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Review

How Are the Smart Readiness Indicators Expected to Affect the Energy Performance of Buildings: First Evidence and Perspectives

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Abstract: In 2018, the European Commission adopted the Smart Readiness Indicator (SRI) concept in the recast of the directive on the energy efficiency of buildings. The set of SRIs is a measure of the intelligence of buildings systems, and its promotion is expected to contribute to the energy savings of the building sector. These indicators are relatively new and were developed only at the beginning of last decade, within European standards. This study introduces and elaborates on these indicators, as delivered in the final report of the European Commission. Some first results, which are obtained using a tool developed by the European Commission, are also presented. The work identifies gaps and perspectives for improvement of this system, as well as predicting the evolution of its implementation in the coming years, through specific numerical scenarios.

Keywords: Smart Readiness Indicator (SRI); smart building; smart city; indicator

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1. Introduction

The efforts to save energy in the building sector are numerous and date back to the 1970s, with the issuance of the first relevant EU directives [1]. In recent years, and with the explosion of developments around smart buildings and smart cities, there is a strong connection between the field of energy saving and the intelligence of the built environment [2]. Methodologies have been developed that examine the impact of building intelligence on energy savings, but also the ability of smart buildings to integrate into smart cities [3]. At the same time, the digitization of the built environment with the use of digital design tools such as BIM reinforce this effort [4]. The rationale of intelligent design of the built environment also extended to special cases, such as insular systems [5]; at the same time, the management [6] and financing [7] of all these efforts are considered equally crucial for the successful establishment of smart buildings and smart cities.

According to the Directive 2018/844, an optional common Union scheme for rating the smart readiness of buildings should be adopted, based on indicators which were defined as the Smart Readiness Indicators (SRIs) [8]. The first reference to these indicators was found in the Clean Energy for All Europeans package [9]. According to this reference, SRIs should allow the technological readiness evaluation of a building's ability to adapt to the needs of its users as well as to the energy environment. This set of indicators should be a way of evaluating the capacity of the building to become more efficient, as well as to define the readiness of the interaction of a building with regard to its response to the district infrastructure.

A precursor of the SRI was the energy flexibility, which is defined as the potential for using a building for demand response [10]. In 2017, a discussion between the study "Support for setting up a

Smart Readiness Indicator for Buildings and related impact assessment" and the International Energy Agency (IEA) EBC Annex 67 concerning the Energy Flexible Buildings was established. The initiative of the IEA would provide support to the EU study concerning SRI. It is, however, foreseen that Annex 67 of the IEA framework for energy flexible buildings labelling will differ from the Smartness Indicators of the EPBD [11]. Junker et al. [12] presented a dynamic methodology for the definition of the energy flexibility of buildings, entitled flexibility function. The methodology was tailored for the requirements of the IEA Annex 67, but the authors claimed that this study could be a cornerstone for the SRI methodology.

According to the research project D^2EPC, which is funded by the European Commission, and concerns the next-generation dynamic digital energy performance certificates (EPCs) for Enhanced Quality and User Awareness, next-generation EPCs should introduce an agreed list of parameters concerning the level of smartness of buildings which will allow comparable good quality, in order to instill trust in the market and incite investments in energy efficient buildings. The assessment criteria of these SRI should be summarized on a set of criteria, including the heating, cooling, ventilation, lighting, electric vehicles as well as the smart grid integration potentials of buildings, as well as considering the share of renewable energy used in the buildings [13].

Due to the fact that SRI was developed and adopted from May 2018 to September 2020, at the timepoint this study is drafted there are still no sufficient references in the scientific literature for SRIs. Janhunen et al. [14] employed the SRI metrics to examine the economic viability of a real-life smart energy system investment in a building. In this study, though no obvious connection between the SRI performance and the monetization of energy savings is presented, as the authors explained, the SRI is a newly developed scheme which is anticipated to change. Märzinger and Österreicher [15] attempted to extend the scope of SRI, by delivering a set of equations which apply in the case of districts. This study builds on previous announcements of the same authors [16], which discussed the quantitative assessment of the load-shifting potentials in smart buildings. Vigna et al. [17] evaluated the SRI method, while it was still developed, by employing it to a nearly zero-energy office building located in Italy. The evaluation of the methodology was carried out in parallel by two different expert groups composed of technical building systems specialists and researchers. Janhunen et al. [18] also tested the applicability of SRI for countries with a cold climate, concluding that the SRI methodological framework is not applicable under such conditions.

