

Bringing together renovation passport and smart readiness indicator certificate: A case study

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Abstract. The recently published EPBD sets an ambitious trajectory toward a zero-emission building stock, introducing instruments aimed at accelerating deep renovation and digitalization. Among these, the building renovation passport (BRP) supports staged, long-term renovation strategies tailored to individual buildings, while the smart readiness indicator (SRI) certificate assesses the ability of buildings to optimize energy efficiency, respond to occupants’ needs, and interact with the grid. Although conceived for complementary purposes, their combined potential has not been widely investigated yet. Within this framework, a methodology integrating BRP driven renovation planning and SRI assessment is proposed. Starting from an energy audit, the approach defines a tailored, staged renovation plan that includes both traditional and smart-solution measures. The associated benefits are evaluated in terms of primary and final energy use, greenhouse gas emissions, and costs. The procedure is tested on an Italian office building. Embedding smart measures within the renovation plan enables a clearer interpretation of SRI outcomes and highlights their influence on energy performance, flexibility, and comfort. Results show that coupling BRP and SRI certificate fosters a more holistic building assessment, enhances the robustness of staged renovation strategies, and supports informed decision-making for both owners and practitioners in line with the EPBD’s zero-emission ambition.

1 Introduction

The building sector plays a central role in the European Union’s climate and energy objectives, accounting for approximately 36% of final energy consumption and 33% of greenhouse gas emissions at EU level [1, 2]. Within this context, the revised Energy Performance of Buildings Directive (EPBD IV) promotes the transformation of the building stock towards a zero-emission target, reinforcing the need for both deep renovation and increased digitalization of buildings [1]. Buildings are no longer conceived as isolated energy consumers, but as active components of a decarbonized, flexible, and digitally enabled

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energy system, capable of adapting to occupants' needs and responding to external grid signals [3].

Although Energy Performance Certificate (EPC) remain the primary regulatory instrument for assessing building energy performance, its static nature limits its effectiveness in supporting long-term investment planning and operational optimization [4]. To address these limitations, the EPBD introduces complementary policy instruments that target different temporal and functional dimensions of building performance, the Building Renovation Passport (BRP) and the Smart Readiness Indicator (SRI) certificate.

The BRP is conceived as a building-specific, long-term planning instrument aimed at supporting staged deep renovation pathways. As defined in Annex VIII of EPBD IV, it provides a structured renovation roadmap tailored to the characteristics and current performance of a given building, including a sequence of renovation steps and their expected impacts in terms of energy savings, greenhouse gas emission reductions, costs, and EPC classes [1]. Previous studies highlight the potential of BRPs to overcome lock-in effects, support cost-effective staged renovations, and align renovation actions with maintenance cycles and owner priorities [5]. The SRI certificate, introduced by Commission Delegated Regulation (EU) 2020/2155 [6], represents, instead, the formal output of the SRI assessment and is intended to communicate the ability of a building to exploit smart technologies to optimize energy efficiency, adapt to occupants' needs, and interact with the energy grid [7]. Unlike the BRP, the SRI certificate does not aim to define renovation pathways, but provides a snapshot assessment of smart readiness at the date of issuance, potentially accompanied by recommendations for improvements.

Despite their different purposes, the BRP and the SRI certificate share a relevant common ground. Firstly, they both rely on a consistent building identification framework. Moreover, both instruments extend beyond purely energy-related indicators by addressing broader performance dimensions, including comfort, health, usability, and system operation [8]. While the BRP adopts a longitudinal perspective through a staged renovation roadmap, the SRI embeds a forward-looking dimension by explicitly acknowledging that changes to building systems affect smart readiness and require updates to the certificate [6].

The potential complementarity between renovation planning and smart readiness assessment has been explored in several initiatives investigating the integration of smart technologies into renovation roadmaps or the connection between EPCs, BRPs, and SRI outcomes [9, 10]. More recently, the role of digital building logbooks has been highlighted as a key enabler for interoperability and data consistency among EPCs, BRPs, and SRI certificates [11]. However, existing approaches often remain fragmented and do not propose an operational methodology that systematically links staged renovation planning with repeated SRI assessments.

