Implementing Smart Readiness in existing buildings: the RE-SKIN project case study

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***Abstract* - In recent decades, with the intensification of the energy-environmental crisis, the potential for efficient consumption, adaptive-predictive control of operational functions, and dynamic management of renewable sources have made the role of Smart Buildings in the process of decarbonising the built environment increasingly evident. Smart Building, however is a very broad concept, indicating a wide range of technologies and features, not only aimed at energy efficiency. To avoid that, as in so many areas concerning Sustainability, labels are used purely for propaganda purposes to the detriment of real quality, it is necessary to apply appropriate metrics that can quantify actual compliance with set targets, such as energy efficiency targets. A very useful tool in this regard is the Smart Readiness Indicator initiative, promoted by the European Commission. In such a context, this study reports the preliminary outcomes of the Horizon Europe RE-SKIN project, aimed at sustainable and smart retrofit of existing buildings.**

Keywords - Smart Buildings, Smart Readiness Indicator, energy retrofit, energy efficiency.

I. Introduction

The history of artificial intelligence applied to the building sector is recent, but characterised by a very rapid evolution, like that of all ICT-related technologies.

In 1984, the article “Wiring buildings for intelligence” by Frank J. Prial in The New York Times introduced “a new generation of office buildings that seem almost to think for themselves [...] called intelligent buildings” [1]. It mentions “a marriage of two technologies - old-fashioned building management and telecommunication”. The process of building digitalisation is already underway, but for the first time it is officially recognised.

Telecommunications liberalisation, rapid technological development, and the undoubted management advantages associated with it, prompt entrepreneurs and property managers to rapidly adopt the innovations and services available in the field of building automation, inevitably for commercial purposes. However, profit margins are initially small and the enthusiasm of the first hour temporarily wanes.

Technological developments, on the other hand, are increasing exponentially, so much so that in 1995 the Conseil International du Bâtiment formulated the technical definition of an Intelligent Building: “A dynamic and responsive architecture that provides cost-effective and environmentally sustainable productive, economic and ecological conditions for each occupant through the continuous interaction between its four basic elements: places (materials, structures, spaces), processes (automation, control, systems), people (services, users), management (maintenance, performance) and the interrelation between them” [1,2].

At this point, it only remains to draw attention to a factor that has not yet been fully resolved: the human factor [3]. The intelligent building, in fact, manage, controls, monitors, but requires minimal involvement on the part of the user, who is relieved, in intentions, of the burden of management, but in fact is practically excluded from it.

The last, fundamental evolutionary step is accompanied by the introduction of the term “smart” (intelligent yes, but in the sense of active, brilliant, resourceful). In the excellent book ‘What is a smart building?’ [4], Smart Buildings are defined as “buildings that integrate and harness intelligence, services, control, materials, and construction as a single system, placing adaptability rather than reactivity at the centre, in order to meet the drivers of building progress: energy efficiency, durability, comfort, and user satisfaction”. The fundamental difference is precisely the ability to dialogue and interact with the user, in order to optimise management and performance.

In recent decades, with the intensification of the profound energy-environmental crisis on a global scale, the potential for efficient consumption, adaptive-predictive control of operational functions, and dynamic management of renewable sources have made the role of Smart Buildings in the process of decarbonising the built environment increasingly evident.

While conceiving a building as a Smart Building from the design stages is relatively simple, it gets more complicated if we want to transfer the same features to an existing building. In the current European scenario, 85% of the building stock was built before 2000 and amongst those buildings, 75% has a poor energy performance [5]. Furthermore, by 2050 up to 90

% of the present European building stock will still be standing and in operation [6], therefore, the renovation of buildings is a key action to reach the carbon neutrality goal.

In this regard, this study reports the preliminary outcomes of the Horizon Europe RE-SKIN project, funded by the European Union [7], aimed at sustainable and smart retrofit of existing buildings.

II. Energy efficient Smart Buildings

As far as energy efficiency is concerned, Smart Buildings, through appropriate software and hardware (which are increasingly accessible and effective), reduce their own consumption, guarantee comfort as boundary conditions change, and conveniently manage energy and information flows with external systems. This last aspect represents one of their greatest strengths: the building dialogues with the power grid, or rather with the smart grid. The fluctuation of energy surpluses or shortages (which, let us remember, by massive use of renewable sources is unavoidable) can be shared with other nodes/users, compensating and/or integrating the different needs with mutual interest.

