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Article

Smart Readiness Indicator (SRI) as a Decision-Making Tool for Low Carbon Buildings

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Abstract: According to the European Energy Efficiency Directive for Buildings, member states are required to develop long-term strategies to adopt more sustainable, secure, and decarbonized energy systems in buildings by 2050. In this line of approach, an optional common regime has been established to define and calculate the smart readiness of buildings and assess their ability to adapt their operation to the needs of the occupants and the network. Thus, the smart readiness indicator (SRI) emerged, which assesses technological readiness by examining the presence and evaluation of the functionality level of various smart services, aiming at energy savings, the ability of the building to respond to users' needs, and energy flexibility. This paper focuses on examining the SRI calculation methodology's application to an office building, which is currently being deeply renovated. Initially, there is an analysis of the SRI, its calculation methodology, and its goals. This is followed by the practical calculation part of the SRI for a typical office building located in Greece and belonging to the climate zone of southern Europe. The results indicate that the SRIs application is not a straightforward issue since parameters that need to be considered are not regulated to the same degree. On the other hand, SRI can provide a stimulus for exploiting the renovation potential of buildings, precisely by integrating the various aspects and linking those to the use of innovative technologies.

Keywords: climate change mitigation policies; low-carbon economy; circular economy; energy technology plan; smart readiness indicator; smart buildings; energy flexibility; low carbon society; IoT

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1. Introduction

The sustainability of cities has become a global concern, bringing with it a wide range of research and technological challenges that affect many aspects of life. Within the urban environment, a very important role is played by the buildings themselves, which are a subsystem of the city, and in the interior of which most of human life is spent. Access to sustainable energy sources has been a major concern for the member states of the European Union which is the largest energy consumption market in the world. The vision of carbon neutral cities is in total compliance with the European Green Deal Policy [1]. This policy defines the goals of energy efficiency, introduction of renewable energy systems, reduction in CO_2 emissions and environmental impacts promoting the ideas of sustainability, circular economy, and resilience. This framework includes all the sectors like energy production, transportation, industry, buildings, and agriculture [2].

Carbon neutral cities are a polycriteria issue concerning different parties' citizens, government, political parties, municipalities, investors, producers, consumers, and users. Therefore, it is a multitasking problem to be solved, which ought to keep a balance between the different expectations of the interested parties. Concerning the decarbonization of cities, the sectors directly related to city management are mainly transportation, buildings, and waste [3]. Cities are intensive energy consumers, mainly electricity and fuels in relation to ground transportation (road and rail) and the residential and commercial buildings sector. Furthermore, in many regions, industrial activities have developed around and within cities that contribute CO_2 emissions as well. Global urban energy related CO_2 emissions range from 8.8 to 14.3 Gt CO_2 per year, which is between 53% and 87% of the CO_2 emissions from global final energy use [4]. It is important to identify the sectors related to cities which are responsible for CO_2 emissions and environmental impacts. The key parameters affecting cities resilience and sustainability are mainly:

— Energy efficiency, which based on the European Green Deal policy, aims to reach zero emissions, especially in the building sector which accounts for 40% of energy demand.
— Introduction to renewable energy systems and decarbonization of conventional energy supply systems. For instance, based on the EU energy policy, approximately 80% of the European electricity energy supply must be sourced from renewable energy sources by 2050.
— Smart and efficient mobility. Promoting public transport, walking, and cycling, in addition to introducing smart applications and automations is another significant parameter which ensures improvement in terms of CO_2 emissions.
— Waste management based on a circular economy approach, aiming to minimize the use of natural resources and reduce waste and carbon emissions.
— Digitalization in all sectors will ensure reduction in CO_2 emissions and the improvement of the quality of services. Based on the report, ICTs can provide 7.8 Gt CO_2eq of emissions savings, representing around 15% of total emissions in 2020 [4].

Buildings, as crucial parameters of cities, are actually the cornerstone of energy consumption and CO_2 emissions in urban centers, accounting for 36% of total CO_2 emissions and 40% of total energy consumption [5]. In addition, this problem is exacerbated by the fact that a large proportion of the available building stock consists of old structures, which are not energy efficient and require the use of significant amounts of natural resources for their operation [6]. One of the targets set by the European Union for the year 2050 is to reduce greenhouse gas emissions by 80% compared to 1990 levels, in an effort to mitigate the increasing trend in the average global temperature as a result of climate change, which is expected to have dramatic consequences on daily human life [7]. Considering the above mentioned parameters, as well as the need for structuring a well-preserved energy action plan, a five-stage reinforcing approach is established, focusing on the following; (a) security, solidarity, and trust; (b) an integrated internal energy market; (c) energy efficiency; (d) climate action, decarbonizing the economy; and (e) research, innovation, and competitiveness [8]. One way to achieve a significant reduction in carbon emissions is to improve energy and environmental performance in the building sector. Smart buildings can play a key role in transforming the EU into a low carbon society, improving energy efficiency, and increasing the use of renewables. On the topical issue of energy waste and sustainability, the EU has developed a plan that focuses on reducing greenhouse gas emissions, improving energy efficiency and increasing the use of renewable energy sources [9]. All productive sectors can contribute to this transition according to their technological and economic potential. As one of the main sectors with significant energy demand and carbon emissions, the building sector is a priority in the EU's efforts to become climate-friendly and achieve less energy consumption. To achieve this goal, the building stock must significantly improve its energy efficiency and reduce its carbon footprint. There are several ways to achieve this goal, one of which is to turn the current building stock and energy system into a smart one. Several strategies are used in smart buildings to improve their performance, one of which is the integration of Building Energy Management Systems (BEMS). These systems offer control of the environmental parameters in the building through channels of sensors and actuators that either have a central control system or operate in a decentralized manner. A direct consequence of this is that with the application of appropriate control algorithms, it is possible both to ensure comfort conditions and to save energy [10]. Another key issue for efficient energy management in buildings can be energy flexibility. One of the main methods for offering flexibility is thermal energy storage. The thermal mass of a building can be used for load shifting when an energy deficit is detected, since it can store thermal energy for short periods of time [11]. Equally important is the use of renewable energy sources and their operation as on-site electricity producers, as well as the constant monitoring and control of the grid. As the initial step of transforming buildings into smart buildings, it is necessary to know how intelligent the existing building is. To take this step, the smart readiness indicator of buildings was developed, which is part of an ambitious European program launched in 2018 with the aim of highlighting the importance of integrating various automation systems into a building, making it smart as a result.

EU member states are looking for a cost-effective balance between carbonization and reducing the energy consumption of the building stock. Considering the potential of smart buildings in terms of improving energy efficiency and the use of renewable energy sources, it is necessary to renovate the current building stock. Smart technologies in a building can be a cost-effective means of creating a healthier and more comfortable environment within the building, with lower energy use and a smaller carbon footprint, and can also facilitate the integration of renewables into energy systems [12]. Therefore, the European Commission is at the initial stage of this perspective, aiming to transform buildings and their energy systems to be smarter and more efficient, user-centric, and utilize RES as primary energy sources. Knowing the level of smart readiness of today's buildings, it is possible to plan the changes that need to be made, to move in the smarter direction [13]. Renewable energy system contribution is important in order to achieve energy efficiency and carbon neutrality goals. The building sector seems to incorporate a greater percentage of RESs, and this is especially true for residential buildings. More specifically, RESs are integrated in the building sector (residential and services) by 35%, while in the transportation sector, they are only integrated by 5% [14]. With this in mind, the European Commission has published the revised Energy Performance of Buildings Directive [5], laying the foundations for reducing greenhouse gas emissions by freeing buildings from conventional forms of energy and switching to renewables, taking the first step towards the renovation of existing buildings and the construction of new ones, harmonized with the dictates of modern times. One of the focal points of the Energy Performance of Buildings Directive is to better exploit the potential of smart technologies in the building sector. This technical directive establishes the smart readiness indicator (SRI) as a means of assessing the smart readiness of buildings in Europe. The indicator is initially optional and is introduced to assess the technological readiness of buildings in terms of their interaction with the user, flexibility, energy savings, and more efficient operation. The SRI scheme is a European policy initiative that aims to deliver a voluntary framework to measure how "smart-ready" the building stock is [15]. The SRI aims to inform and raise awareness of the benefits of smart building technologies and functions while making their added value more tangible for users, owners, tenants, and smart service providers. It seeks to support innovative technologies in the building sector and create an incentive for the integration of state-of-the-art smart technologies in buildings [16].

