POBOLJŠANJE STRATEGIJA ENERGETSKE EFIKASNOSTI I FLEKSIBILNOSTI KORIŠĆENJEM INDIKATORA INTELIGENCIJE ZGRADE
Uporedna studija slučaja u Sloveniji i Hrvatskoj

REFINING ENERGY EFFICIENCY AND FLEXIBILITY STRATEGIES USING THE SMART READINESS INDICATOR
A comparative case study in Slovenia and Croatia

Boris SUČIĆ[1*], Ružica JURJEVIĆ[2], Marko BIŠĆAN[2], Gašper STEGNAR[1]
[1] Jožef Stefan Institute - Energy Efficiency Centre, Ljubljana, Slovenia
[2] Energy Institute Hrvoje Požar, Zagreb, Croatia

https://doi.org/10.24094/kghk.023.039

Energetska i resursna efikasnost u kombinaciji sa obnovljivim izvorima energije čine okosnicu budućeg održivog razvoja u bilo kom sektoru. U tom kontekstu, smanjenje potrošnje energije u zgradama u kombinaciji sa širokom integracijom obnovljivih izvora energije (OIE) u urbanim sredinama vitalni su elementi za dugoročnu tranziciju ka društvu sa neutralnim emisijama ugljenika. EU je identifikovala zgrade kao cilj koji u kom je poboljšanje energetske efikasnosti donosi najviše efekata i kvantifikovala je značajan potencijal za uštedu energije povezan sa investicijama u infrastrukturu i opremu. Izračunavanje indikatora sposobnosti zgrade da prilagođava svoje sisteme kao odgovor na spoljne podsticaje (Smart Readiness Indicator – SRI) uključuje prikupljanje podataka iz različitih aspekata dizajna, rada i korišćenja zgrade. Tokom procesa prikupljanja podataka, SRI revizor je morao da izvuče korisne podatke iz crteža, dnevnih listova, unapred definisanih očitavanja iz različitih sistema nadzorne kontrole i prikupljanja podataka (SCADA), i iz komunikacije sa energetskim i/ili menadžerima objekata, stanarima i vlasnicima zgrade. Pravilna interpretacija rezultata SRI ključna je za identifikaciju potencijala energetske efikasnosti i fleksibilnosti. Ovaj rad predstavlja uporednu studiju slučaja o primeni SRI u Sloveniji i Hrvatskoj, sa fokusom na izdvajanje mera energetske efikasnosti i fleksibilnosti. Pored toga, ovaj rad daje opšte elemente kodeksa ponašanja za ocenu SRI. Ovi elementi kodeksa ponašanja za ocenjivanje SRI treba da se smatraju indikatorom kvaliteta za klijente (vlasnike zgrada, menadžere objekata, korisnike zgrada, itd.) o tome šta treba da očekuju i zahtevaju od revizora SRI kako bi postigli očekivane koristi. Pored toga, kritički su razmotrene snage i slabosti revizije SRI i njena uloga u procesu donošenja odluka, posebno u izboru optimalnog scenarija energetske obnove.

Ključne reči: *indicator inteligencije zgrade; energetska efikasnost; upravljanje zahtevima; obnovljivi izvori energije; system upravljanja energijom*

Energy and resource efficiency in combination with renewable energy sources constitute the backbone of future sustainable development in any sector. In this context, the reduction of energy consumption in buildings combined with the wide integration of renewable energy sources (RES) in urban areas are vital elements for the long-term transition towards a carbon-neutral society. The EU has identified buildings as the most promising target for improving energy efficiency and has quantified a significant energy-saving potential associated with infrastructure and equipment investments. The calculation of the Smart Readiness Indicator (SRI) involves data collection from various aspects of a building's design, operation, and usage. During the data collection process, the SRI auditor had to extract useful data from drawings, daily log sheets, predefined readings from various Supervisory Control and Data Acquisition systems (SCADA), and from the interview with the energy and/or facility managers, building occupants, and owners. Proper interpretation of SRI scores is crucial for the identification of the energy efficiency and flexibility potentials. This paper presents a comparative case study on the application of SRI in Slovenia and Croatia, focusing on the extraction of energy efficiency and flexibility measures. Additionally, this paper provides general elements of the code of conduct for the smart readiness rating. These elements of the code of conduct for smart readiness rating should be considered as a quality indicator for clients (building owners, facility managers, building users, etc.) on what they should expect and require from SRI auditors in order to achieve expected benefits. Additionally, the strengths and weaknesses of SRI auditing and its role in the decision-making process, specifically in the selection of the optimal energy-renovation scenario, were critically reviewed.

Key words: *smart readiness indicator; energy efficiency; demand side management; renewable energy sources; energy management system*

[*] Corresponding author, e-mail: boris.sucic@ijs.is

1 Introduction

The key objective of the energy-performance assessment of buildings is to provide the necessary background on energy consumption, to support the extensive energy renovation of buildings and to enable informed and cost-effective decisions to be made. The European Union (EU) has adopted policies and programmes to promote general energy efficiency since the 1970s and since the 1980s focusing on buildings [1]. The EU framework for energy and climate envisages a future where Europe's energy system becomes decentralized, decarbonized, and community-led [2]. There is an increasing demand for energy-efficient solutions and intelligent systems in buildings that cannot only enhance comfort and convenience, but also reduce energy consumption and the environmental impact. Although theory often cites the so-called universally applicable solutions, practical experiences confirm that it is not possible to expect the successful implementation of the initially defined energy efficiency plans without the proper decision-support indicators. The ambitious plans to increase the share of renewable energy sources (RES) and enhance energy efficiency in buildings necessitate ongoing advancements in policy and research. These advancements should focus on developing new and efficient approaches and instruments for implementation. To improve building efficiency in terms of energy and other resources, a systematic approach is essential. This approach should extend beyond the current common practice of monitoring and targeting energy consumption.

