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To achieve the energy and emissions reduction goals for the building sector, actions are needed to improve energy efficiency and occupants' wellbeing. To increase the uptake of smart technologies and the awareness upon their benefits, in line with the smart building revolution that is starting, the EPBD recast introduced the Smart Readiness Indicator (SRI) as a tool to evaluate the capability of buildings to easily adapt to both energy systems and occupants' needs. However, there is a growing interest in studying the SRI features in terms of performance assessment, and, thus, dynamic simulation models can be exploited to better analyze its points of strength and weakness. The Energy Center building of Turin was chosen as case study. By means of EnergyPlus modeling, the current situation was simulated, as well as different scenarios of energy management and control, evaluating to what extent these actions can influence the overall SRI assessment. The analysis allowed to deepen and comment on the effectiveness of the SRI of being a real tool of building behavior assessment, able to link the indicator itself with the energy needs of the building and to understand if and how the indicator is sensible to energy needs variations.

Keywords: Smart Readiness Indicator; dynamic energy simulation; smart buildings.

1. Introduction

Buildings are experiencing a transition phase, from unresponsive and highly-energy-demanding elements to highly-efficient micro energy-hubs, which consume, produce, store and supply energy, making the energy system more flexible and efficient (BPIE 2016). However, still the energy and environmental impact of the building stock is relevant, and, thus, in order to reach the ambitious energy and emissions reduction goals identified for it, strong efforts should be put on existing buildings, which play a crucial role in this context. Indeed, about 75% of European buildings are energy inefficient and since, on average, less than 1% of the national building stock is renovated each year (Member States renovation rates range between 0.4% and 1.2%), in order to meet the European Union (EU) climate and energy objectives, the current rates of renovation should at least double (European Commission 2020). Therefore, given the above, it is clear that an acceleration towards a cost-effective renovation of the building stock is needed, in order for it to represent “a win-win option for the European Union economy as a whole” (Saheb Y. et al. 2015), as well as to face and support the future challenges of sustainability, digitalization, decarbonization and circularity. In this context, the Energy Performance of Building Directive (EPBD) recast of 2018 introduced the Long-Term Renovation Strategies (LTRSs), in order to push Member States towards the achievement of a decarbonized building stock by 2050, and to effectively drive the transition of national poorly efficient existing stocks towards Nearly-Zero Energy Buildings (NZEB) (European Commission 2018). Specifically, LTRSs identify a set of policies and actions to stimulate a cost-effective deep renovation of the building stock and to promote the deployment of smart technologies and the diffusion of well-connected buildings and communities, improving at the same time skills and knowledge in the construction sector (European Commission 2018). Moreover, the EPBD revision pushed for reinforcing the use of continuous electronic monitoring and building automation and control within buildings (REHVA).

In this framework, the concept of smartness is getting importance. Even though the discussion about “intelligent buildings” dates back to 1980s (Sinopoli 2010), it is with the last EPBD recast (European Commission 2018) that smartness has been recognized as one of the crucial keys for the building sector to achieve its energy and emissions reduction goals in the framework of a climate-neutral Europe by 2050 (European Commission). Many studies dealt with the definition of smart buildings and the identification of their main features. For the sake of exemplification, Table 1 offers a general overview of the main features of smartness defined for the buildings over the years. From the table, automation appears to be one of the essential aspects for the evolution of the concept. However, besides the single elements and definitions, the crucial point of a smart building environment is that each feature must work simultaneously and synergically with the others, to fully exploit the smartness potential of buildings. Moreover, in recent years, emphasis was put on the role of occupants, who are considered as the beneficiaries of the smart building revolution, together with the energy systems (BPIE 2017a).

Table 1. What makes a built environment smart according to different literature sources.

Sinopoli (2010)	**Lê, Hoang Boi, and Barnett (2012)**	**BPIE (2017b)**	**Energy & Strategy Group School of Management PoliMi (2019)**	**Al Dakheel et al. (2020)**
A smart building involves the installation and use of advanced and integrated building technology systems, including: a) building automation; b) life safety; c) telecommunications; d) user systems; e) facility management systems.	The five basic features of smart homes: a) automation; b) multi-functionality; c) adaptability; d) interactivity; e) efficiency.	The five pillars of a smart building: a) efficient and healthy; b) dynamic operability; c) responsive energy systems; d) renewable energy uptake; e) dynamic and self-learning control systems.	The key components of a smart building: a) building devices and solutions; b) automation technologies; c) management and control systems; d) connectivity e) human component.	The four main features a smart building must have: a) climate response; b) grid response; c) user response; d) monitoring and supervision.

As stressed by BPIE (2017b), the level of smartness of the built environment needs to be strongly accelerated, since Europe seems not to be fully prepared to the smart building revolution. However, it is important to reflect on the fact that what is technologically possible now, thanks to the diffusion of smart meters, Internet of Things (IoT) and Artificial Intelligence (AI) instruments and to connectivity development, was completely out of focus in the (recent) past for the building stock. For this reason, and due to the higher digitalization potential offered by current market solutions, it is important for renovation to become smarter. In particular, traditional definitions of renovation, as the one provided by the Amsterdam Institute for Advanced Metropolitan Solutions (2017), where renovation was defined as the process of "restructuring of existing housing stock to increase buildings' resource efficiency and resource generation capacity involving a structural change in energy and informational flows, actor relations, governance arrangements, and consumer practices", still do not include some aspects related to the building smartness (e.g. building interaction with the grid, building response to climate and occupants' needs) (Al Dakheel et al. 2020). Therefore, as well stated by Al Dakheel et al. (2020), a new definition of smart retrofit should be introduced, defined as "the process to transform the existing building into a smart one, that is a NZEB with the capability to respond to the changing conditions of climate and grid, communicate with the user and predict failures in its operations, through the use of Information and Communication Technologies, Renewable Energy Sources and Building Energy Management Systems" (Al Dakheel et al. 2020).

As the evolution of the smartness concept continues, it is crucial to investigate which tools could support it. In particular, an indicator of interest is the Smart Readiness Indicator (SRI), which was introduced by the last EPBD recast as an effective tool to evaluate and characterize a building according to its smartness, or better, its readiness to smartness (European Commission 2018). The SRI is intended to provide a measure of the building capability to adapt to grids and occupants' needs through electronic systems and information and communication technologies, as well as to evaluate the building overall energy performance. Clearly, the SRI represents a new indicator for the building sector, which can be used to introduce the assessment of the smart services and features of a building into its overall performance evaluation. In this sense, it is interesting to evaluate how and if this new information could communicate with the traditional and well-established methodologies for assessing buildings energy performance.

When considering the energy evaluation of buildings, Energy Performance Certificates (EPCs) appear to be consolidated approaches, aiming to express the energy behavior of buildings based on energy or environmental metrics (e.g. primary energy consumption, energy use intensity, CO_2 emissions, etc.), thanks to the deployment of energy simulations, mainly steady-state. However, EPCs usually assess the energy performance of a building according to standard patterns, which often are not able to take into account the complexity behind the effective building use and the real occupants' behavior. In order to better describe a more realistic building use and energy behavior, dynamic simulations are often deployed as useful tools to investigate the operational conditions of buildings, as well as to test and simulate different strategies of management and control of the devices that might be potentially installed. Even through dynamic energy simulations, typical energy and environmental Key Performance Indicators (KPIs) can be obtained and compared with existing benchmarks, if any.

As the dynamic simulation tools, also the SRI allows to evaluate the operation dynamics of a building, even if with a different perspective, by qualitatively analyzing the smart services present within the building under investigation and highlighting its overall readiness to smartness, without studying its use in energy terms. Even if the SRI tool could be used for buildings not yet constructed, in-use buildings are its main target, justified by the possibility to perform an on-site assessment in support to the overall evaluation.

