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RE-SKIN

D6.5 – Technical components for on-field demonstration I

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Authors	M. Kim
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0.1	10/01/2024	First draft, establishing document structure	M. Kim
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0.3	08/04/2024	Quality review	F. Leonforte, C. Del Pero R. Adhikari (POLIMI)
1.0	06/05/2024	Final version addressing all further comments	M. Kim

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Disclaimer

1. Executive summary

This document describes technical components used for the first on-filed demonstration of the project, i.e., used in the first case-study building. Such components are currently ready to be shipped, or in some cases at the end of the manufacturing phase and will be installed in Milan (Italy) according to the timing of the retrofit works, with the aim to ensure a proper logistic management of the building site and an effective coordination of the various working phases. Specifically, the deliverable focuses on the DC heat pump, smart fan-coil, multi-input/multi-output converter (MIMO), EV charger, battery pack, and Smart Control System (SCS).

Through seven comprehensive chapters, each technical component is thoroughly illustrated, detailing its installation within the building and its interconnections with other components. Each section provides a brief overview of the respective component, clearly illustrates its integration into the building's infrastructure, and outlines its interplay with other technical elements. Furthermore, it furnishes insights into user control and manipulation, along with guidelines for maintenance, renovation, and replacement procedures. The last part of each chapter clarifies manufacturing and testing processes, as well as end-of-life treatment considerations, ensuring a holistic understanding of the project's technological framework.

2. DC Heat pump

2.1. Technical system description

This section focuses on the overview of the heat pump system in Milan case study, and detailed explanation of the components consist of the system.

2.1.1. DC heat pump system overview in Milan case study

The heat pump system consists of the main unit, the indoor heat exchanger, and the buffer/DHW tanks. This system can be divided into refrigerant circuit and hydronic circuit (Fig. 1).

Refrigerant flows in a refrigerant circuit between the main unit and indoor heat exchanger, while it delivers heat from air source to water.

In the hydronic circuit, the water heated or cooled by thermal interaction with refrigerant circuit pumps out to the buffer and DHW tanks by pumps placed inside the main unit. The two tanks store thermal energy to supply pre-heated/cooled water to fan-coil units or to supply domestic hot water to the inhabitants.

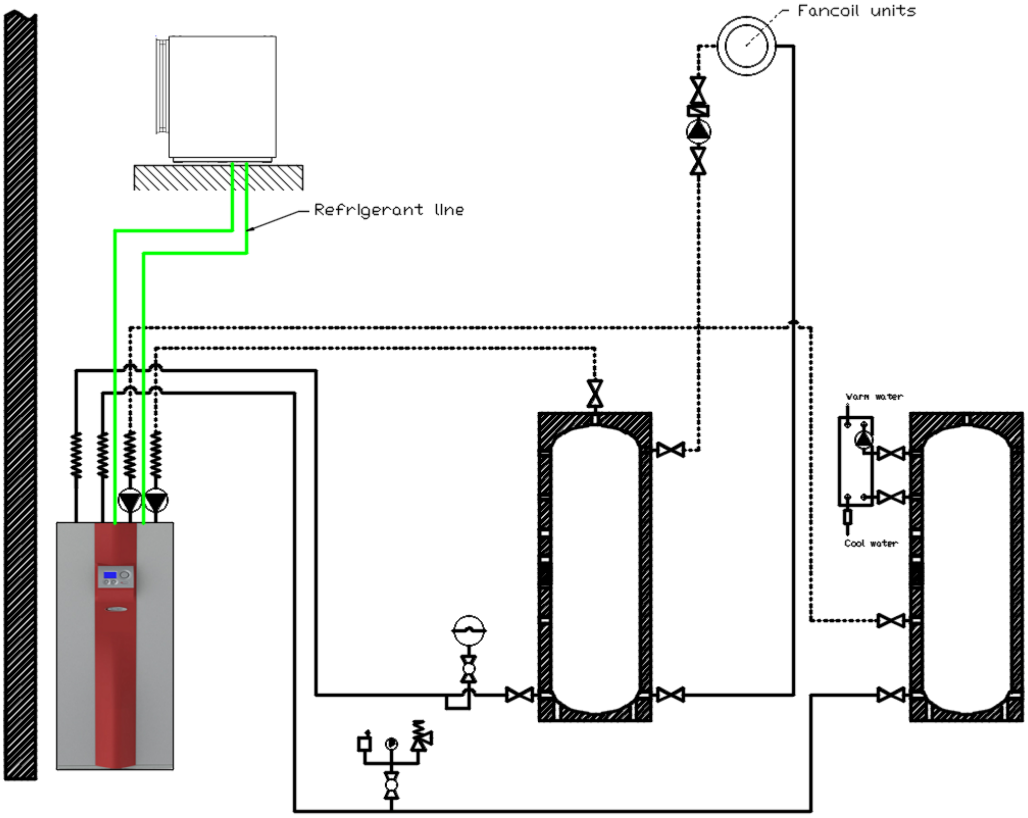

Figure 1. DC Heat pump system main scheme

Besides the mechanical parts, there are electrical interactions between the MIMO converter and the main unit / the indoor heat exchanger unit. Also, the heat pump system is connected to the building management system to share data to manage heating/cooling functions in the building.

2.1.2. Components in DC heat pump system in Milan case study

The first case study is located in Milan, which has a warm climate with outdoor temperatures ranging from -5°C to 15°C in winter and from 30°C to 38°C in summer. Consequently, the target water temperature for the buffer tank is set at 20°C in winter and 25°C in summer. The building requires a buffer tank capable of holding 500 liters of water. For domestic hot water production, an 800-liter water tank is needed with a target supply temperature of 45°C.

Main unit

Considering the operational conditions in Milan, DC heat pump should cover 20 kW of heating and cooling capacity for both space heating/cooling and domestic hot water. Therefore, one unit of 20 kW DC heat pump will be installed in Milan case study. This main unit additionally have 6 kW of electrical heating device for peak season (Fig. 2).

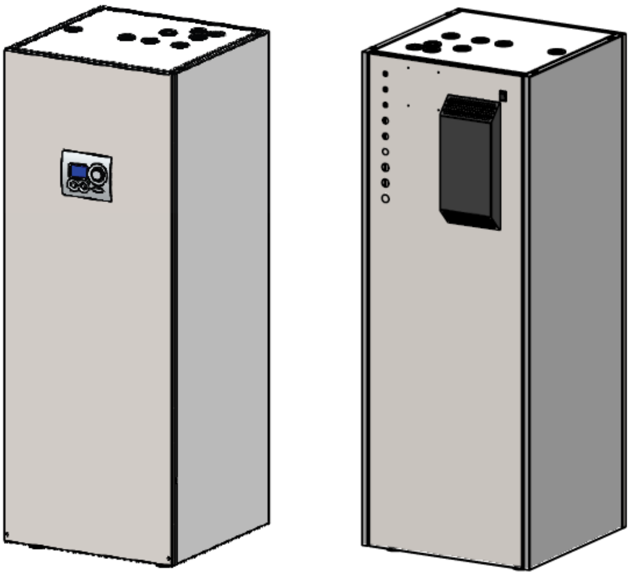

Figure 2. DC heat pump main unit 3D view of front and rear

The dimensional size of the main unit is 674/600/1,600(L/W/H) [mm] and its weight is 185 kg. In the Milan case study, the main unit takes up to 700VDC of electrical input from MIMO device, therefore, a special inverter is added to match the electrical requirement of the compressor, which takes 400VAC as an input. This unit will be located on the ground floor of the building.

Figure 3. Construction progress of the heat pump main unit for Milan case study

All necessary components of the refrigeration circuit are assembled in the heat pump metal frame and refrigerant pipe connections are completed (Fig. 3). The further steps include hydronic pipe connection and electrical components installation. For the moment, one of the electrical components is on the way to be delivered, and once it is arrived, all remaining steps will be carried out.

Indoor heat exchanger

The indoor heat exchanger that will be installed in Milan case study forms 90° of angle between outlet and inlet duct connectors (Fig. 4).

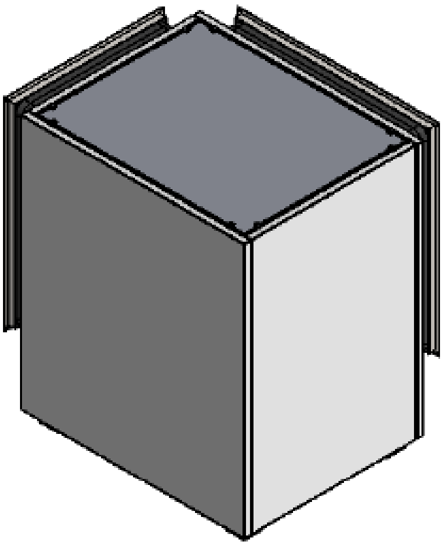

Figure 4. 3D view of Indoor heat exchanger unit

The dimensional size of the indoor heat exchanger is 1145 – 1195/ 940 – 990/ 1240 (L/W/H) [mm]. And the inlet connectors have 900×900 [mm], and the outlet connector have 900×750 [mm], and its weight is about 125 kg. it will be located on the first floor and inside the building.

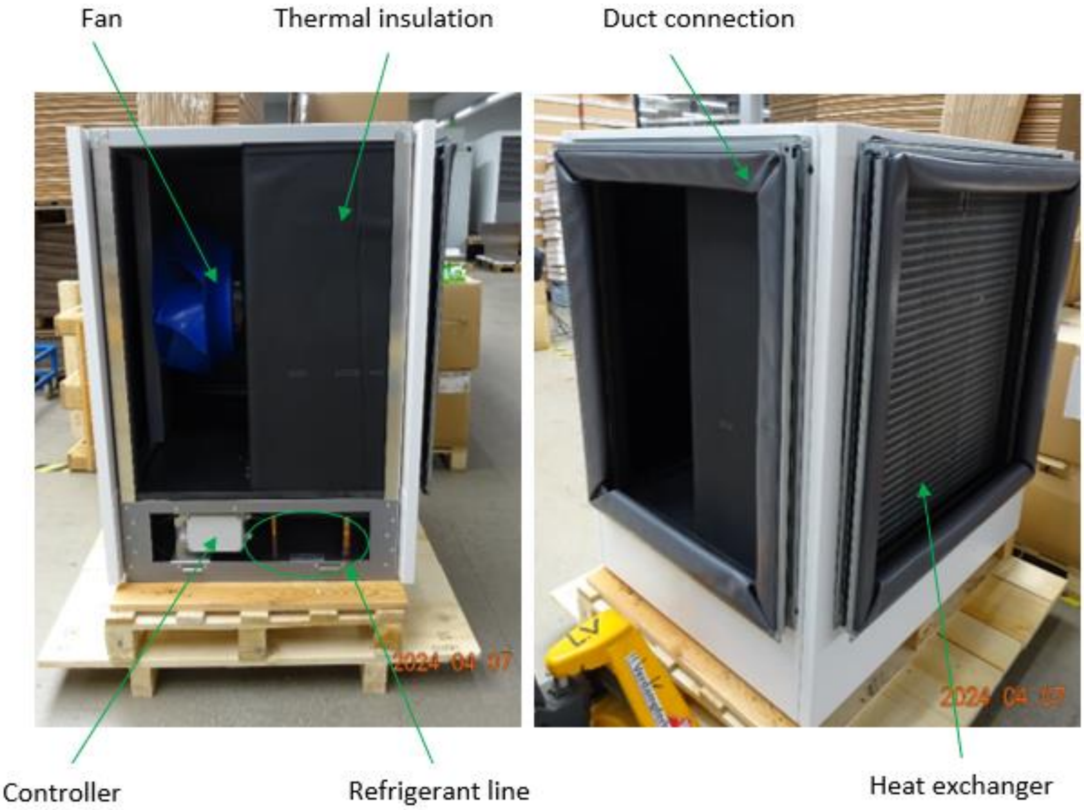

Figure 5. Manufactured indoor heat exchanger for Milan case study

The indoor heat exchanger is already completely built. All components including heat exchanger, fan, control and electrical connections, and duct connectable frame. The frame and the heat exchanger are thermally insulated (Fig. 5).

Buffer and DHW tank

The DHW tank and the buffer tank use same design of water tank, but DHW tank has additional fresh water system that includes plate heat exchanger and pump. This is because the water in the tank is heating water which should not be mixed with fresh water that is supplied directly to the inhabitants (Figs. 6-7).