One innovative solution that has emerged in this context is the Smart Readiness Indicator (SRI). The SRI was introduced by the European Union in 2018 while amending the Energy Performance of Buildings Directive (EPBD) [3] and its subsequent regulations (Delegated Regulation 2020/2155 [4] and Implementing Regulation 2020/2156 [5]), triggering an optional implementation phase by the EU countries. Therefore, the EU countries might decide to implement the SRI on their territory for all buildings or only for certain categories of buildings. It is important to underline that under the amended EPBD, the European Commission was mandated to develop a common framework for the SRI. Following this, a series of studies were carried out to develop the concept of the SRI and create a methodology for its calculation [6-8]. At the moment the SRI is optional and a voluntary EU scheme that will be used to assess the technological readiness of buildings to interact with their occupants, to interact with connected energy grids and to operate more efficiently. The concept of the SRI and proposed seven impact criteria are illustrated in Figure 1.

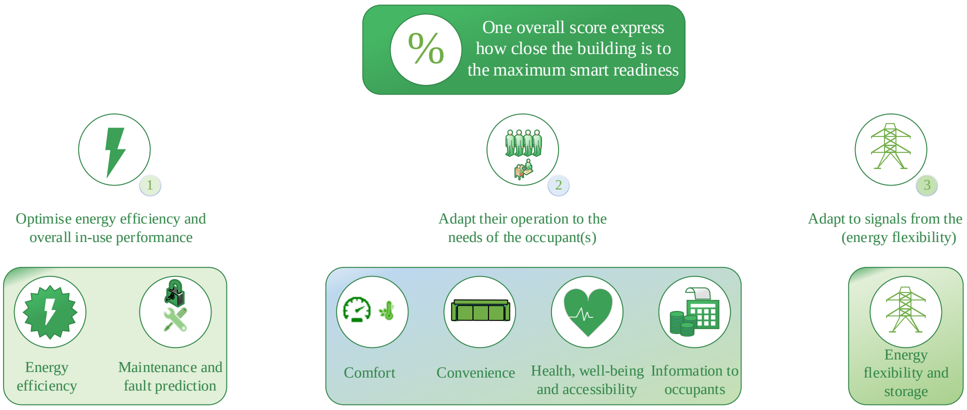

Figure 1: Concept of the SRI and seven selected impact criteria [6]

In a world of unexpected crisis, uncertain energy prices and rapid changes in the power sector, buildings will also have to participate in initiatives providing local flexibility and supporting power system with auxiliary services. Unfortunately, several obstacles must be overcome when it comes to actual application of SRI. According to [9], the weighting factors introduced in the current methodology need some amendments to cover all requirements in the service buildings in the Mediterranean conditions. Kourgiozou et al. [10], proposed a new method for estimating the smart readiness of building stock data using display energy certificate data which has potential to be a solution to the large-scale processing of building information across multiple complex buildings. Spudys et al. [11], demonstrated the application of digital twin principles for the operational energy assessment of buildings, highlighting the significance of adapting the energy assessment of buildings to state-of-the-art practices for digital assessment, such as smart sensors, real-time measurements, and digital twins. This approach marks a significant step forward compared to merely classifying building energy efficiency using the Energy Performance Certificate (EPC). When it comes to an active consumer participation in smart energy systems, optimization can be used in the area of active user integration for the following purposes: (i) minimize the energy demand based on user preferences and (ii) demand side management, where the goal is that building energy consumption is adjusted/shifted in an optimal way based on external signals such as price signals while maintaining the consumer's needs and comfort levels [12]. The readiness of a building's energy systems and appliances to participate in demand-side management is an important element of the SRI rating process. However, when it comes to energy flexibility in buildings, in many countries there are still significant barriers mainly related with the distribution level barrier, and barriers to market entry for demand response, and it is clear that a systemic approach is required for effective exploitation of existing potentials [13]. Also, this opens a door for creation of additional indicators related with energy flexibility, especially those capturing the cost of providing the energy flexibility as this requires a deviation from the optimal control in terms of thermal comfort and economic benefits based on a financial contract between the building owner and the aggregator or grid operator [14].

The research work described in this paper was inspired by the recommendations proposed by Apostolopoulos et al. [15], which recommended focusing future studies on analyzing the impact of smart retrofits on potential energy savings. Conducted research work includes a comparative case study on the application of SRI in Slovenia and Croatia, focusing on the extraction of energy efficiency and flexibility measures. Special attention is given to the softer elements, such as collaboration among building owners, energy experts, facility managers, and utility staff, which are crucial for identifying energy efficiency and flexibility measures and ensuring overall success. In the context of relatively small powers systems like Slovenian or Croatian, the very important challenge that faces the future development of energy efficiency and flexibility in buildings, is how to stimulate future growth in order to achieve set targets and to enable a smooth transformation of entire sector towards a carbon neutral economy. One of the assumptions of this research work is that future energy efficient and flexible buildings will be the backbone of the energy transition towards carbon neutral economy. This paper also evaluates the integration of various methods, such as energy auditing and energy-performance assessment, with SRI rating for analyzing energy efficiency and flexibility in a selected group of buildings. It outlines general elements of a code of conduct for smart readiness rating and critically reviews the strengths and weaknesses of SRI auditing, especially its role in decision-making and selecting optimal energy-renovation scenarios.

