Spotlighting the significance of the SRI methodological tailoring at country level: a case study in Greece

Apostolos Arsenopoulos
Decision Support Systems Laboratory,
School of Electrical and Computer Engineering,
National Technical University of Athens, Greece
aarsenop@epu.ntua.gr

Efstathios Stamatopoulos
Decision Support Systems Laboratory,
School of Electrical and Computer Engineering,
National Technical University of Athens, Greece
sstamatopoulos@epu.ntua.gr

Panagiotis Samaras
Decision Support Systems Laboratory,
School of Electrical and Computer Engineering,
National Technical University of Athens, Greece
panagiwthssam@gmail.com

Georgios Xexakis
Holistic S.A.,
Greece
gxexakis@holisticsa.gr

John Psarras
Decision Support Systems Laboratory,
School of Electrical and Computer Engineering,
National Technical University of Athens, Greece
john@epu.ntua.gr

***Abstract*— In addressing the challenges posed by climate change, energy poverty, and energy crises, there is an increasing focus on transitioning to green and fossil fuel-free alternatives, reflecting a strong commitment to sustainable development. The Smart Readiness Indicator, introduced by the European Union, aims to improve the energy efficiency of buildings, adjust operations to meet occupants' needs, and respond to signals from the electricity grid. Consequently, developing new methods for decarbonising the energy system has become essential to meet the energy demands of industries, businesses, transportation, and residential sectors. This necessitates a comprehensive understanding of the situation and the implementation of various actions to reform the regulatory framework, promote technological advancements, stimulate economic growth, and foster collective social efforts. This study focuses on customising the Smart Readiness Indicator methodological framework by adjusting the weighting factors of different domains based on the "energy balance" method. Currently, the European Commission provides standard domain weighting values, however this study is focused on their tailoring in order to reflect specific climate zones. Utilising open data and consumption patterns, the customised weightings are applied to a typical Greek single-family house to demonstrate the differences and underscore the importance of tailored assessments for extracting more accurate results compared to the "standard" methodology. The findings highlight significant improvements, especially in energy efficiency and occupant comfort functionalities, suggesting that tailored approaches can enhance the accuracy of SRI assessments.**

Keywords—Energy Efficiency, Decarbonisation, Smart Buildings, Energy Systems, Weighting Factors

1. INTRODUCTION

Buildings contribute to 40% of global energy consumption worldwide [1]. In the European Union (EU), this sector accounted approximately for 35% of total energy-related CO_2 emissions back in 2021 [2], underlining the significant impact that energy efficiency within the building sector can have on achieving broader sustainability goals. Recently, various tools have been developed to reduce this consumption, including automation and control systems [3], AI models that consider comfort aspects [4], optimisation techniques for self-consumption [5], and energy consumption forecasting algorithms [6]. In this direction, the concept of Smart Readiness Indicator (SRI) was introduced in 2017, following a technical study issued by the European Commission, aiming at defining the SRI and proposing a methodology for its calculation. The implementation of the SRI gained significant momentum with the 2018 recast of the Energy Performance of Buildings Directive (EPBD) [7], which officially established the SRI as an optional EU system for assessing buildings' smart readiness [8]. Additional regulations [9], [10] and technical studies [11] have laid the groundwork for the formal SRI testing phase at the national level, supported by the SRI support platform. This platform, serving as the official intermediary for Member States, provides technical guidance and assistance for SRI implementation.

The SRI assesses a building's ability to optimise energy efficiency, adapt to grid signals (energy flexibility), and meet occupants' needs, focusing on electromechanical infrastructure rather than the building envelope. The latter has contributed to promoting the adoption of cutting-edge smart technologies. These technologies not only improve the energy performance of buildings but also ensure that they can adapt their operations to the needs of occupants and respond efficiently to electricity grid signals. Such advancements are pivotal for enhancing energy flexibility, which is increasingly critical in the context of fluctuating energy supplies and prices.