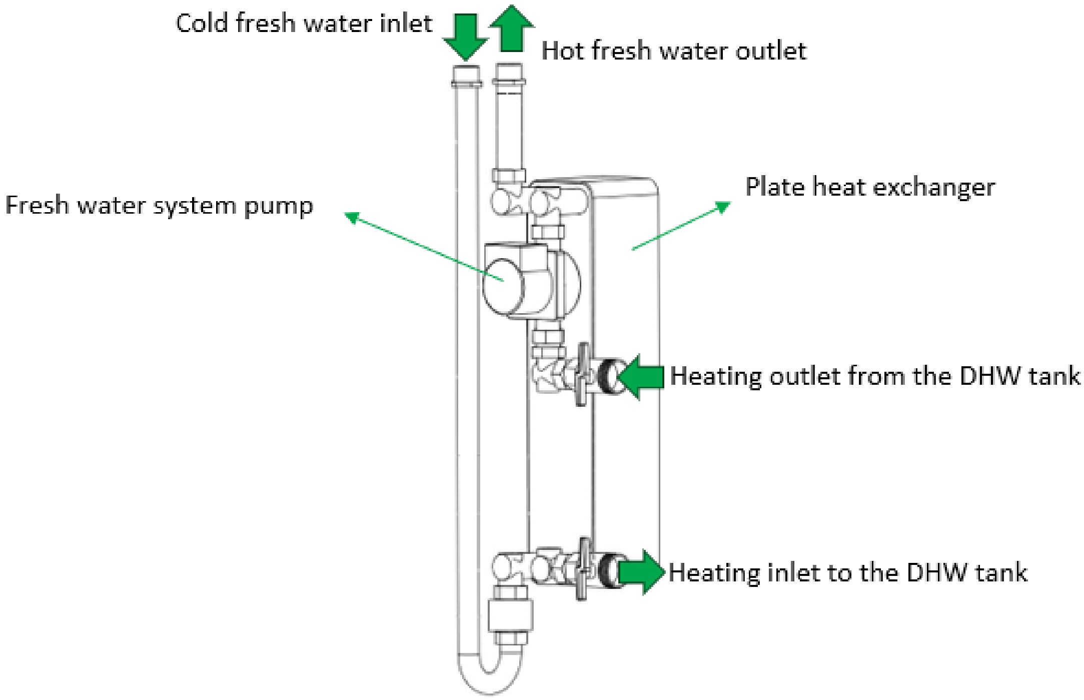

Figure 6. Fresh water system of DHW tank

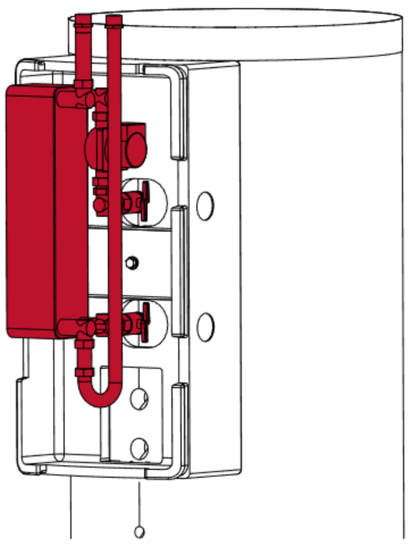

Figure 7. Fresh water system connected to a buffer tank

In the Milan case study, the main unit is connected to an 800-liter DHW tank and a 500-liter buffer tank and supplies heated water to them (Figs. 8-9).

Figure 8. 800-liter DHW tank

Figure 9. 500-liter buffer tank

Both storage tanks are thermally insulated. With insulation included, the buffer tank measures 750 × 1920 mm and weighs 94 kg, while the DHW tank measures 990 × 1990 mm and weighs 165 kg. The DHW tank's fresh water system can deliver hot water at a maximum flow rate of 2400 L/h, which is sufficient given that the building requires 990 L/h.

2.2. On–field system connection

This section provides comprehensive information on the electrical and hydraulic connections between the DC heat pump and other technical components or building elements in Milan case study. Additionally, it explains the data communication protocols between the DC heat pump and the building energy management system.

2.2.1. Electrical connection

In the following scheme (Fig. 10), the different electrical connections of the system are represented.

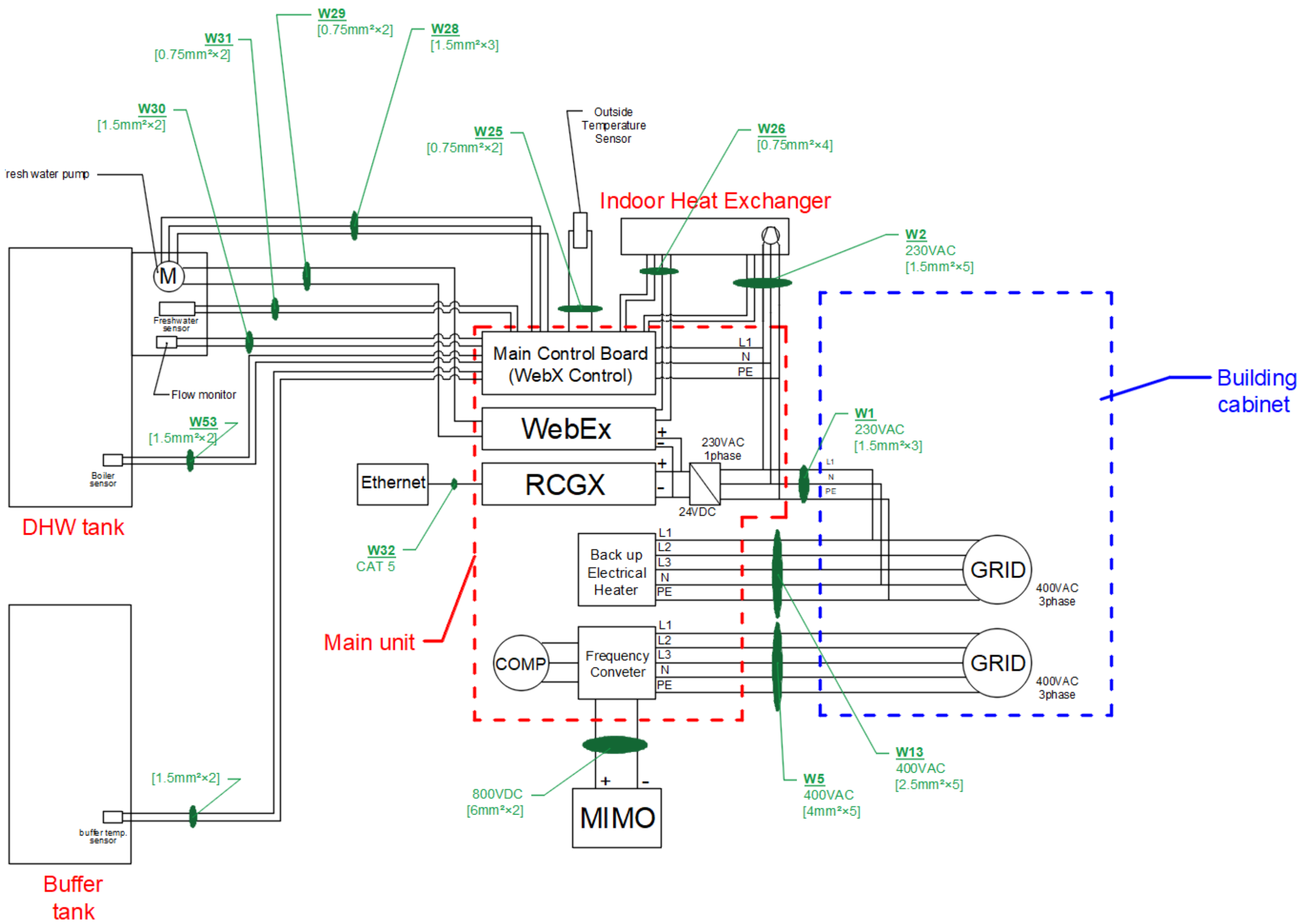

Figure 10. Electrical connection – DC heat pump system

Table 1 provides the information on the electrical connection characteristics of different components.

Table 1. Electrical connection – DC heat pump system

No.	Location	Voltage	Connection
	MIMO – Frequency converter	800VDC	6mm^2 x 2
W5	Grid – Frequency converter	400VAC	4mm^2 x 5
W13	Grid – Electrical heater	400VAC	2.5mm^2 x 5
W1	Grid – AC/DC convert (main unit)	230VAC	1.5mm^2 x 3
W2	Main unit – Indoor heat exchanger	230VAC	1.5mm^2 x 5
W26	(Main control board + WebEx) – Indoor heat exchanger	·	0.75mm^2 x 4
W25	Main control board – outside sensor	·	0.75mm^2 x 2
W28	Main control board – Fresh water pump	·	1.5mm^2 x 3
W29	Main control board – Fresh water pump	·	0.75mm^2 x 2
W31	Main control board – Fresh water sensor	·	0.75mm^2 x 2
W30	Main control board – Flow motor	·	1.5mm^2 x 2
W53	Main control board – Boiler temperature sensor	·	1.5mm^2 x 2
W32	Ethernet	·	CAT 5
	Main control board - Buffer tank sensor	·	1.5mm^2 x 2

2.2.2. Hydraulic connection

The main data related to the hydronic part are reported in Tables 2-3 according to the positioning of inlets and outlets shown in Figs. 11-12.

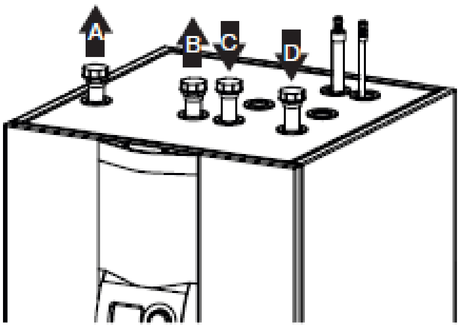

Figure 11. Hydraulic connection to buffer/DHW tanks

Table 2. Hydraulic connection to buffer/DHW tanks

Position (figure 11)	Description	Dimensions
A	Heating outlet	5/4”
B	Domestic hot water outlet	5/4”
C	Domestic hot water inlet	5/4”
D	Heating inlet	5/4”

*All hydraulic connections must be sealed with suitable flat seals.
*Filters must be installed on all hydraulic heating inlet lines.

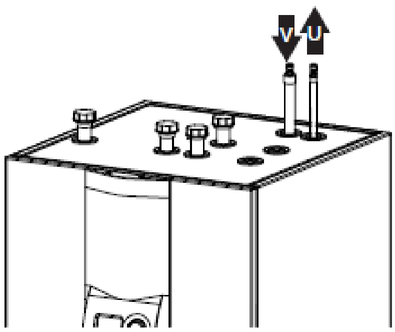

Figure 12. Refrigerant line connection to indoor heat exchanger

Table 3. Refrigerant line connection to Indoor heat exchanger

Position (figure 12)	Description	Dimensions	Length
U	Injection line to indoor heat exchanger	14mm	Up to 25m
V	Suction line from indoor heat exchanger	28mm	Up to 25m

2.2.3. Data communication

Hereafter, necessary data communication between the building energy management system and the DC heat pump are described. The data communication includes read access and write access. Read access is the data that building energy management system can read from the heat pump, while by controlling the data listed in the write access, the building energy management system can command the heat pump. Detailed data points are listed in the following tables.

Read access

The read access data (Table 4) can be read with the function Code 04 for Read Input Registers or function Code 03 for Read Holding Registers.
In case of connection problems with the Modbus RTU, it is to be ensured that the polling interval per register/value is increased e.g., to 500ms per register/value.
If a connection is lost, the Modbus server/master must reconnect to the RCGx (Remote control gateway: module attached on the heat pump main unit and to be connected with MIMO)

Table 4. list of heat pump data points (read access)

Name	Unit	Format	Length (bytes)	Modbus register	Function Code
Outdoor temperature	0.1°C[1]	INT16	2	10	04
DHW temperature	0.1°C	INT16	2	11	04
Heat. outlet temp.	0.1°C	INT16	2	12	04
Heat. Inlet temp.	0.1°C	INT16	2	13	04
Buffer storage temp.	0.1°C	INT16	2	14	04
ES_inlet temp.[2]	0.1°C	INT16	2	15	04
ES_outlet temp.	0.1°C	INT16	2	16	04
Heating circuit pump	ON when <> 0	INT16	2	23	04
Buffer storage pump	ON when <> 0	INT16	2	24	04
compressor	ON when <> 0	INT16	2	25	04
Error	when <> 0	INT16	2	26	04
4 way valve-Air	Defrost mode, when <> 0	INT16	2	27	04
COP	Factor in 0.1	INT16	2	30	04

[1] ex) 280 = 28.0°C
[2] ES = Energy source (air)

Operating hours in DHW mode	h	UNIT32	4	42-43	04
Operating hours in Heat. mode	h	UNIT32	4	44-45	04
Calorimeter_Heating	kW/h	UNIT32	4	60-61	04
Electric meter_Heating	kW/h	UNIT32	4	62-63	04
Calorimeter_DHW	kW/h	UNIT32	4	64-65	04
Electric meter_DHW	kW/h	UNIT32	4	66-67	04
Electric meter_total	kW/h	UNIT32	4	68-69	04
Electric meter_capacity	W	UNIT32	4	70-71	04
Calorimeter_total	kW/h	UNIT32	4	72-73	04
Calorimeter_capacity	kW	UNIT32	4	74-75	04

Write access

The write access (Table 5) data can be described with the function code 06 (Write Single Register) or read with the function code 03 (Read Holding Registers). In general, the registers should be cyclical but not described faster than in a 5 second interval.
If a connection is lost, the Modbus server/master must reconnect to the RCGx.