There is still a lack of methodologies that explicitly embed smart-ready solutions within renovation roadmaps and use SRI outcomes to support the evaluation of renovation strategies over time. This gap limits the interpretability of SRI results in renovation contexts and reduces their potential contribution to informed decision-making aligned with the EPBD IV objectives and the EU's zero-emission goal. To address this gap, this paper proposes an integrated methodology combining BRP-driven renovation planning with SRI assessment. Starting from an energy audit, a tailored staged renovation roadmap is defined, combining traditional energy efficiency measures with smart solutions. The approach is applied to a real office building case study, and the impacts of each renovation step are assessed in terms of energy performance, costs, greenhouse gas emissions, and smart readiness. The results are discussed to highlight the benefits and limitations of coupling the BRP and the SRI certificate, and to identify methodological improvements to support more holistic and robust renovation strategies.

2 Methodology

The methodological framework proposed builds upon and extends the approach presented in Gorrino et al. [12]. Specifically, the workflow starts from an energy audit of a selected building, aimed at achieving a comprehensive knowledge of the building in its current state. Based on the information gathered from the energy audit – such as the condition of the existing building components and technologies, identified inefficiencies, etc. – a tailored, staged renovation plan is then developed, including both traditional and smart-solution measures. Finally, the benefits associated to each renovation stage are assessed according to the evaluations required by the BRP [1] and SRI methodologies [6].

The individual steps of the proposed approach are described in the following sections. In particular, the analysis of the building's current state is presented in Section 2.1, while the generation of the BRP and of the SRI certificate are detailed in 2.2 and 2.3, respectively.

2.1 Building's current state analysis

The analysis of the building in its current state starts with a preliminary contact phase, as outlined in EN 16247-1 [13], aimed at identifying objectives, needs, and expectations of the stakeholders involved. This phase is followed by an extensive data collection, intended to gather all data and information required to develop a tailored energy model. The collected data typically include climatic data, building geometry, building envelope thermal properties, technical building systems characteristics, and operating conditions. These data may be gathered from both onsite visits and analysis of existing data sources, such as project documentation, energy certificates, audit reports, and monitoring reports. Additionally, monitored performance data are required – where available – to calibrate the building energy model, a step that is highly recommended to ensure consistent results with the actual building thermal behaviour. In addition to the data and information required for the development and calibration of an energy model, the data collection procedure should be extended when the smart readiness indicator is envisaged. In particular, the SRI calculation requires the collection of data related to the presence and functionality level of automation, control, and automation systems, such as installed control strategies, availability of sensors, etc. Furthermore, information on connectivity and interoperability, including communication protocols, system integration across technical domains, and the ability to exchange data with external systems, must be considered.

Beyond information about the building in its current state that may derive from energy simulations, the identification of required maintenance and/or replacement due to any damage, inefficiency, or exceedance of technologies' useful life span, is essential to correctly address the development of the deep renovation roadmap of a building. Furthermore, this analysis also aims to identify potential energy efficiency measures to improve the building's energy performance and to ensure the compliance with established energy efficiency targets (e.g., nearly-zero energy building or zero-emission building).

2.2 Deep renovation roadmap development

The selection of energy efficiency measures should address the outcomes of the analysis of the building in its current state, explicitly considering also their economic feasibility. In fact, measures that are not cost-effective may be excluded, while those supported by economic incentives may be prioritised to ensure the economic feasibility of the interventions. Moreover, the combination of planned (or required) maintenance interventions with energy efficiency measures is encouraged as this approach may reduce additional costs as well as disturbances to the building occupants.

Finally, two key aspects must be considered in the definition of the energy efficiency measures packages and their timing (Fig. 1), i.e., the renovation steps. Firstly, required maintenances or replacements determine compulsory intervention timing. Secondly, the optimal sequencing of the energy efficiency measures should follow the “energy efficiency first” principle. Accordingly, priority should be given to improvements to the building passive components (e.g., thermal insulation of the building envelope), followed by measures that affect the building thermal energy needs (e.g., installation of solar shading devices), and lastly, by improvements of active components (e.g., replacement of the heat generators).

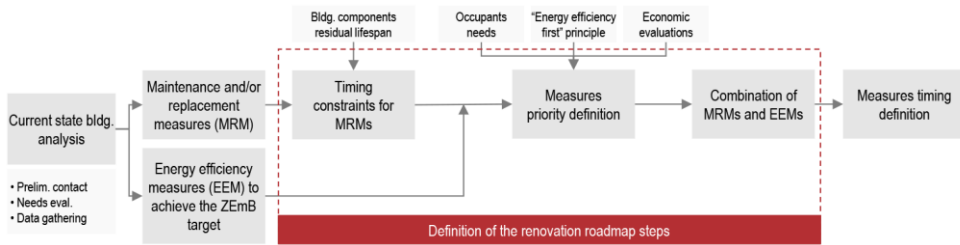


Fig. 1. Workflow of renovation roadmap development.