More than ever before, the strategic role of renewable sources such as photovoltaics or wind power has been so strategic. The shift from concentrated generation in large power stations to distributed generation entails a democratisation of the entire energy market, with undoubted advantages for consumers in particular. Let us remember, however, that we are talking about "non-programmable sources", which do not operate according to pre-set profiles, but according to the availability of the natural resource, not always in phase with consumption needs.

Of course, energy storage systems can be relied upon, but bearing in mind that the costs of implementation, operation, maintenance and decommissioning increase. If, on the other hand, renewable energy can be exploited at the same time as its production, by adopting smart features (e.g. concentrating loads at times of overabundance, when feasible) or exchanging it with other subjects (on the basis of crossing different consumption patterns), its value grows further and its contribution to the overall energy system can become preponderant.

As buildings sector is responsible for 40% of energy consumption and 36% of greenhouse gas emissions in the EU [8], the positive contribution that smart technologies can make to this sector is evident.

Smart Building, however is a very broad concept, indicating a wide range of technologies and features, not only aimed at energy efficiency. To avoid that, as in so many areas concerning Sustainability, labels are used for pure propaganda purposes at the expense of real quality, it is necessary to apply appropriate metrics, capable of quantifying actual compliance with set goals, such as energy efficiency goals.

A very useful tool in this regard is the Smart Readiness Indicator, promoted by the European Commission [9].

III. Smart Readiness Indicator

The smart readiness indicator (SRI) initiative is closely related to the Energy Performance of Buildings Directive recast (EPBD IV) [10] and aims to measure buildings' ability to use smart technologies, increase energy efficiency, reduce environmental impacts, optimize renewables exploitation, as well as to ensure comfort and liveability for occupants [11].

The "smartness" of a building refers to its ability to actively and efficiently sense, interpret, communicate and respond to changing conditions in relation to the building's technical systems operation, the external environment (including energy grids) and the building's occupants needs.

The SRI rates buildings' smart readiness in order to perform 3 main key functionalities [10]:

- energy efficiency optimisation;
- occupant needs adaptation;
- energy grid adaptation and flexibility.

The SRI assessment allows to evaluate the performance of "smart-ready services" categorised in 9 technical domains: heating, cooling, domestic hot water, ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, monitoring and control.

In turn, performance related to each service is evaluated against 7 performance targets, defined as desired impacts: energy efficiency, maintenance and fault prediction, comfort, convenience, health, well-being and accessibility, information to occupants, energy flexibility and storage.

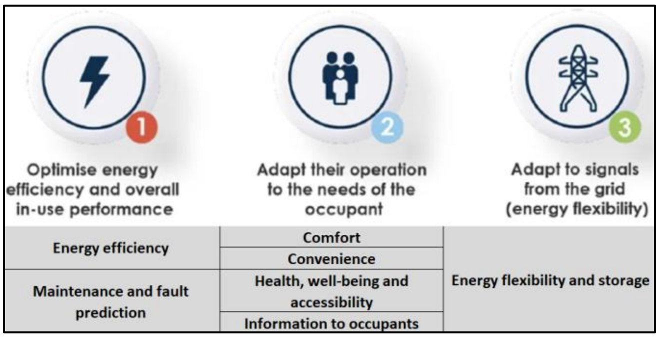

Fig. 1. SRI 3 main key functionalities and related performance targets

The result of this assessment is aggregated into an overall SRI class and SRI score, which expresses how close the building is to maximum smart readiness. In addition, specific scores on each of the 3 key functionalities of building smartness are calculated.

IV. The RE-SKIN Project

RE-SKIN Project (Renewable and Environmental-Sustainable Kit for building Integration) [7], funded in the framework of Horizon Europe, aims to develop and demonstrate an integrated, multi-technology and low-impact renovation toolkit for energy retrofit and smart upgrade of residential, public and commercial buildings. Moreover, the whole project has been conceived according to a circular economy logic, in order to maximise energy performance while at the same time reducing environmental impacts.

