RE-SKIN

D6.1 - Manufacturing design of the technical components I

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History of changes

Version	Date	Comments	Main Authors
0.1	31/03/2023	First draft, establishing document structure	M. Kim (HELIO), F. Leonforte (POLIMI)
0.2	28/04/2023	First version, incorporating input from all participants	M. Kim (HELIO)
0.3	29/04/2023	Quality review	C. Del Pero (POLIMI), A. Vallan (FPM)
1.0	05/05/2023	Final version addressing all further comments	M. Kim (HELIO)

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Disclaimer

1. Executive summary

The document represents the first deliverable of WP6 and describes the manufacturing design of the technical components. More in detail, it contains the general descriptions and the design specifications of each technical subcomponent of the toolkit, along with first indications about installation and operation modes. The components considered in this document are following:

- DC-heat pump;
- Smart fan coil;
- MIMO (Multi-Input Multi-Output power converter);
- EV charger;
- Battery pack;
- SCS (smart control system).

It must be noted that the information reported in the document refers to the first stage of development of each component and of the whole toolkit, thus updates and changes are foreseeable in the next stages of the project.

It should be noted that, in the following releases of the current deliverable (at month 13, 19 and 27, respectively), the detailed aspects related to use, maintenance, end-of-life treatment as well as the manufacturing process and production control strategies will be also described. Furthermore, the supporting documents and certificates will be included.

2. DC Heat Pump

2.1. General description

The proposed Heat Pump (HP) is a device that pumps heat from low temperature to high temperature using a refrigeration cycle powered by a DC compressor. The HP can provide heating, cooling and also DHW, working synergistically with the smart fan coils/boilers developed by STILLE. More in detail, the heat pump consists of 4 major components: the compressor, the condenser, the evaporator, and expansion valve, as shown below.

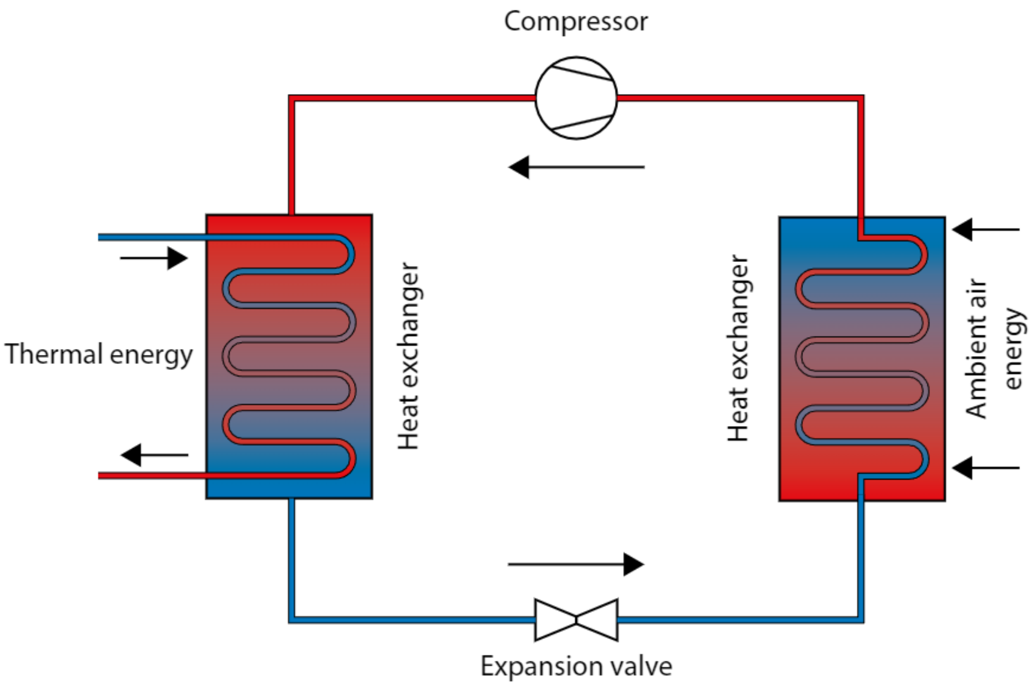

Figure 1. Heat pump principle

As in a standard vapour-compression cycle, the supplied energy causes the liquid refrigerant to evaporate becoming gaseous. The gaseous refrigerant is then compressed by means of an electrically driven compressor, powered by direct current (DC). The heated refrigerant gas is passed through a heat exchanger (condenser), where the gas cools down and liquifies.
More specifically, the proposed HP is an air-water ducted version, i.e., it's a monoblock unit which can be installed in an indoor technical space, and exchanges heat with the ambient air using air ducts, producing heated or chilled water.

2.2. System/component design

2.2.1. Main body

As introduced, the concept of the heat pump is monoblock air-water heat pump, therefore it takes heat source from the ambient air to transfer the heat energy to the water (in winter or in DHW preparation modes) while discharges heat in the ambient air in summer (cooling mode).

Given that it is monoblock, all the main components are placed in one unique block of machine. This allows to save the installation space and improve acoustic and esthetic aspects. Furthermore, since it is run by DC power supply, it can be powered directly by PV energy or energy coming from batteries without an additional inverter.

The heat pump is designed to stay inside the building and take in ambient air from the outside. The heat pump can be divided into two parts, upper and lower parts. In the upper parts, it mainly includes air cooled fin-and-tube heat exchanger and axial fan. To take the ambient air into the upper part of the heat pump, a duct system will be installed. Therefore, the heat pump is designed to be tightly coupled with the duct system. The area for the duct installation has dimension of around 720 × 920 mm. The air flow is routed to the heat exchanger with a support of axial fans. The minimum flow rate for the version under development is 2000 m^3/h and the recommended nominal range is between 5000 – 8000 m^3/h.

Depending on the weather temperature and humidity, frost can be accumulated on the surface of the heat exchanger which disturb heat exchange and reduce the efficiency. This frost is eliminated by de-frosting operation, then the water is drained by condensate drain hose located at the bottom of the heat pump.

The lower part of the heat pump includes the remaining components, i.e. the compressor and the other elements of the refrigeration cycle. In the lower part, there is another heat exchanger where it includes water flow cycle. Water outlet and inlet ports are placed at the bottom of the heat pump. the electrical connection ports are also located at the same place.

The heat pump is controlled by the heat pump network controller which accepts user requests and control the heat pump system, by interfacing with the RE-SKIN energy management system. The heat pump includes remote control service, therefore it is available to analyze and control the heat pumps from remoted place when the heat pumps are under internet network connected circumstance.

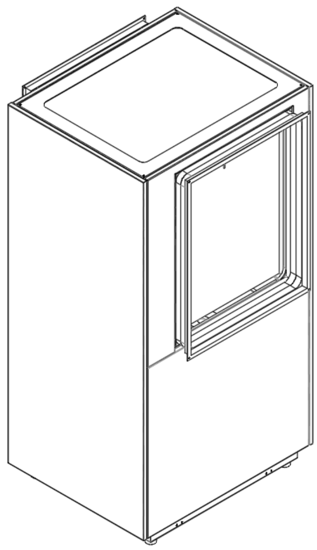

Figure 2. General design of the heat pump

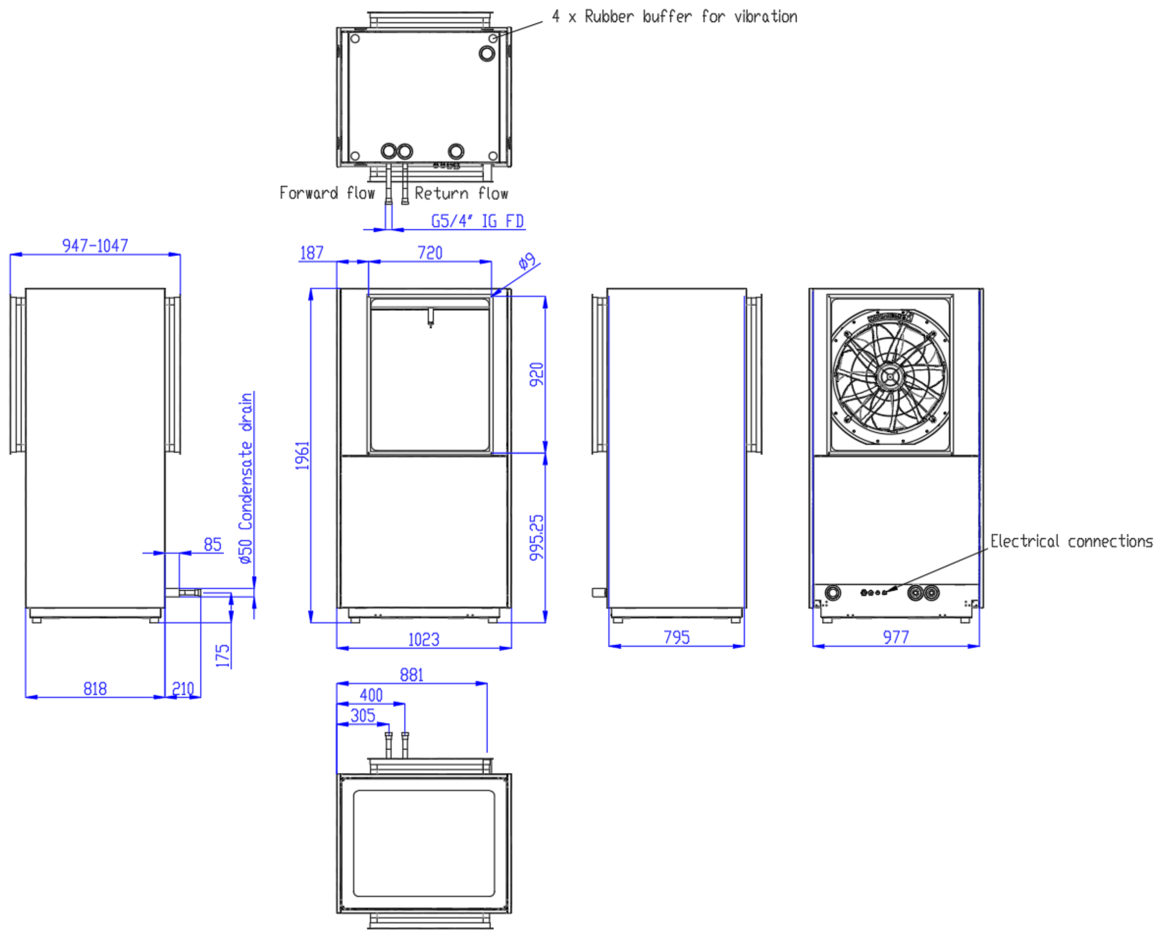

Figure 3. Measurement of the heat pump (unit: mm)

2.2.2. Powerbox

The main body is not designed to include the control system. The latter includes the main control board, the remote control gateway, and the manual controller display. This unit is the main interface with the RE-SKIN energy management system.

