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Technical Note

Smart buildings for smart cities: Analysis of the Smart Readiness Indicator

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Abstract

Subject of this study is the analysis of the Smart Readiness Indicator (SRI), as well as its application for a residential building in Greece. The indicator, which was firstly introduced in the revised EPBD in 2018, assesses the buildings' smart readiness through the examination of the presence and the evaluation of the functionality level of smart services. Its goal is the promotion of buildings that are energy efficient, adaptive to their users' needs, and flexible in respect of their electricity demand, according to the three key - functionalities, as stated by the Directive. A smart building is not only characterized by its sustainability but also by its adaptiveness to the environmental conditions and its users' preferences. Smart buildings are a basic component of smart cities, which utilize a great range of smart technologies aiming at the improvement of their citizens' lives. The Smart Readiness Indicator as well as the sub indicators evaluate the smart buildings using a multicriteria assessment method, which is thoroughly described in this paper. Finally, the indicators' calculation is executed for a residential building in Greece leading to results, which are discussed along with identified methodology shortcomings and difficulties.

Keywords: smart buildings; smart readiness indicator; energy efficiency; adaptiveness; energy flexibility

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1. Introduction

One of Europe's long-term goals for the year 2050 is the carbon emission reduction below 1990's levels by 80%, accompanied by 80% increase in renewable energy use. The building sector, which is responsible for 36% of total CO_2 emissions and 40% of total energy consumption in Europe, will hold a crucial role in achieving these goals [1]. For instance, there are 3.7 million buildings in Greece which are energy inefficient and consume great amounts of natural resources in order to meet their energy needs [2]. Subsequently, it can be deduced that sustainable management of the building sector in general and the energy systems in particular is a matter of utter importance.

The revised European EPBD, which was published in 2018, lays the foundation for addressing the aforementioned matters by introducing the first, voluntary scheme of buildings' smart readiness evaluation in Europe [3]. Its aim is the building sector's disengagement from traditional energy sources by adopting modern, smart technologies and satisfying the Directive's 3 key – functionalities. According to the 3 key – functionalities, all buildings should be not only energy efficient but also flexible regarding their energy demand while simultaneously satisfying their occupants' needs [4]. The building stock is envisioned to be transformed to smart, hence it will have the ability to react and adapt to external, environmental stimuli as well as its users' habits and preferences through the utilization of smart sensors, meters and software in general [5]. As a result, the building sector, as an integral part of the smart environment component along with smart governance, living, economy, mobility and human resources, will be an indispensable component of the smart city. The final goal is the improvement of living conditions, the protection of the environment and the promotion of social equity and equality as the principle of sustainability requires [6].

2. Smart Readiness Indicator

The Smart Readiness Indicator is set to be an instrument for the qualitative assessment of buildings' technological readiness that is expected to promote smart building technology uptake and aid the European building sector decarbonisation while ensuring user satisfaction and well-being [3]. The indicator's methodological framework is supported by 2 technical studies that were commissioned by the European Commission. The produced reports [7-10] analyse the SRI components and its calculation methodology and have been published in the SRI's official website [11]. The first technical study took place in 2018 and laid the indicators foundations, introducing the technical domains, the impact criteria and the calculation methodology. The buildings' smart ready services were organized in 10 technical domains and their evaluation was conducted regarding 8 impact criteria [7]. The second technical study reduced the number of technical domains and impact criteria to 9 and 7 accordingly and developed the 3 assessment methods [8-10]. The final report was published in September 2020 [10].

Given the novelty of this scheme, there is not a great amount of available studies testing the indicator. Marzinger *et al.* proposed a methodology that supports the Smart Readiness Indicator by taking into account the load shifting capacities of smart buildings [1]. This quantitative assessment was further developed and extended from building level to district level [12]. Janhunen *et al*. applied the proposed methodology for 3 case buildings of the tertiary sector in Finland and questioned SRI's ability to take into consideration cold climate countries particularities regarding their buildings' energy profiles and energy grids [13]. As for the Mediterranean countries, Ramezani *et al*. applied the proposed methodology for non-residential buildings and examined whether retrofitting actions can be a feasible investment towards smart readiness achievement [14].

Other studies have raised the issue of historic buildings assessment and smart technology installation [4,15]. In [15] an SRI estimation of the Italian residential building stock, which lacks automation and control systems since they are not mandatory, led to low scores and raised the issue of the indicators comparability between different countries. Furthermore, one prominent issue is the objectivity of the indicator since the assessment of a building' services as well as the determination of which are considered relevant do not have a clear-cut definition [16,17]. This paper deals with the theoretical approach of the indicator's methodological framework in the following subsections and its application for a single-family residential building in Greece in section 3. Its aim is to provide further insight into the indicator's applicability and lead to results concerning small residential buildings in southern Europe.

2.1 Smart Readiness Indicator structure

The Smart Readiness Indicator examines the presence and assesses the functionality level of smart ready services. These services, which are organized in catalogues, make use of communication and internet technologies, sensors, meters as well as a combination of them. Some examples are the natural light and temperature control of a room via sensors and meters, the smart phones' apps that inform users about their building's energy production and / or consumption and the indoor air quality control sensors which can initiate a ventilation system when it is deemed necessary for the occupants well – being [9].

The integration of smart ready services in a building or just a building section is aiming at the successful implementation of the 3 key – functionalities as stated in the revised EPBD: energy savings and operation, respond to user needs and energy flexibility [16]. Every one of the 3 key – functionalities carries equal weight (1/3) in the assessment of the SRI and the sub indicators and includes a specific number of impact criteria (Figure 1). The impact criteria, which are 7 in total, are used in order to evaluate the smart ready services. More specifically, the impact criteria “energy savings” and “maintenance & fault prediction” are included in the key – functionality energy savings and operation with a weighting factor of 16,7% each. The key – functionality respond to user needs includes 4 impact criteria equally weighted with 8,3%: “comfort”, “convenience”, “information to occupant” and “health & wellbeing”. Lastly, the impact criterion “energy flexibility” is the only one of the key – functionality energy flexibility and as a result carries the biggest weight, with the value of 33,3%, in comparison to the other 6 ones [10].

