# D3.3 - Requirements to optimize resilience and maintenance I

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# Deliverable Information Sheet

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# History of changes

| Version | Date | Comments | Main Authors |
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| 0.1 | 19/11/2023 | First draft, establishing document structure | G. Paganin, C. Talamo, N. Atta (Polimi) |
| 0.2 | 5/12/2023 | First version, incorporating input from all participants | G. Paganin, C. Talamo, N. Atta (Polimi) |
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| 1.0 | 30/12/2023 | Final version addressing all further comments | G. Paganin, C. Talamo, N. Atta (Polimi) |

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# 1. Executive summary

The aim of this Deliverable 3.3 of WP3 is the optimization of the RE-SKIN subsystems to ensure their synergic integration and interconnection. The contents of the D3.3 have been developed within the Task T3.3 “Definition of resilience features of sub-components to disruptive events”.

Deliverable D3.3 provides a set of maintainability factors to be used during the basic design stage in order to assess and, if necessary, to improve the configuration of the main sub-components (T3.1-T3.2) of the RE-SKIN system. The same set of factors will be applied, with a different level of detail, during the further detailed design and procurement stages. The information included in the present deliverable may be used within a further specific procedure to perform maintainability reviews during the design process according to methods and contents appropriate for various stages.

The present deliverable lists the main maintainability factors and applies them to the RE-SKIN components in relation to the risk assessment carried out in Task T2.6 and reported in Deliverable D.2.1.

The goal is to improve the ability of the RE-SKIN system to be maintained with a small number of man-hours, low levels of operator specialization, a limited number of low-complexity equipment, under safe conditions. For this purpose, the deliverable proposes an assessment and where necessary, possible modifications of the configuration of the components of the system in order to improve the performance in relation to the requirement of maintainability.

The concept of Maintainability, that is assumed here as a design requirement for the RE-SKIN system, is defined as “*The ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources*” (EN 13306: 2017).

Increasing the levels of maintainability of a technical system allows to:

- minimize the Mean Time to Repair (MTTR);
- guarantee safety maintenance operations;
- boost circularity by enhancing the disassembly of the system for recycling and reuse (see also deliverable D.4.8);
- improve the resilience of the building and its capability to be recovered in a short time from the effects of hazardous events.

Considering this last point, the concept of Resilience, that is assumed here, is “The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions” (IPCC, 2012: Glossary of terms).

# 2. METHODOLOGY

The development of D3.3 has followed seven steps:

1. Finding and selecting international standards and guidelines dealing with design for maintainability requirements;
2. Selection of a set of maintainability factors appropriate in relation to RE-SKIN application;
3. Specification of the assessment criteria for each factor;
4. Selection of most relevant Damage/Impacts affecting the RE-SKIN components related to some possible hazards, identified and analysed in the deliverable D 2.1;
5. Identification of the most appropriate maintenance strategies to apply to the RE-SKIN components to correct/prevent the effects of the events linked to the hazards;
6. For each maintenance strategy, identification of the most appropriate activities and related equipment;
7. Assessment of the maintainability of the RE-SKIN components and suggestions for Opportunities For Improvements (OFI).

# 3. REFERENCE STANDARDS AND REGULATIONS

The following standards have been selected and investigated:

- EN 13306: 2017 Maintenance - Maintenance terminology.
- IPCC, 2012: Glossary of terms.
- EN 17485:2021 Maintenance — Maintenance within physical asset management — Framework for improving the value of the physical assets through their whole life cycle.
- BS EN 17007:2017 Maintenance process and associated indicators.
- BS EN 15341:2019+A1:2022 Maintenance. Maintenance Key Performance Indicator.
- EUROPEAN STANDARD, DRAFT prEN 17902, Furniture - Circularity - Requirement and evaluation methods for dis-/reassembly, September 2022.
- ISO 20887:2020 Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance.
- BS 8887-2:2009 Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Terms and definitions. British Standards Institution, 2009.
- JRC Technical Report, Level(s) indicator 2.3: Design for adaptability and renovation.
- JRC Technical Report, Level(s) indicator 2.4: Design for deconstruction.

# 4. ASSESSMENT CRITERIA FOR THE RE-SKIN COMPONENTS

The maintainability requirement can be break down in some factors. These factors represent the assessment criteria for the RE-SKIN components.
The maintainability factors that have been assumed are listed below.

**1. Accessibility**

It's one of the factors that most affect the maintainability of a building and its components.
It is identified as the ease with which it is possible to reach a subsystem and access its components to perform maintenance operations. The main aspects that affect the accessibility of a part of the building or construction work are the location, the presence of paths and operating spaces in its vicinity and the dimensioning of access.
Accessibility can be considered in relation to two levels:

*a.* a first level, that we can define "external" accessibility, concerns the different parts of the building to be maintained. It is essential that all the parts of the building (envelope, roof, equipment, etc.) can be reached easily and in safe conditions directly or with the use of construction equipment to carry out activities of inspection and of corrective and predictive maintenance.

Various access modes can be considered (Figs. 1, 2):

- inside the building, with balconies, technical rooms, dedicated and protected paths, fixed or mobile walkways, etc. In this case, it is important to consider the dimensions of the paths in relation to the presence of people and equipment and the protection measures;
- from the outside of the building, from its base with construction equipment (ladders, scaffolding, manlifts, cranes, etc.). In this case, it is important to consider data of the construction equipment such as the attainable height, ground load bearing, dimensions of movable arms, weight in order to verify the usability with respect to the morphology of the building and to correctly size the paths on the ground;
- from the outside of the building by permanent means integrated into the architecture as fixed cranes or building maintenance units.

| MINIMUM DIMENSION AND CHARACTERISTICS OF THE MAINTENANCE VEHICLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Light vehicles** | | | | | | | |
| **MODEL** | MIN SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS | | Weight (kg) | Bearable load | Maximum reachable height |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Bunk ladder** | 0,96 | 0,51 | 1,12 | | | 14 | | |
| **Support ladder** | | 0,38 | | | | 3,4 | | 1,85 |
| **Scissor platform** | 1,13 | 0,7 | 1,64 | 1,13 | 0,7 | 235 | 240 | 3,6 |
| **Telescopic boom platform (distance between centers < 2mx2m)** | 1,265 | 0,725 | | 2,265 | 2,725 | 585 | 200 | 25 |
| | | | | | | | | |
| | **Demountable light vehicles** | | | | | | | |
| **MODEL** | MIN SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS anchored, bracketed or positioned | | Peso (kg) | Bearable load | Maximum reachable height or arm length (m) |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Telescopic ladder** | | 0,44 | | | | 17 | | 6,05 |
| **Scaffolds** | 1,55 | 0,76 | | 2,21 | 1,19 | | 150 | 5,2 |
| **Self-lifting scaffolding** | 7,1 | 1 | | | | | 1000 | 80 |
| **Construction lifts** | 1,15 | 1,1 | 1,12 | | | | 400 | 120 |
| **Wall scaffolding** | 2,5 | | | | | 8,5 | 150 | |
| | | | | | | | | |
| | **Heavy vehicles** | | | | | | | |
| **MODEL** | MIN SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS anchored, bracketed or positioned | | Weight (kg) | Bearable load | Maximum reachable height or arm length (m) |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Truck with crane (license B)** | 4,8 | 1,85 | 2,9 | | | 3500 | 200 | 14 |
| **Truck with crane (license C)** | 8,2 | 2,5 | 3,5 | 8,2 | 5 | | 200 | 27 |
| **Telescopic boom platform (distance between centers > 2mx2m)** | 2,3 | 2 | 2,2 | 7,6 | 2,3 | 5900 | 230 | 14,07 |

**Figure 1.** Accessibility – Minimum dimensions and weights by type of vehicle (All dimensions are indicative and should be checked with specific data sheets from manufacturers and/or local laws and regulations)

| MAXIMUM DIMENSION AND CHARACTERISTICS OF THE MAINTENANCE VEHICLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Light vehicles** | | | | | | | |
| **MODEL** | MAX SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS | | Wught (kg) | Bearable load | Maximum reachable height or arm length (m) |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Bunk ladder** | 3,82 | 1,51 | 5,95 | | | 84 | | |
| **Support ladder** | | 0,45 | | | | 15 | | 6,85 |
| **Scissor platform** | 4,7 | 2,29 | 1,1 | 4,7 | 2,29 | 8200 | 900 | 15,24 |
| **Telescopic boom platform (distance between centers < 2mx2m)** | 2 | 1,5 | 2,1 | 6,6 | 1,5 | 7300 | 230 | 15 |
| | **Demountable light vehicles** | | | | | | | |
| **MODEL** | MAX SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS anchored, bracketed or positioned | | Weight (kg) | Bearable load | Maximum reachable height or arm length (m) |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Telescopic ladder** | | 0,44 | | | | 38,2 | | 12,5 |
| **Scaffolds** | 1,97 | 1,06 | | 2,5 | 1,2 | | 200 | 19,7 |
| **Self-lifting scaffolding** | 28 | 1 | | | | | 3500 | 120 |
| **Construction lifts** | 3,29 | 4,88 | 2,5 | | | | 2000 | 220 |
| **Wall scaffolding** | 2,5 | 1,15 | | 2,5 | 2 | | 300 | |
| | **Heavy vehicles** | | | | | | | |
| **MODEL** | MAX SIZE AND WEIGHT | | | | | | | |
| | DIMENSIONS OF VEHICLE IN TRANSIT | | | VEHICLE DIMENSIONS anchored, bracketed or positioned | | Weight (kg) | Bearable load | Maximum reachable height or arm length (m) |
| | Length (m) | Width (m) | Height of vehicle (m) | Length (m) | Width (m) | | | |
| **Truck with crane (license B)** | 6,54 | | 2,285 | | | 3500 | 200 | 18,5 |
| **Truck with crane (license C)** | 10,8 | 2,5 | 3,9 | 10,8 | 6,4 | | 400 | 56 |
| **Telescopic boom platform (distance between centers > 2mx2m)** | 12,3 | 2,5 | 3,05 | 14,5 | 2,5 | 20600 | 450 | 40,2 |

