D4.8 - Optimized installation and disassembly procedures I

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Authors	C. Talamo, G. Paganin, N. Atta (POLIMI)
Contributing Partners	ALL INDUSTRIAL PARTNER
Reviewers	F. Leonforte (POLIMI), A. Vallan (FPM)

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Disclaimer

1. Executive summary

This document represents the Deliverable 4.8 of WP4 “Holistic integration of subsystems”, whose aim is the holistic optimization and pre-construction development of RE-SKIN subsystems to ensure their synergic integration and interconnection.
The contents of the D4.8 have been developed within the Task 4.5 “Definition of standardised and optimised procedures for decommissioning and disassembly of the system”.
The deliverable proposes a framework of requirements, defined on the basis of some selected international standards, in order to assess the configuration of each component of RE-SKIN system in relation to the criteria of “design for disassembly” and to orient possible improvements in the detailed design phase.
In line with “London Plan Guidance - Circular Economy Statements” (March 2022) the framework is oriented to improve the attitude to disassembly sections of a building and “enable their direct reuse ideally on the site or, where this is not possible, off site (with nearby sites preferred). This approach also includes careful selective deconstruction of the building and material types i.e., taking apart each layer and material type as much as possible, minimising damage to parts and maintaining their value, and then reusing those elements and materials. If reuse is not possible, materials may be carefully and selectively separated for processing and recycling into new elements, materials and objects”.
The framework can be applied to assemblies and systems that can be disassembled at the end-of-life, or renovated during the service life, with the potential for components to be reused/remanufactured for other purposes and for the materials to be recycled.
The framework is composed of a list of requirements extracted and adapted from the following international and European standards:

- ISO 20887 “Sustainability in buildings and civil engineering - Design for disassembly and adaptability - Principles, requirements and guidance”;
- Level(s) indicator 2.4: Design for deconstruction.

Each of the requirements in the framework allows to assess the attitude to be disassembled of each component, highlighting areas of improvement and issues to be more investigated in relation to different aspects of the disassembly activities. The requirements are related to:

- ease of access to components and services;
- independence;
- avoidance of unnecessary treatments and finishes;
- supporting re-use (circular economy) business models;
- simplicity;
- standardization;

- safety of disassembly.

Considering that most of the components of RE-SKIN are still a version under development, the proposed framework of requirements is useful for proposing improvements to apply in the next stages of the research.

2. METHODOLOGY

The development of D4.8 has followed six steps:

1. Finding and selection of international standards and guidelines dealing with design for disassembly;
2. Selection of a set of requirements more appropriate in relation to RE-SKIN application;
3. Specification of the assessment criteria for each requirement;
4. Development of a framework, composed of the selected requirements, oriented to highlight opportunities for improvements;
5. Interviews with the partners of the research that are in charge of the design, manufacturing and supply of the RE-SKIN components in order to integrate the information already available;
6. Application of the framework to the RE-SKIN components above listed, test of applicability and improvements of the framework contents.

3. REFERENCE STANDARDS AND REGULATIONS

The following standards have been selected and investigated:

- 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 2.2: Construction and Demolition waste and materials:
- JRC Technical Report, Level(s) indicator 2.4: Design for deconstruction.

In particular, in the development of the framework, the specific set of requirements has been selected and adapted from the ISO 20887:2020 and from the JRC Technical Report, Level(s) indicator 2.4.

4. ASSESSMENT CRITERIA FOR THE RE-SKIN COMPONENTS

The assessment criteria deal with a list of deconstruction design concepts. The proposed framework for the D4.8 is oriented to boost 'circularity' of the RE-SKIN system by supporting a design process in which the stakeholders can be aware of the issues connected with the recovery of building parts for reuse/remanufacturing (either in situ within a new building or on another site) or recycling of materials to make new products (either for building sector or for other sectors).
The criteria can be applied both at the Conceptual design phase and at the Detailed design phase. In the Detailed design phase, the criteria may be integrated with indicators. These indicators will be applied to the pilots that will be developed in the RE-SKIN project in order to report on and improve their performance.
The criteria assumed are useful for three main goals: the assessment of the attitude to ease of disassembly of the RE-SKIN single components/whole system; the proposal of improvements; the development of a disassembly plan.
The following requirements and criteria have been assumed:

REQUIREMENTS	CRITERIA
Ease of recovery	Elements and their parts are independent and easily separable
	Connections are mechanical and reversible
	Connections are easily accessible and sequentially reversible
	The number and complexity of the disassembly steps are low
Ease of reuse	Specification of elements and parts using standardised dimensions
	Design supports future adaptation to changes in functional needs
Ease of recycling	Parts made of compatible or homogenous materials
	Constituent materials can be easily separated
	There are established recycling options for constituent parts or materials
Accessibility	Connections should be exposed
	Operative areas (activities and tools should be declared/
Independence	Materials or components should be removable without disrupting other components or materials.
Reversible connections	Require standard tools for disassembly
	Use universally recognized connection methods
Simplicity	Minimize the number of elements
Standardization	Adopt modularity

Standardization	Use standardized sub elements
	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally
Safety of disassembly	Intelligibility of the materials and functions
	Ease of isolation of hidden energies
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)

5. RE-SKIN COMPONENTS TO BE ASSESSED

The proposed framework has been applied to:

- hybrid prefabricated photovoltaic-thermal roof, with refurbished PV modules, recycled aluminum 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 assessment.

6. PRELIMINARY ASSESSEMENT

The preliminary assessment has the goal first to develop an analytical and precise investigation in search of critical issues that:

- can make difficult for various aspects (time, tools, number of operators, risks, logistic, etc.) the disassembly activities;
- hinder the 5 Re-actions (Remanufacturing, Recondition, Reuse, Repurposing, Recycling) as well as the maintenance activities (corrective and preventive maintenance).

