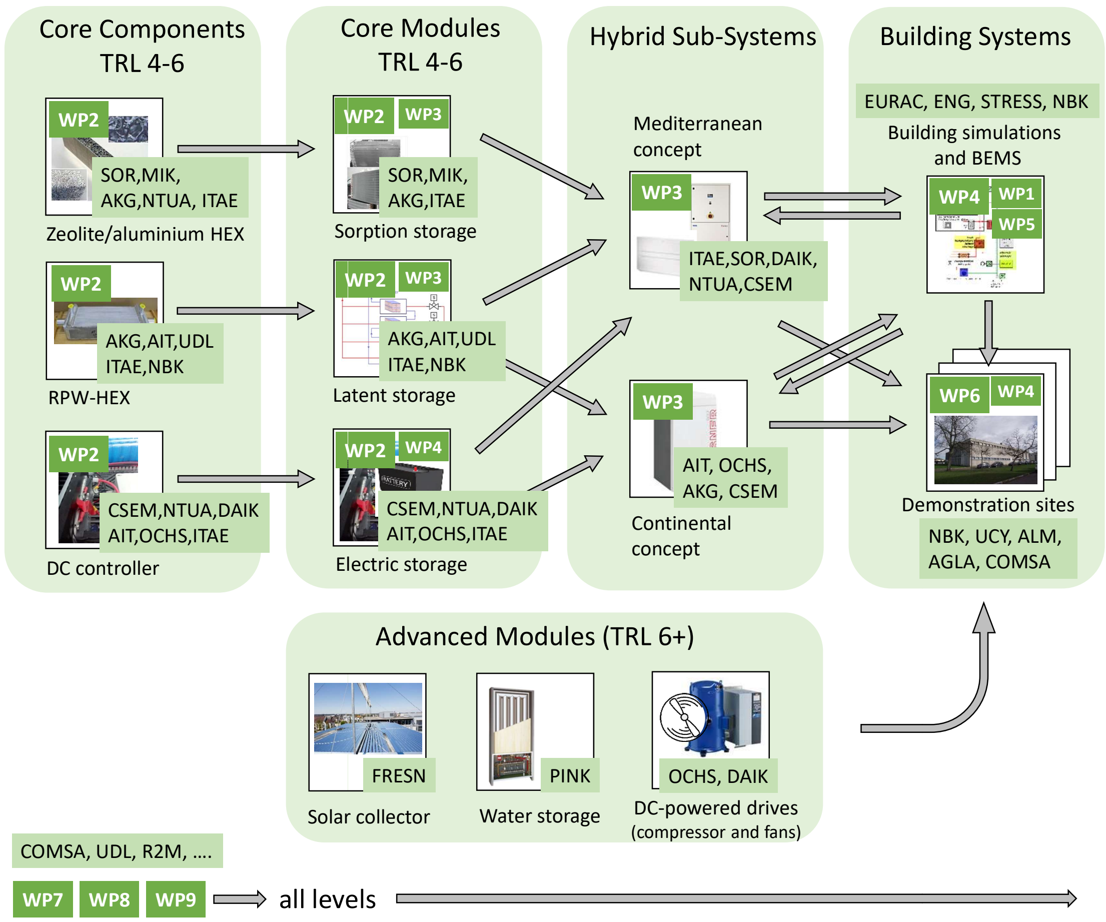


Figure 1-1: Overview of HYBUILD core components, modules, sub-systems, building systems and work packages

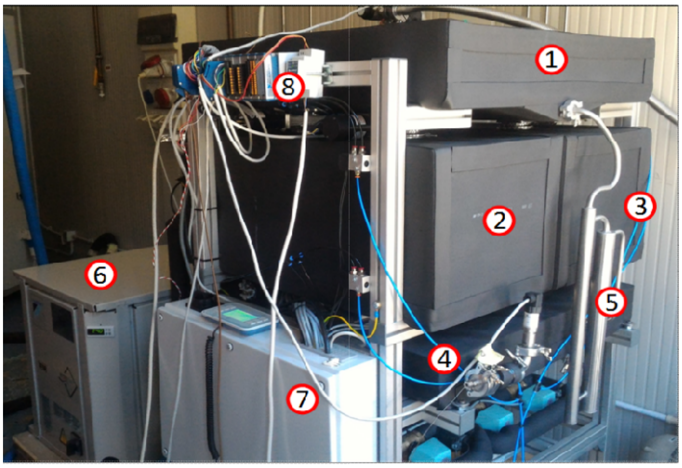
2 Hard- and software communication interfaces for the Hybrid sub-system for the Mediterranean climate (CNR-ITAE)

The hybrid sub-system for the Mediterranean climate tested at CNR-ITAE's thermal laboratory consists of the following components and modules

- the adsorption module manufactured by SOR, MIK and AKG,
- the vapour compression chiller by DAIK and inverter,
- the low temperature RPW-HEX module manufactured by AKG,
- the electrical storage module with the DC controller delivered by CSEM.

The Mediterranean sub-system is tested for various cooling loads, and generation of Domestic Hot Water (DHW) as specified in the use case scenarios for the demo-sites in Aglantzia, Cyprus and Almatret, Spain. The vapour compression chiller with inverter will be tested with the electrical storage and DC controller. Moreover, the different identified sub-system basic operation modes, i.e. charging the RPW-HEX, cooling by discharging the RPW-HEX and direct cooling by the chiller, and generation of DHW by the absorption HP, etc. are tested under dynamic operating conditions. The sub-system will be installed and tested at ITAE's thermal lab.

The first prototype of the integrated sorption module with the vapour compression heat pump has been recently installed at the ITAE's labs, see Figure 2, left for its main components. The DC bus cabinet integrated in a 19" rack was recently installed at CSEM's labs, see Figure 2, right for its main components.



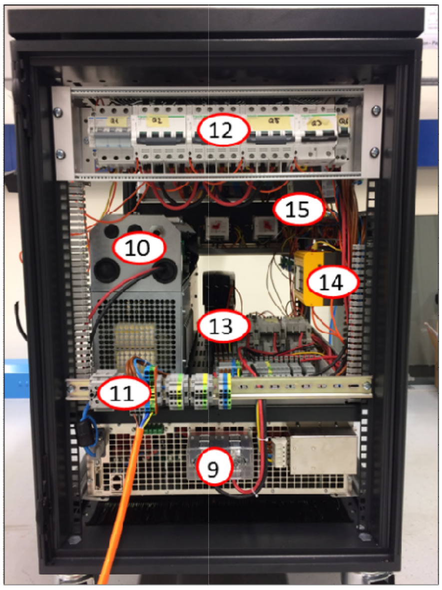


Figure 2: Main components and modules of the hybrid sub-system installations for the Mediterranean climate, 1: condenser adsorption; 2: adsorber 1; 3: adsorber 2; 4: integrated evaporator/condenser; 5: expansion device; 6: vapour compression chiller; 7: electric board adsorption module; 8: data acquisition system; 9: AC/DC grid converter; 10: DC/DC battery converter; 11: terminal blocks; 12: circuit breakers; 13: contactors; 14: grid and insolation monitoring; 15: DC bus controller.

2.1 CNR-ITAE's thermal lab infrastructure (ITAE)

The tests on the sub-system for the Mediterranean climate were carried out in a thermal testing laboratory environment at ITAE. The schematic layout of the testing rig is presented in

Figure 3. The testing rig was designed to supply the power and temperature levels needed for the operation of thermally-operated systems:

- Heat source temperature: 60-95°C;
- Condensation temperature: 25-55°C;
- Evaporation temperature: 5-25°C.

The main components in the testing rig are the hot storage tank, with a volume of 1.5 m^3 and the cold storage tank, with a volume of 1 m^3. A gas heater and an electric heater provide hot water to the hot storage tank, while a vapour compression chiller cools down the water inside the cold storage tank. Water in the High Temperature (HT) circuit of the system is taken directly from the hot water tank, while the temperature levels for the Medium Temperature (MT) and Low Temperature (LT) circuits are obtained by mixing the water in the two storages through motorised mixing valves controlled with a PID algorithm. The heat transfer fluid in all circuits is water. All the pipes are thermally insulated and equipped with variable speed pumps. Class A type T thermocouples are installed in inlet/outlet pipes of all circuits and inside the storages. Flow rates are measured with MVM 0-250 PA magnetic flow meters.

Data from transducers are monitored and recorded using NI hardware (cDAQ) and LabVIEW®2015 environment.

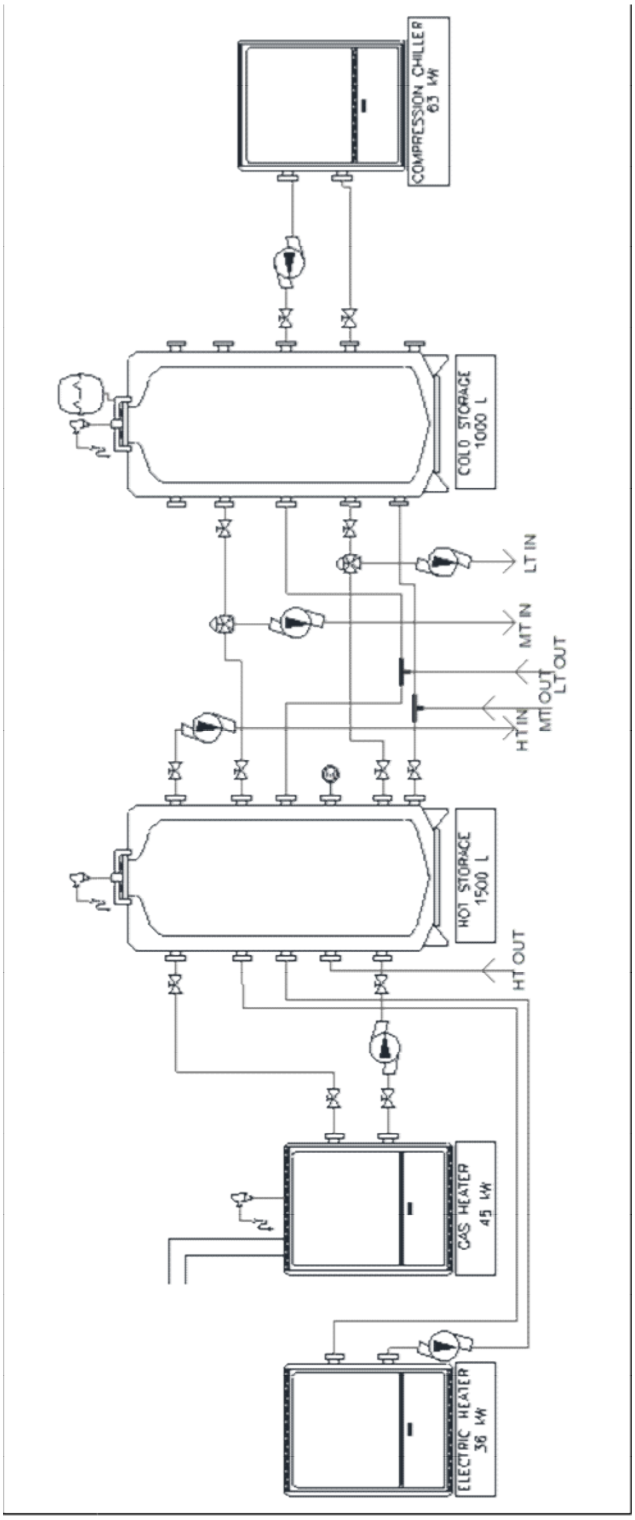


Figure 3: Layout of the thermal test rig at CNR-ITAE.

The electrical storage software and communication will be tested in the ITAE lab environment.

In Figure 4, the hardware and communication scheme of the electrical storage including the interfaces between the battery series with supervisor, DC/DC Converter and Aux power supply is reported.

