RE-SKIN

D4.4 - Verification of the final configuration of the system I

Funded by
the European Union

Deliverable Information Sheet

Version	1.0
Grant Agreement Number	101079957
Project Acronym	RE-SKIN
Project Title	Renewable and Environmental-Sustainable Kit for building Integration
Project Call	HORIZON-CL5-2021-D4-02-02
Project Duration	42
Deliverable Number	D4.4
Contractual Delivery Date	31-07-2023
Actual Delivery Date	28-07-2023
Deliverable Title	Verification of the final configuration of the system I
Deliverable Type	R
Deliverable Dissemination Level	PU
Work Package	4
Lead Partner	ENTPE
Authors	Joud Aljumaa Aldakheel (ENTPE), Myriam Bahrar (ENTPE), Yamna Soussi (ENTPE)
Contributing Partners	n.a.
Reviewers	G. Paganin, R. Adhikari (POLIMI)

History of changes

Version	Date	Comments	Main Authors
0.1	16-06-2023	First draft, establishing document structure	Joud Aljumaa Aldakheel (ENTPE), Myriam Bahrar (ENTPE)
0.2	16-07-2023	First version, incorporating input from all participants	Yamna Soussi (ENTPE), Joud Aljumaa Aldakheel (ENTPE)
0.3	16-07-2023	Quality review	G. Paganin, R. Adhikari (POLIMI)
1.0	27-07-2023	Final version addressing all further comments	Yamna Soussi (ENTPE), Joud Aljumaa Aldakheel (ENTPE)

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Disclaimer

1. Executive summary

This document describes the first stage of the verification of the interactions among RE-SKINs' system's components, in terms of their operating conditions, interactions and the behavior of the entire system. It describes technical features to identify any potential problems, the verification process is focused to identify eventual issues by testing the systems individually.

At this stage (M7), the document provides comprehensive information and description of each component, successfully with design divers and typical applications, then sizing and operation requirements, and monitoring and control requirements about the integration into RE-SKIN. Additionally, criticalities and barriers to the integration. It also gives an overview on the interconnection and compatibility among different subsystems.

An updated version of this report is scheduled for month 14. The next deliverable will implement the TRNSYS simulation initial results showing the interconnection of RE-SKIN components.

2. Hybrid Building-Integrated Photovoltaic - Thermal (BIPVT) system

2.1. Description of the technology

The implementation of the Building Integrated Photovoltaic Thermal (BIPVT) system in the project showcases a remarkable and developed approach to sustainable and energy-efficient building design. The BIPVT system offers a multitude of advantages, making it an exceptional solution for environmentally conscious construction. One of its key benefits is the simultaneous generation of electricity and heat, which addresses the dual requirements of power and thermal energy in buildings. The BIPVT system implemented in the project revolutionizes building design by offering a holistic and sustainable solution that promotes energy efficiency and environmental responsibility.

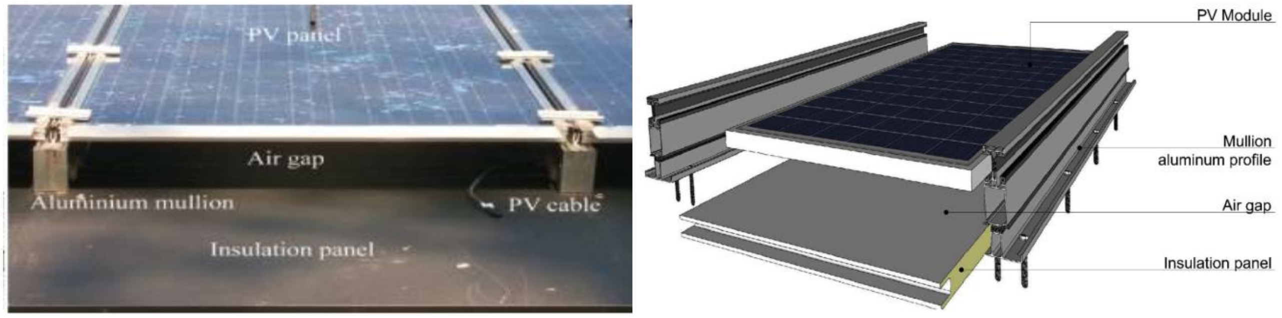

Figure 1. General 3D view of the BIPVT Roof System

2.2. Design drivers and typical applications

The BIPVT system provides a solution designed to coherently integrate into common sloped roofs, effectively replacing the external covering, waterproofing by installing horizontal T shaped frames between the PV modules to protect against infiltration along the slope direction, based on this, we have to implement a thorough testing process to evaluate the system's waterproofing capability, and insulation layers. This innovative integration enhances the aesthetics of the building while maximizing energy efficiency. The system uses a special airflow mechanism within the gap between the PV panel and the insulation layer, which can be achieved through either forced flow using a fan or natural convection utilising the buoyancy effect.

By facilitating the circulation of fresh air, the system efficiently removes the heat absorbed by the collector, while also cooling the rear of the PV module, this cooling effect significantly increases the electrical conversion efficiency.

The BIPVT system comprises various components. The profile consists of two aluminum profiles that are overlapped and connected by two parallel thermal break insulation spacer profiles, which are made of recycled aluminum, these profiles serve as a connection between the existing roof and the PV modules. As well as the refurbished PV module that is manufactured to match the dimensions of the most popular modules available on the market. Additionally, the thermal insulation panel features bio-polyurethane foam, biodegradable and sustainable material known for outstanding thermal resistivity and a minimal ecological footprint, the thickness of the insulation panel might range from 50 to 120 mm, depending on the specific thermal insulation requirements of the case. Completion modules are also included, which are special parts like blind panels that are integrated into the aluminum profiles for areas of the roof where BIPVT installation is not intended. Supply and return channels also are installed at the eaves of the roof to facilitate ventilation and maintain balanced airflow within the BIPVT system.