**Figure 2.** Accessibility – Maximum dimensions and weights by type of vehicle (All dimensions are indicative and should be checked with specific data sheets from manufacturers and/or local laws and regulations)

*b.* The second level, that we can define as "internal" accessibility, consists in the possibility of easy access to the internal parts of the subsystem/component. Once an operator has reached the subsystem to be maintained, it is necessary that the subsystems or components could allow easy access to their constituent parts. This can be made possible by checking at the design stage that the solutions adopted are not characterized by an excessive technical complexity and that the component/components to be maintained are reachable without disassembling or worse, demolishing other parts of the subsystem.

2. **Ergonomics**
   It is very important to consider the anthropometric dimensions (Figs. 3, 4) in order to allow maintenance operators to access and execute in an appropriate manner their tasks when using the means and devices for accessing and maintaining the technical elements or components. According to the possible maintenance actions to be carried out, it regards aspects such as dimensions of the access and operating spaces, morphology (handling) and weight of the elements, and also dimensions, the weight and mode of operation of any ancillary materials and equipment.

3. **Diagnosability**
   It is a characteristic that expresses the ability of a subsystem to reveal its state (functioning, degraded or broken) or the state of a component. The degree of diagnosability of a component is determined by two aspects: one that depends on the configuration and characteristics of the system and therefore the possibility of making visible and/or detectable the present conditions, degradation signals, symptoms of abnormalities; the other depends on the presence of a series of aids that allow you to know the status (for example, pressure meters, flow meters, smoke detectors, etc.). There are also other factors connected with the concept of diagnosability. One factor, for example, is the ability to inspect a component to check the state of its operation. The degree of inspection of a technical element depends on: the possibility of viewing the constituent parts thereby minimizing disassembly actions; the level of technological complexity; its accessibility; functional and technological clarity.

*4.* **Isolability/Independence**
   It is the ability of a technical element to be isolated from other elements in order to minimize/avoid interference to better inspect it, for easier interpretation of any anomalies and for easier maintenance. Materials or components should be removable without disrupting other components or materials.

5. **Reversibility**
   It is the ability of a system to return it to its original function after maintenance activities avoiding demolition and/or reconstruction. This feature depends significantly on the possibility of undergoing simple disassembly and reassembly actions without additional processing.

6. **Modularity**

   It is the characteristic of a system when the parts that compose it are: easily identifiable from a physical and geometric point of view; morphologically well identifiable; with dimensions equal to, multiple or sub-multiple to the other parts of the system.

7. **Interchangeability**

   It is the ability of a system (subsystem, component, material) to be replaced with another similar entity for physical configuration and/or function. Interchangeability is facilitated by modularity and standardisation.

8. **Standardization**

   It is the use of elements that have been designed and manufactured according to norms or shared standards taken as reference (standardization can regard of dimensions, materials, etc.).

9. **Cleanability (easy cleaning)**

   It is the attitude to allow the removal of dirt and unwanted substances. It can be pursued through several strategies: accessibility, the choice of materials (refractory to dirt, self-cleaning, etc.), the provision of devices for self-cleaning (robotic systems, built-in cleaning systems, etc.). Cleaning actions have an important role in maintaining the performance of the appearance of buildings and in preventing degradation due to the presence of deposits and substances, from the environment, aggressive for surfaces and technical elements.

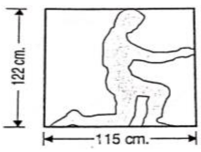
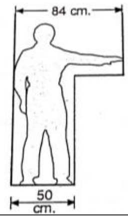
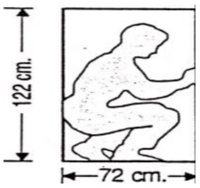
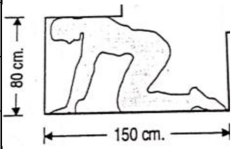
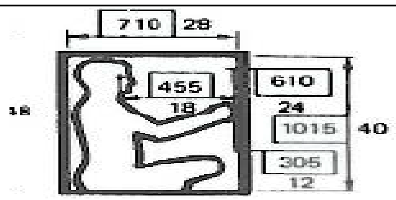
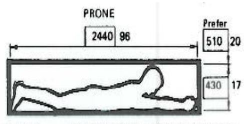
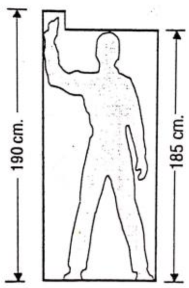
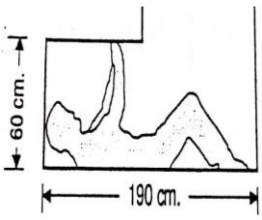
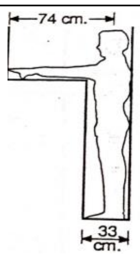
| Ergonomics (person - space) | | | | | |
|---|---|---|---|---|---|
| **Kneeling** | |   | **With arm extended to the** | |   |
| Length (cm) | 115 | | Height (cm) | 185 | |
| Height (cm) | 112 | | Extended arm (cm) | 84 | |
| Width (cm) | 50 | | Width (cm) | 50 | |
| **Crouched** | |   | **All fours position** | |   |
| Length (cm) | 72 | | Length (cm) | 80 | |
| Height (cm) | 112 | | Height (cm) | 150 | |
| Width (cm) | 50 | | Width | 50 | |
| **Sitting** | |   | **Prone lying position** | |   |
| Length (cm) | 0,71 | | Length (cm) | 46 | |
| Height (cm) | 1,01 | | Height (cm) | 216 | |
| Width (cm) | 50 | | Width (cm) | 50 | |
| **Overhead work** | |   | **Supine lying position** | |   |
| Height of man standing (cm) | 185 | | Length (cm) | 190 | |
| Minimum processing height (cm) | 190 | | Height (cm) | 60 | |
| Width (cm) | 50 | | Width (cm) | 50 | |
| **With arm extended forward** | |   | | | |
| Height (cm) | 185 | | | | |
| Extended arm (cm) | 74 | | | | |
| Width (cm) | 33 | | | | |
| Sources: Ramsay, Sleeper (Antropometric data). Molinari (Procedimenti e metodi della manutenzione edilizia) | | | | | |

**Figure 3.** Ergonomics person-space (All dimensions are indicative and should be checked with local laws and regulations)

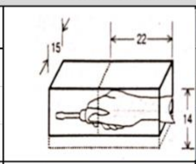
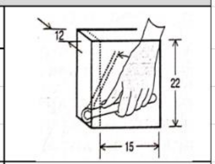
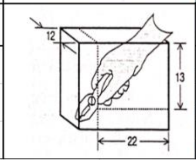
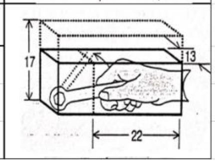
| Use of tools and utensils | | | | | |
|---|---|---|---|---|---|
| **Screwdriver** | |  | **Key1** | |  |
| Width (cm) | 14 | | Width (cm) | 22 | |
| Length (cm) | 15 | | Length (cm) | 12 | |
| Height(cm) | 22 | | Height(cm) | 15 | |
| **Pliers** | |  | **Key2** | |  |
| Width (cm) | 12 | | Width (cm) | 17 | |
| Length (cm) | 13 | | Length (cm) | 13 | |
| Height(cm) | 22 | | Height(cm) | 22 | |

**Figure 4.** Ergonomics – use of utensils (All dimensions are indicative and should be checked with local laws and regulations)

# 5. RE-SKIN COMPONENTS TO BE ASSESSED

The proposed assessment has been applied to:

- Hybrid prefabricated photovoltaic-thermal roof, with refurbished PV modules, recycled aluminum profiles, boxed sustainable steel and bio-sourced insulation;
- Multifunctional prefabricated façade with self-supporting panels and bio-sourced 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 Control System;
- Smart Fan Coil;
- EV charger.