The investigation regards three levels:

- the configuration of each category of the components of the RE-SKIN system;
- the relations between the components within the RE-SKIN system;
- the relation between the RE-SKIN system and the building.

The investigation is conducted according to a framework composed of a list of requirements extracted from two traced sources (L 2.4 (EU Level(s) and ISO 20887) and clarified in their reference criteria.

A synthetic assessment indicates the level of satisfaction of the single requirement F, P, NA (Full, Partial, Not Applicable).

An analytical assessment indicates any issues and provides possible suggestions/improvements.

Finally, comments, where necessary, are introduced such as request of further information, supplementary documentation, opinion of the manufacturer or of experts.

The investigation provides improvements for the next step of the research i.e., the detailed design of the system.

6.1. Modular multifunctional façade cladding

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND AREAS OF IMPROVEMENT	COMMENTS
Ease of recovery	Elements and their parts are independent	L 2.4 (EU Level7s)	P	Although the elements are all separable, in the disassembly of a single panel it is necessary to disassemble a whole column of	The facade system includes a device for regulating the air flow in the cavity but this

	and easily separable			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.	device is not described in a sufficient way to allow an evaluation. Additional information is requested to the manufacturer.
Ease of recovery	Connections are mechanical and reversible	L 2.4	F	The connections are mechanical and reversible. (Fig.3) The only wet jointing element appears to be the PIR foam in the vertical joint between the panels which, however, only has an air and watertight and non-mechanical function and can be easily removed.	According to INDRES the insulation panels can be screwed and unscrewed (to be again put in place or reused in a different location) more than one time (needed more detailed info after the redesign phase).
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	P	The connections are hidden by the profile of the insulation panels (tongue-and-groove profiles). (Figs. 1,2) Therefore to remove a connection of a single panel it is necessary to disassemble a whole column of panels. 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 insulation panels.	This impossibility has been confirmed at present by GAR and INDRES during the interviews. The manufacturer must provide information on this (details and installation and connection diagram).
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F	The complexity of disassembling the current sections of the facade can be reduced by modifying the tongue-and-groove profiles of the insulation panels (Fig.1).	
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	F	Sandwich panels have standard dimensions in one direction (e.g., 1150 mm height) as a result of the manufacturing process. The width can vary from 250 to 4000 mm.	

Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	NA		
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	F		
Ease of recycling	Constituent materials can be easily separated	L 2.4	P	The separation of the three components of the sandwich panels (insulating layer and two layers of internal and external finishing steel) (Fig.4) is not easy to perform. The other materials are easily separated.	From the interview with INDRES it emerges that the panel can be mechanically disassembled offsite to separate the metal sheet from the core of (bio)PUR insulation foam (more info needed on the subsequent "cleaning" actions to remove the residues of insulation foam from the metal sheet). Another issue is related to the application of the GreenCoat to the external layer of steel in the sandwich panels. It should be clarified from the manufacturer in which way the coat can be separated from the steel (wherever necessary).
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	The manufacturer must specify any methods of recycling the sandwich panels.	INDRES mechanically recycles the insulation foam in-house by processing the material into a powder use for the subsequent production of new panels that, however, have low-performance with respect to the original one (less thermal properties).

					Chemical recycling is possible but expensive. Understand more about the recycling methods GreenCoat® sustainable steel outer layer (Fig.4).
Accessibility	Connections should be exposed	ISO 20887	P	The connections of the sandwich panels to the wall are not exposed because they are covered by the upper panel (see above ease of recovery) (Fig.3).	
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	P	The operating spaces required for the disassembly of the facade are not declared. These spaces depend on the configuration methods of the facade itself when applied to the building. In principle, the spaces and tools required are the same used for the assembly of the facade and can therefore be recorded in the initial installation phase and included in the execution documents (as built information).	Disassembly scheme (activities and works) should be provided by the manufacturer.
Independence	Materials or components should be removable without disrupting other components or materials.	ISO 20887	F	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 panels.	According to INDRES the insulation panels can be screwed and unscrewed (to be again put in place or reused in a different location) more than one time (needed more detailed info after the redesign phase).
Reversible connections	require standard tools for disassembly;	ISO 20887	F	The manufacturer should confirm this assessment and list the tools required for disassembly.	
Reversible connections	Use universally recognized	ISO 20887	F	The connection systems are universal (screws and dowels).	

	connection methods				
Simplicity	Minimize the number of elements	ISO 20887	F		
Standardization	Adopt modularity	ISO 20887	F	See comments above	
Standardization	Use standardized sub elements	ISO 20887	F	The facade panels and the other profiles are fully standardized.	
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F		
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	F		
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	NA		
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics, etc.)	ISO 20887	P	The facade elements can reach – depending on the project choices – lengths of 4000 mm and these dimensions make them unwieldy during disassembly.	It is suggested to consider in the design phase of the facade to use smaller dimensions such as 2000 mm.