2. Theoretical Background

It is a fact that presently, there are not many studies or data about the smart readiness indicator of buildings. This subject is recent, and even the subject of smart buildings is something that is still being explored and developed. In their recent study, researchers [17] studied the latest directive on the energy performance of buildings and in particular the procedure for calculating the SRI, stating that this indicator can be applied to any building use, providing clear results in terms of displacement of energy loads and the interaction of the building with energy networks. They concluded that the SRI can be a key tool in quantifying the use of communication technologies and electrical systems, which can adapt their operation to the needs of occupants and networks, improving the overall performance of the building. Nevertheless, they noticed that the method of calculating the indicator is based on the purely subjective judgment of the scholar, and the process can become quite time consuming. Another study applied the SRI calculation methodology to three residential buildings and one educational building in the Czech Republic [18]. They concluded that the methodology has some limitations, such as the inability to consider multiple combined heat sources, as well as the insufficient characterization of certain impact criteria, such as "health and well-being", which can easily reach the high scores, due to the small number of services included. Others observed that the process of calculating the SRI requires extensive analysis by the scholar and suggested the creation of an algorithm to automate the process according to specific simulation models [19]. Earlier, the importance of input data for the calculation of various indicators was stressed [20]. The subject of one study was an intelligent campus building in Odense, Denmark, where researchers carried out a detailed analysis to assess the impact of the number of services examined and the impact criteria proposed by the SRI methodology. Another study applied the SRI calculation methodology to discuss its suitability for the cold climates of Northern Europe [21]. Specifically, they studied two educational buildings of different construction periods and an office building in Helsinki, Finland. They concluded that the methodology presents some limitations in the recognition of some specific characteristics of buildings in cold climates and in particular regarding advanced district heating systems. Consequently, the authors expressed some concerns about the feasibility of a homogenous application of the calculation in all EU member states. It was also emphasized that at certain stages of the calculation process, the subjective choices of the scholar play a key role, leading to significant consequences for the result. In order to mitigate the impact of these aspects, they proposed two specific alternative variants of the methodology. Another study, concerning the Italian residential building stock, explained that historic buildings subject to architectural constraints have some restrictions and therefore, it may not be possible to achieve activity in some domains. Therefore these restrictions and aspects should be taken into account when defining the reference buildings [22]. At the same time, other researchers examined and applied the SRI calculation to two case study buildings in Portugal. The SRI of these two buildings was compared and its effects on indoor environmental quality and energy efficiency were investigated. According to these results, despite the weakness of the proposed methodology in predicting energy consumption among different end-users, this framework was very capable of adapting to Mediterranean climatic conditions [23]. Furthermore, recent research has shown that the methodology used to calculate the SRI needs to be adapted to different types of buildings and revealed that the technical systems within buildings vary based on their intended purpose. This study also concluded that by accurately calculating the SRI, it is possible to identify buildings that can contribute to the generation of energy and manage the utilities in terms of generation, transmission, and distribution. Public buildings, such as educational buildings, are particularly significant in this regard [24]. Finally, within the next few years, after the SRI is consolidated and its weaknesses are improved, it will cease to be optional and is expected to be included in the calculation of the energy class of buildings, incorporating the result of the indicator in the energy certificate [25].

Given the lack of research and practical studies in this field, this paper aims to provide empirical evidence and examine aspects and potential weaknesses of the SRI calculation methodology, especially in non-residential buildings in Southern Europe, which have many differences in terms of thermal and cooling needs in relation to the rest of Europe, as the need for cooling during summer months is great. The question that this publication aims to answer is whether the SRI methodology is applicable to real buildings, and which approach yields the most reliable results. Moreover, it is worth looking for the benefits that can be obtained from the implementation of the SRI and how energy efficiency is promoted through the indicator.

In the next chapter, the SRI's methodological framework is described, which is followed by its application for a non-residential building in Greece. The building that was chosen is real and generally approximates the characteristics of a similar type of building. The same calculation procedure is followed for a theoretical scenario of upgrading the building. The fourth chapter provides the SRI results and analysis of the SRI improvement.

This work ends with the discussion of the key findings and a summary of key conclusions about the SRI procedure framework.

3. Materials and Methods

The new provision of the amended EU directive establishes the optional smart readiness indicator (SRI) rating scheme as a "common language" for assessing the ability of buildings to use information technologies and advanced electrical systems. This indicator is introduced as a tool to facilitate the achievement of smart building targets regarding energy consumption and storage, as well as to create a healthier, more convenient, and ideal indoor environment for occupants [5]. The index is part of an ambitious European program launched in 2018 with the aim of highlighting the importance of integrating various automation systems into a building, making it smart as a result. This importance can be expressed through a reduction in energy consumption, which entails a significant reduction in greenhouse gas emissions and consumption of natural resources, as well as a reduction in operating costs. It essentially expresses the technological readiness of the building but is not limited to that, since it also assesses the adaptability of the building under consideration to the users' needs and its efficiency and flexibility in terms of its energy behavior. The SRI is expected to be incorporated into the legislation of the member states of the European Union in the coming years, being voluntary at first, and aims at being the first common, reliable tool for assessing the smart readiness of buildings. It is therefore expected to become an incentive for the further development of smart technologies and their integration into the building sector through the recognition of the additional commercial value that their application gives to the building as an asset, and having an impact on further investments in the renovation of existing buildings and the construction of new buildings that will not be only sustainable, but also intelligent, flexible, and resilient [26].

3.1. Calculation Methodology

The detailed methodology for calculating the SRI is described in the final report on the technical support to the development of a smart readiness indicator for buildings [16]. The proposed SRI methodology is based on the assessment of the smart-ready services that can exist in a building. Services that contribute to smart readiness are those that make use of the respective technologies and are examined by the combination of smart technologies that govern them. To support this, two separate lists of smart readiness services have been compiled, a detailed method (method B) which is suitable for non-residential buildings and a simplified method (method A) which is mainly suitable for residential buildings as well as small buildings of other uses, each with a separate number of services. Each method lists the services concerned and describes their main expected impact on tenants and the grid. Many of these services are based on international technical standards. For each of the services, 2 to 5 levels of functionality are defined. A higher level of functionality reflects a "smarter" implementation of the service, which generally provides more beneficial effects on users and the network, compared to services that have a lower level of functionality. In the latest version of the catalogue, 52 smart-ready services have been defined. Smart services function as a subset of a wider category and are divided into 9 technical domains, namely:

- Heating;
- Domestic hot water (DHW);
- Cooling;
- Controlled ventilation (CV);
- Lighting;
- Dynamic building envelope (DBE);
- Electricity;
- Electric vehicle charging (EV);
- Monitoring and control (MC).

The assessment of smart-ready services is based on their impact on occupants, the building, and the grid, according to some distinct criteria defined by the SRI calculation methodology. In other words, the returns resulting from the services of each technical domain are classified into impact criteria. These criteria are 7 in total and are as follows:

- Energy savings;
- Maintenance and fault prediction;
- Comfort;
- Convenience;
- Information to occupants;
- Health and well-being;
- Information to occupants;
- Energy flexibility and storage.

These impact criteria are further clustered under three key functionalities which carry equal weights (1/3) in the overall SRI score and reflect the main goals of the SRI, which is depicted in Figure 1. In line with the requirements of the revised directive (EPBD), these three key functionalities have been considered when defining the services for the SRI:

- Energy performance and operation;
- Response to the needs of the occupants;
- Energy flexibility.

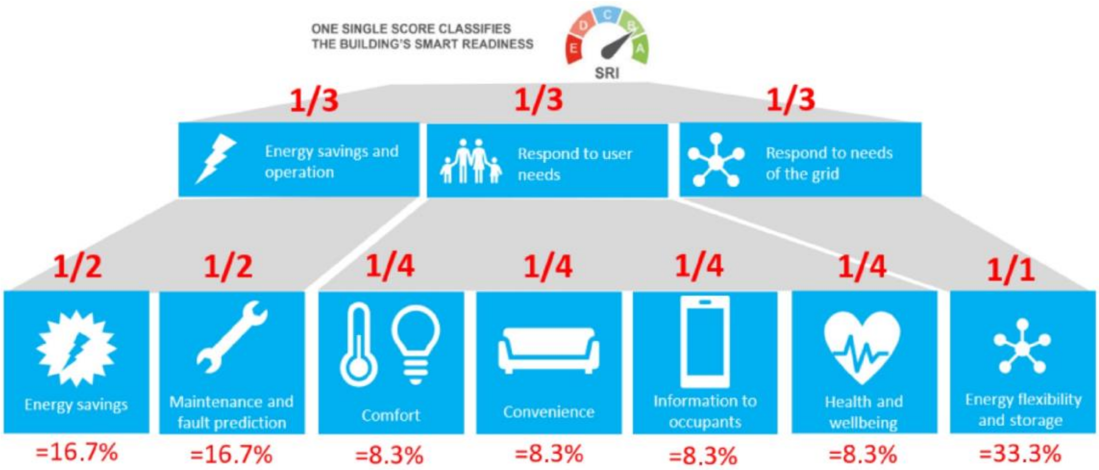

Figure 1. The 3 key functionalities, 7 impact criteria and their weighting factors [16].

3.2. Weighting Factors

Each score of any technical domain represents its relative importance in relation to the impact criteria. For each of the nine technical domains, weighting factors are assigned as percentages, relative to the seven impact criteria, the total sum of which is 100%. The proposed methodology provides default weighting factors which are differentiated by building type and climate zone. Conceptually, three approaches can be numbered, namely three different kinds of weighting factors as shown in Figure 2: the fixed weights, the equal weights, and the energy balance weights, depending on domain and impact.