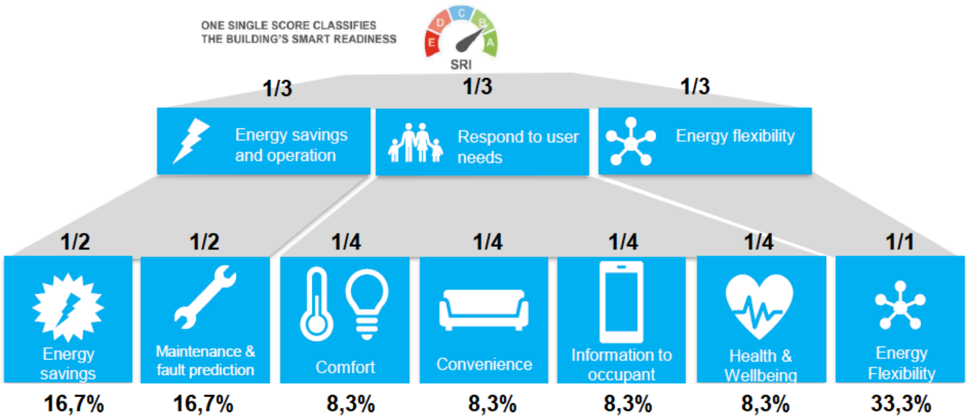

Figure 1 The 3 key - functionalities, 7 impact criteria and their weighting factors [10].

Smart ready services are organized in 9 technical domains: heating, domestic hot water, cooling, controlled ventilation, lighting, electricity, electric vehicle charging, dynamic building envelope and monitoring & control (Figure 2) [8-10]. Their smart readiness assessment regarding the 7 impact criteria depends on 3 kinds of weighting factors, the energy balance weights, the equal weights and the fixed weights [10]:

- Energy balance weights are determined in relation to 2 factors, the building’s use (there is a distinction between residential use and other uses) and its geographic location. Europe is divided in 5 climate zones. The energy balance weights are applicable in technical domains: heating, domestic hot water, cooling, ventilation, lighting, electricity and electric vehicle charging of the key – functionalities energy savings and operation and energy flexibility.
- The equal weights take part in the indicator’s calculation only for the key - functionality respond to user needs for all technical domains except for monitoring & control.
- Fixed weights are relevant for the technical domains monitoring & control and dynamic envelope for the key – functionalities energy savings and operation and energy flexibility.

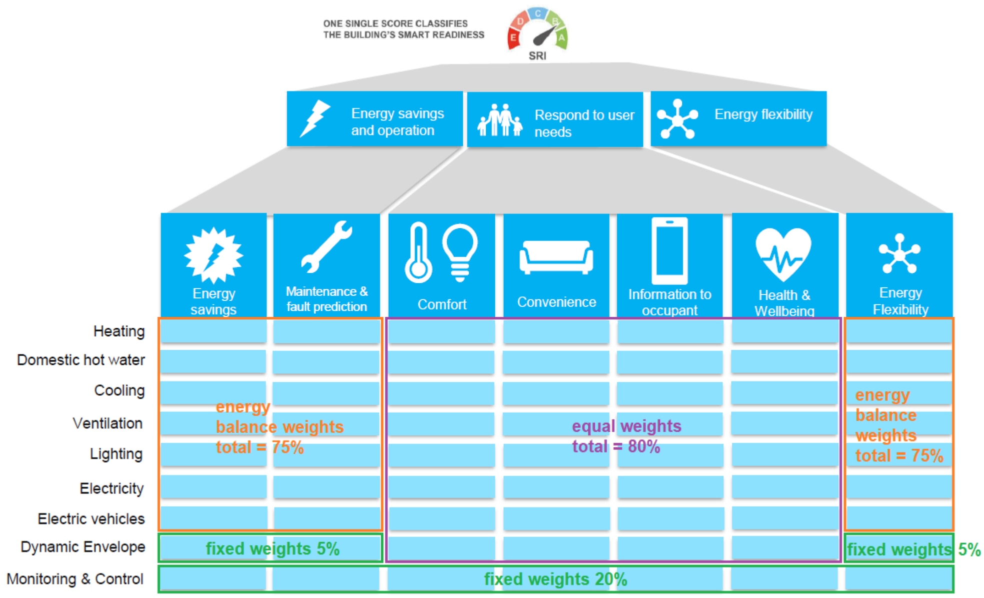

Figure 2 Technical domains and their weighting factors [10].

The values of the fixed weighting factors can be either 5% for the technical domain dynamic envelope regarding impact criteria "energy savings", "maintenance & fault control" and "energy flexibility" or 20% for the technical domain monitoring & control regarding all 7 impact criteria. As for the energy balance and equal weights assessment there are 2 different approaches. Their values can be drawn upon matrixes that accompany the relative published technical studies (Table 1) [18,19] or they can be calculated according to the following formulas:

- The equal weights depend on the fixed weights and the number of relevant technical domains:

$$f equal\ weights_{technical\ domain, impact\ criterion} = \frac{100 - \sum(fixed\ weights)}{number\ of\ relevant\ technical\ domains} \quad (1)$$

- The energy balance weights depend on the equal weights and the $a_{technical\ domain}$ coefficient.

$$f energy\ balance\ weights_{tecnical\ domain, impact\ criterion} = (100 - \sum(fixed\ weights)) \times a_{tecnical\ domain} \quad (2)$$

The $a_{technical\ domain}$ coefficient values can also derive from matrixes (Table 2) or they can be calculated as the quotient of primary energy consumption caused by the examined technical domain to the total primary energy consumption of the building, which includes the domains: heating, domestic hot water, cooling, ventilation, lighting as well as renewable energy production.

$$a_{technical\ domain} = \frac{Q_{technical\ domain}}{Q_{total}} \quad (3)$$

where:

$$Q_{tecnical\ domain} = \{Q_{Heating}, Q_{Domestic\ Hot\ Water}, Q_{Cooling}, Q_{Ventilation}, Q_{Lighting}, Q_{Renewable\ Energy}.\} \quad (4)$$

$$Q\_total = Q\_Heating + Q\_(Domestic\ Hot\ Water) + Q\_Cooling + Q\_Ventilation + Q\_Lighting + Q\_(Renewable\ Energy) \quad (5)$$

Table 1 Weighting factors for residential buildings in North Europe [18].

