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Estimating the Smart Readiness Indicator in the Italian Residential Building Stock in Different Scenarios

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Abstract: The Energy Performance of Buildings Directive 2018/844/EU introduced the smart readiness indicator (SRI) to provide a framework to evaluate and promote building smartness in Europe. In order to establish a methodological framework for the SRI calculation, two technical studies were launched, at the end of which a consolidated methodology to calculate the SRI of a building basing on a flexible and modular multicriteria assessment has been proposed. In this paper the authors applied the above-mentioned methodology to estimate the SRI of the Italian residential building stock in different scenarios. To this end, eight "smart building typologies", representative of the Italian residential building stock, have been identified. For each smart building typology, the SRI was calculated in three scenarios: (a) base scenario (building stock as it is); (b) an "energy scenario" (simple energy retrofit) and (c) a "smart energy scenario" (energy retrofit from a smart perspective). It was therefore possible to estimate a national average SRI value of 5.0%, 15.7%, and 27.5% in the three above defined scenarios, respectively.

Keywords: smart buildings; smart readiness indicator; energy efficiency; Italian building stock; energy saving; energy performance of buildings directive

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1. Introduction

In the European Union (EU) the building sector is responsible for around 40% of energy consumption and 36% of CO_2 emissions [1]. In order to address the energy problem, in recent years numerous EU directives have been issued and targeted incentives have been introduced. In particular, the Energy Performance of Building Directive (EPBD), starting from 2002 [2], has promoted a series of measures to enhance the energy performance of buildings. The last recent amendment of the EPBD (2018/844/EU) [3] integrated and modified the previous versions, introducing some new objectives: (*i*) promoting sustainable mobility [4,5]; (*ii*) encouraging the use of smart technologies for new and existing buildings [6,7]; (*iii*) raising end-users' awareness in energy use [8–10]; (*iv*) incentivizing decarbonization through the development of a nearly zero energy building (nZEB) and zeroing of greenhouse gas emissions by 2050 [11,12]. In particular, increasing importance is being given to buildings that not only meet stringent energy performance requirements (i.e., nZEB) but also associate this feature with the ability to interact actively with both end-users and energy grids. In this sense, the smart building concept presents a series of improvement factors with respect to an nZEB [13] such as: (*i*) the possibility for occupants and operators to interact with the building easily [14]; (*ii*) the collection of useful information from and for the occupants; (*iii*) integration with the electricity network [15];

(*iv*) the applicability of load control systems on the electricity network [16]; (*v*) a greater security [17,18]; (*vi*) a greater comfort [14,19]; (*vii*) the reduction of CO_2 emissions [20]; (*viii*) the reduction of operating costs of heating, cooling, and lighting [21].

In this context, the smart readiness indicator (SRI) has been introduced, aiming at providing a framework for assessing and promoting the smartness of buildings in Europe. In particular, SRI aims to measure the building's ability to adapt its operation to the needs of both the occupants and the network and to improve its efficiency and overall energy performance To this aim, the European Commission has issued a delegated regulation [22] and an implementing regulation [23] which define, respectively, a methodological framework for calculating the SRI and provide various possible implementation pathways for the member states that will decide to implement the common European scheme. To provide support for the definition of the SRI calculation methodology, DG ENERGY of the European Commission has promoted two technical studies conducted by a research consortium [24,25], which led to the definition of a catalogue of "smart ready services" and to the development of a methodology for calculating the indicator. Thus, for the estimation of the SRI, nine evaluation domains are considered, each with different functionality levels [26]. In the context of the above-mentioned technical studies, a first beta-testing of the proposed methodology was initiated and two specific automated spreadsheets were also made available to stakeholders to support a uniform SRI calculation process among EU member states. Stakeholders from 21 member states participated to the beta testing, with 112 buildings evaluated (of which 57 were residential and 65 non-residential, most of them built after 2010) [27]. Italy participated to the public beta testing phase of the second technical study by performing over fifteen SRI assessments in real case studies buildings (e.g., residential buildings, schools, offices, hospitals) [24,25].

Few studies are available in the literature that analyze the SRI in detail, with reference to both the calculation methodology and the application to different case study buildings. Marzinger et al. [26] proposed a simplified methodology for the quantitative assessment of the load shifting potential of buildings with the aim of providing a numerical approach that allows to classify the buildings basing on their energy storage capacity, load and their network interaction. The same authors have further developed their approach based on numerical models on the evaluation of entire districts [28]. Janhunen et al. [29] applied the calculation of the SRI in some buildings in northern Europe showing that, in its current form, the SRI is unable to recognize the peculiarities of cold climate buildings, particularly those employing advanced district heating systems. Another implication of [29] is that the applicability of SRI in all Member States of the EU could be problematic due to the subjective nature of the proposed process for the selection of relevant services. Vigna et al. [30] assessed the impact of subjective nature of the SRI methodology, adopting a two-step assessment with the involvement of two teams of experts. The authors also present a series of recommendations for an effective and broad implementation of the SRI for increasing the relevance of its assessment and effectiveness, as well as for improving the comparability of smart building readiness. Fokaides et al. [31] highlighted SRI values are particularly penalizing in small buildings where there are no BMS (building management systems), concluding that although the indicator is promising, there are several aspects that need to be improved. In [32] the SRI methodology is applied in two service buildings located in the Mediterranean climate, and possible effects of retrofit actions and smart functionalities on energy performance and indoor environment quality were evaluated. The results showed that the defined weighting factors are not able to capture the energy performance of the service buildings and need a revision. Becchio et al. [33] performed a dynamic simulation of the Energy Center building of Turin in different scenarios (current state and increased level of management and control), and evaluated the influence of these actions on the overall SRI assessment. The results allowed them to link the SRI with the energy needs of the building.

Italy, as with other EU member states, is called to decide whether to implement the SRI calculation and, in this case, to define a suitable methodology taking into account the real peculiarities and characteristics of the national building stock. To this end, the EU Implementing Regulation [23] provides for a non-binding testing phase, after which the member state will be able to decide whether to implement the calculation system. In this sense, testing the application of the general SRI methodology on different buildings (i.e., residential and non-residential, existing and new buildings, retrofitted and not-retrofitted, etc.) will be useful to identify the most significant case-study buildings for the testing phase.

In this context, the aim of this work is to apply the SRI methodology developed during the second European technical study to estimate both the actual and potential smartness of the Italian residential building stock in different scenarios. To this end, eight "smart building typologies" (SBT) representative of the Italian residential building stock were identified by using the information available in the existing national buildings databases [34–36]. The analysis of the regulatory and legislative framework regarding the building automation and control systems (BACS) in Italy was also performed to define the following three application scenarios: (*a*) a "base scenario" (building stock as it is); (*b*) an "energy scenario" (simple energy retrofit); and (*c*) a "smart energy scenario" (energy retrofit from a smart perspective).

