RE-SKIN

D4.2 - Optimized technical specifications of each component II

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Deliverable Information Sheet

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Version	Date	Comments	Main Authors
0.1	12/12/2023	First draft, establishing document structure	N. Aste, F. Leonforte, C. Del Pero (POLIMI)
0.2	18/01/2024	First version, incorporating input from all participants	F. Leonforte, C. Del Pero (POLIMI)
0.3	29/01/2024	Quality review	A. Miglioli (ZH), A. Vallan (FPM)
1.0	31/01/2024	Final version addressing all further comments	F. Leonforte, C. Del Pero

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Disclaimer

1. Executive summary

This document contains the second release of the optimized technical specifications of each component of the RE-SKIN Toolkit. Thus, it represents the update of D4.1 and substantially describe the specifications of the components that will be installed in the first case study.

More in detail, in Chapter 2, an overview of the main components involved in RE-SKIN has been provided. In Chapter 3, a brief description of the methodology to carry out the preliminary LCA analysis for each component (according to the manufacturing data provided by the partners) has been reported. After that, in Chapters from 4 to 12, the technical specifications of each new or updated element were defined, in order to allow its synergic integration, considering the project objectives and the constraints related to the integration needs. The activity has been carried out updating the features of the components/solutions of each consortium partner, considering the development reached in the first 12 months of the project.

In Chapter 13, the components developed in RE-SKIN are identified by a unique and standardised way in order to create a registry where all the information, organised in datasheets, and the documents concerning different characteristics and performances can be collected, updated and shared between all the partners and stakeholders over time.

Further updates of each component will be documented in the next releases of this deliverable.

2. Overview of the RE-SKIN's components

RE-SKIN is a multifunctional toolkit within which tools and subcomponents cooperate organically to achieve high levels of energy efficiency and allow for an effective interface with the Smart Grid. The system is driven by a cloud-based platform, concentrating on management and operational logics that supports decision-making in the planning phase and optimizes energy performance during the whole lifecycle.

The main subcomponents developed within the project, preliminary described in the present document, are the following:

- Hybrid prefabricated photovoltaic-thermal roof, with refurbished PV modules, recycled aluminium profiles, boxed sustainable steel and biosourced insulation;
- Multifunctional prefabricated façade with self-supporting panels and biosourced insulation;
- Multi-Input/Multi-Output power controller to optimize interconnection among generation, storage and electric loads;
- Hydronic air-to-water DC modular heat pump;
- Battery pack for PV electricity storage and pick management, made with recycled electric vehicle batteries;
- Smart DC fan-coils for heating/cooling to replace existing radiators and be connected to the existing heating pipes;
- Cloud-based platform with DSS and BEMS functions;
- Smart charger for electric vehicles;

In the following sections a brief description of each component, as well as the main technical specifications, have been provided.

3. LCA evaluation method for the RE-SKIN's components

In line with RE-SKIN project goals and according to Level(s) – the EU framework for sustainable buildings – all components included into the proposed kit were subject to a Life Cycle Assessment (LCA) study. The LCA evaluation has been conducted using SimaPro software and Ecoinvent database, from which all background data were selected, except where specific Environmental Product Declarations (EPDs) are available.

In compliance with the LCA requirements set by Level(s), the main reference standard providing the calculation method is EN 15804 +A2. Although it includes characterisation, normalisation and weighting, the characterisation results are selected to evaluate the potential environmental impacts of RE-SKIN components. In particular, the focus is on the Global Warming Potential (GWP) of the greenhouse gases emitted, expressed in terms of kgCO2 equivalents and broken down into the different subcategories:

- Climate change - Fossil
- Climate change - Biogenic
- Climate change - Land use and LU change.

Moreover, with the aim to go a step further, other impact categories than GWP have been considered in performing LCA, for providing an overview of the most significant environmental hotspots and limiting the risk of burden shifting. For this purpose, the following additional indicators (total of 10 including GWP) has been examined:

- Climate change
- Ozone depletion
- Acidification
- Eutrophication, freshwater
- Eutrophication, marine
- Eutrophication, terrestrial
- Photochemical ozone formation
- Resource use, fossils
- Resource use, minerals and metals
- Water use.

The Functional Unit (FU) depends by the component at issue, being specified in the following sections in line with the reference unit used for the data collection (e.g., 1 piece, 1 kg, 1 ton).

Concerning the system boundaries, the LCA follows a from-cradle-to-gate approach. The assessment then evaluates all processes from the raw material extraction phase to the exit from the production plant (modules A1-A3) and excludes the phases of construction (A4-A5), use (B1-B7) and end-of-life (C1-C4). The decision to limit the system to the production phase was made to push from the outset the involved industrial partners to the collection of primary data related to the upstream and core phases of the component supply chain. During the project, the goal is to achieve a higher granularity of data for increasing the accuracy and reliability of LCA impacts, also extending the assessment to the downstream phases and shifting from the component level to the building level (case studies).

In the LCA modelling particular attention was paid to the selection of country-specific datasets, according to the location of the different production plants (currently considered the same of the industrial partners). Moreover, in case of missing data, all assessments consider an average transport distance of 1000 km via lorry with emission classes EURO 5, whereas they exclude the packaging of the input materials. Both scopes require further exploration, ultimately checking the mass balance and comparing LCA impacts with baseline models, in order to improve the LCA study. The following sections make evidence of the LCA analysis of each component, disclosing the LCA environmental impacts and hotspot analysis, focusing in particular on GWP.

It must be mentioned that these are Preliminary LCAs, intended as a simplified assessment that is conducted in the early phases of the project, to provide an initial estimation of the potential environmental impacts associated with RE-SKIN components. The objective is to identify for each component the key hotspots and, whenever possible, guide decision-making toward more sustainable solutions. Preliminary LCAs are seen as part of an iterative and evolving process. As more data becomes available and as the project advances, the LCAs will be refined and updated, both for the foreground and background systems, to provide more accurate and detailed insights.

4. Hybrid building-integrated photovoltaic-thermal (BIPVT) system

The BIPVT roofing system (Fig. 1) is organized according to a modular structure. The system is designed in order to be integrated in common sloped roofs, replacing the external covering, waterproof and insulation layers.

The upper cover is constituted by PV modules that can be characterized by various sizes. Within the module, the cell area can cover the entire glazed surface or can be distributed in a grid where the spacing between adjacent columns and rows can allow a direct gain of solar radiation to the backward absorber plate. Different performances can be achieved by changing the cell area density in order to balance electricity and thermal energy outputs of the system. The airflow into the gap (between the PV panel and the absorber plate) can be generated by using a fan (forced convection) or through buoyancy effect (natural convection). Fresh air removes the heat absorbed by the collector, cooling at the same time the rear of the PV module with the effect of an increment in the electrical conversion efficiency.

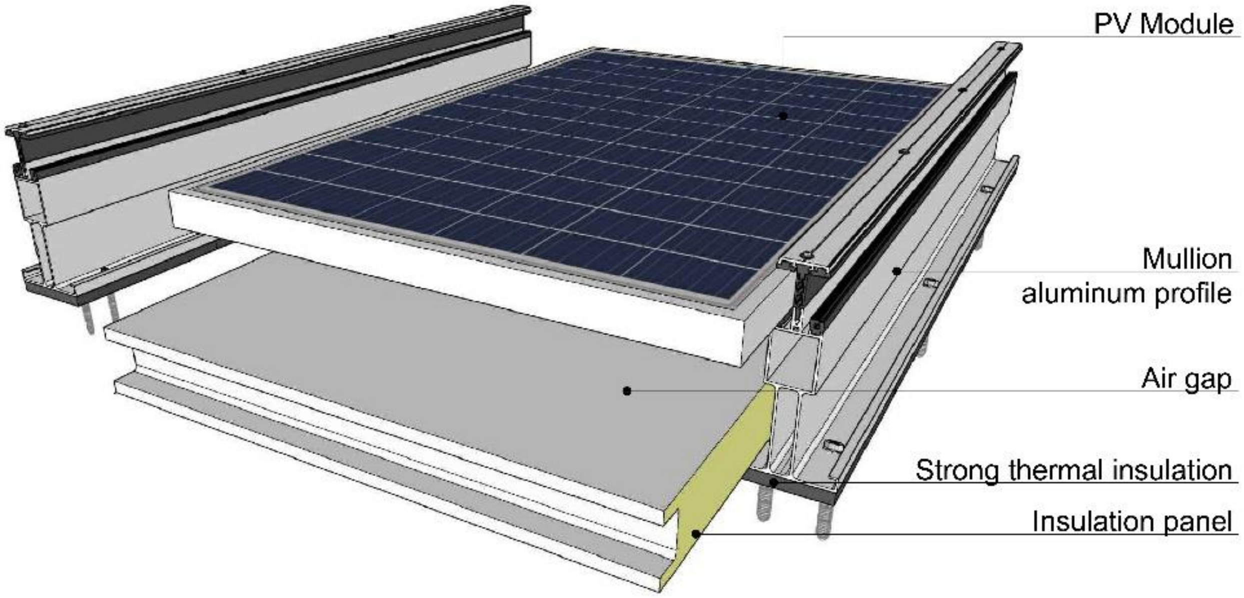


Figure 1. Schematic view of the BIPVT roof

The installation of the PV modules is provided through recycled aluminium profiles, joined to the underlying slab or roof framework. Inside the air gap formed by the channelled hybrid modules, box-shaped sheet metal panels, containing 8 cm thickness of bio-polyurethane foam.

The recycled aluminium profiles constitute the core interface structure and perform the functions of fixing, mechanical resistance, structural stability.
The PV modules are housed in the profiles in the same way as glass curtain façades and the gaskets guarantee water tightness and airtightness.
More in detail, the metallic profile has been designed with a cup-shape cross section, in order to allow, in the lower part, the perfect installation of the insulating box and, in the intermediate part, an air gap which enables the rear-ventilation of the modules, preventing them from overheating and heat recovery.
The profile is wider in the upper part, narrower in correspondence of the insulation housing and spread out at the base in a longitudinal plate with buttonholes for fixing screws to the underlying structure.
The profile is made by only 1 extruded piece in order to guarantee stability and resistant from wind, rain and snow and a strong thermal break insulation of 1.5 cm will be installed on the lower part of the profile to solve the thermal bridge.

In order to allow and balance the ventilation within the BIPVT system, a supply duct will be installed at the eaves of the roof, with grilles for air intake from outside. This horizontal duct will connect in parallel ducts made between the profiles below the photovoltaic modules, which at the top will be connected to a similar return duct near the roof ridge, connected to the heat pump (Fig. 2).

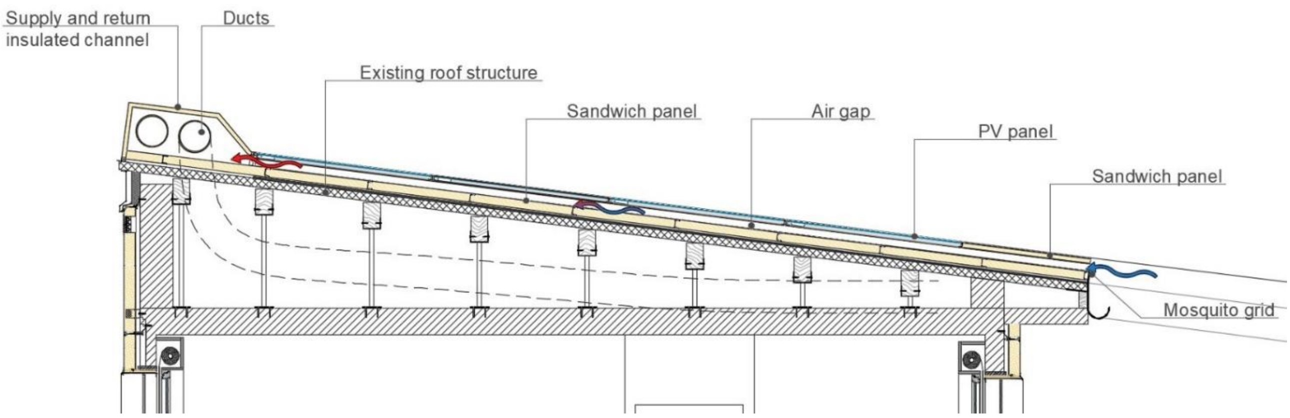


Figure 2. Section of the supply and return channel

4.1. Technical data and performances

The main technical data and performances of the system are listed below. It should be noted that the technical data reported hereafter are strictly related to the module size.

Dimensions

- Size of the modular system unit (Width/Height/Thickness) [cm]: 90-120/100-165/21.3-25 (as per refurbished PV modules available on the market)
- Weight [kg/m^2]: 25-30

Technical features

- Sound attenuation in operating conditions [dBA]: ≈ 30
- Water penetration: sealed
- Air tightness: Class A
- Reaction to fire (class): BS3D0

Energy performances

- Thermal transmittance [W/m^{2}K]: <0.25
- Electric efficiency [%]: 15-20
- Electric power output in STC [W$_p$/ m^2]: 150-200
- Maximum system voltage [V]: ≈ 1000
- Solar thermal power [W/m^2]: 150-200
- Thermal efficiency (UNI 8937) [%]: 20-45

4.2. Notes

The system is designed to host different sizes of PV module, for this reason the dimensions of the modular system unit are variable.

The metal profiles also serve as housing for the electrical wires of the system.

To complete the roof system, a special piece, called blind panel, will be integrated in aluminium profiles instead of the PV module. It consists of a folded metal sheet, manufactured in different sizes to be integrated in the BIPVT roof. Through this configuration it is possible to achieve an aesthetic uniformity of the roof. Such blind panels, in fact, can be used as special connection pieces for irregularly shaped application surfaces.

The portions of the roof not covered by the BIPVT system or by blind panels, will be equipped with standing seam sheeting, back insulated with the biosourced foam used in the BIPV roof.

4.3. LCA analysis

The BIPVT system included into RE-SKIN roof jointly integrates the photovoltaic modules, the thermal insulation panels and a ventilated air gap. As a supporting and connecting elements among the different parts, a set of longitudinal aluminium profiles (see 5.3 for LCA details) are placed in the form of interface structure over the flat/pitched roof, allowing the installation in sequence from bottom to top of insulating sandwich panels (see 5.3 for LCA details), free space for air circulation and the photovoltaic modules (see 11.3 for LCA details).