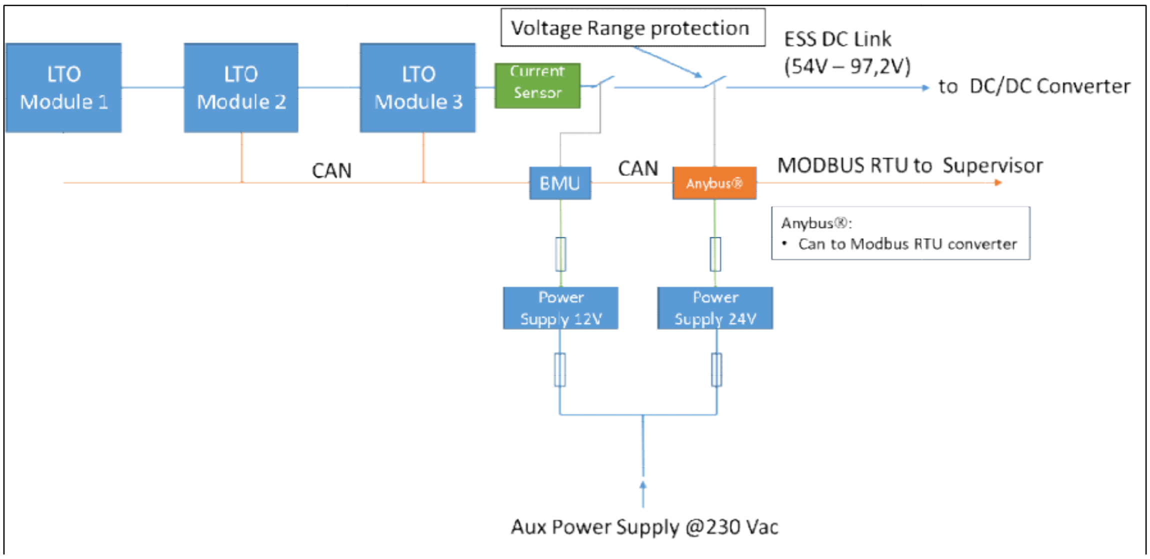


Figure 4: layout of the electrical storage configuration for debugging and testing at CNR-ITAE.

- The Battery Management Unit (BMU) is the control and communication board provided by the manufacturer able to acquire through CAN BUS serial standard, all the single battery parameters (Cell Voltage, Current, Temperatures, Warning and Faults)
- Anybus® is the CAN to MODBUS converter managed and programmed by CNR-ITAE

The communication test will be carried out connecting the Battery Management Unit (BMU) to a NI 9862 CAN Host in order to verify and acquire CAN frames coming from the BMU.

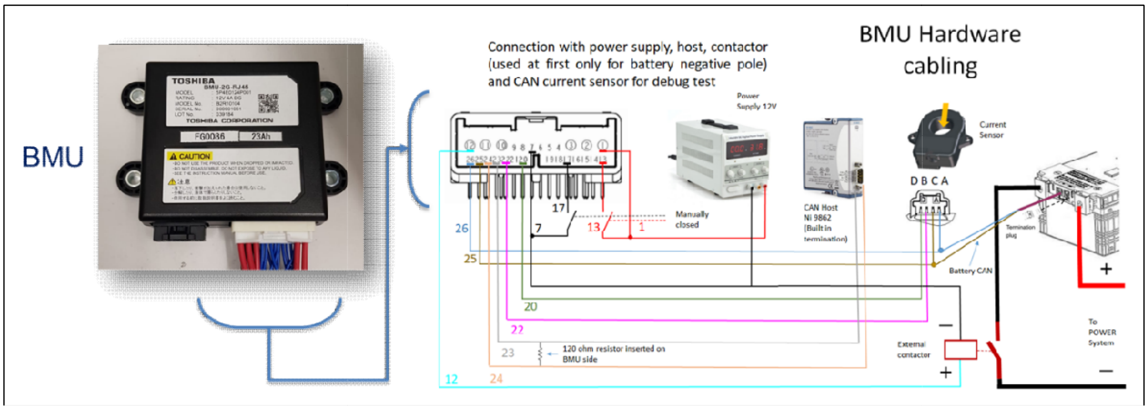


Figure 5: BMU CAN protocol testing at CNR-ITAE.

The whole battery system are tested under load conditions thanks to a Arbin Battery cycler Instruments EVTS-X (Characteristics: Voltage range 0-150 V; Max Current 200 A; Max Power 30 kW) and a Angelantoni Discovery 600L Climatic Chamber (Characteristics: Safety degree EUCAR 6; Temperature range: -40 °C - +180 °C; Humidity range: 10% - 98%).

Figure 6: Battery cycler and Climatic chamber used for testing at CNR-ITAE.

2.2 Integration of the hybrid sub-system (ITAE)

A schematic diagram of the hybrid sub-system for the Mediterranean concept with information flow is shown in Figure 7. For the thermal components, internal controllers in the Fahrenheit module and the vapour compression chiller are available, including monitoring of the basic operation and unit handling. The basic commands for remote on/off of the vapour compression chiller are connected to the Fahrenheit controller that works as the main PLC for the thermal part of the Mediterranean subsystem. The data needed for operation of the RPW-HEX are also passed as an external analogue/temperature input to the Fahrenheit controller. The integration of the thermal and electric components and additional sensors for lab evaluation of system performance is realized through Modbus TCP/IP interface or through direct connection of external sensors to the lab acquisition system, based on NI hardware (cDAQ, cRIO) and LabVIEW 2015. Moreover, the electric storage module, the DC bus, including converters, power meters, PV contactor and DC bus controller are interfaced with a maintenance PC.

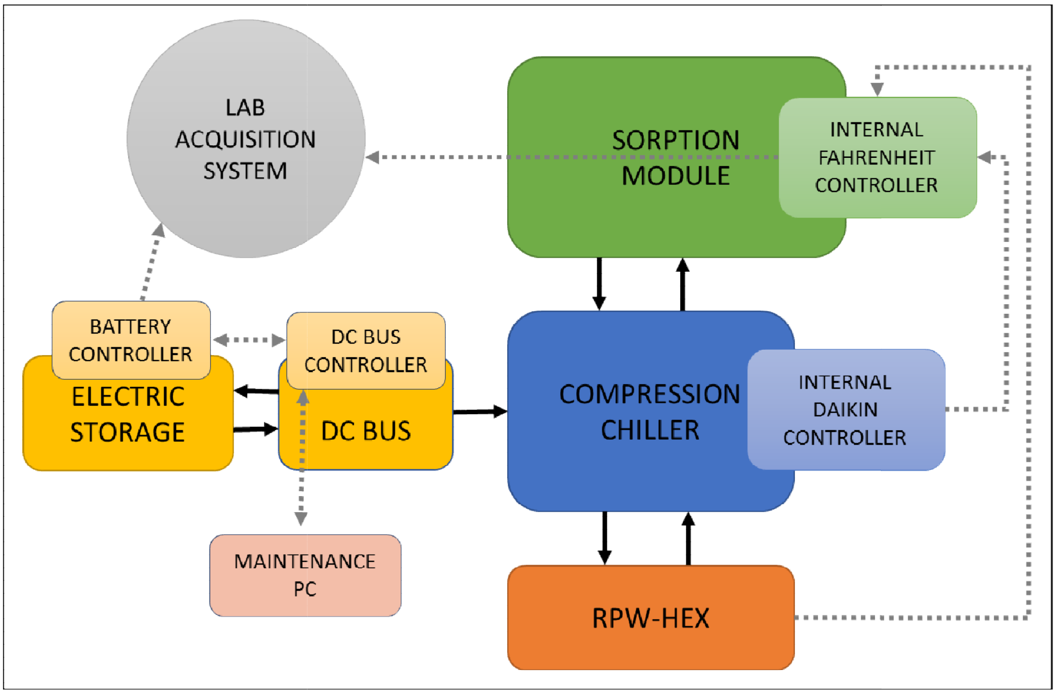


Figure 7: Hydraulic and electric (solid lines) and information flow (dotted lines) of the hybrid sub-system for the Mediterranean climate installed at CNR-ITAE.

The various controllers and their interconnections are shown in Figure 8.

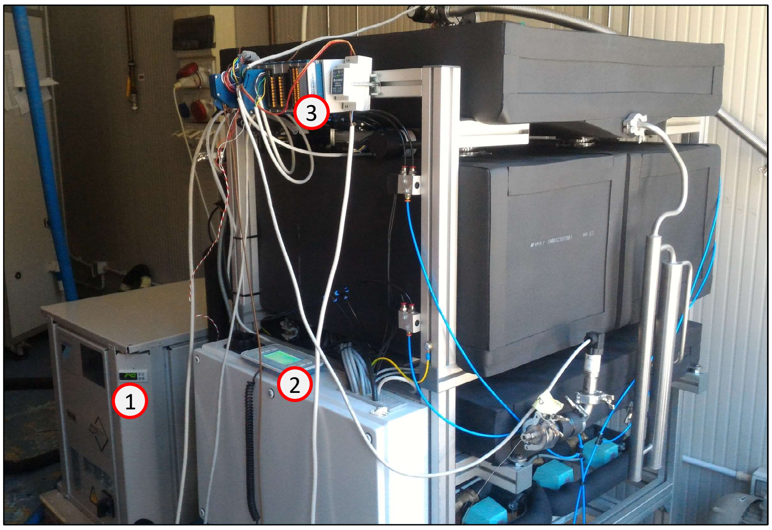


Figure 8: Controllers of the core components. 1: controller for Daikin's compression chiller; 2: controller for Fahrenheit's sorption module; 3: data acquisition system in the lab.

A screenshot of the user interface (VI in Labview) is shown in Figure 9. It can be highlighted that the control panel integrates both the signals coming from the prototype under testing and from the testing rig. In this way, it is possible to manage and control the lab-scale activity by means of a single interface. This interface will further integrate also the electrical storage control part, in order to properly manage the full process.

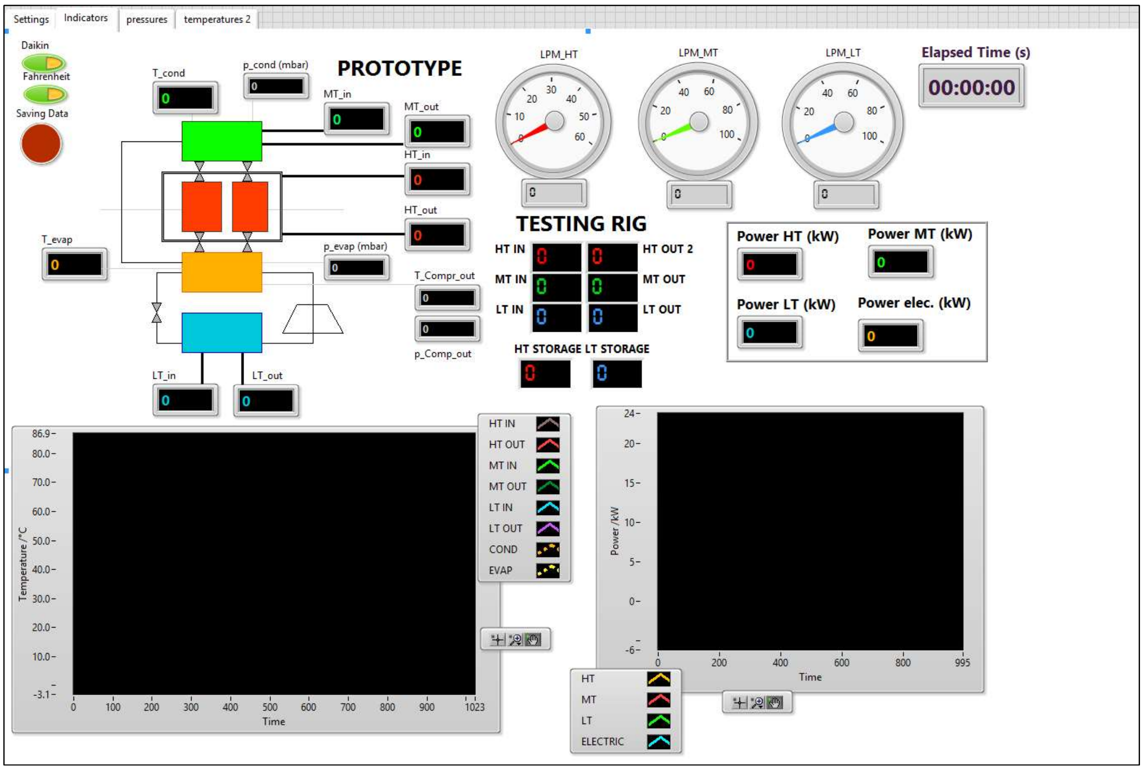


Figure 9: User interface for monitoring and control of the hybrid sub-system installed at CNR-ITAE's lab.