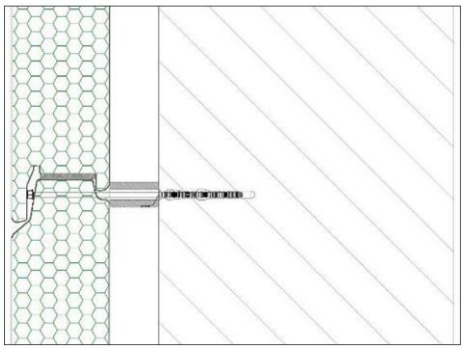

Figure 1. Tongue-and-groove joint

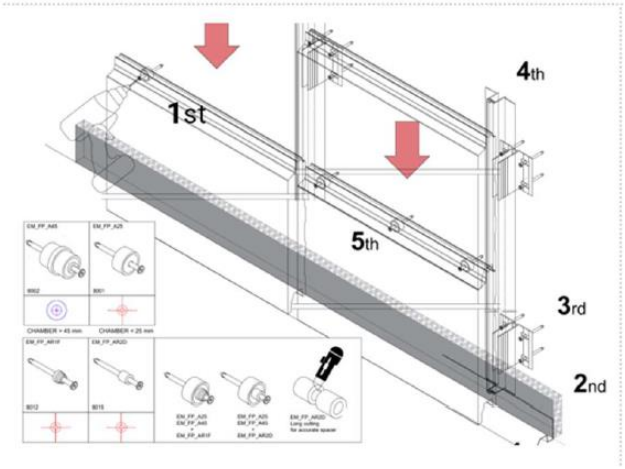

Figure 2. Scheme of sequence of assembly of the panels

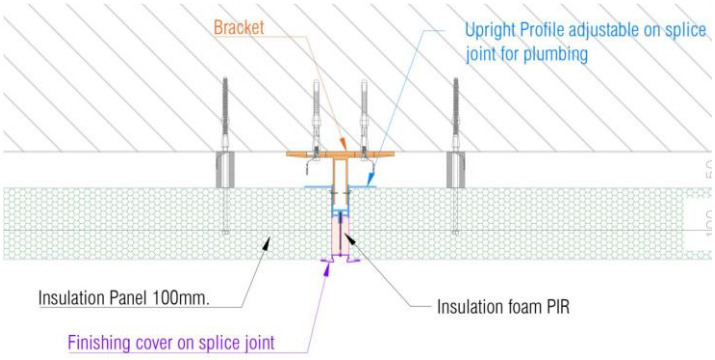

Figure 3. The system of connections

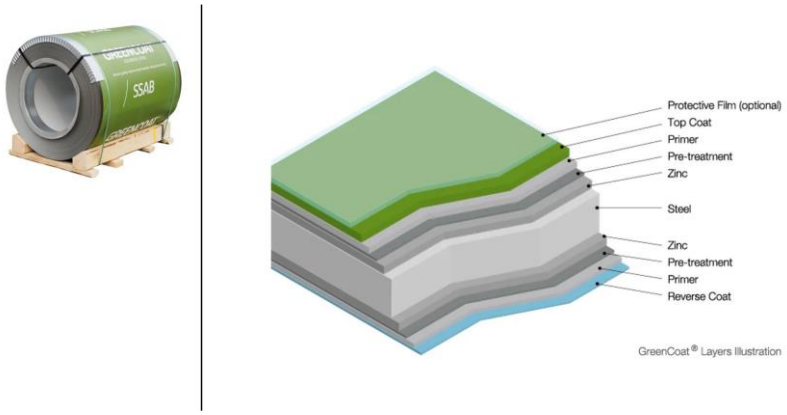

Figure 4. GreenCoat® components

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

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND AREAS OF IMPROVEMENT	SUGGESTIONS & REQUESTS
Ease of recovery	Elements and their parts are independent and easily separable	L 2.4 (EU Level/s)	P	Although the elements are all separable, the removal of the insulating panels is not very easy since they are embedded in the profiles and for their removal it is necessary to remove all the panels upstream. (Fig.6).	
Ease of recovery	Connections are mechanical and reversible	L 2.4	F	The connections are mechanical and reversible (Fig.5).	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	F	The connections are all easily accessible by retracing the assembly sequence in reverse (Fig.5).	Extendable metal profiles for PV panels of different thicknesses From 3.5 to 5 cm (RINOVA).

Ease of recovery	The number and complexity of the disassembly steps are low	L 2.4	F	The complexity of disassembling the current sections of the roof appears reduced and with few steps to perform.	At the moment the position of the MIMO remote unit for the PV panel is not specified and this could influence the complexity of the disassembly. The same issue relates to the system that will be used to modify the ventilation conditions of the air cavity between PV panel and the thermal insulation.
Ease of reuse	Specification of elements and parts using standardized dimensions	L 2.4	F	The elements are standardized.	
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	F	The modular configuration of the roofing system allows the replacement of the PV panels with other roofing panels.	
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	F		
Ease of recycling	Constituent materials can be easily separated	L 2.4	F		
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	The manufacturer must specify any methods of recycling the insulation panels. The manufacturer musty specify any methods of recycling the PV panels.	INDRES mechanically recycles the insulation foam in-house by processing the material into a powder use for the subsequent production of new panels that,

					however, have low-performance with respect to the original one (less thermal properties). Chemical recycling is possible but expensive.
Accessibility	Connections should be exposed	ISO 20887	F	The connections are exposed and easily accessible by removing the snap cover. There is not enough information on how to lay and connect horizontal profiles (horizontal T shaped frames).	The manufacturer must provide information on this point (details and installation and connection diagram).
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	P	The operating spaces required for the disassembly of the roof are not declared. These spaces depend on: • size of the insulating panel that must be inserted from above into the groove of the profiles; • length of the profiles for positioning the panels and PV modules; • length of the presser for blocking the PV panels. Pressure plate and snap cover lengths are not stated. A not excessive length of the pressure plate (for example coinciding with the module) would be useful to reduce the need for space on the roof for the removal of the panels. If the pressure plate is interrupted, however, each module must be checked whether this modification affects the water tightness of the system (Fig.5). The spaces and tools required are the same used for the assembly of the roof and can therefore be recorded in the initial installation phase and included in the execution documents (as built information).	As resulting from the interview with RINOVA, the PV modules are NOT walkable therefore it is necessary to identify paths for the passage of people and tools for maintenance activities.