Due to the diverse information that these tools (energy simulation on the one hand, and SRI on the other hand) can manage and provide, this paper aims to investigate the possibility to connect the results of the SRI assessment with the ones of the dynamic simulation. In particular, it is of interest to understand if the potential introduction of some smart services or the enhancement of the management of the existing ones might be read as an improvement of both the overall SRI score of the building and its energy performance (i.e. reduction of building energy needs). In other words, the study intends to explore if the SRI score is sensible to the improvement of the energy performance, exploring if a building that performs better (i.e. with lower energy needs) can be also considered as smarter (i.e. with a higher SRI).

The dynamic simulation modeling is used as an instrument to test and assess the effectiveness of the SRI, as well as a powerful tool to reproduce the behavior of a building and its occupants, taking care of its dynamicity. Considering the growing interest in studying the possibilities and criticalities of the SRI regarding the performance assessment, in terms of complexity, replicability and specificity, the analysis allowed to deepen and comment on its efficacy of being a real tool of building behavior assessment, able to link the indicator itself with the energy needs of the building, as well as to understand if and how the indicator is sensible to energy needs variations.

In line with the above, the paper aims to explore different levels of knowledge and detail of a new office building located in Turin (North-West of Italy), the Energy

Center at the Politecnico di Torino, selected as case study, being an example of newly-constructed office buildings. First, the building was analyzed through the calculation of the SRI, which allowed to synthesize the overall building technological features and readiness to smartness, in terms of capability to easily respond and adapt to both energy systems and occupants' needs, through the use of a multi-criteria assessment method. Then, using the EnergyPlus simulation tool, an energy-dynamic model of the building was developed and calibrated according to available project data. Different scenarios of building energy management and control were simultaneously simulated using EnergyPlus and assessed through the SRI calculation, in order to evaluate to what extent the SRI assessment would be sensible to these actions, and thus to investigate if SRI scores and building energy results could go hand-in-hand in representing the overall performance of the building.

Some insights on the SRI definition and assessment are reported in section 2; section 3 describes the main methodological steps through which the analysis is conducted, while section 4 reports their application to the Energy Center case study. Finally, the main results and their discussion are summarized in section 5, while section 6 draws the main conclusions and the future perspectives.

2. Smart Readiness Indicator: main features and assessment method

As previously mentioned, the Smart Readiness Indicator was introduced in the EPBD revision of 2018, as a tool for easily expressing in a unique value the readiness to smartness of buildings. Supervised by the European Commission DG Energy, the SRI development involved different actors towards its final definition on September 2020, when the final deliverables were released. The calculations of this paper referred to the Interim Reports (VITO, Waide and DG Energy Commission), due to the fact that authors participated to the SRI public bèta testing in 2019, using the Energy Center as case study.

As underlined in the EPBD revision (European Commission, 2018), "the methodology shall rely on three key functionalities relating to the building and its technical building systems:

- the ability to maintain energy performance and operation of the building through the adaptation of energy consumption for example through the use of energy from renewable sources;
- the ability to adapt its operation mode in response to the needs of the occupant while paying attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and the ability to report on energy use;
- the flexibility of a building's overall electricity demand, including its ability to enable participation in active and passive as well as implicit and explicit demand response, in relation to the grid, for example through flexibility and load shifting capacities."

The methodology proposed for the SRI calculation exploits a multi-criteria assessment method to score the smart-ready services and technologies present within a building, involving nine domains (i.e. the categories to which a certain service belongs) and seven impact criteria, to evaluate the impact of the assessed services around the three EPBD pillars: energy performance ("Energy Savings on Site", "Maintenance & Fault Prediction" impact criteria), users ("Comfort", "Convenience", "Health & Wellbeing", "Information to occupants" criteria) and grid ("Flexibility for the Grid & Storage" criterium). Focusing on the default method, which is of interest for this paper, the streamlined service catalogue proposed 54 smart-ready services, each representing a particular service potentially present in a building and belonging to a specific domain.

For the sake of exemplification, for the “Heating” domain, “Heat emission control” is considered a smart-ready service, while “Occupancy control for indoor lighting” is a service belonging to the “Lighting” domain. Domains and impact criteria are reported in Table 2.

Table 2. Domains and impact criteria extracted from (VITO, Waide and DG Energy Commission).

DOMAINS	IMPACT CRITERIA
Heating	Energy Savings on Site
Domestic Hot Water	Maintenance & Fault Prediction
Cooling	Comfort
Controlled Ventilation	Convenience
Lighting	Health & Wellbeing
Dynamic Envelope	Information to occupants
Electricity	Flexibility for the Grid & Storage
Electric Vehicle (EV) Charging	
Monitoring & Control	

The overall SRI score is a percentage value that indicates how close (or far) the building under study is with respect to the maximum smart readiness it could achieve. By definition, the higher the final percentage, the smarter the building is. It is important to specify that the SRI calculation is building-specific, and thus the maximum smart readiness (based on which the final score is compared) is not calculated considering the entire set of 54 smart-ready services a priori. Indeed, services are distinguished between: i) relevant, because present in the building under study; ii) desirable from a policy perspective, even if absent in the building under study; and iii) not relevant, since for instance they can be considered as mutually exclusive.

The services to be considered in the SRI assessment for a building are identified based on this definition of relevance, according to which, depending on the building specificities, some services could be excluded from the assessment. In order to assess the SRI for a specific building, the general methodological procedure for its assessment can be summarized in the following steps:

(1) An initial triage process is conducted, through which the relevant services within the building under investigation are determined. This step is of fundamental importance, since it allows to identify the overall number of services involved in the assessment (excluding the not relevant ones from the total of 54 potential services). Specifically, using a check-list approach, the smart-ready services present in the building under study are individually assessed, by determining their associated functionality level. A higher functionality level means a smarter implementation of a service, providing more benefits if comparing with a lower one. Then, for each service, an impact score is assigned for each of the seven impact criteria involved in the assessment.

(2) Once the impact scores for all the individual services are obtained, an aggregated impact score is evaluated, for each of the nine domains, as the ratio between the individual scores of the domain services (according to the functionality level assigned) and the theoretical maximum individual scores achievable.

(3) For each impact criterion, a sub-score is then calculated as the weighted sum of the domain impact scores; at this point, the weight of a certain domain will depend on its relative importance for the considered impact.

(4) The overall SRI score is finally derived as the weighted sum of the seven impact criteria, taking into consideration the relative importance of each impact criterion in defining the smart readiness of the building.

According to the methodological approach, ad-hoc weighting factors are used to evaluate the influence of the domains over the impacts. Energy balance factors, which can be either defined by default considering the climate zone and the intended use of the building, or possibly tailored according to the building EPC, are introduced for the impacts belonging to the EPBD pillars of “energy performance” and “grid”; instead, as regards the EPBD pillar “occupants”, equal weights are shared among the domains. Moreover, for some domains involved in the energy balanced impacts (e.g. “Monitoring & Control” and “Dynamic Envelope”), fixed weights are considered. To compute the final score, specific weights are assigned to each impact criterion, defined on the basis of the three key EPBD pillars subdivision (VITO, Waide and DG Energy Commission).

According to its definition and scope, the SRI aims to raise awareness about the current and potential smartness of a building and to push towards a more efficient, flexible and smarter built environment. Therefore, even if the tool has been introduced within the European context, it might be exploited as a powerful instrument also at a broader level, as investigated by Markoska et al. (2020), who explored the use of the SRI assessment for Australian buildings through a case study application.