Table 5. List of heat pump data points (write access)

Name	Unit	Format	Length (bytes)	Modbus register	Function Code
Operating mode	0 = off 1 = Auto 2 = Cool 3 = Summer 4 = Continuous 5 = Decrease 6 = Holiday 7 = Party 8 = Screed dry out 9 = Uco. block 10 = Main switch OFF	UNIT16	2	100	03, 06, 16
HC setpoint (room setpoint temp)[3]	0.1°C	INT16	2	102	03, 06, 16
HC setpoint (Heat.inlet Setpoint temp) – Active	0 or 1[4]	UNIT16	2	103	03, 06, 16
HI.T min Cool[5]	0.1°C	INT16	2	104	03, 06, 16

[3] HC = Heating Circuit
[4] If 1, modbus resister for HC setpoint (102) activates
[5] HI.T = Heating Inlet Temperature

DHW Normal temp.	0.1°C	INT16	2	105	03, 06, 16
DHW Minimum temp.	0.1°C	INT16	2	106	03, 06, 16
PV request	0 or 1	UNIT16	2	117	03, 06, 16
Power input specification	W	UNIT16	2	125	03, 06, 16
Clear (error, reset)	0 or 1	UNIT16	2	128	03, 06, 16
Outdoor temperature value	0.1°C	INT16	2	129	03, 06, 16
Outdoor temperature - Active	0 or 1[6]	UNIT16	2	130	03, 06, 16
Buffer temperature value	0.1°C	INT16	2	131	03, 06, 16
Buffer temperature - Active	0 or 1	UNIT16	2	132	03, 06, 16
DHW temp. value	0.1°C	INT16	2	133	03, 06, 16
DHW temp. - Active	0 or 1	UNIT16	2	134	03, 06, 16

2.3. Use

Building energy manager who is allowed to control the heat pump can easily control the heat pump by control element (Fig. 13) in the heat pump.

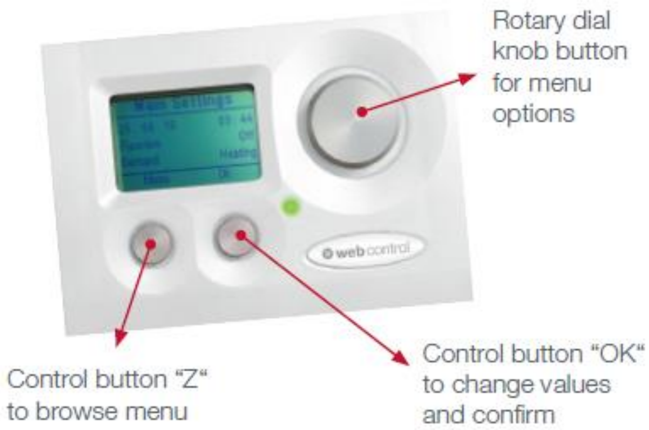

Figure 13. Heat pump control device

All required functions to control the heat pump are described in detail in instruction manual distributed to the building energy manager. More in detail, the manager can change operating mode, adjust desiring buffer and DHW temperature, and set time program to find suitable operating conditions that they desire.

[6] If 1, modbus resister for outdoor temperature value (129) activates

2.4. Maintenance, renovation and replacement

Annual inspection of the individual system components must be carried out as described in Table 6 in order to ensure the safe operation. The inspection must be carried out by an authorized and trained specialist and keep records at all times.

Table 6. Maintenance intervals

Maintenance work	Interval	Component/ System
Care	Annual	Heat pump
Refrigeration Circuit Inspection	Annual	Refrigeration circuit with split lines
Hydraulics Inspection	Annual	Hydraulic block and heating system
Control and electric Inspection	Annual	Control and electrical
Energy source Inspection	Annual	Energy source/ outdoor evaporator

Refrigerant circuit inspection

- Leaks and damage inspection on the refrigerant circuit inside the main unit/ indoor heat exchanger and refrigerant line between the main unit and the indoor heat exchanger.
- Checking for unusual noise from the compressor after restarting the heat pump.

Hydraulics inspection

- Water Leaks and damage inspection on hydraulic circuits between the main unit and buffer/ DHW tanks. Specifically, the heating circuit pump and the switch valve must be inspected.
- The remaining maintenance must be carried out for the safety equipment and fittings. They include membrane expansion tank, safety valve, and other facilities that are required by the situation.

Control and electric inspection

Inspection for burned or damaged electrical connection.

Energy source inspection

Inspection of the power source is described in the installation manual of the indoor heat exchanger.

2.5. End of life treatment

Preparation

Upon decommissioning the heat pump unit, first ensure that the heat pump is disabled. Next, the heat pump system must be disconnected from the main power supply.

Disconnect from the heating system

The heating system must be disconnected from the heat pump by means of shut-off valves to prevent leakage. Only then can the heat pump work can be completed in the heating system.

Vacuum refrigerant

All works on the refrigeration circuit may only by performed by a certified refrigeration technician, so that refrigerant cannot be released into the atmosphere. The technicians must wear personal protective gears.

In order to separate the refrigerant lines from the indoor heat exchanger, the refrigerant must be pumped from the entire refrigerant circuit into a designated refrigerant bottle, according to guidelines. The refrigerant line caps are to be cut with pipe cutters.

2.6. Manufacturing and testing process

Components assembly

Various components that are relatively heavy are assembled to form the core structure of the heat pump. This includes the compressor, heat exchangers, liquid separator and collector.

Copper tubes are connected to all mechanical components on the refrigerant circuit. Copper tubes are cut into specific lengths and bended by bending machines to meet the design requirements. The components that have relatively light weight are assembled in this stage. This stage includes brazing to join the various components securely so that it creates strong and leak-tight joints.

Electrical Wiring and Control System Installation

The electrical components and control systems are installed, connecting sensors, controllers and other electronic parts.

Insulation and Encapsulation

Insulation is added to critical components to prevent heat loss and maintain efficiency. The entire assembly may also be encapsulated to protect it from external elements.

Quality control and testing

The heat pump undergoes rigorous testing to ensure it meets quality standards. It includes leak testing where it fills up the refrigerant cycle with nitrogen and check if the pressure in the cycle changes after a while. After leak testing, it goes through testing run to check high pressure and low pressure, and if control system is functional.

3. Smart fan-coil

3.1. Technical system description

The smart fan-coils are conceived to substitute radiators, using the existing hydronic pipes when they are in good maintenance state, or new pipes added within the RE-SKIN facade if existing pipes are compromised. The units operate as small water-to-air heat pumps, by extracting or releasing heat to the hydronic network and thus providing heating/cooling/dehumidification in every room. More in details, the smart fan-coils will use a DC compressor to increase/decrease the temperature of the water coming from the centralized DC heat pump, according to the energy demand of each room. This allows to minimize heat losses on the existing distributions pipes and to avoid condensation in not insulated piping (due to low temperature water, as in standard fan coils) in cooling mode.

These devices will also integrate several sensors to allow the precise control of room temperature and the monitoring of detailed energy consumption.

In order to reduce the embodied energy, the enclosures of the fan-coils will be made of sustainable steel sheets.

The units that make up the smart fan-coil are following main components (Fig. 14):

- Air outlet grille
- Front or lateral intake grille
- Air filters
- Adjustable anti-vibration feet
- Water connections
- Power cable

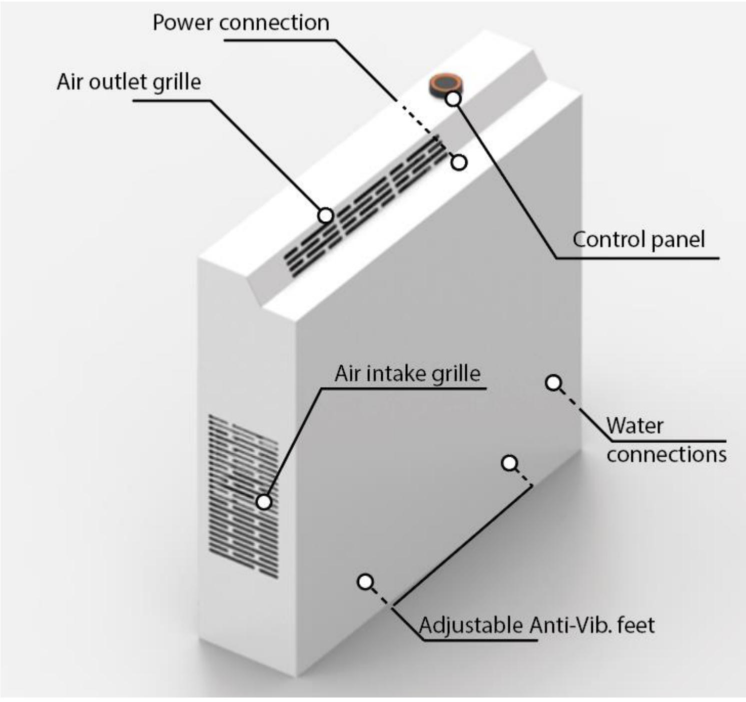

Figure 14. Smart fan-coil main components

3.2. On–field system connection

The fan-coil unit will be installed on a wall where old radiator was positioned. It will be fixed in the position with using two brackets (Fig. 15). Two 8mm of anchorage holes should be drilled on the wall to install the brackets. Once the unit is completely fixed onto the wall and air filter box is installed in the unit, the fan-coil unit casing will cover the body (Fig. 16).

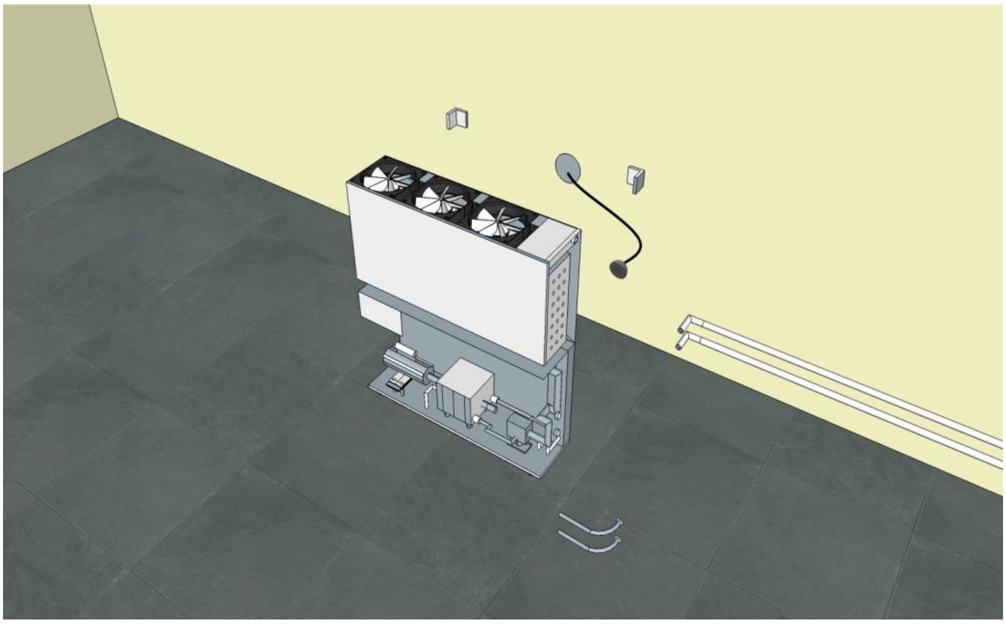

Figure 15. Bracket installation and mounting the fan-coil unit on the brackets

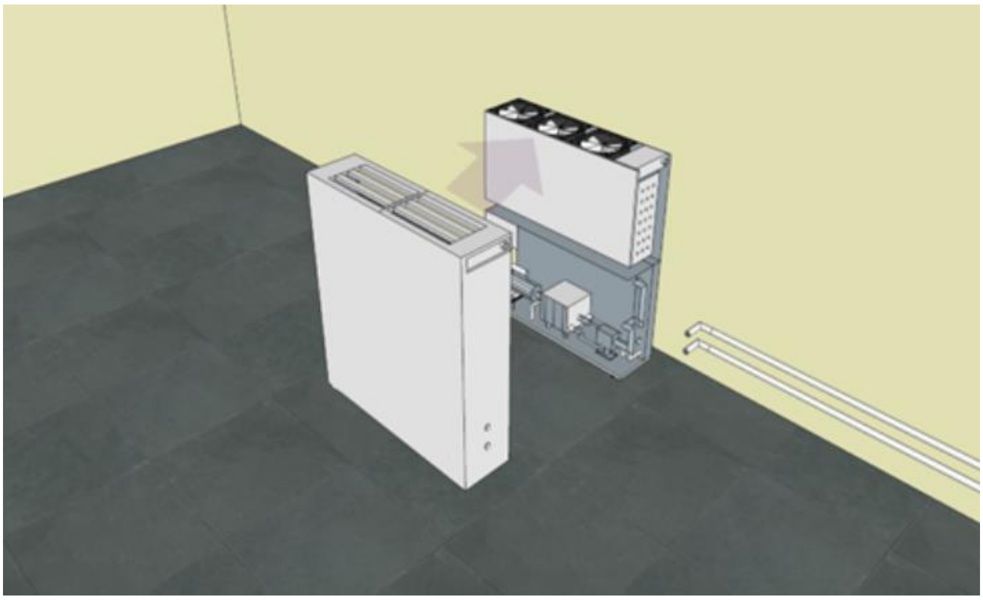

Figure 16. Mounting the fan-coil unit cover

The fan-coil unit is equipped with two 1/2" female hooks on the right side, at a height of about 14cm. To connect the fan-coil unit to the building water supply hoses, the end of the hoses needs to have male connector. Therefore, it may be necessary to provide adapters to ensure correct connections (Fig. 17).