2 Methodology

The SRI is a comprehensive indicator, considering a wide range of factors and providing a holistic picture of a building's smart readiness. A key part of the methodology for the calculation of the SRI is data collection. Accurate data is needed for a range of variables, including the building's technical systems, its use and occupancy, the external conditions it faces, and the control systems in place. This information is crucial for accurately calculating the SRI. Data can be in through several ways, including site visits, interviews with owners, occupants, energy or building managers, and automated data collection systems such as smart meters or building-energy-management systems. It can be also combined with energy audits or energy-performance assessment.

In practice, the calculation of SRI involves a technical assessment of several aspects of a building, including its installed building-automation-and-control technologies, energy-management capabilities, and readiness to manage and optimize its consumption and generation of renewable energy. The SRI audit, if conducted in a systematic and comprehensive manner, has a potential to identify energy efficiency and flexibility measures that can improve the overall performance of a building. It should be carried out through a sequence of activities aimed at determining current energy performance, the level of smartness, and identifying opportunities to improve performance and reduce costs. In presented research work, recommendations from EN 16247 – 1 [16] and EN 16247 – 2 [17] have been followed and an overview of this process in given in Figure 2.

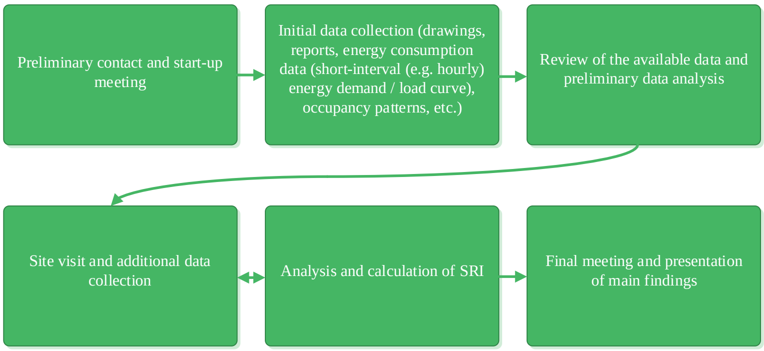

Figure 2: Main elements of the SRI auditing based on EN 16247 – 1 [16] and EN 16247 – 2 [17]

In the case that during the analysis and the calculation of the SRI crucial data are found to be missing, it might be necessary to repeat or supplement some of the activities. The SRI auditing requires accurate and comprehensive data to produce reliable results and recommendations. During the review of the available data and a preliminary data analysis, the SRI auditor must go through the data that was collected during the preliminary phase and identify which data are missing and determine how these data will be collected during the site visit. In the case that a lack of crucial data is identified during the analysis and calculation process, a plan for additional data collection should be created, and this may involve revisiting the building site, reviewing the building documentation and interviewing the building operators or occupants. To prevent similar issues in the future, data-collection tools or procedures must be constantly updated. It is important to note that while it can be time-consuming and potentially costly to collect missing data after a site visit, it is often more costly in the long run to make decisions based on incomplete or inaccurate data. Ensuring that the SRI rating is as accurate and complete as possible can help to ensure that the building's energy efficiency, smartness, flexibility and sustainability performance are accurately assessed and that the most effective improvement measures are identified and presented to the owner/decision maker.

During the site visit the auditor has to check all the data extracted from drawings and previous reports, such as its age, size, construction materials, insulation levels, and gather other missing data about the building, such as HVAC systems, lighting systems, types of appliances used, occupancy rates, hours of operation, and how different spaces within the building are used. This is a crucial step as it sets the base for further calculations and analyses. In order to be able to propose sound energy-efficiency and flexibility-improvement measures, the auditor should collect data on energy consumption, typically from utility bills or smart-meter readings. This includes electricity, gas, and any other forms of energy used in the building. Information about any smart systems and controls installed in the building must also be collected. This includes smart thermostats, smart lighting systems, energy-management systems, and any other technology that contributes to the building's smart readiness. This data is crucial for calculating the SRI, as the indicator is intended to measure a building's capacity to use new technologies and systems for managing its energy use more efficiently and flexibly. The majority of this data can often be collected from the building's energy-management system or various control systems, if they are present.

Once the necessary information about the building and its operation has been collected, these data can be used to calculate the SRI. For the calculation of the SRI, a standard SRI-assessment package comprising a calculation sheet is used. The SRI-assessment package is available free of charge and it can be provided upon request by filling out a form available at the EUSurvey service web site [8]. In the framework of the presented research work, a detailed assessment method (Method B) was used for the calculation of SRI for the selected buildings. Detailed descriptions of this method is given in [18]. Also, the general framework for the contribution of building automation, controls and building management on the energy performance of buildings is given in European Standard EN ISO 52120-1 [19]. The SRI service catalogue is mainly a Building Automation and Control Systems (BACS) checklist that was derived from this standard.