Fixed weights: The fixed weights are independent of the use of the building and the climate zone to which it belongs. The weight assigned to the technical sector "monitoring and control" is 20% for each of the seven impact criteria. With regard to the impact criteria "energy savings" and "maintenance and fault prediction" and "energy flexibility and storage", a weighting of 5% is assigned for the technical domains "electric vehicle charging" and "dynamic building envelope".

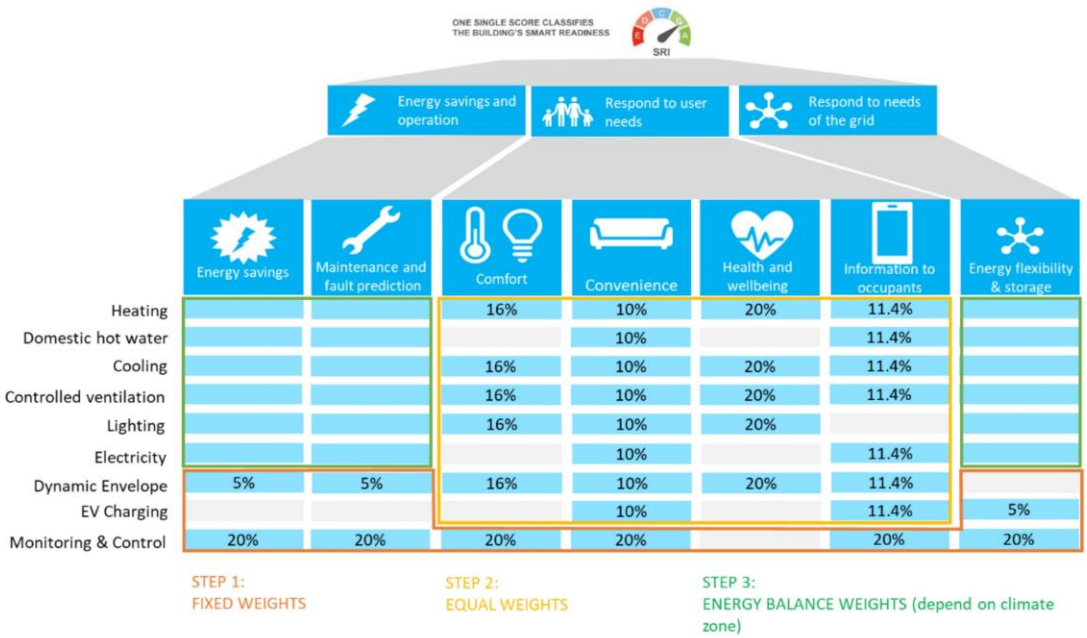

Figure 2. Overview of the proposed weighting scheme [16].

Equal weights: The equivalent weighting factors are also independent of the type of building and the climate zone and are attributed to all the impact criteria that belong to the key functionality "response to the needs of the occupants". In other words, it concerns the impact criteria "comfort", "convenience", "health and wellbeing", and "information to occupants" and relates to all technical areas except the area "monitoring and control" where the coefficient is fixed and equal to 20% as mentioned above. Finally, the equal weights are calculated by the following formula, where $f_{domain,imp,criterion}$ is the weight of the domain per impact criterion.

$$f_{domain,imp,criterion} = \frac{100 - \Sigma(fixed\ weights)}{number\ of\ relevant\ domains}$$

Energy balance weights: The values for the energy balance weighting factors are the only ones that depend on the type of use and the climate zone in which the building under study is located. Also, these values can change when using an alternative energy balance as explained below. The energy balance weights are assigned to the impact criteria "energy savings", "maintenance and fault prediction", and "energy flexibility and storage". The value of the weighting factor is obtained by multiplying the remaining percentage for the given impact criterion (100% − Σ(fixed weights)) by the relative importance of the domain in the energy balance. Namely:

$$f_{domain,imp,criterion} = (100 - \Sigma(fixed\ weights)) \times a_{domain}$$

— Fixed weights are the weighting factors mentioned above;
— a_{domain} is the relative importance of the sector in the energy balance.

Alternative way of calculating energy balance weighting factors: In addition to the classic way of rendering energy balance weights mentioned above, an additional possibility is given to the designer, where the calculation of these weights is made using the energy balance specifically related to the examined building, for which the primary energy uses for heating, domestic hot water, cooling, mechanical ventilation, lighting, and electricity should be available. For example, it is possible to use the primary energy data from energy performance certificates for the six domains and calculate the a_{domain} as follows:

$$\alpha_{domain} = \frac{Q_{domain}}{Q_{total}}$$

$$\begin{aligned} Q_{domain} &= \{Q_{HEAT}, Q_{DHW}, Q_{COOL}, Q_{VENT}, Q_{LIGHT}, Q_{RENEW}\} \\ Q_{total} &= Q_{HEAT} + Q_{DHW} + Q_{COOL} + Q_{VENT} + Q_{LIGHT} + Q_{RENEW} \end{aligned}$$

According to the procedure of developing an effective and sustainable decision-making framework related to interventions for buildings refurbishment the following categories are taken into consideration. In other words, criteria for selecting a refurbishment strategy and the appropriate interventions for each case should be summarized to the following general categories:

I. Technical;
II. Energy efficiency;
III. Economic feasibility;
IV. Environmental impact assessment.

The sectors which are directly affected and at the same time are affected by cities are transportation, buildings, and waste. These parameters are also drivers for reducing CO_2 emissions in cities. Of course, the multi-dimensional issue of the sustainability and resilience of cities is also affected by other parameters like population, density, heating/cooling, income, and size. Macknsey [27] separates the management and the different interventions to cities not only by sector but also with regard to the cities size as well as economic growth.

Under the criteria of technical feasibility, there several subcriteria to take into consideration; for example, structural and functional elements, the type of building, the surface, the occupancy, the orientation, the year of construction, the location, and the orientation. In terms of the energy efficiency subcriteria that affect energy consumption and should be taken into consideration in the evaluation procedure, there are the climatic conditions, the type and structure of energy systems (size, type, capacity, energy coefficient, and lifespan), thermal comfort conditions, indoor air quality (CO_2, CO, temperature, and humidity), HVAC, lighting and other electrical equipment, automations, and envelope characteristics (construction typology and insulation/materials). Regarding the environmental impact assessment subcriteria relevant to the quantification of the environmental impact, there is the determination of the technical parameters mentioned above (such as the energy systems, the envelope structural characteristics), the energy consumption, the transportation, the water consumption, the waste production, and the lifespan of the system studied. Another significant pillar that is always under evaluation and affects the decision-making process is the cost effectiveness: the investment cost, the operational cost, the maintenance and replacement cost, the definition of capital rate, and the service life are all taken into consideration. Last but not least, considering the building environment is of significance, under the social parameter. The users, the quality of living, and the services in the buildings are of major importance. Issues like health and wellbeing, security and facilities, accessibility to view, and thermal comfort are included in the list of social impacts of the built environment.

Tools and methodologies that are used for the determination of the above-mentioned criteria in the decision-making process of the built environment are the Energy Audits, which lead to the energy certification; optional tools and methodologies like Carbon Footprint Analysis; and Life Cycle Analysis, which does not lead to certification but offers a holistic approach to the system's evaluation. Green certification schemes like LEED, BREEAM, and DGNB evaluate the building in terms of technical requirements, energy efficiency, economic feasibility of interventions, environmental impact assessment, as well as health and well-being of users. Considering the cost effectiveness, several economic indicators can be used, like Net Present Value (NPV), Life Cycle Cost Analysis (LCCA), payback period, and Internal Rate of Return (IRR) [28]. The above-mentioned tools and methodologies can be in total compliance and synergy with SRI methodology, supporting the parameters that affect a building's performance.

4. Case Study

The methodology has been applied to an existing office building located in Thessaloniki, Greece (latitude 40°38′36″ N, longitude 22°55′51″ E). The city has a Mediterranean—humid subtropical climate (Cfa on the Koeppen scale), belonging to climate zone C, according to Greece's energy efficiency for buildings regulation KENAK [29], or, respectively, to the climate zone of Southern Europe according to the SRI methodology. It is similar to cities like Toulon, France or Split, Croatia, characterized by mild wet winters and warm to hot, dry summers [30]. Thessaloniki is the second-largest city in Greece, in terms of area and population, with over one million inhabitants, combining characteristics of both a metropolitan and a coastal area [31]. Climate change is expected to intensify in the coming years and the Mediterranean region is predicted to be one of those most affected, so Thessaloniki is included in the group of those areas in Europe with the highest "aggregate potential impact of climate change" [32,33]. This subsequently creates the need for resilience, and buildings must be able to adapt to new conditions, responding to users' needs and promoting energy savings.