2. Provisions of EPBD Recast (2018/844) on Smart Readiness Indicator

2.1. EPBD Recast

The SRI measures the ability of buildings to use building automation and communication technologies in order to adapt their operation to the needs of the users and the network, improving the overall energy efficiency. The SRI of Buildings aims to raise awareness among homeowners and tenants of the value of building automation and monitoring for building technical systems, and inspire tenants to adopt building smart technologies with new enhanced features. The commission adopted acts in order to amend the Directive 2010/31/EU to align with the technological progress by establishing the "Smart Readiness Indicator" of buildings and a methodology according to that which is calculated. For the commission, appropriate consultations, including experts, are particularly important during the preparatory work. Since December 2019, the commission adopted delegated acts in order to establish an optional common Union system for the assessment of the smart readiness of buildings according to Article 23 of the amended EPBD.

Since December 2019, The Commission consulted the parties concerned and adopted an implementation act specifying the technical details for the effective implementation of this system, including a timetable for non-binding pilot application at the national level. The SRI is based on features and capabilities resulting from more interconnected and smart devices. The methodology considers certain elements and their detailed functions such as Building Management systems, automation and control systems, self-modulated devices for thermal comfort, electric vehicle, charging points and energy storage. The methodology developed is based on three key functions related to building technical systems:

- The ability to adjust the energy consumption based on the demand of the users while maintaining energy efficiency levels;
- The ability to adapt the operation of the building according to the occupants' needs, considering human comfort conditions and providing the users with information about energy consumption;
- The building's flexibility in the overall electricity demand, including its ability to participate in both active and passive demand as well as its direct and indirect response to grid demand.

The methodology should also consider the interoperability between building technical systems and the positive impact of existing communications networks, in accordance to the relevant Union data protection and privacy legislation and best available cyber security techniques. Moreover, according to the EPBD recast, the SRI should be identified in a simple and transparent way in order to be easily understood by consumers, users and investors. The technical and policy-making processes for establishing the SRI that have developed over the last three years are approaching completion. Under current assumptions, the legal acts establishing the SRI scheme and detailing the technical modalities for implementing it should be adopted by the end of October 2020 [19].

2.2. Support for Setting Up a Smart Readiness Indicator—Current Status of Implementation

In order to support the new provisions of revised EPBD towards the uptake of smart technologies (SRT), two technical studies were conducted and supervised by the European Commission services (DG ENERGY). The studies intended to provide technical support to the Directorate-General for Energy of the European Commission services on the establishment of the methodological framework of SRI. The first technical study, which concluded in August 2018, was a preliminary investigation of the potential scope and characteristics the indicator. The outcomes of the study resulted in a multi-criteria assessment method of calculating the SRI based on a catalogue of various smart ready devices to be inspected in the buildings, based on various degrees of "smartness" referred to as "functionality levels". The services are divided into multiple domains (heating, cooling, ventilation, etc.) and associated with impact scores for the users and the grid. The individual impact criteria of devices, as well as their weight on the final SRI score, were also established in the first study. In order to avoid "unnecessary" or not-related services, the SRI methodology was normalised so that the inspected services' weight impact scores are harmonized to site-specific characteristics and climatic conditions.

Based on the capitalization of the technical inputs of the first study, the second technical support study was launched with the aim of finalizing the definition of the SRI by enriching the technical input associated with the calculation methodology. Moreover, the study explored potential implementation pathways as well as their impact on EU level. The second study resulted in two SRI assessment methods, introducing a third for future development. Method A is a simplified method suitable for residential and small-scale buildings which includes a simplified and reduced cervices list for the inspection. This method includes an online assessment tool that can be performed by the user in addition to the third-party assessment. Method B is a detailed assessment based on an enriched service check list. This method is addressed to non-residential buildings and can be performed by third-party qualified experts. The third method was only introduced for future development and will concern, in the first stage, a metered/measured method. The study concluded in December 2018, with the active participation of stakeholders and member state representatives. Relevant stakeholders participated throughout the entire study through open public consultations, provision of feedback, and the open public testing of a beta version of the calculation methodology, resulting in 112 assessments. The resulting calculation datasheets, as well as the Interim Reports of both studies, are available to the public through the official SRI website.