2.3 Building renovation passport generation

The renovation passport is the tool envisaged by the EPBD IV to provide building owners or managers with clear and structured information regarding the roadmap developed to improve a building’s performance over time. The key requirements for the renovation passport are defined in Annex VIII of the EPBD IV [1]. Among these, the mandatory information considered in this study include (i) the energy performance and the expected energy savings for each renovation stage, expressed in terms of primary and final energy, (ii) the estimated reduction in operational greenhouse gas emissions (GHG), (iii) the expected savings on energy bills, and (iv) the share of self-consumed renewable energy. In addition, the optional features selected include an indicative timeline for each renovation step and the estimated construction costs associated with each renovation step. These key performance indicators were selected as they are the ones currently applicable and available within the Italian legislative and regulatory context.

2.4 Smart readiness indicator certificate generation

The smart readiness indicator (SRI) enables the assessment, rating, and communication of a building’s capability to optimize energy efficiency, adapt its operation to occupants’ needs, and interact with the energy grid, thereby improving overall in-use performance. The methodology defined in the Commission Delegated Regulation (EU) 2020/2155 [6] is based on the evaluation of smart-ready services or planned (at design stage) in a building.

Within the proposed methodological workflow, the SRI assessment was carried out in accordance with Commission Delegated Regulation (EU) 2020/2155, adopting the “smart possible” approach defined by the European Commission [14]. Under this approach, the final SRI is penalized when services are not present, hence providing stimuli for upgrading existing buildings with additional (smart) services. For instance, penalizing the absence of a controlled ventilation system could create an incentive to install such a system to improve the SRI score. The calculation was carried out using the official SRI assessment spreadsheet tool provided by the European Commission, applying the detailed assessment approach

(Approach B). Standard weighting factors for impact criteria and key functionalities, as defined in the Regulation, were applied.

In accordance with Annex IX of Regulation (EU) 2020/2155 [14], the results of the SRI assessment are communicated to the stakeholders interested through an SRI certificate. In the present methodological workflow, the following contents were selected: (i) smart readiness class of the building, (ii) total smart readiness score, (iii) smart readiness scores for the three key functionalities, and (iv) smart readiness scores per impact criterion.

2.5 Integration of BRP and SRI certificate

From the Author's perspective, a key regulatory element supporting the integration of BRP and SRI certificate can be found in Annex IX of Commission Delegated Regulation (EU) 2020/2155 [6]. It specifies that the SRI certificate reflects the smart readiness of the building at the date of issuance and that any significant modification to the building or its systems would affect smart readiness, thereby requiring an update of the certificate. This provision implicitly recognizes a dynamic nature of smart readiness and establishes a conceptual link between building modifications and the evolution of SRI results.

Building on this premise, the proposed integration approach consists of explicitly linking the BRP and the SRI certificate by associating an SRI assessment with each renovation step defined in the renovation passport. In practice, the SRI is calculated for the building in its initial state and subsequently recalculated after the implementation of each renovation step, with the results represented within the graphical roadmap of the BRP. This approach preserves the methodological independence of the two instruments while enabling a coherent interpretation of how staged renovation measures influence not only energy performance but also smart readiness.

By embedding the evolution of SRI results within the BRP roadmap, the combined use of the two instruments allows stakeholders to visualize the progressive enhancement of both energy-related and smart-readiness characteristics over time. This integrated representation supports a more comprehensive and holistic assessment of renovation strategies and enhances the transparency and robustness of decision-making in line with the objectives of EPBD IV.

3 Application and results

3.1 Case study description

To test its applicability within the Italian legislative framework, the methodological approach presented in Section 2 was applied to an office building sited in Northern Italy, which was undergoing the design phase of an energy renovation at the time of the analysis. The selected building, built in the early 2000's, consists of an unconditioned underground story, two conditioned stories, and an attic, with a total net conditioned floor area of approximately 600 m².

The building envelope is characterized by cavity double-brick masonry with external thermal insulation, reinforced concrete slabs, and a timber roof. The average thermal transmittances (U -value) of the opaque envelope components are 0,75 W·m⁻²·K⁻¹ for external walls, 0,80 W·m⁻²·K⁻¹ for the roof, and 0,60 W·m⁻²·K⁻¹ for floors. The transparent envelope is instead characterised by double-glazed windows with aluminium and wooden frames, with an average U -value of 1,70 W·m⁻²·K⁻¹, and internal venetian blinds with manual operation (corresponding to functionality level 0 of the service DE-1 in the SRI assessment methodology).