The SRI auditor must provide comprehensive comments on the assessed systems and components. Proper interpretation of the SRI scores is crucial for identifying the energy-efficiency and flexibility potentials. High SRI scores generally mean the building has substantial smart-technology integration. However, there might be a gap between the available technology and its effective utilization for energy efficiency and grid flexibility. Auditors should be aware that even buildings with advanced smart systems might not be utilizing them to their full potential. During the SRI audit the auditors must identify the most important systems (for example HVAC, lighting, server rooms, etc.) and check whether they are properly calibrated, configured and operated. Also, high SRI scores might indicate a building's potential to integrate with RESs. However, this can also be misleading, and auditors should identify realistic opportunities to connect to local solar or another renewable-energy generation asset (for example biomass for heating or heat pumps for heating/cooling). This not only saves energy but also offers flexibility potential in terms of energy storage and demand response. Buildings with heat pumps or other bigger, controllable electric loads are likely primed for demand-response initiatives. Large electrical loads can adjust their energy use in real-time based on grid signals, thereby aiding grid stability and benefiting from cost savings. Also, auditor should never forget to analyse the building's capacity to shift heating or cooling loads to times when energy demand is low, thus reducing peak load and energy costs. In this context the auditor should always explore opportunities for battery or heat storage, allowing the building to store locally generated renewable energy during off-peak times and use it during peak times.

A low SRI score could indicate that the building lacks the technology, systems, or practices that facilitate smart operation. This can also be an indication of untapped potential and should be systematically investigated. For buildings with a lower SRI score, the auditor should identify potential upgrades to smart devices or systems that can improve both energy efficiency and flexibility. This can include smart thermostats, automated lighting, or energy-efficient HVAC systems with variable-frequency drives (VSD). At present, the VSD application represents the greatest potential for reducing electricity consumption by replacing the traditional regulation of pressure and fluids flows by throttling, by adjusting the vanes and blades of pumps and fans and by by-passing lines.

3 Results and Discussion

This chapter presents results of SRI auditing and assessment of the energy performance of different buildings in Slovenia and Croatia. In the scope of the conducted research work, 7 different buildings were analysed, 2 in Croatia and 5 in Slovenia (Figure 3). The selection includes buildings with different uses, sizes, energy performance, spatial and constructive characteristics, aiming to cover the diverse possibilities of the building stock in tertiary sector. All 7 buildings were identified as non-residential buildings. The majority of them, 4 out of 7, belong to the education sector (1 in Croatia and 3 in Slovenia).

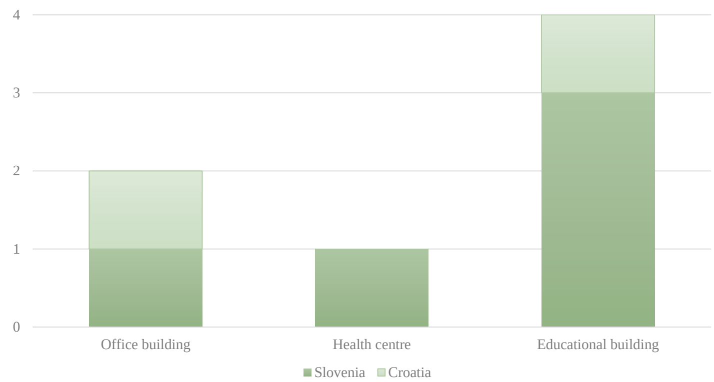

Figure 3: Brief overview of the selected buildings

Selected builindgs provided a real testing environment with the full support of owners and maintenance staff and open access to all requested data necessary for the SRI and sustainability rating. According to [20], this represents an opportunity with unusual research access. The data used for the SRI calculation was derived from energy audits, energy consumption data and interviews conducted with the building owners, facility and energy managers. Methods B with default domain weightings, along with tool variant 4.5, was utilized to assess the smart readiness of each building. During the site visit and in communication with the energy and facility managers, the smart features present in each building were identified. These can include intelligent energy-management systems, automation and control systems, renewable energy integration, smart lighting, HVAC systems, and sensor networks. In all the assessed buildings, energy performance was also evaluated. The analysis considered factors such as energy-consumption patterns, implemented energy-efficiency measures and the utilization of renewable energy sources. By employing this approach, a comprehensive evaluation was conducted to determine the level of smart readiness of the buildings and identify areas for potential improvement. Table 1 shows the buildings that were selected for the analysis.

Table 1. Overview of analysed Croatian and Slovenian buildings

Building Code	Building type	Status
HR-01	Office building	Existing, after renovation
HR-02	Educational building - kindergarten	Existing
SI-01	Educational building – primary school	Existing, not-renovated
SI-02	Health centre	Existing, after renovation
SI-03	Offices	Existing, after renovation
SI-05	Educational building – primary and secondary school	Existing, not-renovated
SI-08	Educational building – primary school	Existing, not-renovated

The building HR-01 is an office building and all the domains present, and they have been evaluated. The main issues identified in the heating system include the absence of occupancy detection and variable-speed pump control, which affect its efficiency. Similarly, in the domestic hot water (DHW) production, there is a lack of integration with renewable energy sources and no provision for demand-based supply, leading to inefficiencies. The cooling system also faces challenges with the absence of occupancy detection and variable-speed pump control, impacting its performance. The ventilation system lacks advanced air-quality sensors and load-dependent compensation, hampering its effectiveness. Furthermore, the lighting system lacks central control, and the window shading controls are manual. There is no on-site electricity generation, and information regarding electricity consumption is not shared. The electric vehicle (EV) charging infrastructure is rudimentary and lacks optimization capabilities. Additionally, monitoring-and-control systems are deficient in fault predictions and demand forecasting. Overall, there is a lack of information available to occupants and facility managers regarding the building's systems. Furthermore, the low grid flexibility observed is primarily due to the limitations imposed by current legal restrictions, which offer minimal opportunities for monetizing flexibility through investment and savings.