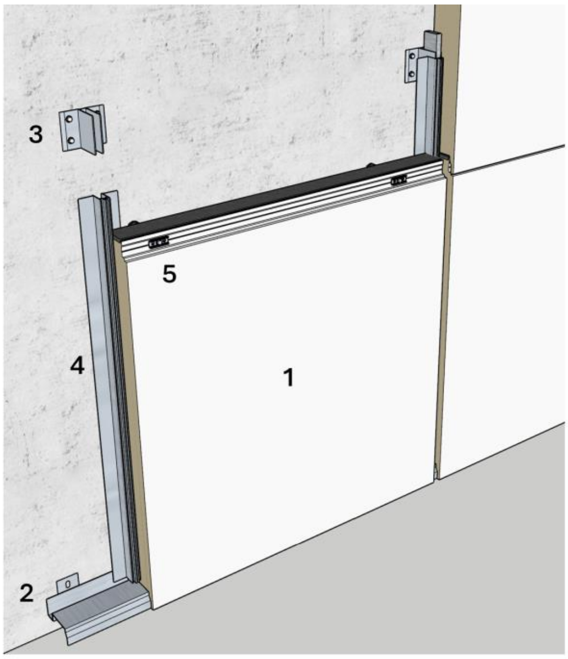
5. Modular multifunctional façade cladding

The multifunctional prefabricated façade system is organized according to a modular structure. The system is designed to be integrated into vertical facades, adding the outer layers of cladding, waterproofing and insulation.

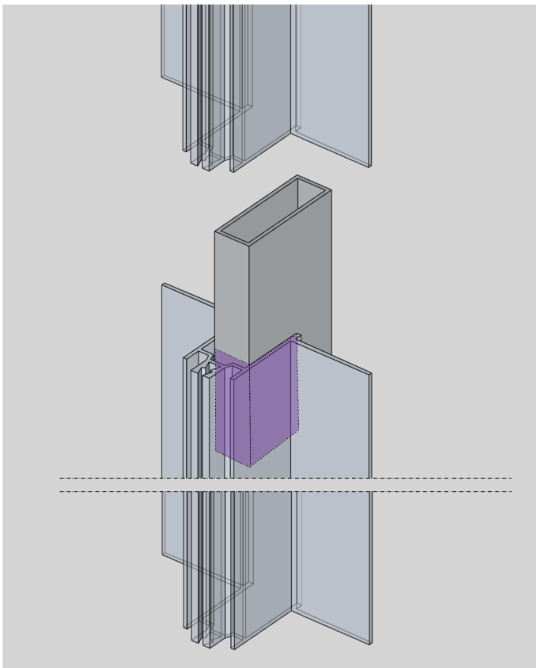
It comprises prefabricated panels in standardized size modules joined by a tongue-and-groove system that ensures watertightness and modularity to be adapted to variable geometries of buildings (Fig. 3).

The panels are made of high-strength steel sheets with weatherproofing and biobased coating on their outer face. The insulating section is incorporated with the injection of organic polyurethane compound with bioformulation. This way, it is possible to align with the environmental objectives of a circular economy and benefits of high energy savings in the different use cases.

The installation system is designed with an adaptive sealed chamber, spacing with a separation from the current façade, sufficient to host the new technical elements (e.g., wires, pipes, etc.). The internal chamber works as a thermal resistance when it acts as a sealed airtight gap in cold seasons, varying the transmissivity when the ventilation is opened in warm seasons.



1. Insulating panel
2. System start section for internal chamber regulation
3. Vertical profile fixing bracket
4. Vertical planimetry profile
5. Insulating panel direct fixings



Detail of the planimetry profile union of the system. In purple, the fixed part of the connector to the profile. The sliding part protrudes to absorb system expansions.

Figure 3. Main elements of the multifunctional cladding system

The installation is carried out with rectification profiles by which the system panels are supported, being fixed to the resistant facing by point fixings, allowing high design flexibility while minimizing thermal bridges. The profiles are made of aluminium and steel, with installation by means of extension connectors and brackets to absorb plumb and level imperfections of the existing walls.

5.1. Technical data and performances

The main technical data of the system are listed below.

Composition

- Foam core*:* bioPUR (Biobased content 60-70 %)
- Metallic sheet inner layer: 0.55 mm. S320GD + Z275. GreenCoat Pural BT – ca. 50 µm
- Metallic sheet outer layer: 0.70 mm. S280GD + Z275. GreenCoat Pural BT – ca. 50 µm

Dimensions

- Length [cm]: 25 - 600
- Width [cm]: 100
- Thickness [cm]: 6, 8, 10, 12
- Weight [kg/m^2]: 13.6, 14.4, 15.2, 15.9

Technical features

- Sound attenuation in operating conditions [dBA]: ≈ 30
- Water penetration: sealed
- Air tightness: Class A
- Reaction to fire (class): TBD

Mechanical performance

Simple SPAN (EN 14509-1)					
Bending Loads (Kg/m^2) L/200 *(Evenly distributed loads in kg/m^2)*					
	5	6	7	8	10
1.5 m	166	185	198	212	229
2.0 m	139	158	172	181	193
2.5 m	108	126	141	151	160
3.0 m	74	92	106	123	135
3.5 m	48	66	83	92	115

Double SPAN (EN 14509-1)					
Bending Loads (Kg/m^2) L/200 *(Evenly distributed loads in kg/m^2)*					
	5	6	7	8	10
1.5 m	255	284	304	310	318
2.0 m	214	243	265	278	298
2.5 m	166	194	216	231	238
3.0 m	114	141	164	181	197
3.5 m	74	102	127	131	149

** The values are estimated based on a similar panel used in the HEART project.*

Energy performances

- Thermal transmittance [W/m^{2}K]: <0.33 (thickness 60 mm)
- Thermal transmittance [W/m^{2}K]: <0.30 (thickness 80 mm)
- Thermal transmittance [W/m^{2}K]: <0.26 (thickness 100 mm)

5.2. Notes

At the junction points with individual façade elements (windows, corners, etc...), the specific elements will be designed and developed to compensate the dimensional tolerances.

On balconies it is possible to maintain the same solution as the rest of the façade, unless the dimensions are too small or there are installations that cannot be removed. In the latter case, a tailored solution will be proposed.

The coverage of gas piping will be resolved with specific elements that ensure ventilation and thus compliance with fire prevention rules.

It should be noted that before the application of the panel on the facade, a substructure must be installed. The main properties of the substructure are as follows:

- Mounting profiles and brackets material: Aluminium and galvanized steel
- Recycled content rate of Aluminium: 98%
- Reaction to fire (class): A1 (No contribution to fire)

5.3. LCA analysis

RE-SKIN toolkit includes a precast solution for both the façade and roof systems, composed of sandwich panels interconnected by means of tongue-and-groove joint and subsequently installed over a substructure to cover the existing building. The sandwich panels consist of a core of a novel biosourced polyurethane (bioPUR) foam with two different coating layers depending on exposure. The outer layer is made of Greencoat sustainable steel sourced from SSAB, while the inner layer is made of steel.

Since the sandwich panel is still under development within RE-SKIN project, the preliminary LCA analysis is carried out for the specific constituent elements based on the available data retrieved from producers. It should be mentioned that the finished component for the roof solution is now in the prototyping phase at the plant of INDRE's and GAR's subcontractor, that will thereafter take care of the façade system solution.

BioPUR foam

The functional unit of the LCA study is 1 kg of BioPUR rigid foam, specifically *BioPUR-polIso 11.78* insulation (UF = 1 kg), with the distinct technical and performance features of the RE-SKIN component provided by INDRE. Note that the reference unit used by the manufacturer for the data collection is 500 kg of BioPUR foam. For setting the LCA inventory, the quantitative data were therefore converted into 1 kg.

BioPUR foam - UF = 1 kg		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	5,12E+00	kg CO2 eq
Climate change - Fossil	5,65E+00	kg CO2 eq
Climate change - Biogenic	-7,59E-01	kg CO2 eq
Climate change - Land use and LU change	2,20E-01	kg CO2 eq
other environmental impacts		
Ozone depletion	5,74E-07	kg CFC11 eq
Acidification	4,15E-02	mol H+ eq
Eutrophication, freshwater	1,76E-03	kg P eq
Eutrophication, marine	1,37E-02	kg N eq
Eutrophication, terrestrial	9,59E-02	mol N eq
Photochemical ozone formation	2,19E-02	kg NMVOC eq
Resource use, fossils	8,90E+01	MJ
Resource use, minerals and metals	7,41E-05	kg Sb eq
Water use	3,74E+00	m3 depriv.

Figure 4. Environmental impacts (A1-A3) of BioPUR foam, UF = 1 kg.

The BioPUR foam modelling (Fig. 4) turns out to be mostly complete, apart from the missing quantitative data on the packaging of the input materials. Instead, primary data related to the packaging of the finished component are included, as well as transport distances actually travelled from supplier to the production plant is considered. Note that the inventory omits polyols specifications, because of extremely sensitive information, only accessible to the people involved in the LCA study. For this reason, polyols are anonymised (*Polyol A / B / C / D*) and the composition is expressed as the overall amount of kg. By considering the production plant in Spain (ES), country-specific datasets were selected for waste and energy, including both the electricity for injection machine and compressor.

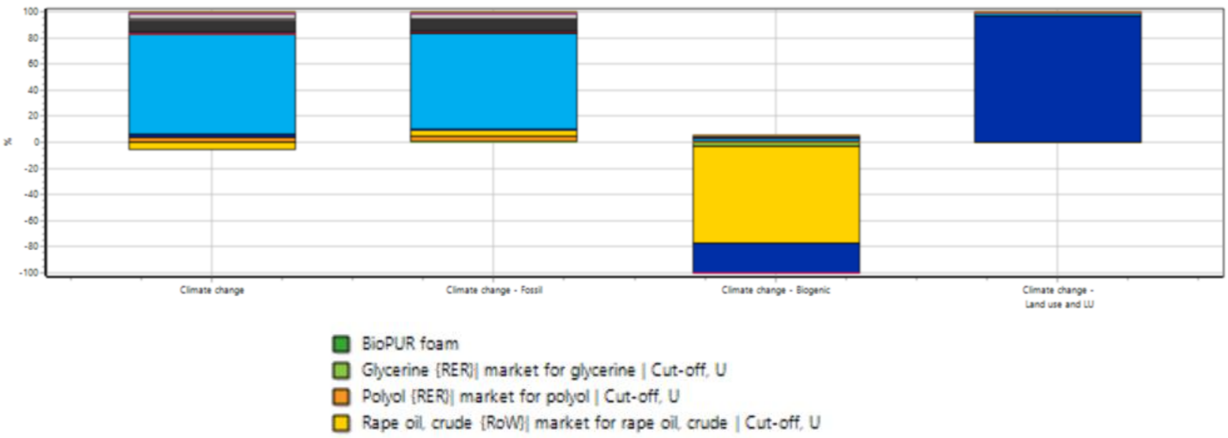


Figure 5. GWP hotspot analysis (A1-A3) of BioPUR foam, UF = 1 kg.
Colours that do not appear in the legend are described in the text.

From LCA results of BioPUR foam (Fig. 5), the most significant environmental hotspot results to be *Isocyanate* (light blue-coloured), corresponding to 76.5% of total GWP impacts. To a slightly lesser degree, it is followed by IBC Container (black-coloured) with a rate of 9.6% of total GWP impacts. Regarding the GWP impacts related to biogenic sources, it is important to highlight that the negative values are associated specifically to *Polyol C* (yellow-coloured) and to *Polyol D* (blue-coloured). Even *Tris phosphate* used during the process as fire retardant is remarkable for other environmental impacts.

GreenCoat steel

The outer layer of sandwich panel is made of GreenCoat steel, a material for which EPD certification is available on the market. Specific EPD-sourced data are thus reported for the LCA study. The certification owner is SSAB and the program operator is International EPD System. The LCA evaluation at the base of the EPD is developed with GaBi software and GaBi LCA Databases, adopting the EN 15804 +A1 and EN 15804 +A2 calculation methods.

The EPD functional unit is 1 tonne of colour coated steel sheets and coils (UF = 1 ton). Note that GreenCoat products are available in a wide variety of colours and finishes, with typical thickness ranging from 0.45 mm to 1.5 mm. Here, the composition of GreenCoat steel is based on a typical example of colour coated product used especially within construction industry. In particular, the weight percentages have been calculated for a colour coated product with 0.45 mm steel thickness with Z100 zinc coating.

GreenCoat steel - UF = 1 ton		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	2,71E+03	kg CO2 eq
Climate change - Fossil	2,71E+03	kg CO2 eq
Climate change - Biogenic	8,93E-01	kg CO2 eq
Climate change - Land use and LU change	8,90E-01	kg CO2 eq
other environmental impacts		
Ozone depletion	1,54E-08	kg CFC11 eq
Acidification	7,27E+00	mol H+ eq
Eutrophication, freshwater	2,86E-03	kg P eq
Eutrophication, marine	1,82E+00	kg N eq
Eutrophication, terrestrial	1,96E+01	mol N eq
Photochemical ozone formation	5,49E+00	kg NMVOC eq
Resource use, fossils	3,34E+04	MJ
Resource use, minerals and metals	1,74E-01	kg Sb eq
Water use	2,06E+02	m3 depriv.

Figure 6. Environmental impacts (A1-A3) of GreenCoat steel, UF = 1 ton.

The scope of the declaration covers from cradle to the gate (modules A1-A3), including end-of-life processing (modules C3-C4) and recycling (module D). Consistent with the other RE-SKIN components, the focus is on the production process of SSAB colour coated steel coils and sheets, which occur in the manufacturing plants in Finland and in Sweden. The system boundary therefore extends from (A1) the mining of raw materials, such as iron ore and coal; (A2) transport to and within the manufacturing site; (A3) coke, iron and steel manufacture; ancillary service operations; hot rolling of steel products, cold rolling, metal coating, colour coating and packaging for dispatch to customers at the exit gate of the manufacturing site. It also includes manufacture of other required input materials, transport between processing operations, the production of external services such as electricity, natural gas and water, and the production of by-products within the steelmaking process.
From the LCA results (Fig. 6), it is worth mentioning that GreenCoat products feature a Bio-based Technology (BT) coating with a substantial portion of the traditional fossil oil replaced by Swedish rapeseed oil. This patented SSAB solution reduces the environmental footprint of GreenCoat products, exploiting also approximately 20% of scrap steel in conjunction with steel production in the Nordics.

Aluminium substructure

The functional unit of the LCA study is 1 tonne of recycled aluminium mounting structure (UF = 1 ton), with the distinct technical and performance features of the RE-SKIN component provided by Garcia Rama. According to the declaration of the supplier EXLABESA, the recycled aluminium rate is 98% for the profiles provided to attach sandwich panels to the existing façade. The LCA results are shown in Fig. 7.