2.3 Details on control hardware, interfaces and data points of the hybrid sub-system core components

The Mediterranean hybrid sub-system features four core components: the vapour compression chiller (2.3.1), the sorption storage module (2.3.2), the electrical storage module (2.3.3) and the latent storage module (2.3.4). The following sections provide detail explanations of the accessible data points (readable and writeable) of each of these units, as well as critical information for communicating with and controlling them.

2.3.1 Vapour compression chiller (NTUA, DAIK)

- Controller hardware: Standard chiller controller with EKAC 10C Communication Card
- MODBUS/RTU communication Interface: RS-485
- Baud rate: 9600
- Parity: none
- No. of stopping bits: 2

A complete list of all data is shown in Table 1.

Table 1: Modbus RTU data list of the vapour compression chiller for the Mediterranean system.

Name	Data Type	Memory address DEC	Access Level	Description
Boolean Variables				
/d	Boolean	005	R/W	Temperature measuring unit °C(0)/°F(1)
H23	Boolean	011	R/W	Address card connection selection: Modbus(1)/Remote

				user interface(0)
H6	Boolean	014	R/W	Enable(1)/Disable(0) remote cooling/heating digital input
H7	Boolean	015	R/W	Enable(1)/Disable(0) remote on/off digital input
H0b	Boolean	016	R/W	Lock(0)/Unlock(1) controller keyboard
H1	Boolean	041	R	Circuit Alarm: A1 or HP1 or LP1 alarms[1]
L1	Boolean	045	R	General Alarm: FL alarm[2]
FL	Boolean	046	R	Defective NTC Probe Alarm: E1 OR E2 OR E3 alarms[3]
E3	Boolean	053	R	Input of flow-switch alarm CLOSED(1)/OPEN(0)
E2	Boolean	054	R	Input of changeable digital S7S input CLOSED(1)/OPEN(0)
E1	Boolean	055	R	Input of high pressure switch or discharge protector or overcurrent alarm CLOSED(1)/OPEN(0)
		056		Input of low pressure switch alarm CLOSED(1)/OPEN(0)
n1	Boolean	057	R	Input of changeable digital S9S input CLOSED(1)/OPEN(0)
	Boolean	059	R	Output of compressor 1 ON(1)/OFF(0)
	Boolean	060	R	Output of compressor 2 ON(1)/OFF(0)
	Boolean	061	R	Output of pump ON(1)/OFF(0)
	Boolean	062	R	Output of reversing valve ON(1)/OFF(0)
	Boolean	063	R	Alarm ON(1)/OFF(0)
	Boolean	064	R/W	Indicates ON (1) or OFF (0) state
	Boolean	065	R/W	Indicates cooling (1) or heating mode (0)
Integer Variables				
c9	Int16	122	R	Total running hours of compressor 1 (100*hours)
cA	Int16	123	R	Total running hours of compressor 2 (100*hours)
cC	Int16	126	R	Total running hours of pump (100*hours)
c7	Int16	238	R/W	Time delay between pump and compressor start-up (sec)
c8	Int16	239	R/W	Time delay between unit and pump shutdown (min)
cb	Int16	241	R/W	Time threshold for maintenance warning (100*hours)
H10	Int16	256	R/W	Serial address
P09	Int16	277	R/W	Changeable digital input selection: • 0 = no function • 9 = remote cool/heat • 13 = remote dual set-point
P34	Int16	329	R/W	Changeable digital input selection: • 0 = no function • 13 = remote dual set-point • 23 = remote on/off

[1] **A1**: anti-freeze alarm, **HP1**: high pressure switch or compressor over-current protection or thermal discharge protection or ambient temperature defective NTC probe, **LP1**: low pressure switch
[2] **FL**: flow-switch or pump over-current protection
[3] **E1**: defective NTC in evaporator inlet, **E2**: defective NTC in evaporator outlet

Analog Variables				
r1	Int16	041	R/W	Cooling set-point (0.1*°C)
r2	Int16	042	R/W	Cooling difference (0.1*°C)
r3	Int16	043	R/W	Heating set-point (0.1*°C)
r4	Int16	044	R/W	Heating difference (0.1°C)
	Int16	102	R	Evaporator inlet water temperature (0.1*°C)
	Int16	103	R	Evaporator outlet water temperature (0.1*°C)
	Int16	104	R	Condenser inlet temperature (0.1*°C)

2.3.2 Sorption storage module (Fahrenheit, ITAE, AKG, MIKR)

The sorption module provided by Fahrenheit has a 4 vacuum chamber architecture: 2 adsorption modules working in counter-phase, which are connected to a single condenser chamber and a single evaporator chamber. Such a configuration allows a quasi-continuous cooling production and the possibility of integrating the refrigerant circuit of the bottoming vapour compression chiller inside the evaporator heat exchanger of the adsorption machine. Furthermore, it includes hydraulic connection to high temperature (HT), medium temperature (MT) and low temperature (LT) circuits (refrigerant circuit of HP). The whole module is equipped with 3-way deviating valves installed on the high temperature and medium temperature circuit, to ensure the proper switching between the various phases of the sorption cycle. In addition, 8 vacuum gate valves ensure the connection of the adsorption modules with both evaporator and condenser. Variable speed pumps are also installed on the high and medium temperature circuits of the chiller.

Hydraulic and vacuum components are managed by Fahrenheit's internal controller. A complete list of data managed by such a component is shown in Table 2.

Table 2: Modbus TCP/IP data list for the sorption module for the Mediterranean system.

Name	Data type	Unit	Access Level	Holding register	Description
eCoo mode	Int16	N/A	R/W	100	on/off of the chiller and maintenance mode
T_SET_EXT	Int16	°C	R/W	101	Set-point cooling water
Min Adsorption time	Int16	s	R/W	102	Minimum duration of the adsorption phase
Max Adsorption time	Int16	s	R/W	103	Maximum duration of the adsorption phase
Phase time	Int16	s	R	200	Time of the last half cycle
Time counter half cycle	Int16	s	R	201	Counter starts at the beginning of a new adsorption phase and stops/resets at the end of the heat recovery phase

Time counter HR	Int16	s	R	202	Counter starts at the beginning of the heat recovery phase and is set to 0 when the heat recovery ends.
Phase	Int16	N/A	R	203	Current phase of the adsorption chiller
T_LT_IN	Int16	°C	R	204	Inlet temperature cooling circuit
T_LT_OUT	Int16	°C	R	205	Outlet temperature cooling circuit
T_HT_IN	Int16	°C	R	206	Inlet temperature high temperature circuit
T_HT_OUT	Int16	°C	R	207	Outlet temperature high temperature circuit
T_C_IN	Int16	°C	R	208	Inlet temperature condenser
T_C_OUT	Int16	°C	R	209	Outlet temperature condenser
T_A1_IN	Int16	°C	R	210	Inlet temperature adsorber 1
T_A1_OUT	Int16	°C	R	211	Outlet temperature adsorber 1
T_A2_IN	Int16	°C	R	212	Inlet temperature adsorber 2
T_A2_OUT	Int16	°C	R	213	Outlet temperature adsorber 2
Speed HT Pump	Int16	%	R	214	Pump speed internal high temperature circuit
Speed MT Pump	Int16	%	R	215	Pump speed internal re-cooling circuit

In addition to that, for the installation and testing in the lab, the sorption module is equipped with the following sensors:

- Pt100 1/10 DIN to measure inlet and outlet temperature in all the hydraulic circuits;
- MVM 0-250 PA magnetic flow meters with ±2.5% full scale accuracy;
- “T” thermocouples class A immersed in the liquid refrigerant pool in the condenser of the adsorption unit and the integrated evaporator/condenser;
- Wika S-20 0…600 mbar pressure transmitter in the vacuum chambers of the condenser of the adsorption unit and the integrated evaporator/condenser;
- Electricity meter with class 1 tolerances to measure the electricity consumption of the components (compressor, controllers, pumps, valve motors) in the system.

The position of the sensors is shown in Figure 10, while a list of the additional sensors is reported in Table 3.

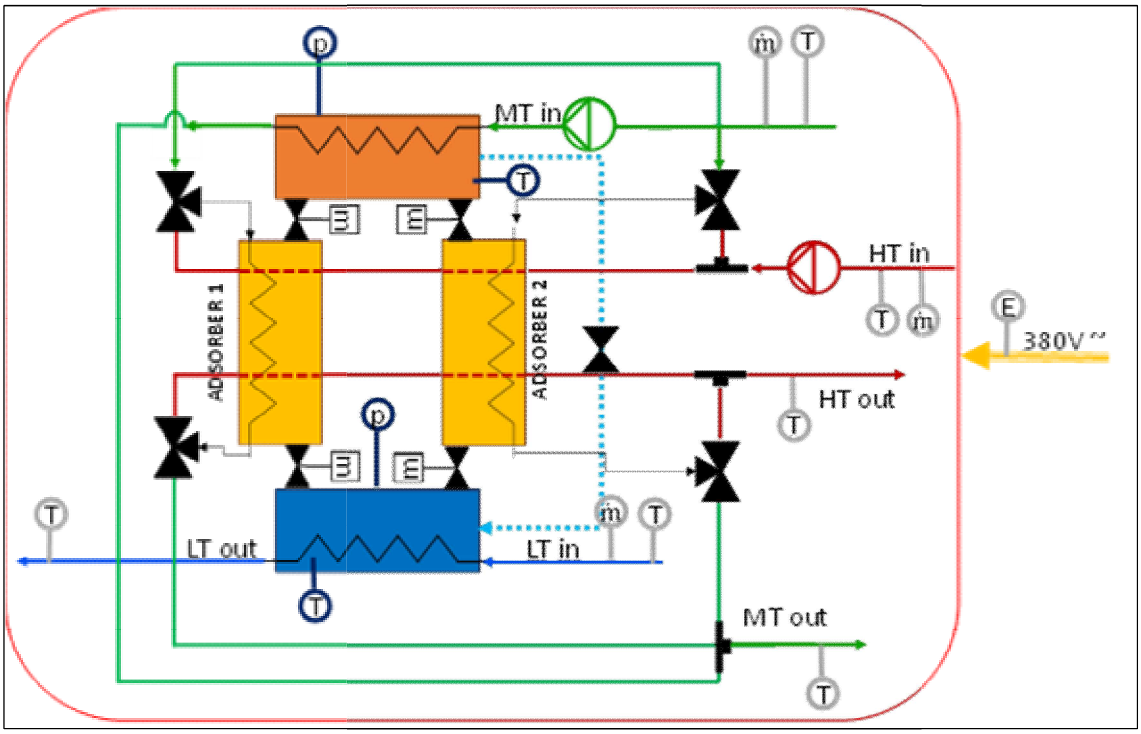


Figure 10: additional sensors for performance assessment at CNR-ITAE's labs.

Table 3: List of additional sensors installed at CNR-ITAE for performance assessment of the sorption module.

Name	Type of sensor	Accuracy	Data type (Labview acquisition VI)	Description
HT_in	Pt100	±0.1 °C	Real	Inlet of HT circuit
HT_out	Pt100	±0.1 °C	Real	Outlet of HT circuit
MT_in	Pt100	±0.1 °C	Real	Inlet of MT circuit
MT_out	Pt100	±0.1 °C	Real	Outlet of MT circuit
LT_in	Pt100	±0.1 °C	Real	Inlet of LT circuit
LT_out	Pt100	±0.1 °C	Real	Outlet of MT circuit
T_cond	TC type T	±0.5 °C	Real	Temperature of water inside the condenser
T_evap	TC type T	±0.5 °C	Real	Temperature of water inside evaporator
p_cond	Piezoresistive, 4-20 mA output	±0.5% FS	Real	Absolute pressure in the condenser
p_evap	Piezoresistive, 4-20 mA output	±0.5% FS	Real	Absolute pressure in the evaporator
FR_HT	Magnetic, 4-20 mA output	±2.5% FS	Real	Flow rate of heat transfer fluid, HT circuit
FR_MT	Magnetic, 4-20 mA output	±2.5% FS	Real	Flow rate of heat transfer fluid, MT circuit
FR_LT	Magnetic, 4-20 mA output	±2.5% FS	Real	Flow rate of heat transfer

				fluid, LT circuit
E_elec	4-20 Ma output	±2.5% FS	Real	Overall electric consumption

2.3.3 Electrical storage module (CSEM, CNR-ITAE, NTUA)

The electrical sub-system storage modules comprise the DC bus, including converters, power meters, PV contactor and a PLC. The components and modules are described first. Second, the electric storage and its battery management unit (BMU/ controller) is presented.