The BIPVT system offers diverse performances by modifying the cell area density, assuring a balanced output of electricity and thermal energy. The system has a unique profile design with a wider upper part, a narrower section aligned with the insulation housing, and a spread-out base that includes a longitudinal plate with buttonholes for a secure connection to the underlying structure. Excess solar heat absorbed by the photovoltaic modules is efficiently dissipated through convection within the air gap, this surplus heat can be used for heating, especially during winter, or displaced outside during summer to maintain optimal temperature control.

The system's matrix dimensioning provides exceptional flexibility, in various installation requirements. The BIPVT system is designed for flexibility and may be installed on almost any type of sloping roof, including masonry and wood structures.

2.3. Integration drivers into RE-SKIN system

By overlapping the existing roof and replacing the waterproofing and airtightness cladding, the BIPVT system integrates with the building envelope, enhancing energy efficiency and sustainability.

This section will outline the setting in which the Building Integrated Photovoltaic-Thermal (BIPVT) system will be integrated as part of the RE-SKIN project. It will go into detail regarding the sizing of the BIPVT system, its operation, monitoring mechanisms, and other pertinent factors necessary to understand its overall functionality within the given project context.

2.3.1. Sizing and Operation requirements

It is important to note that the technical sizing information pertaining specifically to the module size is significant. In this context, a concise summary of the primary technical specifications and performance characteristics of the BIPVT system is provided as follows:

Dimensions:

- Size of the modular system unit (Width/Height/Thickness) [cm]: 90-120/140-180/23-24
- Weight [kg/m^2]: 20 - 30

Technical features:

- Sound attenuation in operating conditions [dBA]: ≈ 30
- Water penetration: sealed
- Air tightness: Class A
- Reaction to fire (class): BS3D0
- Thermal transmittance [W/m^{2}K]: 0.6 - 0.3

Energy performances:

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

2.3.2. Monitoring and Control requirements

The dimensions, performance, and desired characteristics of this system will be thoroughly examined and validated through the initial prototype and testing/monitoring processes.

In the RE-SKIN project, the BIPVT system needs to be monitored and controlled effectively. The need to keep track of how much electricity and heat the system is producing, and the control mechanisms in place to manage the system's load, store excess energy, and distribute power efficiently.

2.4. Criticalities and barriers to the integration

The integration of BIPVT systems with the building envelope and other energy systems, along with the installation process, can present various challenges. Prior to installation, a thorough examination of the existing roof's condition is essential. The strength and bearing capacity of the roof must also be evaluated.

The PV panels are mounted, with the electrical cables connected accordingly, these steps must be carefully executed to ensure a successful integration of the BIPVT system within the project.

For the integration of BIPVT systems in buildings using TRNSYS simulation, several important factors require attention. Firstly, accurate modelling, representation, and connection of the BIPVT system within the software are crucial to ensure reliable simulation results. Secondly, obtaining precise input data is essential for realistic simulations. Additionally, architectural integration should consider aesthetics, structural compatibility, and should be precise and defined to get reliable results.

3. DC heat pump

3.1. Description of the technology

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

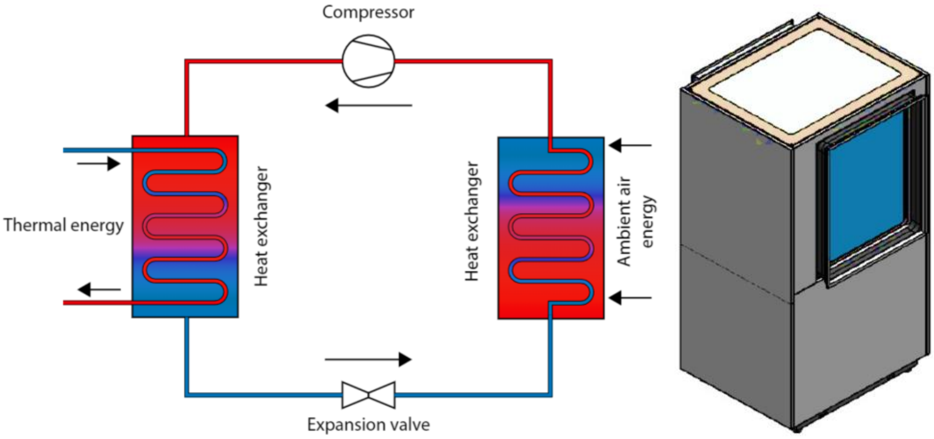

Figure 2. The principle and the design of heat pump

3.2. Design drivers and typical applications

The heat pump is designed to stay inside the building and absorb outside ambient air. Its unique design consists of two parts: the bottom part integrates the compressor, water-side heat exchanger, expansion valve, and other auxiliaries, while the upper part includes the air-side heat exchanger and fans. The casing is specially designed to be well-coupled and tightly jointed with the duct system. This proposed heat pump is an air-water ducted variant that may be installed in an inside technical space, as opposed to conventional air-source heat pumps with exterior units that need additional room and make noise. It efficiently exchanges heat with ambient air using air and produces heated or chilled water.

The heat pump network controller plays a crucial role in accepting user requests and controlling the heat pump system. Furthermore, the hydrobox includes the heating/cooling circuit circulation pump, the domestic hot water pump, and a heating rod, enhancing its functionality and versatility.

3.3. Integration drivers into RE-SKIN system

The heat pump is designed to stay inside the building and take in ambient air from the outside. This allows for efficient heating and cooling functions within the system. What makes it even more advantageous is that it is run by a DC power supply. This means that it can be directly powered by PV energy or energy stored in batteries, without the need for an additional inverter. This integration of the heat pump into the RE-SKIN system offers both energy efficiency and flexibility in utilizing renewable energy sources.