Aluminium substructure - UF = 1 ton		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	1,98E+00	kg CO2 eq
Climate change - Fossil	1,99E+00	kg CO2 eq
Climate change - Biogenic	-1,46E-02	kg CO2 eq
Climate change - Land use and LU change	7,48E-03	kg CO2 eq
other environmental impacts		
Ozone depletion	3,78E-08	kg CFC11 eq
Acidification	7,14E-03	mol H+ eq
Eutrophication, freshwater	6,12E-04	kg P eq
Eutrophication, marine	1,51E-03	kg N eq
Eutrophication, terrestrial	1,47E-02	mol N eq
Photochemical ozone formation	5,51E-03	kg NMVOC eq
Resource use, fossils	2,61E+01	MJ
Resource use, minerals and metals	3,16E-06	kg Sb eq
Water use	-3,75E-01	m3 depriv.

Figure 7. Environmental impacts (A1-A3) of Aluminium substructure, UF = 1 ton.

The modelling of the aluminium substructure is based on the *Environmental Profile Report for the European Aluminium Industry* (https://european-aluminium.eu/wp-content/uploads/2022/10/environmental-profile-report-for-the-european-aluminium-industry.pdf), considering in particular extrusion production. Here, indeed, the specific inputs and outputs are reported respectively for the aluminium extrusion production chain and for the process scrap remelting, normalising data to the production of 1 tonne of extrusion. The breakdown performed by the European Aluminium Association for the quantitative data – extrusion and scrap remelting – allows to assess the specific recycled content of RE-SKIN component. Accordingly, the original inventory for the extruded aluminium is adjusted, accounting the input and output resources with 2% extrusion quantity and 98% scrap remelting quantity. In addition, whenever possible, country-specific datasets are selected for the modelling, considering the production site in Spain (ES).

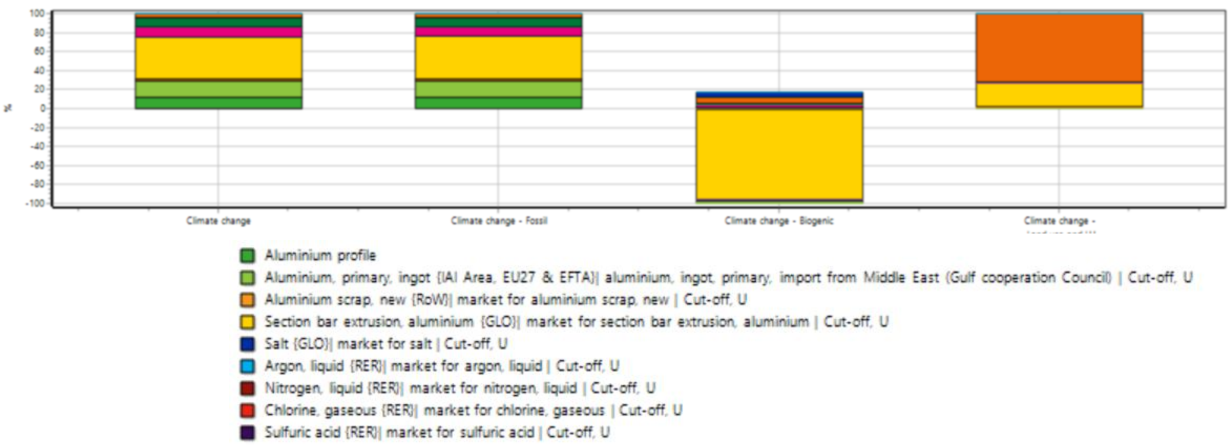


Figure 8. GWP hotspot analysis (A1-A3) of Aluminium substructure, UF = 1 ton. Colours that do not appear in the legend are described in the text.

LCA results (Fig. 8) show how the most significant environmental hotspot of Aluminium substructure is *Section bar extrusion* (yellow-coloured), accounting 44.6% of total GWP impacts, followed by *Aluminium ingot* (light green-coloured) and *Aluminium direct emissions* (medium green-coloured), respectively with a share of 17.5% and 11.6% of total GWP impacts. By widening the attention to other environmental impacts, also *Natural gas, Transport* and *Electricity* turn out to be crucial, with different contributes depending on the category under investigation.

6. Smart fan-coil

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

Figure 9. Preliminary view of the smart fan-coil without (left) and with (right) metal casing

6.1. Technical features and performances

The main technical features and performances of the fan-coil are listed below.

<u>Dimensions</u>

- Size (Length, Width, Height) [mm]: 1000, 200, 700
- Weight [kg]: 44

Technical features

- Power supply voltage [V]: 48
- Power supply current [A]: 3-18
- Maximum air flow rate [m^3/h]: 360
- Compressor type: DC compressor, TWIN ROTOR

Energy performances

- Maximum useful thermal power (heating mode) [kW]: 1.4 - 2.8
- Maximum useful thermal power (cooling mode) [kW]: 1.2 - 1.7
- COP: 5 (W15A20)
- EER: 7.2 (W15A26)
- Maximum sound pressure in operating conditions [dBA]: ≈ 35

6.2. LCA analysis

The functional unit of the LCA study is 1 Smart fan-coil (UF = 1 p), with the distinct technical and performance features of the RE-SKIN component provided by the manufacture (STILLE).

Smart fan-coil - UF = 1 p		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	1,32E+03	kg CO2 eq
Climate change - Fossil	1,24E+03	kg CO2 eq
Climate change - Biogenic	8,32E+01	kg CO2 eq
Climate change - Land use and LU change	7,48E-01	kg CO2 eq
other environmental impacts		
Ozone depletion	2,27E-05	kg CFC11 eq
Acidification	1,95E+01	mol H+ eq
Eutrophication, freshwater	1,68E+00	kg P eq
Eutrophication, marine	1,58E+00	kg N eq
Eutrophication, terrestrial	1,58E+01	mol N eq
Photochemical ozone formation	5,21E+00	kg NMVOC eq
Resource use, fossils	1,80E+04	MJ
Resource use, minerals and metals	1,33E-01	kg Sb eq
Water use	4,56E+02	m3 depriv.

Figure 10. Environmental impacts (A1-A3) of Smart fan-coil, UF = 1 p.

The present Smart fan-coil LCA modelling (Fig. 10) turns out to be partially incomplete due to missing data especially about the packaging, of both input materials and finished component, as well as for the resources in output. The data gaps on transport were filled in by assuming 1000 km as average distance for the supply of all input materials to the production plant. Further data are expected by the manufacturer in order to extend the assessment. In addition, it should be noted that energy consumption has been evaluated by the manufacturer using reference product, taking into account all energy required for the production processes of pre-assembled units, such as compressor and other parts (fans, valves, etc). The final assembly requires less than 5% of the total amount of energy.

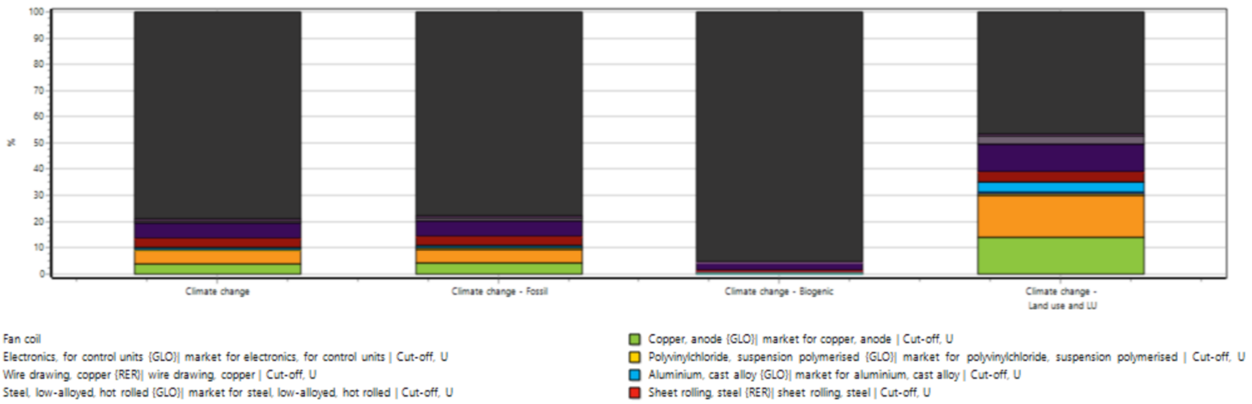


Figure 11. GWP hotspot analysis (A1-A3) of Smart fan-coil, UF = 1 p. Colours that do not appear in the legend are described in the text.

LCA results (Fig. 11) display as leading environmental hotspot of Smart fan-coil the *Electricity low voltage* (dark grey-coloured), modelled with the country-specific energy-mix, considering the production site in Croatia (HR). Indeed, it reaches to 79.1% of total GWP impacts, leaving in second place *Stainless steel* (purple-coloured), accounting 5.9%, and in third place *Electronics for control unit* (orange-coloured) with 4.94% of total GWP impacts. Looking into all environmental impacts, the other contributions towards directing attention are *Copper*, *Steel* and *Brass*.

7. DC Heat Pump

The heat pump is designed to easy substitute an existing boiler using fossil energy sources. It is coupled with buffer tanks to store heat energy. The main energy consumption of the heat pump is due to compressor, and it runs by DC power supply.
The heat pump is air-to-water, therefore, it uses ambient air as an heat source. The typical structure of an air-source heat pump consists in an outdoor unit and an indoor unit, where the outdoor unit acts as an air heat exchanger. However, outdoor units require space outside of the building and create a negative acoustic and esthetic impact. For such reasons, the air heat exchanger in the proposed heat pump model is designed to be placed indoor.
Therefore, the heat pump system consists of two parts: main unit and indoor heat exchanger. The main unit integrates compressor, water-side heat exchanger, expansion valve, and other auxiliaries; the indoor heat exchanger includes air-side heat exchanger and fans. The casing of indoor heat exchanger is specially designed to be well-coupled and tight joint with duct system.
This heat pump system comes with buffer tank and DHW tank. Buffer tank stores heat energy coming from heat pump to prepare warm feed water for fan coil units. The tank for DHW is similar to the buffer tank, but it contains a special heat exchanger. The heat exchanger heats up fresh water and supplies domestic hot water to the inhabitants.

7.1. Technical data and performances

In this section, the technical data of heat pump main unit, indoor heat exchanger and buffer/ DHW tanks, and the performance data of the heat pump are described.

7.1.1. Technical data

Main unit (Fig. 12)

- Dimension (length/ width/ height) [mm]: 670/ 600/ 1,700
- Total weight [kg]: 185

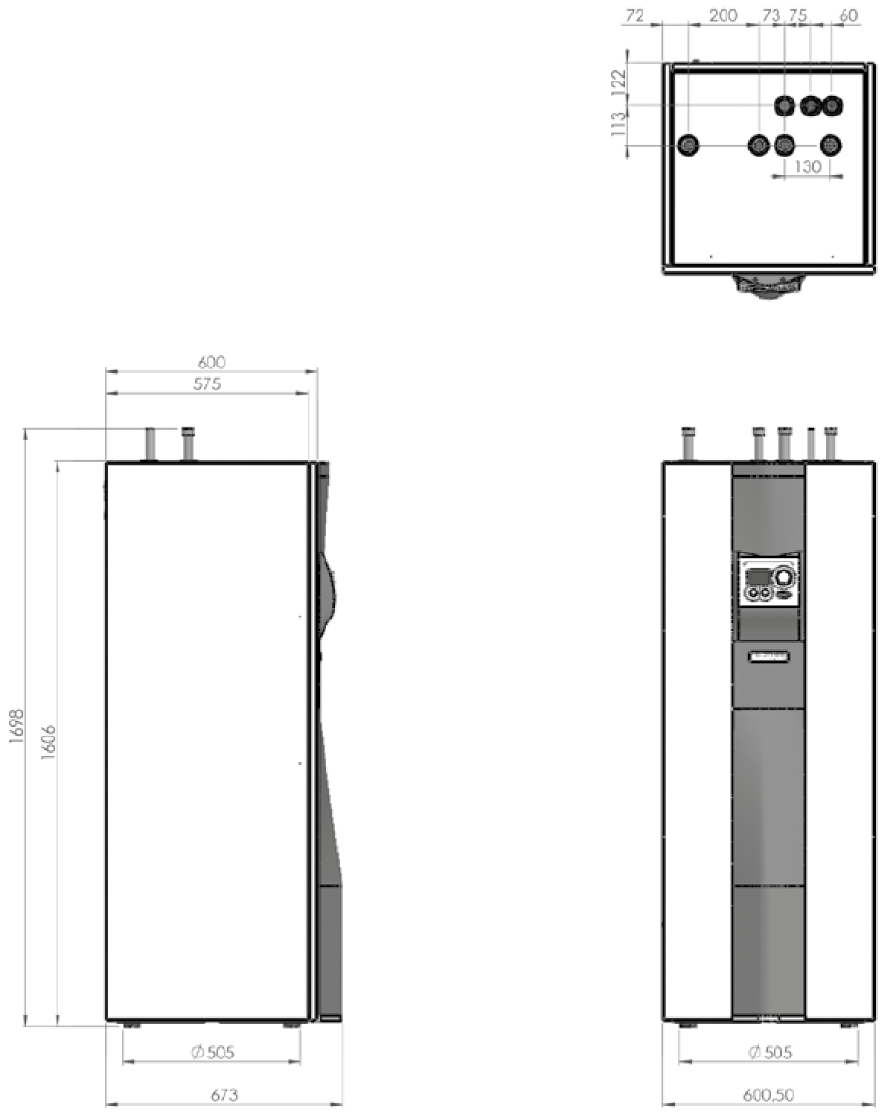


Figure 12. Dimension – main unit

The technical data of the main unit is shown in Table 1.