DC BUS (CSEM)

The DC bus system is meant to physically interconnect the electric components of the HYBUILD system: i.e. distribution grid, PV, HP and battery. The same design will be implemented in both Continental and Mediterranean climate. It includes a 550Vdc unearthed DC bus, an AC/DC bi-directional converter for distribution grid interfacing and a DC/DC bi-directional converter for battery interfacing. Both HP and PV installation (PV panels + string optimizer) are then directly connected to the DC bus. The topology of the electric system is presented in Figure 11.

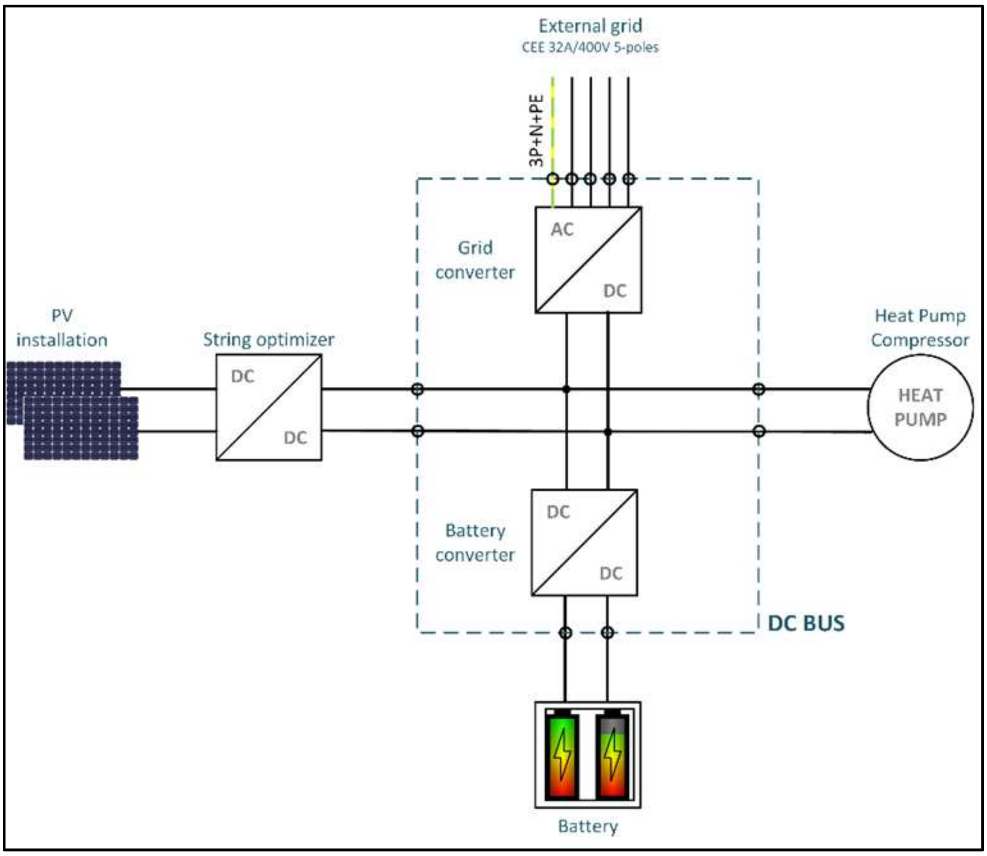


Figure 11: Electrical architecture of the DC bus.

The control and communication system of the DC bus, as well as the different interfaces used, are illustrated on Figure 12.

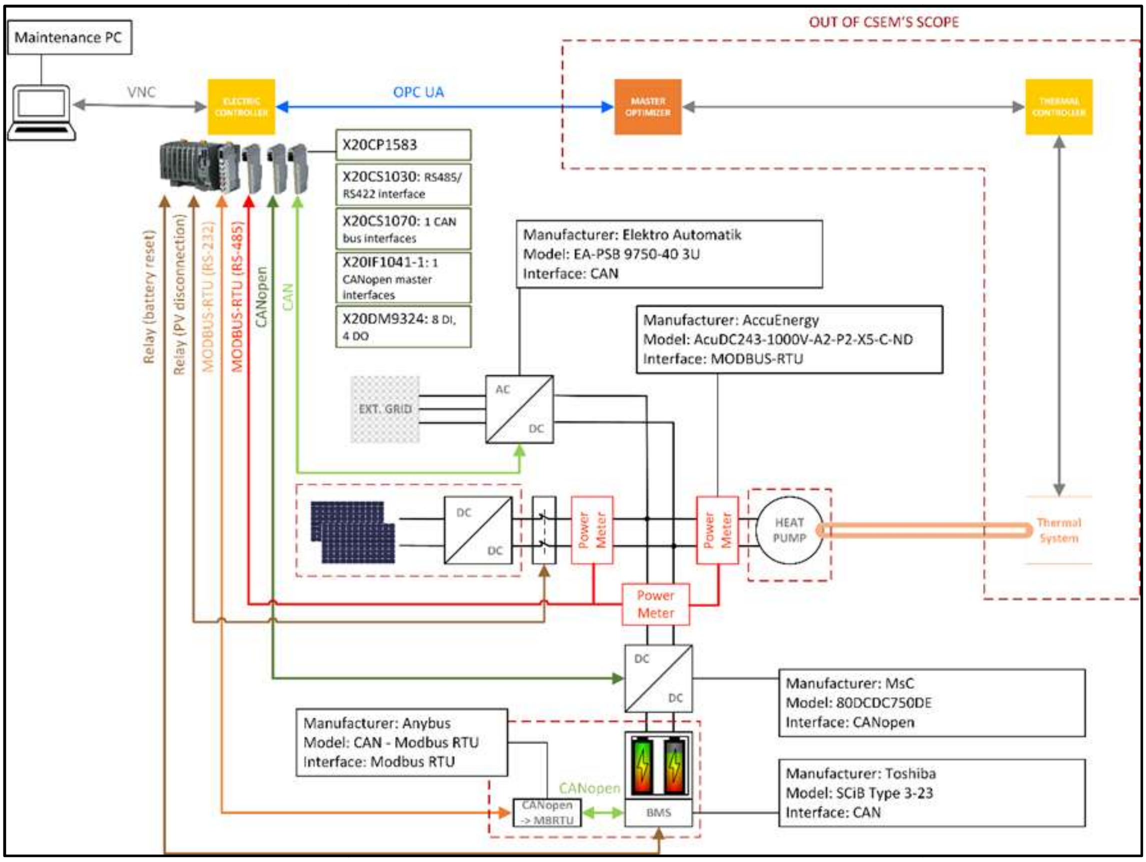


Figure 12: Layout of the control and communication architecture of the DC bus.

The central node of this control and communication architecture is a Bernecker und Rainer (B&R) Programmable Logic Controller (PLC). This PLC manages the low-level control and the monitoring of the internal electric components along with the communication with external entities.

It is composed of a central CPU, which provides the required processing power, and a set of modular interface modules for the communication with the system components. Table 4 enumerates the list of B&R components implemented in the electric controller PLC, as well as a description of their function.

Table 4: List of B&R components implemented in the electric controller PLC.

Reference	Description
X20CP1583	Intel ATOM 333 MHz CPU, Onboard Ethernet (OPC-UA), POWERLINK and USB
X20CS1030	RS485/RS422 interface
X20CS1070	CAN bus interface
X20IF1041-1	CANopen master interface
X20DM9324	8 inputs, 24 VDC, sink / 4 outputs, 24 VDC, 0.5 A, source

The communication interfaces can be split into two categories: the internal ones and the external ones.

The internal communications channels are gathered in Table 5. They are meant to address the internal electric components for control and supervision purposes. Note: the inputs/outputs presented in the table are from the point of view of the addressed device.

Table 5: Internal communication channels.

Addressed device	Protocol	Physical layer	Refreshing rate	Inputs	Outputs
Grid converter	CAN	ISO 11898-2	1Hz	voltage, current, power set-points, enable	voltage, current, power measurements, status, faults
Battery converter	CANopen	ISO 11898-2	1Hz	Current set-point, enable	voltage, current, power measurements, status, faults
Power meters	Modbus-RTU	RS-485	1Hz	-	voltage, current, power measurements
Battery BMS	Modbus-RTU	RS-235	As presented below		
Battery BMS	-	0/12Vdc	Asynch.	Reset signal (relay)	-
PV contactor	-	0-24Vdc	Asynch.	ON/OFF (relay)	-

The external communication channels are meant to allow external entities to act on the electric system with high-level control parameters. Moreover, they make the system state variables available to these entities for monitoring and logging purposes. Two channels have been designed: one with the "Master Optimizer", the other with a "maintenance PC". Their description is presented in Table 6.

Table 6: External communication channels.

Connected device	Protocol	Physical layer	Refresh rate	Inputs to connected device	Outputs from connected device
Master Optimizer	OPC UA	Ethernet	Upon request	System state variables	High-level control parameters
Maintenance PC	RFB (VNC)	Ethernet	Upon request		

The aim of the "Master Optimizer" is to perform high-level optimization of the electric system behaviour based on the knowledge of the system dynamic, its state variables and various forecasts. It is also in charge of logging the state variables.

The communication protocol used is Unified Architecture (OPC UA). OPC UA is a vendor-independent protocol for industrial automation applications based on the client-server principle. This protocol is platform-independent and flexible. It is regarded as the ideal communication protocol for the implementation of Industry 4.0. Moreover, it is built-in in the B&R PLC and thus, easily implementable.

In this topology, the PLC is implemented as server and the Master Optimizer as client. That way, the Master is able to access state variables and write control parameters without any constraints.

The purpose of the Maintenance PC channel is to facilitate the supervision and control of the DC bus system in absence of Master Optimizer during testing procedure by providing the overall system status (communications, converters, voltages, powers) and some control capabilities (mainly by by-passing the Master Optimizer set-points).

It is implemented in the form of a user interface (UI) hosted in the PLC and accessible via a VNC connection. This solution allows to any computer to access the maintenance interface with minimum software requirement (VNC client only). This UI integrates the same inputs/outputs available to the Master Optimizer. They are displayed in the UI and the user has the ability read and write them.

ELECTRICAL STORAGE (CNR-ITAE, NTUA)

The communications protocol between the electric storage system and the controller (BMU) is based on serial interface (HW/SW) consisting of a RS232 port and Modbus line.

Since the battery pack controller BMU has a CANbus interface, a dedicated gateway (Anybus® Communicator CAN Modbus RTU by HMS, in Figure 10) was necessary to:

- ✓ transcode data from CANbus frame to Modbus register (and vice versa),
- ✓ decouple the two networks (Modbus and CANbus) and, therefore, to allow asynchronous communications.

Figure 13: Communication network and used gateway: Anybus® Communicator CAN Modbus RTU.

The (Modbus interface) serial communications settings are:

- ✓ Communication line: 3-wire RS232 (it is possible to convert into 2-wire RS485 by physical switch), db9 female connector
- ✓ Baud rate: 38400 bit/s (can be set differently, if necessary, by physical switches)
- ✓ Parity: None (can be set differently, if necessary, by physical switches)

The Modbus slave ID is currently set to 5 (can be set differently, if necessary, by physical switches).

To provide the PCS with a suitable data interface, as commonly done, the Modbus registers are divided into input (from the PCS to the gateway) and output variables (from the gateway to the PCS). Data types are boolean ("coil status") and integer (to represent numerical values).

Input variables includes battery pack voltage, current, State of Charge (SoC), and State of Health (SoH), maximum and minimum values of both cell voltage and temperature, other battery pack status indications, warning and alarms.

Each Modbus register is 16 bits long, divided into Most Significant Byte (MSB) and Least Significant Byte (LSB), addressed as reported in Table 7:

Table 7: Variables for communication between battery pack and PCS (input, PCS to gateway).