In the scope of reflecting methodologically the technical and context-specific particularities of an SRI assessment, there are several parameters that accommodate great potential in terms of customisation. One of them is the domains' weighting factors against the impact criteria, and more specifically the weightings calculated based on the "energy balance" method. Detailed information on the latter is included in Section 2. The domain weighting values used so far, are drawn from the official numerical values provided by the European Commission, to support the ease-of-application of the proposed SRI framework. The purpose of this study is to present the customised weighting values derived from the "energy balance" method, tailored to the residential building stock of Greece and broken down per climate zone, exploiting open data such as primary energy consumption, conversion factors, etc. These customised values are used in a real-life SRI assessment of a typical Greek single-family house, to highlight the differences compared to the “standard” calculation with the default weighting values, and highlight the importance of such a tailoring towards eliciting accurate results.

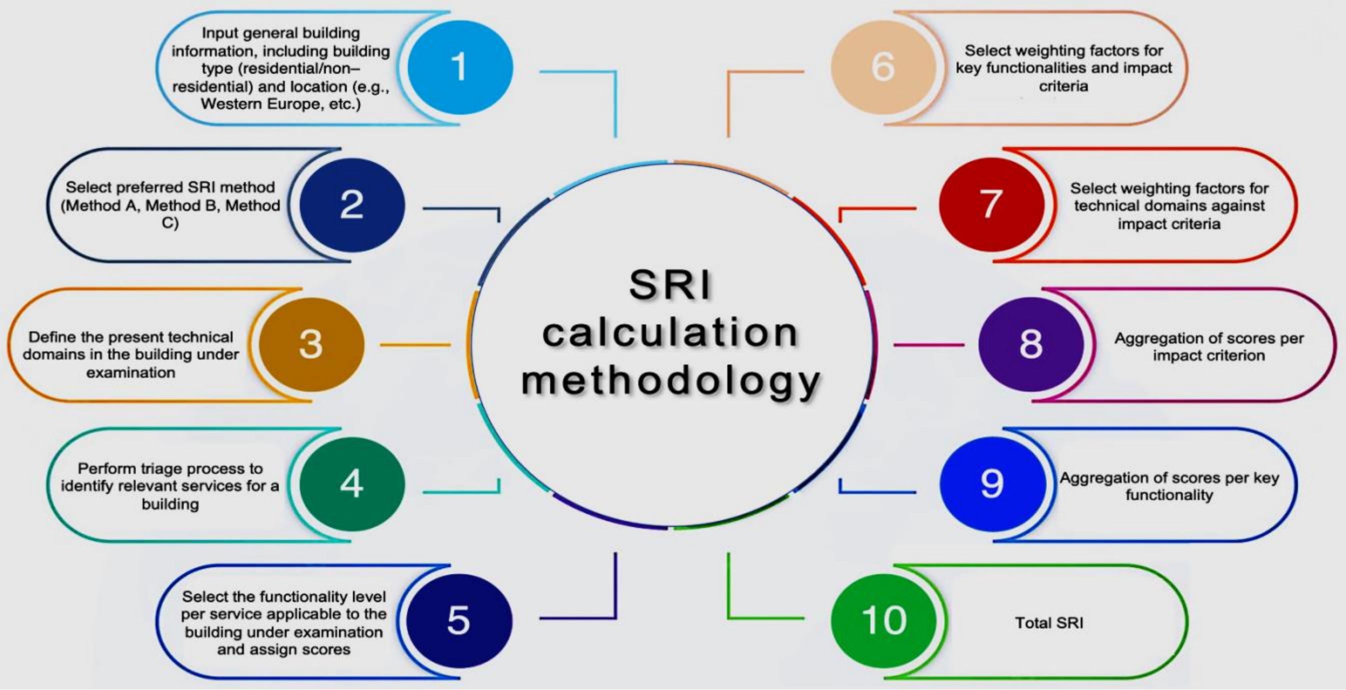

Fig. 1. Methodological framework for the SRI calculation

This paper is structured as follows: Section 2 discusses the methodology behind the SRI, focusing on the different weighting methods applied within the indicator's framework. Furthermore, it delves into the customisation of the Energy Balance Weighting approach, specifically tailored to the Greek residential context. A detailed case study is presented in Section 3, illustrating the application and implications of the customised SRI methodology. This section also discusses the paper’s results and their broader implications. Finally, concluding remarks are laid out in Section 4, which also outlines future research directions.