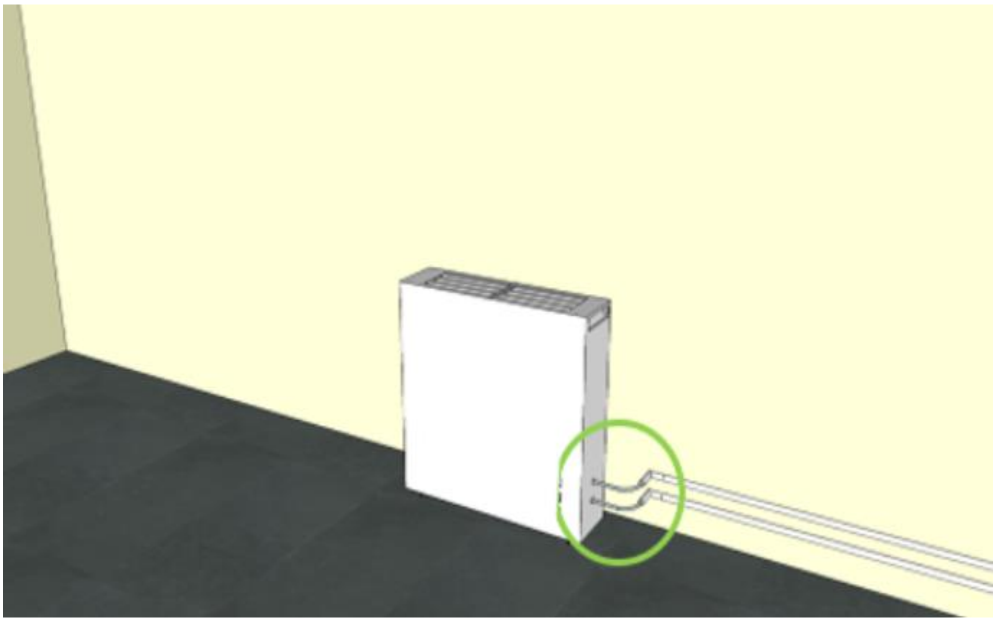

Figure 17. Fan-coil unit water line connection

The appliance requires electrical power supply voltage of 48VDC and current of 3-12A. This electrical power is supplied through the MIMO (Multi-input and multi-output) converter. And it requires a female power connection cord of type IEC C5 (Fig. 18).

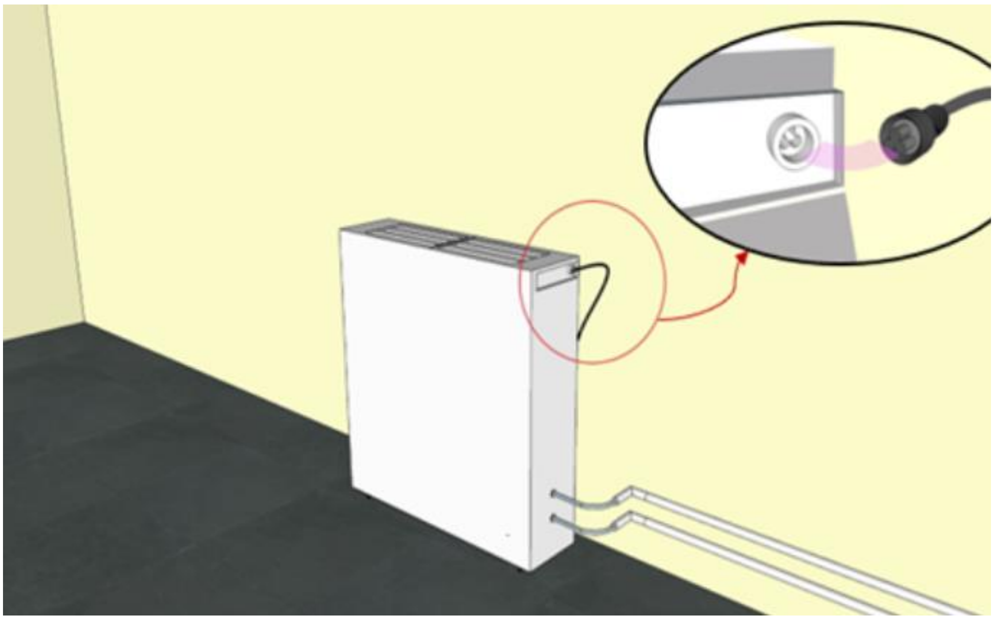

Figure 18. Fan-coil unit electrical connection

The smart fan-coil unit has a control logic to operate the system in an efficient way. The master represents the control unit that coordinates the operation of all the terminals. It consists of a protective casing inside which there are electronic components. Communications between the terminals and the building control system are made via MODBUS TCP (WiFi or ethernet cable).

3.3. Use

The unit is controlled by central commands (M5stack dual unit) that will allow user interface and WiFi connection (Fig. 19). The users can set the following parameters by the control display unit:

- Unit operation on/off
- Max fan speed
- Season (winter/summer)
- Desired room temperature

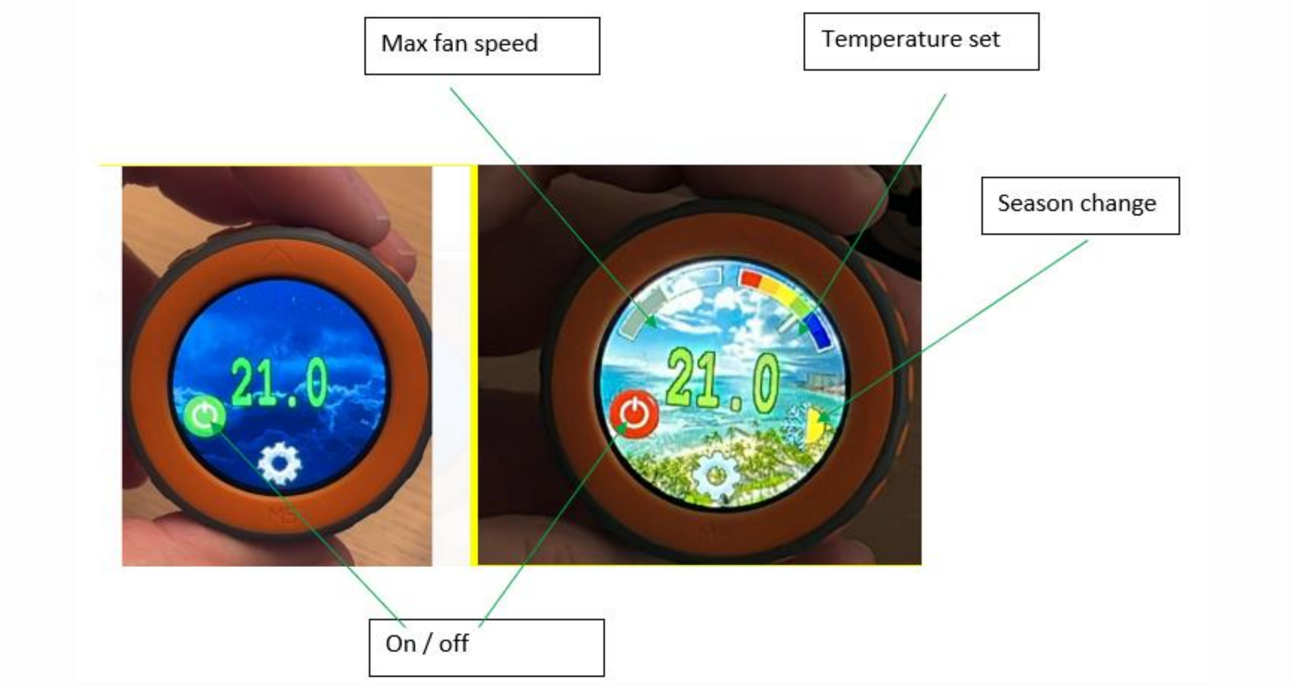

Figure 19. Fan-coil unit controller display

Users can select between winter and summer modes. In the winter mode, the unit operates in active mode when the feeding water temperature is between 8°C and 30°C, and when the feeding water temperature is between 35° and 70°C, it operates in passive mode. In passive mode, the compressor doesn't involve in the operation, therefore, this mode brings huge benefit in terms of electricity saving.
Likewise, during the summer, the compressor runs for the operation (active mode) when the feeding water temperature is higher than 18°C, but when the water temperature is below 16°C, the compressor is switched off and the unit is operated in passive mode.

3.4. Maintenance, renovation and replacement

The Smart fan-coil is the only RE-SKIN subcomponent that is installed inside each dwelling, so the user could slightly interact with it. More in detail, a periodic maintenance is suggested at a frequency that depends on the place of installation and intensity of use. The main required operations for maintenance are listed below:

- Cleaning or washing the room air filter
- Condenser coil cleaning (at each change of season)
- Cleaning of the condensate collection surface and filter
- Cleaning the humidification circuit

To guarantee effective air filtration and good operation of the fan-coil unit, it is essential to clean the air filter, condensate tank filter, and condensate collection tank periodically. The period of the cleaning can be varied according to the environment in which the terminal is working and the intensity of use.
The recommended maximum air filter cleaning interval is up to 30 days, and condensation collection tank and filter need to be cleaned maximum every 90 days. But if those areas are particularly dirty, the cleaning interval should be reduced. Air filter is the only component in the unit that requires periodic replacement, generally every year.
The two air filters are located on the sides of the unit at the two side air intakes, and the condensation filter is located inside the condensate collection tray at the ejection hole.

3.5. End of life treatment

The steps to carry out the disassembly are listed below:

1. Drain all water from the system
2. Empty the refrigeration circuit recuperating the refrigeration gas in accordance with local National and local regulations
3. Disassemble unit
4. Disassemble Electronic components
5. Disassemble Coil (aluminum and copper)
6. Disassemble Valve (brass)
7. Disassemble Compressor (Copper and steel)
8. Disassemble Stainless steel (water tray and gas water heat exchanger)

It should be noted that all the above-mentioned components should be recycled.

3.6. Manufacturing and testing process

The units will be assembled in a factory certified ISO 9001:2015.
All units will be tested "in line" just after production to check if all required specifications are fulfilled. In particular the following test will be accomplished:

- Leakage test
- Compressor test (inverter and rotating parts)
- Fan test
- Electronic components test (sensors and actuators)

3.7. Supporting documents/ certifications

The unit complies with European directives 2006/95/EC, 2004/108/EC, 2002/95/EC, 2002/96/EC.

4. Multi-input/multi-output converter (MIMO)

4.1. Technical system description

The MIMO system is composed of several power converters that enable it to manage the electrical power flow between the roof PV panels, battery packs, heat pump system, fan coils, and the EV charging port. Additionally, it is required to communicate with the Smart Control System, where it takes power flow data from MIMO system, and then commend high-level working orders to MIMO system based on analysis of the data. Furthermore, there is a serial communication with the battery BMS to ensure proper care of the battery packs.

Figure 20 shows the block diagram of the MIMO system for the Milan case study where the voltages have been updated according to the requirements of all connected systems, and the PV optimizers have been substituted by an extra DC-DC converter. This new converter, designated as "converter #4", will perform MPPT by measuring the PV panels string current and modifying the panel DC bus voltage. This will provide enough DC range to make a number of PV panel configurations feasible.

"Converter #1" is a 3-phase boost PFC comprising 4 SiC Cascode legs and "converter #2" and "converter #4" are DAB composed of 2 full bridges SiC Cascode (with 2 legs each). Those converters (DAB and PFC) will share the leg-structure-based design.

In order to modulate, sense, communicate and control all the elements influenced by MIMO, the system includes a control platform. This platform will be in charge of the following tasks:

- Measuring all relevant voltages, currents, temperatures, etc.
- Communicating with battery BMS (CANbus with DB9) and with supervisor system (TCP with Ethernet cable)
- Generating all gating signals of converters #1, #2, and #4
- Being able to handle digital inputs/outputs for contactors, security protections, etc.

This board includes a SOC (FPGA + micro-controllers), which contains one of the latest devices in the market. This board has almost unlimited power and is quite suitable for embedded controlling.