MB_reg# (DEC)	Data type	MSB	LSB
1	16 x 1 bit (coil)	Battery pack Status	Status additional information
2	16 x 1 bit (coil)	Charge/discharge complete	Operational limitations reached
3	UINT16	Battery pack State of Charge	
4	UINT16	Battery pack State of Health	
5	UINT16	Highest cell voltage in the battery pack	
6	UINT16	Lowest cell voltage in the battery pack	
7	INT8	---	Highest cell temperature
8	INT8	---	Lowest cell temperature
9	UINT16	Actual current (charge phase)	
10	UINT16	Actual current (discharge phase)	
11	UINT16	Battery pack voltage	
12	UINT8	---	SoC%
13	3 x 1bit (coil)	---	Modules controllers failure

The output variables reported in Table 8 are used to send:

- start/stop commands (as required at the start-up, in case of external alarms),
- information on the battery pack voltage measurement (from PCS, to verify the measurement alignment and coherence),
- PCS presence signal (to bring the battery pack in “protection mode”, i.e. disconnection, in case of connection loss or PCS fault),
- a 64-bit timestamp to synchronize data for recording.

Table 8: Data mapping from PCS to battery pack controller (Modbus interface, output, gateway to PCS).

MB_reg# (DEC)	Data type	MSB	LSB
1025	8 x 1bit (coil)	PCS signaling	1
1026	UINT16	Battery pack voltage (external measurement)	
1028 – 1031	UINT16	Timestamp	

In order to verify the correct communication between the two networks, a debug application was developed in LabVIEW environment. Figure 14 shows the main panel of the operator interface to read the storage unit electrical variables and working status (normal operation / warning / alarm).

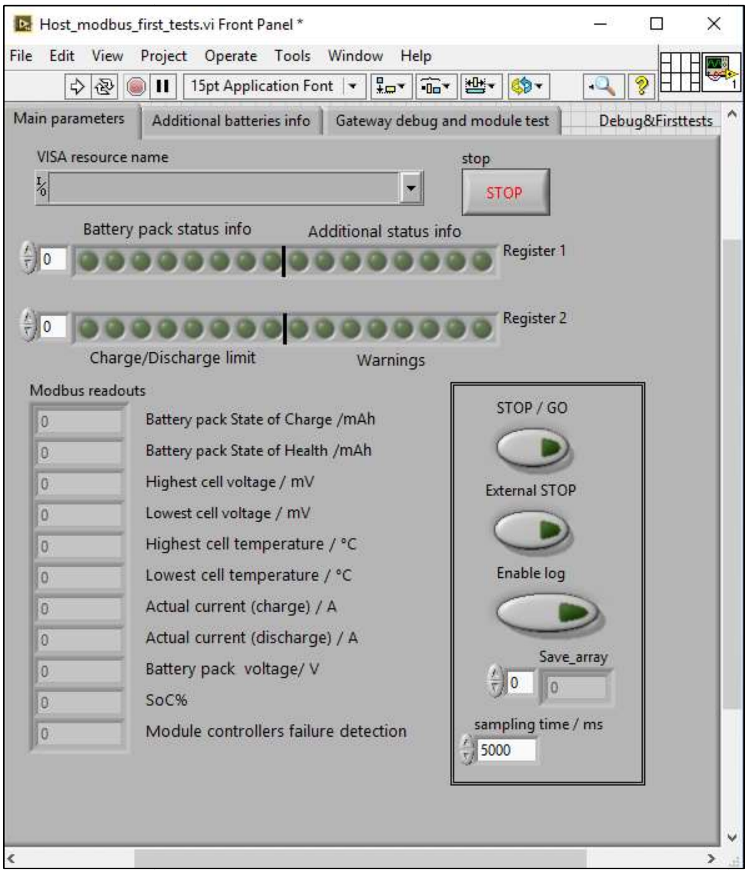


Figure 14: Main panel of the user interface of the application to verify the data communication and transcoding.

2.3.4 Latent storage module (NTUA/ AKG/ UDL)

The three fluid RPW-HEX linked to the compression chiller for the Mediterranean sub-system will be installed and tested in NTUA's lab test rig. The current layout of the test rig consists of a cooling tower, used as a heat sink for the condenser and roof fan-coil unit, being the heat source of the evaporator. Motorized 3way valves allow the reversibility of the chiller between cooling and heating modes, by swapping the hydraulic circuits. Inflow Resistance Temperature Detectors (PT100) are used for measuring the water temperatures in both the condenser and the evaporator while a supersonic flow meter and a differential pressure instrument over a standard balancing valve are used for measuring the water flow in the hydraulic circuits. A power meter measures the compressor active and apparent power and the rest of the electrical parameters.

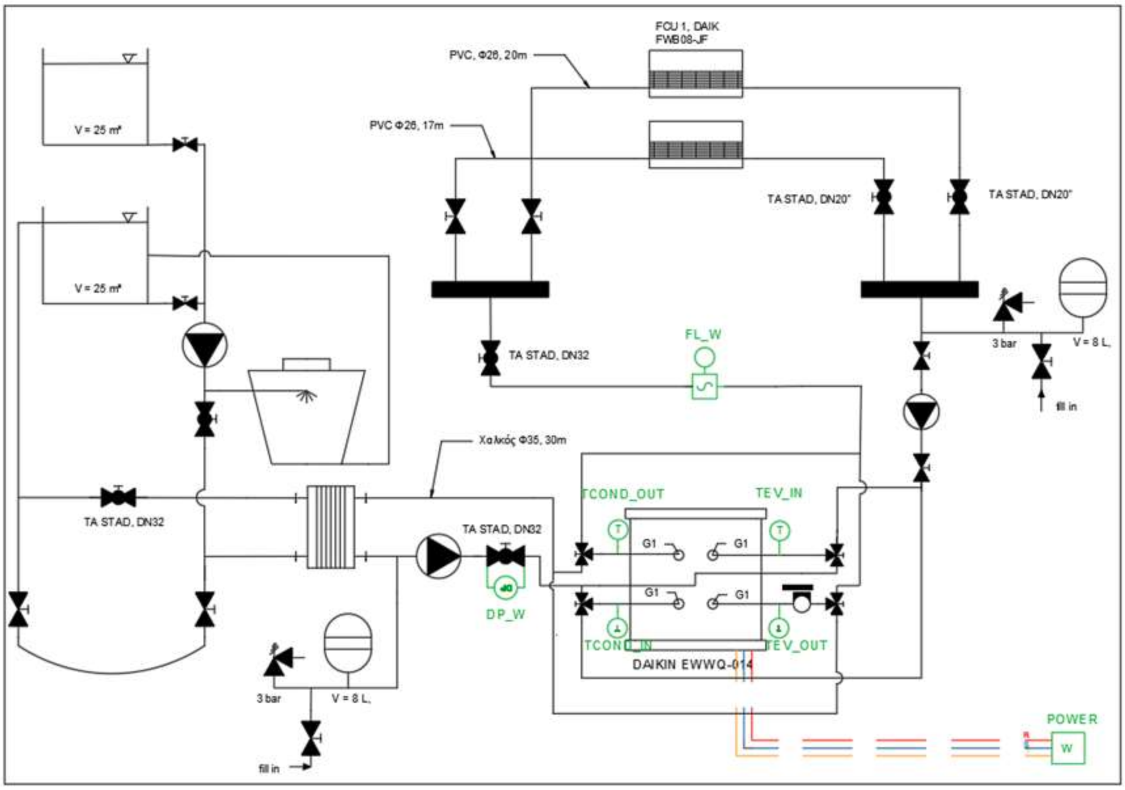


Figure 15: Schematic of NTUA's test rig and sensors (marked green).

The Mediterranean heat pump was modified (retrofitting), and additional sensors were installed as depicted in the following diagram:

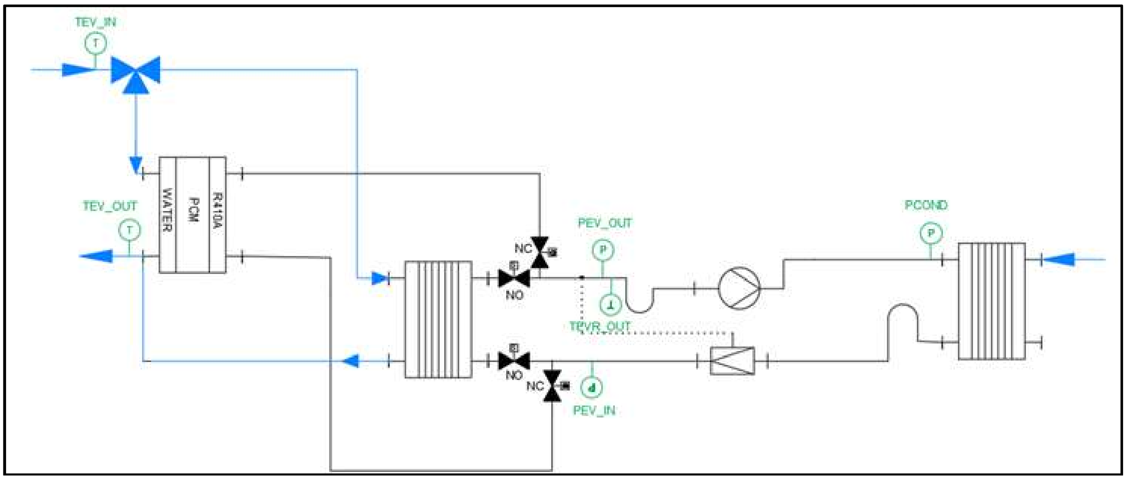


Figure 16: Schematic of modified heat pump and RPW-HEX with additionally installed sensors (marked green).

The following table summarizes the additionally installed sensors, including those in NTUA's test rig (see Figure 15) and those installed for the retrofitting of the heat pump (see Figure 16).

Table 9: Additional sensors in NTUA's test rig.

Name	Type of sensor	Accuracy	Manufacturer	Description
TEV_IN	Pt100	±0.1 °C	UTECO	Water entering the evaporator(s)
TEV_OUT	Pt100	±0.1 °C	UTECO	Water leaving the evaporator(s)
TCOND_IN	Pt100	±0.1 °C	UTECO	Water entering the condenser
TCOND_OUT	Pt100	±0.1 °C	UTECO	Water leaving the condenser
POWER	Network Analyzer with RS485 interface	I: 0,5% F.S. V: 0,5% F.S. W: 1% F.S.	DUCATI Energia	Electrical consumption of compressor
PEV_IN	Piesoresistive with 4-20mA transmitter	±1% F.S.	ALCO Controls	Inlet of evaporator(s)
PEV_OUT	Piesoresistive with 4-20mA transmitter	±1% F.S.	ALCO Controls	Outlet of evaporator(s)
PCOND	Piesoresistive with 4-20mA transmitter	±2% F.S.	ALCO Controls	Inlet of condenser
TEVR_OUT	Pt100	±0.1 °C	UTECO	Refrigerant outlet temperature (external)
FLW	Supersonic Flow Meter	±1% Reading	General Electric	Heat source flow rate
DPW	Differential Pressure Sensor Flow Meter over standard balancing valves	ΔP: ±1% Reading Flow: ±1% Reading if not throttling	IMI Hydronic	Heat sink flow rate

The signals from the installed sensors are acquired from a self-developed LabVIEW 2018 interface, which allows the data log, supervision and control of the sub-system, using Advantech's hardware as ADCs/DACs (ADAM 4000 series RS-485 I/O Modules). The aforementioned data acquisition system allows communication with the heat pump's internal controller by means of Modbus RTU (see Section 2.3.1, and Figure 17).

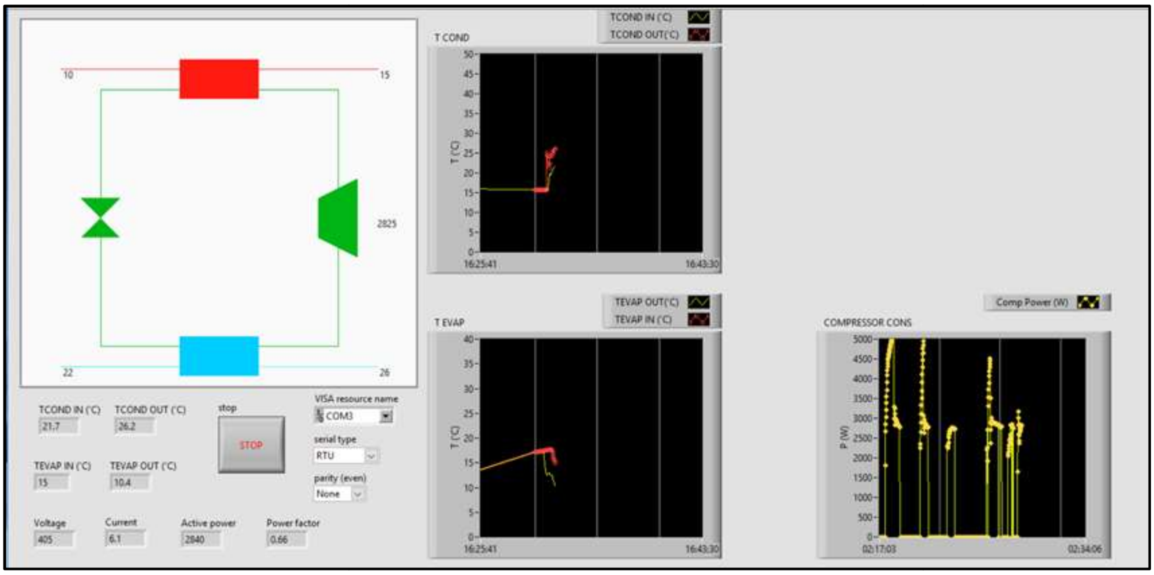


Figure 17: Labview interface for data acquisition in NTUA's labs.