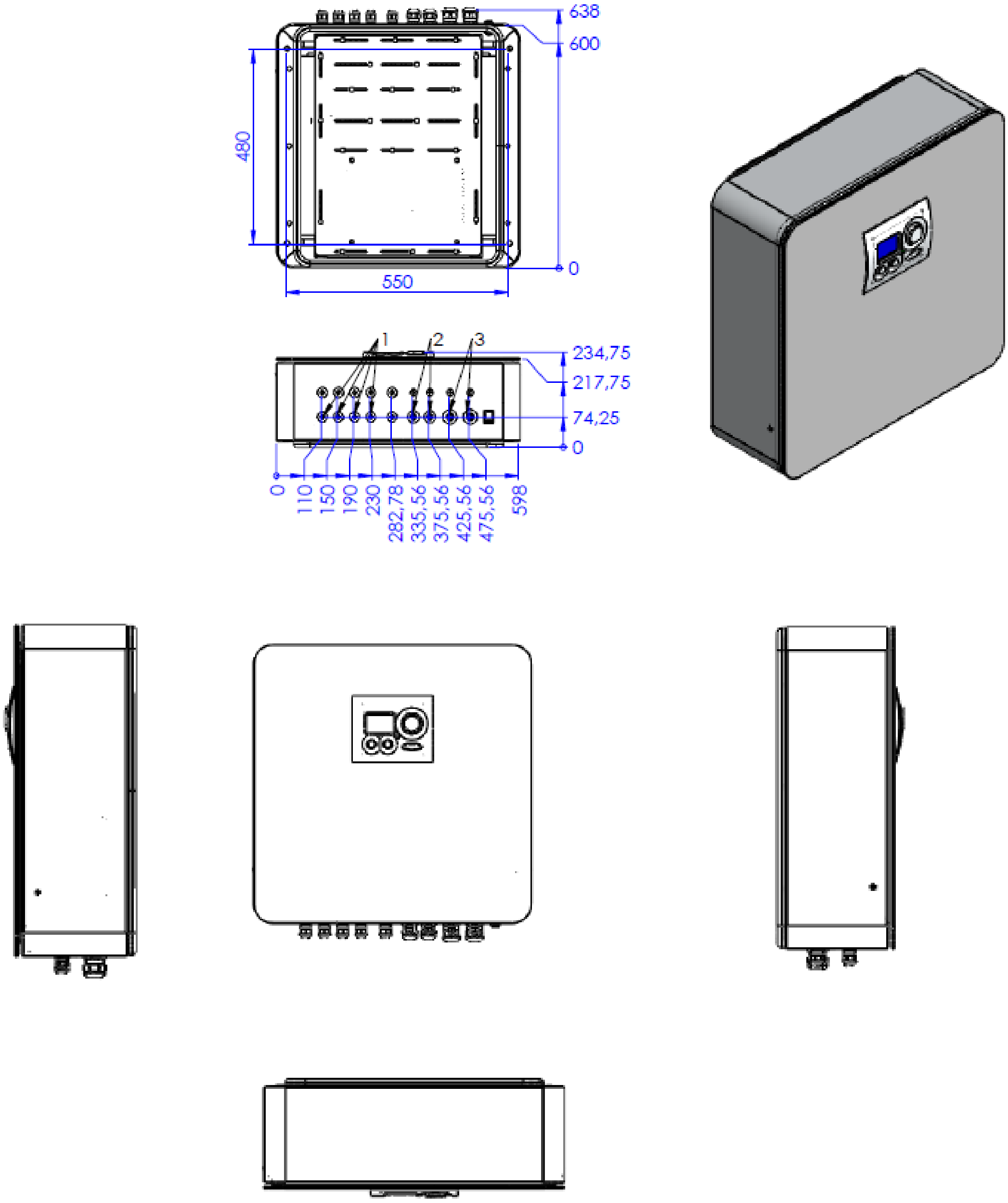

Figure 4. Design and measurement of the powerbox (unit: mm)

2.2.3. Hydrobox

The hydrobox contains the heating/cooling circuit circulation pump, the domestic hot water pump, and heating rod. It can be installed as an optional, depending on the requirements of the installation site. The size of the pumps is varied and must be decided according to the HVAC system design of each building.

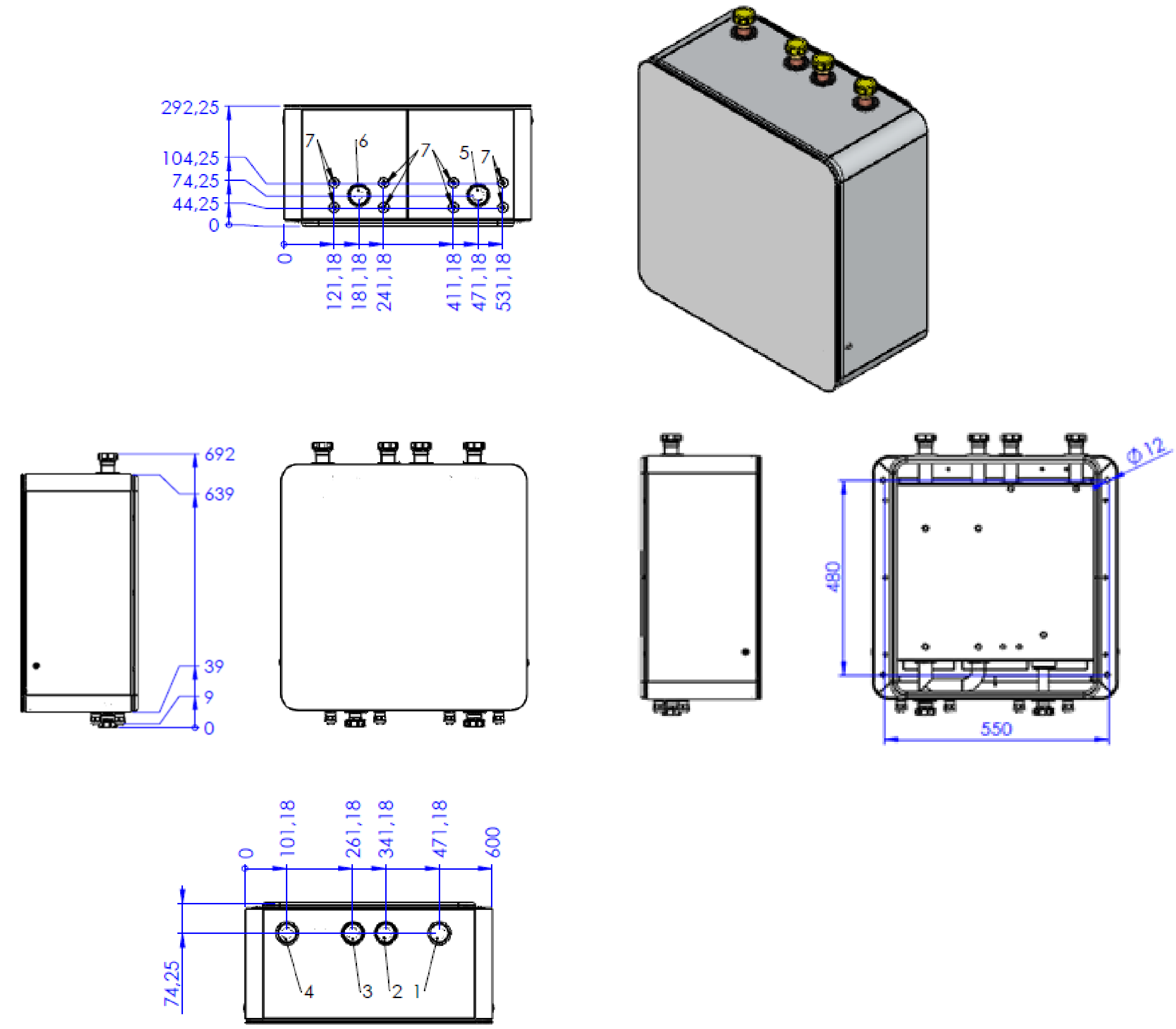

Figure 5. Design and measurement of the hydrobox (unit: mm)

2.3. Installation mode

The heat pump must be installed by HELIO or by an authorized specialized company. In addition, the employees of such a company are required to attend and have completed the HELIO expert training program.
More in detail:

- it is necessary to ensure that the process of installation, commissioning, maintenance and service personnel reads and understands the manual, the heat pump's operating manual and has understood all safety instructions;
- it must be ensured that the electrical connection is installed by a certified electrician who is qualified to perform work and is qualified for electrical systems and approved by the utility company;
- it must be ensured that service and maintenance work is performed only by certified refrigeration technicians that are familiar with the refrigerant cycle, qualified to work on electrical systems and approved by the utility company.

This chapter covers mainly installation place requirements for the components and detailed electrical and hydronic connections are not explained.

2.3.1. Space requirement

Sufficient minimum space distance must be available around the heat pump to easily carry out any necessary maintenance work. The HP units should be minimum 50 cm away from obstructions. The upper half of front and back side are connected to air ducts, however, the bottom half needs to remain free of obstructions.

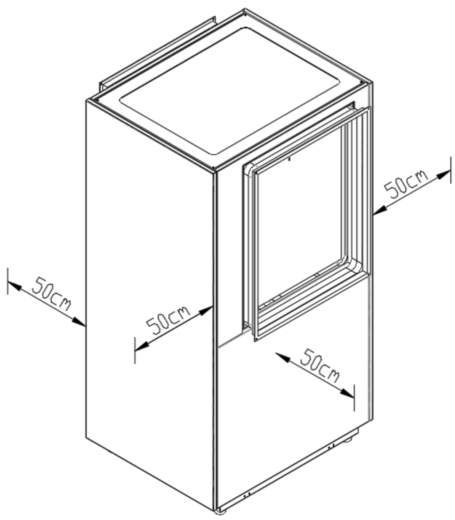

Figure 6. Recommended minimum distances

2.3.2. Air flow direction

The air flow direction is to be noted when installing the heat pump. The fan draws the air through the finned heat exchanger and blows the air directly out. In such respect it is important that the both the inlet and the outlet side are not obstructed.

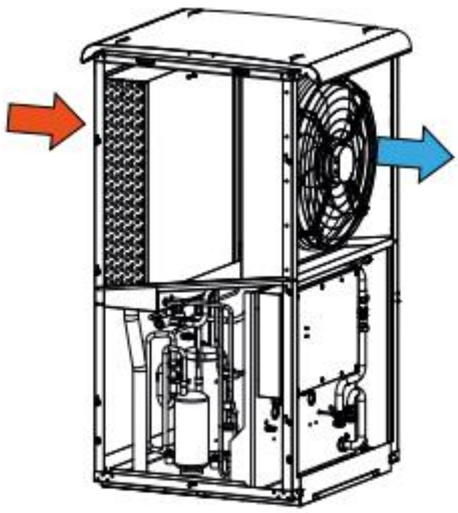

Figure 7. Heat pump air flow direction

2.3.3. Installation site of the heat pump

When identifying the installation site, some essential things must be considered to ensure an optimal heat pump function and to prevent conflicts, such as:

- it should not be installed on an uneven floor;
- enough space around the heat pump should be guaranteed;
- when possible, the heat pump must not be installed in the corner of the building. Acoustic reflections on the wall can lead to amplification of the emitted sound;
- the selected installation site should only be at a maximum of 1500 m above sea level;
- during operation, especially during defrost mode, a considerable amount of condensate water is generated, which runs beneath the heat pump by means of the pre-assembled condensate line. Afterwards, the condensation must be routed frost-free and with a steady gradient into a drain or seepage shaft. Direct discharge into a clarifier or septic tank is not allowed, as aggressive vapors may permanently damage the evaporator.

2.3.4. Space requirement for powerbox and hydrobox

These units must be mounted as described below, so that there is enough space for operation and any maintenance or repair work.