Independence	Materials or components should be removable without disrupting other components or materials.	ISO 20887	P	All elements can be removed without breaking other elements. However, complete independence of the elements is not ensured because to remove a single insulating panel it is necessary to remove a whole "column" of panels (laid from bottom to top). The PV modules considered individually are independent and their disassembly can take place individually after removing the pressure plate and snap cover. 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. There is no project documentation available to evaluate the electrical connections, their position and the interface mode between the electrical cables inserted in the uprights and the individual PV panels. As far as the electric cables in the uprights are concerned, it should also be noted that there is no project information on the methods with which it is expected to manage the terminal elements of the cables that will have to converge on the MIMO. There is no information on the final closing elements. In particular as regards the lower and upper horizontal closure (eaves and ridge). The independence of the system, the ergonomic requirement and the ventilation functions are therefore not fully verified.	Evaluate the possibility of disassembling the individual PV modules. Provide information on: position and method of interface between the electric cables inserted in the uprights and the individual PV panels. closing elements of the system (gutter and ridge) From the interview with RINOVA, it emerged the need to have a frame on all the four sides of the PV panels.

Reversible connections	Require standard tools for disassembly	ISO 20887	F	The manufacturer should confirm this assessment and list the tools required for disassembly.	The manufacturer should list the tools required for disassembly. Redesign in progress (as stated by GAR and INDRES during the interviews). Moreover, INDRES has a sub-supplier that is PANELCOAT that participates to the design choices (panel-assembly operator).
Reversible connections	Use universally recognized connection methods	ISO 20887	F	The connection systems are universal (screws and dowels).	
Simplicity	Minimize the number of elements	ISO 20887	F		
Standardization	Adopt modularity	ISO 20887	F	The system is modular.	
Standardization	Use standardized sub elements	ISO 20887	F	All elements are standardized.	
	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	P	The system was created to be adapted to different roofing configurations. A limit to standardization is found in the fact that the heights of the profiles in which the PV panels are positioned seem fixed and consequently the replacement of a PV panel with alternative panels may not be possible. A possible solution lies in having available a series of "thermal break insulation spacers" profiles of different heights to be	To be verified with GAR.

				able to house panels of different heights with respect to the PV module.	
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	P	There is no information on the walkability of the panels which could cause workers to fall. The presence of a lifeline that is somehow integrated into the system is not specified.	The PV panels are not walkable. A design of the lifeline system should be developed.
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	There is no information on the electrical safety procedures of the system for its disassembly (PV panels and MIMO remote units).	Provide information on electrical safety (e.g., lockout tagout procedures applicable to the system).
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	There is no information on the lengths of the profiles: mullion pressure plate and snap cover which, if longer than 3 meters (standard length of mullion curtain walls) could be difficult to handle.	

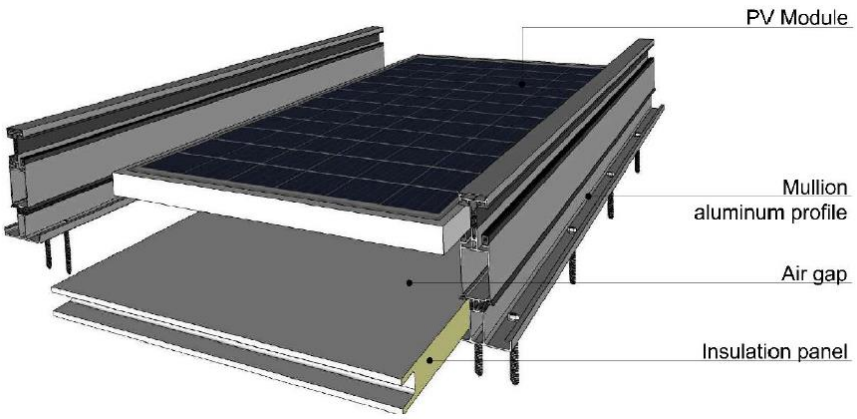

Figure 5. General view of the roofing system integrating PV

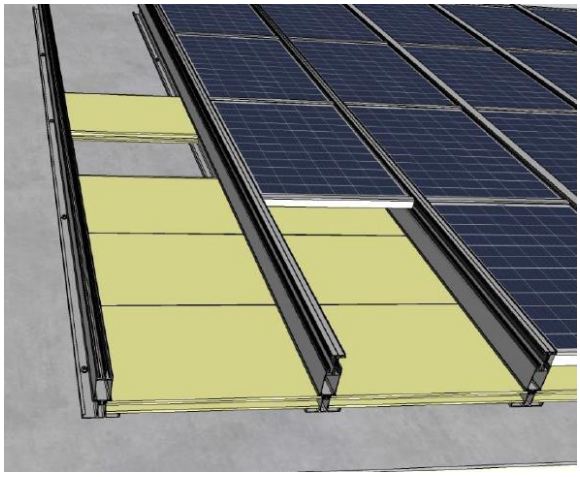

Figure 6. Installation sequence (mullions, insulation, PV)

6.3. SMART FAN-COIL

The assessment of the ease of disassembly for the SMART FAN COIL (SMFC) system is developed considering two levels of analysis:

1. SMART FAN COIL as whole system in relation with the building and its parts
2. SMART FAN COIL analyzed in each single unit ("inside the box/case")

For the second level of analysis (inside the box/case) the SMART FAN COILS ease to disassembly shall be further analyzed in cooperation with the manufacturer considering:

- the connections between the electronic parts and the metal case
- the connections between the mechanical parts (compressor, fans, …) and the metal case
- the connections of the refrigerant gas piping.