3 Hard- and software communication interfaces for the Hybrid sub-system for the Continental climate (AIT)

The hybrid sub-system for the Continental climate tested at AIT's thermal laboratory infrastructure consists of the following components and modules

- the compression HP (OCHS), an outdoor unit, which is installed in a climate chamber for the assessment of ice aggregation at the evaporator HEX and de-icing operation. The DC powered operation of the HP compressor is tested using a DC generator;
- the RPW-HEX module (manufactured by AKG) integrated in the hot superheated section of the refrigerant cycle;

The Continental sub-system is tested for various heating and cooling loads, EN14825, for average climate and intermediate heating temperatures (similar to the demo-site in Talence, France) as well as for DHW load profiles, EN16147, and the DC driven HP compressor operation. Moreover, the different identified sub-system basic operation modes, i.e. heating and charging the RPW-HEX, cooling and charging the RPW-HEX, discharging the RPW-HEX for generation of DHW, etc. are tested under dynamic operating conditions. The sub-system installed in the climate chamber at AIT thermal laboratory is shown in Figure 18.

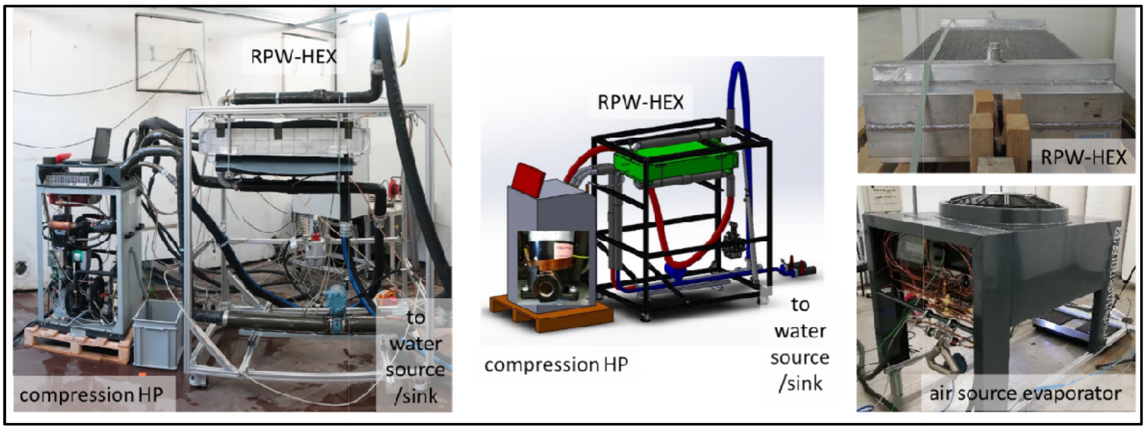


Figure 18: Main components and modules of the thermal sub-system installations for the Continental climate.

3.1 AIT's thermal lab infrastructure (AIT)

AIT uses the Renewable Heating and Cooling (RHC) Lab 1 and RHC Lab 3 large research infrastructure for heat pump tests. The infrastructure is described below, Figure 19 shows RHC LAB 3 with the sub-system installed.

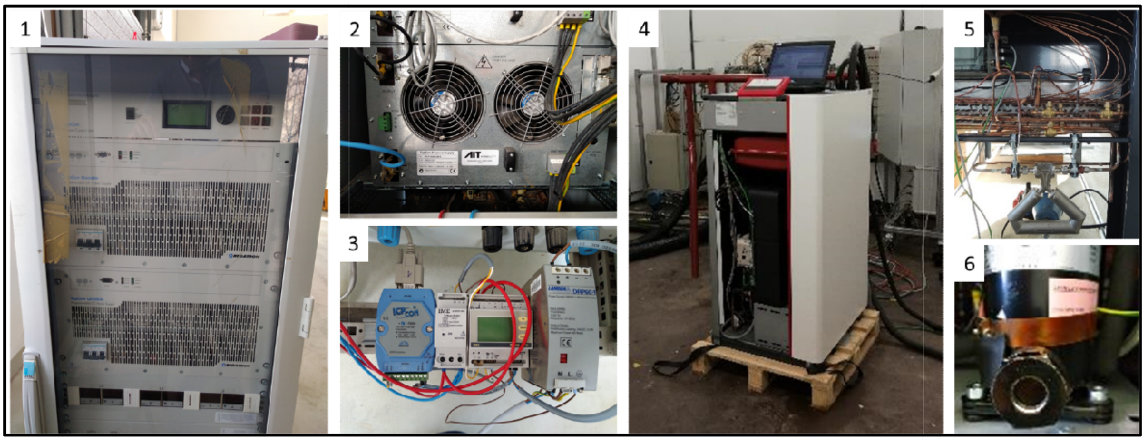


Figure 19: Hybrid sub-system installations for the Continental climate set up in AIT's thermal lab, DC generator (1) with power supply (2) and data acquisition system (3); compression HP (4) with Coriolis mass flow sensor (5) and HP compressor (6).

RHC Lab 1 is a laboratory with a floor space of 906 m² equipped with three climate chambers, several connections to a centralized heat and cold supply system a facility for testing district heating sub-stations (30 to 500 kW). Depending on the actual research question, the facilities of this lab are used for various purposes including performance and durability tests of different components and sub-components such as different types heat exchangers, different types of heat pumps (air/water, brine/water, water/water, direct expansion systems). Within the lab experimental setups and tests ranging from individual small-scale components up to entire units (approx. 100 kW) can be performed (e.g. for lab scale proof-of-concept of technologies)

RHC lab 3 is a laboratory with a floor space of 416 m² equipped with two climatic chambers. The two climatic chambers are used for purposes comparable with those described for RHC lab 1 (see description above). The maximum thermal capacity is around 10 kW.

For tests in HYBUILD the heat pump is connected to the water cycle of the infrastructure to control water flow rates and water temperatures. The heat pump evaporator is placed in a climate chamber where the temperature and humidity are controlled. Calibrated sensors are used for temperature, humidity, pressure, pressure drop and mass-flow rate measurements.

3.2 Integration of the hybrid sub-system (AIT)

A schematic diagram of the hybrid sub-system for the Continental concept with information flow is shown in Figure 20. For the compression HP, OCHS provides an internal controller for basic control with a communication interface external read/write operations and supervision. Additional sensors and actors needed for analysis and operation of the integrated HP and RPW-HEX are directly passed to AIT's lab automation and data acquisition system. The DC generator works as a standalone unit, it is equipped with sensors for recording the electrical power and energy consumption and is operated with an existing individual control and data acquisition system.

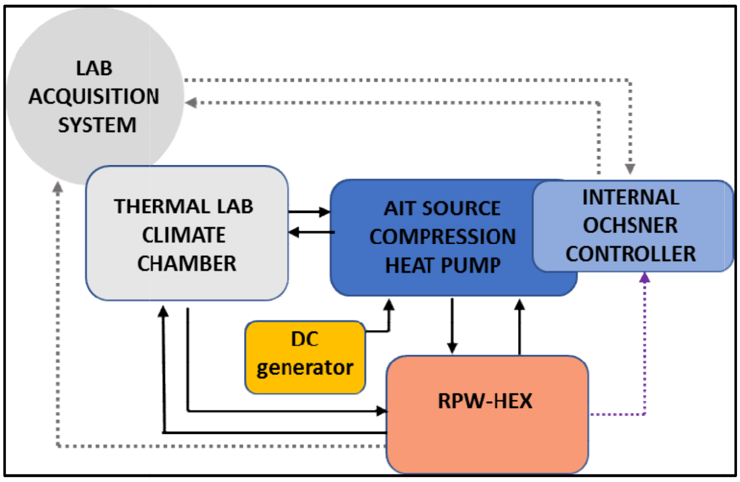


Figure 20: Hydraulic and electric (solid lines) and information flow (dotted lines) of the hybrid sub-system for the Continental climate installed at AIT.

The hydraulic installation of the hybrid sub-system for the Continental climate in the AIT laboratory infrastructure is shown in Figure 21 including heat pump internal and additional sensor and actors. For additional measurements calibrated sensors are used to limit the measurement error to a minimum. Details about the sensors are listed in Table 10.

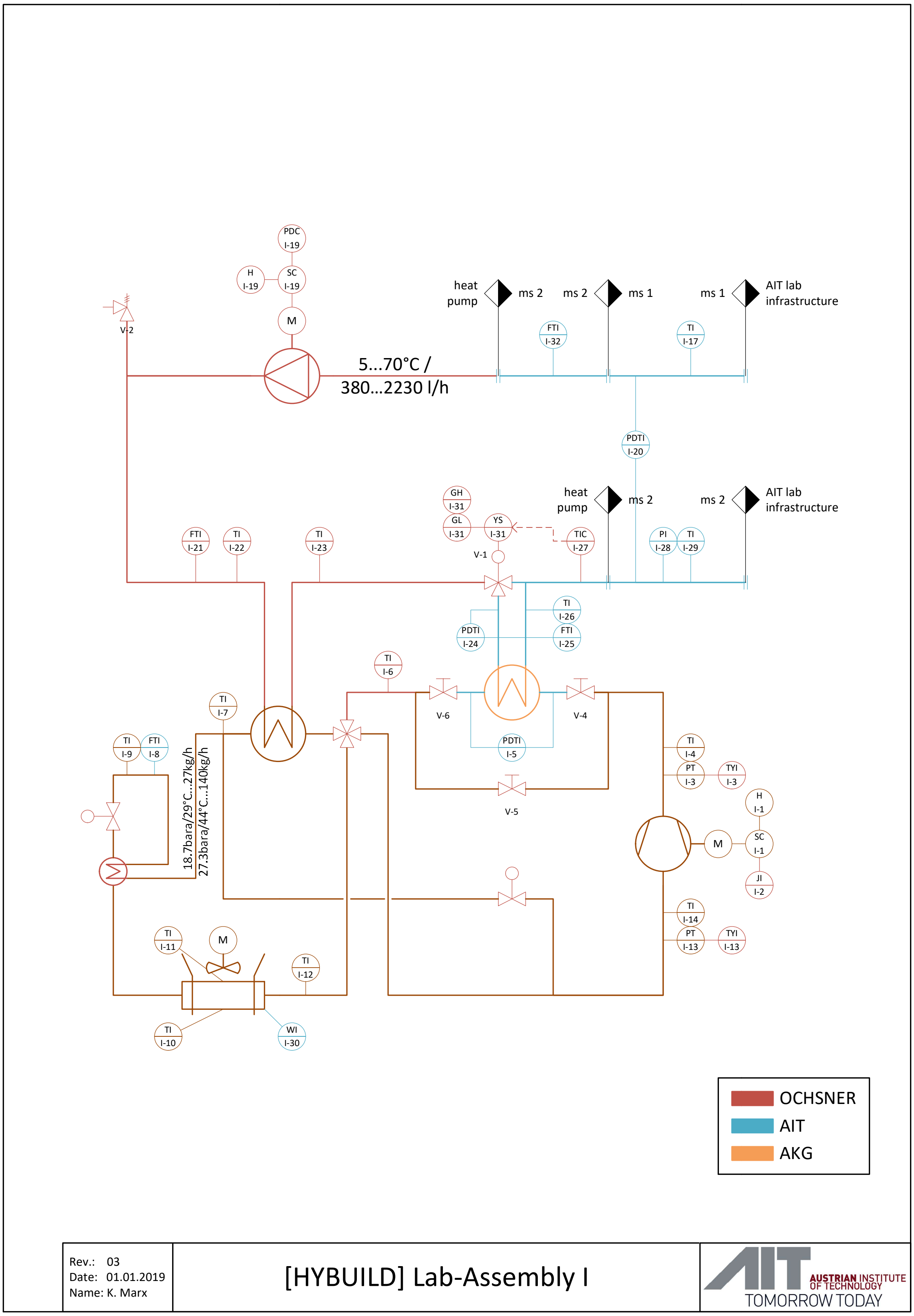


Figure 21: Installation scheme of the HYBUILD hybrid sub-system for the Continental climate at AIT thermal laboratory infrastructure.