In terms of installation, there are crucial elements for achieving the best performance. Firstly, ensure sufficient space and accessibility for the air inlet connection to the outside environment, allowing up to 8000 cm/h of air intake. Place the heat pump in a sound-isolated area or use soundproofing materials to reduce noise. Other key issues include ensuring proper ventilation to minimize heat buildup and equipment damage and allowing enough cleaning space for easy maintenance. Evaluate the technical room's proximity to the serviced areas and the distribution of conditioned air in the building to optimize energy efficiency and comfort.

It is crucial to have the heat pump installed by HELIO or by an authorized specialized company. This ensures that the installation process is conducted by professionals with the necessary expertise and knowledge. Furthermore, employees from the installation company are required to attend and successfully complete the HELIO expert training program. This program equips them with the necessary skills to handle the installation and maintenance of the heat pump effectively, ensuring reliable and safe operation within the RE-SKIN system.

3.3.1. Sizing and Operation requirements

When it comes to sizing and operation requirements, there are several important factors to consider. Firstly, the area for the duct installation should have dimensions of around 720 × 920 mm. This ensures proper space allocation for the system. The air flow within the system is facilitated by axial fans, which help route the airflow to the heat exchanger. For the version currently under development, the minimum flow rate is set at 2000 m^3/h, ensuring sufficient ventilation. However, the recommended nominal range for optimal performance falls between 5000 – 8000 m^3/h, allowing for efficient heating and cooling operations.

It is significant to consider the technical sizing information of the heat pump system. In this regard, a brief overview of the key technical specifications and performance characteristics of the heat pump is provided as follows:

Dimensions

- Size of the modular system unit (Width/Height/Depth) [cm]: 100-130/190-230/100-120
- Weight [kg]: 300 - 400

Technical features

- Air volume [m^3/h]: 2000 – 8000

- Air inlet flow temperature [°C]: -15 – 45
- Volume water flow [m^3/h]: 0.5 – 3.5
- Heat pump water outlet temperature [°C]: 20 - 60
- Working fluid: R515B
- Compressor: Scroll
- Compressor speed [rpm]: 1200 – 5000
- Fill amount [Liter]: 4 – 8
- Oil amount [Liter]: 1 – 3
- Power supply type: DC
  Input voltage [V]: 600 – 700
- Compressor input voltage [V]: 400
- Frequency [Hz]: 50
- Current [A]: 15 – 25
- Fuse-fan: thermal relay
- Max. nominal current – fan [A]: 1.1 – 1.7
- Earth leakage circuit breaker [mA]: 30
- Fan power [W]: 50 – 500

Energy performances

- Nominal heating capacity [kW]: 12 – 18
- Nominal cooling capacity [kW]: 9 - 12
- Compressor power consumption [kW]: 2 – 10
- COP (heating): 2.5 – 5.5 (air source: -10 – 10°C, water target temperature: 25 – 45°C)
- EER (cooling): 3.5 – 6 (air source: 35°C – 20°C, water target temperature: 7 – 12°C)

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

Main operation features – air side:

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

Main operation features – water side:

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

- Maximum hydraulic system pressure [bar]: 6

3.3.2. Monitoring and Control requirements

Monitoring and control requirements for a heat pump typically include the need to monitor temperatures at various points within the system. This is crucial for ensuring that the heat pump operates within the desired temperature ranges. Additionally, monitoring the pressure within the heat pump system is essential for maintaining optimal operation and efficiency. By keeping track of the pressure, any irregularities or deviations can be identified and addressed promptly. Furthermore, monitoring the flow rate of the heat transfer fluid, whether it is water or refrigerant, is of utmost importance to ensure efficient heat transfer throughout the system.

3.4. Criticalities and barriers to the integration

Integration of heat pumps can face several criticalities and barriers. Heat pumps involve complex electrical connections and refrigerant cycles, both of which demand specialized expertise for safe and efficient operation. Engaging qualified professionals is crucial to ensure proper installation, maintenance, and service of heat pumps.

During installation, it is important to consider specific factors to guarantee optimal performance. Heat pumps should not be installed on an uneven floor as it can affect stability and proper functioning. Sufficient space around the heat pump must be provided to facilitate proper airflow and maintenance. Additionally, the selected installation site should not be in the corner of a building because it leads to limited airflow, reducing efficiency and potentially risking overheating. It also hinders easy access to maintenance, making examinations and repairs more challenging, and the maximum elevation should not exceed 1500 meters above sea level.

Another aspect to consider is the management of condensate water generated by heat pumps, particularly during defrost mode. Proper disposal of condensate is vital to prevent water damage or system malfunction.

The integration of the heat pump with the MIMO converter and the grid presents potential challenges regarding voltage compatibility and operation of auxiliary components. The MIMO converter supplies 600-700 V DC to the heat pump, while the auxiliaries operate at 230-400 V AC. This voltage mismatch can result in electrical compatibility issues, necessitating proper voltage conversion and coordination.

Lastly, heat pumps are complex systems comprising various components like compressors, heat exchangers, and expansion valves. Accurate modeling of these components in TRNSYS simulation software can be challenging and requires a detailed understanding of their operation and performance characteristics. Careful consideration and precise modeling are crucial to accurately simulate heat pump behavior and assess system performance.

4. Storage System

4.1. Description of the technology

The battery system serves as an essential electrical energy storage solution for powering various electrical equipment. Its primary function is to store photovoltaic (PV) electricity, which can be utilized to operate the DC heat pump and DC smart fan coils. The specific battery cell type used is the LEV40, sourced from the Mitsubishi Outlander PHEV. Additionally, the battery system includes a Battery Management System (BMS), which is integrated into the battery bank and facilitates direct communication with the MIMO board.