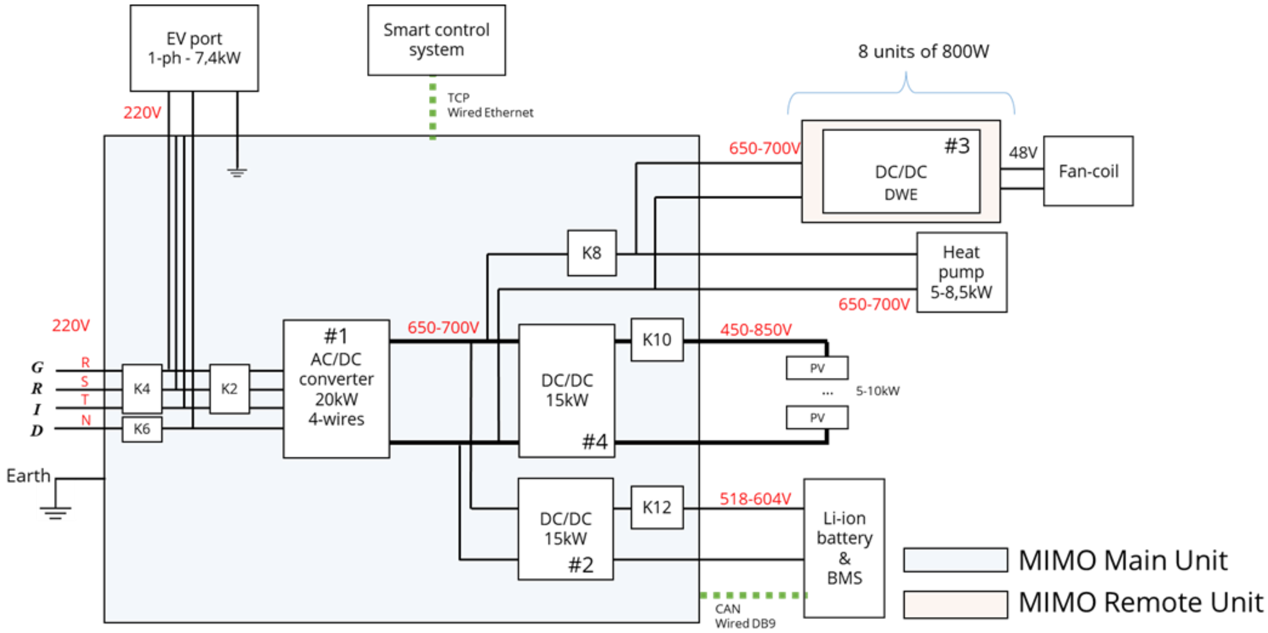

Figure 20. MIMO main block diagram in the Milan case study

MIMO system comprises 2 different units: a main unit and several remote units (Fig. 20):

- Main unit is intended to be placed in a service room located inside the building such as a cellar, a place under roof, etc. This unit contains all the intelligence of the system, main capabilities, and most of the wirings.
- Remote units supply power to fan coils and can be connected to multiple fan coils as long as the power doesn't exceed the maximum power level available for MIMO main unit. This units can be placed remotely from the main units, for example, in different floors.
- MIMO provides a 1-phase connection for EV charger with a power of 7.4 kW in Milan case study

4.1.1. MIMO main unit in the Milan case study

The envelope of the MIMO main unit is shaped as a standard 19-inch rack of around 210 kg and 1.5 m of height. The system contains the following features:

- Horizontal lateral forced air flow
- Connections centralised in right lateral and are protected by covers
- Front panel contains all serial communications and some status LEDs
- Front panel contains selector switches and emergency contact

Internally, the envelope is organised into four sections and each section is located in a different sub-rack assembly. Each section holds the following components:

- Inverter
- PV DAB converter
- Battery DAB converter
- Controller and communication with BMS

All panels from the rack can be removed by the use of standard tools in order to facilitate the installer and maintaining company its access. Figures 21-23 provide the overview of the envelope design.

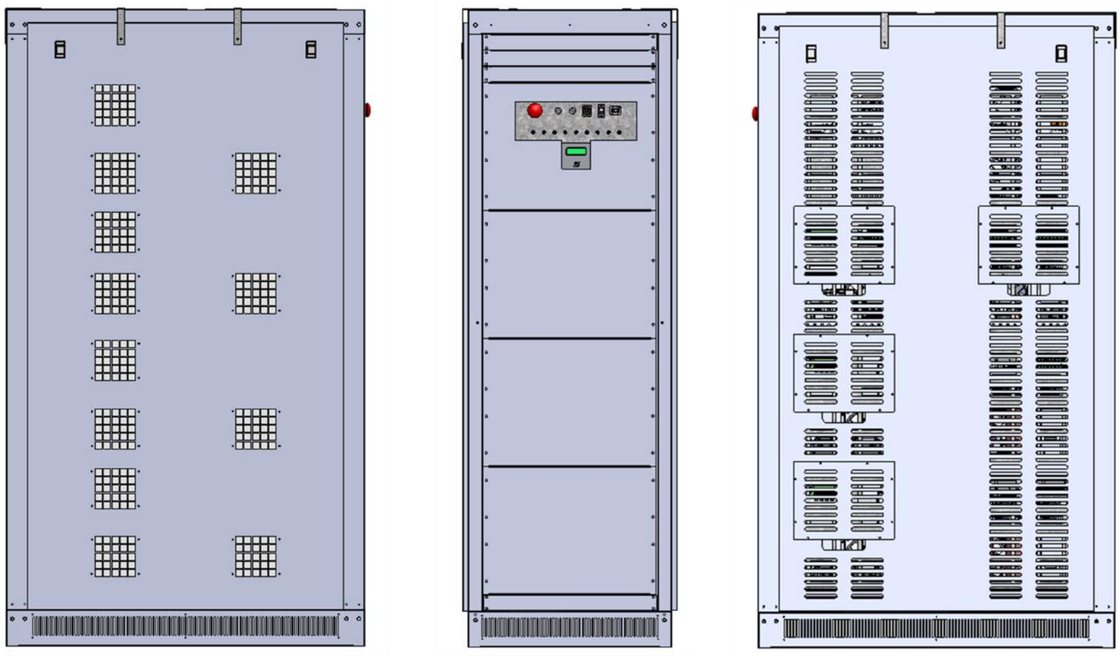

Figure 21. General views of MIMO main unit

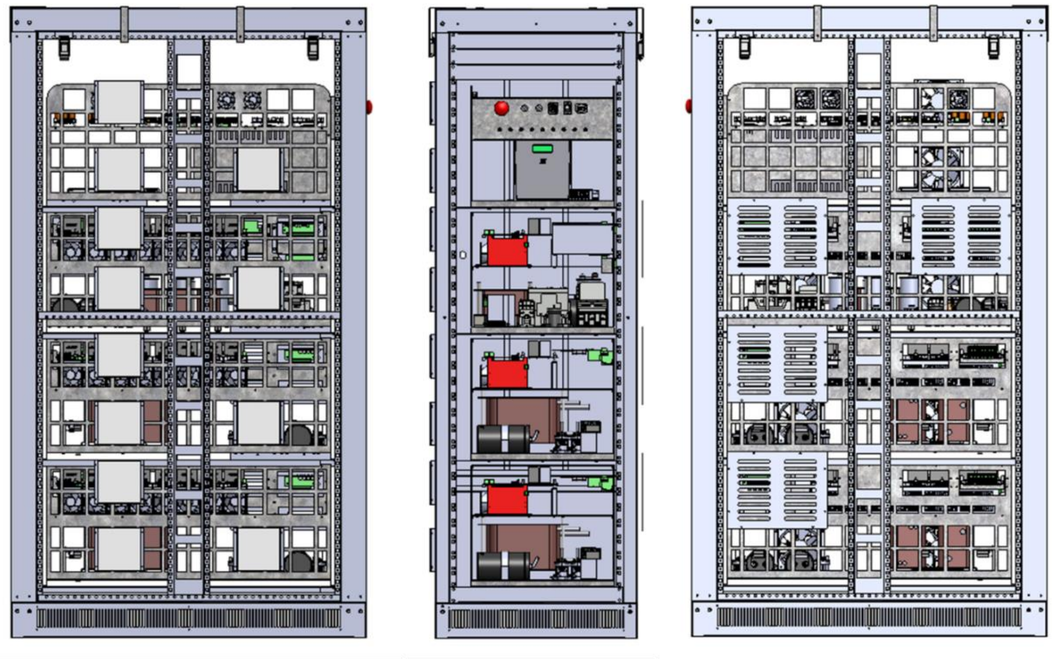

Figure 22. Internal view of MIMO main unit

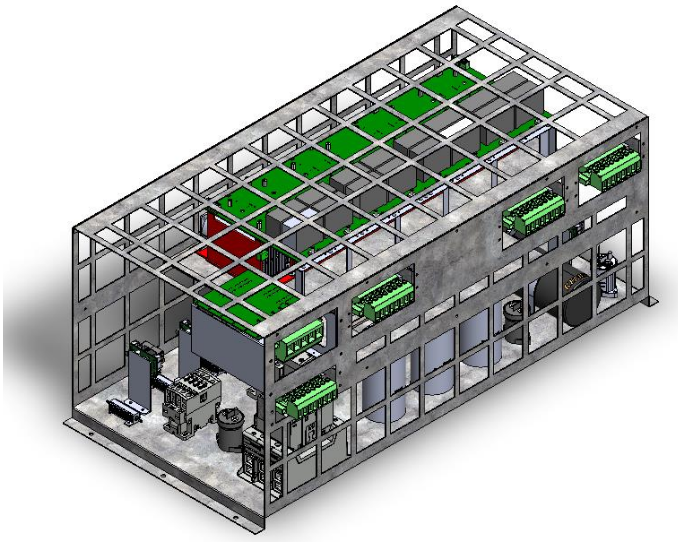

Figure 23. 3D view of the inverter in a sub-rack section in the MIMO main unit

The main unit is being manufactured and it is planned to be finished and tested by end of May 2024. The unit should be installed in an indoor ventilated place where no condensation occurs and with a temperature below 45°C. A 30 cm of clearance must be given in all lateral sides to ease air flow.

4.1.2. MIMO remote unit

The remote units (Fig. 24) will be placed under the roof of the building. Each remote unit converts 700VDC to 48VDC. In Milan case study, 8 remote units will be installed under the roof of the building.

Figure 24. MIMO remote converter unit

Two MIMO remote units are working in parallel and feed three fan-coil units. The electrical connection will be done as shown in Fig. 25.

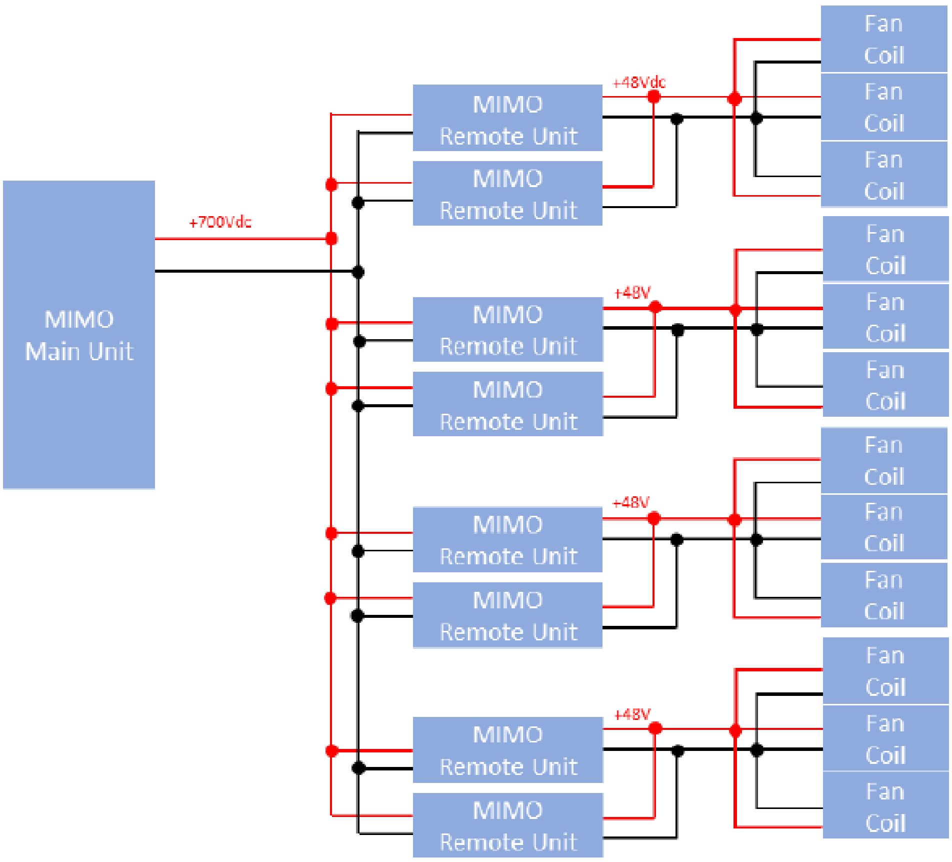

Figure 25. Connection scheme between MIMO main unit, MIMO remote units, and fan-coil units

4.2. On–field system connection

All connection wires should be installed in places that enable MIMO main and remote units to function properly. MIMO systems will be supplied by PSC to the installer who installs and connects MIMO main and remote units to the building wires and the other sub-systems. Installer should note that the MIMO switch will be activated only by PSC team when installation has been completed.

4.2.1. Electrical connection

MIMO interact with the following systems: grid, EV charger, MIMO remote units for fan coil, heat pump, PV panels and Battery pack. Connections with Battery BMS and Smart controller system are covered in section 4.2.2. Data communication.
Below describes characteristics of each connection:

Grid

- All details are referred to nominal conditions
- Voltage: 3-phase 220Vac – 50Hz
- Power: 30 kW
- Number of wires: 5 (phase A, phase B, Phase C, Neutral and Electrical Protection)
- MIMO requires to have an external Residual-Current-Circuit-Breaker and a Current-Limiting-Breaker of suitable power connected between MIMO and the general grid of the building.

EV charger

- All details are referred to nominal conditions
- Voltage: 220Vac – 50Hz, 1 phase or 3-phase
- Power: 7.4 kW (1-phase) or 30 kW (3-phase)
- Number of wires: 5 (Phase A, Phase B, Phase C, Neutral, and Electrical Protection)
- MIMO requires to have an external Residual-Current-Circuit-Breaker and a Current-Limiting-Breaker of suitable power connected between MIMO and the EV chargers.