Table 10: Heat pump additional measurements.

TAG	Electric connection	Sensor type	Manufacturer	Type	Description
PDTI-5	4…20mA	Differential Pressure Transmitter	EMERSON	3501	RPW-HEX Pressure Refrigerant Side
FTI-8	4…20mA HART	Coriolis Mass Flow Meter	EMERSON	CMF025	Refrigerant Mass Flow
TI-17	4-wire PT-100	Resistance			Water return temperature
PDTI-20	4…20mA	Differential Pressure Transmitter	EMERSON	3501	Heat Pump Pressure Drop
FTI-32	4…20mA HART	Coriolis Mass Flow Meter	EMERSON	CMF100	Feed water flow rate
PDTI-24	4…20mA	Pressure Transmitter	EMERSON	3501	RPW-HEX Pressure Drop Water Side
FTI-25	4…20mA HART	Magnetic Flow Meter	EMERSON	8711-30F	RPW-HEX Water Flow Rate
TI-26	4-wire PT-100	Resistance			RPW-HEX Outlet Temperature
PI-28	4…20mA	Pressure Transmitter	EMERSON	2008	Heat Pump Outlet Pressure
TI-29	4-wire PT-100	Resistance			Heat Pump Feed Temperature
WI-30	OPC-UA	Scale	Mettler Toledo	XPE155KSC	Evaporator Weight

Sensors are connected to the existing automation system, an industrial PCS system from Bernecker und Rainer using the APROL® software and X20 PLC hardware, see Figure 22.

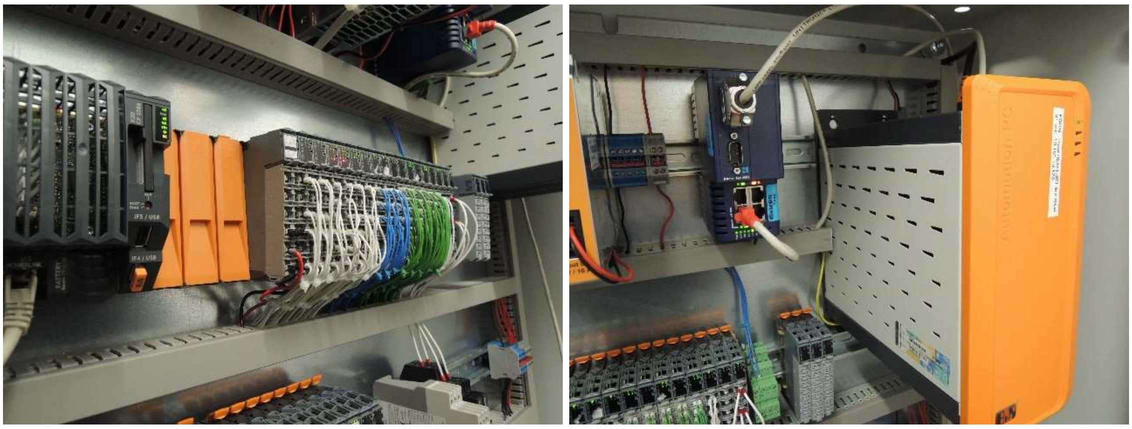
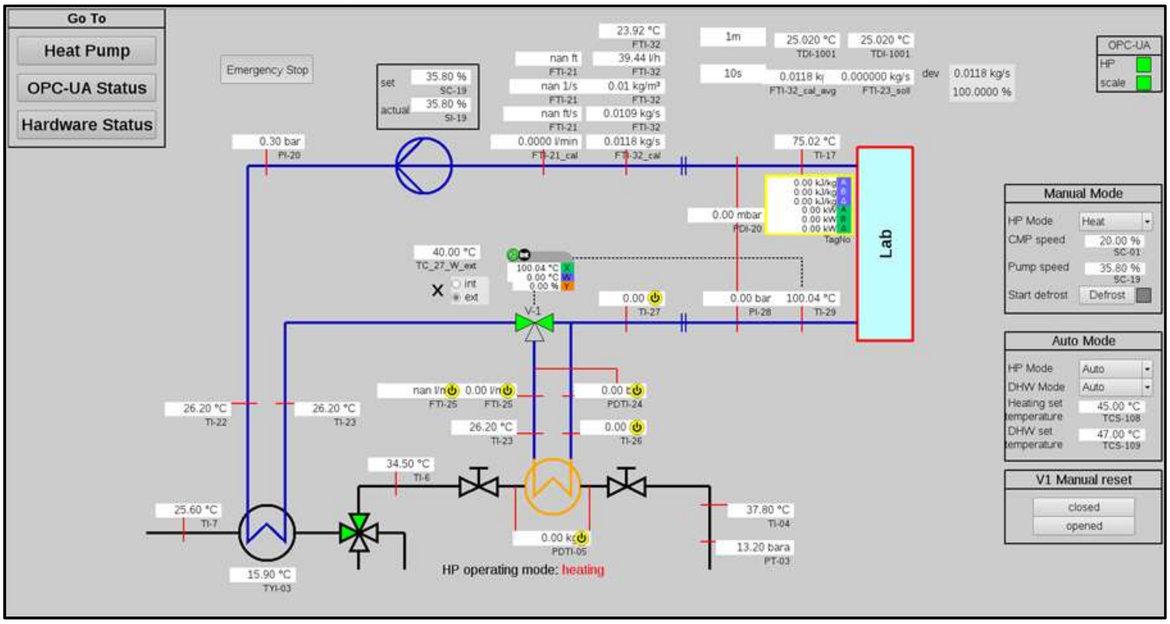


Figure 22: Bernecker und Rainer industrial hardware used in AIT thermal laboratory.

The software is equipped with an OPC-UA client solution which pulls the data via the OPC-UA to ModBus converter from the OCSHNER heat pump and vice versa. Data from the heat pump and the AIT sensors are shown online allowing observation of the heat pump operation with ease. Parameter trends can be viewed and analysed via the proprietary Bernecker und Rainer TrendViewer.



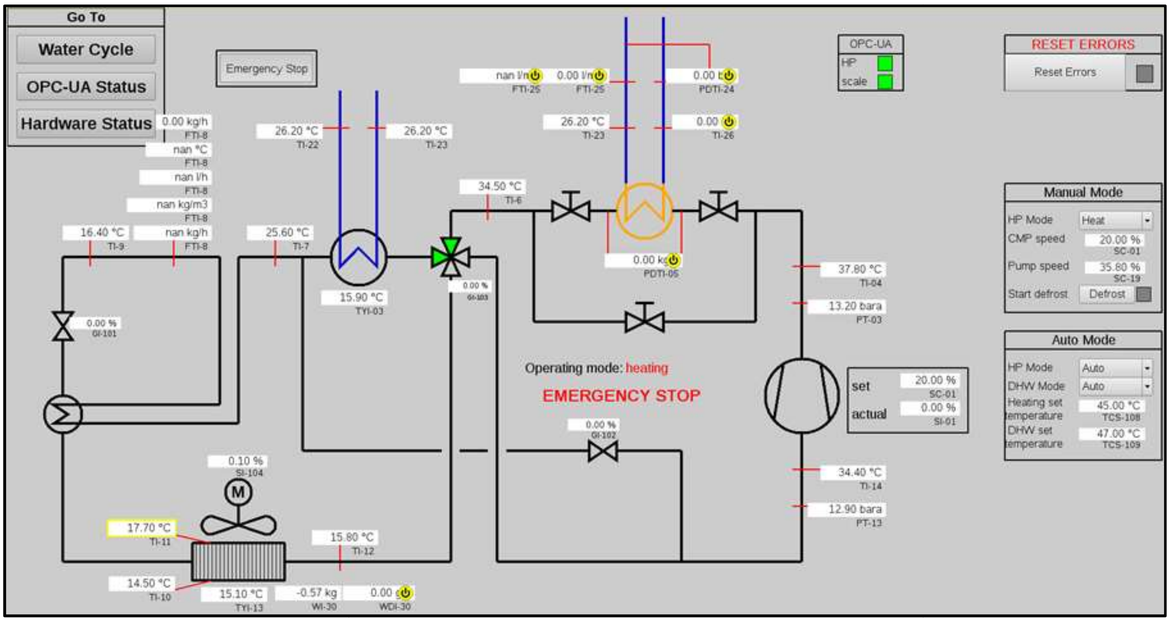


Figure 23: Graphical User Interface for supervision and control of experiments of the Continental sub-system at AIT thermal laboratory.

3.3 Details on control hardware, interfaces and data points of the hybrid sub-system core components

The Continental hybrid sub-system features four core components: the vapour compression heat pump (3.3.1), the vapour compression heat pump interface converter (3.3.2), the DC generator (3.3.3) and the latent storage module (3.3.4). The following sections provide detail explanations of the accessible data points (readable and writeable) of each of these units, as well as critical information for communicating with and controlling them.

3.3.1 Vapour compression HP (OCHSNER, AIT)

The vapour compression heat pump uses a Siemens POL698 controller which is equipped with a ModBus RTU communication interface. The interface configuration is listed below.

Table 11: Modbus RTU configuration of the vapour compression HP for the Continental system.

Item	Value
Address	1
Baud rate	9600
Parity	none
Stop-Bits	2

A complete list of all variables accessible on the interface is given in Table 12.

Table 12: Modbus RTU data list of the vapour compression HP for the Continental system.

Name	Slave ID	Function code	Register address HEX	Access Level	Data type	Unit conversion factor	Description
HP\HPAggr.EmgOff	1	4	0001	w	UInt32	1	Heat pump emergency off [0 – Auto | 1- Off]
HC1\HC1.OpMMan	1	4	0002	w	UInt32	1	Heat pump operation mode [0 – auto | 1 – heating | 2 – cooling]
HC1\SpTFl.Sp	1	4	0003	w	UInt32	0.1	Set-point feed water temperature [°C]
DHW\DHW.OpMMan	1	4	0004	w	UInt32	1	Operation mode DHW generation [0 – auto | 1 – off]
DHW\DHW.SpMan	1	4	0005	w	UInt32	0.1	Set-point temperature DHW generation [°C]
	1	4	0006	w	UInt32	1	Reset errors [0 – default | 1 – reset]

HP\HPAggr.OpModMan	1	4	0010	w	UInt32	1	Manual mode [0 – auto | 1 – heating | 2 – cooling]
HP\HPAggr.SpdManOp	1	4	0011	w	UInt32	0.1	Set-point compressor-speed [%]
RefCrt\RfCrt.ReqDefrFrcd	1	4	0012	w	UInt32	1	Start defrosting [0 -default | 1 – start]
IO\HP.Pu.Cmd	1	4	0013	w	UInt32	0.1	Water pump speed [%]
IO\HP.Pu.Cmd	1	4	0020	r	UInt32	0.1	Pump speed [%]
IO\HP.TFl.Val	1	4	0021	r	UInt32	0.1	Temperature water condenser out [°C]
IO\HP.TRt.Val	1	4	0022	r	UInt32	0.1	Temperature water condenser in (return) [°C]
IO\HP.Fl.Val	1	4	0023	r	UInt32	0.01	Water flow rate [m³/h]
IO\PRt.Val	1	4	0024	r	UInt32	0.1	Pressure water pump discharge [barg]
IO\DHW.TStkTop.Val	1	4	0025	r	UInt32	0.1	Temperature water feed [°C]
IO\RefCrt.TSrcIn.Val	1	4	0026	r	UInt32	0.1	Temperature evaporator air in [°C]
IO\RefCrt.TSrcOut.Val	1	4	0027	r	UInt32	0.1	Temperature evaporator air out [°C]
IO\RefCrt.TSuctEvp.Val	1	4	0028	r	UInt32	0.1	Temperature evaporator refrigerant out [°C]
IO\RefCrt.TSuct.Val	1	4	0029	r	UInt32	0.1	Temperature compressor suction side [°C]
IO\RefCrt.PAbsEvp.Val	1	4	0030	r	UInt32	0.1	Pressure compressor suction side [bar]
IO\RefCrt.TEvp.Val	1	4	0031	r	UInt32	0.1	Evaporation temperature (calculated) [°C]
IO\RefCrt.PAbsCdn.Val	1	4	0032	r	UInt32	0.1	Pressure compressor discharge [bar]
IO\RefCrt.TCdn.Val	1	4	0033	r	UInt32	0.1	Condensation temperature (calculated) [°C]
IO\RefCrt.TDcrg.Val	1	4	0034	r	UInt32	0.1	Temperature compressor discharge [°C]
	1	4	0035	r	UInt32	0.1	Temperature RPW-HEX refrigerant out [°C]
IO\RefCrt.TCndOut.Val	1	4	0036	r	UInt32	0.1	Temperature condenser refrigerant out [°C]
IO\RefCrt.TExps.Val	1	4	0037	r	UInt32	0.1	Temperature expansion vale inlet [°C]