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

4.2. Design drivers and typical applications

For the first prototype, the battery bank will be constructed using recycled battery cells of the LEV40 type, sourced from the Mitsubishi Outlander PHEV. These cells are manufactured by GS-Yuasa, a Japanese company. Each individual cell has a nominal voltage of 3.75 V. They are arranged in groups of eight cells connected in series, forming what is known as a "battery bank" with a nominal voltage of 30 V.

Multiple battery packs can be connected in parallel to satisfy the unique storage needs of each building. This allows for the needed capacity to be achieved by combining the individual battery packs together.

4.3. Integration drivers into RE-SKIN system

The battery enclosure will house the batteries along with their associated electronics such as the Battery Management System (BMS) and contactors. Once installed, the battery banks will be connected to the MIMO via electrical and communication cables. It is important to ensure that the battery installation is in a dry environment with a minimum room temperature of 5°C and a maximum temperature of 30°C. To enhance safety, the room should also be equipped with smoke alarm detectors and high-temperature detectors.

The primary function of the battery bank is to receive and store electrical energy generated by the PV panels. The charging and discharging operations of the battery bank will be determined by the

RE-SKIN smart control system and executed through the MIMO, utilizing the functionalities provided by the BMS. Through this integration, the RE-SKIN system's energy flow from the battery may be managed effectively.

4.3.1. Sizing and Operation requirements

A list of the key technical specifications and performance attributes associated with each individual battery cell is listed below.

Dimensions:

- Length [mm]: 171 (±0.5)
- Width [mm]: 32.5 (±0.5)
- Height (over terminals) [mm]: 111 (±1)
- Weight [kg]: 1.4

Technical features:

- Storage temperature (recommended) [°C]: -20 to +35
- Charge temperature [°C]: -25 to +60
- Discharge temperature [°C]: -25 to +60
- Lifecycle: 5500 cycles (with 80% of initial capacity)

Energy performances:

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

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

- Nominal voltage [V]: 600
- Operating voltage range [V]: 440 to 656
- Nominal capacity (new cells) [kWh]: 0.11

- Expected capacity at time of installation [kWh]: 16.8 kWh

The main features of the battery bank are summarized below.

Electric features:

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

Mechanical features:

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

Enclosure features:

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

4.3.2. Monitoring and Control requirements

Within the project framework, the battery system requires various monitoring and control measures. These include tracking battery voltage and temperature for performance evaluation and safety, and monitoring battery current for effective energy management. Communication and integration with the MIMO board and RE-SKIN smart control system enable coordinated control and data exchange. Fault detection mechanisms and alarms should be in place to identify abnormalities. By implementing these requirements, the battery system can be efficiently managed and integrated within the project framework to achieve optimal energy storage.

4.4. Criticalities and barriers to the integration

Integrating the battery system within the project framework can face challenges such as when integrating the battery system with existing electrical systems or devices. Complexity may arise during integration, requiring expertise in aligning electrical connections, configuring control interfaces. This integration also requires addressing critical safety concerns, particularly regarding fire risks related to the batteries. Safety measures including sealed enclosures, and fire suppression systems are crucial to protect occupants and property while efficiently using energy storage.

Integrating the battery system into a TRNSYS simulation involves several considerations. First, ensure the availability of a suitable battery model within the TRNSYS library or develop a custom model. Calibrate the model parameters to match the real-world battery system behavior.

5. Smart fan coils

5.1. Description of the technology

Smart fan-coil technology introduces an innovative approach to temperature regulation within buildings. These cutting-edge fan-coils are equipped with a DC compressor that enables precise adjustment of the water temperature sourced from a centralized DC heat pump. By dynamically responding to the energy demands of each room, the smart fan-coils ensure optimal heating or cooling efficiency. A notable feature of this technology is the use of enclosures constructed from sustainable steel sheets with bio-sourced insulation, highlighting its environmentally conscious design, significantly reducing the embodied energy associated with their production. This forward-thinking combination of advanced temperature control and eco-friendly materials positions the smart fan-coil technology as a sustainable and energy-efficient solution for climate control in buildings.

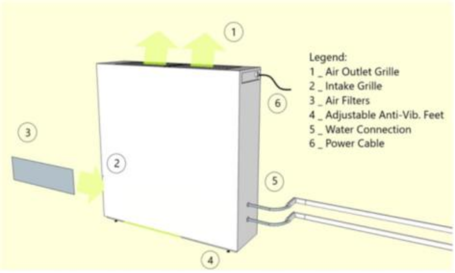

Figure 4. Smart fan-coil

5.2. Design drivers and typical applications

Design drivers for the smart fan-coil technology encompass energy efficiency, precise temperature control, and sustainability. These drivers guide the development of the system, ensuring optimal performance while minimizing environmental impact. The core of the smart fan-coil is a reverse-cycle water source heat pump system, designed for installation within dwellings. These fan-coils offer versatile heating and cooling capabilities through the integration of a small-size rotary DC compressor, enabling the amplification of thermal power from the centralized DC heat pump. The system operates in both heating and cooling modes, with a maximum thermal power output of 3.2 kW.

Notable enhancements in this system include the adoption of a different compressor and ventilating fan, leading to improved energy performance compared to reciprocating models. The implementation of snap-in fittings instead of welded connections simplifies installation and maintenance processes.

With its modular design, the system can include any number of individual self-contained water source heat pump air-conditioning units connected to the closed water loop system.