3. The Smart Readiness Indicator Assessment Scheme

3.1. Smart Readiness Indicator Domains Assessment

In order to establish the SRI methodology, three technical studies were prepared and delivered by Vito, on the request of the European Union [20]. In these studies, an assessment scheme for a brief and detailed classification of the smartness rate of buildings was developed. The Vito rating scheme assesses the following nine domains:

- Heating;
- Cooling;
- Domestic hot water;
- Controlled ventilation;
- Lighting;
- Dynamic building envelope;
- Demand side management;
- Electric vehicle charging;
- Monitoring and control.

Each domain has specific aspects and elements which are evaluated with regard to different impact categories, and its smartness rating is delivered based on the performance of each individual component (see Figure 1).

- **Heating and cooling systems** are assessed based on ten individual elements, four of which are also evaluated in the simplified scheme. The heat emission units are rated according to the units' control. The smartness scales consider different levels of control including central, individual or even occupancy detection control, the latter being the smartest level. Heat generators' intelligence is defined according to the variance in temperature control, which may depend on the ambient temperature or on the heating load. The fluid distribution network is assessed in accordance with the use of compensation and demand-based control. The functionality levels of the heat storage assess the availability of storage vessels and the capability of heat storage control with the use of external signals. As far as the distribution pumps are concerned, their functionality levels depend on the pump speed control. Similar functionality levels are also applied for heat pump units. Other building services which are included in the heating system rating include the performance of thermal activated building systems (TABS), the sequencing of the performance of different heat generators and the interaction of the heating system with the grid. Reporting of the performance of heating systems is similar in several domains and considers the real-time and historical data logging, as well as the preventive maintenance ability of the systems. Similar domains are also assessed for **cooling systems**. An additional element considered in cooling systems is the interlock of heating and cooling in the same thermal zone ("no interlock", "partial", "total interlock avoiding simultaneous heating and cooling");
- The assessment of **domestic hot water** is based on five categories. The domain is evaluated according to the energy source for heating, namely thermal boiler, electric heating with element, or heat pump and solar heating. For each of these services, the functionality levels range from on/off to demand and grid-oriented supply. Sequencing and reporting are also considered as performance criteria;
- **Lighting systems** are rated according to the control of the lighting system (on/off, dimmable, occupancy sensors) and the interaction between the artificial and natural lighting in a space;
- **Controlled ventilation** systems are assessed based on six categories, according to air flow, air temperature, heat recovery, free cooling and indoor air quality (IAQ). The air flow control at the room level is rated according to its control functions. The air flow control ranges from on/off to automatic control. The prevention of overheating is defined according to sensors in air exhaust

or multiple temperature sensors. The air temperature control at the air handling unit level are rated based on the control of the set temperature of ventilation. The free cooling with the mechanical ventilation system is assessed in accordance with the night cooling, free cooling and H,x-directed control. Another performance criterion for this domain is the reporting information regarding IAQ;

- **Dynamic building envelope domain** is evaluated in window shading systems with rating levels scaled according to the existence of manual or automatic control and if there is control based on combination with HVAC and predictive blind control;
- The assessment of **demand side management** is based on seven criteria. Storage of electricity is one of the categories and is evaluated according to the technology energy that is stored. The optimizing self-consumption of locally generated electricity is defined according to the scheduled or automated management of electricity consumption based on renewable energy availability and predicted energy needs. The combined heat and power plant (CHP) is rated according to the different levels of control, based on scheduled management, on RES availability and the correlation with the grid. Support of grid operation modes is also an assessed criterion and is defined according to the variance in the automated management of electricity consumption and supply. Reporting regarding local electricity generation, energy storage and electricity consumption is used for evaluation, considering values, historical data, real time feedback, performance and benchmarking;
- The assessment of **electric vehicle charging** is based on EV charging capacity where the functionality levels depend on the percentage of the parking spaces with charging points. The assessment is also based on EV charging grid balancing defined according to uncontrolled charging, and one-way and two-way controlled charging, and finally is based on the EV charging information and connectivity;
- Concerning **monitoring and control,** the final domain is based on eight categories. The main aspects which are examined are the run-time management of HVAC systems and the ability to detect faults in the technical buildings of systems. The occupancy detection, the central reporting, the smart grid integration and the interaction with the DSM are also rated.