The building is equipped with a 34 kW condensing boiler serving both space heating and domestic hot water production, the latter supported by a thermal storage system with a charging automatic control (service DHW-1b, level 1). The heating emission sub-system is characterised by radiators installed on insulated external walls, while the control sub-system consists in thermostatic valves (service H-1a, level 2) installed on each radiator and an external weather sensor regulating supply water temperature (service H-1c, level 1 / service H-1b, level 1); however, it does not allow for individual internal set-point temperatures nor for optimal start-and-stop operation. Furthermore, the distribution sub-system, characterised by variable speed pumps (service H-1d, level 3), is not thermally insulated.

Space cooling is provided by direct expansion heat pumps units (splits) installed and controlled in each space (service C-1a, level 2). The cooling generators are capable of varying their cooling capacity depending on the cooling loads (service C-2a, level 2). Mechanical ventilation is provided by air vents supplying a constant primary airflow (service V-1c, level 1) to each space, without any control regulation (service V-1a, level 0). Finally, the artificial lighting system consists exclusively of LED luminaires with manual on/off control (service L-1a, level 0 / service L-2, level 0).

In its current state, the building is not equipped with any automation and control systems; furthermore, occupant engagement and reporting functionalities is largely absent. Historical data are available for heating energy consumptions (service H-3, level 3), while electricity energy consumptions is monitored only at the whole-building level (service E-12, level 0). As a result, no specific historical data are available for cooling energy consumptions (service C-3, level 0).

3.2 Building's current state analysis

The preliminary contact phase took place in 2024 and allowed for the definition of the objectives, needs, and expectations of the building owner, identified as the main stakeholder involved in the renovation process. Specifically, it enabled the identification of the main priorities driving the development of the renovation roadmap, with particular emphasis on improving occupant comfort, ensuring regulatory compliance, and aligning renovation measures with planned maintenance and replacement needs.

The onsite visit took place along with the preliminary contact and allowed to gather all the relevant data and information about the building. Comprehensive documentation of the building design, as well as existing energy models developed for the building permit applications, was directly provided by the building owner. Monitored performance data were recorded in the months following the preliminary contact. In particular, natural gas consumptions were recorded on a weekly basis for approximately one year, covering both one heating season and one domestic hot water-only production period. In addition, actual schedules for internal heat gains (i.e., occupants, electrical equipment, and lighting), natural ventilation airflow rates, and electricity consumptions associated with office appliances were derived from questionnaires submitted to the occupants during the same monitoring period. These monitored performance data were used in the calibration process of the building energy model; this consisted of a two-step procedure focusing first on the calibration of the parameters relative to the building fabric and subsequently on those related to the technical building systems. The creation of the building energy model, the calculation methods adopted, as well as the calibration procedure, are detailed in detail in Gorrino et al. (2025).

The identification of the required energy efficiency measures was based on three complementary approaches. Firstly, the preliminary contact phase led to the decision to replace the existing windows and solar shading devices, as improving occupancy comfort emerged as a primary concern for the building owner. Secondly, the analysis of the residual lifespan of the building components (presented in Fig. 2) highlighted the need to replace the

existing heating and domestic hot water production generator, whose lifespan had expired approximately five years before the time of the present analysis. Furthermore, both opaque and transparent building envelope components were identified as approaching the end of their useful life, with a hypothetical lifespan ending in 2030. The residual lifespan analysis was conducted considering both standard values – according to EN 15459-1 [15] – and an evaluation of the actual degradation state. Finally, the energy audit confirmed the need to replace the existing boiler due to non-compliance with current Italian national requirements. Similarly, the analysis highlighted the need to increase the thermal insulation of the opaque building components in order to meet the regulatory requirements. Lastly, these measures should be complemented with the installation of a photovoltaic system to ensure the compliance with the minimum renewable energy share requirements.

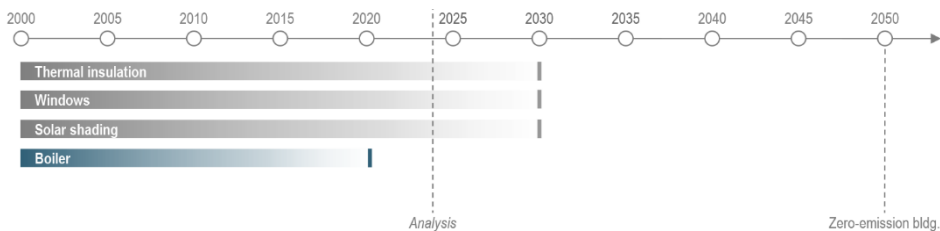


Fig. 2. Building components’ residual life span analysis.

