RE-SKIN

D4.9 - Optimized installation and disassembly procedures II

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Table of Contents

1. Executive summary 4

2. METHODOLOGY 5

3. REFERENCE STANDARDS AND REGULATIONS 6

4. ASSESSMENT CRITERIA FOR THE RE-SKIN COMPONENTS 7

5. RE-SKIN COMPONENTS TO BE ASSESSED 9

6. PRELIMINARY ASSESSEMENT 10

6.1. Modular multifunctional façade cladding 11

6.2. Hybrid building-integrated photovoltaic-thermal (BIPVT) system 16

6.3. SMART FAN-COIL 21

6.4. BATTERY PACK 25

6.5. MULTI-INPUT/MULTI-OUTPUT CONVERTER (MIMO) 29

6.6. DC HEAT PUMP 33

7. NEXT STEPS 38

List of Figures

Figure 1. Tongue-and-groove joint 16
Figure 2. Scheme of sequence of assembly of the panels 16
Figure 3. The system of connections 16
Figure 4. GreenCoat® components 17
Figure 5. General view of the roofing system integrating PV 22
Figure 6. Installation sequence (mullions, insulation, PV) 23
Figure 7. Main subcompoments of the Smart Fan Coil Unit 27
Figure 8. Installation scheme for the Smart Fan Coil Unit 28
Figure 9. Battery banks with cells in series 32
Figure 10. Steel enclosure for the battery banks 32
Figure 11. MIMO main unit 38
Figure 12. MIMO remote units (to Smart Fan Coil on the left and to PV panels on the right) 38
Figure 13. DC heat pump scheme and dimensions) 43
Figure 14. Air flow constraints for DC heat pump 44

Disclaimer

1. Executive summary

This document represents the update of the Deliverable 4.8, the objective of which is the holistic optimization and pre-construction development of RE-SKIN subsystems to ensure their synergic integration and interconnection.
The contents of the D4.9 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.
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.

The Framework defined in deliverable D.4.8 is applied in this stage of the project to assess the system as it has been adapted to the Milan pilot project. The reference design deliverables (drawings issued by ZH) used in the assessment are dated May 2024.

2. METHODOLOGY

The assessment methodology used in the drafting of D.4.9 is based on what was already defined in the development of D4.8 according to the followings:

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 consortium partners who 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 above listed framework to the RE-SKIN components, test of applicability and improvements of the framework contents.

Based on the above described methodology, the assessment has been carried out not on the basic design information available at the beginning of the research but on the design of the systems and components developed for the first pilot project to be executed in Milan, Via Amantea n.5 Italy.

3. REFERENCE STANDARDS AND REGULATIONS

The following European and international standards have been selected and investigated. In particular, this document distinguishes between technical standards, and directives and regulations.

Among the regulations and directives, the following ones are considered:

- SWD (2016) 180 final, EU Green Public Procurement (GPP) for Office Building Design, Construction and Management;
- Regulation (EU) 2020/852, EU Taxonomy.

While among the technical standards, the following ones are considered:

- BS 8887-2:2009, Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Terms and definitions;
- EN 15978:2011, Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method;
- ISO 20887:2020, Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance;
- EN 17902:2023, Furniture. Circularity. Requirement and evaluation methods for dis-/reassembly;
- ISO 59020:2024, Circular economy. Measuring and assessing circularity;
- JRC Technical Report, Level(s) indicator 2.2: Construction and Demolition waste and materials;
- JRC Technical Report, Level(s) indicator 2.3: Design for adaptability and renovation;
- JRC Technical Report, Level(s) indicator 2.4: Design for deconstruction.

Additionally, this document also considers some key national (Italian) references for circularity assessment, including the following:

- CAM (Criteri Ambientali Minimi – Minimum Environmental Criteria);
- UNI/TS 11820:2022 - Misurazione della circolarità. Metodi ed indicatori per la misurazione dei processi circolari nelle organizzazioni.

Particularly, in the development of the framework, the specific set of requirements has been selected and adapted from the ISO 20887:2020 and 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 D4.9 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.
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 peack 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.