0x2203 'IO\RefCrt.CprFb.Val'	1	4	0050	r	UInt32	0.1	Compressor speed [%]
0x2203 'IO\RefCrt.ExpsFb.Val'	1	4	0051	r	UInt32	0.1	Expansion valve opening [%]
0x2203 'IO\RefCrt.ExpsEcoFb.Val'	1	4	0052	r	UInt32	0.1	Expansion valve liquid injection opening [%]
0x2207 'IO\RefCrt.VlvRvr.Cmd'	1	4	0053	r	UInt32	1	Flow reversal value position [0 – normal | 1 – reverse]]
0x2206 'IO\RefCrt.Fan.Cmd'	1	4	0054	r	UInt32	0.1	Fan speed evaporator [%]
	1	4	0055	r	UInt32	0.1	Mixing value DHW opening position [%]

3.3.2 Vapour Compression Heat Pump Interface Converter

To allow for communication of the OCHSNER heat pump with the AIT lab infrastructure an interface converter (eWON - Flexy 205 from HMS Industrial Networks) converting from ModBus RTU to OPC-UA is used.

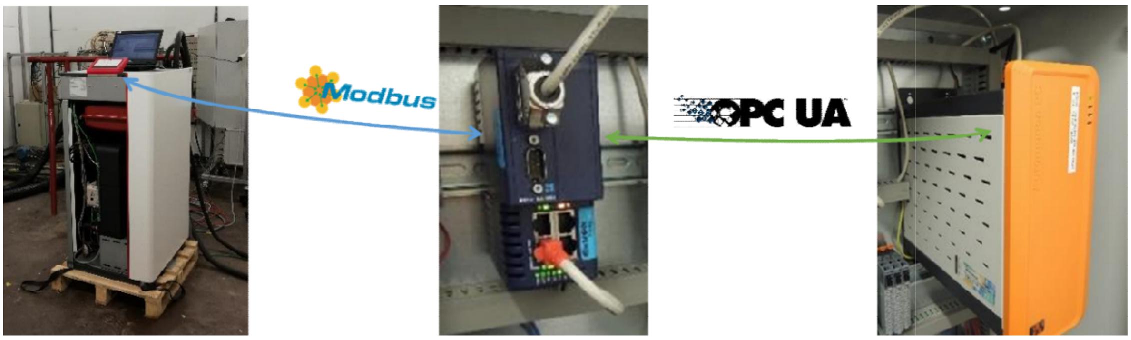


Figure 24: Communication between Ochsner HP controller and Bernecker und Rainer APROL® industrial PC.

The interface configuration is listed below.

Table 13: Modbus RTU configuration of the vapour compression HP for the Continental sub-system.

Item	Value
OPC-UA address	192.168.1.100
Port	4840
Login	Anonym
Security	None

A complete list of all variables accessible on the OPC-UA interface is given in Table 14.

Table 14: OPC-UA data list of the ModBus RTU to OPC-UA converter for the Continental sub-system.

ModBus name	OPC-UA					Unit conversion factor	Description
	Namespace Index	Identifier Type	Identifier	Access Level	Data type		
HP\HPAggr.EmgOff	4	string	HYB_OCH1_w_HS_106	w	UInt32	1	Heat pump emergency off [0 – Auto | 1- Off]
HC1\HC1.OpMMan	4	string	HYB_OCH1_w_HS_110	w	UInt32	1	Heat pump operation mode [0 – auto | 1 – heating | 2 – cooling]
HC1\SpTFl.Sp	4	string	HYB_OCH1_w_TCS_108	w	UInt32	0.1	Set-point feed water temperature [°C]
DHW\DHW.OpMMan	4	string	HYB_OCH1_w_HS_107	w	UInt32	1	Operation mode DHW generation [0 – auto | 1 – off]
DHW\DHW.SpMan	4	string	HYB_OCH1_w_TCS_109	w	UInt32	0.1	Set-point temperature DHW generation [°C]
	4	string	HYB_OCH1_Reset	w	UInt32	1	Reset errors [0 – default | 1 – reset]
HP\HPAggr.OpModMan	4	string	HYB_OCH1_w_HS_111	w	UInt32	1	Manual mode [0 – auto | 1 – heating | 2 – cooling]
HP\HPAggr.SpdManOp	4	string	HYB_OCH1_w_SC_01	w	UInt32	0.1	Set-point compressor-speed [%]
RefCrt\RfCrt.ReqDefrFrcd	4	string	HYB_OCH1_w_KC_105	w	UInt32	1	Start defrosting [0 -default | 1 – start]
IO\HP.Pu.Cmd	4	string	HYB_OCH1_w_SC_19	w	UInt32	0.1	Water pump speed [%]
IO\HP.Pu.Cmd	4	string	HYB_OCH1_SI_19	r	UInt32	0.1	Water pump speed reading [%]
IO\HP.TFl.Val	4	string	HYB_OCH1_TI_23	r	UInt32	0.1	Temperature water condenser out [°C]
IO\HP.TRt.Val	4	string	HYB_OCH1_TI_22	r	UInt32	0.1	Temperature water condenser in (return) [°C]
IO\HP.Fl.Val	4	string	HYB_OCH1_FI_21	r	UInt32	0.01	Water flow rate [m^3/h]
IO\PRt.Val	4	string	HYB_OCH1_PTI_20	r	UInt32	0.1	Pressure water pump discharge [barg]
IO\DHW.TStkTop.Val	4	string	HYB_OCH1_TI_27	r	UInt32	0.1	Temperature water feed [°C]
IO\RefCrt.TSrcIn.Val	4	string	HYB_OCH1_TI_10	r	UInt32	0.1	Temperature evaporator air in [°C]

IO\RefCrt.TSrcOut.Val	4	string	HYB_OCH1_TI_11	r	UInt32	0.1	Temperature evaporator air out [°C]
IO\RefCrt.TSuctEvp.Val	4	string	HYB_OCH1_TI_12	r	UInt32	0.1	Temperature evaporator refrigerant out [°C]
IO\RefCrt.TSuct.Val	4	string	HYB_OCH1_TI_14	r	UInt32	0.1	Temperature compressor suction side [°C]
IO\RefCrt.PAbsEvp.Val	4	string	HYB_OCH1_PT_13	r	UInt32	0.1	Pressure compressor suction side [bar]
IO\RefCrt.TEvp.Val	4	string	HYB_OCH1_TYI_13	r	UInt32	0.1	Evaporation temperature (calculated) [°C]
IO\RefCrt.PAbsCdn.Val	4	string	HYB_OCH1_PT_03	r	UInt32	0.1	Pressure compressor discharge [bar]
IO\RefCrt.TCdn.Val	4	string	HYB_OCH1_TYI_03	r	UInt32	0.1	Condensation temperature (calculated) [°C]
IO\RefCrt.TDcrg.Val	4	string	HYB_OCH1_TI_04	r	UInt32	0.1	Temperature compressor discharge [°C]
	4	string	HYB_OCH1_TI_06	r	UInt32	0.1	Temperature RPW-HEX refrigerant out [°C]
IO\RefCrt.TCndOut.Val	4	string	HYB_OCH1_TI_07	r	UInt32	0.1	Temperature condenser refrigerant out [°C]
IO\RefCrt.TExps.Val	4	string	HYB_OCH1_TI_09	r	UInt32	0.1	Temperature expansion vale inlet [°C]
0x2203 'IO\RefCrt.CprFb.Val'	4	string	HYB_OCH1_r_SI_01	r	UInt32	0.1	Compressor speed [%]
0x2203 'IO\RefCrt.ExpsFb.Val'	4	string	HYB_OCH1_r_GI_101	r	UInt32	0.1	Expansion valve opening [%]
0x2203 'IO\RefCrt.ExpsEcoFb.Val'	4	0052	HYB_OCH1_r_GI_102	r	UInt32	0.1	Expansion valve liquid injection opening [%]
0x2207 'IO\RefCrt.VlvRvr.Cmd'	4	0053	HYB_OCH1_r_GI_103	r	UInt32	1	Flow reversal value position [0 – normal | 1 – reverse]]
0x2206 'IO\RefCrt.Fan.Cmd'	4	0054	HYB_OCH1_r_SI_104	r	UInt32	0.1	Fan speed evaporator [%]
	4	0055		r	UInt32	0.1	Mixing value DHW opening position [%]

3.3.3 DC generator (AIT EES)

For the demo building, the same DC bus and battery storage as for the Mediterranean climate will be implemented for the Continental one (in the final system). In Task 3.2, the DC bus and battery storage modules are tested at CNR-ITAE and CSEM, together with the thermal sub-system for the Mediterranean system. In contrast, the tests of the Continental thermal sub-system at AIT's thermal labs are carried out using a DC generator which powers the compressor of the air source heat pump. This DC generator works as a standalone unit, it is equipped with sensors for recording the electrical power and energy consumption and is operated with individual existing control and data acquisition system. The DC generator is depicted in Figure 19 on the left. Electrical power is supplied by 2 serial Regatron TOP Con: TC.P.16.600.400.S. The data acquisition unit is Nemo D4-Dc with an input divider: AVMFD150, the I/O signals are interfaced with an ICP Con 7520 with Rs232 communication interface, the data is accessed via an interface converter to RS 485. The DC voltage, current, electrical power are recorded every second and saved in a csv file.

3.3.4 Latent storage module (AIT/ AKG/ UDL)

The conditions at the inlet and outlet of the RPW-HEX are measured, on both the water side and the refrigerant side, using existing AIT sensors. The sensors are directly connected to the above-mentioned PCS system from Bernecker und Rainer (B&R, existing automation system of AIT's thermal lab infrastructure) using a B&R X20 based hardware and suitable IO-hardware modules. The sensors are listed below in Table 10.

4 Conclusions

The main objective of WP3 is the development and realization of the hybrid storage sub-systems both for Mediterranean and Continental climates.

It was managed to put in place all necessary technical requirements to establish communication between all relevant hybrid storage sub-system components and modules for the automated conduction and analysis of experiments. Moreover, tools for automation, supervision, control and data acquisition were developed.

This Deliverable D3.2 provides a comprehensive description of the hard- and software communication interfaces between all actors, sensors, build-in controllers of the components and modules of the hybrid thermal and electrical sub-systems, and the existing automation systems used in the thermal control laboratory infrastructure at CNR-ITAE, NTUA, CSEM and AIT. Detailed information on their configuration, developed human machine interfaces and interfaces to software for advanced control and simulation are given.

As follow up, in Task 3.2 the following actions will be taken:

- integration of the hybrid storages at CNR-ITAE’s and AIT’s labs, with particular focus on the hydraulic and electric integration of the main components, and preparation of corresponding D3.3 “Full hybrid storage integrated”;
- conduction of experimental tests on the performance of full-scale hybrid storage modules under realistic operating scenarios;
- generation of data for validation of design decisions (WP2 and Task 3.1), models (WP2 and Task 3.1, 4.1) and basic control schemes (Task 3.2);
- analysis of main experimental outcomes obtained from the testing;
- derivation of design decisions of the hybrid sub-systems for the demo-sites, and preparation of corresponding D3.4 “Report on the experimental tests and the final design of the hybrid sub-systems”.