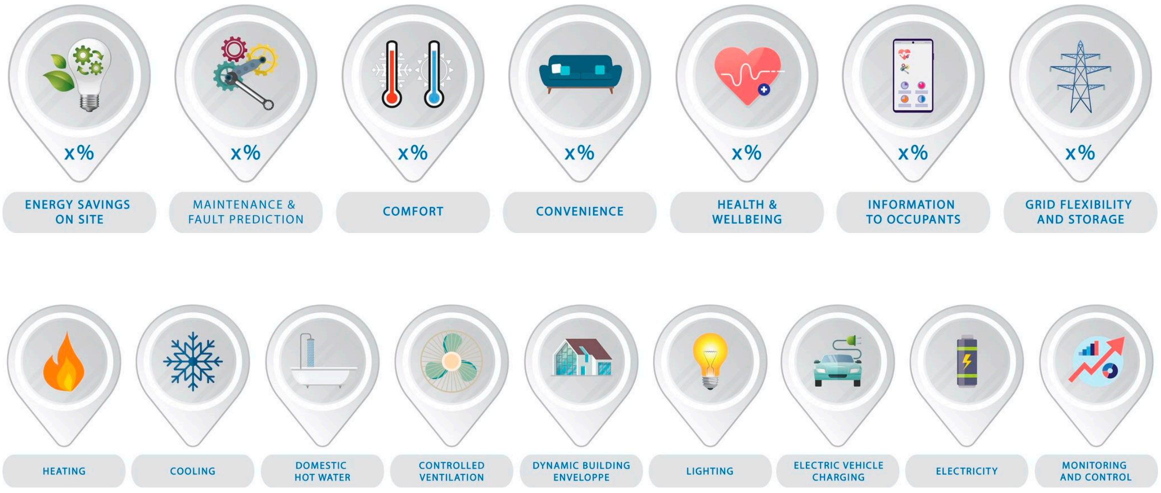


Figure 1. Smart Readiness Indicators' domains and impact categories.

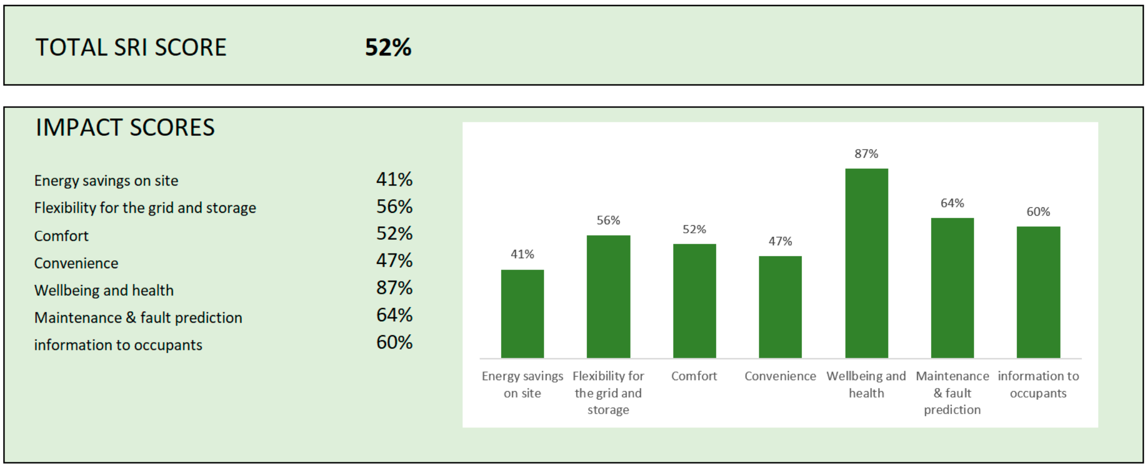
3.2. *Smart Readiness Indicator Worked Example*