	Energy savings	**Maintenance & fault prediction**	**Comfort**	**Convenience**	**Information to occupant**	**Health & well-being**	**Energy flexibility**
Heating	0,32	0,33	0,16	0,10	0,11	0,16	0,38
Domestic Hot Water	0,10	0,10	0,00	0,10	0,11	0,00	0,12
Cooling	0,07	0,07	0,16	0,10	0,11	0,16	0,08
Ventilation	0,09	0,10	0,16	0,10	0,11	0,16	0,00
Lighting	0,03	0,00	0,16	0,10	0,00	0,16	0,00
Electricity	0,15	0,15	0,00	0,10	0,11	0,00	0,17
Electric vehicles	0,05	0,05	0,16	0,10	0,11	0,16	0,00
Dynamic envelope	0,00	0,00	0,00	0,10	0,11	0,00	0,05
Monitoring & control	0,20	0,20	0,20	0,20	0,20	0,20	0,20

Table 2 $a_{technical\ domain}$ values for residential buildings per Europe's climate zone [18].

$a_{technical\ domain}$	**North Europe**	**West Europe**	**South Europe**	**North-East Europe**	**South-East Europe**
Heating	39,9	45,3	42,2	40,5	27,5
Domestic Hot Water	12,4	10,2	13,3	18,6	7,7
Cooling	0,0	4,1	9,2	0,0	19,5
Ventilation	25,0	23,8	12,3	25,4	14,4
Lighting	4,9	2,0	3,6	0,8	1,2
Electricity	17,8	14,8	19,5	14,7	29,6

2.2 Calculation methodology

There are 3 methods of SRI and sub indicators calculation [9-11]:

- According to the simplified method A, which was applied in this study, a catalogue of 27 services is assessed. This method can produce fast results and is suitable for residential and small non–residential buildings and can be applied by their users or a qualified inspector. In the first case, the building users are going to be able to assess their building's smart readiness using an online tool while the second one requires on-site inspection and will lead to a formal certificate.
- In detailed method B, the number of smart ready services that are assessed is 54 and is therefore preferred for large and more

complex buildings. Additionally, the functionality levels of the evaluated services can be higher than those of method A. This method is more time consuming than the previous one and can be applied by a technical expert using an online assessment tool or by a qualified expert after on-site inspection that can lead to the building's certification.

- Method C is under investigation and will be utilizing real data regarding the energy performance of the building or building section under examination. These data can come from EPC calculations or technical building systems reports on energy performance if they are available. Therefore, this process requires a long amount of time and the number of technical domains that take part in calculations may be limited. Also, an additional limitation is the fact that this method can be only applied in existing buildings.

Despite the differences between methods A and B there is one common SRI calculation methodology. It can be described in seven steps [9,10].

(1) <u>Triage process</u>

The first step is the process of examining the building and documenting the present smart services included in the 9 technical domains. As for the absent services it is examined whether a number or all of them are desired or ought to be present according to legislation. The triage process is time consuming, especially for large, complex buildings and plays a significant role in the next steps and the determination of the final results.

(2) <u>Functionality level evaluation</u>

The triage process is followed by the services' functionality level assessment. Functionality levels vary from the value 0, when the examined service is deemed not functional at all to the maximum value 4. For instance, the functionality level of a service in relation to heat emission control would be zero if there is not automatic control or would be graded with the maximum score if control utilising sensors and information to the user are provided for each room of a building. This step may require in site inspection, technical documents studying / provision or a combination of them depending on the building.

(3) <u>Impact assessment</u>

After having determined each service's functionality level their impact scores for the 7 impact criteria can be assessed. Afterwards, the impact scores of the services included in each technical domain are summed.

$$I(d, i_c) = \sum_i^{N_d} I_{ic}\,(FL(S_{i,d}) \tag{6}$$

where:

d: number of technical domain, $d \in \mathbb{N}$,

i_c: number of impact criterion, $i_c \in \mathbb{N}$,

N_d: total number of services per technical domain d, $N_d \in \mathbb{N}$,

$S_{i,d}$: service i of technical domain d, d, $i \in \mathbb{N}$, $1 \leq i \leq NS_d$,

$FL(S_{i,d})$: functionality level of smart ready service $S_{i,d}$,

$I_{ic}(FL(S_{i,d}))$: impact of service $S_{i,d}$ per impact criterion i_c, according its functionality level, $I_{ic}(FL(S_{i,d})) \in \mathbb{N}$,

$I(d,i_c)$: total impact of technical domain d per impact criterion i_c, $I(d,i_c) \in \mathbb{N}$.

In the case where a service is present in more than one different parts of the same building and it is characterised by varied functionality levels its impact can be calculated as a weighted sum of its partial impacts. The area of the different building parts can play the role of the weighting factor. This is an issue that is expected to be met mostly in large buildings.

(4) Maximum impact assessment

This step bears a strong resemblance to the one described before. The only difference is that its goal is the calculation of the maximum sum of impact scores that each technical domain can obtain.

$$I_{max}(d, i_c) = \sum_{i}^{N_d} I_{ic}\left(FL_{max}(S_{i,d})\right) \quad (7)$$

where $FL_{\max}(S_{i,d})$: maximum functionality level of smart ready service $S_{i,d}$,

$I_{ic}(FL_{\max}(S_{i,d}))$: maximum impact of the smart ready service characterised by maximum functionality level, $I_{ic}(FL_{\max}(S_{i,d})) \in \mathbb{N}$,

$I_{\max}(d, i_c)$: total maximum impact of impact criterion i_c for technical domain d, $I_{\max}(d, i_c) \in \mathbb{N}$.