Few recent publications dealt with the SRI assessment, providing case study applications to put in evidence the main pros and cons of its definition. An important aspect assessed in literature is the role of the actors conducting the assessment, who can affect the replicability of the results. This aspect has been recently deepened by Vigna et al. (2020), who aimed to study the effects of subjective evaluations on the SRI assessment. In particular, the paper discussed the differences in terms of results aroused when two panels of experts are separately involved in the triage process. Based on this application, authors concluded that “coupled with quantitative indicators to be assessed and monitored, the SRI methodology could become relevant not only as an evaluation of building smartness, but can be adopted during different phases of the life cycle”

(Vigna et al. 2020). The topic was also investigated by Janhunen et al. (2019), who criticized the high subjectivity of some steps of the SRI assessment, stating how this aspect could affect the results, and stressing the need to develop a more tailored approach, especially for cold climates. In particular, three diverse triage processes were tested on two educational buildings and an office in Helsinki, in order to analyze the sensibility of the indicator to the different approaches used for the assessments. Other studies on the SRI were developed by Horàk and Kabele (2019), assessing four buildings located in Czech Republic (both residential and non-residential); in their work, authors commented the weakness of the triage process and the insufficient number of services influencing some impact criteria (e.g. “Health and wellbeing”), with respect to others. Trying to overcome these issues by automating the process, the study conducted by Markoska et al. (2019) proposed an algorithm to faster calculate the SRI in an efficient way, testing and commenting it for scoring a university campus in Denmark. Finally, Foikades, Panteli, and Panyidou (2020) stressed another gap of the SRI definition, highlighting the need to define a common database for assessing the intelligence of the buildings, considering that the proposed level of functionalities need to be better defined on a larger sample of buildings. Despite the criticalities aroused, authors concluded that it is of fundamental importance to develop a more comprehensive methodology for the SRI assessment, in order to include the evaluation of a building smartness or intelligence in the definition of the energy classes, traditionally based on energy performance assessments (Foikaides, Panteli, and Panyidou 2020).

Although still few papers investigated this relatively new topic, a growing interest upon the SRI assessment is currently spreading. However, to the best of authors’ knowledge, few literature works have investigated the possible links between

SRI and traditional tools of buildings performance assessment. For this reason, the paper intends to explore the possible connection between the smartness and the energy performance of buildings. Trying to stress its points of strength and to identify its main criticalities, this work encourages the discussion about the SRI. By recognizing the need to develop new metrics to push towards the adoption of smart solutions, increasing the awareness about their potentialities, the paper analyses the potential link between SRI and energy dynamic simulation, to evaluate the future exploitation of combined or integrated approaches for the assessments of buildings.

3. Materials and methods

In order to deeply comment the sensibility of the indicator to a smarter management of the building and its services, a five-step methodological approach is proposed.

(1) Once selected the building object of the analysis, the first step consists in the SRI assessment of the current state.

(2) Based on the results of the first step (i.e. single domain sub-scores and overall SRI score), the study concentrates on the identification of the domains and the specific services to be potentially included or improved, in order to achieve a higher level of smartness, both at single domain and overall score level.

(3) The impact of the introduction of new services or the improvements of the existing ones is also explored in energy terms, by means of building energy simulations. For this reason, the modelling of the current state of the building is performed using an energy dynamic simulation software, selected in place of other tools, due to its capability of performing a detailed

simulation of building systems. Starting from the current state results in terms of energy needs and consumptions, different scenarios are modelled and simulated, assuming to introduce the services previously identified in the second step.

(4) Simultaneously, the SRI assessment must be reconducted, updating the triage process and the check-list assessment with the new or improved services and their associated functionality levels.

(5) Simulation results in terms of energy needs variations and updated SRI scores are finally discussed, in order to explore if the higher energy performance visible from the energy simulation outcomes are reflected also in higher SRI scores, according to the multi-criteria procedure.

Based on this methodological approach, it is possible to comment if the SRI framework and the energy dynamic simulation are both able to quantitatively reflect the adoption of either new smart solutions or smarter strategies (higher SRI scores on one side, and energy needs reduction on the other side) for the building under investigation.

4. Application to the case study

The Energy Center (EC) at the Politecnico di Torino was chosen as case study (see Figure 1). Completed in 2017, the challenge behind its construction was to create a space where different actors and knowledge can be merged, pursuing together innovation in energy and environmental fields (Borchiellini et al. 2017). It can be classified as an office building, where public and private entities can meet and work. The project was based on the idea to create a multi-energy environment, integrating different energy production systems and resources, among which renewable technologies, to be used also for meeting energy needs and for further research. In addition, an advanced monitoring system and control was developed to achieve an efficient management of the entire building. The Energy Center was selected as case study since it can be representative of new office buildings built after 2010; moreover, due to its recent construction, the building presents many of the smart-ready services included in the SRI assessment, allowing a deeper investigation of the tool and of its methodological approach.

Figure 1. The Energy Center building of Turin.

The EC is a five-story office building, with a basement, a ground floor hosting an auditorium and a full-height exposition hall, and three floors accommodating offices and meeting rooms, for both private enterprisers and university researchers. Building energy demands are satisfied by two main energy vectors: electricity, through the connection to the Medium Voltage electricity grid, and heat, thanks to the connection to the District Heating network of the city of Turin. In addition, two on-field Renewable Energy Sources are exploited: a 47 kW_p photovoltaic system and a 30 m^2 solar thermal plant for domestic hot water production. HVAC generation systems are installed in the technical room; specifically, a geothermal Polyvalent Heat Pump, exploiting the aquifer as heat source in winter and heat sink in summer, is used for providing space cooling and eventually heat recovery, while, in the winter period, priority is given to the District Heating network. Domestic hot water needs are satisfied using a boiler of 1500 l, coupled with a solar thermal plant with a 1000 l capacity. Finally, two Thermal Energy Storages for hot and cold water (4000 l each) are present. The adopted HVAC terminals vary according to the different spaces. Specifically, all-air systems serve the basement and the auditorium, while primary air systems are installed in the hall and the offices, coupled with floor or ceiling radiant panels; direct expansion split systems are used for the Technical Rooms, the Control Room and the UPS Room, fan-coils are installed in the laboratory and radiators in the sanitary facilities.

4.1 SRI assessment for the case study

Once defined the case study, the initial SRI assessment of the current state was conducted. Using the check-list approach defined in section 2, 45 smart-ready services (out of the 54 defined in the SRI methodology) were identified as relevant and present within the building, as listed in table 3.

Table 3. List of 45 smart-ready services evaluated for the EC current state.

DOMAIN	SMART-READY SERVICE
Heating	Heat emission control
	Control of distribution fluid temperature (supply or return air flow or water flow)
	Control of distribution pumps in networks
	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns
	Thermal Energy Storage (TES) for building heating (excluding TABS)
	Building pre-heating control
	Heat generator control (all except heat pump)
	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)
	Sequencing of different heat generators
	Reporting information regarding heating system performance
DHW	Control of DHW storage charging (using hot water generation)

	Control of DHW storage charging (with solar collector and supplementary heat generation)
	Report information regarding domestic hot water performance
Cooling	Cooling emission control
	Control of distribution network chilled water temperature (supply or return)
	Control of distribution pumps in networks
	Intermittent control of emission and/or distribution
	Interlock between heating and cooling control of emission and/or distribution
	Control of Thermal Energy Storage (TES) operation
	Generator control for cooling
	Sequencing of different cooling generators
	Report information regarding cooling system performance
Controlled ventilation	Supply air flow control at the room level
	Adjust the outdoor air flow or exhaust air rate
	Air flow or pressure control at the air handler level
	Room air temp. control (all-air systems)
	Heat recovery control: prevention of overheating
	Supply air temperature control
	Free cooling with mechanical ventilation system
	Reporting information regarding IAQ
Lighting	Occupancy control for indoor lighting
	Control artificial lighting power based on daylight levels
Electricity	Reporting information regarding energy generation
	Storage of locally generated energy
	Optimizing self-consumption of locally generated energy
EV Charging	EV Charging Capacity
	EV Charging Grid balancing
	EV charging information and connectivity
Monitoring & Control	Run time management of HVAC systems
	Detecting faults of technical building systems and providing support to the diagnosis of these faults
	Occupancy detection: connected services
	Central reporting of TBS performance and energy use
	Smart Grid Integration
	Reporting information regarding DSM
	Override of DSM control

4.2 Possible improvements for the SRI assessment of the case study

Among the nine domains reported in Table 2, the Dynamic Envelope was the sole not accounted in the SRI assessment, since its relative services are currently not present in the case study. For this reason, the domain was selected for further analysis, due to its potential impact on the overall assessment for a newly constructed building as the Energy Center, equipped with large windows.