5.3. Integration drivers into RE-SKIN system

Integration into the RE-SKIN system involves the seamless substitution of radiators with smart fan-coils, utilizing either the existing hydronic pipes in good condition or new pipes incorporated within the RE-SKIN facade if the existing ones are compromised. These smart fan-coils form a reverse-cycle water source heat pump system that must be installed inside the dwellings. The terminal units of the system can either extract heat from the water loop or inject heat into it. With a thermal capacity of up to 3.2 kW, a single smart fan-coil component is capable of covering the heating and cooling requirements of a room with an average floor area of about 40 m^2. By integrating the smart fan-coils into the RE-SKIN system, buildings can benefit from efficient and adaptable temperature control while leveraging existing infrastructure or incorporating new piping solutions for optimal performance.

Every room that needs heating or cooling must have a smart fan-coil fitted in place of traditional radiators. In order to provide domestic hot water (DHW), smart fan-coil can also be installed in the bathroom or technical area. To create DHW, a new component called the Smart DHW boiler will be created. It utilizes the same compact DC compressor as the previous component and the same general rules of the fan coil unit, along with an insulated water tank and a secondary water heat exchanger, enabling the provision and storage of DHW. For the installation of the DHW system, it is essential to position it above the floor level.

5.3.1. Sizing and Operation requirements

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

Dimensions:

- Size (Length, Width, Height) [mm]: 750, 200, 700
- Weight [kg]: 30 - 40

Technical features:

- Power supply voltage [V]: 48 (72 as an option)
- Power supply current [A]: 5 -7 (may change if 72 V will be adopted)
- Maximum air flow rate [m^3/h]: 500
- Compressor type: DC compressor, reciprocating
- Maximum useful thermal power (heating mode) [kW]: 1.4 - 2.4
- Maximum useful thermal power (cooling mode) [kW]: 1.2
- COP: 4.5 (W15A20)
- EER: 7.2 (W15A26)
- Maximum sound power in operating conditions [dBA]: ≈ 35

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

Technical features and Energy performances:

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

5.3.2. Monitoring and Control requirements

Temperature control is a critical requirement for Smart fan coils, as it enables the monitoring and adjustment of the temperature output to achieve both optimal comfort and energy efficiency. With this feature, the fan coil can be fine-tuned to maintain a desired temperature level, ensuring that occupants are comfortable while minimizing energy consumption. By monitoring the temperature and adjusting as needed, the fan coil can respond to changing conditions and provide an ideal indoor climate. This temperature control capability is essential for creating a comfortable living or working environment and promoting energy-efficient operation.

5.4. Criticalities and barriers to the integration

When installing and positioning the fan coil, it is important to consider providing a clearance of approximately 30 cm to allow easy access for technicians during servicing or repairs, to ensure its optimal functionality, it is crucial to eliminate any obstacles that could obstruct the free circulation of air. Before initiating the disassembly process of an existing radiator, it is essential to ensure that the heating system is not operating. Additionally, confirming that the hydronic pipes connected to the radiator are drained of water is of utmost importance. For electrical connections and maintenance procedures, it is recommended to carry them out after the terminal or device has been positioned in its intended location. While for DHW challenges include compatibility issues with existing infrastructure, technical compatibility with control systems.

The availability of specific Smart fan coil models within libraries like TRNSYS or other compatible ones may be limited. In cases where suitable models are not readily accessible, custom modeling may be necessary, adding complexity and time to the integration process. Smart fan coils are typically integrated into larger building energy systems. To incorporate them effectively into comprehensive building energy models within TRNSYS, alignment with other system components such as HVAC systems, building envelopes, and control strategies is required. Ensuring compatibility and consistency between different system models can present challenges.

6. Modular Multifunctional Façade Cladding

6.1. Description of the technology

The multifunctional prefabricated façade system is organized according to a modular structure. It is a self-supporting system composed primarily of sandwich panels and a substructure, created to increase energy performance, and decrease environmental impact by having less negative effect on the environment using sandwich panels, increasing energy performance, and recyclable materials. The panels are made of high-strength steel sheets with weatherproofing and biobased coating on their outer face. The internal chamber works as a thermal resistance when it acts as a sealed airtight gap in cold seasons, varying the thermal transmittance when the ventilation is opened in warm seasons. While the insulating section is incorporated with the injection of an organic polyurethane compound with bioformulation. The utilization of these products in the RESKIN project is an important step towards achieving a more sustainable and environmentally friendly approach to insulation.

6.2. Design drivers and typical applications

The system is designed to be integrated into vertical facades, adding the outer layers of cladding, waterproofing, and insulation. Furthermore, it consists of three main components: the sandwich panel, the recycled aluminum mounting structure, and the finishing elements. The sandwich panel components are made up of a sustainable steel outer layer sourced from SSAB called Greencoat, a biosourced polyurethane foam core known as bioPUR, and an inner steel layer. The thickness of the panels, ranging from 60 to 100 mm, is determined based on project calculations for different demonstrations. The recycled aluminum mounting structure, along with fixing elements provided by EXLA.

The system's finishing elements are detachable, facilitating installations and inspections in designated areas. In this context, GAR has developed a catalogue of standardized technical details for constructive solutions, including installations of windows, doors, corners, air vents, and panel connections. The prefabricated panels are joined using a tongue-and-groove system, ensuring watertightness and modularity to accommodate variable building geometries. The installation employs rectification profiles that support the system panels, which are fixed to the resistant facing using point fixings, allowing for design flexibility while minimizing thermal bridges.

6.3. Integration drivers into RE-SKIN system

The system is specifically designed to seamlessly integrate into vertical facades. Its installation system includes an adaptive closed chamber, which creates a necessary separation from the existing façade. The panels themselves are ingeniously interconnected using a tongue-and-groove joint, ensuring a secure and tight fit. This careful integration and connection process ensures a cohesive and effective solution for enhancing vertical facades.

6.3.1. Sizing and Operation requirements

The main technical features and performances of the modular multifunctional Façade Cladding are listed below.