MIMO remote units

- All details are referred to nominal conditions
- Voltage: 700Vdc
- Max current: 1.2A
- Nominal power: 800 W
- Number of wires: 3 (DC+, DC- and Electrical Protection)
- In case several MIMO remote units are placed, the (parallel) connection of all unit to the main cable will be made out of MIMO Main Unit. MIMO provides a single connector for this output.

Heat pump

- All details are referred to nominal conditions
- Voltage: 700Vdc
- Max current: 20A
- Nominal power: 8.5 kW
- Number of wires: 3 (DC+, DC- and Electrical Protection)
- MIMO requires heat pump system to be input protected for internal short-circuit issues and for input voltage.

PV string

- All details are referred to nominal conditions
- Voltage: 850Vdc
- Max current: 45A
- Nominal power: 15 kW (maximum 20 kW)
- Number of wires: 3 (DC+, DC- and Electrical Protection)
- In case several PV strings are placed, the (parallel) connection of all unit to the main cable will be made by the electrical installer. MIMO provides a single connector for this output.

Battery

- All details are referred to nominal conditions
- Voltage: 620Vdc
- Max current: 32A
- Nominal power: 15 kW
- Number of wires: 3 (DC+, DC- and Electrical Protection)
- MIMO requires battery system to be input protected for internal short-circuit issues and for input voltage.

4.2.2. Data communication

MIMO communicates with battery BMS and Smart control system.

Battery BMS communication

This communication is between control board in MIMO system and master control slab in the battery system.
This requires a cable with one AWG 26 copper twisted pair of wires covered with the shield as shown in Fig. 26.

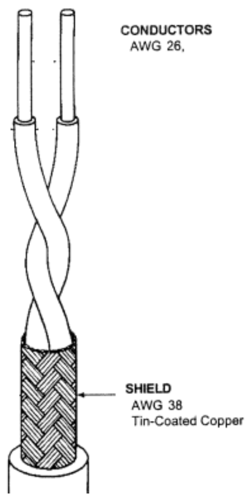

Figure 26. Description of MIMO-Battery communication wire

This wire should be directly conducted and with no interruption or cut from Battery side to MIMO place. The wire should be terminated in each side with a DB9 male connector (Fig. 27) where GND corresponds to the metallic shield of the wire and the 2 twisted wires corresponds to CANL and CANH descriptors (Table 7).

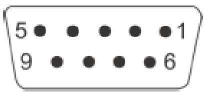

Figure 27. CAN Female DB9 connector front view

Table 7. CAN D89 connector pin designator

PIN	Designator
1	-
2	CANL + TERMINATIION
3	GND
4	-
5	-
6	-
7	CANH + TERMINATION
8	-
9	-

Both DB9 connectors should be connected in a same way to the cable to ensure CANL and CANH lines are not crossed in connection.

Smart control system communication

This communication will be between control board in MIMO system and smart control system. This requires an ethernet shielded CAT6 or higher cable with a metallic male RJ45 connector in each side.

Table 8 shows the data variables to be sent to smart control system.

Table 8. Data communication between MIMO and smart control system

Data point	Data name
Grid Voltage	V_Grid (V, RMS)
Inverter Voltage	V_Inv (V, RMS)
Inverter current	I_ Inv (A, RMS)
Inverter active power	P_ Inv (W)
Inverter reactive power	Q_ Inv (W)
PV voltage	V_PV (V)
PV current	I_PV (A)
Bat voltage	V_Bat (V)
Bat current	I_Bat (A)
Bat SOC	SOC_Bat (%)
Heat-Pump + fan-coil current	I_HPump-FCoil (A)
DC bus voltage	V_DCbus (V)
MIMO mode	Working (“grid-feeding” or “grid-forming”)
Status	Status (“Inv_ON DABpv_OFF DABbat_ON”)
Alarm	Alarm text_with_alarm_info (separated by ‘ ‘)
Error	Error text_with_error_info (separated by ‘ ‘)

4.3. Use

MIMO is designed to be a transparent equipment to the user, MIMO will report all its subsystem status to smart control system and it will provide MIMO the required power flow. MIMO, in case of loss of communication with smart control system, will continue to work in an autonomous way. Status of MIMO can be known by checking all MIMO status LEDs. MIMO will also incorporate a connection port to check its internal status. This connection can only be done by authorised personnel.

4.4. Maintenance, renovation and replacement

Annual inspection of the individual system components must be carried out in order to ensure the safe operation. The inspection must be carried out by an authorized and trained specialist and keeping records at all times. Following maintenance will be carried out annually.

General appearance

- Check the ambient conditions (humidity, separation to ensure air flow, wiring status, etc.)
- Check MIMO status LEDs
- General visual inspection of the components

Maintenance

- Change air filters
- Review error report from MIMO control unit

4.5. End of life treatment

First of all, MIMO units should be electrically disconnected and its anchor to walls or floors removed. Afterward its recycling process can be started with an accredited company. Electronic devices are not easy to recycle, that is why MIMO has been designed in such a modular way to improve recycling process.

4.6. Manufacturing and testing process

Manufacturing of MIMO Main unit will be subcontracted by PSC to a known-good assembling company. Production control will be performed by this subcontracted company and PSC will perform a full testing in its own facilities.

Components assembly

MIMO assembled is composed of a 19 inch rack in which all internal components are installed. Each converter is placed as a rack unit so its modularity and interchangeability of pieces is assured. External connections with other sub-circuits are placed on the right side of the rack and its connection will be done by rugged industrial connector.

MIMO also includes one ventilation system per converter, those fans assure a controlled inner temperature. As ventilation goes from left to right side it is mandatory that MIMO has a gap of at least 30 cm in any of its sides to ensure air flow.

Electrical wiring and control system installation

MIMO will be supplied with all internal connection completed and this includes its control system and sensor stages.

Insulation and Encapsulation

Electrical insulation is added to critical components to prevent current drains and maintain efficiency. The entire assembly is aimed to protect it from external elements.

Quality Control and Testing

MIMO undergoes rigorous testing to ensure it to meet quality standards. It includes a full functional test during several hours and testing most relevant working scenarios like grid forming and grid feeding for the inverter.

Packaging and Shipping

Once all quality checks are passed, it is packaged for shipping to customers.

5. EV charger

5.1. Technical system description

As shown in Fig. 28, the solution chosen for the Milan case study is the Juicebox Start/Easy: AC charging infrastructure, capable of connecting one vehicle at a time. It is a single-phase line which provide a power equal to 7.4 kW.

1 Cable
2 RFID Reader
3 LED indicator
4 Connector

Figure 28. Juicebox Start/ Easy

Hereafter the technical data and performances of the model are reported. Figures 29-30 show the details of dimensions of mounting bracket and Juicebox.

Dimensions

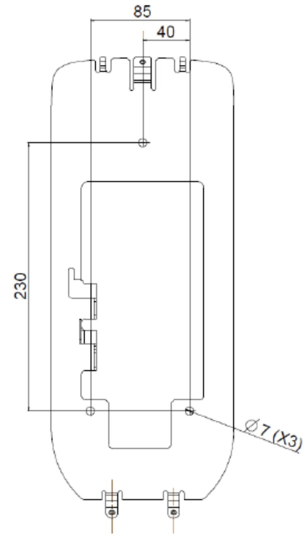

Figure 29. Mounting bracket (dimensions in mm)

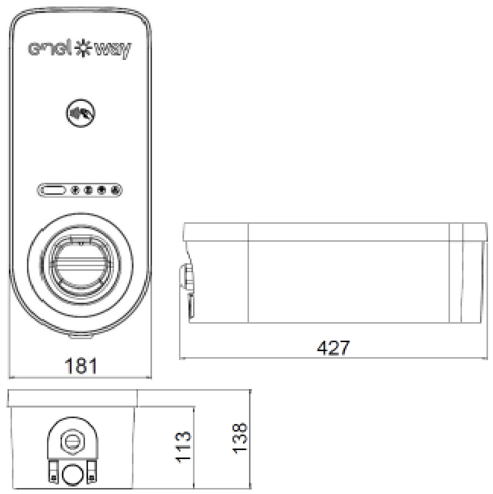

Figure 30. Juicebox with cable (dimensions in mm)

Output power

- Up to 7 kW, 32A

Input voltage

- Single-phase: 230 VAC

Recharge mode

- Mode 3

Standard and Certifications

- IEC 61851-1
- CE
- CE RED

Protection

The Juicebox has internal detector of DC fault currents above 6 mA.
The following external protections are required:

- Type A differential circuit breaker
- Curve C thermal-magnetic circuit breaker
- Current throw release coil

5.2. On–field system connection

Connection in the building

When installing the Juicebox, it is crucial to consider its proximity to the vehicle charging port, ensuring convenient accessibility for users. The device should be mounted at a height that provides 150-160 cm from the floor level to the top of the Juicebox, optimizing ease of use. Additionally, placement within the range of the local Wi-Fi network is essential for seamless connectivity. In instances where the Juicebox is integrated into a column with data connection capabilities, it is preferable to locate it in an area with robust mobile data network coverage. In cases where reception may be compromised, the installation of an external antenna is required. This antenna, equipped with a standard male SMA connector (plug), will enhance signal strength, ensuring optimal performance. If the measured signal falls below -80 dBm, indicating potential signal degradation (e.g., -85 dBm), the installation of a dedicated external antenna becomes a necessity to maintain reliable connectivity.

Electrical connection

The Juicebox is compatible with the networks shown in Table 9. The Milan case study uses single-phase connection and the distribution type of TN-S.

Table 9. Juicebox and grid compatibility

Distribution		Neutral	Voltage
Single-phase	TT	Yes	230VAC
Three-phase		Yes	400VAC
Single-phase	TN-S TN-C-S	Yes	230 VAC
Three-phase		Yes	400VAC
Single-phase	IT	No	230VAC

The selection of cross-sectional area of the power cables, insulating materials and composition of power cables should be made in line with the size of the switches and in accordance with applicable local standards.

Table 10 shows the minimum cross-sectional areas for different installation conditions. According to the table, the recommended cross-sectional area of the power cable is 6mm^2 for a standard installation using copper cables. In some cases, such as when cables have to cover large distances, a certified installer may adopt cables with larger cross-sections, considering the maximum cable cross-section of 10mm^2.

Table 10. Power cables dimensions

JUICEBOX		Minimum cross section
Single-phase	UP to 3.7kW, 16A	4 mm^2
	Up to 7.4 kW, 32 A	6 mm^2
Three-phase	Up to 11 kW, 16 A	4 mm^2
	Up to 22 kW, 32 A	6 mm^2

5.3. Use

5.3.1. Charging in Unlock to Charge mode (Charging with permission)

This section outlines the procedures for recharging a vehicle using the Juicebox in Unlock To Charge mode, employing either the Enel X Way app or an RFID card.

- Recharge using Enel X Way app

To initiate a recharge, the users need to access the Juicebox section through the Enel X Way app and select START RECHARGE. Subsequently, the vehicle should be connected within 90 seconds of unlocking, utilizing the Juicebox cable for the cable version or attaching the charging cable to the Juicebox socket and the vehicle for the socket version. Charging commences automatically, allowing users to monitor the session on-screen. To conclude the charging process, users simply tap on END RECHARGE, prompting automatic stop, after which the charging cable can be safely removed.

- Recharge using RFID card (if available)

The RFID card, commonly known as the Enel X Way Card, enables the initiation of a Juicebox charging session under specific conditions. Firstly, the Juicebox must be associated with the Enel X Way app account, and the "Recharge with Authorization (Unlock to Charge)" mode must be selected. Additionally, the RFID card needs to be linked to the Enel X Way app account. To commence charging, place the RFID card near the Juicebox RFID reader and connect the vehicle within 90 seconds of authorization, following the same cable or socket connection process as described above. Charging initiates automatically, and users can monitor the session via the app in the Juicebox section. To cease charging, bring the RFID card near the Juicebox RFID reader again, prompting automatic termination, allowing for the removal of the charging cable.

5.3.2. Charging in Connect & Charge mode (Free charging)

This mode is recommended for instances where the Juicebox is situated in a private area. Not requiring any authentication for the initiation or termination of charging, this mode prioritizes ease of use but limits access to certain smart charging functionalities like scheduled charging.
While the Juicebox is initially configured to operate in Connect&Charge mode, it is advised to follow the commissioning steps via the Enel X Way app. This enables remote management of recharges, configuration of Juicebox settings, and adjustment of other parameters.

To commence a recharge in Connect&Charge mode, the users simply need to connect the vehicle to the Juicebox. For the cable version, the Juicebox cable needs to be connected to the vehicle, and for the socket version, the charging cable needs to be attached to the Juicebox's socket and the vehicle. Charging will commence automatically. Monitoring the charging sessions is facilitated through the Enel X Way app by accessing the Juicebox section. To conclude the charging process, users need to send a stop command from the vehicle and subsequently disconnect it from the Juicebox.

5.4. End of life treatment

In compliance with local legislation and as stipulated in article 14 of Directive 2012/19/EU concerning waste electrical and electronic equipment, the presence of a crossed-out waste bin symbol on the equipment or its packaging signifies that the product must be discarded separately from household waste. Upon reaching the end of its lifespan, it is imperative to transport the product to a designated collection point established by local authorities. This practice of separate collection and recycling is essential to preserve natural resources and to guarantee that the recycling process is conducted in a manner that protects human health and the environment.