Table 4. Smart-ready services belonging to the DE domain; adapted from the SRI service catalogue (VITO, Waide and DG Energy Commission).

Code	Smart-ready service	Functionality level 0 (as non-smart default)	Functionality level 1 F1	Functionality level 2 F2	Functionality level 3 F3	Functionality level 4 F4
DE-1	Window solar shading control	No sun shading or only manual operation	Motorized operation with manual control	Motorized operation with automatic control based on sensor data	Combined light / blind / HVAC control	Predictive blind control (e.g. based on weather forecast)
DE-2	Window open/closed control, combined with HVAC system	Manual operation or only fixed windows	Open/closed detection to shut down heating or cooling systems	Level 1 + Automized mechanical window opening based on room sensor data	Level 2 + Centralized coordination of operable windows	
DE-4	Reporting information regarding performance	No reporting	Position of each product & fault detection	Position of each product & fault detection & predictive maintenance	Position of each product, fault detection, predictive maintenance, real-time sensor data	Position of each product, fault detection, predictive maintenance, real-time & historical sensor data

4.3 Building energy modeling through EnergyPlus software

In order to parallelly investigate the smartness and the energy performance of the case study, the Energy Center building was modelled and simulated by means of dynamic energy simulations, using EnergyPlus software (version 9.2.0). Specifically, the model development phase was supported by available technical documents related to the building project, which allowed to validate the simulation results for the current state. The model consists of a heated area of approximately 5’500 m^2 and a cooled area of 4’460 m^2, and it has a L structure, with the long side oriented to North-West (NW) and South-East (SE), and a window-to-wall ratio of 20.3%. The EC model was subdivided into different thermal zones, distinguishing among hall, offices at different floors and with different expositions, toilets, archives, technical rooms, laboratory, auditorium, also taking care of their differences in terms of conditioning settings. Totally, 41 thermal zones were modeled, as detailed in the followings:

- In each floor from the 1st to the 3rd, 4 typologies of office thermal zone were modelled, each dependent on the exposition and on the boundary conditions. The meeting rooms present in the building were modelled as offices. Per each floor, 2 thermal zones were used to model the corridors, while the remaining small conditioned spaces were modelled as technical rooms.
- For the auditorium and the laboratory on the ground floor, proper thermal zones were defined.
- Other spaces not occupied by people, but available for services, were modeled as unconditioned spaces.
- The mezzanine level was subdivided into a technical room and a control room, both conditioned.
- Toilets were modelled as conditioned spaces, considering one thermal zone per floor.
- The hall on the ground floor is a full-height space, and, thus, it was modelled as a unique thermal zone going from the base floor to the third one, including the stairs.
- The basement was subdivided into two thermal zones: the first zone, conditioned, consisted of an exhibition area, a toilet and a UPS room, while the spaces dedicated to host HVAC plants and other services were assumed as unconditioned.

Generally, the assumptions done for the identification of the thermal zones were in line with the available technical documents. Despite some minor differences done for the sake of simplicity, the model fully respected the geometric features of the real building. In figure 2, the AutoCAD geometric model defined in EnergyPlus is reported.

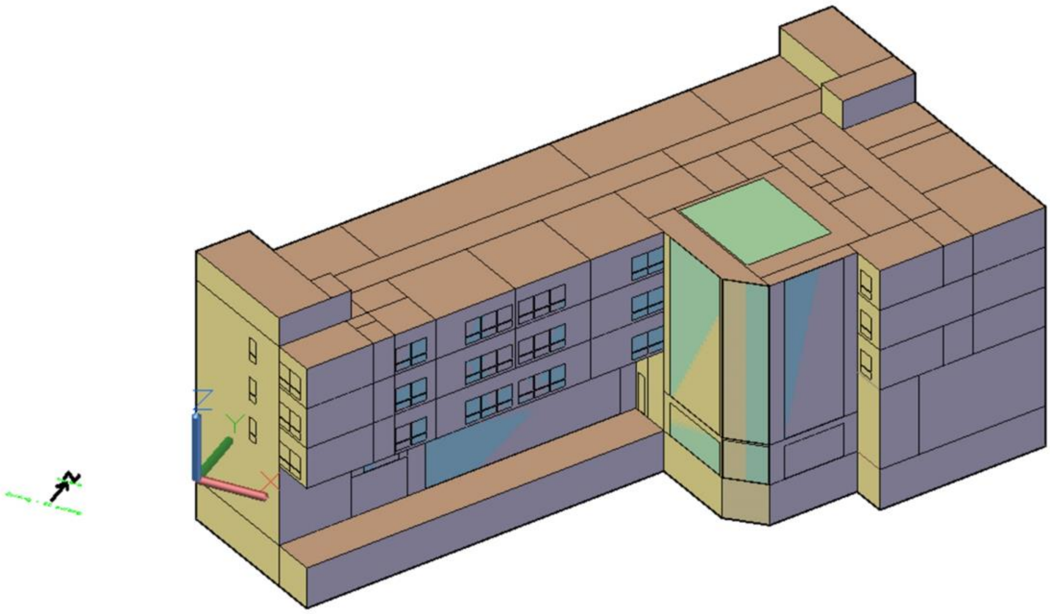


Figure 2. Energy Center AUTOCAD 3D output.

In relation to materials and constructions, Table 5 summarizes the thermal properties of the main opaque and glazed surfaces (i.e. U-values and solar factor).

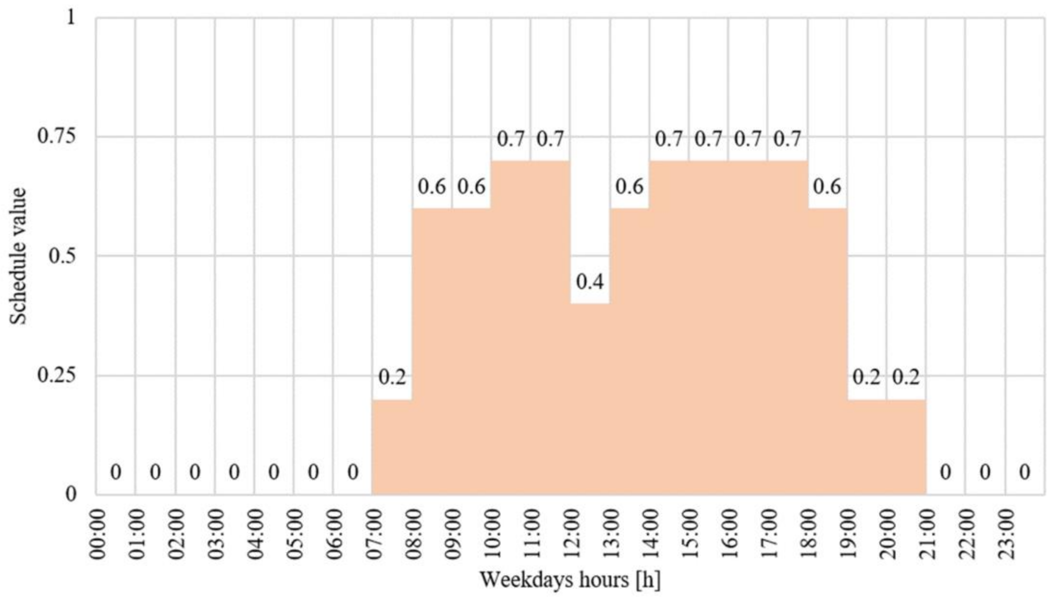
Table 5. Thermal properties of the main envelope elements.