Moreover, the case study comprises an office building that represents the typical office building of the country. The examined building is located in the city center; it was designed by the architects D. Daparliagkas—Salto and its construction was completed in 1968. Its structural design is characterized by a nine-story configuration, including a ground floor, a mezzanine, and two basements, with an armed concrete bearing structure. The building's design features two glazed façades on its southeastern and southwestern elevations, while the remaining sides are closely bordered by neighboring structures as shown in Figure 3.

Figure 3. Exterior façade of the examined building.

The building chosen for this case study, a typical 1960s office structure located in the heart of an urban center and untouched by significant renovations since its completion, serves as an ideal subject for evaluating the SRI. Its selection is driven by its representation of a prevalent architectural era in Greece, which provides a unique opportunity to explore the retrofitting possibilities for enhancing energy efficiency and integrating smart technologies within buildings of this period. The central location underscores the environmental and operational challenges it faces, such as high energy demand and urban microclimate exposure, setting the stage for potential significant improvements. Its classification as Class E in energy efficiency (according to the EPC scheme) underscores the urgent need for upgrades to meet modern standards. Such buildings constitute a large volume of the existing building stock both in Greece and in the rest of Europe. It is therefore important to examine and evaluate this type of building to determine their weaknesses and elaborate on the corresponding interventions. This study aims not only to address the specific challenges and improvement opportunities for this building but also to generate insights that could be applied to similar structures across Greece and Europe, contributing to broader energy efficiency and sustainability goals.

4.1. Building Description

The total heated area of the office building is 2730 m^2 (length: 20.40 m, width: 12.50 m, height: 27.60 m) and the heated and cooled volume is 7038 m^3. The building includes open plan and cellular offices, 14 WC spaces, 2 elevator shafts, a stairwell area, a revolving entrance door on the southwest façade of the building, 2 basements, a conference room, a boiler room, and a space for customer service. The building has two Matrix type oil-fired boilers, which are placed in the basement and are connected in parallel, the water supply temperature being 75 °C. The system operates five days a week, from 6:30 a.m. to 3:00 p.m., and there may be changes to the schedule depending on weather conditions and staff requirements. There are no room thermostats, nor any other automations that regulate water circulation and temperature. In addition, on the second and eighth floors, there are four convectors installed to heat these spaces sufficiently, since the central heating system does not cover the eighth floor. As for the heat distribution, the ground floor and mezzanine are served independently from the other floors since they were designed as customer services' areas. As for the cooling system, the mezzanine and ground floor have a single-zone, constant volume flow air conditioning system (HVAC) rated at 246 kW (840.000 BTU/h). For the other floors, local air conditioning units are used, the powers of which are shown in Table 1.

Table 1. Air conditioning units per floor.

	Room Air Conditioners (kW)			
	1	**2**	**3**	**4**
Ground Floor	-	-	-	-
Mezzanine	-	-	-	-
1st	2.34	-	-	-
2nd	7.35	2.34	-	-
3rd	2.34	2.34	-	-
4th	7.03	5.28	5.28	-
5th	7.35	7.12	5.28	5.28
6th	7.35	3.52	-	-
7th	7.35	5.28	5.28	5.28
8th	7.32	5.28	5.28	2.64

The building has two artificial lighting systems. The first system consists of energy-saving lamps and spotlights on the ground and on the mezzanine. The second system consists of fluorescent lights with reflectors. However, the lighting system does not have a motion detection system or any other energy-saving mechanism. The summarized features of the considered office building are presented in Table 2.

Table 2. Features of the existing building.

Building's Characteristics	
Construction Year	1965
City	Thessaloniki
Location	Urban Built Environment
Building Usage	Office Building/Customer Services
Area	2730 m^2

Table 2. *Cont.*

Building's Characteristics	
Floors	9
Height	27.60 m
Width	12.50 m
Length	20.40 m
Volume	7038 m^3
Working Hours	7:00 a.m.–2:30 p.m.
Number of Employees	100
Building Envelope	Single glazed windows with aluminum frames without thermal bridges
Heating system	Oil-fired boilers/radiators-hydronic system/room air-conditioners/electric convectors/AHU
Cooling system	Room air-conditioners/AHU
Ventilation system	Mechanical ventilation without heat recovery at ground floor and mezzanine
Shading system	Internal blinds in most offices
DHW	No
Lighting	Fluorescent lamps with reflectors/Spot fixtures/Energy saving bulbs
Elevators	Semi-automatic elevator doors
Equipment usage	Computers/Printers
Thermal comfort conditions (Summer)	Almost inappropriate
RES	-
BACS (EN 15232)	Class D
Primary energy consumption	306.2 kWh/m^2
Energy class (KENAK)	Class E

4.2. Building Energy Performance

The evaluation of the energy performance of the office building was examined using the TEE-KENAK software tool version v1.29.1.19_20_05_12, which is the official tool for assessing the energy performance of buildings and issuing energy performance certificates in Greece. The building is divided into three different thermal zones and both the technical characteristics of the building service systems, and the building envelope features are considered. Additional information about the KENAK software and calculation data can be found in the Appendix A. Regarding the results, the energy class of the building under consideration belongs to category E, meaning that it is energy inefficient, while the consumption values per use are shown in Table 3, compared to the reference building. This result is expected, as this building is a representative example of a building constructed in the 1960s in terms of its energy behavior.

At this point, it is worth mentioning that since April 2022, the building is undergoing deep renovation, which is expected to be finished in March 2024. The scenario of the building's reconstruction is going to be studied and the SRI to be recalculated based on the study that has been conducted for the renovation of the building. Therefore, the results of the SRI in case of upgrading the building are currently more theoretical, but after the completion of the renovation there will be real and measurable data, which can be studied with further research in the future.

Table 3. Primary energy consumption per use.

	Reference Building	Existing Building
Heating	21.8	54.7
Cooling	16.4	196.7
Lighting	120.2	54.8
RES	0	0
Total Primary Energy Consumption (kWh/m^2)	158.5	306.2
CO_2 Emissions (kg/m^2)	54.7	114.7
Energy Class	-	E

4.3. SRI Calculation Scenarios

As part of the investigation of the SRI, two main calculation scenarios were developed. The calculation in the first case was made for the existing building's systems, while in the second case, the calculation was made for the scenario of upgrading the building. For both cases, the level of smartness was considered, taking into consideration three sub-scenarios. The difference between the sub-scenarios lies in the number of technical domains involved in the calculation. In the first scenario, the default values are used to determine the weighting factors of the technical domains according to the SRI calculation methodology, while for the other two scenarios, the weighting factors of the energy balance are recalculated based on the energy balance and the primary energy usage data calculated by the TEE-KENAK software tool.

In the development of sub-scenarios 2 and 3, we refined the weighting factors by integrating the outcomes derived from the energy performance analysis software. This recalibration process was underpinned by two distinct methodologies. Initially, we adopted a straightforward approach where the energy balance weights were adjusted without altering the predefined, uniform factors. This methodology ensures a direct reflection of the building's energy balance as determined by the software, without additional modifications to the fixed and equal weighting factors. Conversely, the second methodology adopted a different approach, focusing exclusively on those sectors significantly contributing to the building's energy balance. This consideration was based on the primary energy usage data generated by the energy analysis software, allowing for a more nuanced and building-specific recalibration of the weights. Table 4 outlines the configurations of the various scenarios and sub-scenarios, demonstrating the application of each method in the SRI calculation process.

Table 4. SRI's calculation scenarios.

Scenarios	Sub-Scenario	Technical Domains	Weighting Factors
Existing Building	1	All	Default
	2	All	Energy Balance
	3	Heating, Cooling, Lighting	Energy Balance
Upgraded Building	1	All	Default
	2	All	Energy Balance
	3	Heating, Cooling, Lighting	Energy Balance

In sub-scenarios 2 and 3, we meticulously recalculated the weighting factors to accurately reflect the unique energy profile of the building under study. This recalibration was informed by the building's energy balance, as detailed in Table 3. By analyzing this balance, we were able to adjust the weighting factors in a manner that aligns more closely with the actual energy usage patterns and priorities of the building. These adjustments ensure that our SRI calculations not only adhere to theoretical models but also incorporate real-world data, providing a nuanced and accurate assessment of the building's smart readiness. The resulting configurations for these sub-scenarios, along with the recalibrated weighting factors, are systematically presented in Tables 5 and 6 for clear comparison and analysis. This study not only aims to identify the specific interventions needed to elevate its SRI score but also to evaluate which sub-scenario most accurately reflects the building's smart readiness, ensuring that the findings can inform broader efforts to enhance energy performance and indoor environmental quality across similar existing buildings.

Table 5. Weighting factors of the second sub-scenario.

	Energy Efficiency	Energy Flexibility and Storage	Comfort	Convenience	Health, Well-Being and Accessibility	Maintenance and Fault Prediction	Information to Occupants
Heating	0.13	0.13	0.16	0.1	0.2	0.13	0.11
Domestic hot water	0.00	0.00	0.00	0.1	0	0.00	0.11
Cooling	0.48	0.48	0.16	0.1	0.2	0.48	0.11
Ventilation	0.00	0.00	0.16	0.1	0.20	0.00	0.11
Lighting	0.14	0.14	0.16	0.1	0.00	0.14	0.00
Electricity	0.00	0.00	0.00	0.1	0.00	0.00	0.11
Dynamic building envelope	0.05	0	0.16	0.1	0.20	0.05	0.11
Electric vehicle charging	0	0.05	0	0.1	0	0	0.11
Monitoring and control	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 6. Weighting factors of the third sub-scenario.