For each element, a set of (condition-based and corrective) maintenance activities is outlined for each hazard identified in the deliverable D2.1.
In relation to the identified maintenance activities, the maintainability requirements are outlined.
Depending on the different specificity of the RE-SKIN components, the maintainability requirements are articulated specifically for each hazard (e.g., roof and façade) or grouped for maintenance activities (batteries, heat pump, MIMO, smart fan-coils, EV charger, smart control).

# 6. PRELIMINARY ASSESSEMENT

The preliminary assessment has the goal to develop an analytical and precise investigation of the categories of components, listed in section 5, in search of critical issues that can make difficult or unsustainable for various aspects (time, costs, tools, number of operators, safety, risks, logistic, pollution, etc.) the maintenance activities.
In relation to the most relevant Damage/Impacts related to some possible Hazards, identified and analysed in the deliverable D 2.1, some maintenance strategies, and related activities, have been identified as follows:

- *Condition based maintenance (visual inspection, inspection with the support of appropriate devices, functional test and monitoring)*
- *Corrective maintenance (repair, partial substitution, total substitution, etc.).*

The components are assessed considering, for the possible maintenance activities, the maintainability factors (listed in section 4) mainly involved and how each component performs its functions in relation to the maintainability requirement.
The analytical assessment indicates any issues and provides possible suggestions/improvements.
The investigation provides improvements for the next step of the research i.e., the detailed design of the system and the development of the maintenance plan.

## 6.1. Modular multifunctional façade cladding

**Brief system description**

The multifunctional prefabricated façade system is organized according to a modular structure (Fig. 5). The system is designed to be integrated into vertical facades, adding the outer layers of cladding, waterproofing and insulation.

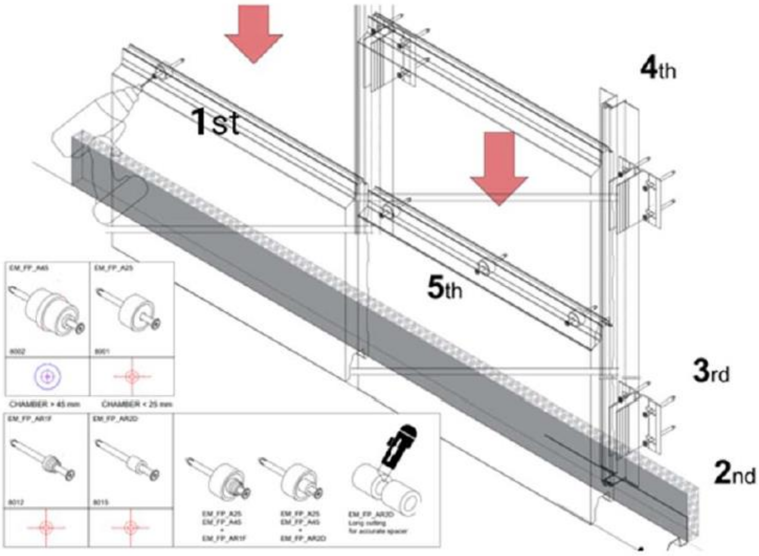



**Figure 5.** Scheme of sequence of assembly of the panels

It comprises prefabricated panels in standardized size modules joined by a tongue-and-groove system (Fig. 6) that ensures watertightness and modularity to be adapted to variable geometries of buildings.

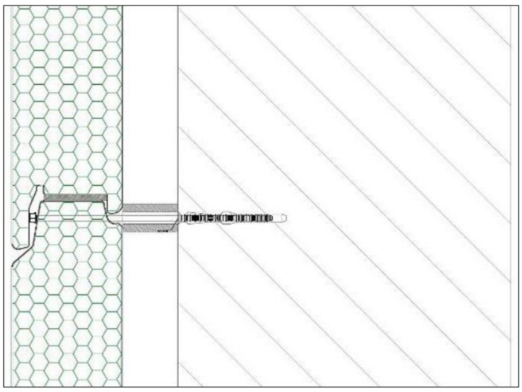


**Figure 6.** Tongue-and-groove joint

The panels are made of high-strength steel sheets with weatherproofing and biobased coating on their outer face (Fig. 7). The insulating section is incorporated with the injection of organic polyurethane compound with bioformulation.

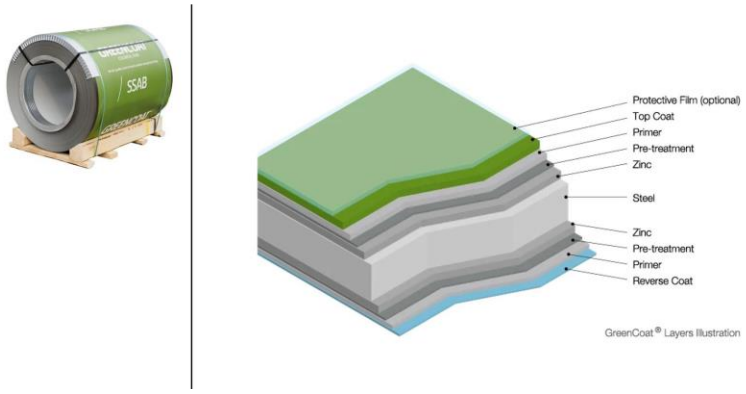



**Figure 7.** GreenCoat® components

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 - Application context periodic update I)

**1. SOCIETAL HAZARD (BEHAVIORAL)**

***Potentially damaged/impacted Subsystem:*** Outer layer.

***Type of physical damage/impact suffered by the subsystem:*** Damage by vandalism or falling objects, affecting its appearance and structure.

***Protection factors/mitigation measures:*** Using impact-resistant materials for the outer layer. Regular maintenance and repair. Installing protective barriers.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**Condition-based maintenance**

**Int.1.1** Direct visual check
**Int.1.2** Visual check through drone
**Int.1.3** Visual check through binoculars

**Corrective maintenance**

**Corr. Int. 1.1** Replacement of the sandwich panel
**Corr. Int. 1.2** Cleaning of the outer layer steel coating

**MAINTAINABILITY REQUIREMENTS**

**Condition-based maintenance**

**Accessibility**
**Int. 1.1** Direct visual check
For areas to be inspected at a height higher than 2 meters from the ground (to be adapted to local legal requirements)

- access with equipment or operating machines (scaffolding, cranes, manlifts, …) (Figs. 1, 2):
    - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
    - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access (Fig. 3) via dedicated paths (Fig. 3) integrated into the building or technical spaces for maintenance. As a general criterion (to be verified according to local regulations or constraints) the width of the passages for the maintenance operators (doors, traps, pathways, …) shall be at least 70 cm. An appropriate space shall be considered in order to allow for the handling of sandwich panels.

**Int.1.2** Visual check through drone
**Int.1.3** Visual check through binoculars
The space surrounding the building must be free of vegetation to an extent commensurate with the size of the facade to be observed.

**Corrective maintenance**
**Corr. Int. 1.1** Replacement of the sandwich panel

**Accessibility**
In consideration of the dismantling method which involves the dismantling of the entire column of panels, access must take place with the aid of equipment or operating machines (scaffolding, cranes, manlifts, …) (Figs. 1, 2):

- The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
- A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot;
- in relation to the configuration of the building it is advisable to check for the presence of protrusions that could prevent the approach to the surface.

**Independence**
Although the elements are all separable, in the disassembly of a single panel it is necessary to disassemble a whole column of panels (Figs. 1, 2). It is advisable to evaluate the possibility of making

each single panel removable independently from the contiguous panels by modifying the current horizontal interlocking joint between the panels.
The complexity of disassembling the current sections of the facade can be reduced by modifying the tongue-and-groove profiles of the insulation panels.
All elements can be removed without breaking other elements except breaking the joint of PUR foam which is expanded into the vertical connection between two panel.

**Ergonomics**
The facade elements can reach – depending on the project choices – lengths of 4000 mm and these dimensions make them unwieldy during disassembly and replacement. It is suggested, whenever possible, to consider in the design phase of the facade to use smaller dimensions such as 2000 mm.

**Corr. Int. 1.2** Cleaning of the outer layer steel coating
For areas to be cleaned at a height higher than 2 meters from the ground (to be adapted to local legal requirements)

- access with equipment or operating machines (scaffolding, cranes, …) (Figs. 1, 2):
    - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
    - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot
- direct access via dedicated paths (Fig. 3) integrated into the building or technical spaces for maintenance. As a general criterion (to be verified according to local regulations or constraints) the width of the passages for the maintenance operators (doors, traps, pathways, …) shall be at least 70 cm.