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND IMPROVEMENTS AREAS	COMMENTS
Ease of recovery	Elements and their parts are independent and easily separable	L 2.4 (EU Level7s)	F	Level 1 The Smart Fan-coil unit is easily separable from the building.	The connection between the SMFC and the existing pipe of the building is not fully described. This part shall be further

					discussed considering different configurations of the existing building heating system. The use of fittings or brazing should be discussed with the manufacturer.
Ease of recovery	Connections are mechanical and reversible	L 2.4	F	Level 1 The connections (Fig.8) between the SMFC and the building are mechanical and reversible (brackets, bolts and screws).	The connection between the SMFC and the existing pipe of the building is not fully described. This part shall be further discussed considering different configurations of the existing building heating system. The use of fittings or brazing should be discussed with the manufacturer.
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	F	Level 1 The SMFC unit is easily accessible as it will be hosted in the rooms of the different dwellings. The connections can be disconnected in a reverse sequence compared to the installation. The connections with the existing water pipes look easily accessible as it is foreseen a specific water connection.	The water connection is not fully described at present, and it shall be discussed with the manufacturer as it's a critical point for the disassembly procedure.
Ease of recovery	The number and complexity of the	L 2.4	F	Level 1	The water connection is not fully described at present, and it shall

	disassembly steps are low.			The complexity of disassembling the SMFC units is low as it is enough to remove the SMFC from the brackets. (Fig.7) For the water connection see comments.	be discussed with the manufacturer as it's a critical point for the disassembly procedure.
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer.
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer.
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer.
Ease of recycling	Constituent materials can be easily separated	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer.
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer	Verify with manufacturer detailed material data sheets. The refrigerant gas is not fully specified in the deliverable D.6.1: to be further investigated.
Accessibility	Connections should be exposed	ISO 20887	F	Level 1 The connections of the SMFC are fully exposed.	
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	F	Level 1 The manufacturer has specified the areas to be considered around the SMFC in order to allow installation and maintenance.	Request disassembly scheme (activities and works).

Independence	Materials or components should be removable without disrupting other components or materials.	ISO 20887	F	At present it seems that the SMFC can be removed easily without any disruption.	The specification of the connections with existing water pipes shall be clarified from the manufacturer.
Reversible connections	require standard tools for disassembly;	ISO 20887	F	The manufacturer should confirm this assessment and list the tools required for disassembly.	
Reversible connections	Use universally recognized connection methods	ISO 20887	F	Level 1 The connection systems between SMFC units and the building are simply bolts and brackets.	The specification of the connections with existing water pipes shall be clarified from the manufacturer.
Simplicity	Minimize the number of elements	ISO 20887	F	At level 1 the number of elements is minimized (1 per room).	
Standardization	Adopt modularity	ISO 20887	F	The SMFC units are standardized	
Standardization	Use standardized sub elements	ISO 20887	P	This part relates to level 2 and it will be further investigated with the manufacturer.	
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F	The SMFC has been designed to be compatible with existing water pipes of heating systems.	The water connection should be further analysed with the manufacturer to check compatibility with the different diameters and materials of existing water pipes.
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	F	Level 1 The system is clearly recognizable. Level 2 To be declared by the manufacturer.	

Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	To be further investigated with the manufacturer.	
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	Even if SMFC weight is not specified in D.6.1 it seems that the handling is not very easy both for dimensions and weight.	Further investigation with the manufacturer is required.

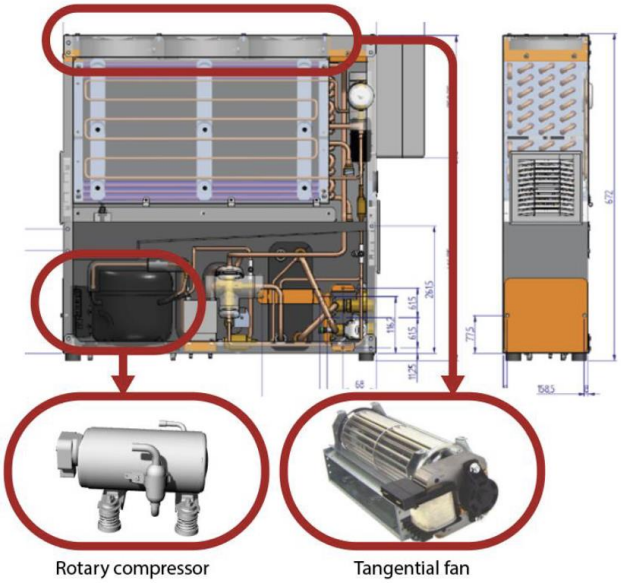

Figure 7. Main subcompoments of the Smart Fan Coil Unit

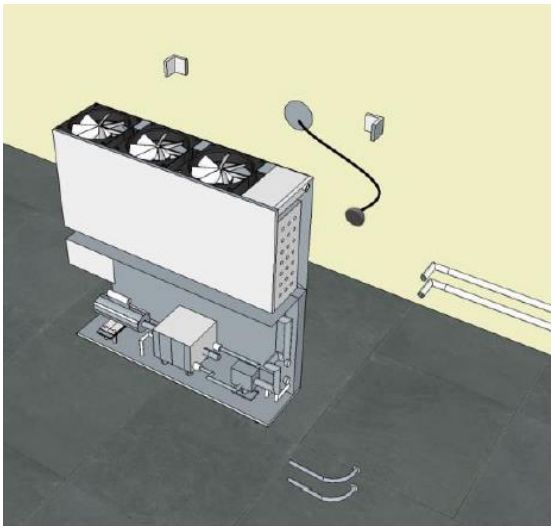

Figure 8. Installation scheme for the Smart Fan Coil Unit

6.4. BATTERY PACK

The assessment of the ease of disassembly for the BATTERY PACK system is developed considering three levels of analysis:

1. BATTERY PACK as whole system in relation with the building and its parts
2. BATTERY PACK analyzed in each single unit ("inside the box/case").