	Energy Efficiency	Energy Flexibility and Storage	Comfort	Convenience	Health, Well-Being and Accessibility	Maintenance and Fault Prediction	Information to Occupants
Heating	0.18	0.18	0.33	0.3333	0.5	0.18	0.50
Domestic hot water	0.00	0.00	0.00	0	0	0.00	0.00
Cooling	0.64	0.64	0.33	0.3334	0.5	0.64	0.50
Ventilation	0.00	0.00	0.00	0	0.00	0.00	0.00
Lighting	0.18	0.18	0.33	0.3333	0.00	0.18	0.00
Electricity	0.00	0.00	0.00	0	0.00	0.00	0.00
Dynamic building envelope	0	0	0.00	0	0.00	0	0.00
Electric vehicle charging	0	0	0	0	0	0	0.00
Monitoring and control	0	0	0	0	0	0	0

5. Results

As the first step of SRI assessment, the relevant building's smart services were selected in the triage process though a review of the buildings' technical documents, an on-site inspection, and a consultation with the buildings' technician. After finding the relevant services, the level of functionality of each one was evaluated. With regard to the existing building, some of the technical domains were omitted because they were absent and not mandatory, according to the technical guide. These domains were "domestic hot water", "electric vehicle charging", and "monitoring and control". Similarly, in the upgraded building, the technical areas that were ignored were "domestic hot water" and "electric vehicle charging"; both are not mandatory for the renovation of the buildings. After these technical domains were eliminated, an evaluation of the relevant smart services was taken into account for the assessment of the SRI for each domain that is present. Eventually, the SRI for the existing building was calculated according to the detailed method (B) which is suitable for non-residential buildings. This was followed by the calculation of the indicator for the case of upgrading the building. Using the calculation tool provided by the European Commission in form of an MS-Excel file and based on the weighting factors calculated, the following results were obtained for each case.

Figures 4 and 5 present the results of simulations carried out to calculate the SRI scores.

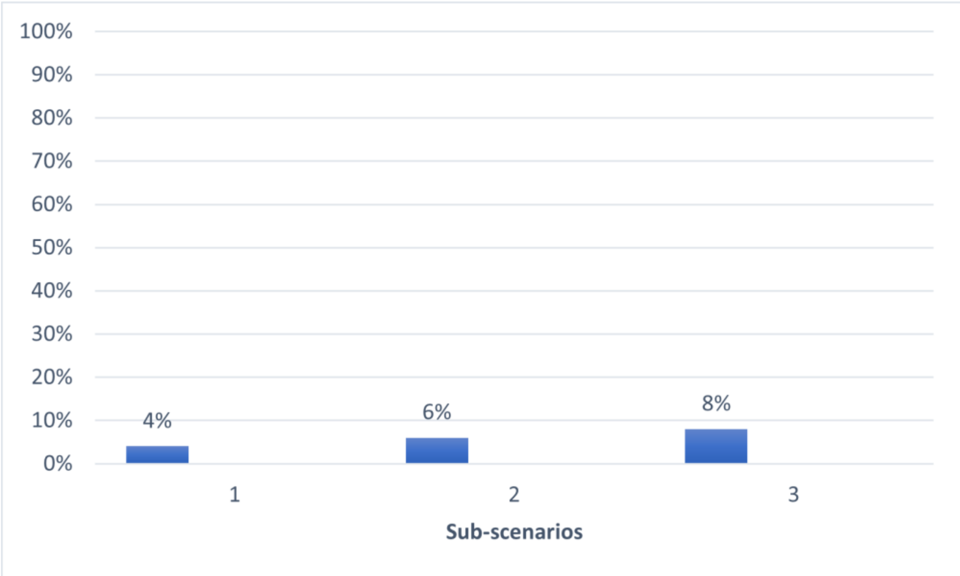

Figure 4. SRI scores for the existing building.

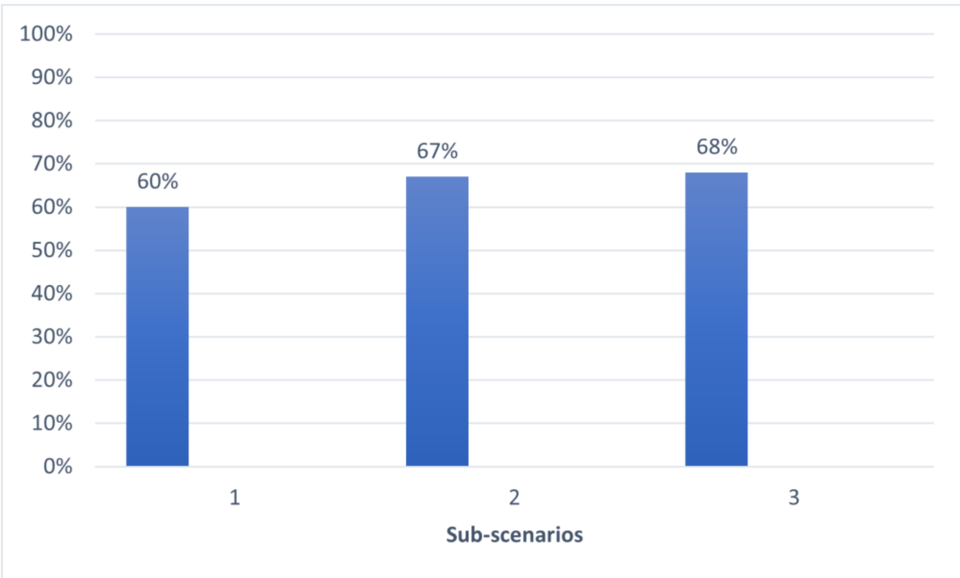

Figure 5. SRI scores for the upgraded building.

In the case of the ongoing renovation of the building, it is assumed that the building will have advanced monitoring and control systems, especially for the heating, cooling, and lighting systems, which will operate with presence control and based on the actual needs. It is also assumed that they will be able to monitor and store data. The building will have class A BMS (Building Management Systems) optimizing the control and performance of the building's indoor conditions [34]. Furthermore, regarding air conditioning, this will consist of a VRF (Variable Refrigerant Flow) system with thermostatic control in all zones.

A total of 5 kW of PV panels will be installed on the roof of the building, while the facades will have external vertical sun protection fins, their orientation being optimized based on incident radiation.

In addition, the detailed calculation results of the SRI for the first sub-scenario are indicated below in Figures 6 and 7. They include the separate scores for each impact criterion, while the corresponding calculations for the other two sub-scenarios are listed in Appendix A.

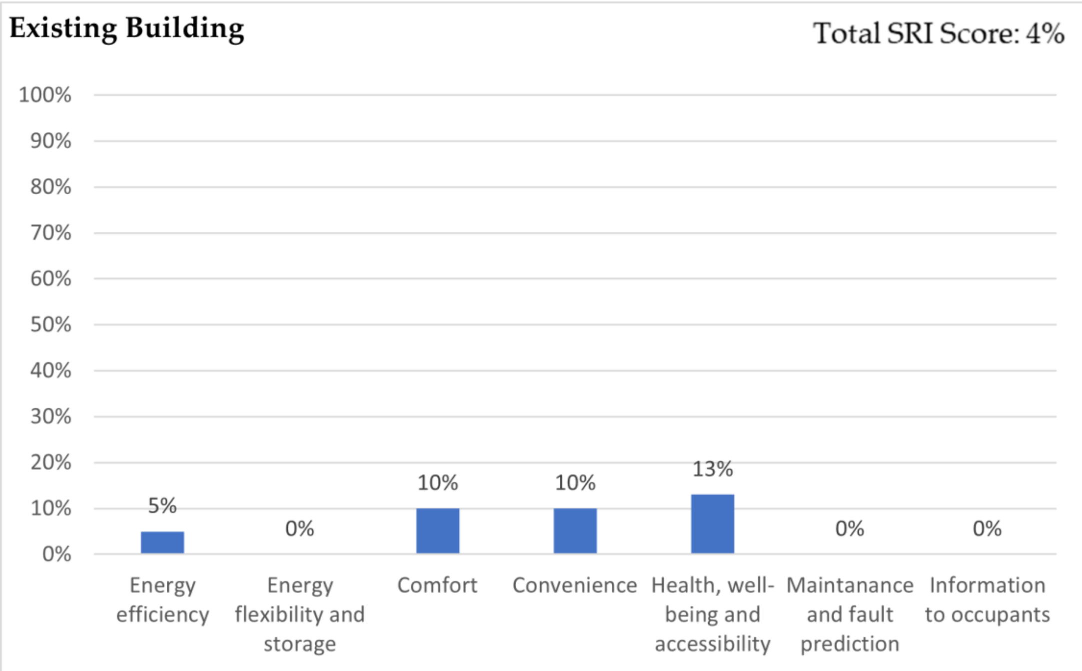

Figure 6. SRI for sub-scenario 1 of the existing building.