Dimensions:

- Length [cm]: up to 500
- Width [cm]: 100 ‐ 115
- Thickness [cm]: 6, 8, 10
- Weight [kg/m^2]: 13.6, 14.4, 15.2

Technical features:

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

Energy performances

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

6.3.2. Monitoring and Control requirements

Successful installation of the multifunctional façade system involves a comprehensive approach that considers various factors. Firstly, the complexity of the façade and accessibility conditions are carefully monitored to determine the most suitable installation system. To ensure structural integrity, dynamometer tests are conducted to assess the strength and endurance of the pre-existing wall structure. Control is maintained throughout the installation process to guarantee the proper fixing of brackets and base profiles, providing a secure and reliable foundation for the system. Additionally, close monitoring is carried out during the installation of finishing elements, including window frames, jambs, rain gutters, and gables, to ensure their correct placement and alignment.

6.4. Criticalities and barriers to the integration

When implementing the multifunctional façade system in balconies, it is crucial to identify and establish fixed dimensions, as well as consider the coverage of gas piping by openings strategically placed in the multifunctional façade design to maintain a continual flow of fresh air. The complexity of the façade design and the accessibility conditions can present challenges when determining the most suitable installation system. A significant aspect of the installation process involves affixing the façade panels to the substructure and wall.

The development of representative models within TRNSYS for the different components of the façade cladding system requires careful attention due to its complexity. It involves obtaining detailed information about the specific characteristics of the façade components, such as their thermal properties, insulation values and material specifications. This information is necessary to ensure the simulation models accurately reflect the behavior and performance of the actual system.

7. Multi-input/multi-output converter

7.1. Description of the technology

The multi-input/multi-output (MIMO) converter is an innovative device that enables the seamless integration of diverse energy sources such as photovoltaic (PV) panels, batteries, and the electricity grid, while efficiently supplying various loads in both direct current (DC) and alternating current (AC) forms. This converter plays a crucial role in managing the power flow between these different sources and loads. Its special configuration was carefully planned to achieve excellent conversion efficiencies, maintain small size and lightweight properties, and function independently.

Figure 5. MIMO Remote Unit physical appearance, DC-DC fan-coil 300 W unit (left) and DC-DC panel optimiser unit (right)

7.2. Design drivers and typical applications

The MIMO converter presents a grid-connected four-leg AC/DC converter with multiple accessible DC ports, ensuring convenient connectivity. One of the notable features of the MIMO configuration is the inclusion of an easily accessible DC port operating at the rated DC-bus voltage. To accommodate various battery voltage ratings, the design of the DC/DC converter is customized accordingly. The MIMO system consists of distinct subcomponents including the MIMO Main Unit, this unit comprises a control card responsible for communication with both the RE-SKIN energy management system and the battery management system (BMS). Additionally, it consists of two power converters: a 4-leg AC-DC inverter with a power range of 15 - 20 kW, facilitating the integration with the utility grid, and a bidirectional 10 kW DC-DC converter, serving as the interface for the battery. The MIMO Remote Units play a crucial role in interacting with specific parts of the building sub-systems such as PV panels and smart fan-coils. For each fan coil device, there is one dedicated DC/DC unit, while each PV panel is accompanied by a power optimizer. Furthermore, a single DC/DC unit caters to multiple fan coils, ensuring efficient operation and management of the entire MIMO system.

7.3. Integration drivers into RE-SKIN system

The proposed solution focuses on the integration of various components within a converter system. On the DC side, the converter combines photovoltaic (PV) modules and batteries while providing power to the heat pump and smart fan coils. Additionally, an intelligent electric vehicle (EV) charger can be connected on the AC side. To accommodate the voltage requirements of the smart fan coils, two potential solutions have been considered. The first option involves installing a dedicated DC/DC converter for each fan coil, while the second option is to install DC/DC converters to supply specific sections of the building. A comparative analysis will be conducted to determine the final solution, considering both the building's characteristics and the proposed configurations. Currently, a technical discussion is underway with SOLAR to determine the optimal choice in this regard. The MIMO main unit is planned to be installed in a service room within the main building. In the case of multiple smaller DC-DC units being selected, the MIMO remote units for fan coils should be positioned near each fan coil, outside individual flats. Lastly, the MIMO remote unit for PV panels will be mounted below the panels and attached to the aluminum support.

7.3.1. Sizing and Operation requirements

The technical sizing of the system within RE-SKIN project is as follows:

Dimensions:

- Main unit (Width/Height/Depth) [cm]: 60 x 60 x 40
- Power optimizer (Width/Height/Depth) [cm]: < 10 x 10 x 8
- Fan coil DC/DC - 300 W (Width/Height/Depth) [cm]: < 10 x 10 x 8
- Fan coil DC/DC - 3 kW (Width/Height/Depth) [cm]: < 25 x 25 x 24

Technical features:

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

Energy performances:

- AC/DC Four-leg converter port efficiency [%]: > 94
- DC-DC battery converter efficiency [%] > 93
- PV system efficiency [%] > 90
- DC-DC fan coil converter efficiency:

- ☐ Solution 1: individual DC-DC fan coil converter efficiency [%]: > 90
- ☐ Solution 2: Concentrated DC/DC converters efficiency [%]: > 92

MIMO Main Unit:

- Size (Width, Height, Length) [mm]: 600 x 600 x 400
- Weight [kg]: 40 - 50

MIMO Remote Unit: DC-DC fan coils 300W:

- Size (Length, Width, Height) [mm]: 240 x 120 x 70
- weight [kg]: 2.5

MIMO Remote Unit: DC-DC panel optimisers:

- Size (Length, Width, Height) [mm]: 140 x 140 x 25
- weight [kg]: 0.5

7.3.2. Monitoring and Control requirements

The monitoring and control requirements of the components within the MIMO system encompass several key aspects. Firstly, power monitoring is crucial for measuring and tracking the real-time power consumption, generation, and flow of each component, including batteries, heat pumps, smart fan coils, PV panels, EV charger, and the grid. Additionally, the state of each component needs to be monitored, including factors such as operational status and temperature. Communication and connectivity between components and the energy management system are essential for data exchange and coordination. These monitoring and control requirements facilitate real-time monitoring, efficient power management, historical analysis, and effective communication within the MIMO system.