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND IMPROVEMENTS AREAS	COMMENTS
Ease of recovery	Elements and their parts are independent and easily separable	L 2.4 (EU Level7s)	F	The unit (BATTERY PACK) is easily separable from the building. The battery banks, placed inside the enclosure, are independent and easily separable from each other and from the enclosure (Fig.9).	The location of the battery pack should be carefully studied considering the heavy load (around 1000 kg) and the temperature limits specified for the operations (+5<T<30°C).

					The way in which the fire fighting system (aerosol type) will be placed inside the enclosure should be specified.
Ease of recovery	Connections are mechanical and reversible	L 2.4	F	The connections are mechanical and fully reversible.	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	F	The connections between the battery banks are easily accessible due to the double door provided in the enclosure (Fig.10). The enclosure is simply leaning of the floor. It can be removed after removing the battery banks from the inside.	
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F	The complexity of disassembling the battery pack is very low as the battery banks are removable from the enclosure.	No information is provided concerning the electrical connections between the battery pack and the MIMO.
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	F	The batteries are standard elements and the enclosure is procured from the market.	
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	N A	To be further investigated with the manufacturer.	Verify with SOLAR
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	F	The case is made of steel (homogeneous and recyclable). The batteries are homogeneous between them.	
Ease of recycling	Constituent materials can be easily separated	L 2.4	F	The enclosure and the battery banks can be easily separated.	

Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	The metal case can be easily recycled as it is made of steel. The lithium-ion batteries when disconnected can have criticalities in the recycling process.	It should be verified the presence of appropriate recycling facilities of lithium-ion batteries in the different countries where the pilot projects will be realized.
Accessibility	Connections should be exposed	ISO 20887	F	The connections are exposed once the steel enclosure is open.	
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	P	To be further investigated with the manufacturer. Activities required disassembling the unit are not yet specified.	Request disassembly scheme (activities and works).
Independence	Materials or components should be removable without disrupting other components or materials.	ISO 20887	F	All elements can be removed without breaking other elements.	
Reversible connections	require standard tools for disassembly;	ISO 20887	F	The manufacturer should confirm this assessment and list the tools required for disassembly.	
Reversible connections	Use universally recognized connection methods	ISO 20887	F	The manufacturer should confirm this assessment and specify the connection methods.	
Simplicity	Minimize the number of elements	ISO 20887	F	The number of the elements is limited and predefined.	
Standardization	Adopt modularity	ISO 20887	F	The battery banks are modular (Fig.9).	
Standardization	Use standardized sub elements	ISO 20887	F	The batteries are standard and they come from automotive industry. The enclosure is available on the market.	

Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	P	The fire resistance performance of the enclosure is not declared.	In case of fire scenario in the building it should be important for the enclosure to be able to resist to fire (fire resistance performance). In the detailed design of RE SKIN system it should be specified the class of fire resistance.
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	F	The system is clearly recognizable.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	To be investigated with the manufacturer.	To check how the energy isolation can be implemented and how the isolation can be done also for the fire fighting system.
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	The battery banks are easy to handle by 1 person (dimensions and weight are limited). The enclosure once the batteries are removed could be not heavy but it needs two persons to move it.	It is suggested to consider the presence of two workers in dimensioning the operational area round the system. Also the path from the enclosure location to outside should be appropriately dimensioned.

Figure 9. Battery banks with cells in series

Figure 10. Steel enclosure for the battery banks

6.5. MULTI-INPUT/MULTI-OUTPUT CONVERTER (MIMO)

The assessment of the ease of disassembly for the MIMO system is developed considering three levels of analysis:

1. MI-MO as whole system in relation with the building and its parts
2. MI-MO as assembly of different units (main units/remote units)
3. MI-MO analysed in each single unit ("inside the box/case")

For the last level of analysis (inside the box/case) the items (main unit, remote unit PV, remote unit fan-coils) are intrinsically easy to disassembly because:

- all the connections between the electronic parts and the metal case are reversible (screws);
- the electronic parts when disconnected can be easily processed as Waste from Electrical and Electronic Equipment (WEEE);
- the metal case once disconnected from the electronic parts can be reused or remanufactured or recycled;
- the disconnection between the electronic parts and the metal case can be done both in situ and off-site.

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND IMPROVEMENTS AREAS	COMMENTS
Ease of recovery	Elements and their parts are independent and easily separable	L 2.4 (EU Level7s)	F	Level 1 The main unit is easily separable from the building as it is foreseen to be installed into a technical room. It is also easily separable from the other electric components because they are simply connected through cables. It is not possible at present to fully assess the ease of recovery of the remote units because the way in which they will be connected to the PV panels or incorporated into the façade is not yet described	Due to the fact that RE-SKIN system is intended for retrofit of existing building, the position of the connecting cables should be carefully designed to find a correct positioning in the existing building (vertical/horizontal conduit).

				in the manufacturing description. Level 2 The main units and remote units are connected with electrical wiring so the separation of the different units is very easy. It is not specified at this level of development the way in which electrical wires will be connected to the units (screw terminals or fasteners).	
Ease of recovery	Connections are mechanical and reversible	L 2.4	F	Level 1 The connections between the system and the building or its parts are in principle mechanical and reversible. It is not possible at present to fully assess the ease of recovery of the remote units because the way in which they will be connected to the PV panels or incorporated into the façade is not yet described in the manufacturing description. Level 2 The connections are mechanical and fully reversible.	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	P	Level 1 The main unit is easily accessible as it will be hosted in a technical room/space. At present it is not clear how the remote units will be connected to the building. In any case to access the connections it is necessary to dismantle the façade panels and the PV panels in the roof.	Level 1 The dimension of the air cavity in the façade and in the roof shall be determined considering the size and the installation constraints specified by the manufacturer; an assembly tolerance shall also be considered.