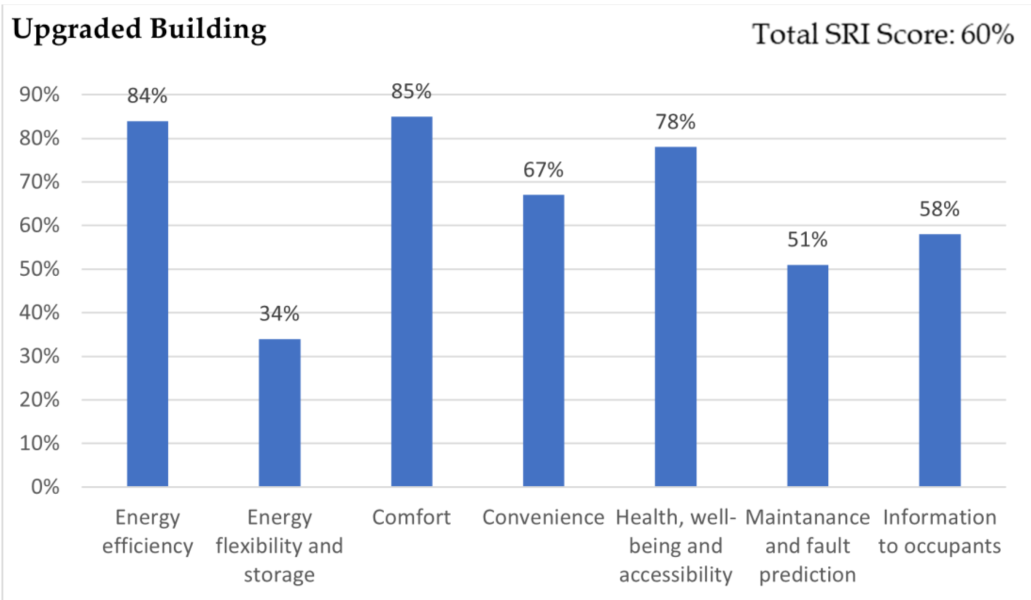

Figure 7. SRI for sub-scenario 1 of the upgraded version of the building.

From the results presented, it is evident that in the case of the existing building, very low SRI scores are obtained for all sub-scenarios, which is to be expected as the building is a conventional 1960s office building that has few of the smart services considered in the nine domains. In all sub-scenarios of the existing building, the indicator ranges from 4% to 8%. This practically means that the building's systems are outdated and energy inefficient, while at the same time, they do not offer ideal comfort conditions to users.

Moreover, the impact criteria "maintenance and fault prediction", "information to occupants", "energy flexibility and storage", and subsequently, the key functionality "energy flexibility" receive zero scores, significantly reducing the final score of the SRI and showing that the building's systems do not allow the network to adapt to the needs of users and energy demand. However, the highest value of smartness is the key functionality 2—used for all sub-scenarios of the existing building, but without reaching the desired levels. On the other hand, the low values of the indicator show that there is much room for improvement in terms of the smart readiness of the building, which is already evidenced by the much higher scores in the upgraded scenarios. This clearly shows that with some targeted interventions, the existing building can greatly increase its intelligence, which ultimately contributes to better living conditions for users and energy savings.

It is worthwhile to dwell on the discrepancies that arise in the various sub-scenarios where the weighting factors differ between them. In the first sub-scenario, the default weighting factors are used based on the initial calculation methodology of the indicator, which leads to the lowest values. In the second case, the results of the calculation of the energy balance are used and certain weighting factors affected by them are changed, without ignoring the other technical domains. In fact, the second sub-scenario adjusts some factors based on the energy balance analysis, ensuring a comprehensive inclusion of all technical domains. In the third sub-scenario, only technical sectors contributing to the energy balance are considered.

Each sub-scenario gives us different results, with the third sub-scenario always having the best scores, so the question arises as to which scenario most accurately calculates the indicator. In the first case we have a more general calculation model, which has been defined as a representative evaluation of the indicator, but the other two sub-scenarios are considered more representative as they modify weighting factors based on the actual data of the building and its energy efficiency. In order to find the most representative between the second and third sub-scenarios, we should take a close look at the technical domains and services of each. Although the third sub-scenario only takes into account the technical domains involved in the energy balance, it ultimately ignores the important factors that must be present in the calculation of the indicator, especially in cases where they are present, such as the participation of electricity, renewable sources, and air conditioning. This selective approach, despite yielding higher scores, could potentially miss critical elements required for a holistic assessment, especially when regulatory mandates necessitate the inclusion of renewable energy sources (RES).

A comparative analysis of these scenarios suggests that while the first offers a broad but less tailored evaluation, the third may provide an overly narrow focus on energy balance-contributing domains, ignoring other important sectors. The second sub-scenario; however, strikes a balance by recalibrating weighting factors based on actual building data and energy efficiency, without neglecting any technical domain. This method not only reflects the building's specific energy consumption patterns but also accommodates the broader spectrum of smart readiness features. Consequently, the second sub-scenario emerges as the most accurate and representative approach for calculating the SRI, effectively balancing detailed analysis with comprehensive coverage of the building's smart readiness capabilities.

Finally, there is a significant increase in the SRI in the case of upgrading of the building for all sub-scenarios. This is due to the new automation and control systems that are installed in the building, thus proving that with some targeted interventions the building can become significantly smarter, enabling the user to stay in a healthy and comfortable building, which promotes energy efficiency and convenience. Both the number of sectors and the increase in the functionality of services contribute to this huge rise in the SRI score. All impact criteria receive satisfactory values, showing a rapid increase compared to before, except for the criterion "energy flexibility and storage" which is still at low levels despite its increase. In the first sub-scenario, the value obtained by the indicator is much higher than that of the existing building and reaches 60%, while the other two sub-scenarios rate 67% and 68%, respectively. As in the existing building, this difference between the different sub-scenarios demonstrates that there may be large variations depending on the method chosen by the designer to calculate the SRI.

6. Discussion

This paper has delved into the smart readiness indicator (SRI) introduced by the European Commission, elucidating its final form as of September 2020 and exploring its practical implementation using a real building as an example. Valuable insights have been gleaned regarding the efficacy of the SRI as a tool and its potential impact on enhancing the efficiency and performance of buildings.

The SRI methodology, with its nine technical domains and seven impact criteria, has demonstrated remarkable flexibility in encompassing the myriad aspects that influence a building's performance. Notably, the delineation of three key functionalities—energy savings and operation, ability to respond to user needs, and energy flexibility—has underscored the essential requirements of contemporary buildings. Moreover, the incorporation of weighting factors tailored to the building's use and location enhances the SRI's adaptability and relevance across diverse contexts.

Furthermore, the introduction of weighting factors allows for taking functional and commercial parameters into consideration, which offers a well-needed degree of flexibility. Another comment that can be made, is the importance of the calculation of the individual indicators of the technical sectors and the key functionalities, through which it is possible to properly plan targeted interventions to upgrade the areas that need greater improvement. Similarly, the inclusion of renewable energy systems in a building's energy balance can possibly be considered with a higher weight, as part of Europe's climate neutrality goals.

A not less important conclusion that can be drawn is that the process of calculating the SRI indicator is not particularly demanding and is user-friendly. Finding the necessary data and technical documents of the building services of the building, such as heating, cooling, lighting, air conditioning, automation, and control systems is of major importance There are aspects that need to be more refined; for example, the levels of functionality that should be better clarified, to reduce the personal judgment factor to a minimum.

In addition, the application of the SRI to a representative Greek office building from the 1960s has shed light on critical areas necessitating improvement, such as outdated systems and the inadequate indoor environmental conditions of such buildings. This is being mirrored in the SRI results and the findings pinpoint the areas that need immediate improvement by means of targeted interventions. Whilst this is also achieved by the energy performance certificates, the SRI has two advantages that are important: (a) it emphasizes the importance of "smartness", mainly by means of automation and controls in a much more detailed way than EPCs do; and (b) it quantifies functionality, maintainability, and in a sense, the user-friendliness of the building, which is a critical parameter beyond energy efficiency. The SRI's meticulous analysis has provided a roadmap for targeted interventions to bolster the building's smart readiness, thereby aligning it with modern standards of efficiency and functionality.

Another issue raised during the SRI calculation process is that the evaluation of the functionality level of each service can be affected by personal judgment. The triage process is quite free and blurred in some places with the result that the indicator is ultimately largely affected by the evaluator's opinion. Another issue that needs to be further analyzed is the further separation of the weighting factors based on the use of the building and making the results even more accurate and representative. It is also necessary to redefine the thermal zones and weighting factors set by the SRI methodology, as the conditions of each country within each thermal zone can vary greatly. Representative examples are the data in the building that was studied, where the values of the weighting factors proposed by the SRI methodology are quite different from the reality. The "cooling" domain is much more important than suggested in the original model, while the reverse is true for the “heating” sector, which makes sense based on the climate of Greece, which has increased needs for cooling during hot summers. Based on the above, further separation is needed to cover all the climate conditions and building types.