OPAQUE ENVELOPE	**U-FACTOR [W/(m^{2}K)]**	
Drywall with steel covering	0.136	
Concrete blocks with exterior insulation	0.214	
Drywall with glass covering	0.136	
Drywall with opaque panels covering	0.195	
Opaque exterior with opaque glass - NW	0.226	
Opaque exterior blind facade - SE	0.222	
Opaque exterior with steel covering	0.192	
On terrace 1	0.193	
On terrace 2	0.146	
Floor on portico	0.176	
Floor	0.271	
GLAZED ENVELOPE	**GLASS U-FACTOR [W/(m^{2}K)]**	**SHGC [-]**
Cellular Facade	1.166	0.34

Occupancy, lighting and equipment internal heat gains were set based on UNI 10339 (1995), UNI EN ISO 7730 (2006), UNI EN 16798-1 (2019), while their schedules were set using the “Schedule: Compact” field. Input data and assumptions were tailored on the specific thermal zones. Starting from ISO 18523-1 (2016) and UNI EN 16798-1 (2019), schedules were elaborated to simulate the real building operation, which is closed on Saturday afternoon and on Sunday. Examples of the scheduling procedure adopted for the occupancy of the offices during weekdays are given in Figure 3 (UNI EN 16798-1:2019). Focusing on office zones, different internal gains were considered, in order to reflect their real characteristics. Specifically, for the open spaces (long side located office rooms) a value of 0.12 pers/m^2 was considered (UNI 10339:1995), while for the single office (short side located office rooms) a value of 0.06 pers/m^2 was adopted (UNI 10339:1995); for all office rooms, a value of 12 W/m^2 was considered for lighting and electrical equipment density (ISO 18523-1:2016, UNI EN 16798-1:2019). Heating and cooling temperature set-points were equally set in each zone, considering a set-point of 20°C in the winter season (set-back of 18°C) and of 26°C in the cooling season (set-back of 27°C), during the occupied hours. All the zones were both heated and cooled, with the sole exception of the laboratory and the toilets, where the cooling system is not present. Finally, natural ventilation requirements were fixed according to the available technical documents depending on the zone, while a 0.1

ach infiltration was considered in all the spaces. No solar shadings for windows are present in this model.

a)



b)

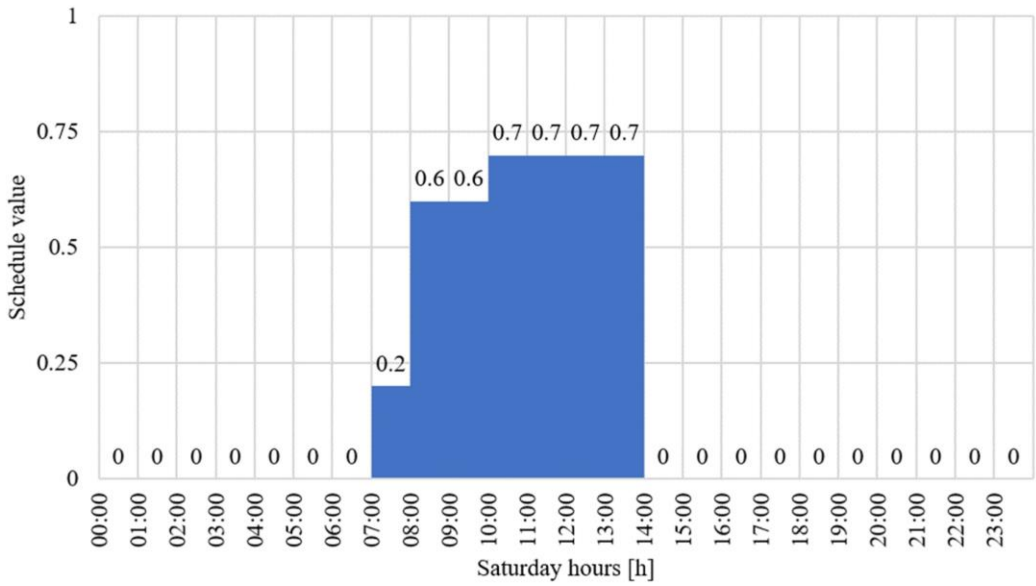


Figure 3. Occupancy schedule for offices. a) Weekday; b) Saturday.

Aiming to study the building envelope and its impact on the energy needs, the analysis did not consider the HVAC systems modelling. Indeed, this preliminary dynamic model focused on the estimation of the building space heating and cooling needs, and therefore, the Ideal Loads Air System was modeled. This option does not require to specify air or water loops, or detailed plant modeling, but it only needs the setting of zone controls characteristics, zone equipment configurations and the ideal loads system components.

Annual simulations, with a sub-hourly time step, were run, using the climate characteristics (in terms of outdoor air temperature and humidity, and winter and summer design days) extracted from DOE Weather for Energy Calculation Database of Climatic Data (U.S. Department of Energy); in particular, the IWEC weather file of Turin (Middle Climate zone, Heating Degree Days = 2617) was used.

In order to simulate the new services to be potentially added to the existing building (see section 4.2), specific EnergyPlus models were developed to simulate the smart services DE-1 (window solar shading control) and DE-2 (window open/closed control, combined with HVAC system) (see table 4). In particular, 3 scenarios were developed considering the DE-1 service, one per each functionality level, from 1 to 3, and a single scenario was developed simulating the functionality level 2 of the DE-2 service. Going into detail, the following assumptions were done:

(1) DE-1 F1: the functionality level 1 was applied to all the fenestration surfaces of offices, auditorium and laboratory, by introducing four different types of solar shadings and the relative control.

(2) DE-1 F2: the functionality level 2 was introduced, adding an automatic control on the shading systems introduced in the previous DE-1 F1 scenario.

(3) DE-1 F3: the functionality level 3 was applied, simulating a strategy able to introduce an advanced control solution on the shading systems only in the office rooms and in the auditorium.

(4) DE-2 F2: the functionality level 2 was proposed, simulating the presence of an automatic control on window opening and closing for all the zones.

It is important to cite that, in the described scenarios, DE-1 and DE-2 services were applied not simultaneously; more precisely, when DE-1 is considered, DE-2 is assumed equal to the functionality level 0, and vice versa. In other words, when one service operates, the other is "frozen", in order to consider their individual effect on the building energy needs.

In its current state, the Energy Center model did not consider the presence of window solar shading control. When service DE-1 was considered (scenarios DE-1 F1, DE-1 F2, and DE-1 F3), sun shading systems were introduced in the model. In order to investigate the differences in terms of performance among several kinds of window solar shading types, four options were proposed:

- Exterior blind;
- Between-glass blind;
- Interior blind;
- Interior shade.

The first three options considered the use of the same shading material ("Blind with medium reflectivity slats"), while its position with respect to the window varies (exterior, between glass, interior). As regards the interior shades, instead, a different material was introduced ("Medium reflect-medium slats shade"). In all scenarios, materials for the shading systems were extracted from EnergyPlus library, using default values. As previously mentioned, these shading systems were introduced only in offices, auditorium and laboratory, while all the other windows characteristics were kept fixed as in the original model (and thus with no shading devices and control).

Deepening on the three scenarios related to the DE-1 service, the following assumptions were done for developing the EnergyPlus models in accordance with the different control strategies and in line with the functionality levels proposed in the SRI catalogue (see Table 5).

- To simulate the DE-1 F1 scenario (which considers a motorized operation of the installed shading systems with manual control), a schedule for the use of solar shading devices was added, considering their use only during the occupied hours. Moreover, it was assumed that solar shadings were used only when the indoor temperature reaches and overcomes the set-point of 26°C. These assumptions were valid for all the considered typologies of shading device. Of course, this scenario simulates an optimal situation, far from reality, which does not consider the unpredictable and subjective occupants' behavior or further lighting evaluations (i.e. glare and daylighting controls).
- To simulate the DE-1 F2 scenario (which considers a motorized operation of the installed shading systems with automatic control based on sensor data), a control mechanism based on the incident radiation was set. Specifically, the EnergyPlus setting "On if high solar on window" was chosen, which simulates a situation in which solar shadings are automatically closed in case the incident radiation on windows exceeds 250 W/m^2, only during the summer season.
- To simulate the DE-1 F3 scenario (which considers a combined light / blind / HVAC control of the installed shading systems), the "glare control" was added to the settings of the DE-1 F2. This assumption allowed a joint control of glare

and sun, and thus it permitted to simulate the activation of the shading systems when the solar radiation on window or the glare from the window is too high. This latter control was modeled by introducing daylighting controls and reference points within the model, setting the maximum allowable discomfort glare index to 22, equal to the default value recommended for the office environment (U.S. Department of Energy).