Table 1. DC heat pump technical data – main unit

	Unit	Value
Heating water		
Content	Liter	3.0
Volume flow	m^3/h	1.8 - 3.7
Pressure loss	mH_2O	2.1
Max. Outlet temperature at Air 0°C	°C	62

Hydraulic block		BC – HYD15
Residual pressure head	mH_2O	3.9
Electric values		
Nominal voltage		3/N/PE 400V/ 50Hz
Nominal current	A	22
Starting current	A	22
Stall current	A	74
Fuse type C (slow)	A	25
Nominal voltage – additional heating		3/N/PE 400V/ 50Hz
Nominal current – additional heating	A	10
Electric power – additional heating	kW	6
Fuse type C (slow) – additional heating	A	3 × 13
Nominal voltage – control circuit		1/N/PE 230V/ 50Hz
Nominal current – control circuit	A	11
Fuse type C (slow) – control circuit	A	13
Earth leakage circuit breaker	mA	30
Electric input power		
Max. compressor input power	kW	8.5
Refrigerant cycle		
Working fluid		R-410A
Split lines fill amount at 10m	kg	13.0
Compressor	type	scroll
Compressor speed	1/min	1,200 – 5,400
Oil amount	Liter	2.3
Connections		
Heating water outlet and inlet	Inch	5/4"
Injection line (to indoor heat exchanger)	mm	14
Suction line (from indoor heat exchanger)	mm	28
Assessed acoustic capacity – human level		
Min. output	dB (A)	42
Max. output	dB (A)	53

Indoor heat exchanger (Fig. 13)

- Dimension (length/ width/ height) [mm]: 1,145 – 1,195/ 940 – 990/ 1,240
- Total weight [kg]: 125

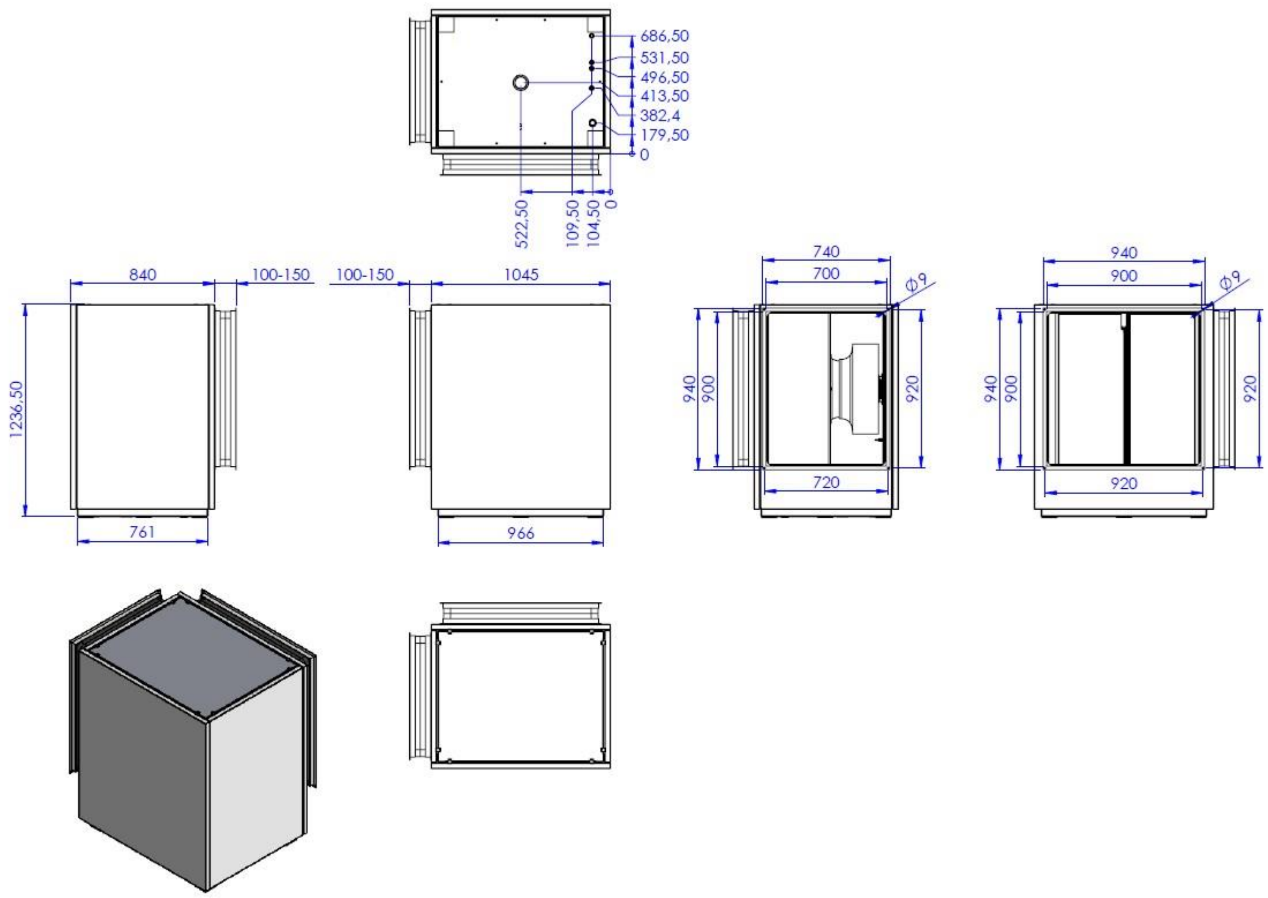


Figure 13. Dimension – indoor heat exchanger

The technical data of the indoor heat exchanger is shown in Table 2.

Table 2. DC heat pump technical data – Indoor heat exchanger

	Unit	Value
Energy source		
Air volume	m^3/h	2,500 – 6,000
Evaporation area	m^2	120
Max. air inlet flow temperature	°C	-25
Min. air inlet flow temperature	°C	45
Electric values		
Nominal voltage		1/N/PE 230V/ 50Hz
Nominal current	A	2.2

Time lag fuse		Thermal relay
Electric input power fan	W	Up to 500
Fan pressure increase	Pa	248
Fan Speed	1/min	1170
Assessed acoustic capacity – human level		
Min. output	dB (A)	43
Max. output	dB (A)	51

DHW & Buffer storage (Fig. 14)

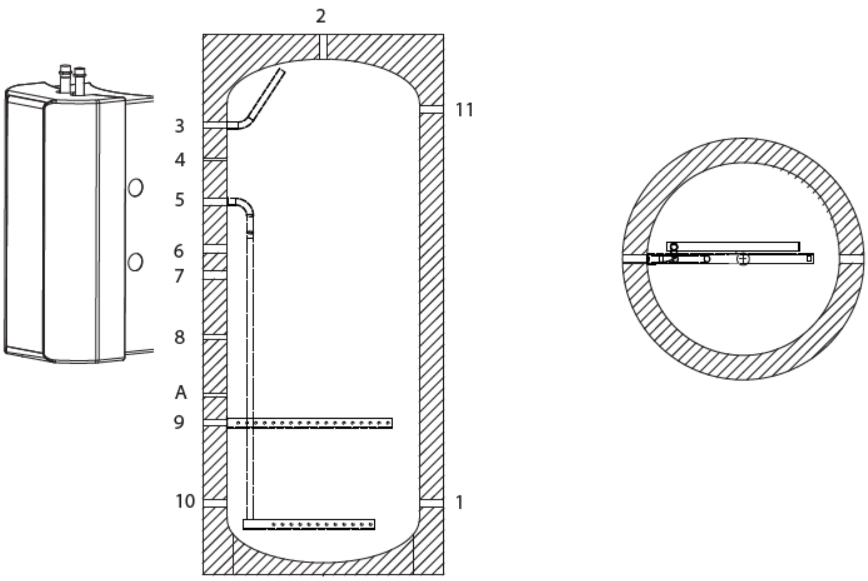


Figure 14. Scheme of buffer/ DHW tank

The technical data of the Buffer/ DHW tank is shown in Table 3.

Table 3. DC heat pump technical data – Buffer/ DHW tank

	Buffer storage	DHW storage
Total content	476 Liter	805 Liter
Empty weight	94 kg	165 kg
Dimensions without insulation	600 × 1920 mm	790 × 1990 mm
Dimensions with insulation	750 × 1920 mm	990 × 1990 mm

Insulation removable	No	Yes
Measurement of fresh water system (D)	370 mm	370 mm
Dimensions fresh water system (H×W)	900 × 460 mm	900 × 460 mm
Tilted dimension	2029 mm	2015 mm
Max. permitted heating pressure	3 bar	3 bar
Max. permitted temperature	95°C	95°C
Heat energy cost at 65°C	1.83 kWh/24h	2.34 kWh/24h
Energy efficiency class	B	B
Max. hot water flow amount		40L/min

7.1.2. Performance data

The performance data described in this section are compliant to EU standard EN14825. This standard establishes the testing and rating procedures for residential heating and cooling systems, providing a standardized way to assess their performances.
The standard categorizes climates into three zones (medium, warmer, colder) to evaluate heating performance. Each climate zone considers different ranges of outside air temperature. Additionally, the standard specifies water outlet temperatures, acknowledging the significance of this parameter alongside air temperature in the assessment process.

- Medium: -9°C – 15°C
- Warmer: 2°C – 15°C
- Colder: -22°C – 15°C

- Low water temperature: 35°C
- Medium water temperature: 45°C
- High water temperature: 55°C

The indicator representing the heating performance of a heat pump system is the Seasonal Coefficient of Performance (SCOP). The SCOP is to measure the efficiency of a heat pump system during the heating season. To calculate the SCOP, EN14825 provides a table (Table 4) specifying the number of hours per air temperature for each climate zone, as follows.

Table 4. The number of hours per air temperature specified in EN14825 – Heating

Air temperature [°C]	Warmer [hour]	Medium [hour]	Colder [hour]
-22	0	0	1
-21	0	0	6
-20	0	0	13
-19	0	0	17
-18	0	0	19
-17	0	0	26
-16	0	0	39
-15	0	0	41
-14	0	0	35
-13	0	0	52
-12	0	0	37
-11	0	0	41
-10	0	1	43
-9	0	25	54
-8	0	23	90
-7	0	24	125
-6	0	27	169
-5	0	68	195
-4	0	91	278
-3	0	89	306
-2	0	165	454
-1	0	173	385
0	0	240	490
1	0	280	533
2	3	320	380
3	22	357	228
4	63	356	2261
5	63	303	279
6	175	330	229
7	162	326	269
8	259	348	233
9	360	335	230

10	426	315	243
11	430	215	191
12	503	169	146
13	444	151	150
14	384	105	97
15	294	74	61

Following the Table 4, SCOPs in full load operation (i.e., 18 kW of heating and cooling capacity in this project), are computed for different outlet water temperature levels. The Table 5 presents the average calculated SCOPs based on different climate zones and varying outlet temperature levels.

Table 5. Performance in Full load and seasonal performance factor – Heating

Climate zone	Outlet temperature level	P_{design} [kW]	SCOP
Medium (Strasbourg)	Low (35°C)	18.0	5.21
	medium (45°C)	16.0	4.23
	high (55°C)	16.0	3.61
Warmer (Athens)	Low (35°C)	18.0	6.56
	medium (45°C)	18.0	5.54
	high (55°C)	18.0	4.63
Colder (Helsinki)	Low (35°C)	18.0	4.38
	medium (45°C)	18.0	3.69
	high (55°C)	18.0	3.14

The indicator used to assess cooling performance is the Seasonal Energy Efficiency Ratio (SEER). The SEER is employed to measure the efficiency of a heat pump system during the cooling season. Unlike the evaluation of heating performance, no separate climate zones were delineated for cooling performance. Nevertheless, a similar approach was adopted, defining the range of outside air temperatures during the summer season (17°C – 39°C) and specifying the number of hours per temperature within this range (Table 6).

Table 6. The number of hours per air temperature specified in EN14825 – Cooling

T [°C]	hour	T [°C]	hour
17	205	29	88

18	227	30	63
19	225	31	39
20	225	32	31
21	216	33	24
22	215	34	17
23	218	35	13
24	197	36	9
25	178	37	4
26	158	38	3
27	137	39	1
28	109	40	0

Table 7 presents the average SEER value for water outlet temperatures of 11.5°C, 10°C, 8.5°C, and 7°C during full load operation.

Table 7. Performance in Full load and seasonal performance factor - Cooling

Full load in cooling mode for convector fans	SPF in cooling mode for convector fans
P_{design} = 18kW	SEER = 5.55

Table 8 shows the estimated SCOP in heating mode when the outlet temperature is corresponding to the RE-SKIN project (20 °C), based on the calculations from EN14825.

Table 8. Full load performance at lower outlet temperature demand

Climate zone	Outlet temperature level	P_{design} [kW]	SCOP
Medium (Strasbourg)	20°C	18.0	> 6
Warmer (Athens)		18.0	> 7
Colder (Helsinki)		18.0	> 5

7.2. Notes

The main unit is derived by a HELIO standard product and the indoor heat exchanger is specially designed for the project, requiring the unit to be installed indoor. The technical specifications described in this section is the data of the final design of the unit to be installed in the first case study (Milan).

The performance data for heating and cooling is adhere to EU standard EN14825.

Performance data at lower outlet temperature demand is estimated.

The heating energy output is variable depending on the air source conditions, and COP changes accordingly.

7.3. LCA analysis

The functional unit of the LCA study (Fig. 15) is 1 DC heat pump (UF = 1 p), with the distinct technical and performance features of the RE-SKIN component provided by HELIO.

DC heat pump - UF = 1 p		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	2,38E+03	kg CO2 eq
Climate change - Fossil	2,37E+03	kg CO2 eq
Climate change - Biogenic	7,97E+00	kg CO2 eq
Climate change - Land use and LU change	4,29E+00	kg CO2 eq
other environmental impacts		
Ozone depletion	1,02E-02	kg CFC11 eq
Acidification	4,13E+01	mol H+ eq
Eutrophication, freshwater	2,17E+00	kg P eq
Eutrophication, marine	3,17E+00	kg N eq
Eutrophication, terrestrial	3,66E+01	mol N eq
Photochemical ozone formation	1,23E+01	kg NMVOC eq
Resource use, fossils	2,46E+04	MJ
Resource use, minerals and metals	4,50E-01	kg Sb eq
Water use	8,44E+02	m3 depriv.

Figure 15. Environmental impacts (A1-A3) of DC heat pump, UF = 1 p.

The LCA modelling of DC heat pump currently excludes the impacts associated to the packaging of the input materials, constituting its main data gaps. The packaging used for the finished component is instead included. Regarding transports, for most materials the distances were provided by the manufacturer, as well as the transport mode. They turn out to be mostly by road (if lacking information, distance of 1000 km), apart from *Aluminium alloy* and *Lubricating oil* for which it is specified by air. In this case, it was deemed appropriate to change it, assuming the transport by sea. Note that besides energy datasets, country-specific datasets are selected for output resources, considering the production site in Germany (DE).

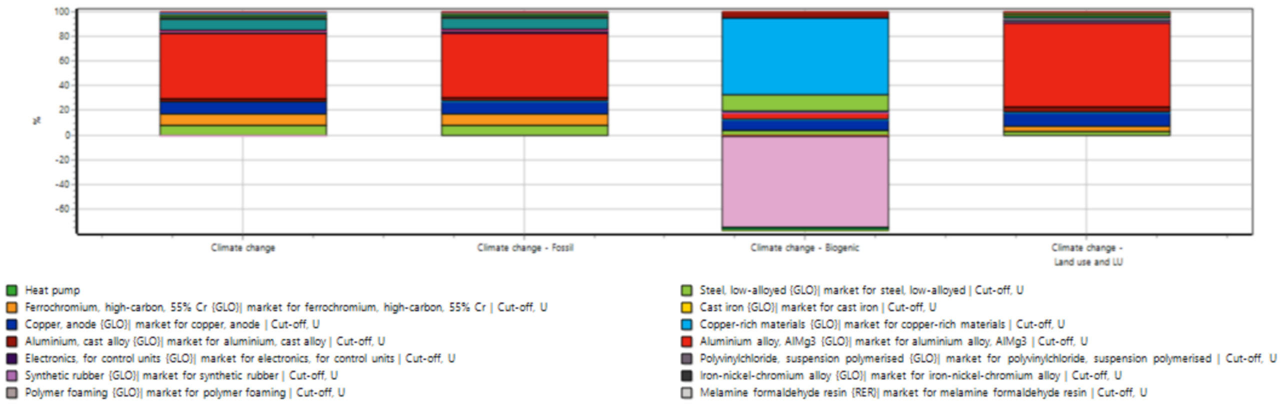


Figure 16. GWP hotspot analysis (A1-A3) of DC heat pump, UF = 1 p.
Colours that do not appear in the legend are described in the text.