**2. ENVIRONMENTAL HAZARD (AIR POLLUTION)**
***Potentially damaged/impacted Subsystem:*** Outer layer.
***Type of physical damage/impact suffered by the subsystem:*** Air pollution may degrade.
materials over time
***Protection factors/mitigation measures:*** Regular cleaning and maintenance. Using weather resistant materials. Design consideration.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**<u>Condition-based maintenance</u>**
**Int. 1.1** Direct visual check
**Int. 1.2** Visual check through drone
**Int. 1.3** Visual check through binoculars

**<u>Corrective maintenance</u>**
**Corr. Int. 1.1** Cleaning of the outer layer steel coating

## MAINTAINABILITY REQUIREMENTS

### Condition-based maintenance

**Accessibility**

**Int.1.1** Direct visual check

For areas to be inspected at a height higher than 2 meters from the ground (to be adapted to local legal requirements)

- access with equipment or operating machines (scaffolding, cranes, …) (Fig. 1, 2):
  - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment or heavy vehicles;
  - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access via dedicated paths (Fig. 3) integrated into the building or technical spaces for maintenance. As a general criterion (to be verified according to local regulations or constraints) the width of the passages for the maintenance operators (doors, traps, pathways, …) shall be at least 70 cm.

**Int.1.2** Visual check through drone

**Int.1.3** Visual check through binoculars

The space surrounding the building must be free of vegetation to an extent commensurate with the size of the facade to be observed.

### Corrective maintenance

**Corr. Int. 1.1** Cleaning of the outer layer steel coating

**Accessibility**

For areas to be cleaned at a height higher than 2 meters from the ground (to be adapted to local legal requirements)

- access with equipment or operating machines (scaffolding, cranes, …) (Fig. 1, 2):
  - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
  - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access (Fig. 3) via dedicated paths integrated into the building or technical spaces for maintenance. As a general criterion (to be verified according to local regulations or constraints) the width of the passages for the maintenance operators (doors, traps, pathways, …) shall be at least 70 cm.
  - in relation to the configuration of the building it is advisable to check for the presence of protrusions that could prevent the approach to the surface.

## 6.2. Hybrid building-integrated photovoltaic-thermal (BIPVT) system

**Brief system description**

The BIPVT roofing system is organized according to a modular structure, the upper cover is constituted by PV modules (Fig. 8). 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 (Fig. 9).

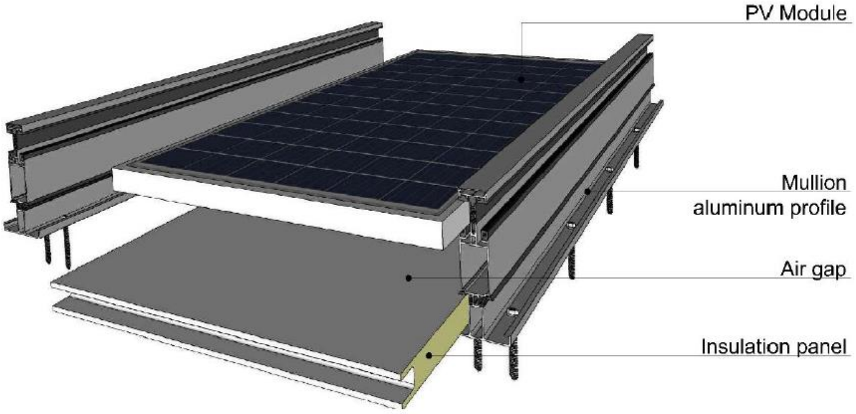



**Figure 8.** General view of the roofing system integrating PV

The installation of the PV modules is provided through metal profiles, joined to the underlying slab or roof framework.

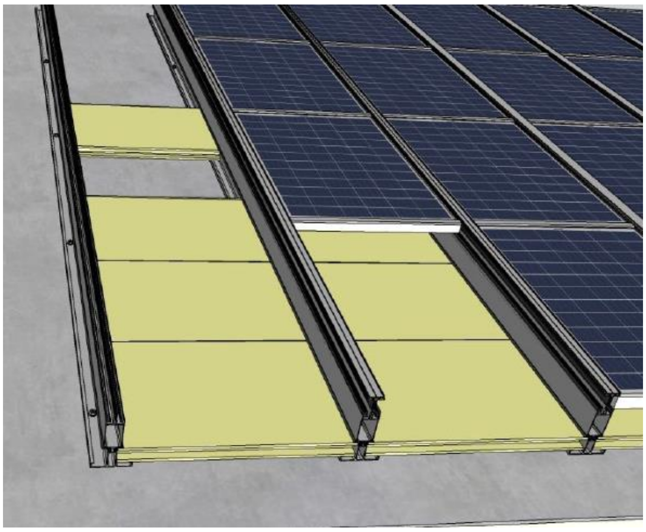


**Figure 9.**Installation sequence (mullions, insulation, PV)

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 Application context periodic update I)

### 1. HAILSTORM HAZARD

***Damage/Impact:*** Glass breakage, which can occur due to the impact of hailstones.
***Protection Factors/Mitigation Measures:*** Ensuring the use of high-quality glass to enhance its resilience against hailstones.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**Condition-based maintenance**
**Int. 1.1** Direct visual check
**Int. 1.2** Visual check through drone
**Int. 1.3** Visual check through video camera
**Int. 1.4** Monitoring of production data

**Corrective maintenance**
**Corr. Int. 1.1** PV module replacement

**MAINTAINABILITY REQUIREMENTS**

**Condition-based maintenance**

**Accessibility**
**Int. 1.1** Direct visual check

- access with equipment or operating machines (scaffolding, cranes, …):
    - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light, light demountable or heavy vehicles;
    - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access, with integrated paths (e.g., footbridges).

**Int. 1.3** Visual check through video camera
It would be advisable to provide for the installation of video cameras positioned to remotely view the entire surface of the photovoltaic roof.
It would be advisable to provide ways of accessing the video camera for its maintenance (with construction equipment's or integrated paths).

**Corrective maintenance**

**Corr. Int. 1.1** PV module replacement

**Accessibility**
*Accessibility - Exogenous*

- access with equipment or operating machines (scaffolding, cranes, manlifts, …):
  - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
  - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot;
- Direct access via dedicated paths integrated into the building or temporary systems (e.g. trapdoors, doors, passageways or load distribution systems to make the PV panels walkable).
- If it is not possible to provide, in part or in whole, collective protection measures (guardrails, safety nets, etc.), it is necessary that work at height is carried out with the use of personal fall protection devices. Already in the design phase of the RE-SKIN retrofit project, the characteristics and placement of the devices on stable parts must be foreseen, where the worker can attach themselves (according to the different alternatives proposed in the standard EN 795:2012). There must be the presence of paths at height adequately dimensioned to support the weight of one or more operators with the appropriate maintenance tools.

*Accessibility - Endogenous*
No specific requirements

**Ergonomics**
The operating spaces required for the disassembly of the PV panels must be sized on the max size of the panels 120-180 (see deliverable D.4.1) and of the fixing elements like the pressure plate (NB: it shall be noted that pressure plate maximum length is not declared) to allow their adequate handling for positioning. In steeply sloping roofs, the space for the simultaneous storage of the removed panels and those to be installed must be planned; this system must ensure the safety of the panels to prevent them from falling.

**Independency**
All elements can be removed without breaking other elements. The PV modules are independent and their disassembly can take place individually after removing the pressure plate and snap cover (where present). However, the system as a whole is not fully independent and to pursue this objective, the configuration of the whole system would have to be reconsidered, for example using a configuration similar to the one of curtain walls with independent cells.

**Reversible connections**
No additional requirements (see D4.8)
**Standardization**
No additional requirements (see D4.8)

**2. STRONG WINDS**

***Potentially Damaged/Impacted Subsystem:*** Attacks on the system due to the wind force.

***Type of Physical Damage/Impact Suffered by the Subsystem:*** Failure to hold attachments caused by strong winds.
***Protection Factors/Mitigation Measures:*** Conducting a tightness check based on the wind regulations specific to the country of installation. This measure aims to ensure the system's stability and ability to withstand high wind pressures.
**NOTE:** in the following it is assumed that the strong winds may lead to damage of the PV panels and not only of the fixing devices

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**Condition-based maintenance**
**Int. 2.1** Direct visual check
**Int. 2.2** Visual check through drone
**Int. 2.3** Visual check through video camera
**Int. 2.4** Monitoring of production data

**Corrective maintenance**
**Corr. Int. 2.1** PV module replacement

**MAINTAINABILITY REQUIREMENTS**

**Condition-based maintenance**

**Accessibility**
**Int. 2.1** Direct visual check

- access with equipment or operating machines (scaffolding, cranes, …):
  - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light, light demountable or heavy vehicles;
  - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access, with integrated paths (e.g., footbridges)

**Int. 2.2** Visual check through drone
The presence of trees or vegetation close to the building shall be verified.

**Int. 2.3** Visual check through video camera
It would be advisable to provide for the installation of video cameras positioned to remotely view the entire surface of the photovoltaic roof.
It would be advisable to provide ways of accessing the video camera for its maintenance (with equipment or integrated paths).