In this section, a worked example of the calculation of the SRI indicator is presented. The calculation was performed for a building of mixed use, and particularly for the main wing of Frederick University in Cyprus. Frederick's new wing building is a two-storey 2000 m^2 building, built in 2007. University's cafeteria is on the ground floor; on the first floor, there are three seminar halls with capacity for 220 students and offices are found on the second floor (see Table 1). The building can host up to 390 people. The services that are provided within the building include heating, cooling, ventilation, lighting and electrical appliances. A 3 kW Solar Water Heating System is currently installed in the building. The building has already a BMS system installed for the monitoring and control of the building's HVAC systems, lighting and appliances.

The building was initially simulated with regard to its energy performance with a BIM tool (Autodesk Revit) and the energy loads of the buildings were extracted with the use of the Energy Assessment tool of Revit, which used the calculation procedures of Energy Plus. In Figure 2, the construction details and the simulated drawings of the case study are presented. The calculation of the energy loads of the building, as well as loads of alternative assessments of the building, are provided in Table 2.

Figure 2. Building Sections and Plan Views—Frederick University, Nicosia Campus.

Figures 3 and 4 present the SRIs of the investigated case study. As can be seen, the total SRI score of the examined case study is at 52%, whereas the assessment of the individual domains reveals that the control and monitoring aspects of the examined building are quite high, mainly due to the installed BMS system of the building. A major finding is the fact that although the building appears to have a relatively good score in SRI, its energy class according to its energy performance certificate is D, revealing that the actual energy performance of the examined building is not in line with its smartness.

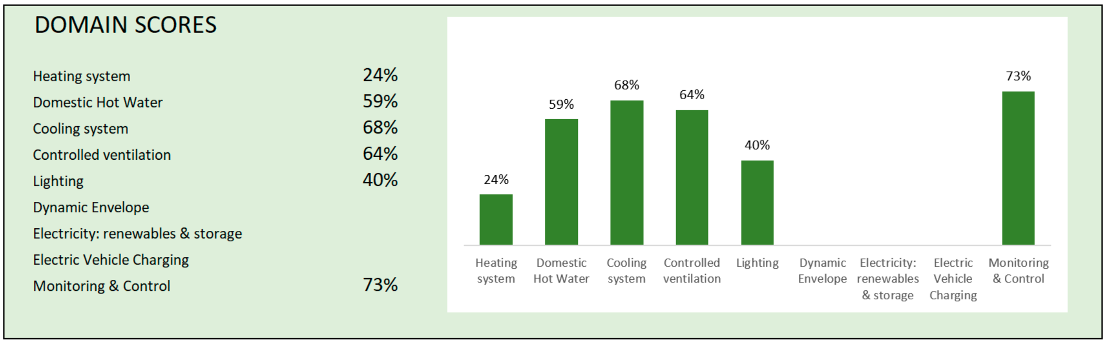


TOTAL SRI SCORE 52%

IMPACT SCORES

Energy savings on site	41%
Flexibility for the grid and storage	56%
Comfort	52%
Convenience	47%
Wellbeing and health	87%
Maintenance & fault prediction	64%
information to occupants	60%

Figure 3. Total SRI score assessment of case study building.



DOMAIN SCORES

Heating system	24%
Domestic Hot Water	59%
Cooling system	68%
Controlled ventilation	64%
Lighting	40%
Dynamic Envelope	
Electricity: renewables & storage	
Electric Vehicle Charging	
Monitoring & Control	73%

Figure 4. SRI domain scores of case study building.

Table 1. SRI case study—information.

Area/Construction Date	**Living Area of 2000 m^2/2007**
Building materials/elements	Hollow Bricks, Plaster, Reinforced Concrete, Double Pane Glazing, Central Cooling-Heating System, BMS unit
Energy Usage	Total Energy consumption: 140 kWh/m^2/year Heating-Cooling: 90 kWh/m^2/year
Existing EPC scale	Class D

Table 2. CO_2 equivalent emissions of buildings performance (kg CO_2).