(5) Smart Readiness Indicator per impact criterion

Afterwards, the smart readiness indicator per impact criterion can be calculated as the quotient of the weighted sum produced in step 3 to the maximum weighted sum of step 4. The weighting factors derive from the "importance" of every technical domain regarding each impact criterion.

$$SR_{ic} = \frac{\sum_{d=1}^{N} W_{d,ic} \times I(d,ic)}{\sum_{d=1}^{N} W_{d,ic} \times I_{max}(d,ic)} \times 100 \quad (8)$$

where:

d: number of technical domain, $d \in \mathbb{N}$,

N: total number of technical domains, $N \in \mathbb{N}$,

$W_{d,\mathrm{ic}}$: weighting factor of technical domain d per impact criterion i_c,

S_{Ric}: Smart Readiness sub indicator per impact criterion i_c.

Alternatively, the smart readiness indicator of every technical domain for every impact criterion can be calculated according to the formula:

$$SR_{d,ic} = \frac{I(d,ic)}{I_{max}(d,ic)} \times 100 \tag{9}$$

(6) Smart Readiness Indicator per key – functionality

$$SR_f = \sum_{ic=1}^{M} W_f\,(ic) \times SR_{ic} \tag{10}$$

SR_f: Smart Readiness Indicator per key – functionality f,

M: total number of impact criteria, $M \in \mathbb{N}$,

W_f: weighting factor of key – functionality f per impact criterion,

SR_{ic}: Smart Readiness Sub – indicator per impact criterion i_c.

(7) Smart Readiness Indicator (total)

Finally, aggregating the sub indicators described in the last step, the total Smart Readiness Indicator regarding the building or the building part can be assessed.

SRI: Smart Readiness Indicator

S_{rfi}: Sub indicator per key – functionality f_i (i_1=energy savings and operation, i_2=respond to user needs, i_3=energy flexibility)

3. Case Study

3.1 Building description

For the application of the methodology described in the previous chapter of this study a single family residential building in Greece was chosen (climate zone: South Europe). The building is located in Pieria province, hence it belongs in climate zone C according to the national regulation for building energy performance (KENAK) [20]. It can be described as a typical example of a conventional, Greek residential building [21]. Its total area is 197,30 m^2, it was built in 1992 and has never been renovated. The building is poorly insulated and equipped with heating, cooling and domestic hot water production systems. The characteristics of the heating and cooling systems are assumed to follow the characteristics of the reference building according to KENAK as a premise that will lead to more generalized results. The building is highly energy consuming and classified in energy class Z according to KENAK. It can be described as a typical example of a conventional, Greek residential building [21]. For the calculation of SRI Method A was regarded as the most suitable one.

3.1.1 Architectural description

The examined building is a semi - detached two - storey building with a basement. The north wall is in contact with the neighbouring building and the rest of the façades are in contact with the ambient environment. Only the west façade is shadowed by a neighboring building. The structural frame of the building is made of reinforced concrete and is not insulated. The roof is inclined and its structural components are made of wood. The masonry is made of insulating bricks (according to the owner). All openings are comprised of double glazed panes and aluminum frames with the exception of the basement openings which are metallic and single glazed. The first storey, where 3 bedrooms and a W.C. are located, is built in a recess while the basement and the ground floor share the exact same outline. The ground floor is raised and can be approached through an outdoor straight staircase made of concrete. The basement is a not heated space and it is used mainly for storage. The indoor U-shaped staircase is also unheated and separated from the heated residential spaces of the ground and the first floor with masonry and wooden doors (Figure 3).