**Corrective maintenance**
**Corr. Int. 2.1** PV module replacement

**Accessibility**

*Accessibility - Exogenous*

- access with equipment or operating machines (scaffolding, cranes, …):
    - The spaces on the surrounding areas of the building must allow for the assembly, parking and dismantling of light and/or light demountable equipment's or heavy vehicles;
    - A check shall be made concerning the presence of architectural barriers that could inhibit the passage of light, light demountable or heavy vehicles on the routes within the plot or in the parking spaces on the plot.
- direct access via dedicated paths integrated into the building or temporary systems (e.g. trapdoors, doors, passageways or load distribution systems to make the PV panels walkable).
- If it is not possible to provide, in part or in whole, collective protection measures (guardrails, safety nets, etc.), it is necessary that work at heights is carried out with the use of personal fall protection devices. Already in the design phase of the building, the characteristics and placement of the devices on stable parts must be foreseen, where the workers can attach themselves (according to the different alternatives proposed in the standard EN 795:2012). There must be the presence of paths at height adequately dimensioned to support the weight of one or more operators with the appropriate maintenance tools.

*Accessibility - Endogenous*

No specific requirements

**Ergonomics**

The operating spaces required for the disassembly of the PV panels they must be sized on the max size of the panels 120-180 (see deliverable D.4.1) and of the fixing elements like the pressure plate (NB: it shall be noted that pressure plate maximum length is not declared) to allow their adequate handling for positioning.
In steeply sloping roofs, the space for the simultaneous storage of the removed panels and those to be installed must be planned; this system must ensure the safety of the panels to prevent them from falling.

**Independency**

All elements can be removed without breaking other elements. The PV modules are independent and their disassembly can take place individually after removing the pressure plate and snap cover (where present). However, the system as a whole is not fully independent and to pursue this objective, the configuration of the whole system would have to be reconsidered, for example using a configuration similar to the one of curtain walls with independent cells.

**Reversible connections**

No additional requirements (see D.4.8)

**Standardization**

No additional requirements (see D.4.8)

## 6.3. Battery Pack – Electrical storage

**Brief system 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).

**Figure 10.** Battery banks with cells in series

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. They are enclosed in a plastic tray in group of 8 battery cell in series, forming a “battery bank”. The battery pack will be made by 18 battery banks for a total of 144 cells.


**Figure 11.** Steel enclosure for the battery banks

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 - Application context periodic update I)

**1. METEOROLOGICAL AND HYDROLOGICAL (FLOOD) HAZARD**

***Potentially Damaged/Impacted Subsystem***: Lithium Battery cells and electricals flooded.

***Type of Physical Damage/Impact Suffered by the Subsystem***: Short circuit with possible fire and production of $H_2$, leading to equipment loss.

***Protection Factors/Mitigation Measures:*** Prevent water from easily entering the battery room and battery enclosure to avoid flood-related damage.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**Condition-based maintenance**

**Int. 1.1** Visual check for detecting possible impact damages: visually check the linearity and integrity of the battery case and battery surfaces (external damages, such as dents or fractures, have an adverse impact on the battery's performance).

**Int. 1.2** Visual inspection for detecting possible loose terminals which can disrupt the connections among the battery cells.

**Int. 1.3** Inspection of the integrity of the electrical connection of the battery pack to the central power electronic board.

**Int. 1.4** Functional test.

**Corrective maintenance**

**Corr. Int. 1.1** Replacement of a cell

**Corr. Int. 1.2** Replacement of the battery case

**Corr. Int. 1.3** Replacement of the whole battery pack

**2. MARINE HAZARD**

***Potentially Damaged/Impacted Subsystem***: Battery terminals and related electronics.

***Type of Physical Damage/Impact Suffered by the Subsystem***: Corrosion due to exposure to salt water or saltwater mist, leading to functionality loss or even thermal runaway self-igniting fire.

***Protection Factors/Mitigation Measures:*** Enclose the system in a maritime-grade IP65 enclosure to protect it from marine environments.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

**Planned maintenance**

**Int. 2.1** Regular check of the conditions of the battery enclosure

**Condition-based maintenance**

**Int. 2.2** Visual inspection of the battery terminals for any indication of corrosion (corroded terminals often manifest as a powdery white substance surrounding the post connections. The presence of such corrosion can impede the battery's ability to charge effectively)

<u>**Corrective maintenance**</u>
**Corr. Int. 2.1** Replacement of battery terminals
**Corr. Int. 2.2** Replacement of the battery pack
**Corr. Int. 2.3** Replacement of the battery enclosure

**3. INFRASTRUCTURE FAILURE- POWER OUTAGE FOR MORE THAN ONE DAY IN A ROW**
***Potentially Damaged/Impacted Subsystem***: Lithium battery cells.
***Type of Physical Damage/Impact Suffered by the Subsystem***: Self-discharge below a recoverable limit during prolonged power outages.
***Protection Factors/Mitigation Measures:*** Ensure that batteries are electrically disconnected from even small loads during long power outages and periodically recharge them to maintain their functionality.

**MAINTENANCE STRATEGIES AND ACTIVITIES**
<u>**Planned and Condition-based maintenance**</u>
**NOTE: the periodic control of the charge status and of the charging and storage capacity of the RE-SKIN system batteries is carried out by the BMS**
**Int. 3.1** Visual check for detecting possible impact damages: visually check the linearity and integrity of the battery case and battery surfaces (external damages, such as dents or fractures, have an adverse impact on the battery's performance).
**Int. 3.2** Visual inspection for detecting possible loose terminals which can disrupt the connections among the battery cells.
**Int. 3.3** Inspection of the integrity of the electrical connection of the battery pack to the central power electronic board.
**Int. 3.4** Functional test.

<u>**Corrective maintenance**</u>
**Corr. Int. 3.1** Replacement of a cell
**Corr. Int. 3.2** Replacement of the battery case
**Corr. Int. 3.3** Replacement of battery terminals
**Corr. Int. 3.4** Replacement of the whole battery pack

**4. VANDALIC ACTS**
***Potentially Damaged/Impacted Subsystem***: Battery system.
***Type of Physical Damage/Impact Suffered by the Subsystem***: Loss of system or system functionality due to theft or vandalism.
***Protection Factors/Mitigation Measures:*** Implement classical anti-theft and anti-vandalism measures to protect the battery system from such acts.

**MAINTENANCE STRATEGIES AND ACTIVITIES**

<u>**Condition-based maintenance**</u>

**Int. 4.1** Visual check for detecting possible impact damages: visually check the linearity and integrity of the battery case and battery surfaces (external damages, such as dents or fractures, have an adverse impact on the battery's performance)

**Int. 4.2** Visual inspection for detecting possible loose terminals (which can disrupt the battery connections)

**Int. 4.3** Inspection of the integrity of the electrical connection to the central power electronic board

**Int. 4.4** Functional test

<u>**Corrective maintenance**</u>

**Corr. Int. 4.1** Replacement of a cell

**Corr. Int. 4.2** Replacement of the battery case

**Corr. Int. 4.3** Replacement of the whole battery pack

**MAINTAINABILITY REQUIREMENTS**

<u>**Condition-based maintenance**</u>

**ACTIVITIES:**
**Int. 1.1; Int. 1.2; Int. 1.3; Int. 1.4**
**Int. 2.1; Int. 2.2**
**Int. 3.1; Int. 3.2; Int. 3.3; Int. 3.4**
**Int. 4.1; Int. 4.2; Int. 4.3; Int. 4.4**

**Accessibility**

a. *Accessibility to the battery room*. It is suggested to consider during the detail design phase that there must be sufficient space to allow the passage of operators and testing tools (and related transport tools) from outside to the battery room. The route must be free of obstacles and impediments and any difference in height, ramp or step must be appropriately marked with signs or light strips.
b. *Accessibility to the battery pack* surrounding area for performing inspections. The batteries need to be easily accessible and visible for performing inspections and maintenance activities. It is suggested to consider during the detail design phase that there must be sufficient space (Fig. 3) to allow the movement of batteries and tools for inspection and functional testing of the battery pack.
c. *Accessibility to the single battery cell* for performing inspections and functional tests. It is suggested to consider during the detail design phase that there must be sufficient space (Fig. 4) to allow the extraction of the battery cells for subsequent inspection and functional testing.

Verify the load-bearing capacity of the floor system where the cabinet and the battery pack are located. The capacity must be at least equal to or greater than the total load of the batteries, considering the maximum possible load expected, plus other possible additional accidental and permanent loads. Consider that the weights indicated in the RE-SKIN deliverable D6.1 – "Manufacturing design of the technical components I" currently are as follows:

*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

**Independence**
It is suggested to consider during the detail design phase that in order to perform the visual and instrumental inspections the battery cells should be independent and easily separable from each other and from the enclosure. The steel cases (enclosures) should be easy to be removed (and assembled after the intervention) in order to access to the core to allow a time-efficient inspection activity.

**Reversible connections**
The supplier of the battery packs shall justify that the connections between the battery cells are easy to access and to dis/assembly.