This study was carried out as part of the national three-year research project "Ricerca di Sistema Elettrico", whose main aim is to develop a tailored methodology for the SRI calculation in Italy. This project involves several phases: (*i*) assessing the SRI in the existing building stock; (*ii*) providing a specific market analysis involving the main players in the BACS market (builders, technicians, designers etc.); (*iii*) updating the catalog of services proposed by the European study; and (*iv*) developing a calculation tool for SRI in the national context. The results will be made available to the European working group that is supporting the implementation of the SRI in Europe.

The present paper presents a number of innovative aspects compared to the existing literature: (*i*) unlike precedent studies [29–31], the focus of this work is on residential buildings which, although expected to have a limited impact on the SRI implementation, in Italy represent the majority on existing buildings (about 84% in 2011 [34]); (*ii*) the proposed approach is not focused on single case studies, but presents a more general framework useful for defining reference building typologies for SRI calculation; (*iii*) it provides a quantitative estimate of the SRI potential in a series of statistically representative buildings; and (*iv*) it highlights the actions required for the optimal implementation of SRI in the residential sector.

In the following, the SRI methodology calculation employed within this study is described. Then, the characteristics of the SBT are detailed in each scenario. Finally, results of the SRI calculation at a national scale are presented and discussed.

2. Materials and Methods

The methodological framework for calculating the SRI is described in [24]. A multi-level approach is proposed basing on nine domains (i.e., energy services) and seven impact criteria, as shown in Figure 1.

Figure 1. Domains and impact criteria for the SRI methodology [24].

For each domain, specific smart ready services are defined according to the system characteristics of the service considered. Different levels of functionality are assigned to each service, with each having its own degree of smartness, on an increasing scale from 0 (i.e., "non-intelligent" service) to a maximum value (which can vary from 2 to 5 depending on the service) for advanced features. Since the maximum scores assigned to the different functionality levels are variable, a direct comparison between the different services is not applicable [30].

The scores assigned to the individual services are summed up for each of the domains and divided by the maximum individual scores so as to obtain a "domain impact score". For each impact criterion, the total score is calculated as a weighted sum of the domain impact scores. The SRI is then obtained as a weighted sum of the total impact scores. The SRI evaluator is free to choose the predefined weighting system or to assign different weighting factors based on the specific characteristics of the buildings being evaluated (climatic conditions, characteristics of the national or regional building stock, etc.). In the present study, the predefined weighting system has been applied as suggested in [25]. It is possible to calculate the total building SRI, the SRI per impact criterion, the SRI related to EPBD key capabilities, and the SRI per domain. Figure 2 shows the main steps of the SRI methodology.

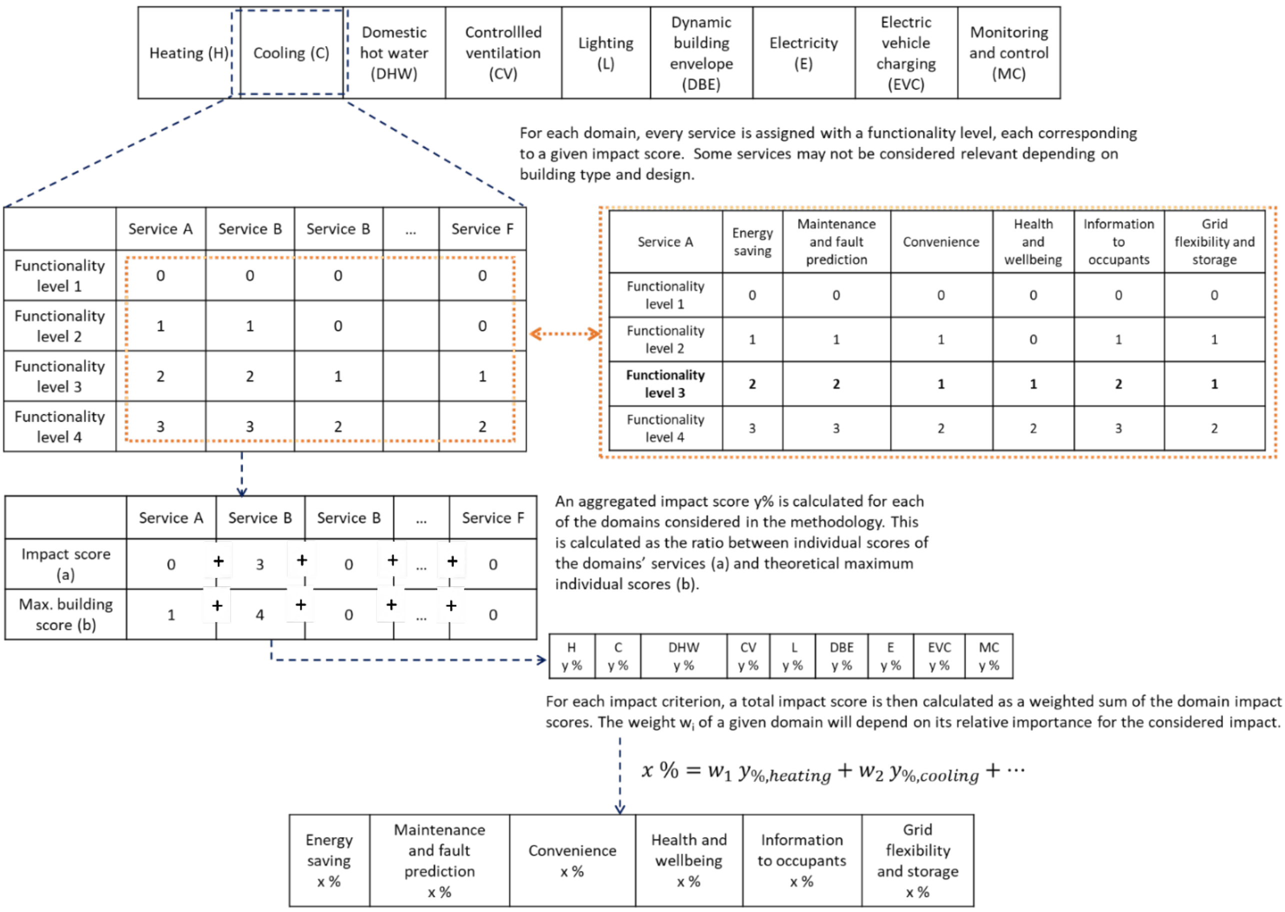


Figure 2. SRI calculation methodology.