The building HR-02 has most of the domains present, and they have been evaluated. The main issues identified in the heating system include the absence of room temperature control, occupancy detection, variable-speed pump control, and a central monitoring-and-control system. In the DHW production, there is no integration with renewable energy sources and no provision for demand-based supply, with no centralized system in place. The cooling system is addressed through local split systems. Unfortunately, there is no ventilation system installed. In terms of lighting, there is no central control, dimming capability, or occupancy detection. Window shading controls are manual. The building does not have on-site electricity generation, and information regarding electricity consumption is not shared. Photovoltaic (PV) systems are not feasible due to legal restrictions. Moreover, there is no EV charging infrastructure available. Monitoring-and-control systems are almost non-existent, leading to a lack of information for occupants and facility managers. The building lacks grid flexibility, primarily due to the limitations imposed by current legal restrictions, which make it nearly impossible to monetize flexibility through investments and savings.

The building SI-01 belongs to the educational sector and lacks cooling, ventilation, a dynamic building envelope and EV charging domains. All other domains are present and they have been evaluated. The building has not undergone renovation, and the installed systems are outdated and energy inefficient. New LED lighting has been installed only in the hallways, while the rest of the building still uses energy-inefficient lighting. An energy-accounting system has been implemented to monitor energy consumption, but no additional energy-consumption measurements are available apart from the official ones. Regarding the building's smart systems, it has been identified that the existing heating system relies on fossil fuels and lacks occupancy-detection sensors and variable-speed pump control, which affects its efficiency. The same issues apply to the DHW. There is also a lack of integration with renewable energy sources and no provision for demand-based supply. Additionally, the lighting system lacks central control, and window shading controls are not present. On-site renewable-electricity generation is absent, and information regarding electricity consumption is not shared. Overall, occupants and facility managers have limited information available regarding the building's systems. Grid flexibility does not exist, primarily due to current legal restrictions, offering minimal opportunities for monetizing flexibility through investment and savings.

The building SI-02 belongs to the health sector and almost all domains are present (EV charging is missing), and they have been evaluated. The building underwent comprehensive energy renovation in 2019. A modern energy-management system is installed, but it lacks demand/response functionalities and feedback to the occupants. The main issues identified in the HVAC system include the absence of occupancy detection which affect its efficiency. Similarly, in the DHW production, there is a lack of integration with RES and no provision for demand-based supply, leading to inefficiencies. Furthermore, the lighting system lacks central control, and the window shading controls are manual. There is no on-site electricity generation, and information regarding electricity consumption is not shared.

The building SI-03 is an office building and almost all domains are present (ventilation, dynamic building envelope and EV charging are missing), and they have been evaluated. The building underwent comprehensive energy renovation in 2013. A modern energy-management system is installed but it lacks demand/response functionalities and feedback to the occupants. The main issues identified in the HVAC system include the absence of occupancy detection, which affects its efficiency. Similarly, in the DHW production, there is a lack of integration with RESs and no provision for demand-based supply, leading to inefficiencies. Furthermore, the lighting system lacks central control, and the window shading controls do not exist. There is no on-site electricity generation, and information regarding electricity consumption is not shared with occupants. As part of the renovation roadmap, it is proposed that the first energy-efficiency measure should be an upgrade of the existing energy-management system with demand/response functionalities and feedback to the occupants. The subsequent steps would involve the renovation of the lighting system, implementation of advanced control systems, reconstruction of the existing HVAC system, which will include advanced CO_2-based ventilation with occupancy detection, installation of a PV system, and the installation of a battery system for the peak-load management, emergency power supply and optimising of the PV production.

The building SI-05 is under cultural heritage protection and belongs to the educational sector. It lacks cooling, ventilation, a dynamic building envelope, EV charging, and monitoring and control domains. All other domains are present and have been evaluated. The building has not undergone renovation, and the installed systems are outdated and energy inefficient. Monitoring-and-control systems are not present, leading to a lack of information for occupants and facility managers. No additional energy-consumption measurements are available apart from the official ones. Regarding the building's smart systems, it has been identified that the existing heating system relies on fossil fuels and lacks occupancy-detection sensors and variable-speed pump control, which affects its efficiency. The same issues apply to the DHW production. There is also a lack of integration with RESs and no provision for demand-based supply. Additionally, the lighting system is outdated and lacks central control, and window-shading controls are not present. On-site renewable electricity generation is absent, and information regarding electricity consumption is not shared. Overall, occupants and facility managers have very limited information available regarding the building systems. The building SI-05 requires major energy renovation, and the main systems need to be replaced.

The building SI-08 belongs to the educational sector and almost all domains are present (only EV charging is missing), and they have been evaluated. The building underwent comprehensive energy renovation in 2022. Unfortunately, an energy-management system is not installed. There is no on-site electricity generation, and information regarding electricity consumption is not shared. The building SI-08 requires an additional upgrade of its energy systems, which will enable additional energy and cost savings. As part of the renovation roadmap, it is proposed that the first energy-efficiency measure should be the installation of a modern energy-management system with demand/response functionalities and feedback to the occupants. The subsequent steps would involve the installation of a PV system, and the installation of a battery system for the peak-load management, emergency power supply and optimising of the PV production.

The site visit was carefully planned and used for the evaluation of the current energy and environmental performance. Its purpose was to establish the existing position regarding smart energy services already available in the addressed buildings, set directions and targets for smartness and performance improvement based on owner's/occupant's preferences, establish the baseline for progress evaluation, and prepare a comprehensive list of measures to improve the smartness, flexibility and energy performance of the addressed buildings.

The SRI calculation results for all seven buildings are presented in Table 2. The current SRI scores are relatively low, being heavily influenced by the year of construction or the most recent reconstructions. The key functionality 3, which relates to grid integration, has the lowest scores, primarily due to relatively low presence of energy generation and storage assets and the low awareness about positive elements of a market for flexibility. These factors greatly limit the building's ability to adapt and contribute to a more flexible grid system.