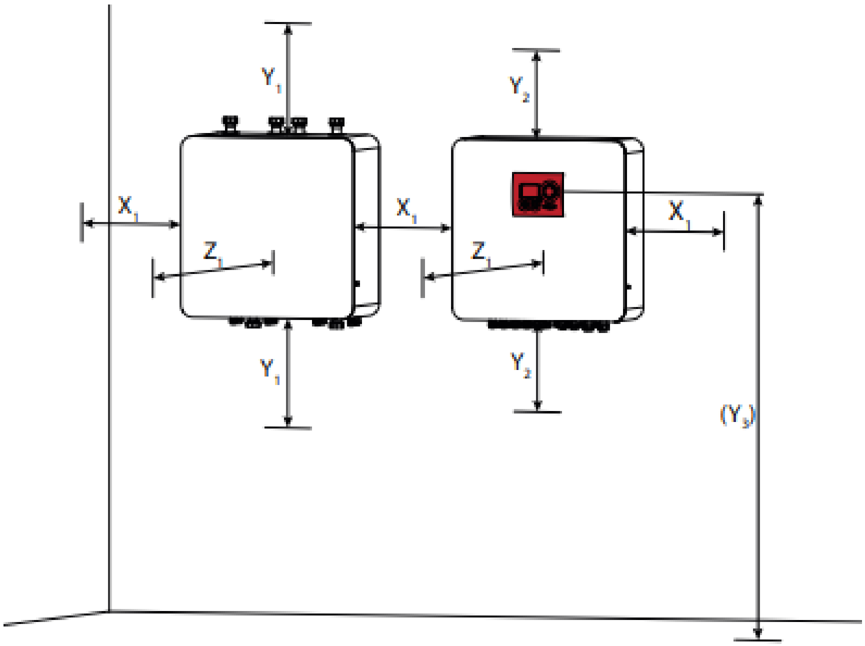

Figure 8. Recommended distances of powerbox and hydrobox (see table below)

Table 1. Recommended minimum distances of the units

Pos.	Description	Distance
X_1	Indoor unit horizontal spacing	50 cm
Y_1	Hydrobox vertical distances	80 cm
Y_2	Powerbox vertical distances	50 cm
Y_3	Control unit height	80 – 160 cm
Z_1	Front distance	80 cm

2.3.5. Storage environment

The HP unit may only be stored in its original package and in a dry place, where it should be vertically positioned. No other items may be placed on the heat pump unit. At the designated storage location, the following climatic conditions must be kept:

Table 2. Storage conditions

Measurement	Unit	Value range
Ambient temperature	°C	+5 / +35
Maximum relative humidity (non-condensing)	-	80%

2.4. Operation mode

The HP is electrically connected with the MIMO converter and the grid. The MIMO provides 600-700 Vdc to HP, while some auxiliaries of the HP are operated in AC at 230V/400V. The communication interface designed by CTIC will allow the communication of input/output parameters between the HP and the RE-SKIN energy management system. The list of input/output parameters defined for the proper control and monitoring is provided in the following table.

Table 3. Input/output parameters

Parameter	Category	IN/OUT
Outdoor air temperature	Sensor	Output
Heat inlet temperature	Sensor	Output
Heat outlet temperature	Sensor	Output
Buffer storage temperature	Sensor	Output
Energy sources inlet temperature	Sensor	Output
Energy sources outlet temperature	Sensor	Output
Coefficient of performance	Sensor	Output
Heating circuit pump	Actuator	Input
Buffer charging pump	Actuator	Input
Compressor	Actuator	Input
Error	System Status	Output
Status of the 4 way valve - air	System Status	Output
Heating/Cooling switch	Actuator	Input
Operating hour in Cooling Mode	Sensor	Output
Operating hours in Heat. Mode	Sensor	Output
Calorimeter_Heating	Sensor	Output
Electric meter_Heating	Sensor	Output
Calorimeter_Cooling	Sensor	Output
Electric meter_Cooling	Sensor	Output
Electric meter_total	Sensor	Output
Electric meter_capacity	Sensor	Output
Calorimeter_total	Sensor	Output
Calorimeter_capacity	Output	Output
Operating mode	Actuator	Input
Heat. inlet Setpoint temperature - Active	Actuator	Input
Clear (error, reset)	Actuator	Input
Outdoor temperature - Active	System Status	Output
Buffer temperature value	Actuator	Input
Buffer temperature - Active	System Status	Output

By the interaction between the different subcomponents, the required information to run the heat pump can be achieved, allowing the HP to be able to flexibly handle the fluctuating thermal loads of the building.

The main operational features of the HP under development are summarized below.

Main operation features – air side

- Maximum air flow rate in heating mode [m^3/h]: 8000
- Minimum air flow rate in heating mode [m^3/h]: 2000
- Maximum air flow rate in cooling mode [m^3/h]: 8000
- Minimum air flow rate in cooling mode [m^3/h]: 2000
- Maximum air inlet temperature [°C]: 45
- Minimum air inlet temperature [°C]: -15
- Maximum operating relative humidity (at max. temperature) [%]: 90
- Minimum operating relative humidity (at min. temperature) [%]: 25

Main operation features – water side

- Maximum output water flow rate [l/s]: 1
- Minimum output water flow rate [l/s]: 0.56
- Maximum water output temperature (heating) [°C]: 60
- Minimum water output temperature (heating) [°C]: 15
- Maximum water input temperature (heating) [°C]: 55
- Minimum water input temperature (heating) [°C]: 10
- Maximum water output temperature (cooling) [°C]: 35
- Minimum water output temperature (cooling) [°C]: 10
- Maximum water input temperature (cooling) [°C]: 40
- Minimum water input temperature (cooling) [°C]: 5
- Nominal input/output temperature drop [°C]: 3
- Maximum hydraulic system pressure [bar]: 6

3. Smart fan-coil

3.1. General description

The smart fan-coils are conceived to substitute radiators, using the existing 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 decentralized water-to-air heat pumps, by extracting or releasing heat to the hydronic network and thus providing heating/cooling/dehumidification in every room according to punctual needs. More in details, the smart fan-coils use a DC compressor to increase the thermal power 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 cooling mode, especially when the existing pipes are not equipped with thermal insulation.

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

3.2. System/components design

The smart fan-coil consists in a reverse-cycle water source heat pump system that must be installed inside the dwellings, with terminal units either taking heat from the water loop or injecting heat into it. The system can include any number of individual self-contained water source heat pump air-conditioning units connected to the closed water loop system.

The smart fan-coils can provide heating, heating/cooling: it consists in a fan coil unit which integrates a small-size rotary DC compressor (tween rotary) to increase the thermal power coming from the centralized DC heat pump, according to the energy demand of each room. It works both in heating and cooling mode. The unit comprises a hermetically sealed refrigeration circuit with refrigerant-to-air and refrigerant-to-water heat exchangers. The refrigeration circuit is reversed automatically by the user’s thermostat. Therefore, each heat exchanger acts either as an evaporator or condenser. The airside heat exchanger adds or removes heat from the room by passing air over the indoor coil, whilst the waterside heat exchanger either adds or extracts heat from the water loop. If the supply temperature from the water loop is enough, the unit can work as a traditional fan-coil unit thanks to the 3 intake fans installed above the heat exchanger. It works both in heating and cooling mode and the maximum thermal power is 3.2 kW.

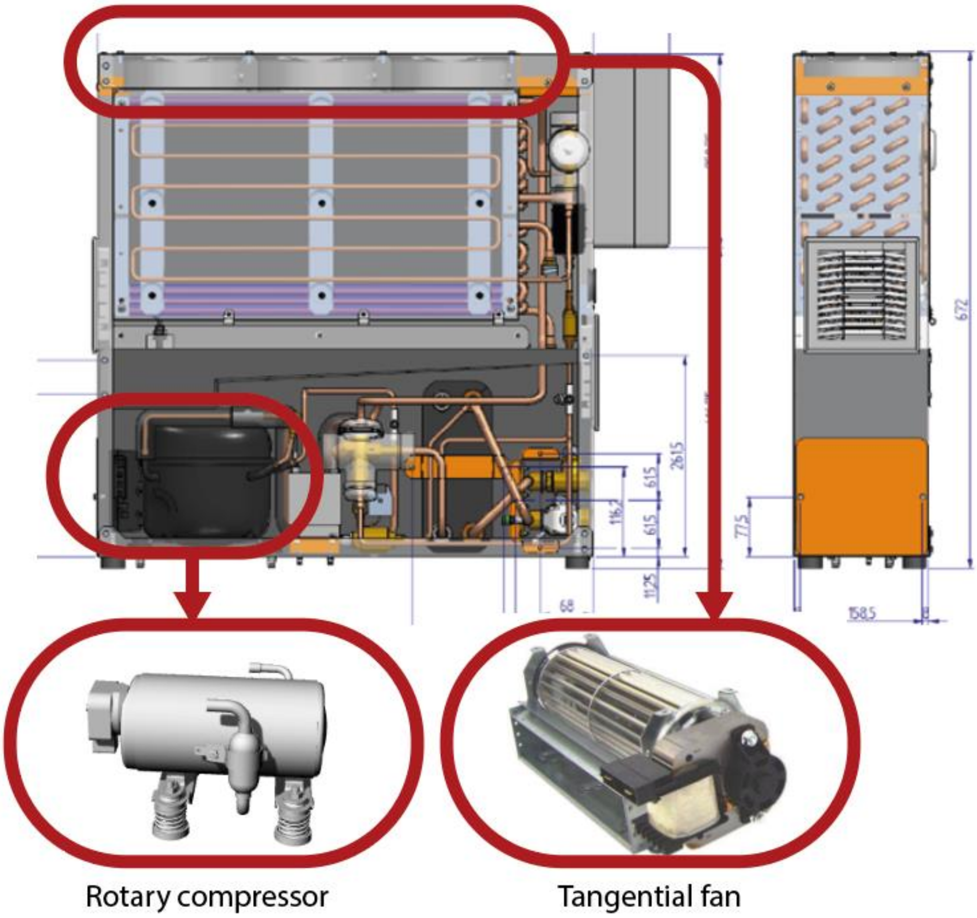

Figure 9. Preliminary size of the fan-coil unit without its cover (size: mm) with its main modification in respect to the HEART baseline

The main modifications in comparison to the component developed in HEART consist in the adoption of a different compressor and a ventilating fan (as shown in the figure above).
More in detail, the compressor consists in a tween rotary type unit which allow to:

- achieve better energy performance than the reciprocating one (used in HEART project);
- to facilitate the installation and maintenance due to the snap-in fittings rather that welded connections.

The adopted fan consists in a tangential type, characterized by higher air flow rate and low acoustic emission.
The main geometrical data of the new 2 components are reported hereafter.