LCA results (Fig. 16) show how the most significant environmental hotspot of DC heat pump is *AlMg3* (red-coloured), accounting 52.4% of total GWP impacts, followed to a lesser extent by *Copper* (blue-coloured) and *Refrigerant* (petrol-coloured), respectively with a share of 9.7% and 9.2% of total GWP impacts. By widening the attention to other environmental impacts, also *Carbon steel*, *Steel alloy, Wooden pallet* and *Waste wood* are crucial, with different contributes depending on the category under investigation.

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

The multi-input/multi-output (MIMO) converter allows to interface different energy sources (e.g., PV panels, batteries, grid) and supplying various loads (DC and AC). The converter configuration is designed in order to ensure high conversion efficiencies, limited size/weight, and standalone operation.

MIMO system is comprised of several power converters that enable it to manage the electrical power flow between the roof PV panels, batteries racks, heat pump system, fan coils and the EV charging port. As well it is required to perform a communication with the Smart Control System in which power flow data will be sent to this supervisor system and the high-level working orders will be received from; and a serial communication with battery BMS to ensure proper care of the battery racks.

Figures 17-18 show the diagram block 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 will perform MPPT (converter #4) by measuring the PV panels string current and modifying the Panel DC bus voltage. This will provide a DC range good enough to make feasible a huge number of PV panel configuration.

Converter #1 is a 3-phase boost PFC comprised of 4 SiC Cascode legs and converters #2 and #4 are a DAB comprised 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 controlling all the elements included or influenced by MIMO system, it includes a control platform. This platform will be in charge of:

- 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), in fact, it contains the Xilinx Kria K26, one of the latest devices releases to the market. This board has almost an unlimited power and is quite suitable for embedded controlling.

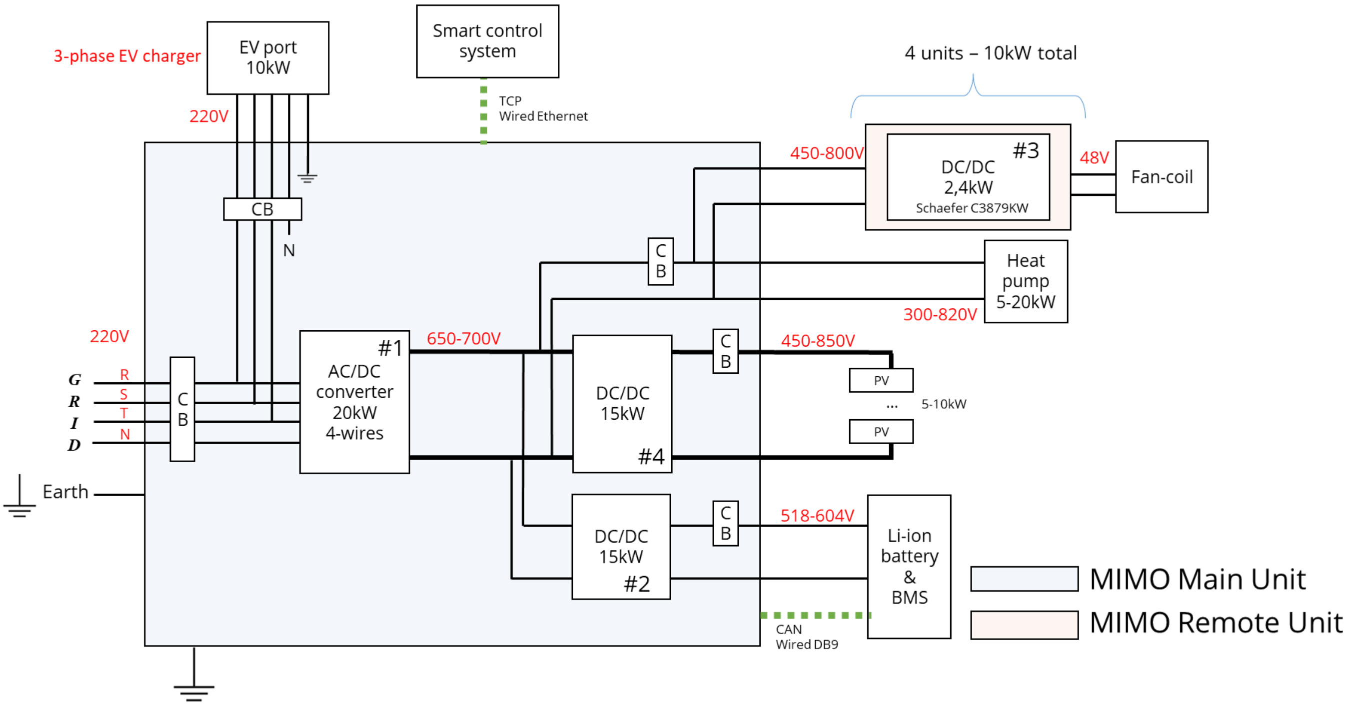


Figure 17. MIMO main block diagram with 3ph EV charger

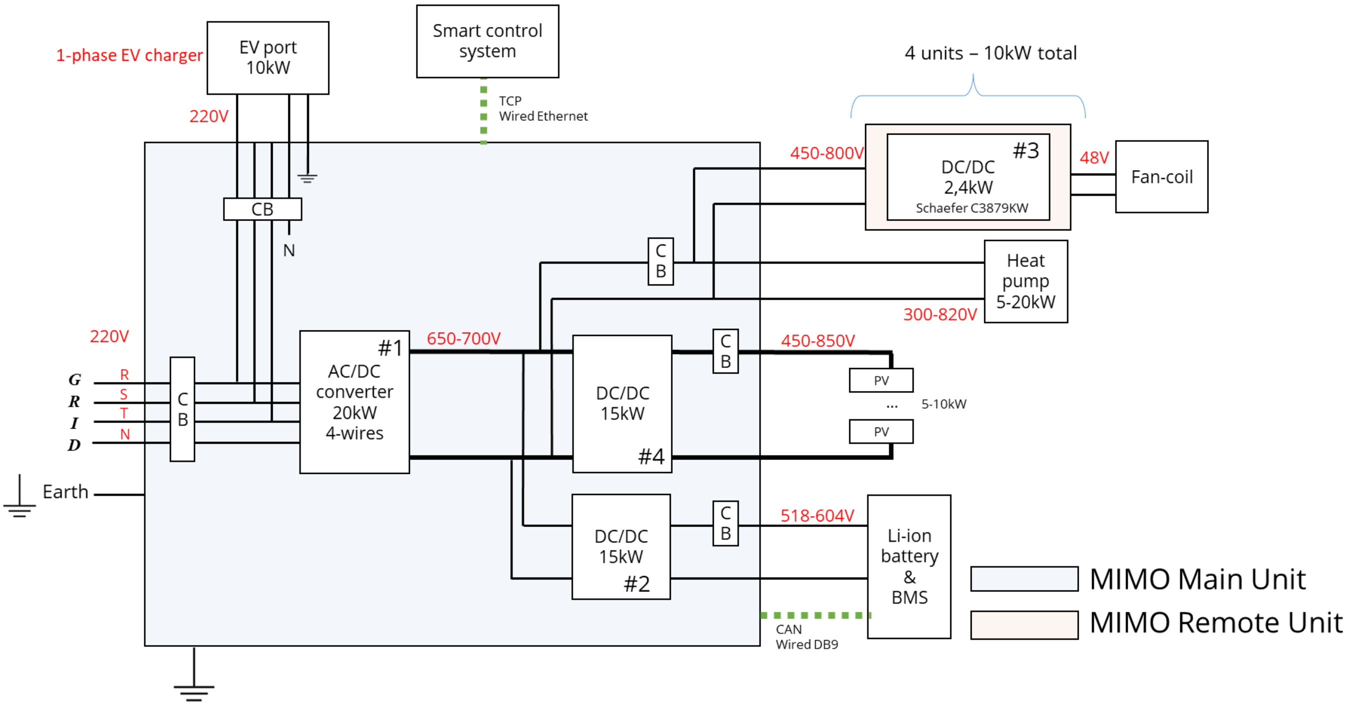


Figure 18. MIMO main block diagram with 1ph EV charger

It should be noted that MIMO system comprises 2 different types of units:

- The main unit is intended to be placed in a service room inside the building as can be a cellar, under roof, etc. This unit contains all the intelligence of the system and the main capabilities and most of the wiring.
- Remote units will be in charge of fan coils power supply and can be connected in a number such to no overcome the maximum power level available by MIMO main unit. This units can be distributed as required among different building floors.

The MIMO converter is intended to provide a 3phase connection for EV charger with a power of 30 kW, 1phase EV chargers can be connected as well as shown in the scheme above.

8.1. Technical data and performances

The main technical data and performances of the converter are listed below.

MIMO Main Unit

Dimension

- Size (Width, Height, Length) [cm]: 65×65×150
- Weight [kg]: 90

Technical features of inverter

- Power supply: 220Vac 3Ph, 50Hz, 20kW
- Other data: includes fuses, AC circuit breakers and DC circuit breakers.

Technical features of DAB battery side

- Battery voltage range: 518-604Vdc
- Max power: 15kW
- Other data: includes circuit breakers and galvanic isolation

Technical features of DAB PV side

- MPPT PV voltage range: 450-850Vdc
- Nominal power: 15kW (Max. 20kW)
- Other data: includes circuit breakers and galvanic isolation

Installation and operation features

- Operating air temperature [°C]: 5-45
- Ambient humidity [%]: 5-80. Condensation is not allowed
- Installation: 30cm in all sides. Placed on a service room with ventilation.
- Protections and connection of PV string shall be done by installer outside MIMO system (MIMO includes 1 DC circuit breaker inside)
- Protections of Battery shall be done by installer outside MIMO system (MIMO includes 1 DC circuit breaker inside)

- Protections of EV charger shall be done by installer outside MIMO system. A Residual-Current-Circuit-Breaker and a Current-Limiting-Breaker are mandatory.

Interconnectivity features

- Communication system: wired ETH for SmartController and wired DB9 CAN for batteries BMS.

Other

- Performance max [%]: 97

MIMO Remote Unit: DC-DC fan coils

Dimension

- Size (Length, Width, Height) [cm]: 36×28×23
- Weight [kg]: 19

Technical features

- Input voltage (DC): 450-800Vdc
- Output voltage (DC): 48Vdc
- Maximum power [w]: 2400
- Performance max [%]: 94

Installation and operation features

- Operating air temperature [°C]: 5-45
- Ambient humidity [%]: 5-80. Condensation is not allowed
- Installation: 30cm in all sides. Placed on a service room with ventilation.
- Air flow from bottom to top.

Model

Schäfer C4779 or similar

The physical appearance of MIMO main unit is shown in Fig. 19.

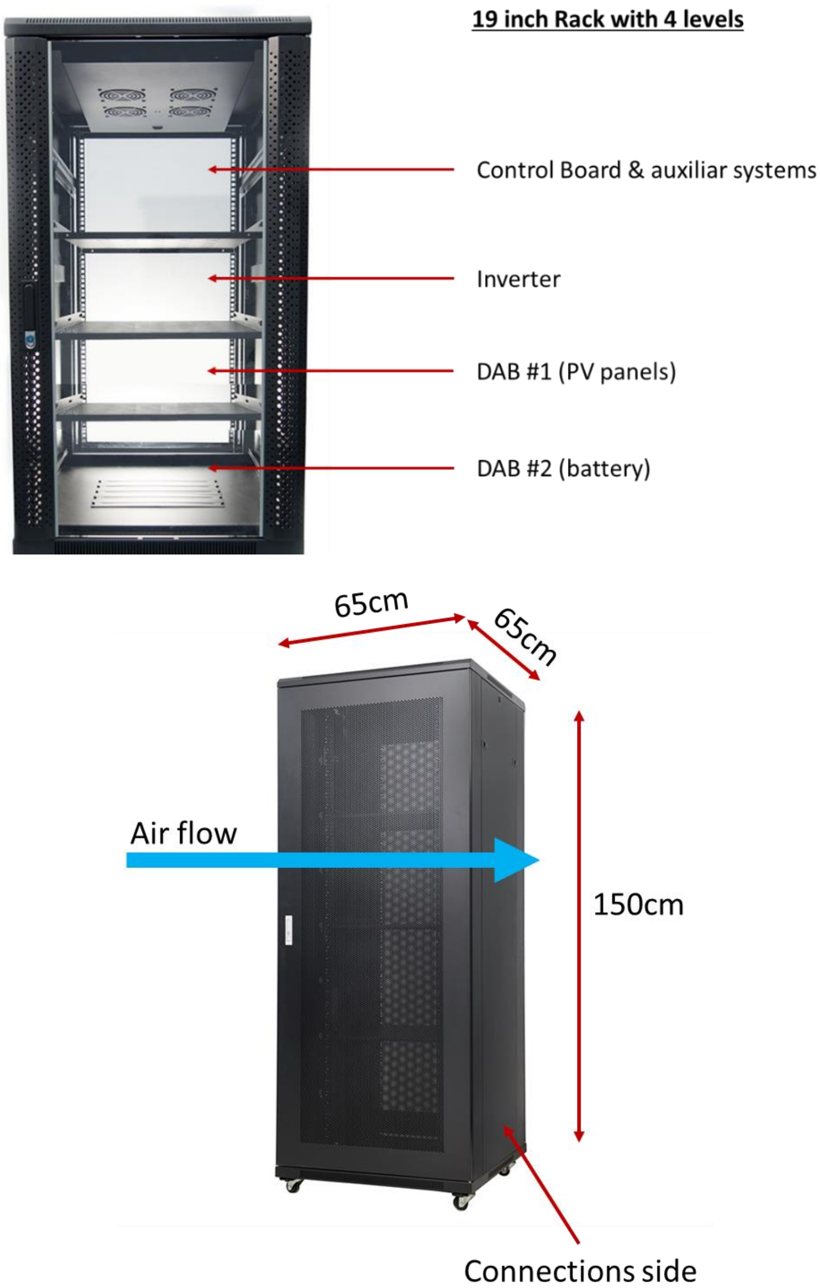


Figure 19. View of the MIMO main unit

The physical appearance of MIMO remote unit is shown in Fig. 20.