7.4. Criticalities and barriers to the integration

Integrating the MIMO system into a project requires addressing compatibility and design considerations, ensuring compatibility with the existing infrastructure, building systems, and managing installation time and procedures efficiently. Integration requires careful consideration of the electrical and mechanical requirements, space availability, and overall project design.

Integrating the MIMO system into a simulation using TRNSYS may present certain criticalities and barriers such as the availability of accurate and validated models of the MIMO system components within the TRNSYS library.

8. EV charger

8.1. Description of the technology

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

Figure 6. the two versions of EV charger (version A “JuiceBox” on the left and B “JuicePole” on the right)

8.2. Design drivers and typical applications

JuiceBox and JuicePole, two innovative AC charging solutions for electric vehicles are introduced within the RE-SKIN project. The JuiceBox is a versatile charging infrastructure designed to charge one vehicle at a time, offering power options ranging from 3.7 kW to 22 kW. With its adaptable power electronics, it accommodates a wide range of EV charging needs. For an EV battery capacity of 80 kWh, the charging time to go from 0% to 100% varies between 4 and 20 hours, depending on the power level selected. On the other hand, the JuicePole shares a similar power electronics system, but its unique advantage lies in its ability to charge up to two vehicles simultaneously, providing a maximum power output of 22 kW. With this increased power capability, the JuicePole significantly reduces the charging time to approximately 4 hours for a full charge from 0% to 100%. Both JuiceBox and JuicePole offer efficient and convenient charging solutions, catering to the diverse needs of electric vehicle owners.

8.3. Integration drivers into RE-SKIN system

The JuiceBox is a perfect solution for single parking slots or small-size applications, offering convenient installation options by mounting it on a nearby wall close to the parking area. However, it is crucial to note that the JuiceBox should only be installed by a qualified electrician, following specific guidelines. These guidelines include placing the unit within the range of the vehicle's charge port and ensuring the provision of a dedicated overcurrent protection device. Additionally, power cables with an earth resistance of less than 150 Ω must be utilized. Correct positioning of the Juicepole on the mounting surface is essential, aligning it according to the indicated direction (front) and ensuring proper cable orientation. These installation instructions are vital for the optimal functioning of the JuiceBox and to prevent any operational issues that may arise.

8.3.1. Sizing and Operation requirements

The technical data and performances of the two models are as follows.

- *VERSION A*

Dimensions:

- Dimensions (Width/Height/Depth) [mm]: 153 x 180 x 42
- Weight [kg]: 5 - 10

Technical features:

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

Energy performances:

- Power [kW]: 3.7 - 22
- Current [A]: 32
- Voltage [V]: 230 (1-phase) or 400 (3-phase)

- *VERSION B*

Dimensions:

- Dimensions (Width/Height/Depth) [mm]: 353 x 1475 x 333
- Weight [kg]: 60

Technical features:

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

Energy performances:

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

8.3.2. Monitoring and Control requirements

The EV charger component within the RE-SKIN project framework has several monitoring and control requirements. It needs to provide real-time monitoring of the charging process, including parameters like charging status, power, energy consumption, and duration. A comprehensive fault detection and diagnostics system is essential to identify and report any issues during charging, while integration with energy management systems and smart grids optimizes charging based on renewable energy sources, and grid demand. Overall, these requirements ensure an efficient and user-friendly charging experience while promoting integration with renewable energy and smart grid technologies.

8.4. Criticalities and barriers to the integration

The integration of an EV charger component within the RE-SKIN project framework can face criticalities and barriers that need to be addressed for successful implementation. Technical compatibility with existing infrastructure, and interoperability with other systems.

The integration of simulation using TRNSYS can encounter criticalities and barriers that need to be overcome for successful implementation, such as developing and validating accurate models.

9. DSS/BEMS Platform

9.1. Description of the technology

The Decision Support System (DSS) is undergoing significant enhancements across multiple dimensions. Collaborating with ENELX and POLIMI, a collection of new models will be developed to specifically address circularity, offering valuable insights for building owners. These models will integrate Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) data, empowering owners with comprehensive information. Furthermore, the DSS will be thoroughly reviewed to enhance the user experience, ensuring a more intuitive interface. To facilitate technical maintenance, a new application will be introduced, enabling efficient management of the models. In addition, the platform will incorporate the Building Energy Management System (BEMS), which will be jointly developed with CTIC/POLIMI, allowing for seamless integration and comprehensive building energy control. These advancements in the DSS will greatly enhance decision-making capabilities and contribute to sustainable and efficient building management.

9.2. Design drivers and typical applications

The RE-SKIN project aims to explore various possibilities for leveraging the principles of WEB 3.0, such as Distributed Applications and Blockchain's Ledger, in the context of building management. The focus will be on enhancing security, accountability, control, ownership, and collaboration concerning the distributed data collected within the building. Additionally, a reporting function will be implemented, enabling academic users to export raw data in CSV or Excel format. This feature will empower users to analyze and combine the data with external sources, enabling them to find answers to their specific queries and gain deeper insights into the building's operations. The RE-SKIN project represents an innovative approach to leveraging cutting-edge technologies for improved data management and decision-making in building environments.