However, the exploration of various sub-scenarios within the SRI framework has underscored a critical need for clarity from responsible authorities regarding the most accurate sub-scenario for SRI evaluation. This research reveals that the selection of an appropriate sub-scenario is not merely procedural but pivotal for ensuring the evaluation’s relevance and precision. As different scenarios may yield varying degrees of smart readiness, it becomes imperative for the guidelines to explicitly recommend or determine the most representative sub-scenario based on building characteristics and energy profiles. Such clarification will prevent the risk of selecting a less appropriate sub-scenario, thereby enhancing the assessment’s overall accuracy and utility. As we move towards a future marked by increased reliance on smart technologies and a pressing need for environmental sustainability, the SRI stands as a critical tool in this journey. This study not only contributes to the existing body of knowledge on smart readiness but also highlights the necessity for future research and policy development to refine and fully exploit the SRI for achieving our global sustainability and climate goals. The call for greater clarity on the selection of sub-scenarios is a step toward ensuring that the SRI can be applied more effectively and accurately across the diverse landscape of European buildings, paving the way for more intelligent, energy-efficient, and sustainable built environments.

Currently, the smart readiness indicator (SRI) calculation primarily relies on the structural components of buildings rather than on empirical data, limiting its precision and effectiveness. Two main calculation methods are in use: a simplified approach (method A) and a more intricate method (method B) which is more applicable to non-residential structures. However, discussions within the Directorate-General for Energy suggest the development of a third method (method C), grounded in actual measurable data. Method C, envisaged as a metered/measured approach, represents a significant advancement over the existing methodologies. In the foreseeable future, advancements in Technical Building Systems (TBS) and Building Automation and Control Systems (BACS) may enable self-reporting of functionality levels, complementing methods A and B. However, method C transcends this by quantifying the real-time performance of operational buildings. It necessitates benchmarking to evaluate the tangible benefits—such as energy savings, enhanced flexibility, and improved comfort—derived from smart technologies.

Alternatively, method C could expand the scope of the current SRI beyond smart controls, focusing on assessing actual building performance. Considering a potential future evolution of certification for commissioned structures, method C faces numerous practical and legal challenges, hindering its swift implementation. Consequently, it is not exhaustively explored in this technical study but is instead viewed as a prospective enhancement of the SRI framework. Embracing method C would propel the SRI to a more comprehensive level, integrating real-time data and emphasizing practical energy management and conservation alongside smart capabilities. This evolution underscores the multifaceted nature of building efficiency and underscores the importance of holistic assessment methodologies.

Moreover, it is essential to recognize that the smart readiness indicator not only contributes to enhancing building efficiency and performance but also plays a crucial role in fostering climate change resilience through smarter systems in residential buildings. By promoting the integration of automation and control technologies, the SRI facilitates the adoption of energy-efficient practices and reduces the carbon footprint of households. This aspect is particularly significant given the imperative to mitigate the impacts of climate change and ensure the sustainability of our built environment.

Furthermore, the SRI serves as a valuable decision-making tool for low carbon buildings, offering insights into the optimization of energy usage and a reduction in greenhouse gas emissions. Through its comprehensive assessment framework, the SRI enables stakeholders to identify areas for improvement and prioritize interventions that maximize energy efficiency while minimizing environmental impact. By aligning building performance with climate goals, the SRI contributes to the transition towards a low-carbon economy and supports efforts to combat global warming.

Looking ahead, future research endeavors should focus on refining the SRI methodology to encompass a broader spectrum of building types and climatic variations across Europe. Furthermore, exploring the integration of energy performance certification software with the SRI methodology holds promise for enhancing building assessment practices and fostering sustainable development. The relationship between the energy efficiency of buildings and the sophistication of their building automation and control systems for technical operations underscores the necessity of concurrently considering both facets to furnish a thorough assessment of a building's overall efficacy. This aspect carries significant implications for policy formulation, particularly concerning the revision of energy performance certificates (EPCs). The integration of SRI into EPC assessments could offer a more precise depiction of its energy performance and suggest the incorporation of smartness walk-through audits into future energy audits, alongside adaptations in energy upgrade measures to encompass smart technology enhancements. There exists a pressing need for deeper integration of the SRI into the evaluation of building energy efficiency. By amalgamating the SRI into energy efficiency evaluations, a more comprehensive understanding of building performance can be attained, facilitating the attainment of energy efficiency objectives and fostering sustainable development.

SRI represents a multifaceted approach to enhancing building intelligence, energy efficiency, and climate resilience. As we continue to confront the challenges of climate change and sustainable development, the SRI emerges as a vital tool for guiding decision-making, promoting innovation, and fostering a more sustainable built environment for current and future generations.

It is also imperative to recognize the pivotal role of SRI in elevating public awareness and understanding of the benefits inherent in smart building technologies. By rendering these advantages tangible to users, owners, and society at large, the SRI fosters a collective appreciation for the transformative potential of intelligent building solutions.

In summary, SRI emerges as a potent instrument for promoting smart building technologies and advancing energy efficiency objectives. By offering a comprehensive framework for evaluation and improvement, the SRI empowers stakeholders to make informed decisions and spearhead meaningful change in the built environment, thus paving the way for a more sustainable future.

7. Conclusions

In conclusion, this research has effectively demonstrated the applicability and significance of the smart readiness indicator in assessing and enhancing the smart readiness of buildings. By conducting a detailed examination of an office building in Greece, this study has shed light on the critical role that SRI plays in identifying opportunities for technological enhancements and energy efficiency improvements. The findings underscore the potential of SRI as a transformative tool for the building sector, enabling stakeholders to make informed decisions that align with sustainability goals and carbon footprint reduction efforts.

Moreover, the exploration of various sub-scenarios within the SRI calculation framework has provided valuable insights into the most accurate and representative methods for assessing a building's smart readiness. This nuanced approach to SRI application highlights the importance of tailoring the evaluation process to the specific characteristics and energy profile of each building, thereby ensuring a more precise and meaningful assessment.

The SRI scores for the existing building across the sub-scenarios were notably low, reflecting its outdated systems and inefficiencies, with values ranging from 4% to 8%. Conversely, the upgraded building scenarios demonstrated a significant improvement in smart readiness, showcasing the impact of targeted technological and energy efficiency interventions. Specifically, the SRI scores for the upgraded building reached up to 60% in the first sub-scenario and even higher, up to 67% and 68%, in the second and third sub-scenarios, respectively. These scores not only reflect the effectiveness of the chosen interventions but also highlight the transformative potential of applying the SRI framework to guide renovations.

In conducting the SRI evaluation for the office building, particular attention was paid to the accuracy and relevance of the chosen sub-scenario. Upon thorough analysis, the second sub-scenario emerged as the most accurate and appropriate for this study. This determination was based on its ability to closely align the SRI calculation with the building's specific energy balance and performance characteristics. Unlike the default weighting factors of the first sub-scenario, the second sub-scenario's recalibrated weighting factors reflect the actual energy consumption patterns and priorities of the building, without excluding the fixed and equal weighting factors that are also important, offering a more precise and representative assessment of its smart readiness. Moreover, it incorporates a comprehensive range of technical domains, ensuring that no critical aspect of the building's smart potential is overlooked. This careful selection underscores the importance of aligning the SRI evaluation method with the specific characteristics of the building under study, thereby ensuring that the SRI score accurately reflects its true smart readiness level. The decision to focus on the second sub-scenario highlights our commitment to methodological rigor and the pursuit of meaningful, data-driven insights into the building's smart readiness.

Furthermore, this research illustrates the pivotal role of the SRI in advancing the agenda for low carbon buildings, serving as an indispensable tool in the drive towards more sustainable, energy-efficient, and intelligent structures. By emphasizing the integration of smart technologies and practices, the SRI not only enhances building functionality and occupant comfort but also significantly contributes to the reduction in carbon emissions in the built environment. As such, the SRI emerges as a strategic component in the broader effort to achieve climate goals and highlights the necessity for continued exploration and application of this framework in the pursuit of low carbon building initiatives.

This study's focus on a building that epitomizes a common architectural era in Greece not only emphasizes the relevance of the SRI for a significant portion of the European building stock but also illustrates the broader applicability and impact of this research. By addressing the unique challenges and improvement opportunities of such buildings, the research contributes to a more comprehensive understanding of how to enhance the smart readiness of buildings across diverse contexts.