Finally, coming to the DE-2 F2 scenario (which considers an open/closed detection to shut down heating or cooling systems coupled with an automatic mechanical window opening based on room sensor data), the model allowed the opening and closing of windows during the night, exploiting free cooling during the unoccupied hours, when the outdoor air temperature is not higher than 25°C.

In all these scenarios (DE-1 F1, DE-1 F2, DE-1 F3, and DE-2 F2), the DE-4 service is assumed to be present, and always associated to the functionality level 2 ("Position of each product & fault detection & predictive maintenance"). It is important to specify that this control strategy of the performance of windows and, when present, of the relative solar shadings, might be implemented in the real operation of the Energy Center building, even though it cannot be simulated through EnergyPlus.

4.4 SRI re-calculation to assess the improved scenarios

What has been said so far was related to the main assumptions for the modeling and simulation of the scenarios through EnergyPlus tool. As mentioned, SRI needs to be re-calculated accordingly to the introduction of the new DE-related smart-ready services and their associated functionality levels. To this purpose, when calculating the SRI, there is the possibility to assign two different functionality levels to a specific service, by applying proper percentage values to weight them. In particular, for the DE-1 service, in order to consider that shading controls were added only to the windows in offices, auditorium and laboratory, the upgrade of the functionality level from 0 to 3 was assigned only to 50% of the building, while the remaining 50% was kept fixed to level 0. This assumption was valid for the scenarios DE1-F1, DE1-F2 and DE1-F3. Conversely, as previously mentioned, the DE2-F2 scenario interested the whole building and, for this reason, the functionality level 2 was associated to 100% of the EC building.

5. Results and discussion

This section summarizes the main results obtained from this study. In particular, following the methodological steps reported in section 3 and section 4, the main results on the current state of the Energy Center building are reported, in terms of both SRI assessment and heating and cooling energy needs coming from the energy simulations. Starting from the SRI calculation, based on the multi-criteria methodological approach described in section 2, an overall smart readiness score of 53% was obtained, based on the 45 smart-ready services considered in the assessment procedure. In Figure 4 and Figure 5, the sub-scores referring to the different domains and impact criteria are reported. According to the SRI framework, the EC obtained good results in the “Lighting”, “Domestic Hot Water” and “Cooling” domains, as well as in the “Comfort”, “Wellbeing and health” and “Energy Saving on Site” impact criteria. Conversely, “Flexibility for the Grid and Storage” seemed to achieve the lowest score (17%) among the impact criteria. Also, the impact criterion “Info to occupants” only reached 40%. As shown in Figure 4, the DE sub-score is not accounted, since in the current state, the Energy Center does not present any DE-related services.

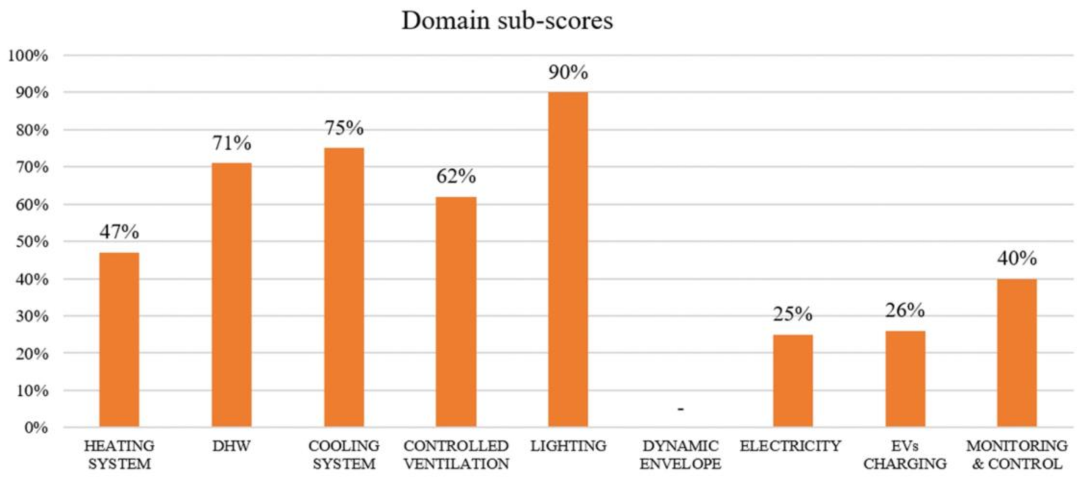


Figure 4. Sub-scores for the assessed domains for the EC building.

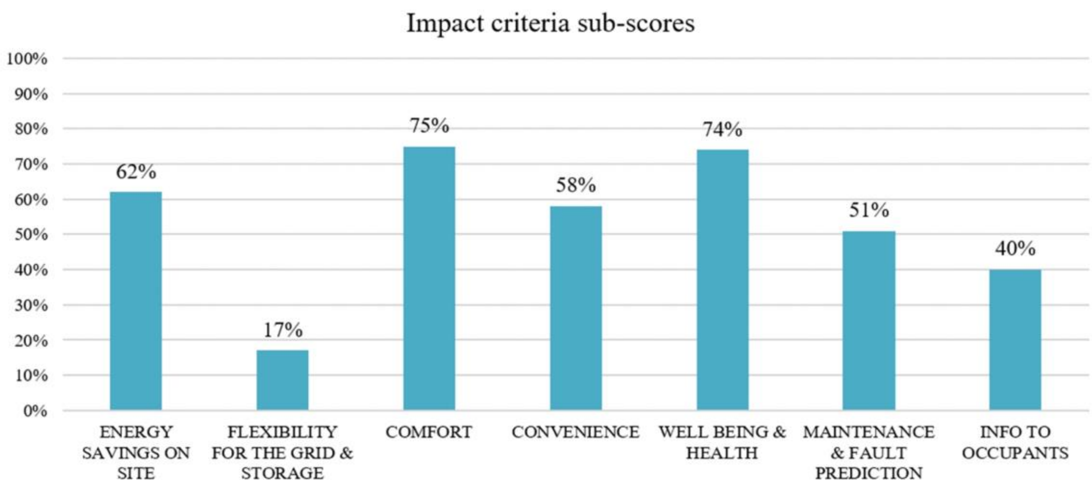


Figure 5. Sub-scores for the impact criteria assessed for the EC building.

Furthermore, based on the EnergyPlus dynamic simulation, it was possible to estimate the annual energy needs of the building, being equal to 102’225 kWh (18.59 kWh/m^2) for heating and 149’270 kWh (33.47 kWh/m^2) for cooling. The results obtained are in accordance with the values reported in the available technical projects (heating and cooling needs calculated according to ISO 13790:2008), used as benchmark for validation.

Coming to the scenario analysis, it is important to mention that all the developed scenarios of energy management and control for the Dynamic Envelope domain were studied only in terms of space cooling savings. The main results are reported in the followings. Focusing on the DE-1 service, Table 6 summarizes the main results obtained in terms of space cooling needs (in kWh/m^2), while Figure 7 reports the percentage cooling savings achieved, as well as the respective DE sub-scores and the overall SRI scores obtained.

Table 6. Space cooling needs obtained due to the improvements on DE-1.