According to the project progress the assessment refers to the pilot case to be built in Milan. The components were modified in the design of details relating to the Milan pilot in a marginal way. Future issues of the deliverable will be compared with the developments of the project to be prepared for subsequent pilot cases.

6. ASSESSEMENT

The assessment has the goal first to develop an analytical and precise investigation to identify 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 in-depth investigation regards three levels:

- the configuration of each category of the components of the RE-SKIN system with reference to the Milan pilot project;
- the relations between the components within the RE-SKIN system in the context of the Milan pilot project;
- 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, namely L 2.4 of the European Level(s) framework and the international standard ISO 20887 and clarified in their reference criteria.
According with the methodology developed in deliverable D.4.8, the assessment indicates the level of satisfaction of the single requirement according to the three criteria: 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, SUGGESTIONS & REQUESTS
Ease of recovery	Elements and their parts are independent and easily separable	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 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.	
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 (Figs. 1,2) are hidden by the profile of the insulation panels (tongue-and-groove profiles). 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.	
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F		
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 maximum width for Milan pilot project is 4600 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.	Issue is related to the application of the GreenCoat to the external layer of steel in the sandwich panels. In the next pilot it should be clarified from the manufacturer in which way the coat can be separated from the steel.
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.	In the next pilot additional information shall be provided about the recycling methods of the 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	Considering that disassembly takes place by column, the operating spaces required for the disassembly of the façade must be guaranteed in relation to the types of work vehicles (defined in the phase of analysis of the maintenance activities).	In the next pilot it should be better specified how the manual regulation of the grids for natural ventilation of the façade takes places and how the wires of the thermocouples are placed within the cavity.
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.	
Reversible connections	Require standard tools for disassembly	ISO 20887	F		
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	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	ISO 20887	F		

	systems both dimensionally and functionally				
Safety of disassembly	Intelligibility of the materials and functions	ISO 20887	F	The different components of the facade system are easily recognizable regarding their location and function.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	NA	At the present progress of detailed design for the Milan pilot there is no evidence of the presence of remote controlled shutters or other power operated devices to control the air flow within the cavity of the façade and due to this there is no information about the presence of hidden energies.	In case of application of electricity driven shutters of air flow control mechanism in the other pilot projects the issue about hidden energies isolation during maintenance or disassembly shall be considered.
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics, etc.)	ISO 20887	P	The facade elements can reach in the Milan pilot project a length of about 4600 mm and these dimensions make them unwieldy during disassembly.	Wherever possible it is suggested to consider in the design phase of the facade to use, if possible, smaller dimensions such as 2000 mm.