In detail, RE-SKIN involves the development of a multifunctional technological package, to be applied to the energy retrofit of existing buildings, capable of making the envelope (facades, windows and roof) and technical systems (HVAC) more efficient, as well as enabling the effective integration of renewable energy sources (photovoltaics, aerothermal energy) and advanced smart technologies (energy management and storage systems, etc.). More in detail, the proposed toolkit includes a roof-integrated hybrid photovoltaic-thermal (BIPVT) system, which produces electricity and heat and at the same time thermally and acoustically insulates the slab beneath. Electricity, from repurposed PV modules, powers the building's loads, which interacts with the grid and EVs charging stations. Heat is used by an air-source heat pump for heating and DHW production. When there is no heat demand, the heat is dispersed outside by natural ventilation, cooling the envelope. The façade is a thermal cladding with self-supporting panels and bio-based insulation, optimised for quick assembly without scaffolding, inside which the wiring for the new installations is housed. Both the roof and the façade are particularly resistant to weather and extreme climatic phenomena, as they use materials that are more resistant and waterproof than traditional ones. The HVAC system consists of an air-water heat pump drawing from the hybrid system, connected to waterloop fan-coils (i.e. decentralized water-to-air heat pumps), which are designed to be connected to the building's heating network, but can provide both heating and cooling, also integrating air-quality sensors. The electricity generated by the PV system can be stored locally in repurposed EVs batteries used for stationary purposes. The whole system is designed according to a circular economy logic, using mostly recycled or bio-based materials, in order to maximise energy performance while reducing environmental impacts.