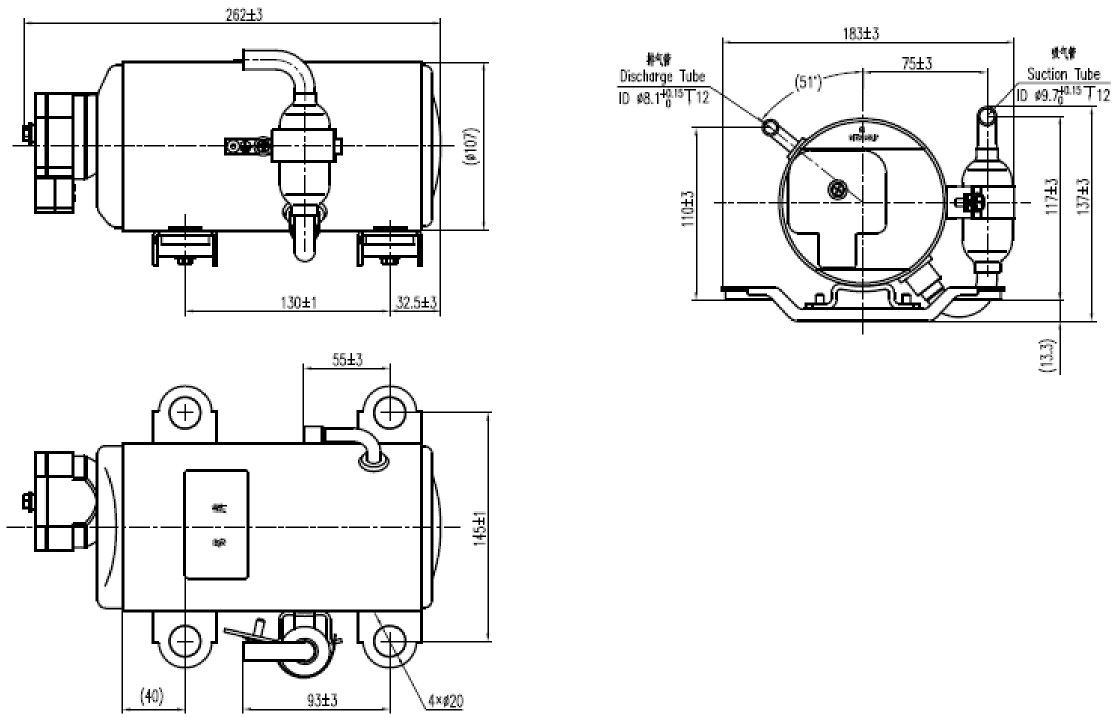

Figure 10. Layout of the tween rotary compressor (size: mm)

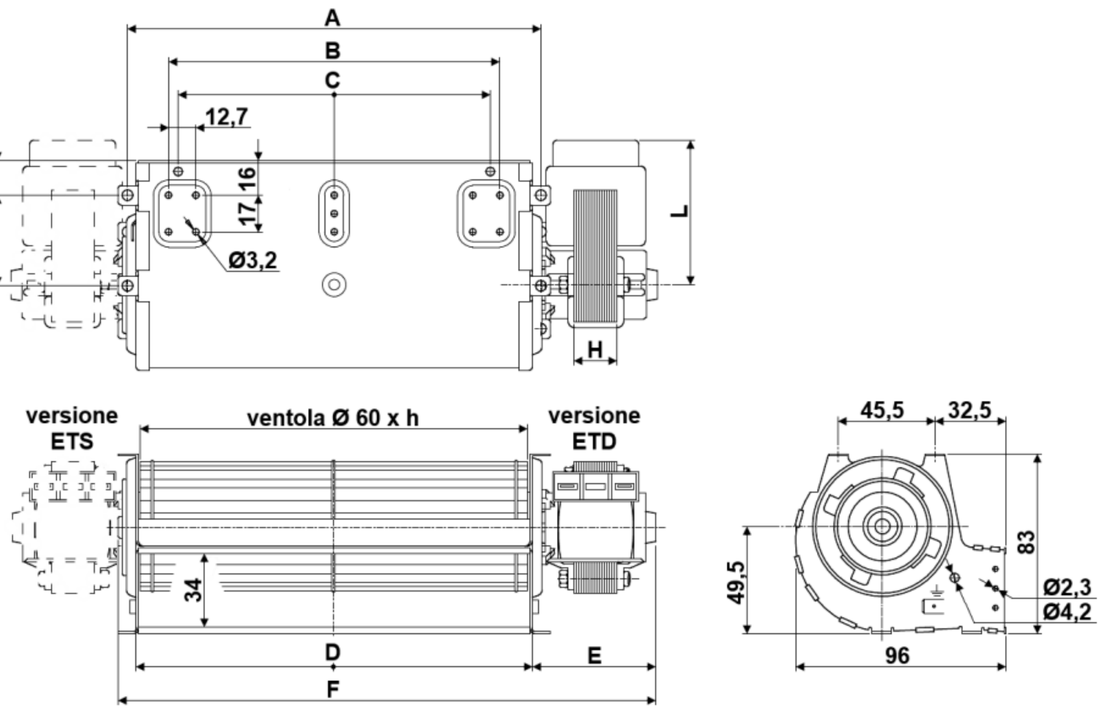

Figure 11. Layout of the tangential fan (size: mm) - A:433 B:394 C:385 D:424 E:86 F:510 H:40

A second component for the production of DHW will be also developed (Smart DHW boiler). It couples the same small-size DC compressor of the previous component to an insulated water tank and a second water heat exchanger, in order to provide and store DHW. The design of such component is ongoing, thus, it will be described in the next release of the deliverable.

3.3. Installation mode

In the following sections, the installation mode of the smart fan coil as well as the smart boiler are presented.

3.3.1. Smart fan coil

Smart fan-coil must be installed in each room that require heating/cooling (in place of traditional radiators) or in the bathroom/technical space in order to provide DHW. Since the component is able to provide a thermal capacity up to 3.2 kW, one component is able to cover heating/cooling needs of a room with an average floor surface of about 40 m^2.

The smart fan-coil unit consists in the following main components:

1) Air outlet grille.
2) Front or lateral intake grille.
3) Air filters.
4) Adjustable anti-vibration feet.
5) Water connections.
6) Power cable.

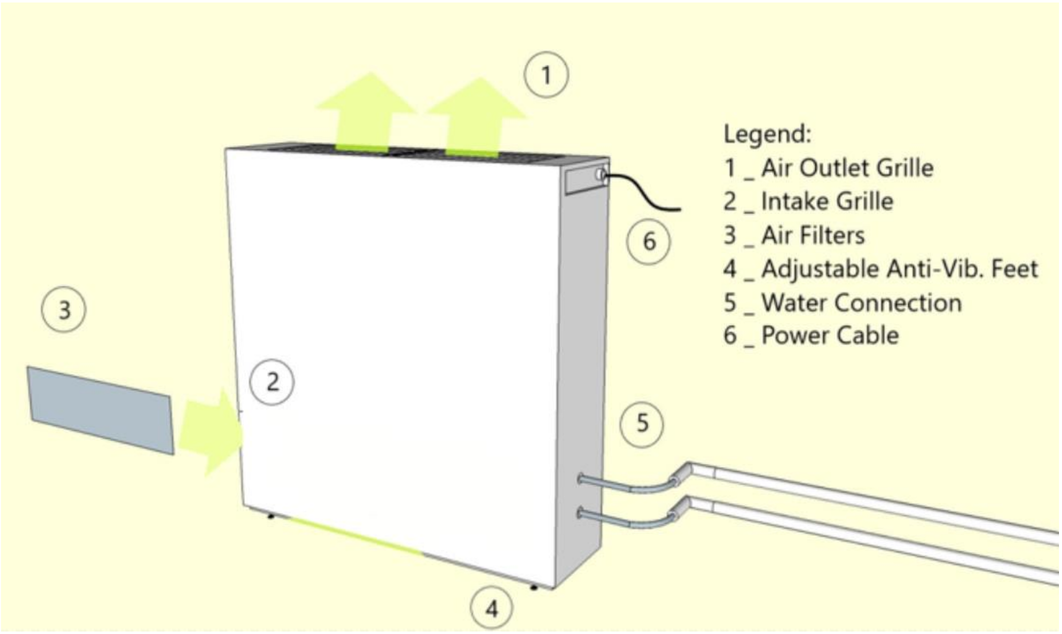

Figure 12. Main components of the smart fan-coil unit main components

In order to obtain the best operation of the terminal and to avoid faults or dangerous conditions, the following requirements must be met:

- leave a space around the unit necessary for possible maintenance operations (around 30 cm);
- there must not be any obstacles (e.g., curtains, plants, furniture) to the free circulation of air in the upper part (air expulsion) and on the lateral suction side; this could cause turbulence to inhibit the correct functioning of the appliance.

Before disassembling the existing radiator, it must be ensured that the heating system is not operating and that the hydronic pipes are empty. The radiator can hold several liters of water, before disassembling it must be equipped with special containers to empty it and rags to dry up any water drains. Remove the radiator from the housing by disconnecting it from the supply lines, removing the support brackets to which it is hanging.

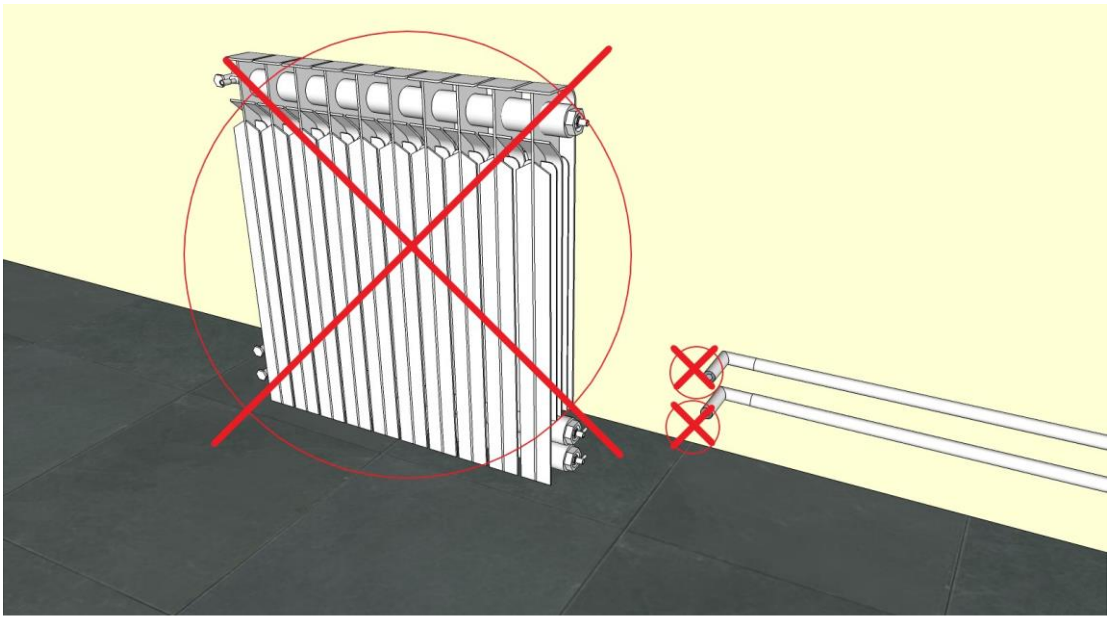

Figure 13. Remove existing radiator

Move the Smart fan-coil to the wall in the position where it will be installed and mark the position of the two anchorage holes of the new brackets.