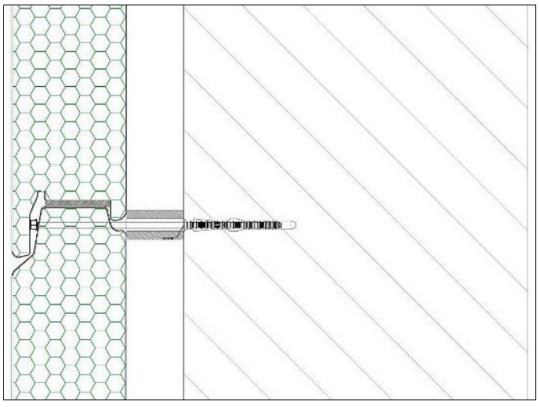

Figure 1. Tongue-and-groove joint

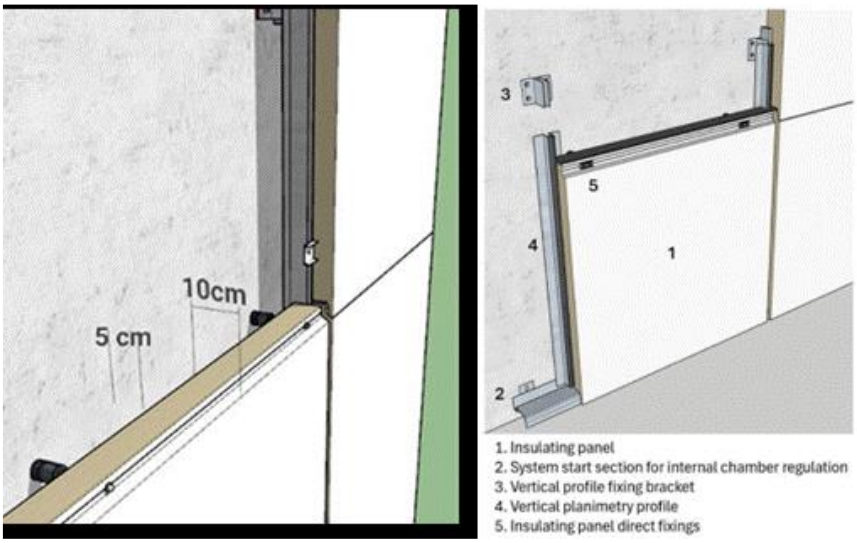

Figure 2. Scheme of sequence of assembly of the panels

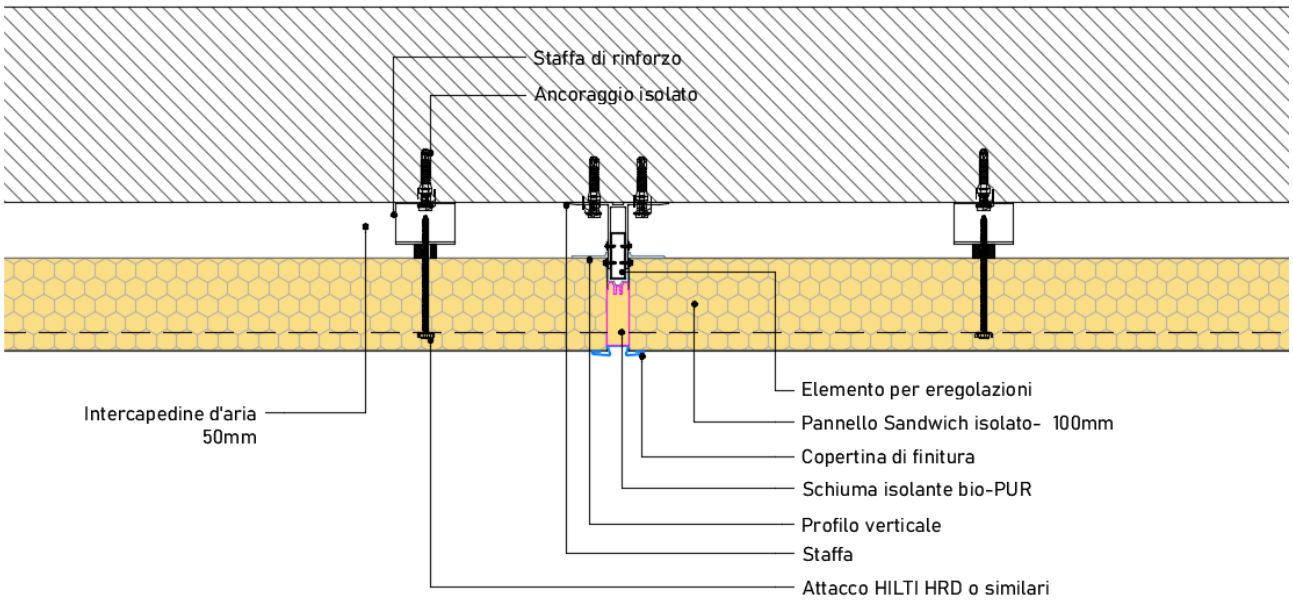

Figure 3. The system of connections

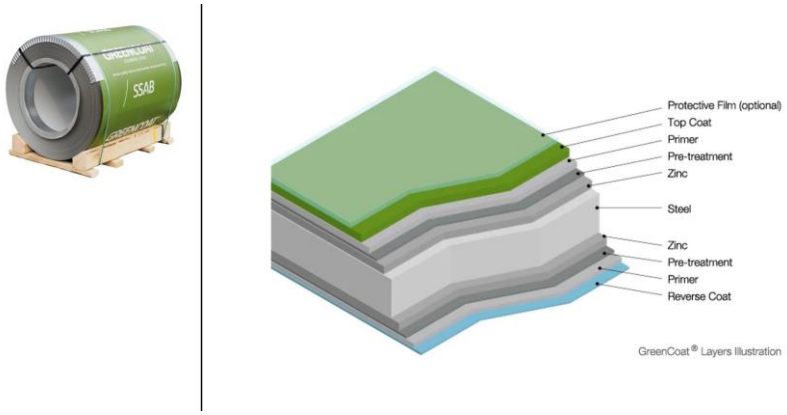

Figure 4. GreenCoat® components

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

REQUIREMENTS	CRITERIA	SOURCE	ASSESSMENT	ASSESSMENT AND AREAS OF IMPROVEMENT	COMMENTS, 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.	The design development for the Milan pilot project does not include the presence of the MIMO terminals inside the air cavity and therefore the disassembly steps can be considered as low.
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	P		In the further steps it should be better clarified the process for separating the external layers of the sandwich panels from the inner insulating BIO PUR.
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P	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 (deterioration in thermal properties).	

Accessibility	Connections should be exposed	ISO 20887	F	The connections are exposed and easily accessible by removing the snap cover.	
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 pressure plate with not excessive length (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).	In Milan pilot project the access on the roof, considering the fact that to walk above PV modules is not allowed, has been provided with a path made with sandwich panels in place of PV modules in some positions. In the next steps the walkability of the sandwich panels should be assessed.
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	In the next pilot projects it should be better specified the position of the electrical connections and the interface mode between the electrical cables inserted in the uprights and the

				individually after removing the pressure plate and snap cover.	individual PV panels.
Reversible connections	Require standard tools for disassembly	ISO 20887	F		
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 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	The presence of a lifeline that is integrated into the system is foreseen in the design development of Milan pilot project. In the next steps it should be better specified how the components of air collection system to convey the air to the exchanger are located.	The PV panels are not walkable. A design of a walkable path in the roof is provided in the Milan pilot project including the provision of lifeline system to be

				In the next steps the shutter and ventilation system should be specified in terms of location, accessibility and replacement steps.	used with safety harnesses.
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P	In the next steps information on the electrical safety procedures of the system for its disassembly (PV panels) should be included (including: electrical safety procedures - e.g., lockout tagout procedures applicable to the system - to be used in the disassembly of the PV panels and of the mechanical ventilation system embedded into the roofing)	
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	In the next steps information on the lengths of the profiles: mullion pressure plate and snap cover should be provided (if longer than 3 meters - standard length of mullion curtain walls - could be difficult to handle).	