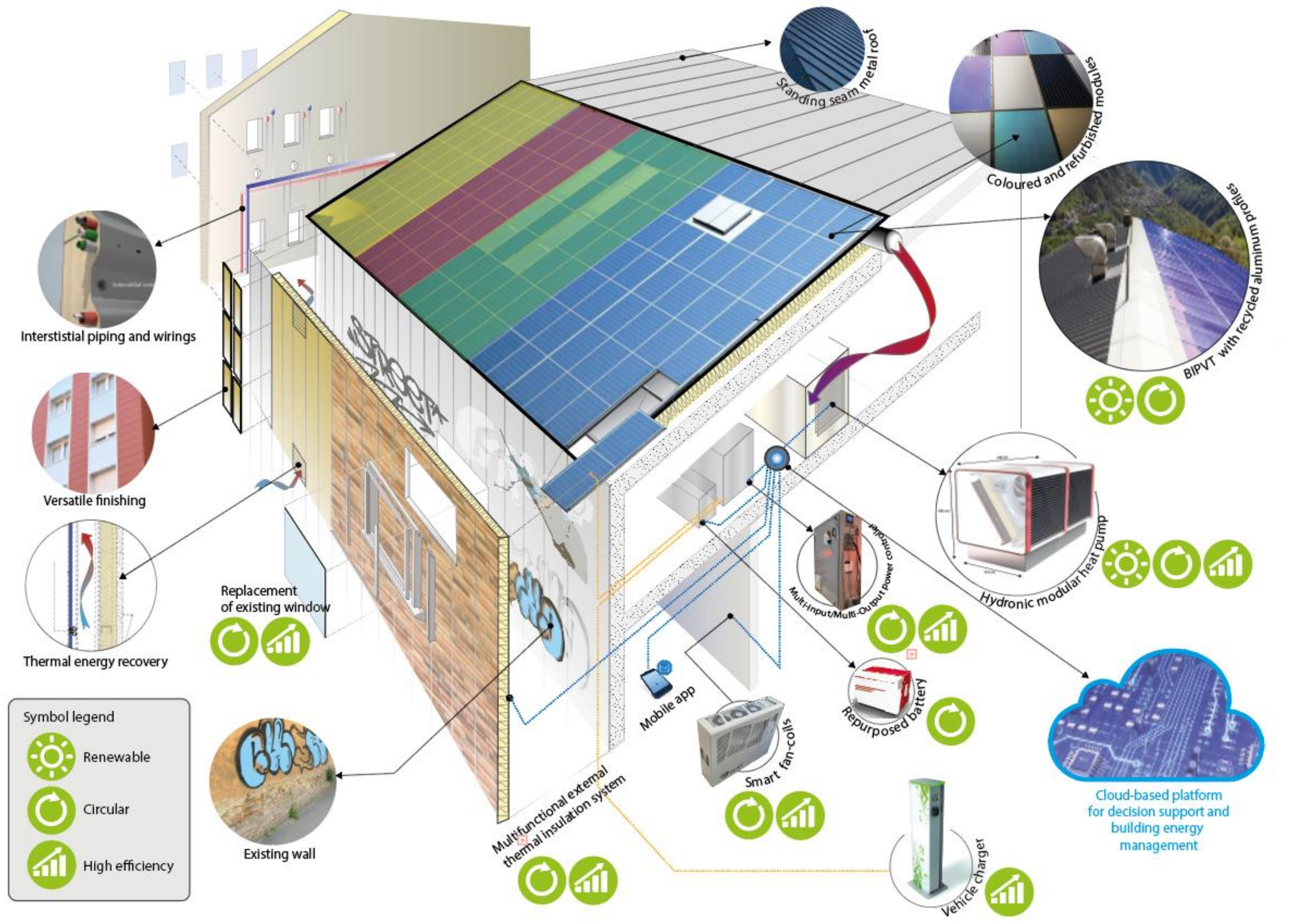

Fig. 2. Main subcomponents of the RE-SKIN package

In addition, the effectiveness of the whole RE-SKIN system is ensured by an ICT platform, which integrates both a Decision Support System (DSS), a Building Energy Management System (BEMS) and a Sustainability Dynamic Rating (SDR) tool to support the whole building retrofit intervention, from decision-making, through design phase, to operational phase.

In the pre-retrofit phase, designers can access a user-friendly procedure and drawing up the building profile, by adding boundary conditions (geometric and constructive data, climate, energy costs, building users' profiles, etc.), restrictions (affordable costs, building codes, etc.) and goals (energy saving, impacts reduction, return on investment, etc.). This first step enables to create a virtual model, which is used in an iterative evaluation procedure that simulates the outputs of different subsystems' combinations and matches. Thus, the DSS shows the economic and environmental performances of different retrofit options, easing the design/decision making process on the basis of life-cycle energy analysis and costs. A specific guided procedure allows to add in the platform also new alternative components that are compatible with RE-SKIN. Once the design decision has been defined, the SDR tool provides a life-cycle rating of the building, with particular reference to the entire energy life-cycle, based on the estimated useful life after retrofit and the expected performance variations and maintenance activities.

This assessment also provides an energy "net present value", estimating at day zero the total energy content (embodied energy + operating energy + decommissioning energy) associated with the intervention. Such a tool is dynamic, since the data can be updated during the operational phase according to the boundary conditions (e.g., climate change, variation of usage patterns, etc.), always providing a very up-to-date and complete representation of the actual environmental and energy performance of the building.

In the post-retrofit phase, the BEMS optimizes the building's operation, by efficiently managing the different energy fluxes, produced locally by the BIPVT plant or collected from the grid, deciding among direct use, electric storage, electric vehicles charging or feeding in the grid, as dictated by timing, convenience and opportunity.

Optimization of energy management and Smart Grid interaction is carried out by harnessing external (weather forecast, variation in energy tariffs, electric vehicle charging needs) or internal (inputs and feedbacks from building's users) information. In this sense, the platform exploits the previously elaborated virtual model applying a predictive-adaptive logic which guides the building-system efficiency.

In addition, by properly driving the package's operation, the logic contributes to enhance active/passive management of energy transfer, by controlling air flows and thermal fluxes in the hybrid roof and in the ventilated façade.

The collection of operational data and the control of active elements will be enabled by an IoT structure of RE-SKIN's components, in which low-cost sensors (e.g. temperature, RH, occupation, CO_2, etc.) and actuators (e.g. motorized dampers, switches, etc.) will be pre-installed. The BEMS allows a continuous detection of the buildings' performance and also enables a direct interaction with the building's users (e.g. inhabitant, facility manager, etc.) which may both be informed on the building's performance and control it by using dedicated apps installed on mobile devices (smartphones and tablets).