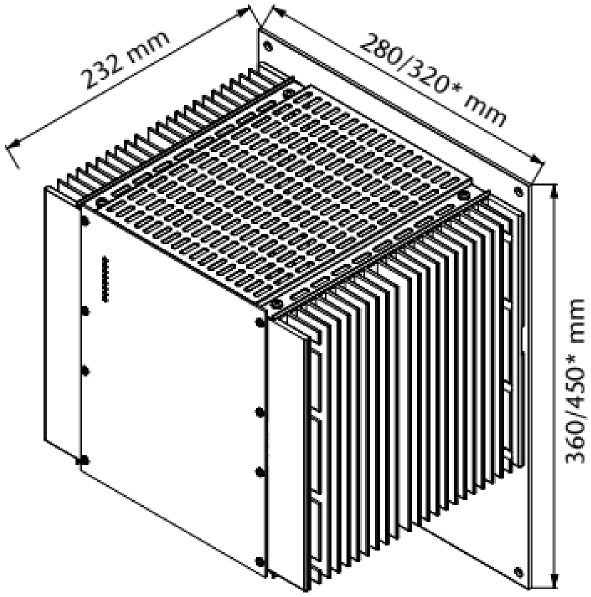


Figure 20. View of the MIMO remote unit

8.2. Notes

The MIMO system will be able to manage and adapt the power levels and electrical characteristics of every item connected. The MIMO will also include an Ethernet RJ45 UDP communication with SmartController and a DB9 CAN communication with battery master BMS module.

The MIMO will operate in a fully autonomous manner which can be conducted by the SmartController to make the most efficient use of all resources involved and to establish high level control consigns.

The MIMO will be able to be a grid load (for example to charge batteries from the grid in case of no PV power available), to work in grid-feeding mode (for example when there is more PV power than consumed) and to work in grid-forming mode (for example in case of a grid fall).

It will also be able to manage not balanced 3-phase loads in grid-forming mode always assuring individual phase nominal power is not overcome.

Full user manual is being prepared and provided with the equipment.

8.3. LCA analysis

The functional unit of the LCA study (Fig. 21) is 1 MIMO converter (UF = 1 p), with the distinct technical and performance features of the RE-SKIN component provided by Power Smart Control.

MIMO converter - UF = 1 p		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	7,22E+02	kg CO2 eq
Climate change - Fossil	7,16E+02	kg CO2 eq
Climate change - Biogenic	4,70E+00	kg CO2 eq
Climate change - Land use and LU change	1,51E+00	kg CO2 eq
other environmental impacts		
Ozone depletion	2,23E-05	kg CFC11 eq
Acidification	5,10E+00	mol H+ eq
Eutrophication, freshwater	5,76E-01	kg P eq
Eutrophication, marine	8,45E-01	kg N eq
Eutrophication, terrestrial	8,83E+00	mol N eq
Photochemical ozone formation	4,16E+00	kg NMVOC eq
Resource use, fossils	9,40E+03	MJ
Resource use, minerals and metals	1,06E-01	kg Sb eq
Water use	1,51E+02	m3 depriv.

Figure 21. Table x. Environmental impacts (A1-A3) of MIMO converter, UF = 1 p.

The LCA modelling of the MIMO converter now omits the packaging of both input materials and finished component, due to missing data on the matter, which thus require further investigation. By contrast, to address the lacking data related to transport, an average distance of 1000 km was assumed for the supply of all input materials to the production plant. The country-specific datasets affect electricity consumption and plastic waste, taking into account Spain (ES) as place of production.

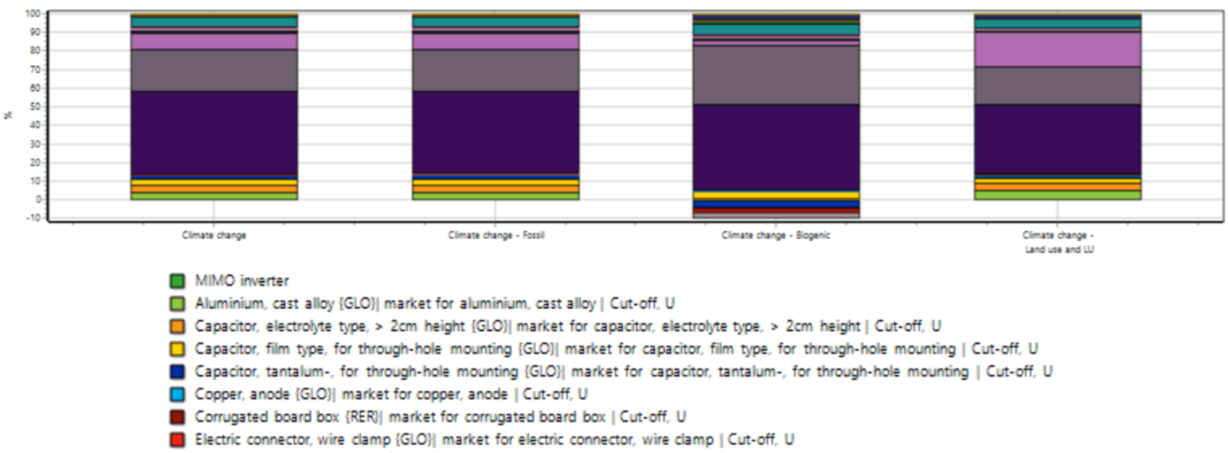


Figure 22. GWP hotspot analysis (A1-A3) of MIMO converter, UF = 1 p.
Colours that do not appear in the legend are described in the text.

LCA results (Fig. 22) reveal that the most notable environmental hotspots of the MIMO converter are associated primarily with *Inductor ring core* (purple-coloured), constituting 44.4% of total GWP impacts, and secondly with *Integrated circuit* (dark grey-coloured) with 22.5%. They are followed by the *Printed wiring board* (lilac-coloured) which account for 8.8% of total GWP impacts. In view of all other environmental impacts, even *Capacitor*, *Transistor* and *Aluminium* emerge as significant contributors.

9. EV charger

Two different types of charging infrastructures will be developed by upgrading/adapting ENELX commercial solutions. More in detail, the 2 proposed versions (Fig. 23) are the following:

A. the first one is an AC charging infrastructure, capable of connecting one vehicle at a time. It has power ranging from 3.7 kW to 22 kW;
B. the second version can connect and charge up to two vehicles simultaneously. It has a power of up to 22 kW.

Figure 23. View of the two versions of EV charger (version A on the left and B on the right)

At this stage of the project, both versions will be considered for the application within the RE-SKIN package. However, a more specific technical assessment will be carried out in the next stages of the project according to the technical specification of the MIMO converter.

9.1. Technical data and performances

Hereafter the technical data and performances of the two models are reported.

VERSION A

Dimensions

- Dimensions (Width/Height/Depth) [mm]: 153x180x42
- Weight [kg]: 5-10

Technical features

- Operative temperature [°C]: -40 ÷ +60
- Operative RH [%]: 5% - 95%
- Max. altitude [m]: 2000

Energy performances

- single-phase
    - Up to 3.7 kW, 16 A
    - Up to 7.4 kW, 32 A
- three-phase
    - Up to 11 kW, 16 A
    - Up to 22 kW, 32 A

VERSION B

Dimensions

- Dimensions (Width/Height/Depth) [mm]: 353x1475x333
- Weight [kg]: 60

Technical features

- Operative temperature [°C]: -25 ÷ +50
- Operative RH [%]: 5% - 95%
- Max. altitude [m]: 2000

Energy performances

- Power [kW]: 22
- Current [A]: 64
- Voltage [V]: 400 (3-phase)

9.2. Notes

While version A allows to charge just one vehicle, the second model allows to recharge also two vehicles simultaneously, with the same maximum power of 22 kW.

Both versions are equipped with two locking systems that prevent unauthorized disconnection of the plugs during charging. They are both suitable for outdoor installation (IP55; IK08)

9.3. LCA analysis

RE-SKIN toolkit includes two different models of charging infrastructures: a wall mounted solution (Veriosn A) and a free-standing solution (Version B) for each of which a specific LCA study was carried out, depending on data availability.

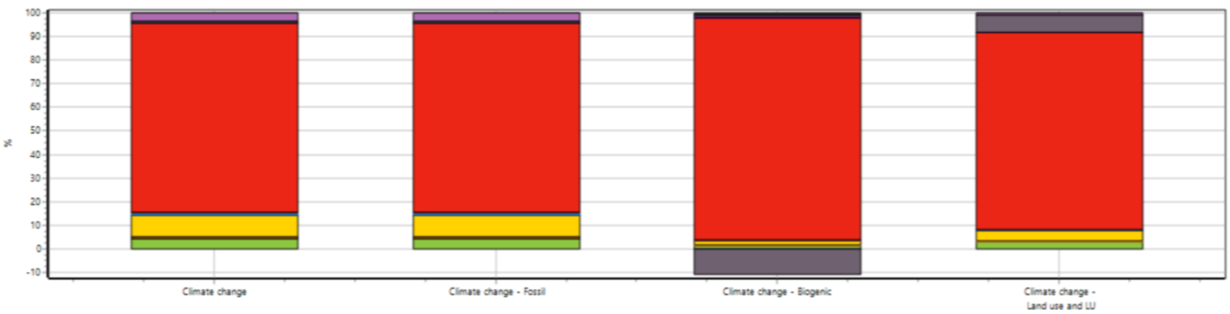
Version A (JuiceBox charger)

The functional unit of the LCA study is 1 vehicle charger, specifically *JuiceBox 4.0 Cord* model (UF = 1 p) (Version 1), with the distinct technical and performance features of the RE-SKIN component provided by ENELX.

EV charger - JuiceBox - UF = 1 p		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	2,37E+02	kg CO2 eq
Climate change - Fossil	2,35E+02	kg CO2 eq
Climate change - Biogenic	1,75E+00	kg CO2 eq
Climate change - Land use and LU change	4,33E-01	kg CO2 eq
other environmental impacts		
Ozone depletion	1,34E-05	kg CFC11 eq
Acidification	1,90E+00	mol H+ eq
Eutrophication, freshwater	3,19E-01	kg P eq
Eutrophication, marine	3,31E-01	kg N eq
Eutrophication, terrestrial	3,58E+00	mol N eq
Photochemical ozone formation	1,05E+00	kg NMVOC eq
Resource use, fossils	3,15E+03	MJ
Resource use, minerals and metals	8,48E-02	kg Sb eq
Water use	5,23E+01	m3 depriv.

Figure 24. Environmental impacts (A1-A3) of vehicle charger, Version A model, UF = 1 p.

The LCA modelling (Fig. 24) of JuiceBox charger currently does not count the packaging of the input materials, as well as the waste in output from the production process, because of data gaps. Both resources are thus excluded from the modelling, calling for further insights. As happens for other RE-SKIN components, in the absence of detail about transport distance and means, all input materials are assumed to be sourced via truck with a distance of 1000 km. Country-specific dataset is chosen for electricity consumption, by considering the production site located in Italy (IT).



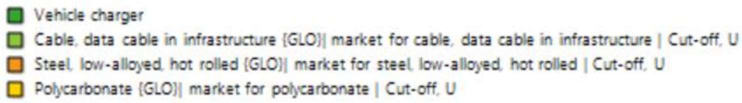


Figure 25. GWP hotspot analysis (A1-A3) of vehicle charger, JuiceBox model, UF = 1 p. Colours that do not appear in the legend are described in the text.

LCA results (Fig. 25) show how the most significant environmental hotspots of JuiceBox charger is *PCBA* (red-coloured), accounting 80.2% of total GWP impacts, followed to a lesser extent by *Polycarbonate* (yellow-coloured) and *Cable* (green-coloured), respectively with a share of 9.4% and 4.3% of total GWP impacts. Concerning the GWP impacts associated with biogenic sources, note that negative contributions derived from the use of *Cardboard*. Furthermore, by looking at the whole set of environmental impacts, also *Transport* and *Brass* are worthy of attention.

Version B (JuicePole charger)

The component under examination has a EPD certification, which was therefore used as a source for the LCA study. The EPD owner is DUCATI Energia S.p.a. and the program operator is EPDItaly. As for the other RE-SKIN components, the LCA evaluation behind the EPD is developed with SimaPro software and Ecoinvent database, adopting the EN 15804:2018 calculation method.
The EPD functional unit is 1 single charging column (UF = 1 p), characterised by 400 V nominal voltage and 50 Hz frequency and capable of powering an electric vehicle with an expected life of 20 years. In particular, *Three-phase/Single-phase* and *Three-phase/Three-phase* charging columns for electric cars of the JP2.1 family are assessed (Fig. 26).

EV charger - JuicePole - UF = 1 p			
IMPACTS	**Value**	**Value**	**Unit**
GWP impacts	JP2.1 Three/Single	JP2.1 Three/Three	
Climate change	1,02E+03	1,04E+03	kg CO2 eq
Climate change - Fossil	1,01E+03	1,04E+03	kg CO2 eq
Climate change - Biogenic	-5,33E+00	-5,55E+00	kg CO2 eq
Climate change - Land use and LU change	1,62E+00	1,65E+00	kg CO2 eq
other environmental impacts			
Ozone depletion	8,26E-05	8,41E-05	kg CFC11 eq
Acidification	9,27E+00	9,65E+00	mol H+ eq
Eutrophication, freshwater	1,40E+00	1,45E+00	kg P eq
Eutrophication, marine	1,40E+00	1,45E+00	kg N eq
Eutrophication, terrestrial	1,52E+01	1,57E+01	mol N eq
Photochemical ozone formation	4,16E+00	4,30E+00	kg NMVOC eq
Resource use, fossils	1,30E+04	1,33E+04	MJ
Resource use, minerals and metals	3,93E-01	4,07E-01	kg Sb eq
Water use	2,94E+02	3,07E+02	m3 depriv.

Figure 26. Environmental impacts (A1-A3) of vehicle charger, JuicePole model, UF = 1 p.

In the JuicePole EPD, the LCA analysis is performed "from cradle to grave" (from A to C modules), extracting here the upstream and core phases included in the production module (A1-A3), in line with what happens for the other RE-SKIN components. The assessment accounts: i) the extraction and processing of raw materials up to the production of the semi-finished products; ii) the transport

of semi-finished products to the Ducati Energia plant located in Romania where assembly, testing and packaging of the product takes place; iii) the assembly, testing and final product packaging. Accordingly, it is considered the energy-mix of Romania.
From LCA results (Fig. 27), it emerges that as JuicePole charging columns for electric cars is environmentally advantageous in view of production phase to adopt the JP2.1 *Three-phase/Single-phase* system, rather than the JP2.1 *Three-phase/Three-phase*.