Three methods have been proposed for the assessment of the SRI:

- *Method A* (simplified): intended for residential buildings or small non-residential buildings. It allows both third-party and self-evaluations;
- *Method B* (detailed): consists of a more detailed assessment including by default on-field verification by an independent expert;
- *Method C* (advanced): consists of a more advanced assessment based on direct monitoring on-field (for example through self-reporting from BACS systems).

The application of method A includes a small number of intelligent services (27 services), while the implementation of methods B allows for the evaluation of more complex buildings and services (54 services). Method C is currently considered to be a potential future evolution of a certification approach for a commissioned building. The analysis carried out in this paper has been performed using method B [24].

In the preliminary phase, it is essential to define the domains present in the building being evaluated, through an initial evaluation process called "triage process" [24]. In this phase, an inventory of the intelligent services present in the analyzed building is made through a simple check-list. In a subsequent phase, the levels of functionality are assigned to each of the smart ready services identified, allowing, eventually, the assessment the total SRI, the domain, and impact SRIs, as shown in the flow chart in Figure 3 [31,37].

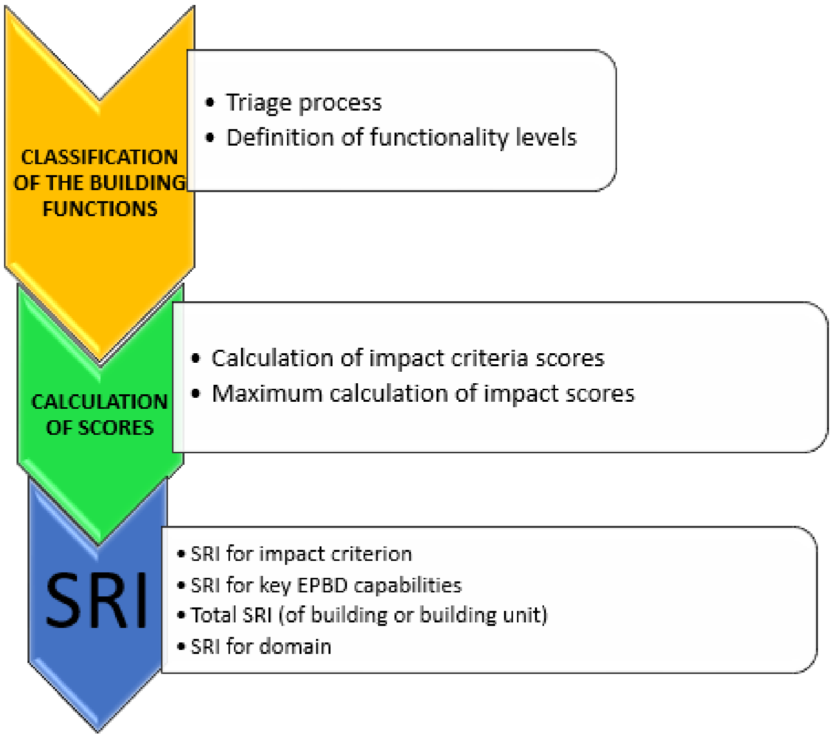


Figure 3. Flow chart of SRI calculation methodology.

2.1. SBT Definition in the Base Scenario

Aimed at obtaining a rough estimation of the SRI of the Italian residential building stock, the authors first analyzed the following data: (*i*) statistical data on buildings and housing derived from the last ISTAT census [34], (*ii*) statistical data on heating, cooling and domestic hot water systems as well as results of the TABULA project for the characterization of building/heating systems typologies [35,36], (*iii*) the regulatory evolution regarding the performance obligations and regulation requirements of the technical systems of buildings belonging to the residential sector in Italy [38–41]. It is believed that the estimate of the SRI of the Italian building stock is substantially determined by the characteristics of heating and domestic hot water systems. In addition, in the residential sector one can highlight: (*i*) the scarce diffusion of controlled mechanical ventilation systems and, generally, the scarce application of HVAC systems [34]; (*ii*) the absence of obligations to install centralized automation systems (i.e., BACS systems, mandatory starting from 2015 only for non-residential buildings and for new residential constructions only in few Italian regions); (*iii*) the lack of a regulatory framework establishing the minimum smartness requirements of residential buildings (i.e., the lack of obligations for the automated and intelligent management of the building systems). Table 1 shows the main legislative references that were useful for associating the related heating system to each SBT.

Table 1. Legislative references for heating plants in residential buildings.

Year	Obligation
1976	Obligation to install a control system of the heat generator based on the measurement of outdoor temperature [38]
1993	For centralized heating systems, obligation to install a single room temperature regulation system on at least two levels driven by an external temperature probe. The outside temperature and the flow/return temperatures of the heat transfer medium must be measured. For autonomous heating systems, a thermoregulation system controlled by one or more room temperature measurement probes with a programmer allowing the regulation of this temperature on at least two temperature levels [39]
2009	Obligation to install a programmable temperature control system and modulating devices for the automatic regulation of the room temperature in single rooms or zones. For centralized heating systems, regulation controlled by internal temperature probes (optional similar control unit for outdoor temperature). For autonomous heating systems, programmer allowing the regulation of the room temperature on two temperature levels [40]
2014	Obligation to install thermal heat accounting systems for heating, cooling and DHW production, for all buildings supplied by centralized heating/cooling systems [41]

Based on the findings of the above-mentioned analysis, eight SBTs were identified based on the following main criteria:

- Type of heating system: two characteristic plant types have been identified: (*i*) "autonomous heating system" or "individual appliances serving the entire house or parts of it" [34], which, respectively, represent 60.5% and 20.7% of the residential building stock [34]; (*ii*) "centralized heating system" (hereinafter "centralized") which represents 18.8% of the residential building stock [34]. This classification was introduced to account for the obligation to install heat accounting systems and temperature regulation devices [38];
- Construction period: four construction periods have been identified taking into account the evolution of legislation on the regulation of heating systems and the construction periods resulting from the analysis of the ISTAT census; the following construction periods were considered: (*i*) prior to 1980; (*ii*) between 1981 and 1990; (*iii*) between 1990 and 2005; and (*iv*) after 2006.

As a final step, following the above-described analyses, a real building was associated to each defined SBT and fully characterized in terms of services and functionality. The information necessary for the characterization was collected through on-site inspections and interviews with users. The details about applicable domains and main systems characteristics resulting from this analysis have been reported in Tables 2 and 3.

Table 2. Domains of the smart building typologies (SBT).