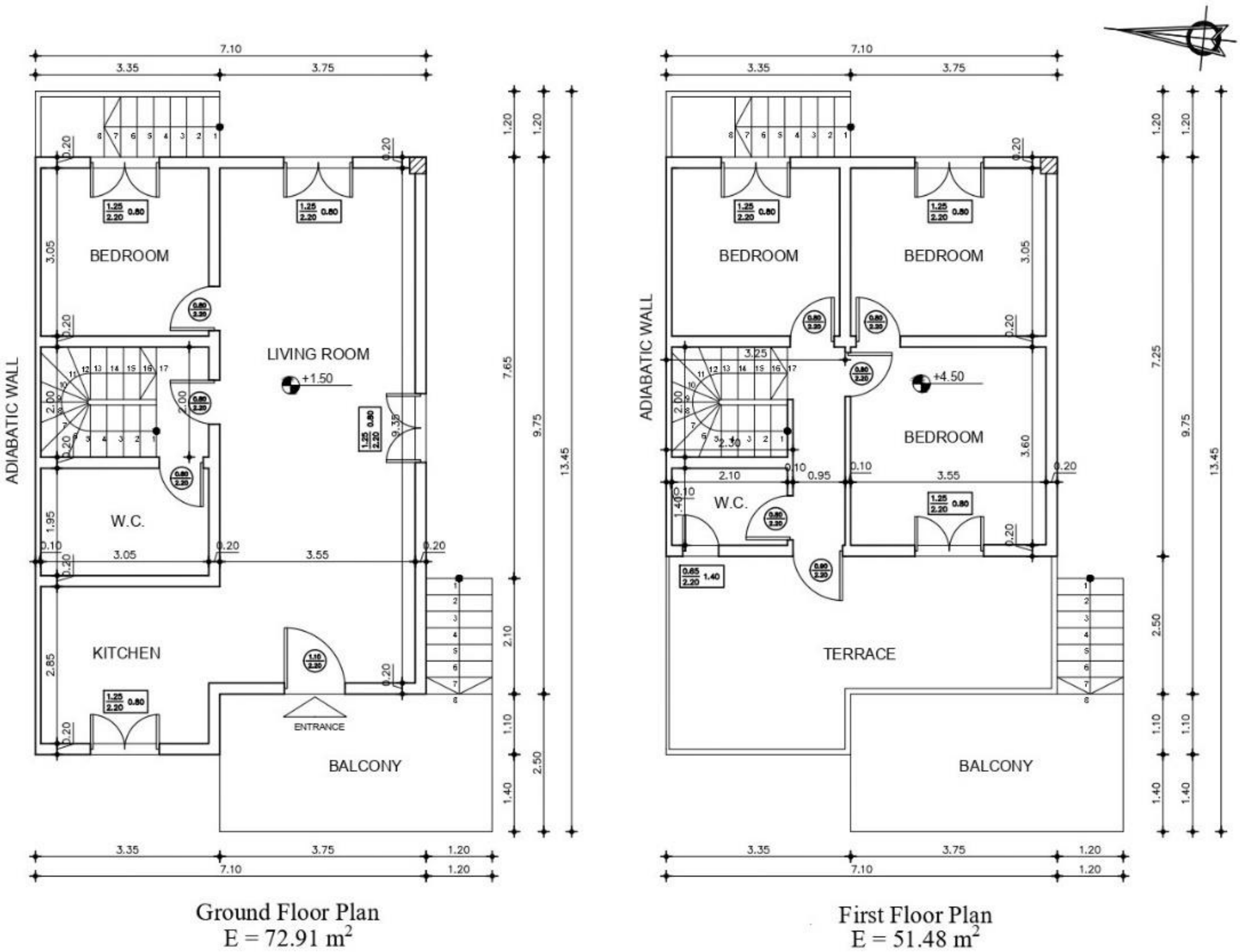

Figure 3 Ground & first floor plan [22].

3.1.2 Building systems

The building is equipped with an oil and a wood boiler for space heating and domestic hot water production. Both systems are used during the winter months but not simultaneously. Each boiler can be operated through its respective central thermostat and the control of heat production is continuous. Additionally, during the summer solar panels are employed for hot water production. There is also an electric boiler that is rarely used as the aforementioned systems cover the residents' needs for domestic hot water successfully. The control of hot water production is not automatic and depends on the users. Cooling needs are covered by one air conditioning unit which is also operated manually. However, in order to produce more generalised results, it was assumed that the heating and cooling systems have the characteristics of those of the reference building according to KENAK. [20].

3.2 Calculation scenarios

In order to calculate the SRI as well as its sub indicators, 2 scenarios were developed, a strict and a lenient one, which differentiated on the number of technical domains taken into account as relevant. Strict scenario included 9 technical domains: heating, domestic hot water, cooling, ventilation, lighting, electricity, electric vehicles, dynamic envelope and monitoring & control while in the lenient scenario only 3 technical domains, heating, domestic hot water and cooling, were deemed relevant. Subsequently, each scenario was divided into 2 sub scenarios of weighting factors calculation. In sub scenarios I the values given in Table 1 regarding residential buildings in southern Europe were used. In sub scenarios II the weighting factors were assessed using the primary energy data regarding this specific building. These data were assessed using TEE – KENAK software which is the national energy performance calculation tool and employs the ISO 13790 quasi steady method [23] (Figure 4). As it was expected due to the building's location according to the national building energy performance regulation, the technical domain of heating was responsible for the biggest amount of primary energy consumption with a share equal to 84% participation, while cooling and hot water demand reached 8% each [22]. The calculation scenarios, their sub scenarios as well as the assumptions that were made for each one are presented in Figure 5.

3.2.1 Strict scenario

For the strict scenario, all smart ready services of the simplified catalogue (Method A) are considered relevant to the indicators' assessment. In the case where a technical domain did not have any present services in the building it was considered that at least those characterised by the minimum functionality level (functionality level = 0) should be present. More particularly, only 5 technical domains' services were present, heating, cooling, domestic hot water, lighting and dynamic building envelope. As for the rest 4 technical domains, controlled ventilation, electricity, electric vehicle charging and monitoring & control, there were not any services present in the building. It is reminded that the building's heating system is controlled automatically with a central thermostat and there is continuous control of heating production. Therefore, the aforementioned services functionality levels are valued with 1 and 0 accordingly. As for the cooling emission control service the functionality level is 0 since it is controlled manually. The same apply for the production of domestic hot water. Finally, the lighting and the dynamic envelope technical domains services' functionality levels are 0 as they are controlled manually with switches and roller shutters respectively.

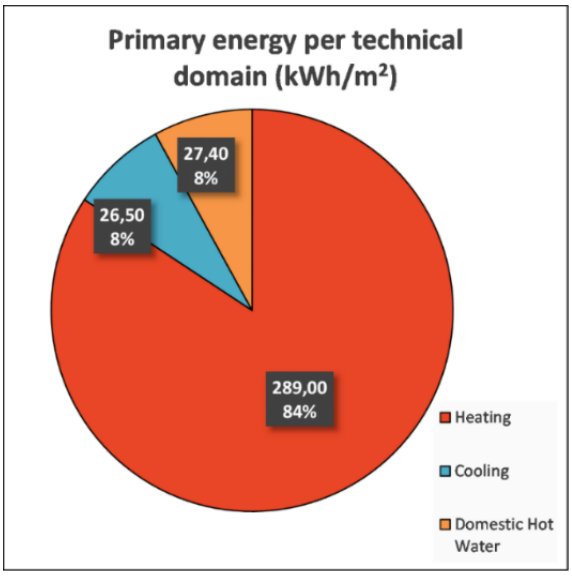

Figure 4 Primary energy consumption per technical domain (kWh/m^2).