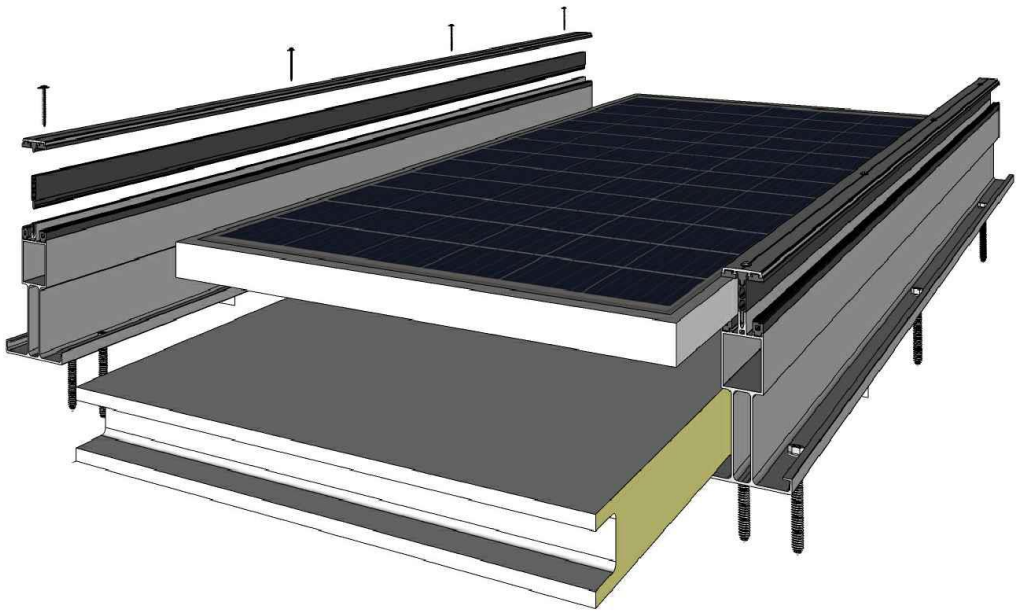

Figure 5. General view of the roofing system integrating PV

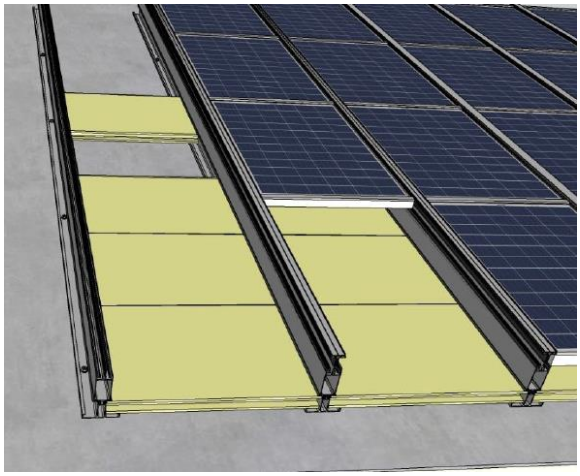

Figure 6. Installation sequence (mullions, insulation, PV)

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.	
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).	In the next steps the connection between the SMFC and the existing pipe of the building should be better described.
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.	In the next steps the water connection should be better described.
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F	Level 1 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.	In the next steps the water connection should be better described.
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.	
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.	
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.	

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.	
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	
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.	
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.	In the next steps the water connection should be better described.
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.	In the next steps the connections with existing water pipes should be better specified.
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		
Standardization	Elements and preassembled	ISO 20887	F	The SMFC has been designed to be compatible	In the next steps the water connection

	subassemblies should be compatible with other systems both dimensionally and functionally			with existing water pipes of heating systems.	should be further specified 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.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P		
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P		