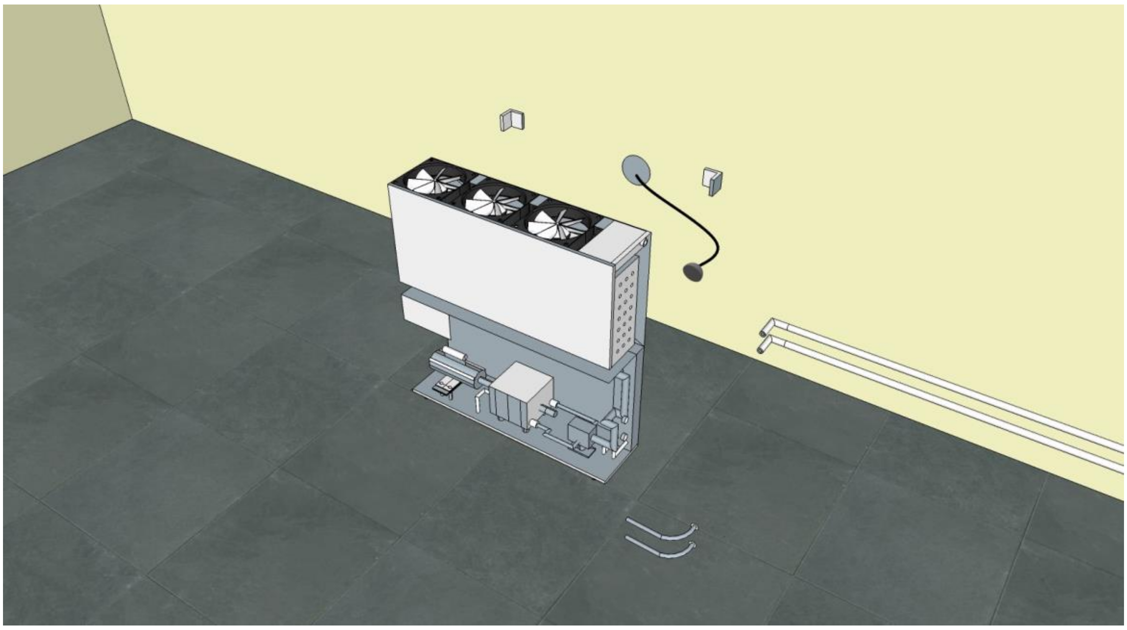

Figure 14. Position the fan-coil unit

After that you can move the terminal and tie the brackets to the wall. In such respect, drill (8 mm narrow) the wall for fixing the brackets, using appropriate equipment that facilitates your work and avoids excessive damage. To avoid the spread of large quantities of dust and debris in the environment, different models of drills can be coupled to suction systems consisting essentially of a vacuum cleaner to be connected to an accessory (suction type) to be placed close to the drill bit. After that bring the terminal close to the wall, making sure to match the wall anchors in the appropriate seats. Adjust the feet of the terminal so that it is perfectly level.

Figure 15. Rubber anchor

Fix the anchors to the metal structure of the terminal with the appropriate screws supplied. The next steps consist into the addition of the air filters inside the specific box in the body at the side air vents and assembly smart fan-coil cover.

Lay the body on the smart fan-coil body and fix it with the appropriate fixing screws.
Using the supplied hoses, it is now possible to connect the terminal to the power supply line. The terminal is equipped with two 1/2" female hooks on the right side, at a height of about 14 cm. Connect the male end of the hose to the terminal, previously wrapped in Teflon-type material or equivalent for ensure maximum water tightness. Tighten the connection properly. Connect the other end of the hose to the supply and drain points.
It should be noted that, depending on the existing connections on the power lines, it may be necessary to provide an adapter to ensure a correct connection. Before starting the installation, evaluate the need to use reducers, bends, or other special parts not supplied with the Smart fan-coil.
Once the water connections have been made it is possible to connect the electrical line. The appliance is ready to plug the power cord (48 V) coming from the wall with the unit.

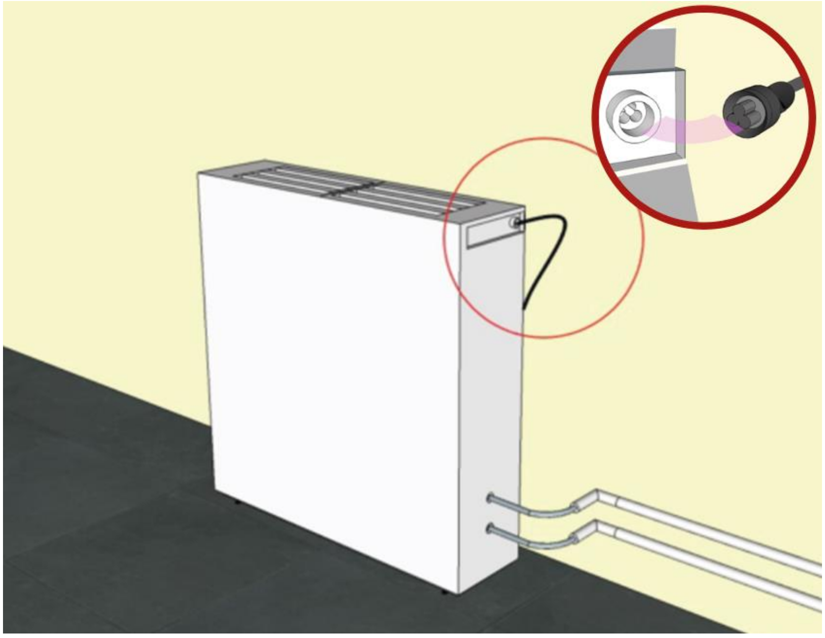

Figure 16. Power line connection

To prevent any risk of electric shock, it is essential to disconnect the main switch before making electrical connections and any maintenance operation on the devices.
These operations must be carried out with the machine already positioned, before completing the electrical connection.
After that the configuration of control logic (Master) and sensor can be done. 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 a bus connection or a wireless connection; this solution is currently under technical evaluation by CTIC.

3.3.2. Smart DHW Boiler

The smart DHW boiler's installation follows the same general rules of the fan coil unit. However, some different guidelines are required since it must be installed above the floor level.
In such respect, a special installation kit is required consisting of:

- n ° 2 L-shaped brackets.
- n ° 4 anchoring feet with anti-vibration bearing for wall installation.
- n ° 4 wall anchors for wall mounting.

After correctly defining the height where the brackets will be fixed, with the help of the drill prepare the wall anchors. The drilling of the wall must be done using appropriate equipment that facilitates your work and avoids excessive damage or disturbance to users. To avoid the spread of large quantities of dust and debris in the environment, different models of drills can be coupled to suction systems consisting essentially of a vacuum cleaner to be connected to an accessory (suction type) to be placed close to the drill bit.
In order to avoid plaster breakage as much as possible, it is necessary to proceed with caution when drilling the hole. If the wall is of poor consistency, it is advisable to use fixing bolts different from the standard Kit, depending on the type of wall and its consistency.
In any case, it is necessary a careful examination of the characteristics and consistency of the wall for the possible choice of pieces specific to particular situations.
Before positioning the terminal above the brackets, it is necessary to check that the support thus created is perfectly level. For correct operation and to avoid vibrations induced by inclinations and wrong positions, with the help of a level, make sure that the terminal is perfectly levelized.
Before laying the terminal on the support brackets, insert the anchor feet in place of the current feet. In order to carry out the replacement, lift the terminal and unscrew the support feet until they are completely unwound, and retighten the new anchoring feet in the same seat.
All lifting operations of the special terminals must be carried out in two or more persons, or with appropriate mechanical means, in order to avoid possible damages due to excessive loads. Place the terminal on its support brackets by matching the threaded parts of the anchor feet with the slots provided on the bracket arm. Before screwing the nuts to the feet place a special plastic gasket and washer.
The smart DHW boiler is also equipped with a power cord with plug (230 V).
Before connecting the smart DHW boiler, make sure that:

- The values of supply voltage and frequency comply with the specifications on the rating plate of the appliance.
- The power supply line is equipped with an effective earth connection and is correctly sized for maximum absorption of the air conditioner (minimum cable cross-section equal to 1.5 mm^2).
- The equipment is powered exclusively through a socket compatible with the plug supplied.

3.4. Operation mode

Both components integrate a small-size 48 DC compressor. Each unit comprises a hermetically sealed refrigeration circuit connected to a heat exchanger. The main performances are reported hereafter.

Technical features

- Power supply voltage [V]: 48 (72 as an option)
- Power supply current [A]: 5-7 (may change if 72 V will be adopted)
- Maximum air flow rate [m^3/h]: 500
- Compressor type: DC compressor, reciprocating
- Maximum useful thermal power (heating mode) [kW]: 1.4 – 3.2
- Maximum useful thermal power (cooling mode) [kW]: 1.2
- COP: 4.5 (W15A20)
- EER: 7.2 (W15A26)
- Maximum sound power in operating conditions [dBA]: ≈ 35

Regarding the control system, the components are equipped with an ON/OFF switch that enable their operation, while the main command such as temperature set, hourly set point, desired fan speed, winter/ summer set up will be managed through the RE-SKIN smart control system.
Since each STILLE system can provide both cooling or heating, regardless of the other units in the system, its configuration can be called a “4-pipes” operation.
Typical 4 pipes operation would be: evaporator inlet water temperature between 22 and 26°C and maximum temperature drop of 10°C. Optimal water flow for maximum performance would be approximately 2 l/min with maximum temperature drop, but this can be reduced according to maximum allowable water flow and the control system would reduce the speed of the compressor.
At a water temperature below 15°C in summer or above 35°C in winter the compressor will be switched off and the water flow will be diverted to the water coil for direct heat exchange with the air flow.
Each DHW storage unit will have total volume in the range 80-120 l and will store water at temperature between 45 and 50°C. DHW storage will be heated by water/water DC units. Since in this range the Legionella can become dangerous, an electric coil has been added in order to increase the temperature at least once a week at 60°C for 2 minutes.

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

4.1. General description

The MIMO is a multiple input multiple output system which is composed of power converters and whose aim is to manage the power flow among the batteries, the heat pump, the smart fan coils, the PV panels, the EV charger and the grid.

The aim of the MIMO system is to do all required power conversion with the highest efficiency, with the final scope to improve and simplify the use of renewable energies, to allow power dispatching at building scale and to reduce the consumption of fossil fuels in existing buildings.

The power levels, voltage levels and the modularity proposed are the ones that makes it most suitable to become a reference in the field from small buildings to large residential/tertiary buildings, covering all intermediate situations.

4.2. System/ components design

To perform in an efficient way, the MIMO is divided into different subcomponents, as follows.

1. *MIMO Main Unit*

   This unit is composed of a control card that will communicate with the RE-SKIN energy management system and with battery BMS system, and two power converters: a 4 leg AC-DC 15-20 kW inverter to interface the utility grid and a bidirectional 10 kW DC-DC converter to interface the battery.

   This whole system will be boxed and will have the appearance shown in the figure below. This box is intended to be stored in a service room with ventilation.

2. *MIMO Remote Units*

   These units are needed to interact with specific parts of the building sub-systems such as the PV panels and smart fan-coils.

   One option under evaluation is to have 1 DC/DC unit of per fan coil device and 1 power optimiser per PV panel.

   It may be possible, due to efficiency and economic reasons, that the remote units for fan coils will have a power rating of 2.5-3 kW instead of 300 W. This option is currently under evaluation.

The general block design of the MIMO is reported below; more in details the option with one DC/DC for each fan coil is presented first, and then the alternative with 1 DC/DC serving multiple fan coils is shown as an alternative.