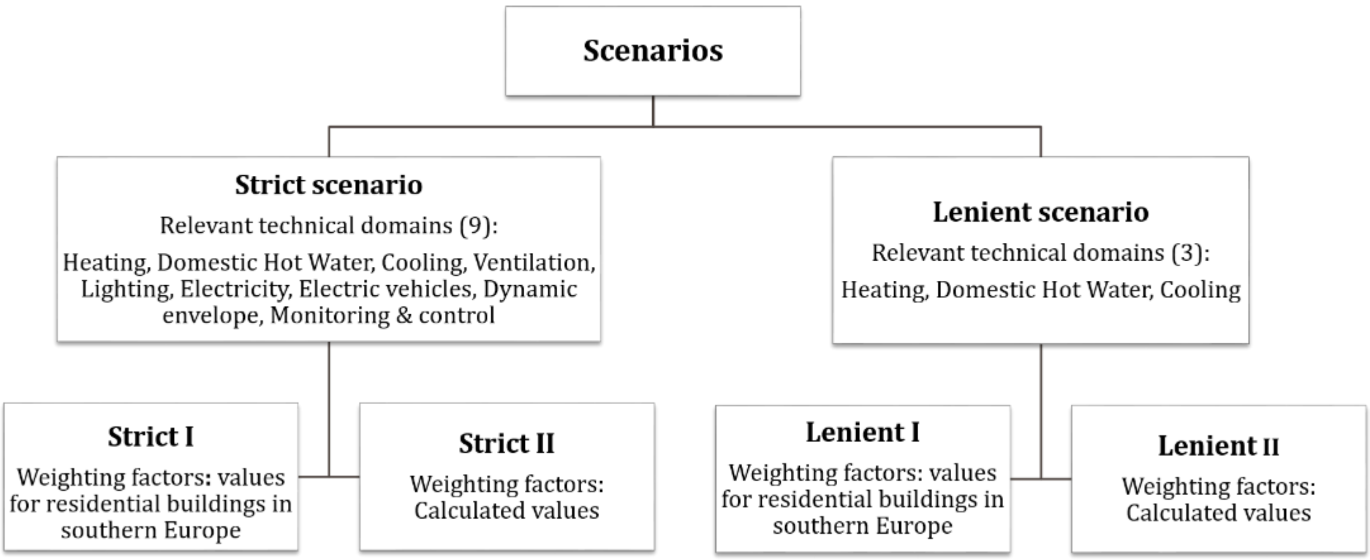

Figure 5 Scenarios overview.

In the first sub scenario “Strict I” the values of Table 1 were used. In the second sub scenario, “Strict II”, the building’s primary energy data were calculated and utilised (Figure 4) and the weighting factors’ values were assessed using Function (3) (Table 3). It can be observed that non zero values were assigned only in technical domains heating, cooling and domestic hot water since these are the domains for which the TEE – KENAK software can calculate the primary energy consumption data for. Nevertheless, the rest 6 technical domains were taken into account in the calculation with zero weights, since they are considered relevant. Heating continues to hold the biggest part of the building’s primary energy consumption and is significantly bigger than the cooling and the domestic hot water consumption parts. Finally, all 3 domains carry the same weights for impact criteria “energy savings”, “energy flexibility” and “maintenance & monitoring” due to the limitations of the used software.

Table 3 Weighting factors of sub scenario “Strict II”.

	Energy savings	**Maintenance & fault prediction**	**Comfort**	**Convenience**	**Information to occupant**	**Health & well-being**	**Energy flexibility**
Heating	0,84	0,84	0,50	0,34	0,34	0,50	0,84
Domestic Hot Water	0,08	0,08	0,00	0,33	0,33	0,00	0,08
Cooling	0,08	0,08	0,50	0,33	0,33	0,50	0,08
Ventilation	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lighting	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electricity	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electric vehicles	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Dynamic envelope	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Monitoring & control	0,00	0,00	0,00	0,00	0,00	0,00	0,00

3.2.2 Lenient scenario

The second scenario’s perspective is that SRI and sub indicators are calculated considering absent services and zero functionality services as not relevant to the assessment. As a result, it can be considered as more propitious than the previous one. In detail, a large number of technical domains including: ventilation, lighting, electricity, dynamic envelope, electric vehicle charging and monitoring & control, is excluded from the calculation process. Therefore, the examined residential building’s smart readiness depends on the remaining 3 technical domains scores: heating, cooling and domestic hot water. Their services’ functionality levels are the same as those in the strict scenario showcasing the building’s systems real strengths and weaknesses.

It is noteworthy that even though the lenient scenario is favorable in the indicators' assessment, it is representative of Greek residential buildings' systems in general and the employment of smart technologies in particular. For instance, considering the country's legislation there are requirements in relation to renewable energy use only regarding the domestic hot water technical domain. According to the Greek Buildings' Energy Performance Directive, 60% of domestic hot water in new and refurbished residential buildings should be produced from solar energy utilisation [24]. Moreover, electric vehicle use has been addressed in legislation only recently [25]. Also, the primary energy calculation of lighting and ventilation systems is not obligatory for residential buildings. Therefore, the exclusion of a significant number of technical domains in SRI calculation can be considered as a logical approach.

After having determined the number of relevant technical domains, the 2 sub scenarios of lenient scenario were developed. In the first one, "Lenient I" the weighting factors of the 6 excluded technical domains were divided equally in the remaining 3 relative domains (Table 4). The equal weights were calculated according to function (1) while the fixed weights got the zero value. It can be noticed that heating still holds the biggest part in primary energy consumption but the difference between cooling and domestic hot water is now smaller. In sub scenario "Lenient II", all weighting factors remain the same as those of "Strict II" since the buildings systems are the same as well as the primary energy consumption (Table 3). Subsequently, the sub scenario's "Lenient II" table and the "Strict II" table are the same despite the initial different approach.

Table 4 Weighting factors of sub scenario "Lenient I".