	SBT A	SBT B	SBT C	SBT D	SBT E	SBT F	SBT G	SBT H
Construction period	<1980	<1980	1981–1990	1981–1990	1990–2005	1990–2005	>2006	>2006
Type of heating system	Auton.	Centr.	Auton.	Centr.	Auton.	Centr.	Auton.	Centr.
Domain								
Heating	×	×	×	×	×	×	×	×
Domestic Hot Water	×	×	×	×	×	×	×	×
Controlled ventilation	-	-	-	-	-	-	-	-
Lighting	×	×	×	×	×	×	×	×
Cooling	-	-	-	-	×	-	×	×
Dynamic Envelope	-	-	-	-	-	-	×	×

Table 2. *Cont.*

	SBT A	SBT B	SBT C	SBT D	SBT E	SBT F	SBT G	SBT H
Renew. Electr. generation and storage	-	-	-	-	-	-	×	×
Elecrtic Vehicle Charge	-	-	-	-	-	-	-	-
Monitoring and Control	-	-	-	-	-	-	-	-

Table 3. Main systems characteristics of the smart building typologies (base scenario).

	Heating	Domestic Hot Water (DHW)	Cooling
A	Electric resistance generators used for heating the individual rooms. No control systems of the generation/emission and regulation system.	Dedicated electric water heater with storage system. No control systems.	-
B	Central heating system with diesel fuel generator for the combined production of heating and DHW. Hydronic vertical distribution system with radiators and variable speed circulation pump. Indirect heat accounting system and mechanical thermostatic valves on each radiator.		-
C	Autonomous heating system powered by a single-stage natural gas boiler with atmospheric burner and climatic regulation for the combined production of heating and DHW. Thermoregulation carried out by means of a central programmable zone thermostat.		-
D	Centralized system with traditional natural gas boiler, equipped with a manually set time programmer. Vertical hydronic distribution system with radiator and variable speed circulation pump. Indirect heat accounting system with insertion time counters and electronic thermostatic radiator valves controlled by a central thermostat.	Autonomous production with electric water heaters or wall mounted boiler fuelled by methane gas.	-
E	Autonomous system with pellet-fired boiler for combined production of heating and DHW, climatic regulation and programmable thermostat. Horizontal hydronic distribution system with convector emission terminals.		Electric absorption chiller, hydronic distribution and convector emission terminals.
F	Centralized system supplied by natural gas fired condensing boiler for combined heating and DHW production. Programmer associated to the main generator to adjust the temperature on at least two levels, measurement of the temperature of the heat transfer fluid and external temperature probe. Horizontal hydronic distribution system with radiator emission and variable speed circulation pump. Direct accounting system with thermal energy meters. Programmable zone thermostat at times. Solar thermal collectors equipped with storage without thermal level management.		-
G	Low temperature condensing boiler powered by natural gas for combined heating and DHW production. Measurement of the temperature of the heat transfer fluid and external temperature probe. Hydronic underfloor heating system. Solar thermal collectors equipped with storage without thermal level management.		Air-to-air heat pump cooling system (multi-split direct expansion system).
H	Centralized system supplied by three air-water heat pump generators for cooling, heating and DHW production. Programmer associated to the main generator to adjust the temperature on at least two levels, measurement of the temperature of the heat transfer fluid and external temperature probe. Multistage control of generators based on actual thermal load. Hydronic distribution system with radiant panel emission embedded in the floor. Direct accounting system with thermal energy and DHW meters. Zone thermostat. Solar thermal collectors for DHW equipped with storage without thermal level management.		

In particular, the active domains, construction period, and type of heating system of the SBTs obtained from the preliminary analysis are highlighted in Table 2, while in Table 3 the main systems characteristics of the SBTs are highlighted for each domain. For the sake of clearness, in Table 3, the "Lighting", "Dynamic Envelope" and "Electricity: renewables and storage" domains have been omitted. The reader should note that, for the "Lighting" domain, the hypothesis of an on/off manual control system has been applied to all cases of the base scenario. The "Dynamic Envelope" and "Electricity: renewables and storage" domains were activated only for SBTs "G" and "H" where, respectively, motorized mobile screens with manual control and PV system without storage have been considered. The remaining domains "Controlled Ventilation", "Electric vehicle charge" and "Monitoring and control" were considered active in none of the SBTs since the analysis of the literature highlighted a scarce diffusion of these systems in the residential sector in Italy.

2.2. "Energy" and "Smart Energy" Scenarios for Retrofit Interventions

In order to evaluate the potential improvement of the overall SRI score of the national building stock, the impacts of various retrofit interventions applied to the selected building typologies were evaluated. In particular, the retrofit interventions were identified keeping in mind the most widespread domains and respective services in the residential sector (i.e., heating, lighting, DHW production, dynamic envelope, and installation of production systems from RES). For the definition of the retrofit scenarios, a preliminary statistical analysis of the retrofit interventions carried out in the 2014–2019 period [42] based on the type of intervention and the potential "smartness" was performed. To this aim, two efficiency scenarios [43] were defined ("energy" and "smart-energy") with increasing level of smartness. The "energy" scenario is based on the hypothesis of retrofitting the building stock accordingly to the 2014–2019 trends, whose main results are described in [42]. The minimum smart functionalities of the new installation/replacement systems for the "energy" scenario are shown in Table 4. In the case of pre-existing system already meeting the minimum established requirements, no replacement/requalification has been considered.

Table 4. Functionality levels of the "energy scenario".

Domain	System	Minimal Functionalities	Example
Heating	Generation	• Detection and control of outdoor temperature and system parameters (fluid temperature, required thermal load) • Demand-based control (fluid temperature of the heat transfer fluid)	Replacement of the single-stage boiler with modulating condensing boiler
	Distribution	• Automatic control based on outdoor temperature and measurement of the heating fluid temperature	
	Emission and control	• Temperature regulation for single room/zone	
Cooling	Generation	• Detection and control of outdoor temperature and system parameters (fluid temperature, required thermal load) • Demand-based control (heat transfer fluid temperature)	Installation of a heat pump cooling system (mono-split or multi-split direct expansion system)
	Distribution	• Automatic control based on outdoor temperature and measurement of the cooling fluid temperature	
	Emission and control	• Temperature regulation for single room/zone	

Table 4. *Cont.*

Domain	System	Minimal Functionalities	Example
Domestic Hot Water (DHW)	Generation	• Renewable production (Solar thermal collectors)	Installation of solar thermal collectors and DHW storage system
	Storage	• Storage without control system	
Lighting	Control	• Control of absorbed power (manual dimming per room/environment)	Installation of manual dimming system
Dynamic envelope	Control	• Motorized mobile screens with manual control	Installation of manually controlled motorized mobile screens
Electricity: renewables & storage	Generation	• Renewable production (photovoltaic system)	Installation of a renewable electricity production system (photovoltaic panels)
	Storage	• No storage	

For the “smart energy” scenario, a series of smart energy efficiency retrofit interventions have been hypothesized, basing also on the results of [43], by acting on individual services and domains with installations not involving substantial changes to the systems. Therefore, the interventions already hypothesized for the “energy” scenario have been revised from a “smart” perspective, thus assuming for the newly installed/replacement systems the minimum additional functions including: WLAN/Wireless connectivity, remote management and control systems, connected sensors for management, control and monitoring purposes. The minimum smart functionalities of the newly installed/replaced systems for the “smart energy” scenario are shown in Table 5.