	Electricity	**Natural Gas**	**LPG**	**Biogas**	**Biomass**	**Diesel Oil**
Heating	62,217.3	6193.2	7949.1	798.1	798.1	8491.8
Cooling	277,705.7	–	–	–	–	–
Interior Lighting	63,224.9	–	–	–	–	–
Interior Equipment	55,303.6	–	–	–	–	–
Total Primary End Uses	458,451.6	402,427	404,183	397,032.3	397,032.3	404,726.1

4. SRI Gaps and Future Perspectives

4.1. How Ready Are the Smart Readiness Indicators?

SRIs were developed in 2017 and relied heavily on EN standards [21], as well as on the VITO project delivered in terms of the ENER/C3/2016-554 tender [20]. The development rationale of the indicators was based on a significant sample of building systems and considered common practices in the perception of a system's performance. It is certain, however, that this first approach will need to be revised in the near future. Specifically, the precision of the evaluation based on the proposed levels of functionalities will need to be improved based on the intelligence results obtained from a significant sample of buildings. An observation resulting from the first application of the scheme is that, in the case of small buildings where there are no built-in Building Management Systems (BMS), the results are worse compared to the performance of large buildings that have the ability to install BMS. This result is not objective, as there are cases of residential buildings that incorporate several smart provisions but fail in their assessment due to the lack of a central monitoring and control system. At this stage there is no commonly accepted database from which building designers and engineers can draw data on the intelligence of building systems. This fact includes, in some cases, the element of subjectivity in the evaluation of the devices of buildings, which is currently based on the understanding and the perception of the designer. Therefore, there is a need to create a common database for assessing the intelligence of building systems.

4.2. SRI Integration into Energy Performance Certificates

Energy efficiency certificates have been at the forefront of European building energy efficiency policy since the early 2000s. The impact of this measure on reducing energy consumption in the building sector in Europe is very significant. This measure has essentially led the developments in this area, and has managed to lead to significant savings in the energy sector. At the present stage of development of SRIs, there is no provision for the integration of this scheme into the energy certification procedure of buildings. The case study presented in Section 3.2 revealed that a building with energy class D revealed a good SRI, proving that steps still need to be made in order to align the SRI with the EPC. This constitutes a major challenge for the energy-related policies of the Member States of the European Union. The development of a comprehensive methodology, by which the intelligence readiness of buildings will be included in the energy class of the building, is of particular importance. This methodology should obviously be based on standardized procedures, therefore there is a need to develop relevant standards that will incorporate this methodology. This should result in the integration of the SRI score of a building to its energy performance certificates, contributing also to the calculation of the energy class of the building. Ideally, in the near future, the SRI evaluation should be an element of the final result of the energy certification of the buildings. Some first efforts to fulfil this gap have already been documented [13].

4.3. Historic Buildings-Tailored SRI

Around 25% of the building stock in Europe was constructed prior to 1950. These buildings, although they are highly valued for their architectural significance, use inefficient building systems. The need to preserve authenticity restricts recently developed building systems solutions to be adapted for use in historic buildings. The SRIs aim to strengthen energy saving policies and practices in buildings. Under these conditions, one would expect the index to apply to all categories of buildings. However, there is at least one category of buildings to which the SRI rationale does not apply, and this is historic buildings. As an indicator that is mainly related to building systems, the SRI ignores a large category of buildings in which there are practical difficulties and general limitations. Specifically, the indicator:

- Does not recognize realities such as the general limitations that exist in historic buildings for the installation of advanced building services and automation systems;
- Does not record the potential smart applications for controlling energy consumption in historic buildings;
- Does not propose a different system for assessing the intelligence of historic buildings.

This gap is considered to be quite significant, and widens the gap that currently exists in the field of energy evaluation and energy saving in historic buildings. The solution in such a case would be quite simple, and would be none other than creating a tailored scheme for the smartness assessments of services installed in historic buildings. Such an evaluation system requires the recognition of the practical difficulties that traditional buildings face in the installation of many of the systems characterized in the SRI, but also the recording and classification of potential intelligent system solutions in historic buildings.