	Energy savings	**Maintenance & fault prediction**	**Comfort**	**Convenience**	**Information to occupant**	**Health & well-being**	**Energy flexibility**
Heating	0,49	0,49	0,50	0,34	0,34	0,50	0,52
Domestic Hot Water	0,27	0,27	0,00	0,33	0,33	0,00	0,26
Cooling	0,24	0,24	0,50	0,33	0,33	0,50	0,22
Ventilation	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lighting	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electricity	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electric vehicles	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Dynamic envelope	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Monitoring & control	0,00	0,00	0,00	0,00	0,00	0,00	0,00

4. Results

All the needed calculations, regarding SRI and the sub indicators, were performed using Excel spreadsheets and the results are presented in a graph form (Figure 6). In the strict scenario, SRI as well as SR_{f1}, SR_{f2} και SR_{f3} (f_1: energy savings and operation, f_2: respond to user needs and f_3: energy flexibility are the 3 key - functionalities) reached low values. More specifically, bigger scores were achieved in sub scenario "Strict II" with SRI = 6,92%, SR_{f1} = 2,37%, SR_{f2} = 3,47% και SR_{f3} = 1,08% and are substantially bigger than those of sub scenario "Strict I": SRI = 2,67%, SR_{f1} = 1,10%, SR_{f2} = 1,37% and SR_{f3} = 0,20%. As for the lenient scenario, its results are different. Differences between its 2 sub scenarios are smaller in comparison to those of the strict scenario. In detail sub scenario's "Lenient I" results are: SRI = 7,44%, SR_{f1} =1,44%, SR_{f2} = 3,47% and SR_{f3} = 2,54%, while the scores achieved in sub scenario's "Lenient II" were: SRI = 6,92%, SR_{f1} = 2,37%, SR_{f2} = 3,47% και SR_{f3} = 1,08%.

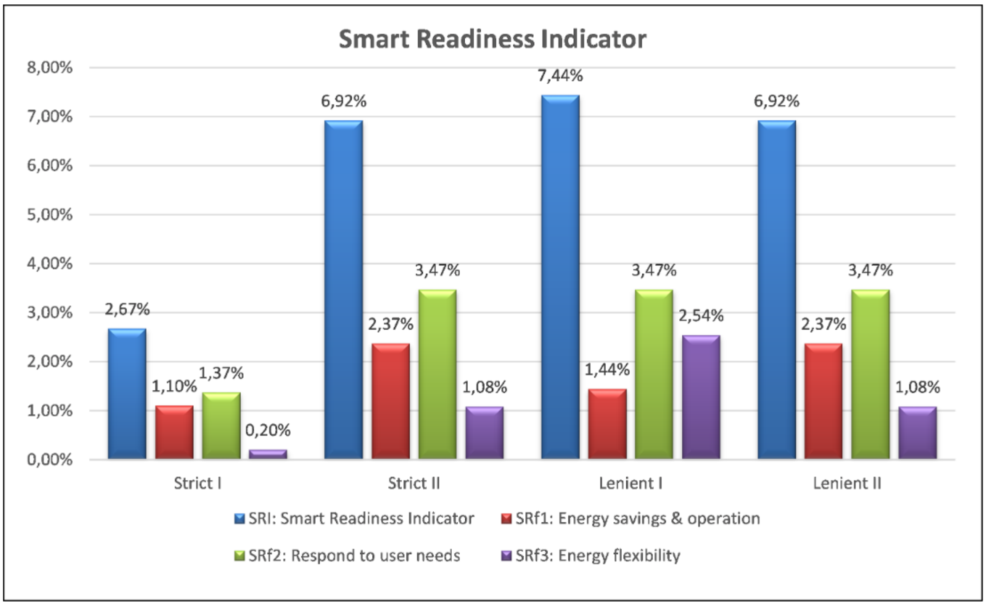

Figure 6 Results of SRI & sub - indicators SR_{f1}, SR_{f2}, SR_{f3}.

Comparing the 2 scenarios it can be noted that the lenient one led to bigger scores. This was an expected outcome due to the exclusion of 6 technical domains from the calculations in the lenient scenario. These domains included services of the minimum functionality level (absent services that were wanted in the building) highlighting that a small number of domains with services of high functionality can lead to bigger scores than a large number of domains with services of low functionality [17]. Moreover, it can be noted that sub scenarios A and B produced the same results since the same weighting factors were used. These issues have been raised in other studies as well [14]. Additionally, there are gaps in the methodology concerning the relevant technical domains and the weighting factors determination and as an outcome the indicator's objectivity is questioned [16,17].

In general, all indicators reached low values. The maximum SRI value was 7,44% in sub scenario “Lenient I”. As for the 3 key – functionalities, the “respond to user needs” was the one with the maximum obtained value of 3,47% while “energy flexibility” was the one with the minimum value of 0,20%. The values of “energy savings & operation” ranged from 1,10% to 2,37%. The low values of the indicators were a logical outcome since the object of examination is a common residential building that lacks the majority of smart ready services that are assessed. Additionally, the present services are not characterized by high functionality levels as it is suggested by the building’s energy flexibility and savings scores. These results are also in line with those presented by Canale *et al*. [15], who estimated the SRI of Italian residential buildings. The Italian and the Greek building stock share similarities, such as old buildings and the lack of legislative obligation to install centralized automation systems leading to low smart readiness scores. Additionally, in both studies the impact criteria “Comfort” and “Convenience” reached the biggest scores (Figure 7) and the technical domains heating and domestic hot water played a major role (Table 5).