Table 5. Functionality levels of the “smart energy scenario”.

Domain	System	Minimal Functionalities	Example
Heating	Generation	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Detection and control of environmental (temperature) and system (delivery temperature, required thermal load) parameters • Smart metering (remote reading and remote management of the consumption of thermal energy/gas/electricity)	• Installation of a smart condensing boiler equipped with a WLAN connectivity and integrated remote management of the system for real-time monitoring; • Installation of a Smart thermostat with self-learning functionality based on user habits and preferences
	Distribution	• Automatic control based on the external temperature and on the heat transfer fluid temperature	
	Emission and control	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Temperature regulation per single room/zone • Self-learning functionalities	
	Information to occupants	• Report of current and historical temperature/consumption values	

Table 5. *Cont.*

Domain	System	Minimal Functionalities	Example
Cooling	Generation	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Detection and control of environmental (temperature) and system (delivery temperature, required thermal load) parameters • Smart metering (remote reading and remote management of the consumption of thermal energy/gas/electricity absorbed by the generator)	• Installation of a heat pump cooling system (multi-split direct expansion system) integrated with monitoring and control system of environmental parameters and energy monitoring system
	Distribution	• Automatic control based on the external temperature and on the heat transfer fluid temperature	
	Emission and control	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Full inter-block • Temperature regulation per single room/zone	
	Information to occupants	• Report of current and historical temperature/consumption values	
Domestic Hot Water (DHW)	Generation	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Renewable production (solar thermal collector)	• Installation of solar thermal collectors with storage and thermal load management
	Storage	• Storage with control of thermal level	
	Information to occupants	• Report of current and historical temperature/consumption values	
Lighting	Control	• Occupant control (manual with auto-off in case of absence) • Control of absorbed power (manual dimming per room/environment)	• Installation of an efficient lighting system with presence sensor and dimmer
Dynamic Envelope	Control	• Motorized mobile screens	• Installation of motorized mobile screens with manual control integrated with an information system on the current status and remote control
	Information to occupants	• Monitoring of the current states and remote control	
Electricity: renewables & storage	Generation	• WLAN/WiFi/etc. connectivity • Remote management and control (on/off, alarms) • Renewable production (photovoltaic system)	• Installation of a photovoltaic system with storage (small batteries) integrated with a monitoring system of the state of charge
	Storage	• Storage present with State of Charge (SOC) control	
	Information to occupants	• Report of current and historical consumption values and SOC	

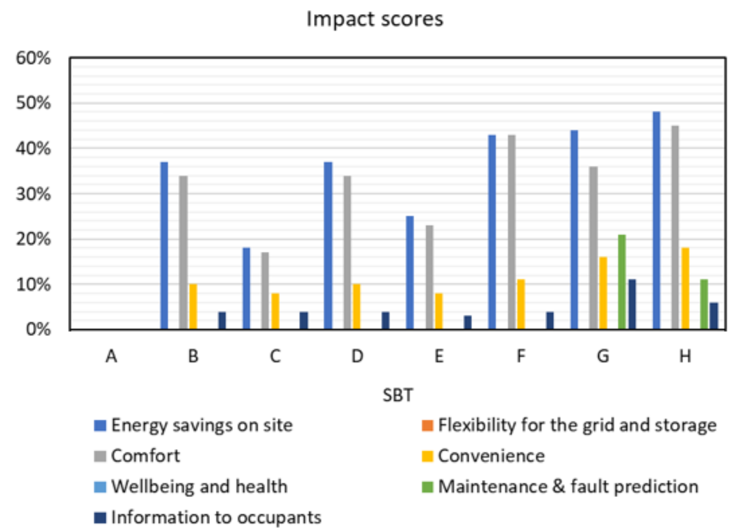
3. Results

3.1. Base Scenario

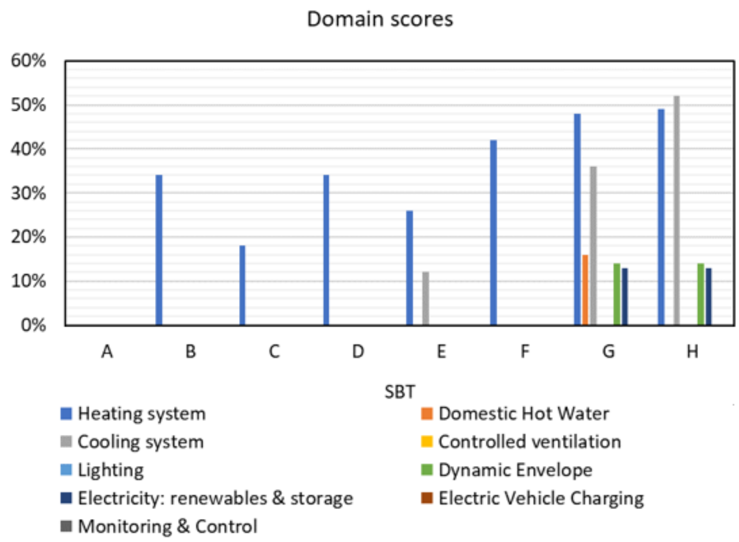
The SRI values for the selected SBTs in the base scenario are shown in Table 6, whereas the relative impact and domain scores are shown in Figure 4a,b.

Table 6. SRI of the eight selected SBT (base scenario).

SBT	Type	Construction Period	SRI
A	Autonomous	<1980	0%
B	Centralized		17%
C	Autonomous	1981–1990	9%
D	Centralized		17%
E	Autonomous	1990–2005	12%
F	Centralized		20%
G	Autonomous	>2006	23%
H	Centralized		23%



(a)



(b)

Figure 4. Impact and domain scores for each SBT in the base scenario. (**a**) Impact scores and (**b**) domain scores.

By observing data in Table 6, the SRI estimated for the single smart building typologies ranges between 0–23%, increasing consistently with the definition of the minimum regulation requirements of the generation system.