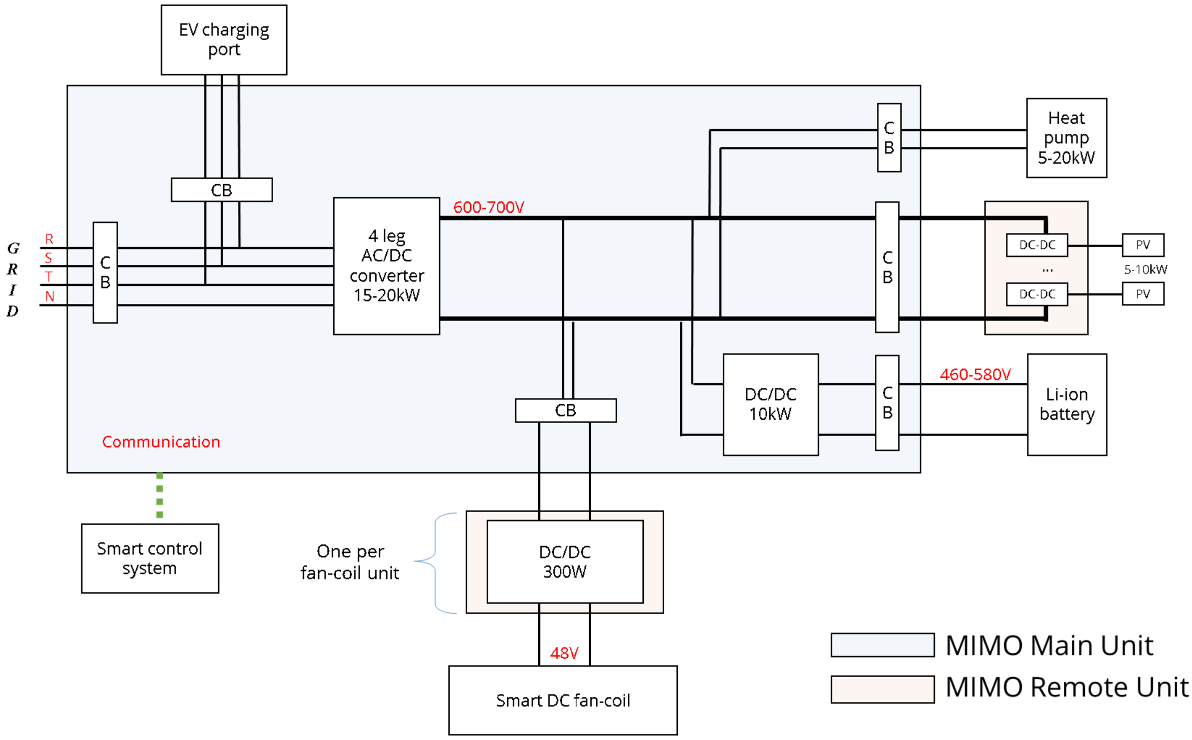

Figure 17. MIMO block design

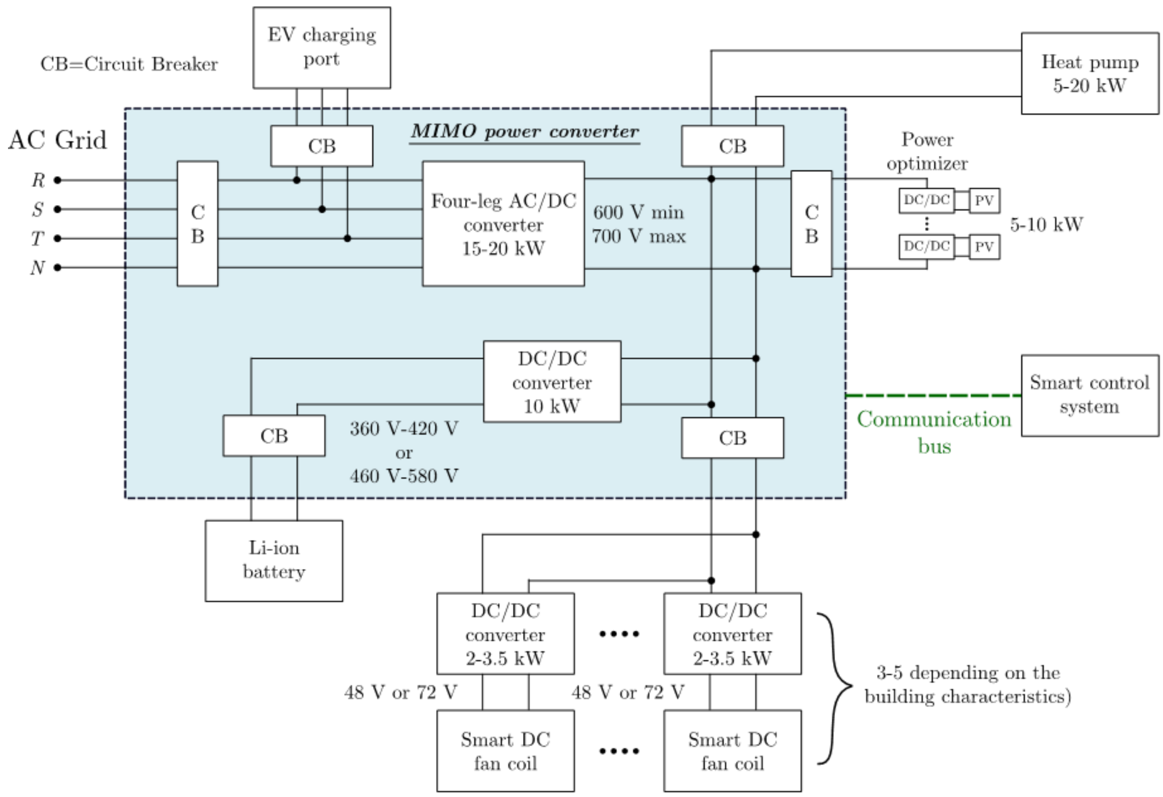

Figure 18. MIMO block design – Alternative configuration

Preliminary views of the above-described MIMO main unit and of the remote units are shown below.

Figure 19. MIMO Main Unit physical appearance

Figure 20. MIMO Remote Unit physical appearance, DC-DC fan-coil 300W unit (left) and DC-DC panel optimiser unit (right)

The main features of the MIMO unit under development are summarized below.

MIMO Main Unit

Size (Width, Height, Length) [mm]: 600*600*400

Weight [kg]: 40-50

MIMO Remote Unit: DC-DC fan coils 300W

Size (Length, Width, Height) [mm]: 240*120*70

weight [kg]: 2.5

MIMO Remote Unit: DC-DC panel optimisers

Size (Length, Width, Height) [mm]: 140*140*25

weight [kg]: 0.5

4.3. Installation mode

The main components of the MIMO system described above will be installed according to the scheme reported below.

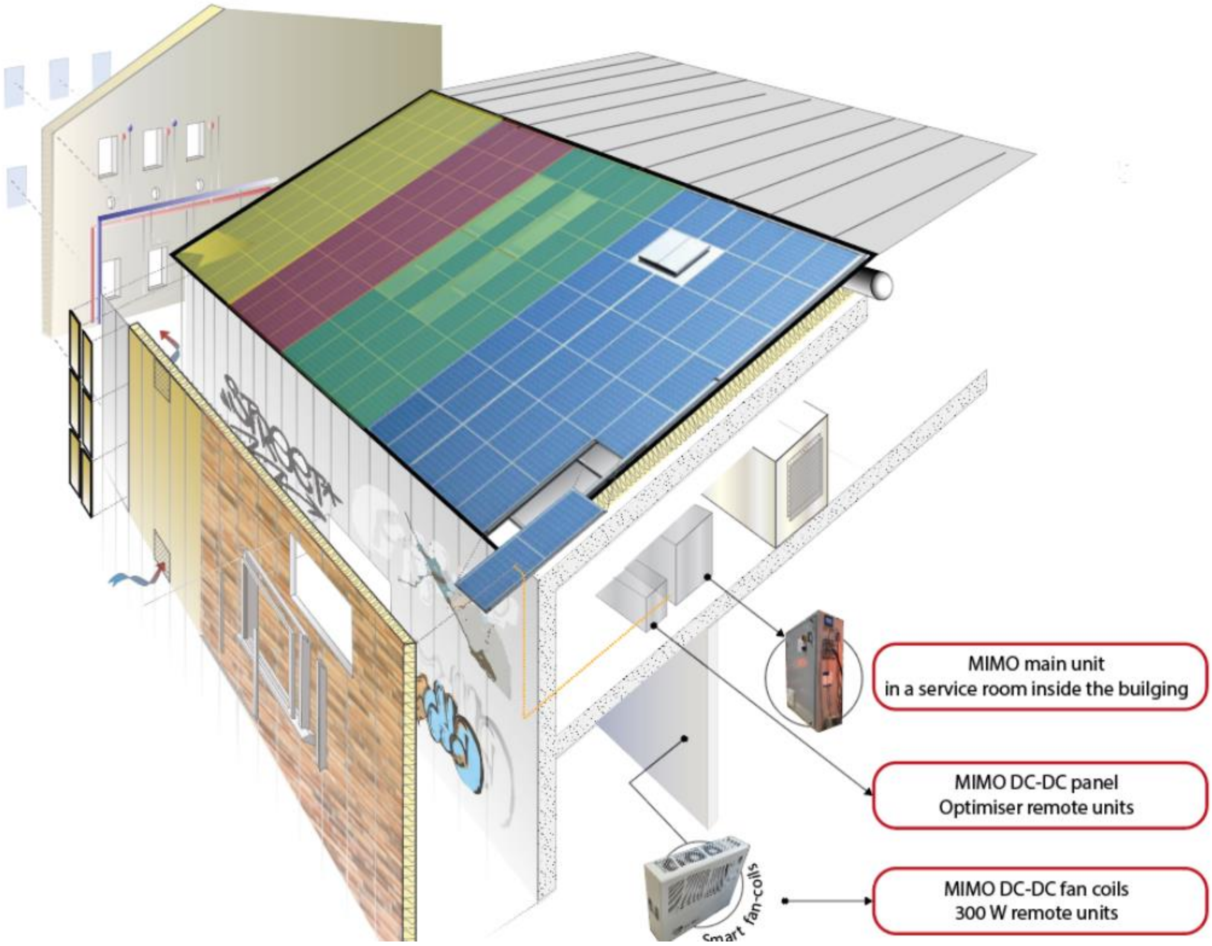

Figure 21. Installation of MIMO main components

Specific installation details are described in the following sections.

4.3.1. MIMO main unit

It must be installed in a service room inside the main building. It will be necessary to ensure certain conditions of temperature and separation with other items, as follows.

- Minimum operating air temperature [°C]: 5.
- Maximum operating air temperature [°C]: 45.
- Installation constraints: 300 mm in all sides except mounting side. Placed on a service room with ventilation.

4.3.2. MIMO remote unit for fan coils

In case multiple small-size DC-DC units are selected, they must be placed close to each fancoil, outside each flat. However, further assessments are ongoing on this topic, also considering the second configuration alternative, with bigger size DC/DC converters.
It will be necessary to ensure certain conditions of temperature and separation with other items, as follows.

- Minimum operating air temperature [°C]: 5
- Maximum operating air temperature [°C]: 45
- Installation constraints: 70 mm in all sides except mounting side. Placed between original wall and new façade of the building, next to windows with fan coil.

4.3.3. MIMO remote unit for PV panels

They will be placed below the PV panels and attached to the aluminium support. It will be necessary to ensure certain conditions of temperature and separation with other items, as follows.

- Minimum operating air temperature [°C]: -30
- Maximum operating air temperature [°C]: 60
- Installation constraints: 70 mm in all sides except mounting side. Placed on bottom side of PV panels.

4.4. Operation mode

To operate, the MIMO main unit will send its state and power balance to RE-SKIN energy management system. The latter will keep a historical analysis of the data of the operation and, by processing such information and other inputs (e.g., weather forecast) will determine the optimum power balance and mange power flows sanding back control signals to the MIMO.
The MIMO will implement the necessary actions to establish that scenario by communicating with connected subcomponents.

The operation of the MIMO, although it will be configurable by the RE-SKIN cloud system, will be invisible to all users/residents of the building and will not require further interaction by them.