10. Battery Pack

The battery system will be contained in a cabinet meant for an outside usage. In fact, it has been established that, where technically feasible, the outdoor installation of the battery pack must be preferred for safety reasons.
A specific cabinet has been chosen to make sure that the battery pack can be installed outdoor, ensuring proper operational conditions.

Cabinet specifications

- **Material:**
  Housing frame: stainless steel 1.4301 (AISI 304)
  Flat parts and plinths: aluminium, AlMg3
  Rain roof: aluminium

- **Dimensions and weight:**
  Width: 800 mm
  Height: 2,000 mm
  Plinth height: 100 mm
  Total height: 2,145 mm
  Depth: 800 mm
  Total weight (including batteries): 600 kg

- **Protection class IP according to IEC 60 529:**
  IP55
  - solid #5 means that it is dust protected/ limited ingress of dust permitted. Dust ingress will not interfere with the operation of the equipment.
  - Liquid #5 means it is protected from jets of water with limited ingress permitted. Water ingress will not interfere with the operation of the equipment.

- **Protection class NEMA**
  NEMA 3R
  NEMA 12

- **IK code**
  IK10

In addition to above-listed specifications, we require an area of at least 1 m in each direction from the cabinet to ensure that the assembling operation on the field will be conducted in a simple and safe way.
The HV battery pack will be assembled starting from 144 cells recycled from the Mitsubishi Outlander PHEV (LEV40), having the specifications listed below.

Battery cells specifications

- **Performances**
    - Nominal voltage 3.75 V
    - Operating voltage range 2.75 to 4.1 V
    - 1-hr rate typical Capacity 25°C 40 Ah

- **Dimensions:**
    - Length 171 (±0.5) mm
    - Width 32.5 (±0.5) mm
    - Height (over terminals) 111 (±1) mm
    - Mass +/- 1.4 kg

- **Terminal Type**
    - Male threaded terminal M8
    - Torque 9-13 Nm

- **Operating Temperature Range**
    - Storage (recommended) -20°C to +35°C
    - Charge -25°C to +60°C
    - Discharge -25°C to +60°C

- **Case Material**
    - Cell case Stainless Steel
    - Insulation film PET

- **Charge Control**
    - Charge voltage limit at 25°C V (continuous) 4.1 V
    - Charge voltage limit at 25°C V (60mSec) 4.2 V
    - Charge termination threshold current <0.5 A

- **Charge Current**
    - Maximum Charge Current (-25°C) 8 A

  - Maximum Charge Current (-10°C) 20 A
  - Maximum Charge Current (0°C) 40 A
  - Maximum Charge Current (10-40°C) 100 A
  - Maximum Charge Current (50°C) 80 A
  - Maximum Charge Current (55°C) 40 A
  - Maximum Charge Current (60°C) 16 A

- **Maximum Discharge Current**
  - current 240 A

- **Cyclic Life Data**
  - 100% DOD @ 25°C. Assuming:
  - Charge - 1C (40Amp) constant current followed by 4.1V constant voltage charge.
  - Charge cut off at 0.5Amps. Discharge - 1C (40Amp) constant current discharge down to 2.75V.
  - 500 cycles (to 80% of initial capacity)

- **Impedance**
  - Measured at 1 kHz 0.55 mΩ

- **Design Life of The New Cell**
  - 1000 cycles at average temperature 25°C 10 years

- **Safety**
  - Installation
    - Can be installed and operated in any orientation.
  - Battery Management
    - When cells are connected together the specified operating conditions must be respected for all cells under the control of a suitable battery management system.
  - Gas Release
    - No gas is released under normal operation due to fully sealed construction.
  - Recycling
    - YUASA's Lithium-ion batteries must be recycled at the end of life in accordance with local and national laws and regulations.

Therefore, the battery pack will have the following estimated pack performances.

Predicted Pack Performance Parameters based on Theory + Initial Cell Assessment.

- **Estimated Battery Pack Max and Min Voltage**: Maximum: 590.4V, Minimum: 518.4V.
  - $Cell\ MaxV * Pack\ Cell\ Count = Theoretical\ Pack\ MaxV$
    - $4.1 * 144 = 590.4V$
  - $Cell\ MinV * Pack\ Cell\ Count = Theoretical\ Pack\ MinV$
    - $3.6 * 144 = 518.4V$
- **Battery Pack Nominal Voltage:** 540V.
  - $Cell\ Nominal\ V * Pack\ Cell\ Count = Theoretical\ Nominal\ Voltage$
    - $3.75 * 144 = 540V$
- **Estimated Battery Pack Capacity:** $\approx$ 30Ah from full charge. (Cell V = 4.1V, Pack V = 590.4V)
- **Calculated Nominal Battery Pack Power at 1C:** $\approx$ 16.2kWh
  - $Pack\ Nominal\ Power\ \approx\ Pack\ Nominal\ V * Current\ at\ nC$
  - Where: $Current\ at\ nC = \frac{Pack\ Capacity\ (Ah)}{nC\ rating}$
  - Where: nC = 1.0, Pack Capacity = 30Ah, and Pack Nominal V = 540V
    - $\frac{30Ah}{1C} = 30A \rightarrow 540V * 30A \approx 16200Wh\ or\ 16.2kWh$
- **Max Continuous Discharge Current:** 50A (software limited)
- **Max Continuous Charge Current**: 50A (software limited)

The battery pack will be controlled by a BMS (battery management system) with the following specifications.

- Li-PO, LiFePO, LiFeYPO, LiCoO, LiMnNiCo and LiMnO Lithium-Ion chemistry
- Master + max 15 Slave combination (max 240 cells)
- single cell voltage measurement (0.1 – 5.0 V, resolution 1 mV)
- single cell internal resistance measurement
- single cell under/over voltage protection
- SOC and SOH calculation
- over temperature protection (up to 3 temperature sensors per Slave unit)
- under temperature charging protection
- passive cell balancing up to 1.3 A per cell with LED indication
- shunt current measurement (resolution 10 mA @ +/- 300 A)
- 3 galvanically isolated user defined multi-purpose inputs/outputs
- 4 programmable relays (normally open and normally closed option)
- 12 V galvanically isolated supply (10.5 – 15 V)
- galvanically isolated RS-485 and CAN communication protocol
- internal battery powered real time-clock (RTC)

- hibernate switch

10.1. Notes

According to the energy storage needs of each building, different battery packs can be connected in parallel to reach the desired capacity.

10.2. LCA analysis

The functional unit of the LCA study is 1 Battery system (UF = 1 p), with the distinct technical and performance features of the RE-SKIN component provided by Solartechno.
The specificity of the battery system at issue is that it is made by a set of reused batteries bought from a supplier who demounts the batteries from cars in The Netherlands. It deals therefore with a repurposed process in order to give a second life to the battery cells extracted from Electrical Vehicles (type LEV40 from Mitsubishi Outlander PHEV). These cells are originally manufactured by the Japanese company GS-Yuasa, with a nominal cell voltage of 3.75 V and enclosed in a plastic tray in group of 8 battery cell in series, forming together a battery bank with a nominal voltage of 30 V. The battery system included into RE-SKIN is composed of 18 battery banks for a total of 144 cells, each weighing 1.4 kg, installed in a cabinet and managed by a Battery Management Systems (BMS).

Battery system - 144 cells - UF = 1 p		
IMPACTS	**Value**	**Unit**
GWP impacts		
Climate change	1,28E+03	kg CO2 eq
Climate change - Fossil	1,27E+03	kg CO2 eq
Climate change - Biogenic	6,40E+00	kg CO2 eq
Climate change - Land use and LU change	1,60E+00	kg CO2 eq
other environmental impacts		
Ozone depletion	8,46E-05	kg CFC11 eq
Acidification	8,12E+00	mol H+ eq
Eutrophication, freshwater	1,21E+00	kg P eq
Eutrophication, marine	1,44E+00	kg N eq
Eutrophication, terrestrial	1,55E+01	mol N eq
Photochemical ozone formation	4,49E+00	kg NMVOC eq
Resource use, fossils	1,64E+04	MJ
Resource use, minerals and metals	3,33E-01	kg Sb eq
Water use	1,81E+02	m3 depriv.

Figure 27. Environmental impacts (A1-A3) of battery system, UF = 1 p.

The LCA modelling (Fig. 27) of battery system – distinguished by repurposed battery cells – follows the *cut-off* allocation method, established by both EN 15804, the standard for Environmental Product Declarations, and by EN 15978, the standard for the assessment of the environmental performance of buildings. The *cut-off* is an input-oriented method, which assess the impacts occurred within the system boundary under study, by allocating impacts directly to the product

generating them. In this way, the *cut-off* method fully assigns to the first life of battery cells (automotive sector): the extraction of raw material, the production process, the first use phase and the waste disposal. It allocates instead to the second life (construction sector, namely RE-SKIN project) the impacts of reuse process, second use phase and disposal. Accordingly, the LCA evaluation rewards to the second life the reduced environmental impact due to reuse (also recycling) of materials: reused (or recycled) materials generally imply lower impacts than the original production because only the impacts of transport and reprocessing are considered without the raw materials. Consistent with this, the LCA inventory of the battery system under study does not take cell production into account.
Despite this, it is worth noting that the modelling is based on incomplete data about the packaging of both input materials and finished components, since for each it is necessary to specify not only the packaging material but also the related weight. In addition, to overcome the missing data from producer about the energy consumption, the amount expressed in kWh is now assumed to be one-tenth of the electricity consumed for battery production sourced from the specific Ecoinvent dataset. Indeed, since the manufacturer does not have a proper production process, energy is stated to be needed just for testing purpose (currently not quantified at the plant). Note that to avoid misleading results about life cycle extension solutions, it is important to deepen the key factors such as transportation for recovery the cells, any regeneration process or maintenance activities, and the related energy required to bring cells back on the market.

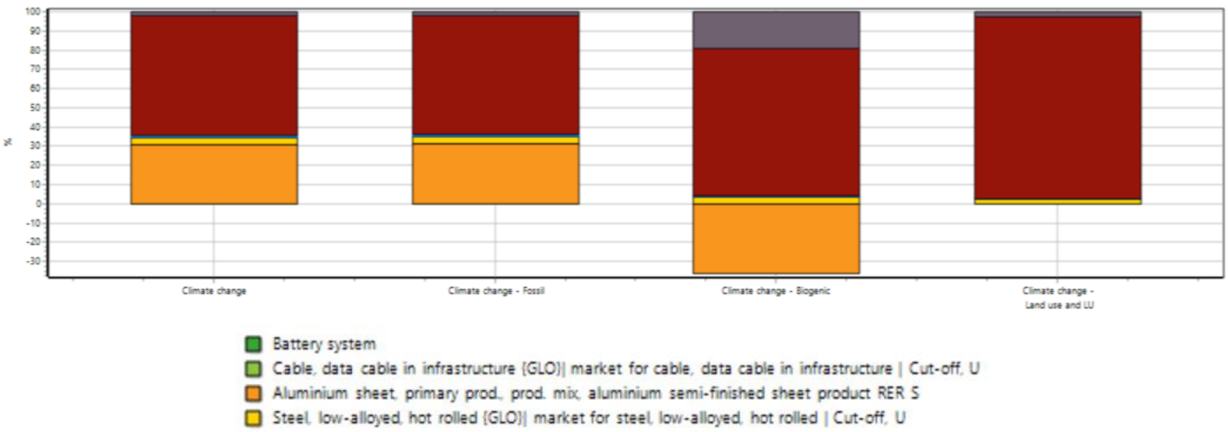


Figure 28. GWP hotspot analysis (A1-A3) of battery system, UF = 1 p.
Colours that do not appear in the legend are described in the text.

Accounting with the *cut-off* method the entire battery system, the LCA results (Fig. 28) display that the *BMS motherboard* (bordeaux-coloured) is responsible for 61.9% of total GWP impacts. Other key hotspots are the *Aluminium sheets* of cabinet (orange-coloured) and the *Steel low alloyed* of mounting shelves (yellow-coloured), respectively with a share of 30.5% and 4.1% of total GWP impacts. Besides these, the waste treatment of *Used Li-ion battery* affects the other environmental impacts.

11. Refurbished PV module

The proposed PV modules derive from a refurbishing process that allows worn-out components to be reused, avoiding their disposal.

At present, the product to be delivered to the first case study is a 3 bus-bar PV module integrating 60 polycrystalline cells (6 inches each), with a nominal power of 255 W_p.

The module has an aluminum frame which encloses a glass-backsheet laminate. The front glass is tempered and has a thickness of 3.2 mm.

The main dimensional features are shown in Fig. 29.

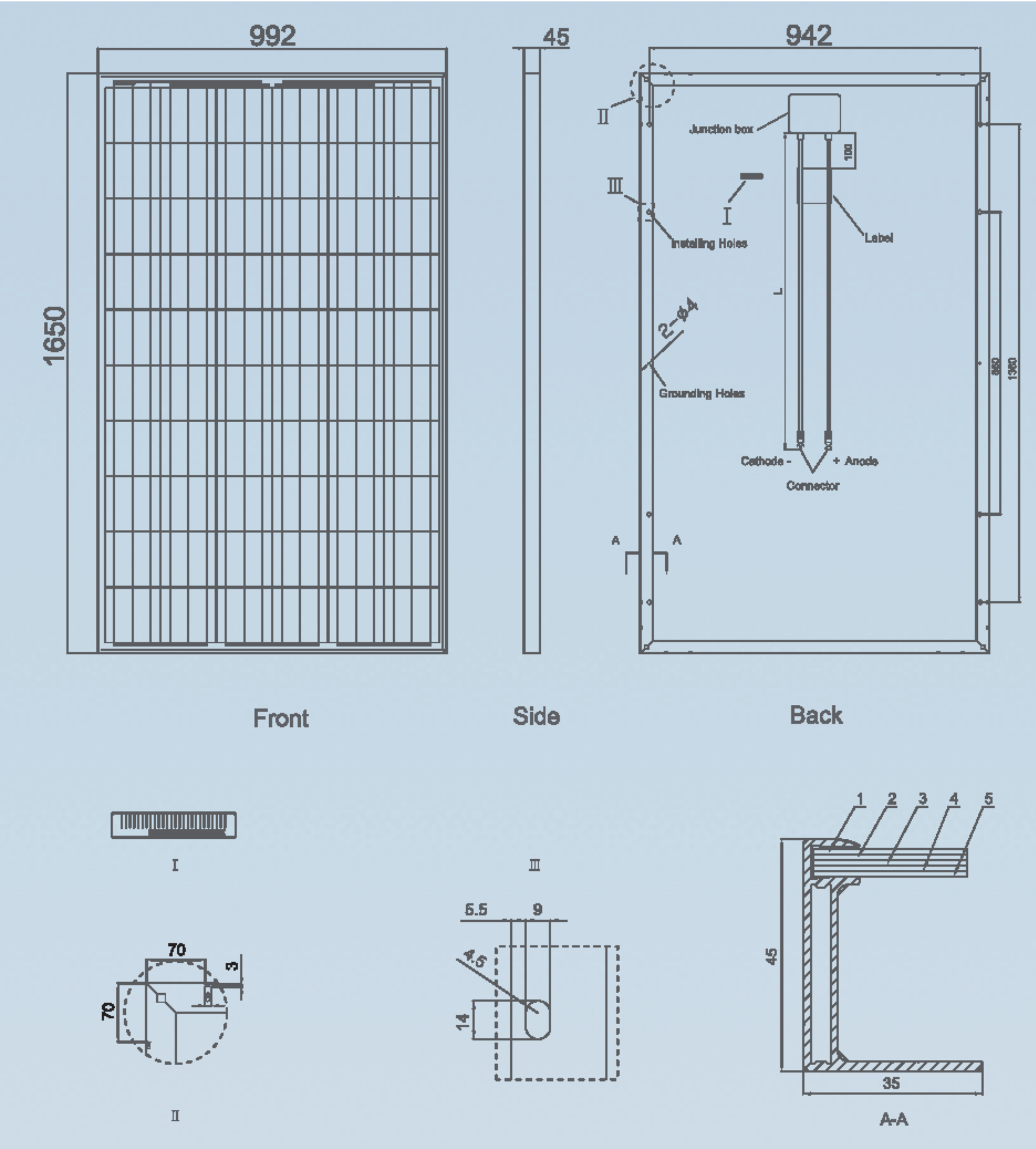


Figure 29. Main features of the refurbished PV modules (size in mm)

11.1. Technical features and performances

The main technical features and performances of the PV module are listed below.