As shown in Figure 4a, it is possible to highlight how the most relevant impacts are represented by those given, respectively, by energy saving (0–48%), comfort (0–45%), and convenience (0–18%). The contributions of information impacts to occupants (0–11%) and predictive maintenance (11–21% only in cases G and H) are less significant. As expected, the most impacting domain is, in almost all cases, that of heating (Figure 4a), with an impact ranging between 0% and 49% followed, where present, by the cooling domain (12–52%). It is also possible to highlight how, within the same construction period, the SRI assumes significantly different values for buildings with autonomous systems compared to buildings with centralized systems. This is essentially due to the effects of Legislative Decree 102/2014, which determined the obligation to install heat accounting systems in buildings supplied by centralized heating systems. Where vertical hydronic distribution systems are present (i.e., the case of almost all buildings with centralized generators before 1980), this obligation has an impact not only on the regulation system of the emission terminals (by introducing temperature regulation for each environment), but also on the adaptation of the distribution system (installation of a variable speed circulation pump for balancing the system) and generation (generator regulation).

The estimate of the national SRI value was carried out through a weighted average on the estimated floor area of each type of buildings and using the SRI obtained from the simulation of the case studies as per Equation (1). The floor areas used in the calculation are shown in Table 7, whereas the weighting coefficients for SRI are shown in Table 8. The average floor area of single-family buildings was set equal to 154 m^2 according to [35], while that of multi-family buildings was set equal to 413 m^2 and obtained through a weighted average of the Italian multi-family buildings. Specifically, weighting coefficients were calculated according to statistical data [34] related to number and type of multi-family building (number of small, medium, and large multi-family buildings), while the relative average floor areas were retrieved from [34,35].

$$SRI = \frac{\sum_{i=A}^{H} SRI_{SBT\ i} \cdot floor\ area_{\mathrm{SBT,i}}}{\text{total floor area}} \tag{1}$$

Table 7. Estimated floor area of buildings in the National Building Stock, [m^2].

Construction Period	Single-Family Building (a)	Multi-Family Buildings (Autonomous Systems) (b)	Multi-Family Buildings (Centralized Systems) (c)
≤1980	750,837,586	1,393,288,493	321,621,222
1981–1990	121,643,704	225,727,608	52,106,071
1991–2005	111,116,313	206,192,502	47,596,664
≥2006	29,935,854	55,550,336	12,823,021

Table 8. SRI of the national building stock (base scenario).

Type	SBT	Floor Area [m^2]	Weight%	SRI	Weighted SRI
(*a*) + (*b*)	A	2,144,126,079	64.42%	0%	0.00%
(*c*)	B	321,621,222	9.66%	17%	1.64%
(*a*) + (*b*)	C	347,371,312	10.44%	9%	0.94%

Table 8. *Cont.*

Type	SBT	Floor Area [m^2]	Weight%	SRI	Weighted SRI
(*c*)	D	52,106,071	1.57%	17%	0.27%
(*a*) + (*b*)	E	317,308,815	9.53%	12%	1.14%
(*c*)	F	47,596,664	1.43%	20%	0.29%
(*a*) + (*b*)	G	85,486,190	2.57%	23%	0.59%
(*c*)	H	12,823,021	0.39%	23%	0.09%
		SRI			5.0%

The data reported in Table 7 was obtained from data elaboration of ISTAT census, by dividing the total number of multi-family buildings into two categories: (*i*) multi-family buildings supplied by autonomous systems (81% of the total); and (*ii*) multi-family buildings supplied by centralized systems (19% of the total).

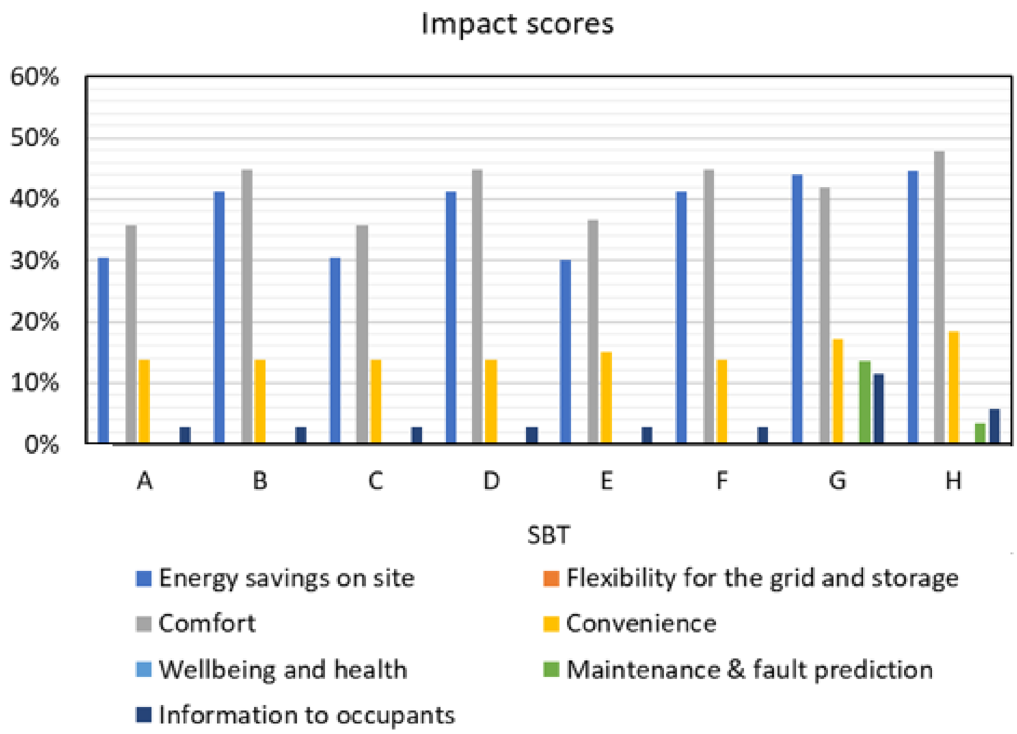
Finally, Table 8 shows the estimate of the national average SRI according to the methodology defined. Data shown in Table 8 highlight how, under the hypotheses introduced in this study, a SRI of 5.0% can be associated with the Italian building stock in the base scenario. It is worthy to observe that this estimate does not consider any efficiency improvements already made to buildings dated before 2005.

3.2. Energy and Smart Energy Scenarios

Table 9 shows the results of the analysis conducted in the above-described scenarios compared with the base scenario, whereas Figures 5 and 6 show the domain and impact scores for each of the cases considered in the two different scenarios. It should be noted that the impacts shown in Table 9 assume that the "energy" and "smart energy" interventions are applied in all the SBTs (i.e., completely retrofitted building stock). Therefore, these values represent a maximum SRI obtainable for each retrofit scenario.