5.5. Manufacturing and testing process

The Juicebox is no longer in the prototype stage, but in production, already sold on the Italian and global markets.
With reference to the production process, which takes place at Enel X's third-party supplier sites, testing is carried out as follows:

- Once the Juicebox comes off the production line, it undergoes a functional test with a simulator that simulates an electric vehicle.
- All the charging stages of an electric vehicle are simulated and the proper function test is performed for each of them.

6. Battery pack

6.1. Technical system description

In this section, an overview of the general concept of the battery pack is provided, followed by a description of the technical and physical configuration specific to the Milan case study.

6.1.1. General concept of the battery pack

The proposed battery pack is envisioned as a self-contained, stand-alone power storage and delivery system. It is designed for seamless integration with external systems or can be incorporated into a comprehensive household solution as outlined in this project. Classified as a High Voltage (HV) battery pack with a Pack Nominal Voltage exceeding 72V, special considerations have been outlined for its construction, operation, maintenance, and safety systems. These design considerations aim to enhance the system's safe handling, serviceability, and align with future-focused product evolution.

The battery pack will be housed in a 19-inch electrical rack-style cabinet specifically rated for outdoor use. The cabinet features cable entry points for external communications and DC traction cables (main power cables). It is versatile for deployment in various operating environments, including indoor, outdoor, and harsh conditions. Additional features include fire resistance, suppression capabilities, and automatic thermal/environmental control.

6.1.2. Design of the battery pack in Milan case study

The battery pack in Milan case study is organized into smaller packs of 16 cells each, overseen by a Battery Management System (BMS). One group of 16 cells is called a “Slab”. These 16-cell slabs, organized into 9 groups, are further connected in series to form the complete 144-cell pack. Each slab is equipped with its own BMS, and these individual slabs are unified into a single Battery Pack Management System by the Master BMS located in the "Control Slab." The Master BMS facilitates interaction with external systems like MIMO, presenting the battery pack at a system level as a single BMS-controlled unit instead of nine separate packs. This ensures the safe operation of the entire system by actively monitoring each cell during operation, eliminating assumptions about groups of unmonitored cells.
The original physical architecture of the battery cabinet was designed to have a height of no less than 2m and 10 levels of shelves. Therefore, each shelf holds one 16-cell slab, and the one of the shelves contains the master BMS as well as any additional system support hardware.

However, the design of the cabinet and internal arrangement needed modification because it was not possible to source the cabinet with the originally intended design within the planned delivery timeline. Accordingly, a different battery enclosure (Fig. 31) was procured, which has internal dimensions of 800×800×1800 (W/D/H)[mm]. Adapting to the diminished vertical space, the layout and dimensions of the power layers were revised, accommodating 2 slabs per layer instead of the original plan for 1 slab per layer. The components that will be installed on each shelf are shown in Fig. 32.

Figure 31. The updated battery enclosure, the wooden panels are placed temporarily for dimensioning and they will be replaced with metallic panels.

Figure 32. The components that will be installed on each shelf (2 battery slabs and 2 BMS)

Efforts were made to uphold the original design intent, meet current requirements, and ensure future product evolution while optimizing functionality. The decision was made to condense the component layout to have the minimum clearance allowed, adhering to engineering standards and regulations. Additionally, component orientation was adjusted to accommodate the condensed layout and the exclusion of some components aligned with the revised functional requirements for the Milan case study.

6.2. On–field system connection

DC cables are initially connected to the terminals of the battery cell bank. The positive lead follows through a fuse and a safety contactor. Subsequently, it extends to an external terminal connection point that accommodates both positive and negative cables. From this point, DC cables run to the MIMO within the dwelling, establishing a connection with the Battery pack located at its designated installation site. Simultaneously, a CAN Bus communication cable runs in parallel with these DC power cables, facilitating communication between the MIMO and the Master BMS (Fig.33).
The DC power cables, rated at $25mm^2$ and 600V/HV, are specifically designed for subterranean conduit routing. The exact outer dimensions for cable glands will be determined once the cable supplier is selected by the MIMO supplier.

The Master BMS unit utilizes a consistent protocol to asynchronously transmit instruction messages and queries to all the Slave BMS units on the bus. Following the initial test of the Master BMS unit, the bus is scanned for Slave BMS devices. Each Slave BMS unit is assigned a distinct RS-485 address to prevent data collision and ensure proper identification. The Master BMS unit then assumes control over each identified Slave BMS unit, providing instructions on tasks such as measurement, balancing, output activation, error signaling, and more. The technical characteristics of the connection between Master BMS and Slave BMS are shown in Fig. 34.

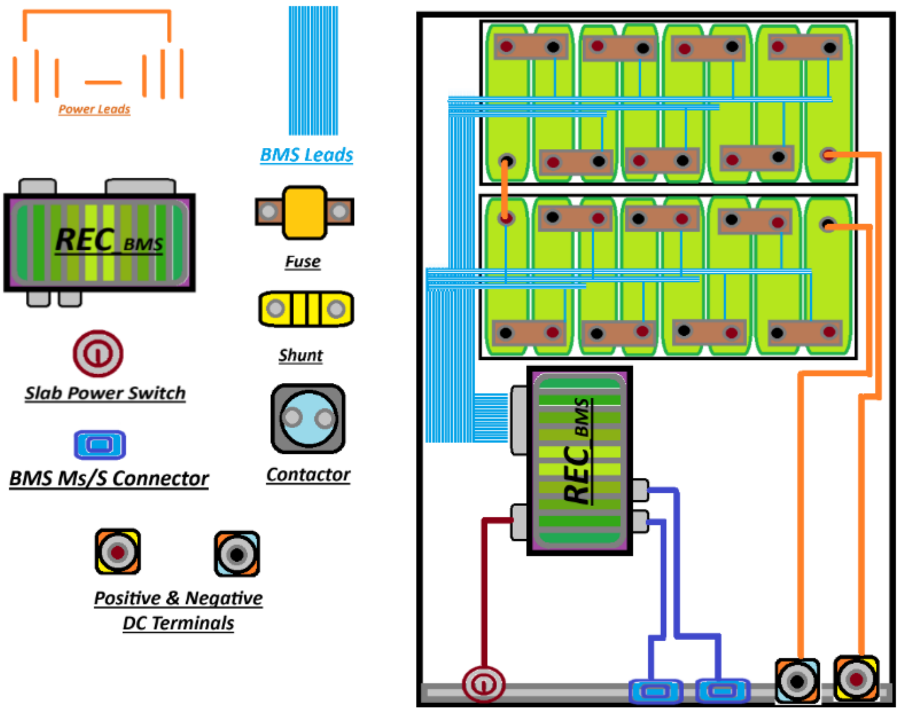

Figure 33. Overview of connection in a battery slab (16 cells)

To establish communication, all BMS Slave units should be daisy-chained to the SLAVE BMS Master unit DB9 RS-485 communication port. A 1k2 termination plug will be employed at the last Slave out port and at the Master BMS unit DB9 connector, ensuring proper termination between RS-485 A and B.

Table 11. Connection between Master BMS and Slave BMS

MASTER BMS DB9 pin	MASTER BMS DESIGNATOR COM	SLAVE BMS DESIGNATOR	SLAVE BMS DESIGNATOR input port	SLAVE BMS DESIGNATOR output port
1	CABLE SHIELD (AGND)	RS-485 CABLE SHIELD	6	12
2	AGND - Master	AGND - Master	5	13
3	RS-485 B	RS-485 B	1	6
4	RS-485 A	RS-485 A	2	7
6	+5V to AGND	RS-485 +5 V	4	14

6.3. Use

The system will be delivered ready to operate in conjunction with the MIMO. Little or no interaction from the customer is required for ongoing operation. If an error occurs, the system will take necessary actions, such as shutdown or isolation, and the MIMO will receive a notification. The customer can monitor performance statistics and error messages, similar to other battery management systems on the market thru the MIMO interface and not directly thru the battery. In case the issue persists, the customer is advised to contact the registered service provider for troubleshooting, following the steps outlined in the user manual. Importantly, the customer, end user, or any third party should never interact with the interior or internal components of the battery pack under any circumstances.

Any interaction by uncertified or unregistered personnel should be conducted exclusively through the battery management app, user control screen (if available), or a specifically designated communication port (if provided).

6.4. Maintenance, renovation and replacement

Maintenance and renovation are easily possible due to the modular nature of the Battery Pack internal Architecture. The parts inside the system can be easily changed or upgraded because they're modular. This means it possible to work on different parts/modules of the battery systems without affecting how they connect to the customer's hardware. For example, a new battery slab can be created with better technology and a newer BMS to match changes in the market. Customers with old systems can get an upgrade where their old battery parts/modules are swapped for the new ones. As all changes are internal to the battery system there is no need for the customer to modify their existing infrastructure. Also, when some parts get old and don't work well anymore, there is no problem to take them out and send them for fixing. After checking, only the parts that really need to be replaced get changed, and the ones that still work well can go back into service. This way, each part lasts longer, and we don't have to throw away components just because one of them is not working. This helps a lot in reducing the carbon footprint of the system.

6.5. End of life treatment

End-of-life treatment will be conducted by certified service providers, aligning with local disposal norms for the specific materials involved. In instances where access to registered service providers is unavailable, efforts will be dedicated to crafting a comprehensive "Decommissioning Procedure." This procedure, once developed, can be executed by an individual or organization possessing the requisite certifications for handling potential hazards. The procedural steps will involve isolating and dismantling the system, facilitating its transportation to the designated material disposal location as stipulated by local regulators or government authorities at the installation site.

6.6. Manufacturing and testing process

Cells for the battery packs will be sourced from recycled EV battery packs. Upon reception at Solartechno, the packs will be systematically disassembled following the recommended steps provided by the original equipment manufacturer (OEM). This disassembly includes separating individual cells, OEM Battery Management Systems (BMS), OEM housing, OEM busbars and fasteners, as well as any additional OEM materials. Subsequently, each cell will be documented in a database/register and individually evaluated for both physical and electrochemical condition against the original OEM specifications when the cell was new.

If a cell is found to be in an acceptable condition for continued service, it will proceed to the next processing steps. Conversely, if a cell is determined to be unsuitable for further use, it will be marked for disposal and flagged accordingly in the cell database. The cells deemed suitable for use will then be charged to a common storage voltage and grouped based on their measured capacities. For example, if the OEM specified a capacity of 40Ah, the cell groups may be categorized as follows: Group A = 39-40Ah, Group B = 37-39Ah, Group C = 35-37Ah, Group D = 33-35Ah, and so forth.

However, instead of recycled cells, new cells could also be used.

The ongoing phase of the project involves the development of the initial prototype, which is currently in progress. The manufacturing process is currently operating at a pre-series production level. In simpler terms, this means that trained personnel and development staff are actively engaged in working on iterative variants of components and systems. The emphasis is on continuous refinement to ensure safe operation, optimal performance, and enhanced serviceability. This iterative phase is crucial for streamlining the manufacturing process, particularly with a focus on prospective lean manufacturing practices as the project scales up.

The ultimate goal is to refine and elevate the current manufacturing methods to a level suitable for large-scale production. This involves aligning the manufacturing processes with relevant industry regulations, certifications, and quality assurance strategies. As the project advances, there is a commitment to ensuring that the manufacturing practices meet the highest standards, complying with industry norms and ensuring the delivery of a product that not only performs exceptionally but also adheres to stringent quality and safety standards.

7. Smart control system (SCS)

7.1. Technical system description

The Smart Control System (SCS) is a critical component in the development of RE-SKIN, as it acts as a high-level unified layer that integrates various technical components, such as MIMO and heat pumps. The SCS is designed to effectively manage communication with these components, offering a complete set of functionalities.

The SCS is planned to be implemented as a software platform for the Internet of Things (IoT). This platform enables seamless integration and orchestration of various technical components regardless of transmission technology and/or communication protocols (with certain limits stipulated as requirements to ensure communications without packet loss). In this way, the aim is to ensure a fully interoperable control system. In addition, the choice of an IoT-based approach aligns with the Edge Computing paradigm that will optimize processing speeds in the RE-SKIN pilots.

The key functions of the SCS are described below.

Agent deployment

The SCS facilitates the deployment of agents or connectors capable of communicating effectively with the rest of the technical components of the project, this includes communications with the MIMO and heat pumps.

Local data storage

Provides a robust mechanism for the storage of time series data generated by the connected technical components. This provides a mechanism for storing time series data generated by the connected technical components and ensures the availability of historical data for analysis and decision making. Likewise, the SCS will facilitate the connection with cloud systems to provide the system with long-term persistence and allow access to information from external networks.

Easy visualization

The SCS includes user-friendly applications that allow stakeholders to visualize the real-time status of the entire system. This enhances the user experience and facilitates monitoring.

Cybersecurity measures

The implementation follows cybersecurity best practices to ensure the integrity and security of the system. This includes measures such as encryption, access controls, and regular security updates.

Monitoring and alerting system

The SCS incorporates a comprehensive monitoring and alerting system that provides real-time information on system performance. This enhances proactive management and problem resolution.

Although the SCS relies on a hardware system (necessary to host all the services as shown in Fig. 34), it is a purely software component.

Figure 34. SCS hardware system

Due to its focus on software instead of hardware, the structure of the subsections differs slightly from other sections in this document:

System Connections

Provides an overview of the architecture at a very high level, emphasizing the software components and their interactions within the system.