	Cooling needs in kWh/m^2		
	DE-1 F1 scenario	**DE-1 F2 scenario**	**DE-1 F3 scenario**
Exterior blind	31.38	29.36	26.88
Between glass blind	32.65	31.83	30.63
Interior blind	33.29	33.01	32.73
Interior shade	32.96	32.52	31.78

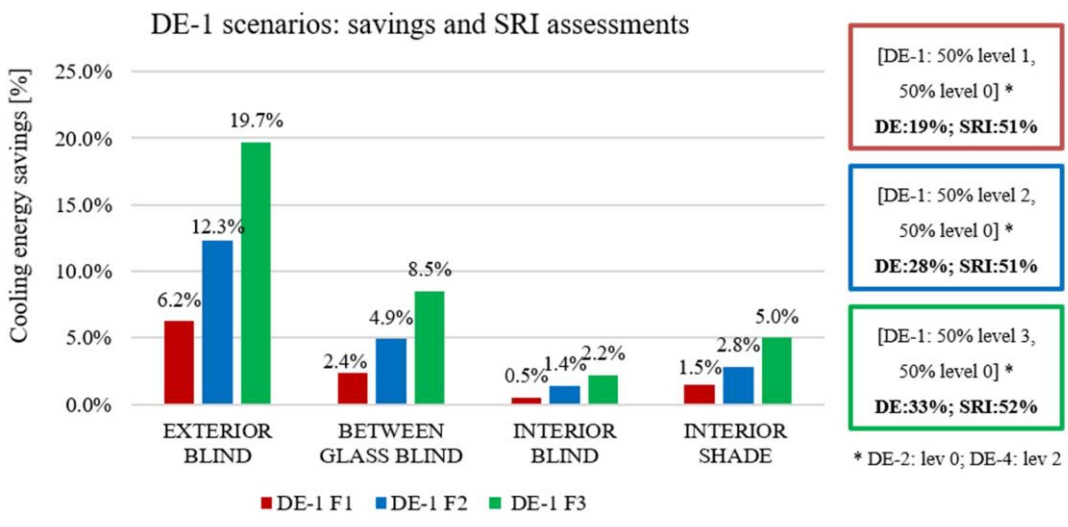


Figure 6. Cooling needs savings and related impact on SRI assessment.

Looking at Figure 6, it appears evident that the 12 values of cooling energy savings obtained from the simulation of the three scenarios (DE-1 F1, DE-1 F2, DE-1

F3) and the four sun shading typologies (for each scenario) correspond only to three score assessments for the SRI. Indeed, according to the SRI assessment method, the type of shading option is not relevant. The SRI seems not to be sensible to the cooling energy needs variations associated with different solar shading options, since it is only influenced by the type of sun shading control (absent, manual, automized), as identified by the functionality level. Going into detail, by focusing on a single solar shading type, the upgrade of the smartness from level 1 to level 3 is correctly translated into a gradual increment of the cooling energy savings, as well as on the SRI final scores (+1% from DE-1 F1 to DE-1 F3). On the other hand, by comparing the solar shading options, as expected, the exterior blind performs much better than the other solutions in energy terms (when comparing the four systems for the same functionality level, the percentage of cooling savings guaranteed by the exterior shading is almost double than those achievable using the other solutions). However, as far as the sun shadings are controlled in the same way (as defined by the functionality level), their impact on SRI scores is identical. Due to the higher relevance that the control option has on the SRI assessment, rather than the typology of shading system, it is interesting to note how, even though exterior blinds with a strategy control of level 1 are more efficient than interior blinds with functionality level 3 (in terms of guaranteed cooling savings), their adoption will result in a SRI lower with respect to that resulting from the adoption of the internal blinds with functionality level 3. These results allow to introduce the first issue upon the efficacy of the SRI tool, showing how the outcomes of the scenario analysis are in line with the open questions about its effectiveness. The SRI seems to be addressed to evaluate only the management and control capabilities of a passive feature (as the solar shading devices), and not the device as it is. For this reason, there is the need to better understand which will be the exploitation of this indicator in the near future. Since it cannot bring information on the energy performance of buildings, as shown in this study, it could be used as a support to existing indicators or tools for buildings. For instance, by coupling the SRI with the well-established EPCs or energy labels, it would be possible to integrate traditional KPIs of buildings energy performance (e.g. primary energy consumption, energy use intensity, CO_2 emissions, etc.) with information on the level of smartness or readiness to smartness of their services, to indicate if they can be operated in a smart way.

As regards the scenario assessing the improvement of the DE-2 service, moving from level 0 to level 2, a cooling needs saving of 8.2% was achieved, resulting in an overall cooling need of 30.72 kWh/m^2, in spite of the original 33.47 kWh/m^2. In parallel, according to the new SRI assessment for this scenario, the DE sub-score obtained was 43%, which is the highest score achieved for the described scenarios, while the overall SRI was equal to 52%.

Furthermore, the results obtained from the scenario analysis were compared with the initial SRI assessment, in order to evaluate the variations induced on the overall SRI scores when the DE service is considered. Three situations were compared:

(1) Null DE: DE is not present (45 services accounted out of 54). This scenario corresponds to the current state of the EC building.

(2) Minimum DE: DE services are introduced (48 services accounted out of 54). In this situation, both DE-1 and DE-2 were associated to the functionality level 0 (for the DE-1 this level corresponds to "no sun shading or only manual operation", while for DE-2 this level corresponds to "manual operation or only fixed windows"). DE-4, instead, was associated to the functionality level 2.

(3) Optimal DE: DE services are introduced and optimized (48 services accounted out of 54). This situation assumes to combine the best configurations of services

DE-1 and DE-2, where "best" means the configuration corresponding to the highest energy savings (according to the previous analysis). Specifically, DE-1 service was assigned to level 3 for 50% of the building and DE-2 service to level 2 for the entire building. DE-4 service was always associated to level 2.

As reported in Figure 7, these scenarios were firstly compared in terms of DE sub-scores and SRI overall scores.

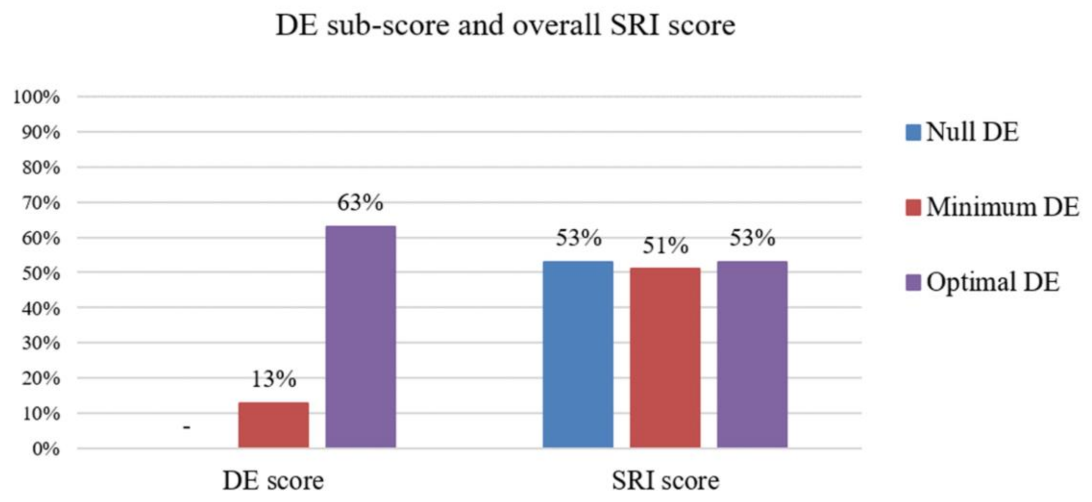


Figure 7. DE and SRI comparison between Null DE, Minimum DE and optimal DE scenarios.

Moving from Null DE to Optimal DE scenario, the DE sub-score progressively increases, showing a maximum value of 63% for the Optimal DE scenario. Conversely, when considering the SRI score, it is possible to see how the same SRI score is obtained for the Null DE scenario and the Optimal DE scenario. This result is explained by the fact that the number of services accounted for the calculation of the SRI are different in the two scenarios; indeed, the case reported in blue refers to the SRI assessment of the Energy Center in its current state, only involving 45 services (DE services not accounted), while in the other two scenario 48 services are evaluated (including the DE services). A direct comparison can be done between the Minimum DE scenario and the Optimal DE scenario, being characterized by the same number of assessed services. As expected, an improvement in terms of DE services can be read both in the sub-score of the domain and in the overall SRI score. However, looking at the little variation that the DE optimization produces on the SRI score, it is possible to note that this domain does not have a significant influence in the overall assessment; this is primarily due to the lower weighting factors assigned to this domain, with respect to others, when energy balance weights are applied (for instance, considering the impact criterion "Energy Savings on Site", a 5% weighting factor is assigned to the DE domain, against a 31% weighting factor for the "Heating" domain).