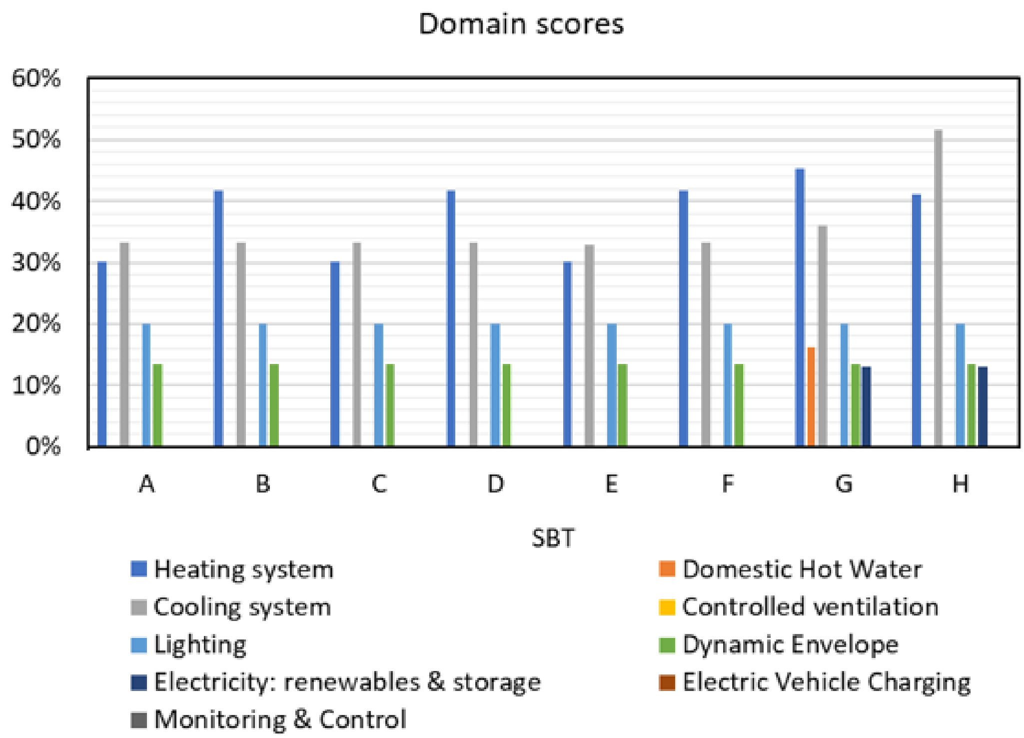
Table 9. Impact of retrofit interventions on the overall SRI.

SBT	Base Scenario	Energy Scenario	Smart Energy Scenario
A	0%	15%	27%
B	17%	19%	31%
C	9%	15%	27%
D	17%	19%	31%
E	12%	15%	27%
F	20%	19%	30%
G	23%	23%	31%
H	23%	23%	28%
Impact	5.0%	15.7%	27.5%



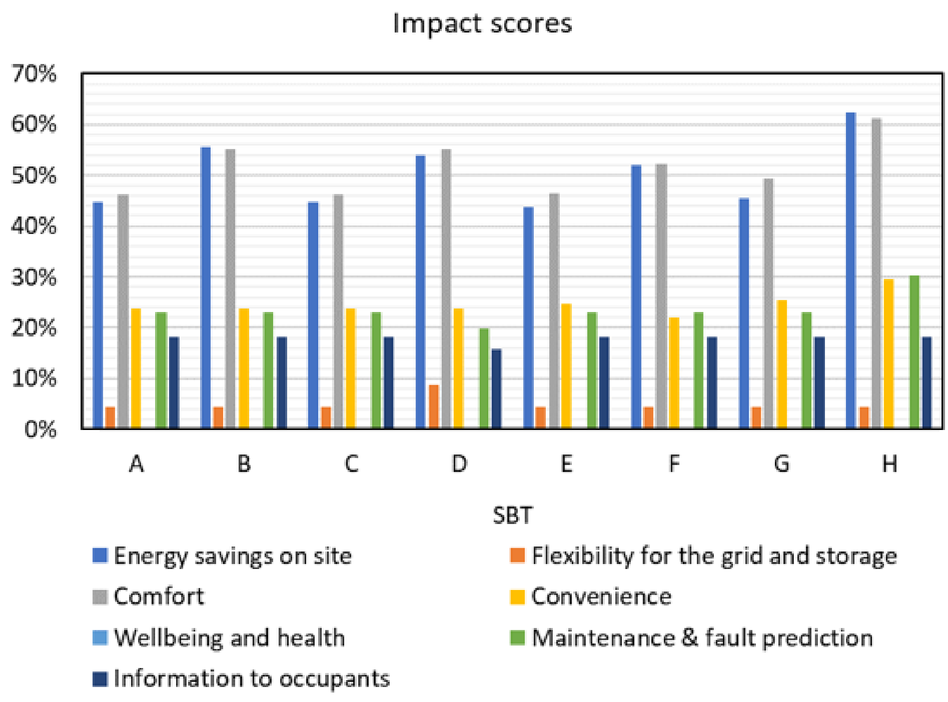
(**a**)

Figure 5. *Cont*.



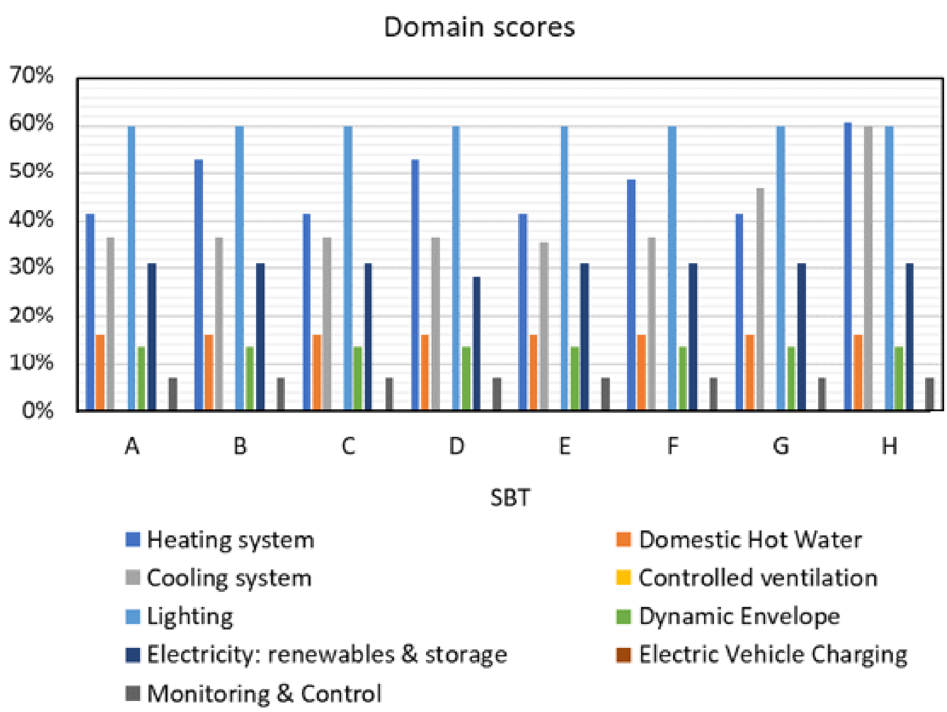
(**b**)

Figure 5. Impact and domain scores for each SBT in the "energy scenario". (**a**) Impact scores and (**b**) domain scores.