Dimensions

- Size of the module (Width/Height/Depth) [mm]: 992/1650/40
- Weight [kg]: 19.5 (module) **+** 0.22 kg (dried out polymer sealing) = 19.72 kg total.
- Specific weight [kg/m^2]: 12.05
- Area [m^2]: 1.637 m^2

Technical features

- Water penetration: sealed, IP65 for the junction box
- Air tightness: Class A
- Fire resistance (class): Class C

Energy performances

- Maximum power at STC [W]: 255
- Voltage at maximum power point [V]: 30.9
- Open-circuit voltage [V]: 38.00
- Current and maximum power point [A]: 8.26
- Short-circuit current [A]: 8.95
- Module efficiency [%]: 15.6
- Maximum system voltage [V]: 1000
- Temperature coefficient on Pmax [%/°C]: -0.41
- NOCT [°C]: 46

11.2. Notes

The power tolerance of the delivered PV modules on the rated value is +/- 3%.

The output cables have a section of 4 mm^2 and a length of 100 cm each.

11.3. LCA analysis

Dealing with refurbished photovoltaic modules, the proposed solution strongly depends on the specific components available on the market and recovered by RINOVA. Here, the refurbishment process of photovoltaic module is structured as follows:

1) categorization of quality level and usability for the treatment;
2) function test and testing isolation (danger of short circuit and remaining power class);
3) washing of module, on both sides;

4) deep drying of module, depending on the polymer;
5) handling operations, for instance, turn the module and reverse it;
6) as optional variation, wipe the polymer varnish with a flexible blade coater;
7) manual or automated spraying on the backside of the module.

The manufacturing plant has indeed two existing lines: one of them is manual operating, while the second is automated (gantry robotics) and allow to stabilize the quality and the process results.
From an LCA point of view, as in the case of battery system – due to the adopted cut-off allocation method – it is critically important to retrieve quantitative data on the refurbishment process (allocated to this second life) to which photovoltaic modules are subjected, rather than on their production (associated to the previous first life). The problem is the complete lack of data, also in terms of energy consumption during the process. Moreover, concerning the polymer varnish, it is not enough to know the main ingredients, but it is pivotal to get the related quantities (not available since confidential). Due to these data gaps, it is not yet possible to perform the LCA study of the RE-SKIN refurbished photovoltaic modules.

12. DSS/BEMS platform

The platform already developed for the HEART project will be improved to support the new requirements for the RE-SKIN project.
In detail, the DSS (Decision Support System) will be extended in several aspects: a set of new models targeting circularity will be created together with ENELX and POLIMI and implemented to provide additional information to support the building owner. This new set of circularity models will be implemented next to the actual Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) models as an independent micro-service allowing to execute the models as a stand-alone application or as integrated to the result of the DSS. While additional screen will be developed for the standalone version of the circularity model, the actual screen of the DSS will be reviewed to take the new models into account. Finally, the resulting dashboard of the DSS will be reviewed to offer a better user experience to the building owner, and a new application will be provided to allow the technical maintenance of the models.
A new Building Energy Management System (BEMS) will be implemented with CTIC/POLIMI and integrated in the platform. RE-SKIN project will analyse the different options to take advantages of WEB 3.0 principles (Distributed Application and Blockchain's Ledger) in term of security, accountability, control, ownership, and collaboration over distributed data that are collected in the building. The migration of the BEMS to WEB 3.0 will infer an update of the current Building Management System (BMS) micro-application and the tenant micro-application. Connectors will be implemented to the new data repositories.
In order to collaborate in the RE-SKIN platform and potentially with other platforms, both DSS and BEMS will rely on a common understanding of the different data that are collected about the buildings. No matter where the data comes from IoT devices installed in the building, from the energy manager filling information in the screens or from architects describing the building, each data must be identified and categorised. Consequently, the actual virtual description of the building must evolve to a multi-layer digital twin of the building. Research will be performed to structure the different layers to take into account the physical static information contained in the BIM, the real time status information from the sensors, the simulation results from the DSS and finally the operational information generated by the regulation component of the BEMS. The semantic of the data and the nomenclature of the systems will be enforced and uniformized across the different layers of the digital twin and reflected in all the modules of the RE-SKIN platform.
A new notification engine will be set to inform users when specific events happen on their devices or within their connected environment. When the device is not sending any data since a certain time or if it has an error status or its readings are outside of the defined boundaries, alerts will be sent to the right person, via email or SMS. Notification flows will adapt to the organization processes

by allowing users to create specific escalation path informing the right users. The users will be able to indirectly integrate alarms based on the BEMS component.

Academic management of the models and parameters will be enforced to ensure long term support of the platform. A reporting function that lets the academic users to export raw data (CSV/Excel) will be provided to allow users to cut across a set of raw data and combine them with external sources to get the answer to their questions.

According to what described above, the planned architecture of the RE-SKIN platform is shown in Fig. 30.

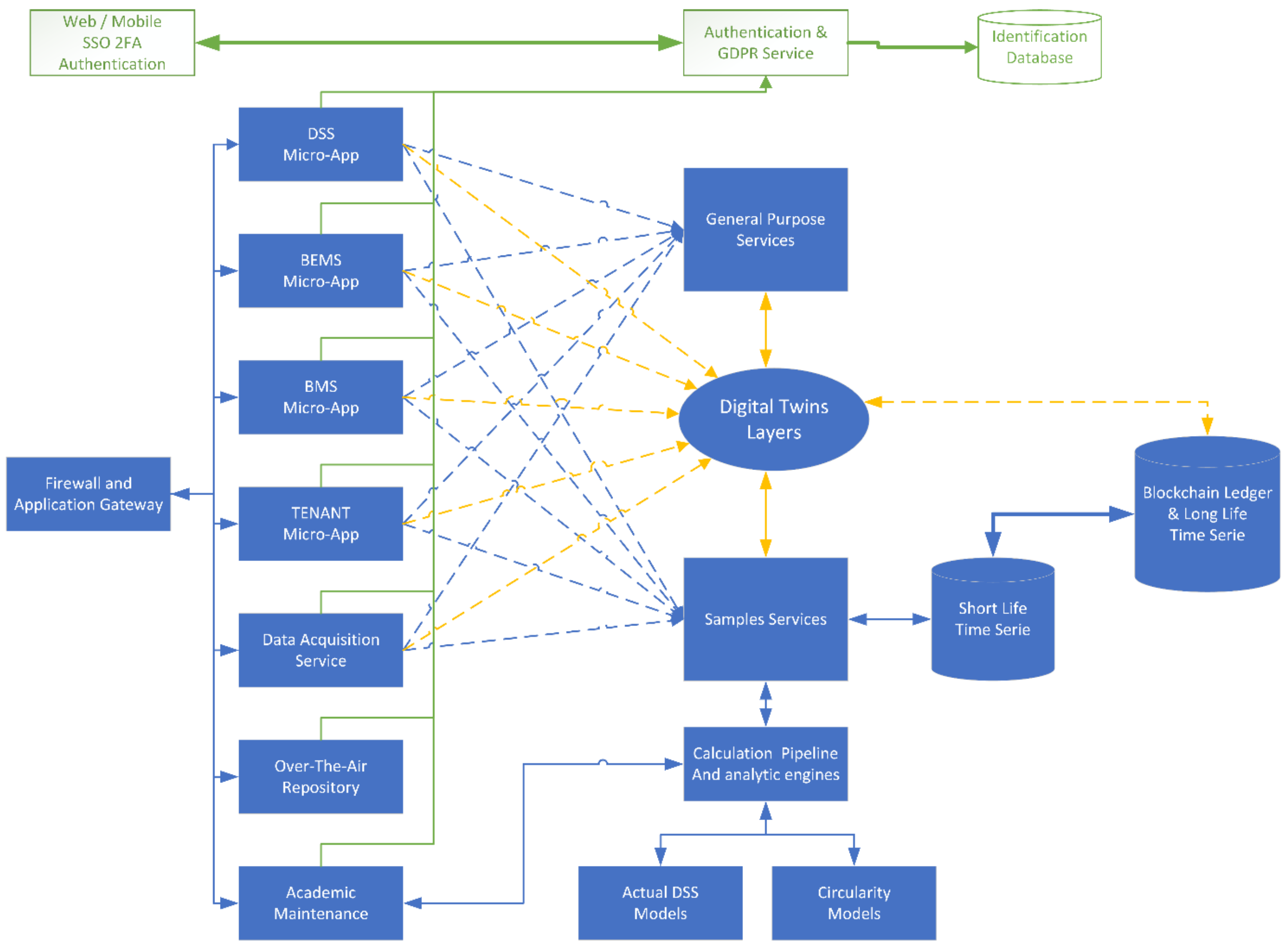


Figure 30. Planned architecture of the RE-SKIN platform

All the communication will be secured by the latest version of the Transport Layer Security (TLS/HTTPS). Communication between the device and platform and between the users and the platform will be only available after Two Factor Authentication process.

The RE-SKIN platform will enforce the privacy of the different users by maintaining a centralized Identity management component, used by all the other components of the platform. Only the required data will be accessible by the module after consent of the user. Revocation process and Consent list will be provided to the users.

Different mechanisms will be implemented to secure the communication and to protect the integrity and the confidentiality of the interactions between the devices and the RE-SKIN platform. The entire communication channel between the Wireless Sensor Node (gateway) and the platform will be encrypted to prevent man-in-the-middle attack and backdoors. This means that even if the message travels through different solutions, it will only be readable when it reaches the platform for processing, decreasing the attack surface whatever using, be it HTTP, AMQP, or MQTT, all over TLS.

13. Components' identification and data collection

During the project, the components developed in RE-SKIN will be identified by a unique and standardised way in order to create a registry where all the information, organised in datasheets, and the documents concerning different characteristics and performances can be collected, updated and shared among all the partners and stakeholder over time.

The proposal is to assume the OmniClass Construction Classification System, also known as OmniClass™ or OCCS, as unique classification system for the entire RE-SKIN system. The choice has fallen on OCCS for its international dissemination and completeness.

The OmniClass Construction Classification System is a classification and coding system used for the organising and retrieving of information for the construction industry. It covers the full facility lifecycle from conception to demolition or reuse, and all types of construction in the built environment. It is useful for Building Information Modelling (BIM), organising reports and object libraries. OmniClass is derived from internationally-accepted standards developed by the International Organisation for Standardisation (ISO) and the International Construction Information Society (ICIS) and has been developed from the early-1990s to the present.

OmniClass comprises 15 tables. Each table can be used independently to classify a particular type of information, or entries on it can be combined with entries on other tables to classify more complex subjects.

The 15 OmniClass tables enable to break down the construction environment into discrete types of information:

Table 11 - Construction Entities by Function
Table 12 - Construction Entities by Form
Table 13 - Spaces by Function
Table 14 - Spaces by Form
Table 21 - Elements
Table 22 - Work Results
Table 23 - Products
Table 31 - Phases
Table 32 - Services
Table 33 - Disciplines
Table 34 - Organizational Roles
Table 35 - Tools
Table 36 - Information
Table 41 - Materials

Table 49 – Properties

Hereafter a classification and coding of the RE-SKIN components extracted from the OCCS Tables 21, 22 and 23 is described.

In the next step a classification and coding of the **characteristics and properties** of the RE-SKIN components (Table 9) will proposed by extracting levels from the OCCS Table 49 – Properties.

Table 9. Classifications and codes for RE-SKIN components according to Construction Classification System

Elements description	Code	Classification	Code	Classification	Code	Classification
	OCCS TABLE 23		**OCCS TABLE 22**		**OCCS TABLE 21**	
Smart fan coil	23-33 33 11	Fan Coil Units	22-23 82 19	Fan Coil Units	21-04 30 20 70	Decentralized Heating Equipment
					21-04 30 30 70	Decentralized Cooling
DC heat pump	23-33 17 11 11	Air Source Packaged Heat Pumps	22-23 82 42 (NOTE: new code assigned - 42)	AIR-to-Water Heat Pump	21-04 30 20 10 Heat	Generation
					21-04 30 30 10	Central Cooling
PV tiles	23-35 11 17 13	Photovoltaic Array	22-26 31 00	Photovoltaic Collectors	21-04 50 10 30	Photovoltaic Collectors
Modular façade thermal insulation	23-13 37 13	Exterior Wall Cladding	22-07 42 13 19	Insulated Metal Wall Panels	21-02 20 10 10	Exterior Wall Veneer
Recycled electric vehicle batteries	23-35 19 15 15	Lithium Batteries	22-26 33 13	Batteries	21-04 50 10 20	Battery Equipment
Back-insulated standing	23-13 39 27 11 11	Metal Roof Panels	22-07 41 13	Metal Roof Panels	21-02 30 10	Roofing

seam metal roofing						
Hybrid building-integrated photovoltaic-thermal (BIPVT) system,			22-23 56 14 Note: new code 14 not existing in Omniclass	Heating Solar Collectors with PV integrated cells		
Components for windows	23-17 13 11 11	Window Sections				
	23-17 13 11 13	Window Linings and Boards				
	23-17 13 11 15	Window Vents				
	23-17 13 11 17	Window Frames				
	23-17 15 11 29	Insulating Glass				