In addition to the energy efficiency measures considered, the installation of an electric vehicle charging infrastructure is also accounted for as an enabling measure to ensure future regulatory compliance and to support the progressive electrification of building-related energy uses.

3.3 Renovation strategies

The renovation strategies identified through the current-state analysis include both traditional and smart solutions. These measures are described below, while their main characteristics are summarized in Table 1.

- **Windows replacement.** This measure consists of the replacement of the existing windows with low-e double-glazed units with wooden frames. The windows are equipped with an opening detection system connected to the heating system, allowing automatic shutdown when open windows are detected (service DE-2, level 1);
- **Solar shading installation.** This measure involves the installation of motorized internal solar blinds (or the replacement of the existing ones) characterized by automatic control based on incident solar radiation sensors data (service DE-1, level 2);
- **Opaque building envelope insulation.** This measure consists of the thermal insulation of the external walls through the installation of an external thermal insulation layer;
- **Heating generator replacement.** This measure consists of the replacement of the existing condensing boiler with an air-to-water heat pump serving both space heating and domestic hot water production. The technology selected is controlled by a multi-stage system capable of activating compressors according to the thermal load (service H-2b, level 1). This renovation measure is further supported by upgrades to the heating emission and distribution sub-systems. For the emission sub-system, the installation of individual room controls interconnected and integrated with the automation and control system (also implemented) is envisaged (service H-1a, level 3). For the distribution sub-system, a demand-based control of the supply/return water flow temperature (service H-1c, level 2) is implemented;

- Photovoltaic system installation. This measure involves the installation of a rooftop photovoltaic system coupled with on-site electrical storage (service E-3, level 4), together with automated electricity use management and optimization (service E-4, level 2). The selected technologies also provide feedback on electricity generation (service E-1, level 3), storage status (service E-11, level 3) and consumptions (service E-12, level 3), including forecasting and benchmarking functionalities;
- Automation and control system installation. This measure consists of the installation of a building automation and control system, including load-based optimal start-and-stop control of the heating and cooling systems (service MC-3, level 2), fault-detection functionalities (service MC-4, level 2), and the integration of a web platform enabling automated control and coordination between technical building systems (service MC-30, level 2). In addition, enhancements were considered for occupant engagement and reporting, specifically related to heating system performance (service H-3, level 4) and overall energy use (service MC-13, level 3);
- Electrical vehicle charging infrastructure installation. This measure consists of the installation of charging stations (service EV-16, level 1) in less than 9% of the existing parking spaces (service EV-15, level 2). The charging infrastructure is equipped with functionalities providing information to occupants on the electrical vehicles' charging status (service EV-17, level 1).

Table 1. Renovation strategies' characteristics.

Measure	Technology	Thermal characteristics	Smart features
Windows replacement	DGU with wooden frame	$U=1,2 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ $g\text{-value}=0,75$	Open/close detection control system (DE-2, level 1)
Solar shading installation	Motorized internal solar blinds	$g\text{-value}^*=0,17$ (*glass plus blind)	Automatic control based on sensor data (DE-1, level 2)
Opaque building envelope insulation	External insulation	$U^*=0,51 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ (*average)	-
Heating generator replacement	Air-to-water heat pump	$P=24 \text{ kW}$	Multi-stage control system (H-2b, level 1)
Photovoltaic system installation	Monocrystalline solar photovoltaic panels	$P=15 \text{ kW}$	Optimal energy use and feed to the grid (E-3, level 4 / E-4, level 2) Forecasting and benchmarking for generation (E-1, level 3), storage (E-11, level 3), and consumption (E-12, level 3)

3.4 Renovation roadmap

Based on the outcomes of the current-state analysis (Section 3.2) and the renovation measures defined in Section 3.3, a staged renovation roadmap was developed in accordance with the “energy efficiency first” principle, with the objective of achieving a zero-emission building by 2050. The proposed roadmap arranges the identified measures into three sequential steps, defined by combining technical coherence, component residual lifespans, and the building

owner’s priorities. The renovation steps are described below, while a graphical representation of the roadmap is presented in Fig. 3.