Table 3 showcases possible improvements, the so-called "smart-renovation scenario" and their corresponding influence on the SRI scores for the analysed buildings, further illustrating the potential for enhancing their smart readiness.

Table 2. Outcomes of the SRI assessment for selected buildings in Croatia and Slovenia – default Method B

Building Code	Building usage	Data sources	SRI score	Key functionality 1 score - building	Key functionality 2 score - user	Key functionality 3 score - grid
HR-01	Office	EPCs, energy audit, energy-consumption data, site visits, interviews, BIM/BEM	30%	34%	37%	18%
HR-02	Kindergarten		9%	9%	13%	5%
SI-01	Primary School		10%	12%	14%	0%
SI-02	Health centre		18%	21%	21%	4%
SI-03	Offices		16%	17%	19%	8%
SI-05	Primary and secondary school		5%	7%	9%	0%
SI-08	Primary school		20%	23%	27%	9%

Table 3. Extracted energy and flexibility measures for analysed buildings in Slovenia and new SRI scores

Building Code	Current SRI score	Key impact	Energy and flexibility measures	New SRI score
HR-01	30%	Flexible-grid office building	Installation of new building-monitoring-and-control system with demand/response func-tionalities and feedback to the occupants Installation of PV and battery system with advanced grid interaction Installation of new control elements and sensors for heating, cooling and ventilation system Installation of new speed-variable pumps Installation of new LED-lighting system with occupancy detection and central control Installation of new EV-charging station with advanced control systems and all system reports	76%
HR-02	9%	Smart-energy kinder-garten	Installation of control elements and sensors for heating system Installation of new variable-speed pumps Installation of new LED-lightning system with dimming control	41%
SI-01	18%	Smart school building	Installation of the modern energy-management system with demand/response functionalities and feedback to the occupants Renovation of lighting system and advanced control systems Installation of PV system	49%

			Reconstruction of the HVAC system – implementation of new heat pump for heating and cooling, new VSD pumps and advanced control of heating and cooling systems	
SI-02	18%	Smart, renewable and flexible health centre	Upgrade of the installed energy-management system with demand/response functionalities and feedback to the occupants Installation of PV system Renovation of lighting system and advanced control systems Installation of the battery system for the peak-load management, emergency power supply and optimising of the PV production	51%
SI-03	23%	Smart and flexible municipality building	Upgrade of the installed energy-management system with demand/response functionalities and feedback to the occupants Installation of PV system Renovation of lighting system and advanced control systems Advanced control of ventilation, heating and cooling systems Installation of the battery system for the peak-load management, emergency power supply and optimising of the PV production	51%
SI-05	5%	Smart, flexible and sustainability aware school	Installation of the modern energy-management system with demand/response functionalities and feedback to the occupants Renovation of lighting system and advanced control systems Installation of PV system Comprehensive reconstruction of the HVAC system and advanced control of heating, cooling and ventilation system Installation of the battery system for the peak-load management, emergency power supply and optimising of the PV production	61%
SI-08	20%	Smart, flexible and renewable school	Installation of the modern energy-management system with demand/response functionalities and feedback to the occupants Installation of PV system Installation of the battery system for the peak-load management, emergency power supply and optimising of the PV production	43%

The relationship between total energy consumption (final energy) and SRI scores, before and after the implementation of the smart renovation scenario for all addressed buildings, is illustrated in Figure 4. It is evident that an improvement in the SRI also signifies an enhancement in the energy performance of the addressed buildings, which is reflected in reduced total energy consumption.

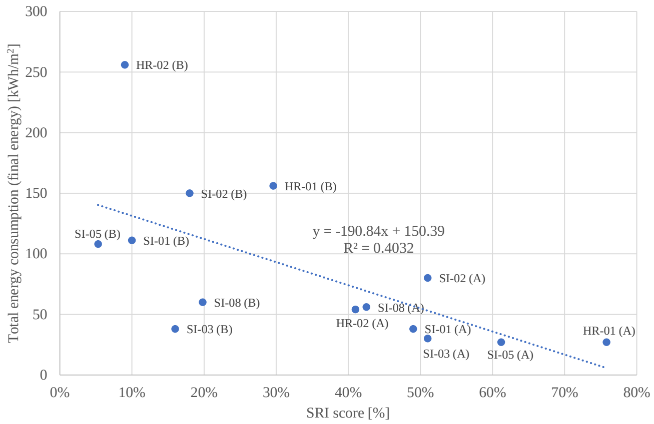

Figure 5: Relationship between total energy consumption (final energy) and SRI scores

During the data collection and calculation of SRI for selected buildings in Croatia and Slovenia the following obstacles, barriers and challenges have been identified:

- Unawareness of opportunities related to the flexibility and maintenance,
- Motivating on-site personnel including owner to actively participate in SRI related activities - actual SRI values are low and demotivating for the owner/occupants,
- High cost of smartness,
- Subjectivity in evaluation of existing systems - SRI is extracted from European Standard EN 15232-1 [19] and it is mainly focused on BACS functionalities which can be easily misinterpreted or overestimated,
- Smartens is perceived as the first step towards implementation of very comprehensive energy-efficiency measures and are always connected with very high implementation costs,
- There is a need for increased energy efficiency and flexibility related educational activities with on-site demonstration.