**Ergonomics**
During the detailed design phase, it must be ensured that the battery pack and the surrounding area of the battery cabinet is properly dimensioned (Figs 3, 4) for performing inspection activities and functional tests.

<u>**Corrective maintenance**</u>

**Activities:**
**Corr. Int. 1.1; Corr. Int. 1.2; Corr. Int. 1.3;**
**Corr. Int. 2.1**; **Corr. Int. 2.2; Corr. Int. 2.3**
**Corr. Int. 3.1**; **Corr. Int. 3.2**; **Corr. Int. 3.3**; **Corr. Int. 3.4**
**Corr. Int. 4.1; Corr. Int. 4.2; Corr. Int. 4.3**

**Accessibility**
a. *Accessibility to the battery room*. It is suggested to consider during the detail design phase that there must be sufficient space to allow the passage of operators from outside to the battery room. The route must be free of obstacles and impediments and any difference in height, ramp or step must be appropriately marked with signs or light strips. The access route shall be wide enough to allow for the passage of the external enclosure of the battery packs.
b. *Accessibility to the battery pack* surrounding area for performing maintenance. The batteries need to be easily accessible and visible for inspection and maintenance activities. It is suggested to verify in the detail design that the dimensions of this area are sufficient for hosting two operators (Fig. 8), spare parts and maintenance tools (as well as related transport tools).
c. *Accessibility to the single battery cell* for performing maintenance. It is suggested to consider during the detail design phase that there must be sufficient space (Fig. 4) to allow the extraction of the battery cells for subsequent maintenance or replacement.

Verify the load-bearing capacity of the floor system where the cabinet and the battery pack are located. The capacity must be at least equal to or greater than the total load of the batteries, considering the maximum possible load expected, plus other possible additional accidental and

permanent loads. Consider that the weights indicated in the RE-SKIN deliverable D6.1 – "Manufacturing design of the technical components I" currently are as follows:
*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

**Independence**
It is suggested to consider during the detail design phase that in order to perform the visual and instrumental inspections the battery cells should be independent and easily separable from each other and from the enclosure. The steel cases (enclosures) should be easy to be removed (and assembled after the intervention) in order to access to the core to allow a time-efficient inspection activity. In the detail design it is important to verify that: (i) all the elements of the battery pack must be easy to be removed without breaking other elements; (ii) the elements are independent from each other to allow the replacement of the single cells, the battery case, battery terminals and the whole battery types.

**Reversible connections**
The supplier of the battery packs shall justify that the connections between the battery cells are easy to access and to dis/assembly.

**Standardization and presence of spare parts on the market**
During the detailed design phase, the design team must verify that the batteries and the cases are standardized in the dimensions, modular and homogeneous in order to be able to find the products or substitutes on the market (RE-SKIN batteries are standard and they come from automotive industry).

**Ergonomics**
During the detailed design phase, it must be ensured that the battery pack and the surrounding area of the battery cabinet is properly dimensioned (Figs. 3, 4) for performing inspection activities and functional tests. It is suggested to consider the presence of one or two maintenance operators (according to the local needs) in dimensioning the operational area round the system to allow replacement. The design team must verify that the path to reach the battery location is appropriately dimensioned to be "walked" by two maintenance operators with related spare parts, products and maintenance tools simultaneously.

## 6.4. Multi-input/multi-output converter (MIMO)

**Brief system 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.

### Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 - Application context periodic update I)

***Hazard:*** Meteorological and hydrological hazards/risks
***Potentially Damaged/Impacted Subsystem:*** AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
***Type of Physical Damage/Impact:*** Delays in manufacturing of the mentioned subsystems.
***Protection Measures:*** Acquiring all parts as soon as possible to mitigate manufacturing delays.
**NOTE:** this is an “off-site” risk dealing with the manufacturing process of MIMO. No maintenance actions required for the RE-SKIN system in operation.

***Hazard:*** Technological hazards/risks, Societal hazards/risks
***Potentially Damaged/Impacted Subsystem:*** AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
***Type of Physical Damage/Impact:*** Delays in manufacturing due to technological issues and societal factors or delays in other RE-SKIN systems.
***Protection Measures:***
1. Acquiring all parts as soon as possible to mitigate manufacturing delays.
2. Making an early prototype and testing all possible scenarios to identify and address technological issues.

**NOTE:** this is an “off-site” risk dealing with the manufacturing process of MIMO. No maintenance actions required for the RE-SKIN system in operation.

## 6.5. Hydronic Air-To-Water DC Heat Pump

**Brief system description**

The heat pump is an air-to-water system that efficiently utilizes ambient air as its heat source. It operates by using a refrigeration cycle powered by a DC compressor, allowing it to transfer heat from lower temperatures to higher temperatures. This heat pump's main goal is to seamlessly replace traditional fossil fuel-based boilers in existing installations. Buffer tanks are used in the design to enable efficient heat energy storage. The compressor, condenser, evaporator, and expansion valve are the heat pump's four essential parts, the heat pump efficiently offers the principles of refrigeration to provide sustainable heating solutions.

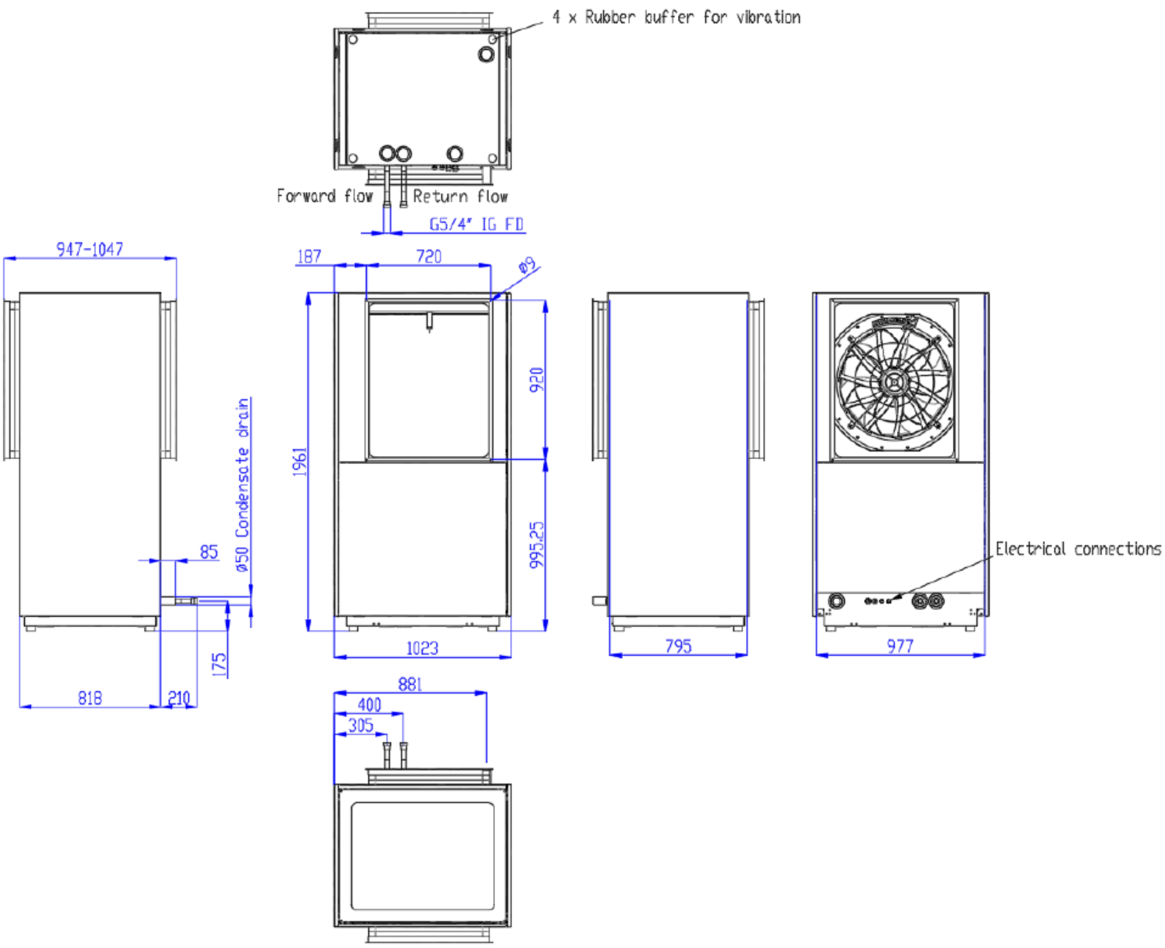



**Figure 12.** DC heat pump scheme and dimensions

The heat pump will be a monoblock or a split version (main unit and ducted heat exchanger), all the main components are placed in one unique block of machine (Fig. 12). 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.