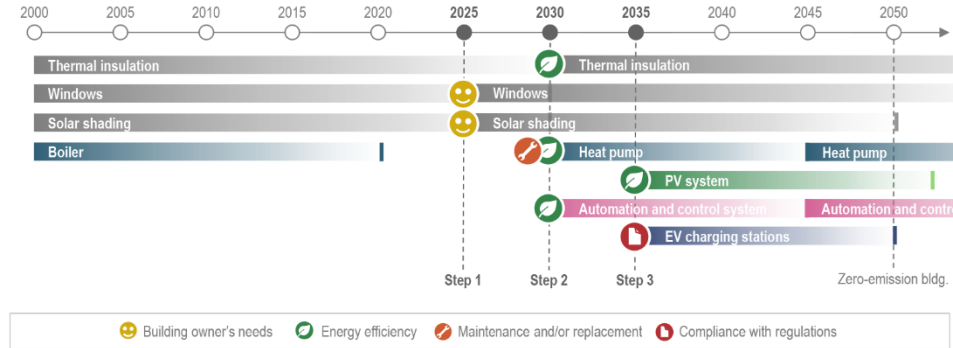


Fig. 3. Renovation steps representation.

Services		Level				
Code	Smart ready service	0	1	2	3	4
H-1a	Heat emission ctrl.			→	→	
H-1c	Control of distribution fluid temp. (supply or return air flow or water flow)		→	→		
H-1d	Control of distribution pumps in networks				→	
H-2°	Heat generator ctrl. (all except HP)					→
H-2b	Heat generator ctrl. (for HP)		→			
H-3	Report info. regarding heating system performance					→
H-4	Flexibility and grid interaction		→	→		
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric HP)					→
DHW-3	Report info. regarding domestic hot water performance					→
C-1a	Cooling emission ctrl.					→
C-1c	Control of distribution network chilled water temp. (supply or return)					→
C-2a	Generator ctrl. for cooling					→
C-3	Report info. regarding cooling system performance					→
C-4	Flexibility and grid interaction					→
V-1a	Supply air flow ctrl. at the room level					→
V-1c	Air flow or pressure ctrl. at the air handler level					→
V-2d	Supply air temp. ctrl. at the air handling unit level					→
V-6	Reporting info. regarding IAQ					→
L-1a	Occupancy ctrl. for indoor lighting					→
L-2	Control artificial lighting power based on daylight levels					→
DE-1	Window solar shading ctrl.		→	→		
DE-2	Window open/closed ctrl., combined with HVAC system		→	→		
DE-4	Reporting info. regarding performance of dynamic building envelope systems					→
E-2	Reporting info. regarding local electricity generation					→
E-3	Storage of (locally generated) electricity					→
E-4	Optimizing self-consumption of locally generated electricity					→
E-11	Reporting info. regarding energy storage					→
E-12	Reporting info. regarding electricity consumption					→
EV-15	EV Charging Capacity					→
EV-16	EV Charging Grid balancing					→
EV-17	EV charging info. and connectivity					→
MC-3	Run time management of HVAC systems					→
MC-4	Detecting faults of TBSs and providing support to the diagnosis of these faults					→
MC-13	Central reporting of TBS performance and energy use					→
MC-30	Single platform for automated ctrl. and coordination between TBS					→

Current state
 Renovation step 1 – 2025
 Renovation step 2 – 2030
 Renovation step 3 – 2035
 No changes
 Upgrade
 New smart ready service

Fig. 4. Smart ready service functionality levels evolution across the renovation steps.

- Renovation step 1 (2025). Although 2030 was identified as the reference year for replacing major building components, the building owner's primary concern regarding occupant comfort led to the anticipation of window replacement with respect to the thermal insulation of the opaque building envelope. Consequently, window replacement, combined with the upgrade of the solar shading devices, was scheduled for 2025. These measures have already been implemented;
- Renovation step 2 (2030). Although the existing boiler system, installed in 2000, is due for replacement, this measure was postponed in order to align it with the renovation of the opaque building envelope, as the boiler still remains operational. Accordingly, the enhancement of the external walls insulation and the replacement of the heating and domestic hot water generator were planned for 2030. This coordinated approach aims to minimize construction time and associated operational disruptions, as well as to avoid systems inefficiencies due to improper sizing of the heat generator. To maximize energy efficiency, these measures are combined with the installation of the building automation and control systems, as described in Section 3.3. This renovation step is mainly driven by the need to improve energy efficiency while addressing mandatory maintenance and replacement requirements;
- Renovation step 3 (2035). The final planned intervention involves the installation of a rooftop photovoltaic system, scheduled for 2035. This step is complemented by the deployment of the electrical vehicle charging infrastructure, planned concurrently in order to exploit on-site electricity generation also for vehicle charging. While uncertainties increase over longer planning horizons, this step remains essential to achieve the 2050 zero-emission target and it is primarily driven by the need to enhance energy efficiency and ensure compliance with Italian and European regulatory requirements.