One of the main issues is understanding what exactly the SRI measures and how to implement it. The SRI score is not just percentage of smartness. The SRI auditor should always try to explain his/her findings with the emphasis on the potential energy efficiency and flexibility improvement measures. While the methodology for calculating the SRI is relatively clear, it can still be complex due to the variety of factors it considers. This complexity can be a barrier to implementation, particularly for smaller buildings or organizations with limited resources.

The SRI methodology includes certain qualitative elements, such as assessing how well occupants understand and can use the smart technology in their building. These subjective factors can be influenced by the individual auditor's judgement, potentially leading to inconsistency in SRI scores. Objective calculation of SRI and sustainability indicators requires significant knowledge and technical skills which means that more extensive implementation will require more in-depth training and practical exercises. The subjectivity of the auditor and the influence on the final SRI results can lead to variation in the scores between different buildings. Clear guidelines and training can help to mitigate this, but it will always be a factor to some degree. To ensure accuracy and consistency, auditors should be well-trained and experienced, and the same auditor should ideally assess all similar buildings in a portfolio. This is very important for the energy or facility managers that managing larger portfolio of similar buildings. Regular audits and reassessments can also help to ensure the ongoing accuracy of the SRI. There's a need for further research and refinement to reduce the subjectivity involved in SRI calculations and ensure the system is robust, transparent, and useful to all stakeholders. Also, the use of smart technologies is adding complexity to the operation of a building. It is clear that additional training will be required for occupants and maintenance staff to use and manage these systems effectively. Without any doubt it can be concluded that training for auditors and other stakeholders (owners, occupants, etc.) is critical to ensuring the effective use of the SRI.

In the context of the future utilisation of the SRI, the main challenge is how to incorporate positive elements of the SRI rating process without making the generation process too complex and costly for the final users. Lessons learned during the presented research clearly confirmed that to make the SRI rating useful, specific and tailored recommendations for performance improvements must be provided to the final user. This means that to be cost-effective, the SRI rating should be combined with energy auditing and energy-performance assessments. Combining of different methods (SRI, energy auditing and energy-performance assessments) and proper understanding of obtained results gives the auditor an additional perspective on the current situation regarding the energy efficiency in the analysed building and has a very good potential for a sound decision support. The potential of using metered data for various calculations has also been recognised in strengthened provisions on EPCs generation requirements, articles 16-19 and annexes V and VI [21].

4 Conclusion

Presented research work clearly confirmed the capabilities of the SRI for the energy efficiency and flexibility analysis in the selected group of buildings. The obtained results confirmed the potentials of SRI auditing to discover the entities with the capacity for energy efficiency and flexibility improvements. By understanding the value of the SRI and its implications, energy and facility managers, owners, and occupants and other stakeholders like energy service companies and utilities can identify numerous measures to improve energy efficiency and flexibility, thus maximizing the benefits of their smart building technologies. Energy efficiency and flexibility measures should always be tailored to the actual energy usage and according to when and how spaces within the building are used.

Calculation of the SRI should be basis for the identification of the performance-improvement opportunities. The first step in this process is the identification of the limitations of installed systems in terms of smart operations and sustainability. The SRI rating does not only focus on energy, but also on adaptability, user comfort, and the building's potential to respond to the grid’s demands. The most crucial step is for the SRI auditor to provide comprehensive comments on the assessed systems and components. For instance, when evaluating the potential for installing a roof-top PV plant for local electricity generation, the auditor should consider the orientation of the roof, potential shading issues, and grid-connection possibilities. Within the SRI report's comments, the auditor should detail the possible size of the PV plant, its distance from the current transformer station, and, if 15-minute interval electricity consumption data is available, provide a basic simulation of future electricity generation. This should also cover self-consumption and potential benefits from optimizing with local storage.

It is clear that the SRI is a relatively new concept, and that additional testing and adaptations of the proposed methodology will be necessary before it can prove its full potential. From its design, the most valuable aspect of the tool is the fact that it provides a common and reference language for the whole of Europe, which enables experts and policy makers to compare progress in the smart readiness of the European building stock. By assessing a building's readiness for smart technologies, promoting the deployment of digital infrastructures, empowering consumers, and supporting the transition to demand-response energy models, the SRI serves a critical role in shaping a more sustainable, efficient, and comfortable built environment for the future. As the importance of energy efficiency and smart buildings continues to grow, the SRI will undoubtedly become an increasingly valuable tool in shaping the buildings of the future. However, several barriers have also been identified, which might affect its smooth development. These include its complexity of use, problems with the subjectivity of the auditor and potential problems with the price for the final users. Objective SRI auditor must inform building owner and occupants that they may need to be prepared for the costs of upgrading their systems to stay current. Implementing smart technology can increase the value of a building but also, due to the complexity and new systems, it increases the maintenance costs. It is clear that smart technologies have a potential to significantly increase a building's energy efficiency. In a combination with advanced energy-management systems, they allow real-time monitoring and control of various systems such as heating, lighting, and cooling. This can result in significant savings of energy and consequently on energy costs and lower environmental impact. Also, smart technologies often increase the comfort and convenience for occupants. Automated lighting and temperature controls, flexibility services, and advanced predictive maintenance features all contribute to a more comfortable and convenient living or working environment. However, the initial cost of implementing smart technologies can be very high. This includes the cost of the technology itself, as well as installation and integration with existing systems. Also, smart technologies evolve quickly, and what is cutting-edge today may be obsolete in just a few years.