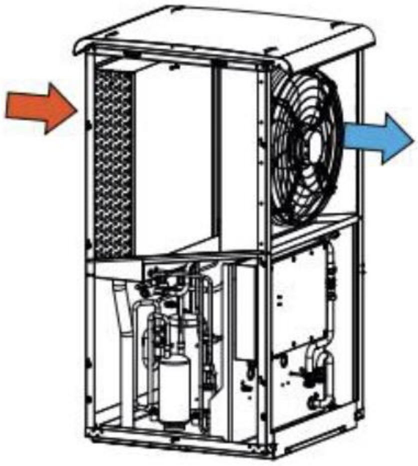


**Figure 13.** Air flow constraints for DC heat pump

The concept of the heat pump is 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) (Fig. 13).

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 Application context periodic update I)

**1. GEOHAZARD (EARTHQUAKE)**

***Potentially Damaged/Impacted Subsystems:*** Compressor, blower motor, fan blades, electrical, and hydronic connections.

***Type of Physical Damage/Impact**:* Risks include oil and refrigerant leaks from compressor vibration, blade breakage, motor malfunction, and damage to electrical and hydronic connections.

***Protection Factors/Mitigation Measures:*** Proper installation following the installation guide.

**Planned maintenance**

**Int. 1.1** Check of the electrical and hydraulic connections, including the tightening of refrigerant and water connections.

**Condition-based maintenance**

**Int. 1.2** Visual inspection after the event (earthquake) to check the integrity of the heat pump and the proper installation according to the guidelines provided by the installing company or the manufacturer.

**Int. 1.3** Functional test.

**Corrective maintenance**

**Corr. Int. 1.1** Repair of the damaged heat pump components (including compressor, blower motor, fan blades, electrical, and hydronic connections).

**Corr. Int. 1.2** Partial replacement: replacement of the damaged heat pump components.

**Corr. Int. 1.3** Replacement of the whole heat pump.

**2. METEOROLOGICAL AND HYDROLOGICAL (FLOOD)**

***Potentially Damaged/Impacted Subsystems:*** Heat exchangers and electrical components (e.g., heat pump control board)

***Type of Physical Damage/Impact:*** Risks include destruction of electrical components and contamination of the heat pump with dirt, debris, and pollutants.

***Protection Factors/Mitigation Measures:*** Implementation of flood barriers and installation of the heat pump in an elevated location

**Planned maintenance**

**Int. 2.1** Periodic control of the integrity of flood barriers

**Condition-based maintenance**

**Int. 2.2** Visual inspection after the event (flood) to check the integrity and proper installation of the heat pump according to the installation guidelines provided by the installing company or the manufacturer.

**Int. 2.3** Functional test.

**Corrective maintenance**

**Corr. Int. 2.1** Cleaning of the heat pump to remove dirt and debris.

**Corr. Int. 2.2** Repair of the damaged heat pump components (including heat exchangers and electrical components).

**Corr. Int. 2.3** Partial replacement: replacement of the damaged heat pump components

**Corr. Int. 2.4** Replacement of the whole heat pump.

**3. TECHNOLOGICAL HAZARD (INFRASTRUCTURE FAILURE)**

***Potentially Damaged/Impacted Subsystems:*** Compressor and coils.

***Type of Physical Damage/Impact:*** Risks include improper compressor shutdown during power outages, leading to overheating and damage, as well as freezing and subsequent cracking of coils during power restoration.

***Protection Factors/Mitigation Measures:*** Provision of a backup power source, such as a generator

**Planned maintenance**

**Int. 3.1** Periodic monitoring of the effectiveness of the power source (that should be the battery pack)

**Condition-based maintenance**

**Int. 3.2** Visual inspection after the event (infrastructure failure) to check the integrity and proper installation of the heat pump according to the installation guidelines provided by the installing company or the manufacturer.

**Int. 3.3** Functional test.

**Corrective maintenance**

**Corr. Int. 3.1** Repair of the damaged heat pump components.

**Corr. Int. 3.2** Partial replacement: replacement of the damaged heat pump components.

**Corr. Int. 3.3** Replacement of the whole heat pump.

**MAINTAINABILITY REQUIREMENTS**

**Planned and condition-based maintenance**

**Activities:**
**Int. 1.1; Int. 1.2; Int. 1.3**
**Int. 2.1; Int. 2.2; Int. 2.3**
**Int. 3.1; Int. 3.2; Int. 3.3**

**Accessibility**

a. *Accessibility to the heat pump location*. It is suggested to consider during the detail design phase that the path to reach the heat pump location should be properly dimensioned to allow the passage of operators and testing tools. The route must be free of obstacles and impediments and any difference in height, ramp or step must be appropriately marked with signs or light strips. Moreover, particular attention must be paid by the design team to the path and work at heights if the heat pump is installed on the roof. In this case, verify the compliance with local and regional laws and directives on maintenance work at heights.
b. *Accessibility of the heat pump* for performing inspections and functional test. The external unit of an air-water heat pump must be positioned in easily accessible place to carry out inspection and functional tests. It is suggested to verify the presence of a properly dimensioned area (Fig. 3) surrounding the heat pump to perform the visual inspections and functional tests.

Moreover, particular attention must be paid by the design team to the path and work at heights if the heat pump is installed on the roof. In this case, verify the compliance with local and regional laws and directives on maintenance work at heights. Moreover, it has to be considered that if the heat pump will be installed on the roof, the presence of an area (properly dimensioned) for the parking of vehicles useful for delivering the heat pump to the roof is necessary (Figs. 1, 2).
Also, verify the load-bearing capacity of the floor system where the heat pump is located. The capacity must be greater than the total load of the heat pump. Please refer to the manufacturer technical datasheets.

**Reversible connections**

During the detailed design it is important to verify that the connections between the heat pump and the building are reversible and exposed (ducts, pipes and MIMO) and that the heat pump components are easy to access and to dis/assembly.

**Ergonomics**

During the detailed design phase, it must be ensured that the path to reach the heat pump is free from obstacles and appropriately dimensioned to allow the proper performing of inspection activities and functional tests. Verify the respect of the manufacturer specifications on the dimensions of the areas to be considered around the heat pump in order to allow inspections and functional tests.

**Corrective maintenance**

**Activities:**
**Corr. Int. 1.1; Corr. Int. 1.2; Corr. Int. 1.3**
**Corr. Int. 2.1; Corr. Int. 2.2; Corr. Int. 2.3; Corr. Int. 2.4**
**Corr. Int. 3.1; Corr. Int. 3.2; Corr. Int. 3.3**

**Accessibility**

a. *Accessibility to the heat pump location*. Verify that the external unit of an air-water heat pump is positioned in an easily accessible place to carry out replacement, that need the presence of more than one maintenance operator. It is suggested to consider during the detail design phase that the path to reach the heat pump location should be properly dimensioned to allow the passage of operators to perform repair or replacement. The route must be free of obstacles and impediments and any difference in height, ramp or step must be appropriately marked with signs or light strips. Moreover, particular attention must be paid by the design team to the path and work at heights if the heat pump is installed on the roof. In this case, verify the compliance with local and regional laws and directives on maintenance work at heights. Moreover, it has to be considered that if the heat pump will be installed on the roof, the presence of an area (properly dimensioned) for the parking of vehicles useful for delivering the heat pump to the roof is necessary (Figs. 1, 2).
b. *Accessibility of the heat pump* for performing inspections and functional test. Verify that the external unit of an air-water heat pump is positioned in easily accessible place to carry out maintenance, repair and replacement. It is suggested to verify also the presence of a properly dimensioned area (Fig. 3) surrounding the heat pump useful for performing the maintenance activities (two or more operators and maintenance tools).

Moreover, verify the load-bearing capacity of the floor system where the heat pump is located. The capacity must be greater than the total load of the heat pump. Please refer to the manufacturer technical datasheets.

**Easy to disconnect**

In the detailed design phase, the design team must verify that the heat pump elements are easily separable and easy to be disconnected without creating damages to connections and components in order to allow the repair and replacement od components. In RE-SKIN system, the elements in the main body of the heat pump are easily separable unless the sealed circuit of the refrigerant gas. The heat pump unit is, in principle, easily separable from the building to which is connected by air ducts, pipes and power supply (MIMO).

**Reversible connections**

In the detailed design phase, the design team must verify that the connections are reversible and exposed. Verify that the connections between the heat pump and the building are reversible and exposed (ducts, pipes and MIMO).

**Standardization and presence of spare parts on the market**

During the detailed design phase, the design team must verify that the heat pump components are standardized in the dimensions, modular and homogeneous in order to be able to find the products or substitutes on the market for partial replacement.

**Ergonomics**

During the detailed design phase, it must be ensured that the path to reach the heat pump is free from obstacles and appropriately dimensioned to allow the proper performing of maintenance activities and replacement. Verify the respect of the manufacturer specifications on the dimensions of the areas to be considered around the heat pump in order to allow maintenance and replacement. It is suggested to verify that the dimensions of the operational area surrounding the heat pump allow the presence of two workers and the spare parts and tools needed to perform maintenance and replacement. Moreover, consider that the handling is not very easy both for dimensions and weight (300-400 kg).