As the building sector continues to evolve in response to technological advancements and environmental imperatives, the SRI stands as a pivotal instrument for guiding progress towards smarter, more energy-efficient, and sustainable buildings. This research, therefore, not only adds to the body of knowledge on smart readiness but also paves the way for future investigations and applications that will further refine and leverage the SRI to achieve global sustainability and climate goals.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

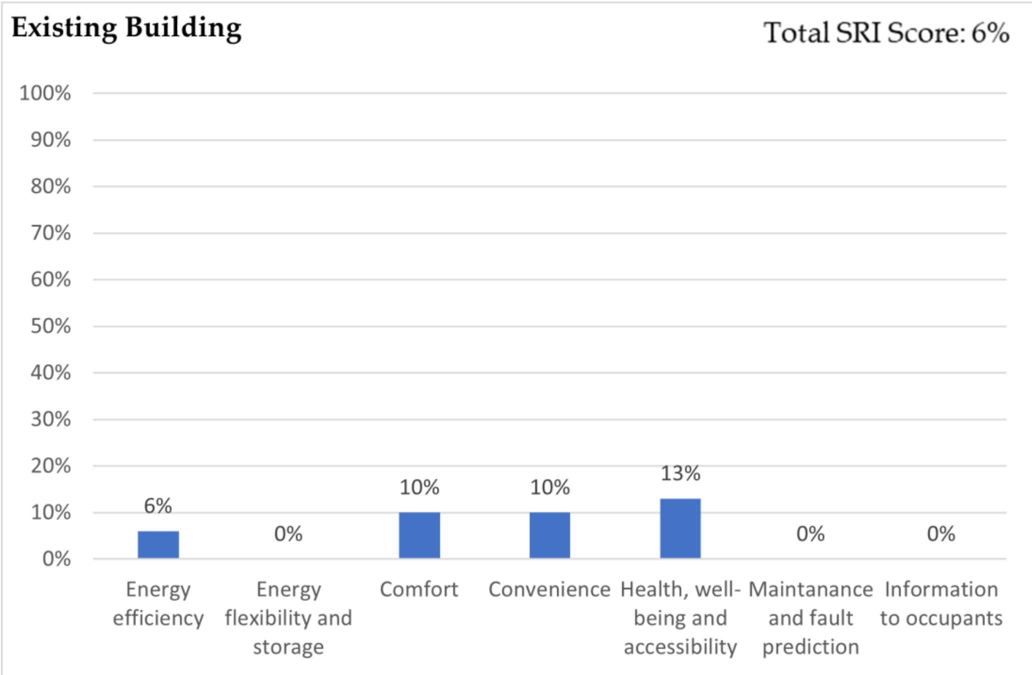

Figure A1. SRI for sub-scenario 2 of the existing building.

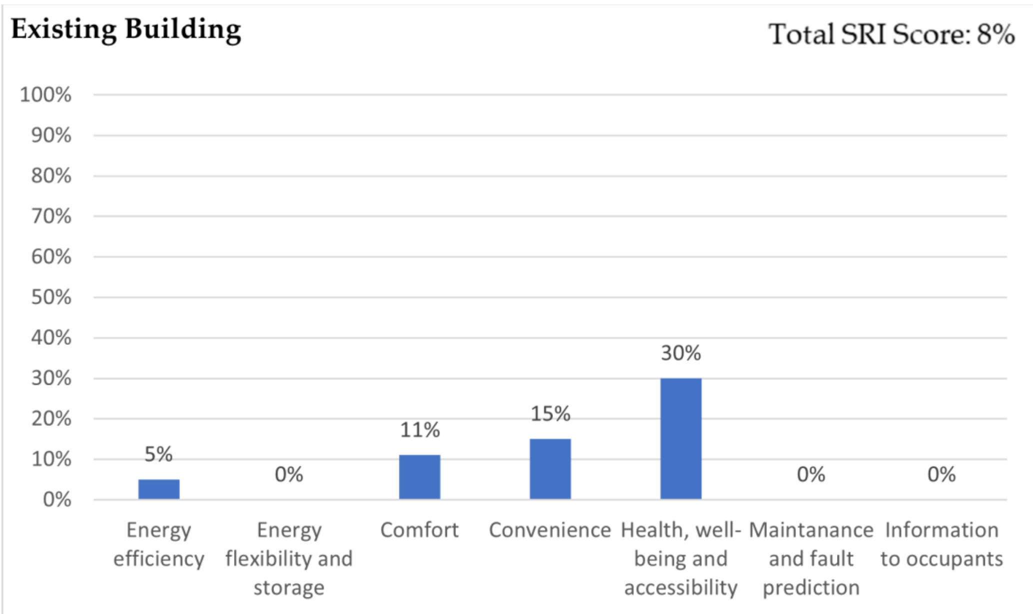

Figure A2. SRI for sub-scenario 3 of the existing building.

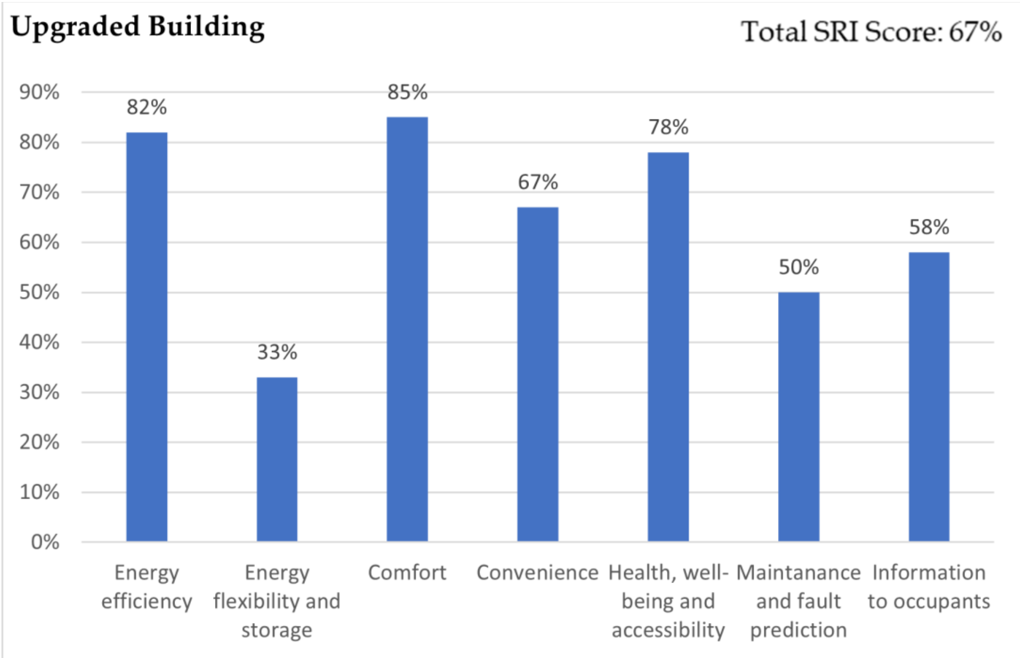

Figure A3. SRI for sub-scenario 2 of the upgraded version of the building.

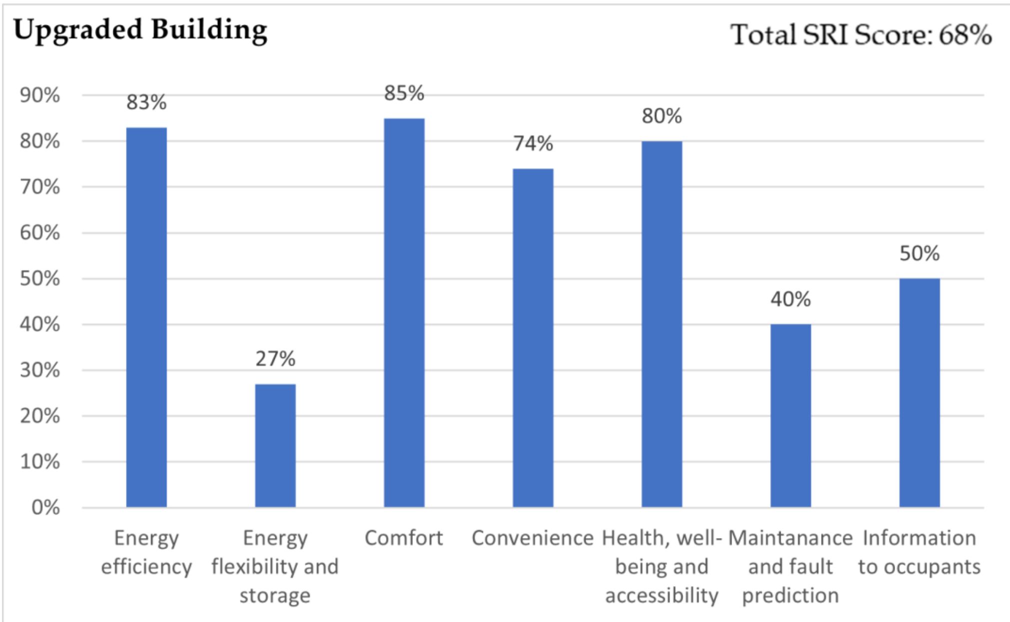

Figure A4. SRI for sub-scenario 3 of the upgraded version of the building.

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