				Level 2 The remote units are designed to be installed in the air cavity of the façade and of the roof; therefore also for level 2 the dismantle of the façade panels and of the PV panels shall be foreseen.	Level 2 The façade and the roof should be designed in order to allow for an easy access to the remote units when their replacement is needed.
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F	Level 1 The complexity of disassembling the remote units is determined by the way in which the façade and the roof can be dismantled (it is necessary to have access to the unit installed in the air cavity to remove it from the building). Level 2 The disassembly steps are reduced to a minimum (removal of the connections to the electrical wires).	
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	P	To be further investigated with the manufacturer.	Verify with PSC
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4		To be further investigated with the manufacturer.	Verify with PSC
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4		The electronic parts when disconnected can be easily processed as Waste from Electrical and Electronic Equipment (WEEE).	
Ease of recycling	Constituent materials can be easily separated	L 2.4	P	The electronic parts when disconnected can be easily processed as Waste from	

				Electrical and Electronic Equipment (WEEE).	
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	The metal case can be easily separated from the electronic parts. The electronic parts when disconnected can be easily processed as Waste from Electrical and Electronic Equipment (WEEE) The metal case can be directly recycled.	
Accessibility	Connections should be exposed	ISO 20887	P	Level 1 The connections of the remote units are not exposed because they are hosted in the air cavity (both façade and roof). Level 2 To be further investigated with the manufacturer.	
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	P	Level 1 To be further investigated with the manufacturers (both façade and roof). Activities required disassembling the main unit and the remote units are not yet specified.	Request disassembly scheme (activities and works). To be discussed with the project team how to connect the remote units to the façade and to the PV panels in order to understand the accessibility once the system is completed on the pilot building. To be discussed with the project team how the remote units shall be monitored during operation and if this requires accessibility.
Independence	Materials or components should be removable	ISO 20887	F	All elements can be removed without breaking other elements.	

	without disrupting other components or materials.				
Reversible connections	require standard tools for disassembly;	ISO 20887	F	The manufacturer should confirm this assessment and list the tools required for disassembly.	
Reversible connections	Use universally recognized connection methods	ISO 20887	F	Level 1 The connection systems between system units and the building are not yet specified. Level 2 The connection systems are universal (screws or fasteners).	
Simplicity	Minimize the number of elements	ISO 20887	F	The number of elements is huge (1 per each PV panels and 1 per each fan-coil).	To be discussed with the manufacturer if the number could be reduced.
Standardization	Adopt modularity	ISO 20887	F	The remote units are several but they are standardized (unit for PV panels and units for fan-coils).	To be investigated with the manufacturer.
Standardization	Use standardized sub elements	ISO 20887	P	Level 1 ok Level 2 ok Level 3 to be investigated with the manufacturer.	To be investigated with the manufacturer.
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F	Level 1 This requirement is influenced by the detail design of the different subsystems.	The detailed design of the Façade and of the PV panel shall include in the design data the constraints given by the remote units.
Safety of disassembly	Intellegibiliy of the materials and functions	ISO 20887	F	Level 1 The system is clearly recognizable. Level 2 Same as Level 1 Level 3	

				To be declared by the manufacturer.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	To be investigated with the manufacturer.	
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	Remote units are easily handy (small and light). Main unit is small but heavy (40-50 kg) and needs two workers to move. (Figs.11,12)	It is suggested to consider the presence of two workers in dimensioning the operational area round the system.

Figure 11. MIMO main unit

Figure 12. MIMO remote units (to Smart Fan Coil on the left and to PV panels on the right)

6.6. DC HEAT PUMP

The assessment of the ease of disassembly for the DC HEAT PUMP system is developed considering two levels of analysis:

1. DC HEAT PUMP as whole system in relation with the building and its parts
2. DC HEAT PUMP analyzed in the single unit ("inside the box/case").

For the second level of analysis (inside the box/case) the DC HEAT PUMP ease to disassembly shall be further analyzed in cooperation with the manufacturer considering:

- the connections between the electronic parts and the metal case
- the connections between the mechanical parts (compressor, fans, …) and the metal case
- the connections of the refrigerant gas piping

The following analysis is related to level 1.

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND IMPROVEMENTS AREAS	COMMENTS
Ease of recovery	Elements and their parts are independent and easily separable	L 2.4 (EU Level7s)	F P	Level 1 The HEAT PUMP unit is, in principle, easily separable from the building to which is connected by air ducts, pipes and power supply (MIMO). Level 2 To be further investigated with the manufacturer. The elements in the main body of the HEAT PUMP are easily separable unless the sealed circuit of the refrigerant gas.	The connection between the HEAT PUMP and the existing pipes of the building is not fully described. This part shall be further discussed considering different configurations of the existing building heating system. The weight of the heat pump is not declared in D.6.1. The location of the ducts for the air inlet-outlet could represent an issue in the dismantling stage.

					The refrigerant gas is not specified.
Ease of recovery	Connections are mechanical and reversible	L 2.4	F P	Level 1 The connections between the HEAT PUMP and the building are mechanical and reversible (ducts, pipes and MIMO). Level 2 To be further investigated with the manufacturer.	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	F ?	Level 1 The HEAT PUMP is easily accessible as it will be hosted in a technical room. The connections (ducts, pipes and MIMO) can be disconnected in a reverse sequence compared to the installation (Fig.13). Level 2 To be further investigated with the manufacturer.	The water connection is not fully described at present and it shall be discussed with the manufacturer as it's a critical point for the disassembly procedure.
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F P	Level 1 The complexity of disassembling the HEAT PUMP is low as it is enough to remove the connections from ducts, pipes and MIMO. Level 2 To be further investigated with the manufacturer.	The water connection is not fully described at present and it shall be discussed with the manufacturer as it may represent a critical point for the disassembly procedure.
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer