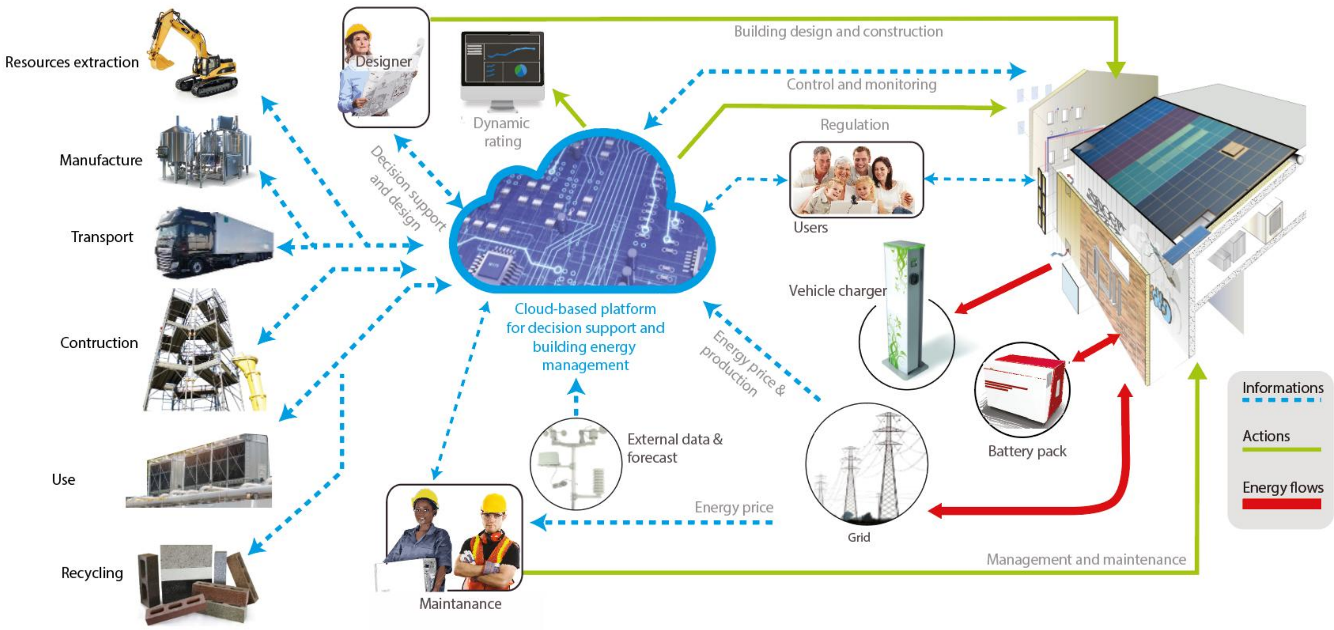

Fig. 3. Scheme of the RE-SKIN could platform

V. RE-SKIN SRI Assessment

Currently, the project is in progress [12], and in early 2025 the renovation of the first case study, located in Milan, began. The first field-collected data will be available starting from summer 2025, however, detailed dynamic simulations have been carried out, calibrated on the basis of laboratory tests of the different components and subsystems composing the holistic toolkit.

Based on these initial results, which will be verified in the prosecution of the research, it is possible to make a preliminary assessment about the smart readiness achievable by the building once it is renovated. The evaluation was carried out by assessing the functionality level achieved by the building in each domain. Below a summary of the results for each domain is outlined.

- *Heating.* The heating domain demonstrates a sophisticated level of smart readiness, characterized by individual room-level control allowed by the use of the proposed emission system (waterloop fan coils). This allows for nuanced thermal zoning, where different rooms can maintain tailored temperature profiles based on usage patterns and occupancy. Such systems enhance both energy efficiency and thermal comfort, leveraging bi-directional data exchange to fine-tune energy delivery in real time.
- *Domestic Hot Water preparation*. In this domain, smart functionalities include performance monitoring paired with forecasting algorithms to anticipate hot water demand. These predictive controls optimize energy use by preparing hot water according to a forecasted profile, reducing thermal losses associated with storage and standby periods. This not only contributes to energy savings but also enhances user satisfaction by ensuring availability when needed, without overproduction.
- *Cooling.* The RE-SKIN cooling system allows variable capacity control linked with demand-side

signaling. This functionality adjusts cooling output dynamically based on internal heat gains, occupancy, and external conditions. By synchronizing with building energy management systems, such setups support load shifting, peak demand reduction, and climate-adaptive control, aligning the building with smart grid requirements and sustainability goals.