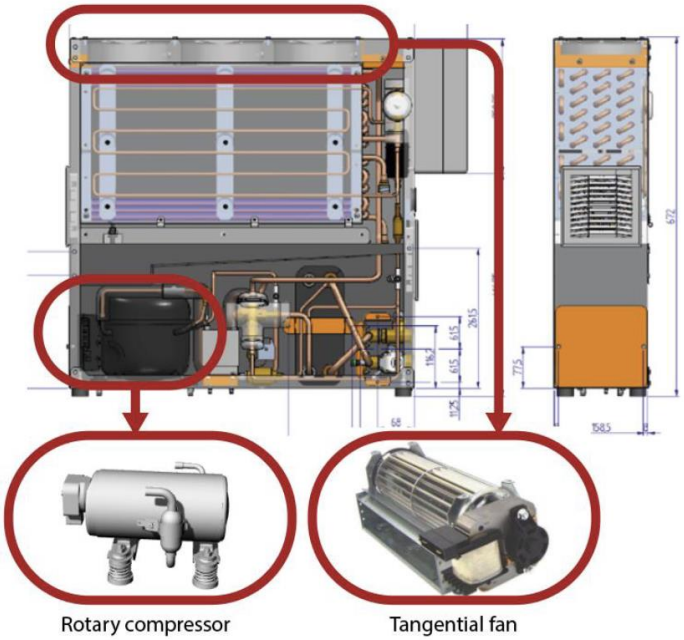

Figure 7. Main subcomponents of the Smart Fan Coil Unit

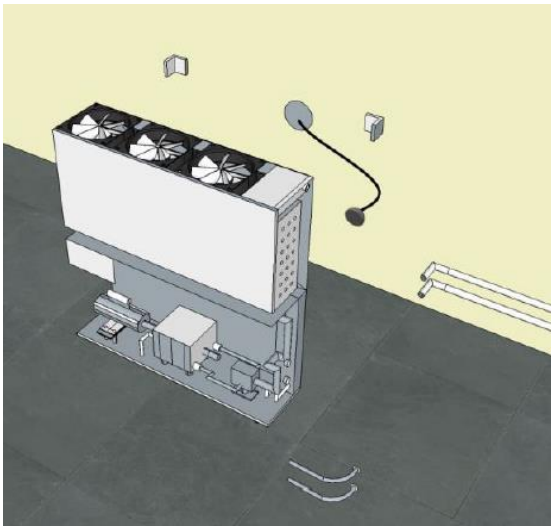

Figure 8. Installation scheme for the Smart Fan Coil Unit

6.4. BATTERY PACK

The assessment of the ease of disassembly for the BATTERY PACK system is developed considering two 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 outside the building, are independent and easily separable from each other (Fig.9).	

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 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.	
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	NA	To be further investigated with the manufacturer in the next steps.	
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.	

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	F		
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		
Reversible connections	Use universally recognized connection methods	ISO 20887	F		
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 should be better specified in the next steps. This is especially valid for Milan pilot project	
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	In the next steps it can be better specified 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 would not be heavy but it needs two persons to move it.	

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. Level 2 The main units and remote units are connected with electrical wiring so the separation of the different units is very easy.	
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. Level 2 The connections are mechanical and fully reversible.	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	P	The main unit is easily accessible as it will be hosted in a technical room/space.	.
Ease of recovery	The number and complexity of the disassembly steps are low.	L 2.4	F		
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	P		

Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	p		
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	F	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		
Accessibility	Operative areas (activities and tools should be declared)	ISO 20887	P		
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		
Reversible connections	Use universally recognized	ISO 20887	F		

	connection methods				
Simplicity	Minimize the number of elements	ISO 20887	F		
Standardization	Adopt modularity	ISO 20887	F	The remote units are standardized.	
Standardization	Use standardized sub elements	ISO 20887	P		
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F		
Safety of disassembly	Intellegibiliy 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		
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P	Remote units are easily handy (small and light).	

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	The HEAT PUMP unit is, in principle, easily separable from the building to which is connected by air ducts, pipes and power supply (MIMO).	

Ease of recovery	Connections are mechanical and reversible	L 2.4	F	The connections between the HEAT PUMP and the building are mechanical and reversible (ducts, pipes and MIMO).	
Ease of recovery	Connections are easily accessible and sequentially reversible	L 2.4	F	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).	In the next steps the water connection should be better described.
Ease of recovery	The number and complexity of the disassembly steps are low	L 2.4	F	The complexity of disassembling the HEAT PUMP is low as it is enough to remove the connections from ducts, pipes and MIMO.	In the next steps the water connection should be better described.
Ease of reuse	Specification of elements and parts using standardised dimensions	L 2.4	P		
Ease of reuse	Design supports future adaptation to changes in functional needs	L 2.4	P		
Ease of recycling	Parts made of compatible or homogenous materials	L 2.4	P		
Ease of recycling	Constituent materials can be easily separated	L 2.4	P		
Ease of recycling	There are established recycling options for constituent parts or materials	L 2.4	P		
Accessibility	Connections should be exposed	ISO 20887	F	The connections of the HEAT PUMP are fully exposed (Fig.14).	