Technical features

- AC/DC Four-leg converter port power [kW]: ≈ 15-20
- MIMO DC-bus voltage range [V]: min. 600 – max. 700
- DC-DC battery converter power [kW]: ≈ 10
- DC-DC battery converter voltage [V]: HV (600 –700) – LV (360 – 420 or 460 – 580)
- PV system power [kW]: ≈ 10 (power optimizer 300W – 600W each)
- DC-DC fan coil converter voltage [V]: HV (600 –700) – LV (48 or 72)
    - Solution 1: DC-DC fan coil converter power [W]: ≈ 300 (one per each fan-coil)
    - Solution 2: Three-to-five DC/DC converters with 2-3.5kW power each.

Energy performances

- AC/DC Four-leg converter port efficiency [%]: > 94
- DC-DC battery converter efficiency [%] > 93
- PV system efficiency [%] > 90
- DC-DC fan coil converter efficiency:
    - Solution 1: individual DC-DC fan coil converter efficiency [%]: > 90
    - Solution 2: Concentrated DC/DC converters efficiency [%]: > 92

5. EV charger

5.1. General description

The proposed electric vehicle charging station is an infrastructure consisting of one or more charging points for rechargeable electric and hybrid vehicles.
More in details, ENELX plans to use in RE-SKIN project different types of charging infrastructures, which can be grouped into the following two models: a wall mounted (JuiceBox) and free-standing (JuicePole) solution, respectively.
In both cases the EV charger will be powered and managed directly by the MIMO system.

5.2. System/ components design

The JuiceBox is an AC charging infrastructure which is capable of charging one vehicle at a time. It has power ranging from 3.7 kW to 22 kW.
It is suitable for single parking slots or for small-size applications, where the unit can be easily installed on a wall close to the parking place.
Considering a capacity of the EV battery of 80 kWh, the maximum charging time from 0% to 100%, takes 4-20 hours.

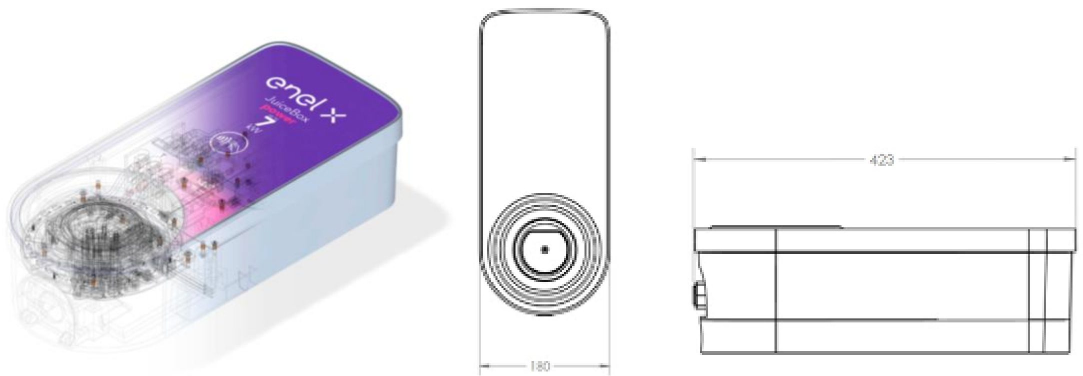

Figure 22. Main views of the JuiceBox EV charger (size: mm)

The JuicePole has a similar power electronics but can charge up to two vehicles simultaneously. It has a power of up to 22 kW.
It is suitable for public areas or parking slots that are not close to the building, thus where a free-standing unit is needed.

Considering a capacity of the EV battery of 80 kWh, the maximum charging time from 0% to 100%, takes around 4 hours.

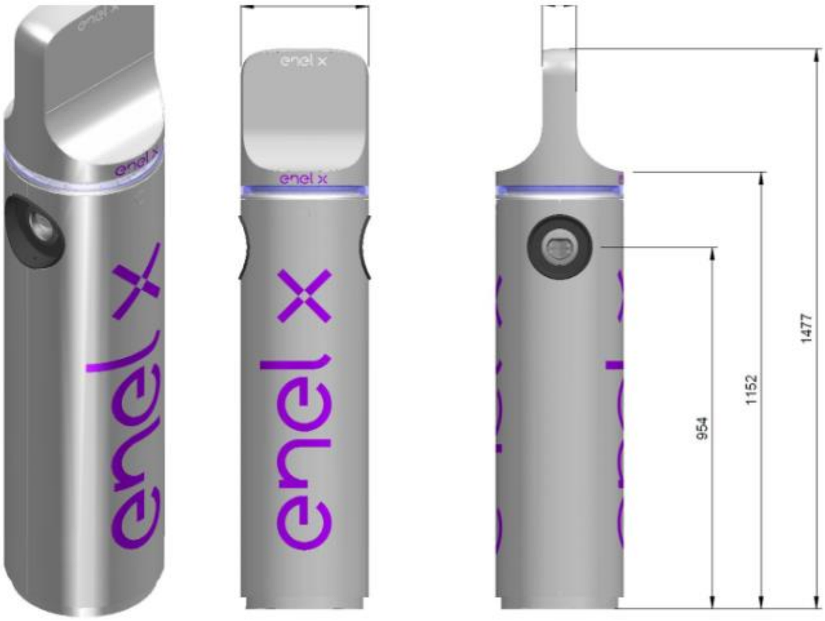

Figure 23. Main views of the JuicePole EV charger (size: mm)

5.3. Installation mode

The main installation instructions are provided below.

5.3.1. Juicebox

The JuiceBox must be installed by a qualified electrician according to the following specifications:

- it must be placed within range of the vehicle's charge port;
- a dedicated overcurrent protection device must be provided. It includes both a Curve D MCB (miniature circuit breaker) and Type A RCD (Residual Current Device), with the features summarized in the table below.

Table 4. Overcurrent protection device on each model of Juicebox

Juicebox model	Curve D MCB	Type A RCD
Juicebox 03 1-Phase 16A (up to 3 kW)	ICC: 6kA In: 25A Poles: 2	Id: 30mA In: 25A Poles: 2

Juicebox 07 1-Phase 32A (up to 7kW)	ICC: 15kA In: 40A Poles: 2	Id: 30mA In: 40A Poles: 2
Juicebox 22 3-Phase 32A (up to 22kW)	ICC: 15kA In: 40A Poles: 4	Id: 30mA In: 25A Poles: 2

- Use power cables with the following characteristics.

Each cable must have an earth resistance of less than 150 Ω. The power cable specifications are reported in the following table and are recommended for a normal installation. In some cases, such as when the cables must cover a large distance, a specific design of the cable is needed.

Table 5. Power cable characteristics (“concealed" refers to wires that are routed inside the walls of the installation site)

Juicebox model	Concealed	Not concealed
Juicebox 03 1-Phase (up to 3 kW)	SWA 230 VAC 1-Phase $4mm^2$ single-core cable for Phase/Neutral $4mm^2$ single core “green/yellow” cable for Earth	$4mm^2$ cables (x3)
Juicebox 07 1-Phase (up to 7kW)	SWA 230 VAC 1-Phase $6mm^2$ single-core cable for Phase/Neutral $6mm^2$ single core “green/yellow” cable for Earth	$6mm^2$ cables (x3)
Juicebox 22 3-Phase (up to 22kW)	SWA 400 VAC 3-Phase $6mm^2$ single-core cable for Phase/Neutral $6mm^2$ single core “green/yellow” cable for Earth	$6mm^2$ cables (x5)

5.3.2. Juicepole

Besides the main indications already provided in the section above, some specific installation guidelines are described hereafter.

Pole pre-disposition

1. Once the pole has been removed from its packaging and placed vertically on the mounting surface. With the key, open the front and back doors making sure to temporarily place them vertically and on a suitable surface, avoiding balancing them precariously.

Figure 24. Juicepole front panel pre-dispositioning

2. Unscrew the front Panel and set it to one side, together with its 10 screws. It should be noted that this step has not to be done with screwdriver.
3. Unscrew the "lexan" protection of the terminal block, placing it with the 2 screws in a safe place.

Positioning the Pole in situ

1. Remove the central cover of the cap and insert it on the clamps in the direction indicated by inserting the power cable in the central hole.
2. Place the pole on the clamp studs in the direction indicated by "FRONT" paying attention to the cable "part".
3. Position the pole on the 4 studs of the Clamps.
4. Fix it to the base with the screws provided.

Ground power wiring

1. Unscrew only on one side the metal cable tie of the terminal block. Prepare the power cable.
2. After having prepared the power cable and the main ground (eyelet cable lugs for M8 screw) operate the connection with the terminal block.

Concluding Operations

- Cross-check all Switches (Magneto-Thermal and Differential - Single phase and/or three phase).
- Reassemble the transparent "lexan" protection.
- Reassemble the terminal block protection.
- Reassemble the front Door.
- Place the 2 doors in their slots and lock them.

- Manage key storage according to established procedures.

After closing it, remove any film that has remained glued onto the top, side, front and back.

Final Operations

Once operations are completed:

- Verify the correct fastening and locking of the Apparatus.
- Verify the “working state” of the Apparatus.
- Retrieve all the equipment and store it away carefully.
- Retrieve any waste produced.
- Leaving the “environment” just as you found it.

5.4. Operation mode

5.4.1. Juciebox

Before setting up the JuiceBox, it is important to select the operating mode. The charger has 2 modes: *Connect & Charge* mode and *Unlock To Charge* mode, as described below.

Connect & Charge mode

- This mode is suggested when the JuiceBox is installed in a private area.
- This mode does not require any authentication to start or stop a charge. In this mode, it is not possible to set up delayed recharges, but the charging process will be managed by the MIMO.
- To start a charge, simply connect the JuiceBox to your vehicle.
- To stop a charge, send a stop command (from the app or your vehicle) and then disconnect your vehicle. JuiceBox is set to operate in *Connect & Charge* mode when first started.
- Is recommended to perform the steps to *Connect & Charge* online in order to remotely manage recharging, configure JuiceBox settings and other parameters.

Unlock-To-Charge mode

- This mode is suggested when the JuiceBox is installed in areas with public access.
- In Unlock-To-Charge mode, the JuiceBox recharges only after it has recognised an authorised user. Recharges are then started and stopped using an authorised profile on the JuicePass App, or an RFID card associated with the JuiceBox.
- This mode also allows to set up delayed recharge.

5.4.2. Juicepole

The two L and R sockets are managed by the internal control system simultaneously; namely it is possible to charge two electric vehicles at the same time.