- *Ventilation.* The ventilation domain is not addressed in the RE-SKIN toolkit. However, the sensors integrated in the fan coils units enable the real-time monitoring capabilities, offering insight into operational parameters such as humidity levels and air quality indicators (e.g., CO_2 concentration). Though primarily diagnostic, these sensors enable data-driven optimization and preventive maintenance, supporting both occupant health and energy-aware air exchange. Historical data logging with the RE-SKIN cloud platform further enhances the SRI level.
- *Lighting.* The lighting domain is not applicable to RE-SKIN since the toolkit does not address the lighting control.
- *Dynamic Building Envelope.* Such domain, that is related to the possibility to change the features of the opaque and transparent envelope according to the boundary conditions, is partially addressed by RE-SKIN. Specifically, the project enhances the performance of the existing envelope through the integration of a ventilated façade system with a variable configuration, modulated according to seasonal climatic conditions.
- *Electricity.* The integration of smart metering technologies in the RE-SKIN toolkit enables real-time monitoring of electricity consumption patterns, allowing the system to achieve the highest functionality level in this domain. The acquired data will be stored in the cloud platform, which allows for the identification of high-consumption appliances and anomalous user behaviors, as well as the historical data tracking. This combination fosters user awareness, encourages behavioral energy savings, and establishes a solid foundation for advanced functionalities such as automated load balancing and grid-responsive demand-side management.
- *Electric Vehicles Charging.* The multifunctional converter developed in the project enables the system to be made ready for electric vehicles (EV) charging. Specifically, the solution includes an AC output port and a dedicated DC port designed for direct connection to a DC charger. This configuration allows EV charging to be managed efficiently by utilizing directly photovoltaic (PV) electricity, thereby enhancing energy self-consumption and system integration.
- *Monitoring and Control.* The cloud platform developed in RE-SKIN allows the monitoring and control domain, providing a centralized interface for visualizing performance data. It will include dashboards, alerts, and fault detection mechanisms, enabling facility managers to respond quickly to inefficiencies or malfunctions. This integrative capability ensures that various smart services operate in concert, aligning with the overarching goals of operational efficiency, resilience, and user-centric building management.

Based on the functionality levels achieved and considering the specific climatic zone, the weighting factor defined by the SRI methodology was applied to calculate a score for each category hereafter reported.

TABLE I. CALCULATION OF THE SRI

Category	Score	
Energy efficiency	83.1%	It is related to the possibility to control the technical systems with BACS and energy management systems.
Energy flexibility and storage	80.2%	It reflects the capacity of RE-SKIN to manage energy loads dynamically and incorporate storage solutions, which is essential for demand-response and grid interaction.
Comfort	88.9%	The high score implies the effective use of smart systems to optimize indoor conditions (e.g., temperature, humidity).
Convenience	73.9%	The relatively low score in this domain is primarily due to the absence of automated window shading systems and programmable appliances scheduling.
Health, well-being and accessibility	100%	The maximum performance is reached, due to advanced monitoring and control systems that acquire information on the air quality. Users can use this data to manage the opening of windows.
Maintenance and fault prediction	85.1%	It reflects the use of predictive maintenance and diagnostics systems, indicating the possibility to assess the status of the technologies.
Information to occupants	90.6%	It suggests excellent provision of real-time and relevant data to occupants (e.g., energy use, indoor environmental quality, etc.), promoting user engagement and informed decision-making.

The results obtained for each category can be aggregated (according to the scheme reported in Fig.1) to obtain the smart readiness across the three key functionalities, as follows.

- *Energy efficiency optimisation* (84.1%): the building demonstrates strong integration of smart technologies for efficient management of energy and comfort, suggesting effective automation and control at the system level.
- *Occupant needs adaptation* (88.4%): the highest score among the three functionalities reflects a strong emphasis on user interaction and empowerment, such as individual control, feedback systems, and adaptability to occupant needs.
- *Energy grid adaptation and flexibility* (80.2%): though slightly lower than the previous ones, the score still indicates an excellent capacity for grid interaction, including demand response and load flexibility potential.

These results suggest a well-balanced smart readiness level, with particular excellence in user-oriented features and solid performance in both building management and grid responsiveness.

The aforementioned results can be further consolidated into a final Smart Readiness Indicator (SRI) equal to 84.2%. This score underscores the effectiveness of the RE-SKIN toolkit in enabling the transformation of an existing building into a smart and energy-efficient building.

VI. Conclusion

The preliminary findings of the RE-SKIN project highlight the effectiveness of smart retrofitting in transforming existing buildings into smart and energy-efficient assets. Achieving an overall SRI score of 84.2%, the case study in Milan demonstrates strong performance across key domains. Notably, it scored 88.4% in occupant needs adaptation, reflecting advanced user control and responsiveness; 84.1% in energy efficiency optimisation, indicating high system-level automation; and 80.2% in energy grid interaction, confirming its readiness for demand-side flexibility. These results highlight the comprehensive functionality of the RE-SKIN toolkit and its alignment with EU decarbonisation goals. Moreover, they confirm the utility of the SRI as a robust metric for evaluating smart capabilities, helping ensure that sustainability claims are backed by measurable performance rather than symbolic labelling.

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