Accessibility	Operative areas (activities and tools should be declared)	ISO 20887	F	The manufacturer has specified the areas to be considered around the HEAT PUMP in order to allow installation and maintenance.	
Independence	Materials or components should be removable without disrupting other components or materials	ISO 20887	F	It seems that the HEAT PUMP can be removed easily without any disruption.	In the next steps the specification of the connections with existing water pipes and with the air ducts shall be better specified.
Reversible connections	Require standard tools for disassembly	ISO 20887	F	No need of special tool is foreseen at present.	
Reversible connections	Use universally recognized connection methods	ISO 20887	F	In the next steps the connection systems between HEAT PUMP and the building (duct, pipes, power) should be better specified.	
Simplicity	Minimize the number of elements	ISO 20887	F	The number of elements is minimized (1 per building).	
Standardization	Adopt modularity	ISO 20887	NA	Not applicable	
Standardization	Use standardized sub elements	ISO 20887	P		
Standardization	Elements and preassembled subassemblies should be compatible with other systems both dimensionally and functionally	ISO 20887	F	In the next steps the water connection should be further analysed 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	The system is clearly recognizable.	
Safety of disassembly	Ease of isolation of hidden energies	ISO 20887	P		
Ergonomics	Ease of handling of the elements (dimensions, weight, morphology, surface characteristics)	ISO 20887	P		

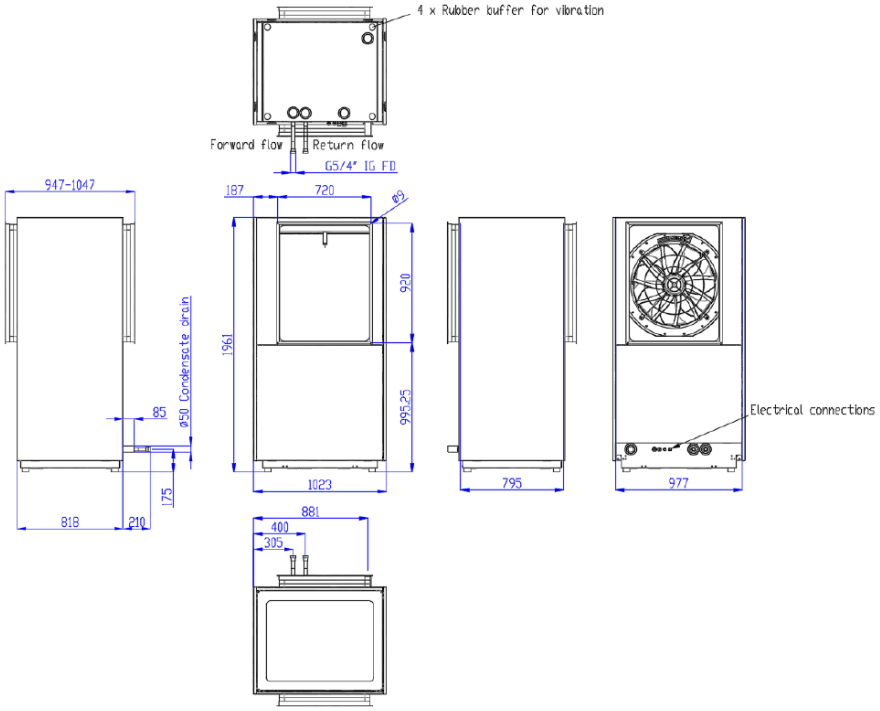

Figure 13. DC heat pump scheme and dimensions

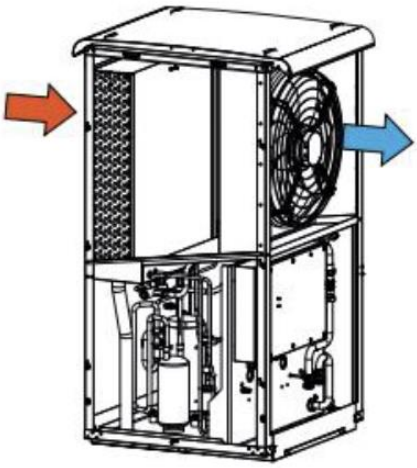

Figure 14. Air flow constraints for DC heat pump

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 optimized in relation to the next pilot cases and technical partners take advantage of the indications provided in the present document. 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, weighted indicators) useful to compare alternative design solutions or to highlight their strengths or weaknesses.