(**a**)

Figure 6. *Cont.*



(**b**)

Figure 6. Impact and domain scores for each SBT in the "smart energy scenario". (**a**) Impact scores; (**b**) Domain scores.

As shown in Table 9, the maximum SRI value of the entire building stock obtainable through different levels of retrofit interventions is, respectively, 15.7% and 27.5% in the "energy" and "smart energy" scenarios.

The increase obtained in the "energy" scenario is mainly attributable to the rollout of the heating generation systems and the activation of the cooling domain (having the same minimum performance requirements required for energy generation systems for heating). The impact of the simple installation of a power consumption control system on the lighting domain (domain score of about 20%) is also noteworthy. As can be seen in Figure 5, the most significant impacts for the "energy" scenario are represented by those given respectively by energy savings (30–45%), comfort (36–45%) and convenience (14–18%).

As shown in Figure 6a, in the "smart energy" scenario, an increase in the impact scores of energy saving (45–62%), comfort (46–61%) and convenience (24–30%) has been observed together with the increase in the impact information to occupants (16–18%) as well as that of the impact scores relating to predictive maintenance (20–30%) and flexibility for networking and storage (4%). These increases are mainly attributable to: (*i*) the installation of a user reporting system for frequent access to energy consumption data and historical data for each domain present; (*ii*) the installation of intelligent thermostats with self-learning functions; (*iii*) the installation of an on-site storage system for the renewable electricity produced on-site; and (*iv*) the installation of an occupancy monitoring system for the management of the lighting domain.

4. Discussions

From this study, some considerations emerge both on the application of the SRI methodology to residential buildings, and on the impact simulation in the different scenarios of the Italian building stock.

The main findings can be summarized as follow:

- The activation of some domains in historic buildings or buildings subject to architectural constraints may not be possible (e.g., controlled ventilation, electricity: renewable and storage, dynamic envelope), and therefore these aspects should be taken into account when defining the reference buildings;
- In the scenario representing the current trend of existing buildings retrofit (i.e., "energy" scenario) the SRI is relatively low, ranging between 15 and 23%. This is mainly due to the low level of automation and control of the systems currently used for the retrofit of existing residential buildings. Indeed, the installation of highly energy efficient systems or of renewable energy production systems does not affect the SRI, but only their level of automation and control;
- In the "smart" energy requalification, the SBTs achieved an overall SRI within 31%. This is due to the fact that installation of centralized BACS (not mandatory, although promoted in case of new constructions and major renovations) was not considered nor complex interactions between the building and the network were envisaged. Indeed, the installation of complex BACS systems seems to be a not common solution and a true bidirectional interaction between building and network, although desirable, is still far from being realized on a large scale;
- To obtain a significant increase in the level of smartness of the national building stock, it is necessary to act mainly on the existing buildings. However, some retrofit interventions (installation of new systems for the activation of new domains and services) may not be technically or economically feasible (possible causes of technical infeasibility could be represented [44,45], for example, by the lack of useful surfaces for the installation of efficient energy production and storage systems, the impossibility of intercepting the distribution pipes, etc.)
- The main recommendations can be summarized as follow:
- To enable an easier application of the SRI methodology in the residential sector, it would be necessary to consider the peculiarities of BACS in residential buildings and those of the tertiary sector. This implies differentiating the catalog of services considering the building category (residential/non-residential);

- To obtain a good correspondence between the catalog of services and functionalities with the actual characteristics of the systems available on the market and to allow the definition of the reference building typologies, it would be required to carry out a specific statistical analysis both on the building automation systems commonly present in residential buildings, and on the intelligent features of the devices available on the market;
- Specific representative buildings both in the residential and in the non-residential sectors should be selected to carry out a technical-economic feasibility analysis and to identify the most suitable retrofit interventions to obtain a significant increase in SRI. A sensitivity analysis of the SRI to the cost of increasing retrofit interventions in existing buildings, in this sense, would be desirable;
- For an actual implementation of the automation and control systems required to obtain a tangible increase in the SRI, a legislative and regulatory effort would be required to define the minimum levels of functionality especially for the services of those domains (e.g., heating, cooling and DHW) that have a greater impact on the building energy consumption in the residential sector.

5. Conclusions

In this paper, aiming at providing a first estimation of the potential of SRI implementation in the Italian building stock, the authors applied the SRI methodology in different scenarios. To this end, the authors developed: (*i*) a preliminary analysis of statistical data of the residential building stock, and (*ii*) an analysis of the regulatory context regarding management and control systems in residential buildings. Eight "smart building typologies" typical of the national building stock were identified and fully characterized in terms of domains and of smart functionalities. The SRI of each single smart building typology has been found to vary from 0% to 23% in absence of any retrofit. This allowed us to estimate the SRI of the entire building stock in the base scenario approximately equal to 5.0%. Moreover, considering two simulated retrofitting scenarios, the potential SRI of the Italian building stock has been estimated to be equal to 15.7% in the case of a simple energy requalification and to 27.5% in the case of a smart energy requalification.

From the results obtained, the following actions may be adopted for the integration and further development of the SRI methodology: (*i*) performing a specific statistical analysis regarding the automation systems commonly present in existing buildings and the smart functionalities of the devices available on the market; (*ii*) defining reference buildings both for residential and non-residential sectors with the consequent update of domains, technical services and functionality levels; (*iii*) developing a catalog of reference services and functionality levels for different construction types; and (*iv*) defining supplementary measures to favor the spread of the SRI taking into account minimum system requirements (e.g., BACS). This would allow a better matching between the smart ready services and the real functionalities of the devices actually available on market.

The results of this work can provide useful information to evaluate the best opportunities for implementing the current SRI methodology at a national level. Indeed, the main contribution of this study is to provide a comprehensive picture of the application of the SRI methodology, defined by the European technical study, to a wide range of residential buildings representative of the Italian building stock. In this sense, this study is preparatory to the testing phase of the SRI envisaged by the European Union not only in Italy, but also in other EU Member States having building stocks with similar characteristics, peculiarities, and climatic conditions. Besides, this study identifies, among the most widespread, the energy retrofit interventions with the greatest impact on the SRI in existing residential buildings, thus being particularly useful for builders, installers and designers active in the smart buildings sector. Further development of this research will concern a specific technical-economic feasibility study aiming at estimating the potential of different smart refurbishment interventions under real application constraints.

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