9.3. Integration drivers into RE-SKIN system

To ensure seamless integration and effective collaboration between the Decision Support System (DSS) and Building Energy Management System (BEMS) within the RE-SKIN project, both systems will depend on a shared understanding of the collected building data. A key aspect of this collaboration is enforcing standardized semantics and nomenclature for the data across the various layers of the digital twin and throughout all modules of the RE-SKIN platform. This standardized approach will enable consistent interpretation and representation of the data, facilitating interoperability and smooth communication between different components of the system. By establishing a common language and structure for the data, the DSS and BEMS can effectively exchange information, analyze it cohesively, and provide comprehensive insights and control over building operations.

9.3.1. Sizing and Operation requirements

The DSS and BEMS platform should be able to handle a lot of data and users, keep data safe and secure, and be able to work with different types of building systems and data formats. The interface should be easy to understand and customize, with tools for analyzing data and creating reports.

9.3.2. Monitoring and Control requirements

Within a project framework for a platform, there are several monitoring and control requirements for the components involved. These requirements include performance monitoring to ensure optimal system performance by tracking metrics like response time and resource utilization. Availability monitoring is essential to ensure uninterrupted service, involving checking uptime and setting up downtime alerts. Security monitoring is crucial for detecting and mitigating threats, such as unauthorized access.

9.4. Criticalities and barriers to the integration

When integrating a Decision Support System (DSS) or Building Energy Management System (BEMS) with a database platform, several issues can arise. Data mapping challenges can arise when aligning data fields and structures between the DSS/BEMS and the project, leading to synchronization errors.

10. Integration of the subsystems in the toolkit

The PV system generates electricity from solar energy, and MIMO controls this power flow among the batteries, the heat pump, the smart fan coils, the PV panels, and the EV charger. The electricity is directed to the various components and appliances in the building. The heat pump, connected to the electrical panel, utilizes this electricity to provide heating or cooling as needed. The smart fan coil unit, also powered by the electrical panel, distributes the conditioned air or water from the heat pump to specific areas or rooms in the building, ensuring optimal comfort, as both, the heat pump and smart fan coil are connected to the grid. The batteries, connected to the electrical panel through a battery management system (BMS), store any excess energy generated by the PV system, allowing for its use during periods of high demand or grid outages. Lastly, the EV charger, linked to the electrical panel, facilitates the charging of electric vehicles using power from the PV system, batteries, or the main electrical grid. This comprehensive interconnection between the systems maximizes the utilization of renewable energy, optimizes energy usage, and promotes overall energy efficiency within the building.

By employing MIMO, all these systems can transmit and receive data, enabling real-time monitoring, control, and coordination of their operation. The flexibility, scalability, and efficiency provided by MIMO technology contribute to seamless integration and effective communication between different components, enhancing the overall system's functionality.

The diagram below provides an overview of how the RE-SKIN systems are interconnected within the overall system setup.

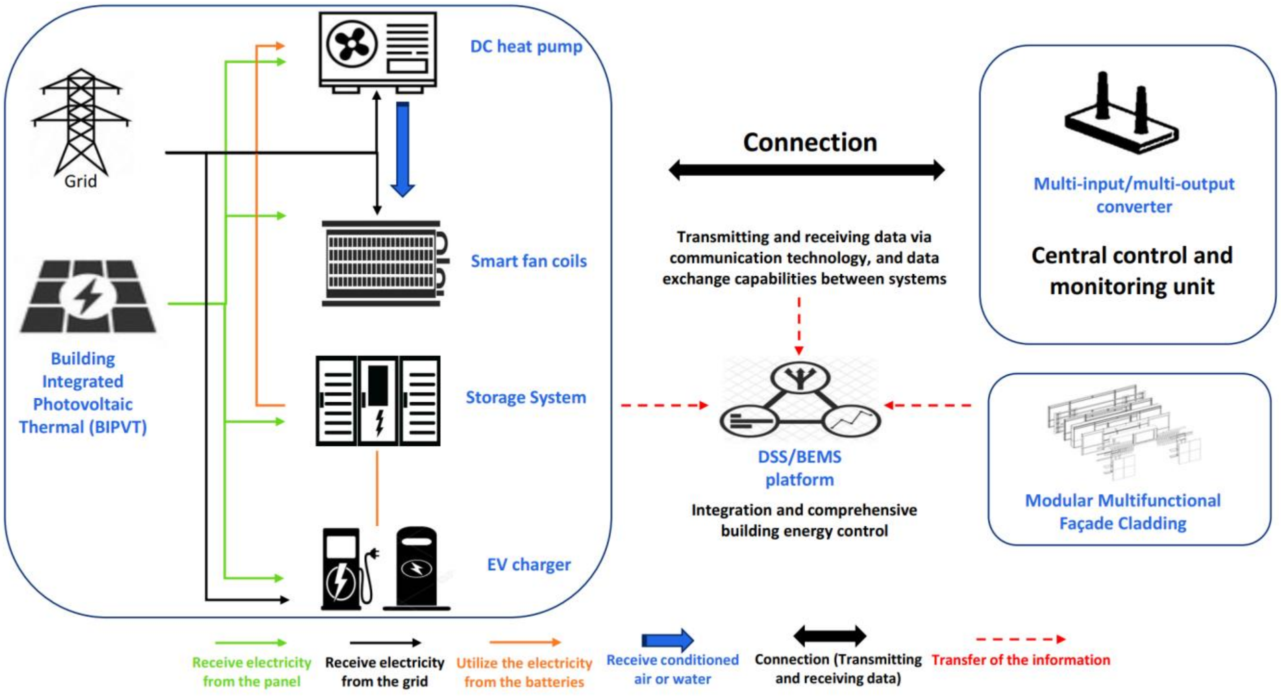

Figure 7. Interconnection systems