Table 7 summarizes the main results obtained comparing the three scenarios from the energy standpoint. In particular, when evaluating the cooling energy savings guaranteed by the Optimal DE scenario with respect to the Null DE scenario (i.e. current state model with no solar shadings neither windows controls), a significant reduction of energy needs (-26.5%) is obtained; this result of energy improvement, as commented above, cannot be read only looking at the obtained SRI scores (i.e. in both cases, a 53% SRI score was achieved).

Table 7. Energy comparison between Null DE, Minimum DE and Optimal DE scenarios.

	Cooling energy need [kWh/y]
Null DE / Minimum DE	149'270
Optimal DE	109'646
Absolute saving	39'624
Percentage of saving	26.5%

The outcome reported in Table 7 helps also clarifying that the triage process is a crucial step for the SRI assessment. Indeed, Null DE and Minimum DE scenarios do not show differences in terms of cooling energy needs, since their energy model is identical (the functionality levels for DE-1, DE-2 and DE-4 associated to the Minimum DE model cannot be captured in the EnergyPlus model). Their difference resides in the initial assumptions for the SRI calculation, done during the triage process. Specifically, in the Null DE scenario, DE is excluded from the SRI calculation from the beginning, and therefore only 45 services were considered in the evaluation. Conversely, in the Minimum DE scenario, DE was not excluded, even if not simulated with EnergyPlus, and DE services were all fixed to functionality level 0 (with the sole exception of DE-4 service, which is always set at level 2); this assumption resulted in a selection of 48 services (instead of 45), which clearly affected the overall SRI score obtained by the two scenarios.

This result opens the way to another SRI challenge, concerning the discussion on “how thin is the line” between “not relevant” and “not present”, and thus if it is better to assess a service as a “smart ready” or as a “smart possible” one. Indeed, looking at the results summarized in Figure 7, it appears that, in the view of the SRI score, it would be better not to consider the DE (Null DE scenario), in spite of having very low functionality levels associated to it (Minimum DE scenario). Therefore, in order for the SRI to become a powerful tool for driving the building sector transition, it is crucial to understand how SRI is effectively able to push for the implementation of new smart instruments and for the recognition of what is present as smart, even if not in a big amount. Moreover, it is also important to deepen the issue of “be relevant or not” associated to the smart-ready services, which assumes a certain importance in terms of overall score. Indeed, if a service is considered as relevant for a specific building type, its accounting becomes mandatory for the overall SRI calculation, and, in case the specific building does not have any features present for this service, there is no possibility to assess functionality levels different from the level 0 (i.e. the non-smart functionality). This consideration highlights a possible improvement of the SRI assessment, which would require to understand which services might be targeted as "relevant" for a particular building, depending, for instance, not only on the typology of use or location, but also, for instance, on other archetypical characteristics (e.g. the year of construction or the renovation level), in order to guarantee an optimal triage process already from the beginning and to provide a common basis for its development.

6. Conclusions

Within the building sector, a smart building revolution is starting, asking for appropriate tools to guide and support this transition. In particular, the Smart Readiness Indicator (introduced by the EPBD recast of 2018), if correctly introduced and assessed, could be a powerful instrument to support and encourage this challenging vision. In this context, it is important to explore how this new indicator could communicate and be integrated with traditional tools used for assessing the building energy performance (e.g. EPCs, energy labels), which mostly aim to study the energy behavior of buildings in terms of energy consumption or environmental impact.

The paper fits with this framework, aiming to discuss on the current strengths and weaknesses of the SRI, as well as on its link with traditional energy metrics, through a case study application. Specifically, the paper focused on the Energy Center, an existing and recent office building located in Italy, and parallelly applied, on one side, the SRI multi-criteria methodology in order to evaluate the building readiness to smartness, and, on the other side, the dynamic energy simulation (with EnergyPlus tool) to estimate its energy needs. Moreover, to deeply evaluate the effectiveness of the SRI in providing information on the energy efficiency of the case study, different scenarios of energy management and control were modeled and simulated, in order to evaluate their impacts in terms of energy needs and SRI scores variations. In other words, the scenario analysis aimed to estimate if the higher energy performance associated to the introduction of smarter services and simulated through EnergyPlus tool may be equally reflected in an improvement of the SRI score.

The results allowed to pinpoint some of the main open criticalities of the SRI, showing how energy performance and readiness to smartness are not always aligned. Through the focus on the Dynamic Envelope and its relative services, it was possible to highlight how the achieved reductions in terms of energy needs resulting from the dynamic simulations did not always correspond to improvements of the SRI scores; for instance, the 26.5% reduction of cooling needs obtained thanks to the optimization of the DE domain (initially absent in the case study), did not correspond to similar trends in the overall SRI scores, since both scenarios obtained an overall score of 53%. A sensible improvement was only evident through the analysis of the DE sub-score, which vary from not assessed to 63%. Moreover, when comparing different shading systems, the SRI appeared not to be capable of taking into account the different performances guaranteed by the installation of diverse devices (i.e. different blinds materials and characteristics), being mostly focused on the control and management strategies of such system, independently from their energy characteristics.

Thanks to the case study application, some interesting outcomes were drawn. Some of the current criticalities of the SRI were encountered; the SRI is still perceived as too subjective, strongly dependent on the experts who conduct the assessment, and on how the relevance of services is interpreted, as discussed in the previous section. Moreover, the application allowed to highlight the need for a more replicable assessment method. Indeed, even though a building-specific procedure allows to better identify and adopt ad-hoc strategies for the building under assessment, it would be interesting to develop a more objective approach, through which the buildings under investigation could be compared with SRI scores resulting from reference buildings with similar characteristics and relevant services.

Furthermore, the paper contributed to discuss upon the possibility that the exploitation of traditional instruments, like energy dynamic simulation tools, could be coupled with the SRI, in order to provide a complete assessment of the buildings under investigation. Indeed, both instruments provide interesting information on buildings, even if with different perspectives and focuses.

For this reason, the paper contributed to highlight the importance of defining ad-hoc indicators and tools to certify the energy performance of a building, taking advantage of the digitalization process that the building sector is experiencing. In particular, the results achieved with the definition and application of the SRI-simulation integrated approach suggested the need to introduce a strategic implementation pathway for the SRI, underling the importance of coupling this tool with energy-related ones, as EPCs, in order to give a greater boost to the building stock renovation, which should aim to both reduce its environmental impact and increase its digitalization and smartness. In line with the above, the ALDREN (ALliance for Deep RENovation in Buildings) European project, funded by the European Commission, proposed to dedicate a page of its “ALDREN EPC” to the SRI, also developing a tool in order to cluster potential upgrades as “action packages”; in this way, the SRI scores are presented for the current situation and for potential improvements (Zirngibl et al. 2021).

In conclusion, a well-defined indicator can represent a key instrument to express and communicate, through a simple score or set of values, the energy behavior of buildings, also to a non-expert audience. However, the indicator needs to be supported by other tools, among which simulation models and/or real data, which, in the era of digitalization, are more and more available. In other words, indicators are very powerful instruments, considering the great amount of information (quantitative and qualitative) they can manage and combine, but it is only through the combination of different tools that the smart building revolution could proceed faster and achieve better results in less time. For this reason, there is the need to identify a better-defined indicator, leading to a more complete description and certification of the built environment in the framework of the energy transition and the smart building revolution. Moreover, it is important to stress that the smart readiness is not the objective, but the instrument thanks to which energy efficiency, comfort and flexibility of building can increase. Now that new advanced instruments and technologies are spreading, it will be fundamental to understand how to manage them together in order to deploy a full approach for responding to the multi-layer energy transition challenges, regarding energy, buildings, environment, transport, and, of course, human beings.

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Disclosure statement

No potential conflict of interest.

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