4.4. Requirement for Sectoral SRIs

The discussion concerning the non-applicability of SRIs to historic buildings sheds light on the need for the development of different schemes of SRIs for different types of buildings. Especially if the tertiary sector is concerned, it is obvious that, based on the activity of the user of the building, the requirements for the control and monitoring of building systems will differ significantly. Taking the example of a restaurant's kitchen, the smartness of the equipment will be judged mainly on the technical features of the ovens, the fridges and the dish-washers. At this point, the SRI does not assess this equipment, whereas a detailed assessment of this equipment would have been of no particular interest for an office or an educational building. This rationale is better understood if the paradigms of sustainability schemes such as the LEED [22] or the BREEAM [23] are considered. Under these schemes, the sustainability of buildings is assessed based on different criteria, according to the type of building. To this end, BREEAM schemes include, for instance, new UK construction, international new construction, UK refurbishment and fit-out, and international refurbishment and fit-out. This leads to the conclusion that, sooner or later, sectoral SRIs and evaluation schemes will need to be developed, which will recognize the variance in the building systems, and their significance per building type.

4.5. SRI Minimum Requirements for New Buildings and Cost Effectiveness

SRI started as a voluntary scheme, which the EU member states were not obliged to transpose to their national legislation. This means that, at this stage, the member states are not required to bring into force regulations, laws and administrative provisions to comply with the SRI scheme. However, this measure will most probably become mandatory, in order to support the energy savings in the building sector. Should that be the case, it is anticipated that the member states will need to define minimum requirements for the SRI total scores for new or refurbished buildings, in a similar manner to the requirements set for the energy performance of buildings. This discussion is anticipated to be initiated in the following years, and it is expected that exercise on a national level will be required to define, in a realistic manner, the minimum levels of SRIs. These indicators might be defined as a total score or even by building device category (for heating, cooling, domestic hot water, etc.). Inevitably the minimum criteria will need to be based on one of the main principles of all European directives for the energy performance of buildings, and that is cost-effectiveness. Therefore, a methodology will need to be defined for the calculation of the cost-effectiveness of building systems' smartness, in a similar manner to the methodology described in Regulation 244/2012 of the European Commission, which establishes a calculation procedure of cost-optimal levels of minimum energy performance requirements for buildings and building elements [24]. This development will lead to the need to monetize the smartness of equipment in terms of energy savings, an exercise which will initiate scientific discussion on this topic.

4.6. Integrating SRI into Practices of the Sustinable Built Environment

In order to establish SRI as a tool that can assess the intelligent behaviour of buildings, the indicator should gradually be integrated into other existing practices of sustainability of the built environment. The following three practices are indicative:

- Life cycle analysis;
- Building sustainability systems;
- Digitization of building design practices.

In terms of life cycle analysis, the practices of holistic definition of environmental impacts from buildings are well identified and established [25]. It is therefore understandable that the next step will be intelligence indicators to consider the environmental performance of a building, according to its ability to dynamically reduce its impact on the environment, by integrating smartness into LCA indicators. As far as sustainability schemes are concerned, due to the fact that they are also a rating scheme of buildings, it is expected that in the near future they will have to be remodelled in such a way that they will also consider "buildings' IQ" as a sustainability indicator. This could be accomplished by simply including the SRI as a building assessment indicator, in the same manner as the EPC rate is currently considered, or even by developing a parallel SRI calculation methodology from data collected during building sustainability assessment. The epitome of integrating SRI into building sustainability practices is expected to be the extraction of SRI from data collected during the digitization of buildings, with tools such as digital log books or BIM files. Such a development will simplify the export of the index and will lead to its establishment.

5. Conclusions

It is obvious that the building physics community is facing a major transition in the way we evaluate the energy behavior of buildings. The integration of SRI is a key development and, at the same time, a major challenge for the research community of building physics and building systems. Like any major change, researchers and scientists should support the development and establishment of SRI through analysis of its aspects. This work aimed to be a first attempt to present and evaluate the SRIs. Although the indicators are very promising, they are still in their infancy, and therefore there are several aspects of them that need to be improved. The indicators should be integrated into other energy-efficiency assessment processes of buildings, and should be broadened to consider the specificities of building types. At the same time, the indicators should lead the developments in the field of building systems, through the establishment of minimum requirements for SRIs. This development requires the monetization of the index, a methodology to which the scientific community should turn its attention in the near future. In general, however, the indicators' first announcement considers most aspects of buildings, and is a good starting point for a comprehensive assessment of building intelligence.

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