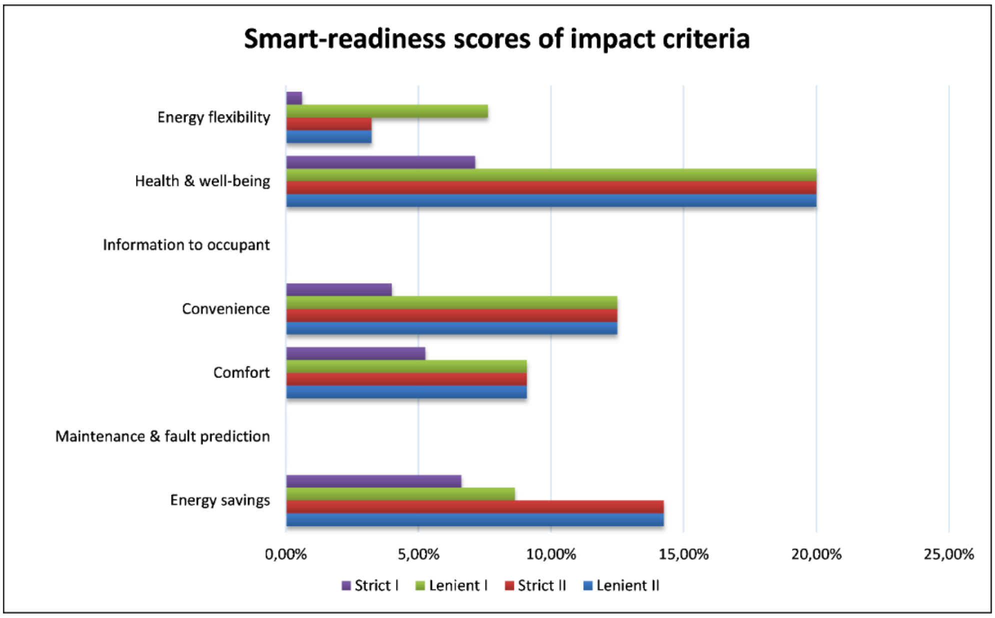

Figure 7 Impact criteria smart readiness scores.

The smart readiness scores per impact criterion and sub scenario are presented in Figure 7. The building’s systems do not have the ability to provide information to the users regarding their energy consumption and their operation leading to zero scores for the impact criteria “Information to occupant” and “Maintenance & fault prediction”. The assessed services smart readiness regarding the health and well-being of the users reached the biggest scores. Additionally, the values of sub scenarios “Strict II”, “Lenient I” and “Lenient II” were the same due to the equal weighting factors assignment. The same principle stands for the values of impact criteria “Convenience” and “Comfort”. This outcome raises questions regarding the indicators weight assignment and the alignment between the results and the occupants' experience [14].

The smart readiness scores of all 4 sub scenarios' technical domains are presented in one common table (Table 5) since they only depend on the functionality level of their respective services and the maximum functionality level that these services can obtain (Function 9). For instance, it can be noted that the technical domain of heating reached a 50,00% score for the impact criterion "Health & wellbeing"($I_{\text{Heating, energy savings}}/ Imax_{\text{Heating, energy savings}}$ = 1,00/6,00) while its score was only 16,67% for "Energy savings" ($I_{\text{Heating, health \& well-being}}$ /$Imax_{\text{Heating, Health \& well-being}}$ = 1,00/2,00) due to the different impact criteria maximum, possible score. The technical domains: ventilation, lighting, electricity, electric vehicles, dynamic envelope and monitoring & control are omitted from Table 5 since their scores are zero in the strict scenario or are not considered relevant in the lenient one.

Table 5 Technical domains smart readiness scores.

	Energy savings	**Maintenance & fault prediction**	**Comfort**	**Convenience**	**Information to occupant**	**Health & well-being**	**Energy flexibility**
Heating	16,67%	0,00%	25,00%	25,00%	0,00%	50,00%	0,00%
Domestic Hot Water	0,00%	0,00%	-	20,00%	0,00%	-	25,00%
Cooling	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

5. Conclusions

The Smart Readiness Indicator, which was first introduced by the revised EPBD in 2018, was the subject of this study. This indicator is an assessment tool regarding the building's smart readiness. It checks the presence of smart ready services and evaluates their functionality levels. Afterwards, a multi – criteria calculation method is utilized in order to determine the scores of each service included in 9 technical domains for the 7 impact criteria. Lastly, the SRI as well as the sub indicators of the 3 key – functionalities *energy savings and operation, respond to user needs and energy flexibility* can be determined.

First of all, the indicator's theoretical structure was analysed. Afterwards, the application was developed. A single-family house in Greece was chosen for the application. This building ranks in energy class Z and lacks the majority of services evaluated for its smart readiness assessment. Moreover, present services are characterized by low functionality levels. As a result, the SRI and SR_{fi} (i=1, 2, 3) reached low scores. On the other hand, the results indicate the opportunities for improvement. In addition, it was deduced that the exclusion of technical domains from the calculations had an effect on the final scores and the weighting factors' determination leading to the development of 2 scenarios. In the first one, the given matrixes were used and the excluded weights were divided equally to those participating in calculations. In the second scenario the weighting factors were determined using primary energy consumption data, calculated with the TEE – KENAK software. It was noted that the smaller the number of relevant technical domains was the smaller the differences between the 2 scenarios were.

Finally, the methodology can be described as simple and easily applicable for small and not complex buildings like the single-family house that was chosen for this study. On the contrary, large buildings that are equipped with numerous mechanical systems are more difficult and time consuming to tackle. Specifically, the triage process, which is of crucial importance, is the most difficult step. This issue should be treated by each European country in an organized way by adapting the relative legislation. In that way, the Smart Readiness Indicator can be utilized as a common meter of comparison in the building sector and subsequently function as an incentive for the application of smart technology in new constructions and when retrofitting the old ones.

Ethics Statement

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Material

Not applicable.

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Competing Interests

The authors have declared that no competing interests exist.

Author Contributions

K.T. conceived the original idea for this paper and was responsible for its review before submission. S.A. performed the numerical calculations and was in charge of writing this manuscript. Both authors contributed to the design and implementation of the research, discussed the results and contributed to the final manuscript.

Abbreviations

The following abbreviations are used in this manuscript:

SRI Smart Readiness Indicator
SR_{f1} Smart Readiness Sub Indicator of key – functionality: energy savings & operation
SR_{f2} Smart Readiness Sub Indicator of key – functionality: respond to user needs
SR_{f3} Smart Readiness Sub Indicator of key – functionality: energy flexibility
KENAK National Building Energy Performance Regulation

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