A graphical representation of the evolution of smart-ready service functionalities, as defined by the SRI assessment methodology, across the renovation steps is presented in Fig. 4.

3.5 Evaluation of the proposed renovation steps

The evaluation of the steps proposed in the developed renovation roadmap is described in this section in terms of primary and final energy uses, greenhouse gas emissions, costs, and smart readiness evaluation. A graphical representation of the integration of BRP and SRI certificate is presented in Fig. 5.

At the current state, the building is characterised by average energy performance, due to the installed building components (both envelope and technical building systems) with an acceptable energy efficiency level. However, annual energy costs are relatively high, combined with the absence of on-site renewable energy generation and self-consumption. From a smart readiness perspective, the SRI score is very low (16,1%), corresponding to the lowest SRI class. This result reflects the limited presence of automation, control, and monitoring functionalities, with smart readiness score driven mainly by basic energy efficiency (impact criterion score of 35,5%) and comfort-related (impact criterion score of 28,8%) services.

The first renovation step, focused on window replacement and solar shading installation, leads to only marginal improvements in energy performance (non-renewable energy performance decrease of -2%, from 68,1 to 66,8 kWh·m⁻²) and operating costs (decrease of -2%), despite the consistent investment costs. This outcome is consistent with the specific scope of the intervention of improving occupants' comfort condition. Nevertheless, the SRI assessment reveals a modest improvement in total score, which increases from 16,1% to 17,6%. This improvement is primarily associated with enhancements in comfort (from 28,8 to 34,5%) and convenience (from 11,6 to 20,8%), driven by the introduction of basic control

functionalities related to windows and solar shading. As a consequence, the user-related key functionality shows the most noticeable increase (from 18,0 to 21,5%). However, the SRI class remains unchanged, indicating that isolated improvements in building automation at component level are insufficient to alter the smart readiness classification.