Study of alternatives

Examination of various IoT platforms, listing and analyzing the pros and cons of each. Emphasis is placed on identifying platforms that align with the objectives of the Software Control System (SCS).

SCS Architecture

Detailed architecture of the IoT Software Control System (SCS) IoT platform. The objective is to provide a comprehensive understanding of the SCS architecture.

7.2. System connection

This section provides an overview of the Software Control System (SCS) architecture, with emphasis on the high-level connections between its major components. The focus is on providing a comprehensive understanding of the software-based interactions within the system.

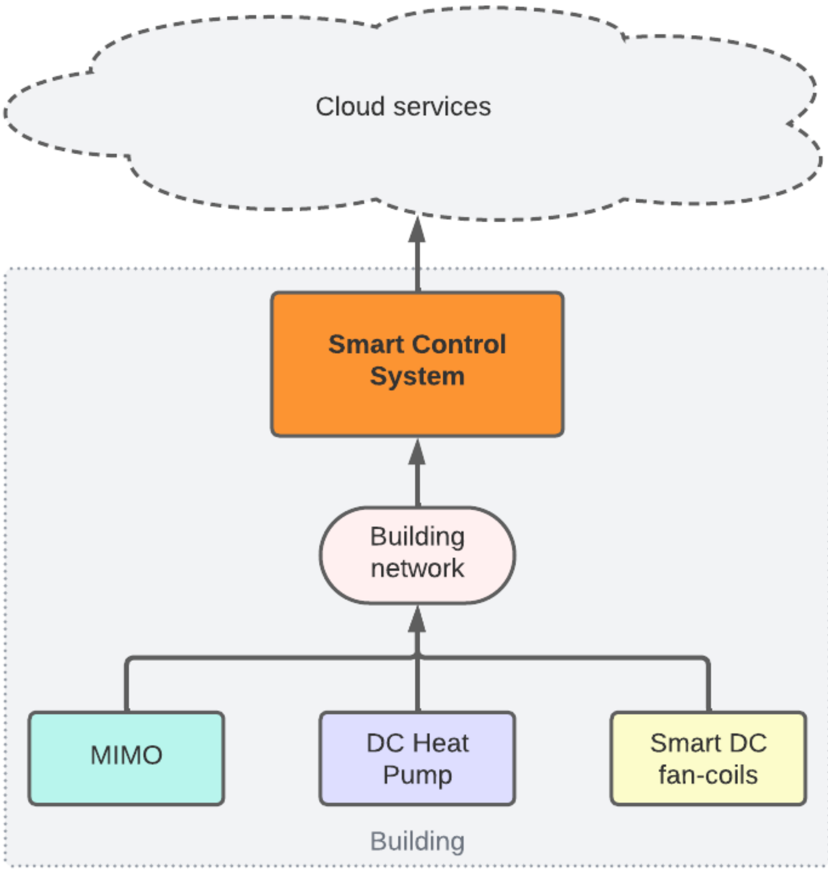

Figure 35. SCS hardware system

In the architecture shown in the Fig, 35, the MIMO (Multi-Input Multi-Output) system, the heat pump and the smart fan coils establish connections through the building network to interact with the SCS (Software Control System). The SCS, in turn, communicates with cloud services to enable seamless data exchange and management.

This document will go in depth on the software components required to build an IoT platform that facilitates data collection and communication with various devices, including MIMO, Heat Pump and Fan-Coils. This covers the development of both the management and visualization platform as well as the essential gateways for data collection. In addition, the document will cover the implementation of databases to ensure persistent storage inside the system.

7.3. Study of alternatives

There are a lot of existing alternatives for deploying a functional IoT platform that addresses the challenges presented by RE-SKIN. This section aims to perform an analysis of software alternatives. The alternatives reviewed cover a range of well-known platforms. The platforms to be examined are ThingsSpeak, ThingsBoard and Mainflux. These platforms represent a mix of industry-proven solutions and emerging technologies, each with its own set of features for different use cases.

The analysis that follows will take a deeper dive into the functionalities, scalability, security features, and adaptability of each platform. By evaluating the pros and cons of these alternatives, the document aims to find an optimal IoT solution that fits the project objectives.

Therefore, we proceed to the detailed analysis of each alternative:

Thingspeak

ThingSpeak is an IoT (Internet of Things) analytics platform service that allows to aggregate, visualize, and analyze live data streams in the cloud. It provides various services exclusively targeted for building IoT applications. ThingSpeak offers the capabilities of real-time data collection, visualizing the collected data in the form of charts, and the ability to create plugins and apps for collaborating with web services, social networks, and other APIs.

ThingSpeak is open-source software written in Ruby. It allows users to communicate with internet-enabled devices and facilitates data access, retrieval, and logging of data by providing an API to both the devices and social network websites.

ThingSpeak is available as a free service for non-commercial small projects. However, commercial users may sign up once for a time-limited free evaluation. All other commercial uses require a standard commercial license. Users of the free option will be limited to sending no more than 3 million messages each year to the ThingSpeak service.

For devices to communicate with ThingSpeak, they must support HTTP or MQTT protocols. Secure connections are recommended and require your device to support TLS 1.2.

Thingsboard

ThingsBoard is an open-source IoT platform that enables rapid development, management, and scaling of IoT projects. It is designed for data collection, processing, visualization, and device administration. It provides a unified view of devices, data, and processes, allowing users to monitor, analyze, and manage IoT devices and data in real-time. It supports both cloud and on-premises deployments.

As for its cost, ThingsBoard is free for both personal and commercial usage. However, they also offer paid plans.

Regarding the supported protocols, ThingsBoard supports the following protocols for device connectivity: MQTT, MQTT Sparkplug, CoAP, HTTP, LwM2M and SNMP.

In addition, Thingsboard allows the creation and deployment of custom gateways that implement connectors to obtain data through MQTT (direct or through a broker), Modbus, BLE, CAN, ODBC, REST, FTP... and, if the necessary protocol is not found, it allows the custom implementation (Custom Connector) to provide interoperability to the system.
It allows the use of relational databases for information or the use of time series databases. It supports, thus, PostgreSQL, TimeScale and Cassandra.

Mainflux
Mainflux is a modern, scalable, and secure open-source IoT cloud platform. It's written in Go and is patent-free. Mainflux accepts user and thing connections over various network protocols, making a seamless bridge between them. It's used as the IoT middleware for building complex IoT solutions. Mainflux is indeed open-source and it's free for both non-commercial and commercial use.
The supported protocols in Mainflux include HTTP, MQTT, WebSocket, and CoAP. It also supports mTLS over HTTP, MQTT, and MQTT over WS protocols.

Pros and cons of different alternative IoT platforms are summarised in Table 12.

Summary of selected alternatives

Table 12. IoT platforms alternatives

Platform	Supported Protocols	Pros	Cons
ThingsSpeak	HTTP, MQTT	• IoT analytics platform that allows aggregation, visualization, and analysis of live data streams in the cloud. • Enables real-time data collection. • Open-source software. - Available as a free service for non-commercial small projects. • Supports containerized deployment. • Commercial users are limited to a time-limited free evaluation. • All other commercial uses require a standard commercial license. • Free option users are limited to sending no more than 3 million messages each year to the	• Commercial users are limited to a time-limited free evaluation. • All other commercial uses require a standard commercial license. • Free option users are limited to sending no more than 3 million messages each year to the ThingSpeak service.
ThingsBoard	MQTT, MQTT Sparkplug, CoAP, HTTP, LwM2M, SNMP, Modbus …	• Open-source IoT platform. • Designed for data collection, processing, visualization, and device administration. • Allows the creation and deployment of custom gateways with custom connectors (supporting almost every protocol). • Free for both personal and commercial usage.	• Paid plans are also offered, but not needed. • Requires development if new connectors need to be created

		• Provides security through transport encryption. • Highly widespread and widely used • Horizontally scalable. • Supports containerized deployment.	
Mainflux	HTTP, MQTT, WebSocket, CoAP	• Modern, scalable, and secure open-source IoT cloud platform. • Open-source and free for both non-commercial and commercial use. • Provides security through transport encryption. • Scalable. • Supports containerized deployment.	• Not widely adopted and has limited support.

After analysis, the decision has been made to deploy a local instance of ThingsBoard and at least one ThingsBoard gateway. This decision is based on ThingsBoard's list protocol support, including Modbus (TCP/RTU), which makes it highly adaptable to a wide range of IoT devices.

As an open-source platform, ThingsBoard allows for significant customization, in alignment with RE-SKIN's specific requirements. The platform's free use for both personal and commercial purposes, robust security features, wide adoption and scalability further contribute to its selection. The decision is reinforced by strong community support and the ability to integrate with various protocols, making ThingsBoard a versatile and cost-effective solution for the envisioned IoT deployment.

7.4. Architecture

In this section, the initial architecture proposed for the implementation of ThingsBoard within the Intelligent Control System will be described. It therefore aims to provide an overall understanding of how ThingsBoard will be deployed and configured to optimize its capabilities in the context of the Intelligent Control System.

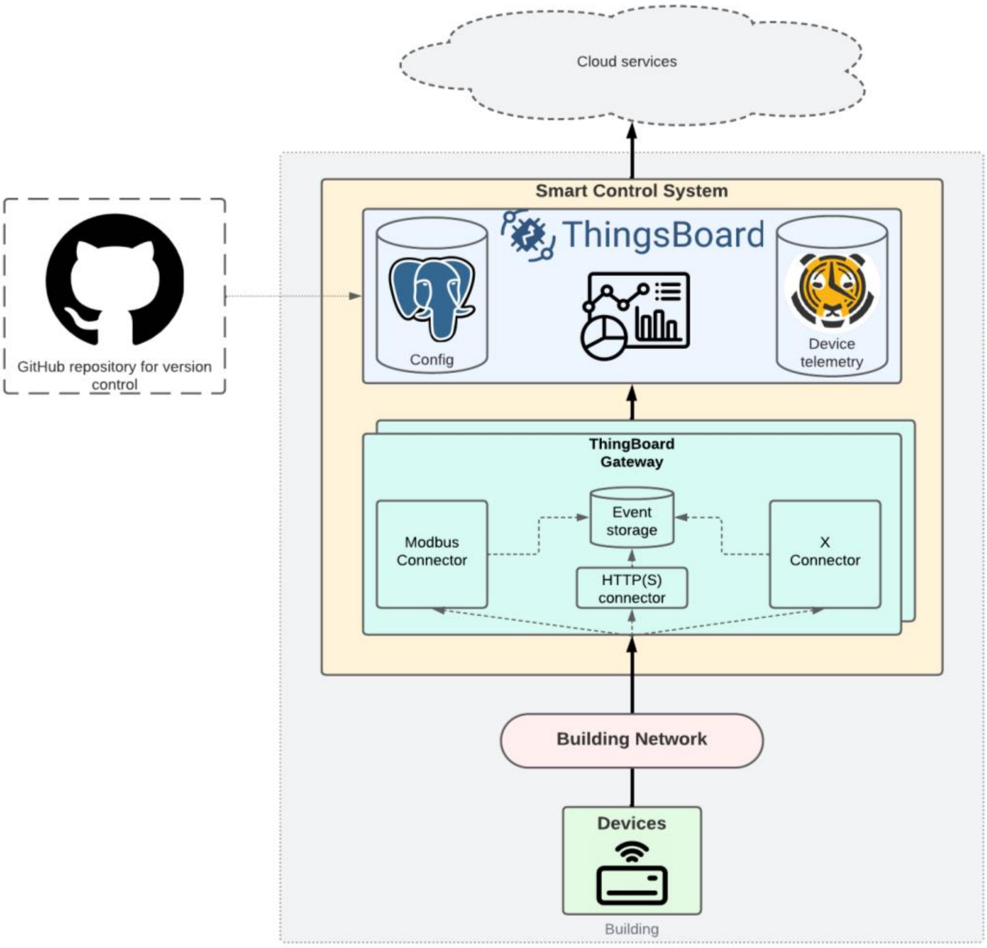

Figure 36. SCS Architecture with ThingsBoard

The proposed initial architecture (Fig. 36) for the smart control system is designed to establish connectivity between devices (such as MIMO, heat pumps or smart fans) and the SCS via the building network.

The SCS will host all necessary services, including ThingsBoard and at least one ThingsBoard Gateway. Docker will be used to deploy containerized services, which offers advantages such as portability and scalability.

The ThingsBoard Gateway, configured to use Modbus TCP over wired connections, will host connectors to retrieve information from devices in the building. As indicated in the gateway architecture, this service will have a local database to retain events.

It is important to note that, in spite of the fact that the ThingsBoard supports a large number of transmission protocols, it is mandatory to use wired technologies not for support reasons, but to avoid problems in communications between devices. In this way, transmissions will be optimized, maximizing speeds and minimizing possible failures.

Data from the gateway services will be transmitted to ThingsBoard (in principle) via MQTT. ThingsBoard will allow centralized management of all connected devices within the building, handling the information received and building visualizations.

The proposed architecture adopts the hybrid format of ThingsBoard, which means that PostgreSQL will be used for configuration and TimeScale for device telemetry (time series data). To ensure version control of devices and configurations, integration with GitHub repositories is expected, which will facilitate testing and restoration in case of errors.

In addition, information collected and stored locally will be transmitted to cloud services used by other project partners, improving data accessibility and long-term persistence.