## 6.6. Smart Control System

**Brief system 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.

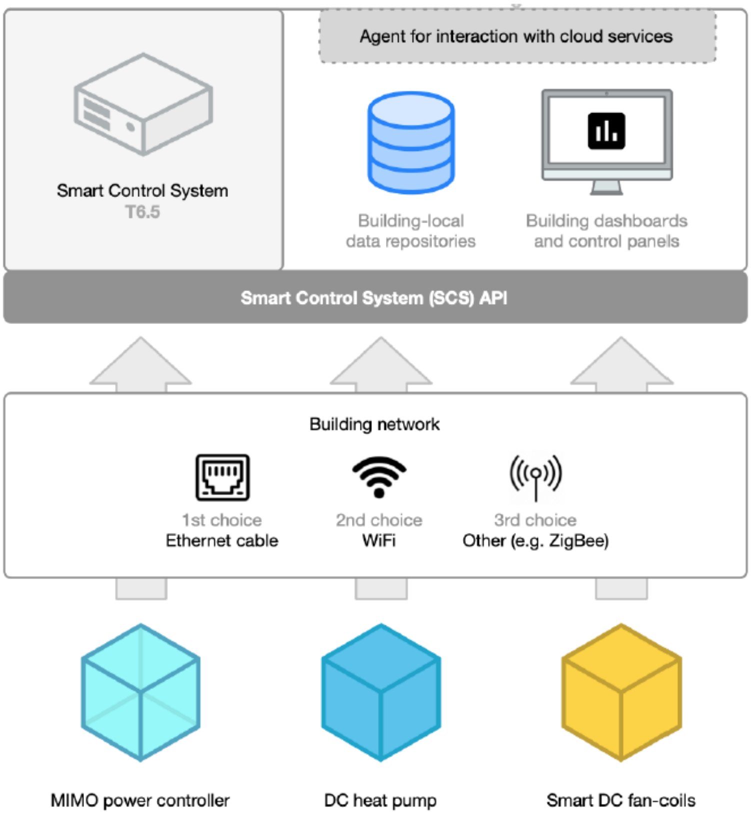



**Figure 14.** Architecture of the SCS system (top half) + network & components (bottom half)

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.

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 Application context periodic update I)

***Hazard:*** Technological Hazard: Infrastructure failure - Potentially Damaged Subsystem: Storage
***Type of Physical Damage/Impact:*** Data loss.
***Protection Measures:*** Critical datasets are stored in cloud services to ensure data preservation even in case of infrastructure failure.
**Maintenance of battery packs will assure the reliability of the SCS**

***Hazard:*** Technological Hazard: Infrastructure failure - Potentially Damaged Subsystem: Network
***Type of Physical Damage/Impact:*** Critical system errors and complete system shutdown.
***Protection Measures:*** Software components are designed to avoid hard dependencies on other services or devices whenever possible, reducing the risk of system errors and shutdowns.
**No maintenance is required for this risk.**

***Hazard:*** Technological Hazard: Cyber hazard - Potentially Damaged Subsystem: The entire system
***Type of Physical Damage/Impact:*** Breach of data privacy and possible monetary costs originating from malicious users controlling the building systems.
***Protection Measures:*** Adopting the Security by Design methodology to strengthen the system's defenses against cyber threats and ensure data privacy.
**No maintenance is required for this risk.**

## 6.7. Smart Fan Coil

**Brief system description**
The smart fan-coils are conceived to substitute radiators, using the existing hydronic pipes when they are in good maintenance state, or new pipes added within the RE-SKIN facade if existing pipes are compromised. The units operate as small water-to-air heat pumps, by extracting or releasing heat to the hydronic network and thus providing heating/cooling/dehumidification in every room according to punctual needs. 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.

**Figure 15.** Preliminary view of the smart fan-coil without (left) and with (right) metal casing

### Maintenance activities and maintainability requirements analysis
(according to the hazards identified in RE-SKIN deliverable D2.1 Application context periodic update I)

***Hazard:*** to be completed in D.2.1
***Type of Physical Damage/Impact:*** to be completed in D.2.1
***Protection Measures:*** to be completed in D.2.1

**General maintainability requirements to be updated according to the risk assessment (see D.2.1)**

**Accessibility**

a. *Accessibility to the smart fan-coil location*. Verify that the unit is positioned in an easily accessible place to carry out replacement, that likely needs the presence of more than one maintenance operator. The route to reach the smart fan-coil is supposed to be accessible as the units will be located inside the dwellings.
b. *Accessibility of the smart fan-coil* for performing inspections and functional test. Verify that the smart fan-coil is positioned in easily accessible place to carry out maintenance, repair and replacement. It is suggested to verify also the presence of a properly dimensioned area surrounding the smart fan-coil useful for performing the maintenance activities.

**Easy to disconnect**

In the detailed design phase, the design team must verify that the smart fan-coils are easily separable and easy to be disconnected without creating damages to connections and components in order to allow the repair and replacement of components. The smart fan-coil unit is, in principle, easily separable from the building to which is connected by pipes and power supply.

**Reversible connections**

In the detailed design phase, the design team must verify that the connections are reversible and exposed. Verify that the connections between the smart fan-coil and the building are reversible and exposed (ducts, pipes and power supply).

**Standardization and presence of spare parts on the market**

During the detailed design phase, the design team must verify that the smart fan-coil components are standardized in the dimensions, modular and homogeneous in order to be able to find the products or substitutes on the market for partial replacement.

**Ergonomics**

During the detailed design phase, it must be ensured that the path to reach the smart fan-coil is free from obstacles and appropriately dimensioned to allow the proper performing of maintenance activities and replacement. Verify the respect of the manufacturer specifications on the dimensions of the areas to be considered around the smart fan-coil in order to allow maintenance and replacement. It is suggested to verify that the dimensions of the operational area surrounding the smart fan-coil allow the presence of two workers and the spare parts and tools needed to perform maintenance and replacement.

## 6.8. EV charger

**Brief system description**

The project considers the development of two types of charging infrastructures for electric and hybrid vehicles, building upon ENELX's existing commercial solutions. The first version, called "JuiceBox" will be an AC charging infrastructure that can connect and charge a single vehicle at a time. The second version, known as "JuicePole" will have the capability to connect and charge up to two vehicles simultaneously. Both versions will be considered for integration into the RE-SKIN package, which aims to provide innovative solutions for electric vehicle charging. Importantly, these EV chargers will be powered and managed directly by the MIMO system, ensuring efficient and reliable charging experiences for users.


**Figure 16.** the two versions of EV charger (version A "JuiceBox" on the left and B "JuicePole" on the right)

## Maintenance activities and maintainability requirements analysis

(according to the hazards identified in RE-SKIN deliverable D2.1 Application context periodic update I)

***Hazard:*** to be completed in D.2.1
***Type of Physical Damage/Impact:*** to be completed in D.2.1
***Protection Measures:*** to be completed in D.2.1

**General maintainability requirements to be updated according to the risk assessment (see D.2.1)**

**Accessibility**

c. *Accessibility to the EV charger location*. Verify that the unit is positioned in an easily accessible place to carry out replacement, that likely needs the presence of more than one maintenance operators. The route to reach the EV charger is supposed to be accessible as the units will be located in parking lots.
d. *Accessibility of the EV charger* for performing inspections and functional test. Verify that the EV charger is positioned in easily accessible place to carry out maintenance, repair and replacement. It is suggested to verify also the presence of a properly dimensioned area (Fig. 3) surrounding the EV charger useful for performing the maintenance activities.

**Easy to disconnect**

In the detailed design phase, the design team must verify that the EV chargers are easily separable and easy to be disconnected without creating damages to connections and components in order to allow the repair and replacement of components. The *EV charger* unit is, in principle, easily separable from the building to which is connected by power supply.

**Reversible connections**

In the detailed design phase, the design team must verify that the connections are reversible and exposed. Verify that the connections between the EV charger and the building are reversible and exposed (basically only power supply).

**Standardization and presence of spare parts on the market**

The supplier must verify that the EV charger components are standardized in the dimensions, modular and homogeneous in order to be able to find the products or substitutes on the market for partial replacement.

**Ergonomics**

During the detailed design phase, it must be ensured that the path to reach the EV charger is free from obstacles and appropriately dimensioned to allow the proper performing of maintenance activities and replacement. Verify the respect of the manufacturer specifications on the dimensions of the areas to be considered around the EV charger in order to allow maintenance and replacement. It is suggested to verify that the dimensions of the operational area surrounding the EV charger allow the presence of two workers and the spare parts and tools needed to perform maintenance and replacement.

# 7. NEXT STEPS

The maintainability assessment, developed in this deliverable, will be further explored and deepened once the RE-SKIN components will be detailed in relation to the pilot cases. In the following stages of the research, the maintainability requirements applied to RE-SKIN elements can be also associated with the maintenance plan and used to compare alternative design solutions or to highlight their strengths or weaknesses.