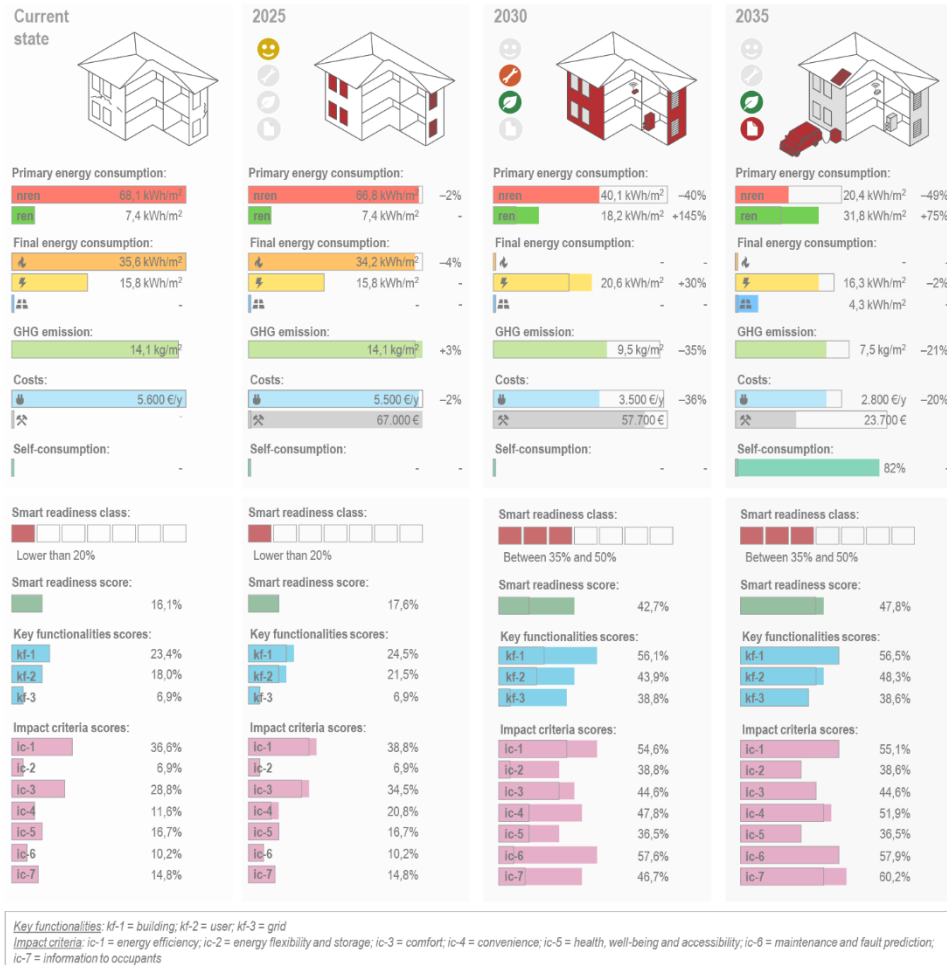


Fig. 5. Graphical representation of the integration of BRP and SRI certificate.

The second renovation step represents a turning point in both energy and smart-readiness performance. The combined effects of opaque envelope insulation, heat generator replacement with a heat pump, and the introduction of advanced automation and control systems lead to a substantial reduction in non-renewable primary energy performance (-40%) and a significant decrease in annual energy costs (-36%), compared to the previous renovation step. Moreover, the reduction in greenhouse gas emissions confirms the effectiveness of this step from a decarbonization perspective (from 14,1 to 9,5 kg·m⁻²). This step has the most noticeable impact on SRI as well, with the total score rising to 42,7% and the SRI class improving by two levels. This result underscores the central role of building automation and control systems in determining smart readiness. In particular, the strong increase in energy flexibility (+31,9%), convenience (+27,0%), maintenance and fault detection (+47,4%), and information to occupants (+31,9%) demonstrates that the renovation

measures considered in this renovation step enable benefits that extend well beyond energy efficiency alone.

Finally, the third renovation step, involving the installation of a photovoltaic system, further enhances the building's energy performance by significantly reducing non-renewable primary energy consumption (-49% , from $40,1$ to $20,4 \text{ kWh}\cdot\text{m}^{-2}$) and enabling a high share of electricity self-consumption (from 0 to 82%), compared to the previous step. However, the SRI assessment reveals that the impact of this step on smart readiness is comparatively limited. Despite the high functionality levels associated with the installed technologies, the total SRI score increases only marginally (from $42,7$ to $47,8\%$), remaining within the same SRI class.

4 Conclusions

This study investigated the combined use of the building renovation passport and the smart readiness indicator certificate as complementary instruments for the assessment and planning of building renovation strategies.

The results confirm that coupling the BRP and the SRI certificate enhances the robustness of staged renovation strategies and supports informed decision-making for both building owners and practitioners. The BRP effectively structures renovation measures over time, integrating energy efficiency improvements with maintenance planning and economic considerations, while the SRI highlights the added value of digitalization and automation beyond energy savings alone. This combined perspective is particularly relevant in the context of the EPBD recast, which simultaneously promotes deep renovation and smart-ready buildings as key enablers of the transition towards a zero-emission building stock.

However, the analysis also revealed methodological challenges in achieving full coherence between improvements in energy performance and corresponding changes in SRI scores. This behavior emerges, for example, in the last renovation step, where substantial reductions in non-renewable primary energy consumption lead only to marginal changes in the SRI score. In this respect, deriving SRI's weighting factors for domains and services based on their relative contribution to a building's energy balance could allow the SRI calculation to better reflect the actual importance of different services in the overall energy use of the building. Therefore, the "energy balance" approach [14] represents a promising avenue for improving the consistency between energy and smart-readiness assessments. In addition to structural characteristics of the SRI framework, this mismatch may also be influenced by current limitations of commercially available building energy simulation tools. In practice, these tools often lack the capability to explicitly model advanced and adaptive control strategies, making it difficult to quantitatively assess the impact of automation and control systems on building energy performance. As a result, the energy benefits associated with smart control solutions may be only partially captured in energy simulations, contributing to discrepancies between energy performance indicators and SRI outcomes.

In conclusion, future research could investigate the impact of adopting more detailed approaches for the definition of SRI weighting factors, rather than deriving them from EPC calculations. This would represent a further and important step towards a deeper integration of the instruments introduced by the EPBD, supporting a more consistent, building-specific, and holistic assessment of energy performance, smart readiness, and decarbonization pathways.

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