Ease of recycling	Constituent materials can be easily separated	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	This part relates to level 2 and it will be further investigated with the manufacturer.	Verify with manufacturer detailed material data sheets. The refrigerant gas is not fully specified in the deliverable D.6.1: to be further investigated.
Accessibility	Connections should be exposed	ISO 20887	F P	Level 1 The connections of the HEAT PUMP are fully exposed (Fig.14). Level 2 To be further investigated with the manufacturer.	
Accessibility	Operative areas (activities and tools should be declared/	ISO 20887	F	Level 1 The manufacturer has specified the areas to be considered around the HEAT PUMP in order to allow installation and maintenance. Level 2 To be further investigated with the manufacturer.	Request disassembly scheme (activities and works)
Independence	Materials or components should be removable without disrupting other components or materials.	ISO 20887	F P	Level 1 At present it seems that the HEAT PUMP can be removed easily without any disruption. Level 2 To be further investigated with the manufacturer.	The specification of the connections with existing water pipes and with the air ducts shall be clarified from the manufacturer.
Reversible connections	require standard tools for disassembly;	ISO 20887	F	Level 1 No need of special tool is foreseen at present.	

			?	Level 2 The manufacturer should confirm this assessment and list the tools required for disassembly.	
Reversible connections	Use universally recognized connection methods	ISO 20887	F/ P ?	Level 1 The connection systems between HEAT PUMP and the building (duct, pipes, power) are not specified. Level 2 To be further investigated with the manufacturer.	The specification of the connections with existing water pipes shall be clarified from the manufacturer.
Simplicity	Minimize the number of elements	ISO 20887	F P	level 1 the number of elements is minimized (1 per building). Level 2 To be further investigated with the manufacturer.	P&I diagrams and detailed design drawings are needed to assess this requirement.
Standardization	Adopt modularity	ISO 20887	N A P	Level 1 Not applicable Level 2 To be further investigated with the manufacturer.	
Standardization	Use standardized sub elements	ISO 20887	P	Level 2 To be further investigated with the manufacturer.	
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F	Level 1 The compatibility with the other RE-SKIN systems (ducts, pipes, MIMO) is generically described but a more detailed analysis is needed.	The water connection should be further analysed with the manufacturer to check compatibility with the different diameters and materials of

					existing water pipes.
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	F P	Level 1 The system is clearly recognizable. Level 2 To be declared by the manufacturer.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	Level 2 To be further investigated with the manufacturer.	
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	Even if HEAT PUMP weight is not specified in D.6.1 it seems that the handling is not very easy both for dimensions and weight.	Further investigation with the manufacturer is required.

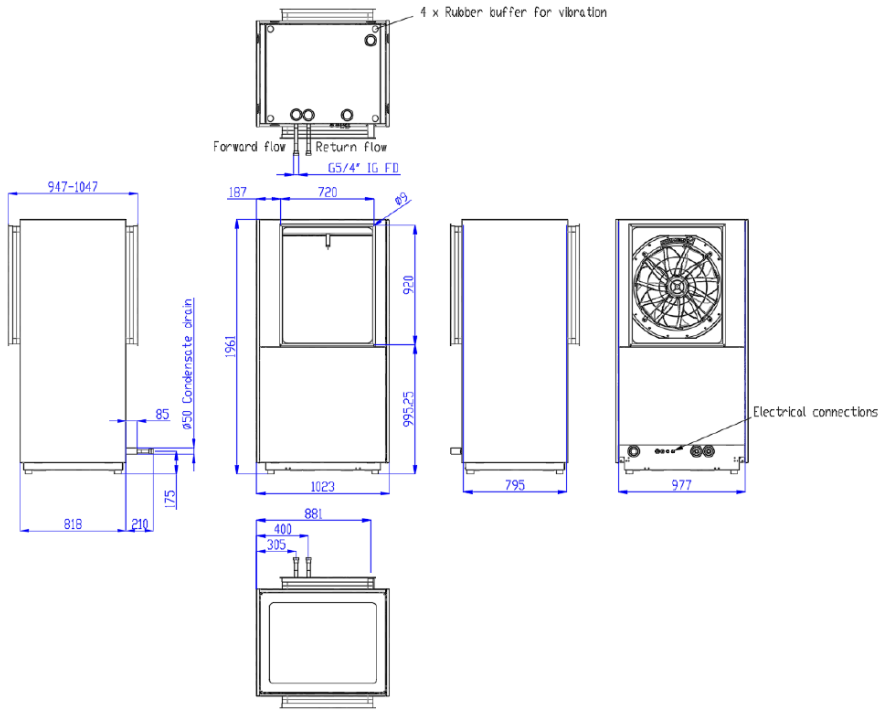

Figure 13. DC heat pump scheme and dimensions

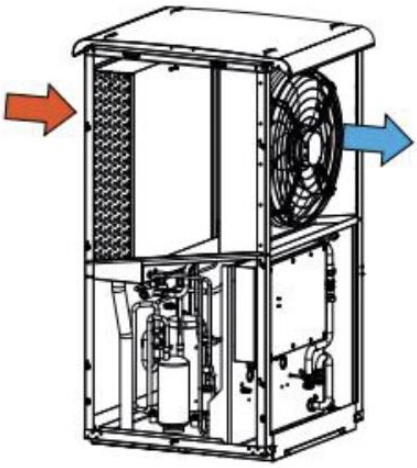

Figure 14. Air flow constraints for DC heat pump

7. NEXT STEPS

The deconstruction design concepts, articulated in the proposed framework, can be further explored and deepened at the level of the whole RE-SKIN system once the RE-SKIN components will be detailed in relation to the pilot cases and technical partners have become more involved in the project. In the following stages of the research the disassembly requirements applied to RE-SKIN elements can be also associated to other parameters (qualitative scores, appropriate indexes, weighed indicators) useful to compare alternative design solutions or to highlight their strengths or weaknesses.