5 Acknowledgements

The authors would like to thank the European Commission and the partners of the European Union’s Horizon 2020 research and innovation programme project »TIMEPAC - Towards innovative methods for energy performance assessment and certification of buildings« (https://cordis.europa.eu/project/id/101033819) for their support. The TIMEPAC project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No. 101033819 as part of the call “LC-SC3-B4E-4-2020 – Next-generation of Energy Performance Assessment and Certification”. Additional information is available in the project Web page https://timepac.eu/.

6 References

[1] **Economidou, M., Todeschi, V., Bertoldi, P., D'Agostino, D., Zangheri, P., Castellazzi, L.,** Review of 50 years of EU energy efficiency policies for buildings, *Energy and Buildings, Vol. 225*, 2020.

[2] **** Clean energy for all Europeans*, European Commission, Luxembourg: Publications Office of the European Union, 2019, available at: https://op.europa.eu/en/publication-detail/-/publication/b4e46873-7528-11e9-9f05-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=null&WT.ria_f=3608&WT.ria_ev=search

[3] **** Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency*, European Parliament, Official Journal of the European Union L 156, pp. 75-91, 2018, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG

[4] **** Commission Delegated Regulation (EU) 2020/2155 of 14 October 2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings*, European Commission, Official Journal of the European Union

L 431, pp. 9-24, 2020, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R2155

[5] *** *Commission Implementing Regulation (EU) 2020/2156 of 14 October 2020 detailing the technical modalities for the effective implementation of an optional common Union scheme for rating the smart readiness of buildings*, European Commission, Official Journal of the European Union L 431, pp. 25-29, 2020, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R2156

[6] *** *The Smart Readiness Indicator (SRI) for rating smart readiness of the European building stock*, European Commission, 2022, available at: https://energy.ec.europa.eu/system/files/2022-04/SRI-Factsheet-v6_0.pdf

[7] *** *SRI test phases web-site*, European Commission, 2023, available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-test-phases_en

[8] *** *Smart Readiness Indicator assessment package (SRI),* Request for the SRI assessment package web form, 2023 Retrieved July 14, 2023, from https://ec.europa.eu/eusurvey/runner/SRI-assessment-package.

[9] **Ramezani, B., Silva, M.G.D., Simões, N.,** Application of smart readiness indicator for Mediterranean buildings in retrofitting actions, *Energy and Buildings, Vol. 249*, 2021.

[10] **Kourgiozou, V., Godoy Shimizu, D., Dowson, M., Commin, A., Tang, R., Rovas, D., Mumovic, D.,** A new method for estimating the smart readiness of building stock data using display energy Certificate data, *Energy and Buildings, Vol. 301*, 2023.

[11] **Spudys, P., Afxentiou, N., Georgali, P-Z., Klumbyte, E., Jurelionis, A., Fokaides, P.,** Classifying the operational energy performance of buildings with the use of digital twins, *Energy and Buildings, Vol. 290*, 2023.

[12] **Schweiger, G., Eckerstorfer, L.V., Hafner, I., Fleischhacker, A., Radl, J., Glock, B., Wastian, M., Rößler, M., Lettner, G., Popper, N., Corcoran, K.,** Active consumer participation in smart energy systems, *Energy and Buildings, Vol. 227*, 2020.

[13] **Le Dréau, J., Lopes, R.A., O'Connell, S., Finn, D., Hu, M., Queiroz, H., Alexander, D., Satchwell, A., Österreicher, D., Polly, B., Arteconi, A., de Andrade Pereira, F., Hall, M., Kırant-Mitić, K., Cai, H., Johra, H., Kazmi, H., Li, R., Liu, A., Nespoli, L., Saeed, M.H.,** Developing energy flexibility in clusters of buildings: A critical analysis of barriers from planning to operation, *Energy and Buildings, Vol. 300*, 2023.

[14] **Kathirgamanathan, A., Péan, T., Zhang, K., De Rosa, M., Salom, J., Kummert, M., Finn, D.P.,** Towards standardising market-independent indicators for quantifying energy flexibility in buildings, *Energy and Buildings, Vol. 220*, 2020.

[15] **Apostolopoulos, V., Giourka, P., Martinopoulos, G., Angelakoglou, K., Kourtzanidis, K., Nikolopoulos, N.,** Smart readiness indicator evaluation and cost estimation of smart retrofitting scenarios - A comparative case-study in European residential buildings, *Sustainable Cities and Society, Vol. 82*, 2022.

[16] *** *EN 16247-1: Energy audits - Part 1: General requirements*, European Committee for Standardisation (CEN), 2022.

[17] *** *EN 16247-2: Energy audits - Part 2: Buildings*, European Committee for Standardisation (CEN), 2022.

[18] **Verbeke, S., Aerts, D., Reynders, G., Ma, Y., Waide, P.**, *Final report on the technical support to the development of a Smart Readiness Indicator for buildings*, Directorate-General for Energy, Directorate C - Renewables, Research and Innovation, Energy Efficiency, Unit C4 – Energy Efficiency: Buildings and Products. European Commission, available at: https://energy.ec.europa.eu/document/download/0f3c48fd-3da5-4a0d-9dba-6c4e8ce18eb3_en

[19] *** *EN ISO 52120-1: Energy performance of buildings - Contribution of building automation, controls and building management-Part 1: General framework and procedures*, European Committee for Standardisation (CEN), 2022.

[20] **Eisenhardt, K.M., Graebner, M.E.**, Theory Building From Cases: Opportunities And Challenges, *Academy of Management Journal, Vol. 50 (1)*, 2007, pp. 25-32.

[21] *** *Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast)*, European Parliament, 2023, available at: https://www.europarl.europa.eu/doceo/document/TA-9-2023-0068_EN.pdf.