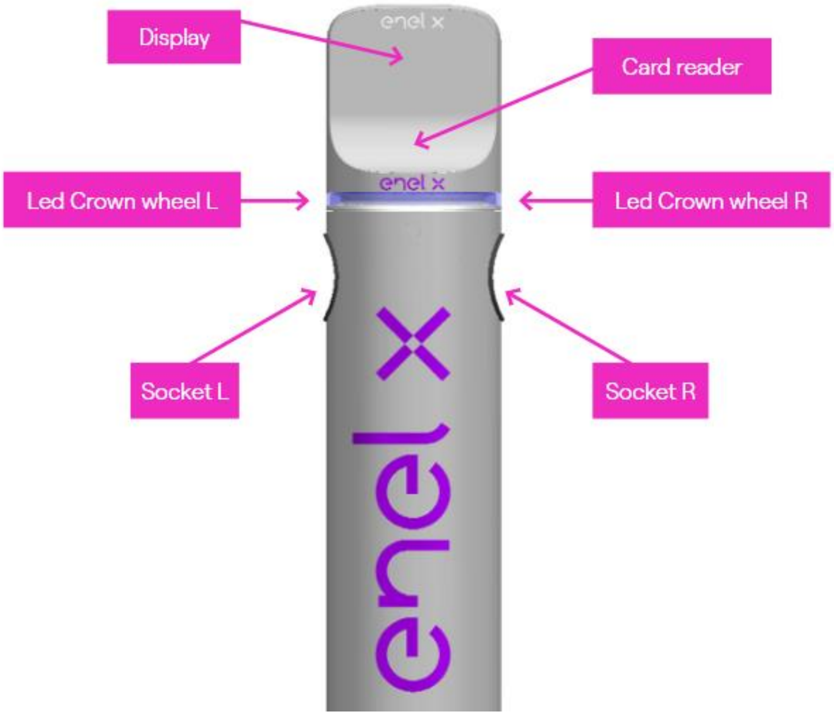

Figure 25. Details of the main elements of the Juicepole

The charging process can be managed just using an identification process; first, the user must identify him/herself via an RFID card or a mobile app; this function will be integrated in the cloud services of RE-SKIN package, also allowing advanced charging scenarios (e.g., the charging process is activated when there is in-excess PV energy). If the RFID card is accepted or the recharge is remotely activated, the display will notify it and the plug of the charging cable must be inserted into the chosen socket within 90 seconds (timeout). When 30 seconds are left, the screen shows a numerical countdown.

As soon as the charging session begins on the side where the plug is inserted, the dispensed energy in kWh will appear on the screen.

If, during the start of the charging session, a second (valid) RFID card is presented to the reader (or by using the mobile app) the plug of the charging cable should be inserted into the free socket within 90 seconds.

The supply from one socket ends when nearing the card to the RFID reader (or by using the app) and the screen summarizes the energy supplied during the charging process.

6. Battery pack

6.1. General description

The battery system is the electrical energy storage/buffer for the electrical appliances connected to the MIMO unit. The main purpose is to store PV electricity to be used to power the DC heat pump, the DC smart fan coils and other auxiliaries (e.g., pumps, fans, etc.).
The battery pack it is made of recycled battery cells extracted from Electrical Vehicles (EV). The pack will be installed preferentially inside the building, or in other protected outbuildings. The battery enclosure for the first prototype will be chosen among commercial solutions; this is because the long time to design and certify new products.

6.2. System/ components design

In detail, the battery bank for the first prototype will be made with recycled battery cells of the type LEV40 extracted from Mitsubishi Outlander PHEV. The cells are manufactured by the Japanese company GS-Yuasa. The nominal cell voltage is 3.75 V. They are enclosed in a plastic tray in group of 8 battery cell in series, forming together what we call a “battery bank” which will have a nominal voltage of 30 V. To limit the power loss in the cables and to limit the cable diameter the battery bank will work at a nominal voltage 540 V, which is the maximum nominal voltage acceptable by the MIMO. Consequently, the battery pack will be made by 18 battery banks for a total of 144 cells.
The fire prevention system will be of the aerosol type. It is triggered by an increment of temperature or by a smoke alarm (whatever happens first). An external alarm light will be installed on top of the enclosure.
The main features of the battery bank are summarized below.

Electric features

- Nominal voltage: 540 V
- Minimum voltage: 518.4 V
- Maximum voltage: 604.8 V
- Max charge current: 100 A software limited to 50 A
- Max discharge current: 240 A, software limited to 50 A
- Nominal Capacity (new battery): 40 Ah
- Min nominal capacity (recycled batteries) 28 Ah
- Energy storage: 15.12 kWh
- Max charging power limited to 27 kW
- Max di charging power limited to 27 kW

Mechanical features

- Dimension (L x W x H): 1640 x 440 x 1550 mm
- Battery cell weight: 1.4 kg/cell
- Battery bank weight: 12.5 kg
- Battery and enclosure total weight: 1000 kg

Enclosure features

- Material: steel
- Protection: IP54
- Protection paint: powder coating
- Opening: two front doors opening symmetrically on the total length

Figure 26. Internal view of 3 battery banks with 8 cells each during a test setup (parallel connection)

Figure 27. View of sealed battery banks with 8 cells in series with on top a single battery cell

Figure 28. Example of battery enclosure with inverters, battery charges, AC junction box

Figure 29. Detail and measurements of a battery enclosure (size:mm)

6.3. Installation mode

The batteries and related electronics (BMS and contactors) will be installed in the battery enclosure. The battery will be fully assembled for testing at SOLAR workplace. The battery cells are considered dangerous goods, therefore they have to be demounted before shipment and transported in certified trays of 8 cells each (i.e. a battery bank) to the final location (the case-study building). The battery banks will have to be installed in the battery enclosure on the building site.

The battery enclosure will be airtight to allow the installation of a gas-based fire extinguisher. It also has to be design in a way that it can be easily lifted and transported thru stairs and doors inside the building. Once in place the battery banks will be installed and connected with electrical and communication cables to the MIMO.

The battery should be installed in a dry place with minimum room temperature of 5°C and max temperature of 30°C. For such a reason, mechanical ventilation or air conditioning might be required. Room should be provided with smoke alarm detector and high temperature detector. A fire extinguisher should be installed in the room in conformity with the local laws.

6.4. Operation mode

As introduced, the battery bank will receive and store the electrical energy from the PV panels. The accumulated energy will be used to power the electrical loads in the building. The battery will be electrically connected only to the MIMO power electronic board which will therefore act also as battery charger/discharger. Furthermore, the BMS (Battery Management System) on board of the battery bank will communicate directly with the MIMO board.
The charging/discharging logics of the battery bank will be determined by the RE-SKIN smart control system and actuated by the MIMO, via the BMS. More in detail, the latter will control a contactor, which in the open position will electrically isolate the battery from the MIMO and the building.
The total number of cells has been chosen so that the minimum and maximum battery voltage are within the working voltage range of the MIMO.

Energy performances

- Nominal voltage [V]: 3.75
- Operating voltage range [V]: 2.75 to 4.1
- 1-hr rate typical Capacity at 25°C [Ah]: 40 Ah
- Charge voltage limit at 25°C (continuous) [V]: 4.1
- Charge voltage limit at 25°C (60mSec) [V]: 4.2
- Charge termination threshold current [A]: <0.5
- Maximum Charge Current (-25°C) [A]: 8
- Maximum Charge Current (-10°C) [A]: 20
- Maximum Charge Current (0°C) [A]: 40
- Maximum Charge Current (10-40°C) [A]: 100
- Maximum Charge Current (50°C) [A]: 80
- Maximum Charge Current (55°C) [A]: 40
- Maximum Charge Current (60°C) [A]: 16
- Maximum discharge continuous current [A]: 240

The main energy performance features of the 160-cells battery pack are provided below.

- Nominal voltage [V]: 600
- Operating voltage range [V]: 440 to 656
- Nominal capacity (new cells) [kWh]: 0.11
- Expected capacity at time of installation [kWh]: 16.8 kWh

7. Smart control system (SCS)

7.1. General Description

The Smart Control System (SCS) is a central component of the RE-SKIN package, orchestrating communication with other components to implement the best control strategy and allow monitoring/visualization services.
Additionally, the SCS communicates with the RE-SKIN cloud infrastructure to send notifications, data streams, and other required events.
Moreover, in accordance with the Edge Computing paradigm, the SCS may also run simple data processing pipelines if it is more efficient to do so compared to running them in the cloud.

7.2. System/ components design

The following figure shows a high-level architectural diagram of the expected SCS system in a single building.

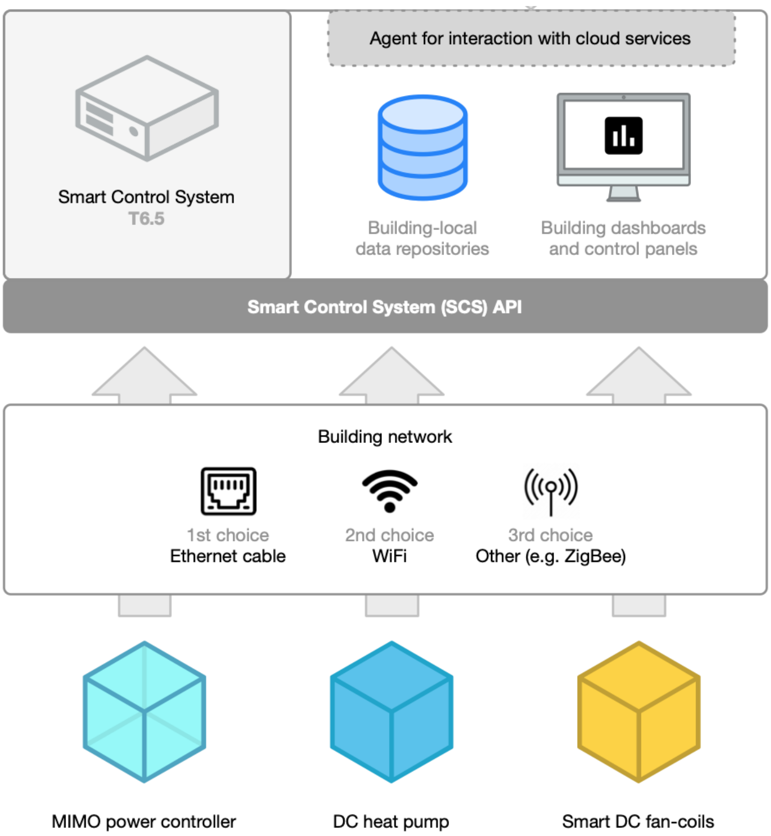

Figure 30. Architecture of the SCS system (top half) + network & components (bottom half)

7.3. Installation/Operation mode

Network communication

Although the network communication is not a part of the SCS, it is essential to the SCS. Because a reliable building network is critical to ensure adequate communication between the SCS and the building components, a fundamental requirement for smooth operation of the RE-SKIN toolkit.

For this reason, a wired bus/ethernet connection is preferred as a first choice, while a stable wireless connection may be an alternative addition. A wired connection is undoubtedly the most recommended option due to its reliability, speed, and low latency. Ethernet provides a stable connection with high bandwidth that guarantees the coverage and quality of transmissions throughout the building, even if it involves running cables through walls[1].

Ethernet wires should be of category 6 (Cat6) or category 7 (Cat7) with STP or SFTP shielding. Cat7 cable is better at protecting against possible degradation caused by crosstalk and EMI. Since Cat6 and Cat7 cables have a maximum cable segment run length of 100 meters, if the distance is greater than that a signal repeater (switch) in the middle is a must. If the cable is going to be secured to the exterior of a building it is recommended to use an exterior-grade Ethernet cable that's UV resistant and coated with PVC or LLDPE.

In cases where using an Ethernet wired connection is not possible, Wi-Fi is the second-best option, preferably using the latest technologies such as Wi-Fi 6 or mesh to ensure the best coverage possible. Nevertheless, the use of Ethernet and Wi-Fi are not mutually exclusive, being possible to use them in the same network, which means that some devices may communicate with the SCS via Ethernet cable and others via Wi-Fi.

SCS API

The SCS API will serve as the primary messaging interface used by most individual components in the RE-SKIN toolkit. This API defines the required data model for enabling interoperability between components.

While some components may use a push-based approach, where the component initiates communication to the SCS, others may use a pull-based approach (often referred to as polling), where the SCS initiates the communication. In any case, all components must comply with the interface of the SCS API.

[1] The hassle of running Ethernet cables through the walls of a residential building is eased by the specific design of the RE-SKIN facades.