2. MATERIALS AND METHODS

2.1. *WEIGHTING METHODS*

The SRI calculation methodology is based on an inventory of “smart-ready services” that influence a building’s smartness through their functionalities. Examples of these services include heat emission control, cooling emission control, supply air flow control, window shading control etc.

According to current EU provisions, there are 54 smart-ready services organised in a list. Each service has different functionality levels that indicate varying degrees of smartness. For instance, the functionality levels for “heat emission control” range from the least smart, “no automatic control”, to the most advanced, “individual room control with communication and presence control”.

These smart-ready services are classified into nine “technical domains” and generate seven types of impacts known as “impact criteria”, which are grouped into three main categories reflecting the primary goals of the SRI, known as “key functionalities” (TABLE IV). To unify the different domains and impact categories within a common methodological framework, a Multi-Criteria Analysis method was proposed and developed as the officially recognised approach for calculating the SRI. This methodology is typically applied by a certified assessor [12] and summarised in Fig. 1.

The approach employed for weighting the “key functionalities” as well as the “impact criteria” is the “equal weighting” method. Fig. 6 presents graphically the way this method operates, and the final weights assigned to the implicated SRI assessment components.

There are three discrete approaches to elicit the weighting factors of the nine “technical domains” against the identified “impact criteria”:

1. “Fixed weighting”: This approach prescribes a weighting method for the domains, that provides fixed estimated impacts of “technical domains” on the score of each “impact criterion”. Following this approach, the weights of “technical domains” could be different across the “impact criteria”. For example, the “heating” domain might account for 60% of the obtainable score for the “energy savings” impact category, whereas for other impacts such as “convenience” or “comfort”, might be lower, e.g. 25%. One of the main implications in diving into such an approach is the underlying subjectivity it implies, since it is heavily relied on experts’ personal experiences and knowledge with no scientific evidence to support it.
2. “Equal weighting”: This approach provisions an equal allocation of weights among the implicated “technical domains” and diverts from the ambition to weight the domains according to their perceived relative importance to the total score for an “impact criterion”. Following this approach, the weights of “technical domains” could differ as well among the “impact criteria” (same as “fixed weighting”), however they remain the same in terms of value within each impact category. It should also be noted that the hierarchical approach is maintained between domains and included services. As of that, a domain with

more services will not end up having a higher weight compared to one with fewer services, as depicted in Fig. 2. The value of the weighting factor is obtained by dividing the remaining weight for a given “impact criterion” by the number of domains that are relevant for the given “impact criterion”:

$$WF_{ewd} = \frac{100\% - \sum(\text{fixed weights})\%}{RD} \qquad (1)$$

Where:

WF_{ewd} stands for the weighting factor of a domain based on the “Equal weighting” method,

RD represents the number of all relevant domains.

3. “Energy balance weighting”: This approach is established upon providing a weighting scheme for the “technical domains” that incorporates the estimated impact of the domains on the building’s energy balance. Typically, an energy balance allows the derivation of the relative importance of different domains, taking into account individualised buildings’ characteristics such as the building type and climate zone based on location. Regarding the building context, two types of buildings have been identified based on the respective EU legislation: (a) residential buildings; and (b) non-residential buildings. Although a further break-down of non-residential buildings (e.g. offices, hotels, educational institutions, etc.) could add on the insights drawn from the overall SRI assessment, such a provision is not currently supported by quantified data and thus has been encountered as an alternative option. As for the geographical context, five aggregated climate zones are defined: (a) Northern Europe (Denmark, Finland, Iceland, Norway, Sweden); (b) Western Europe (Austria, Belgium, France, Germany, Ireland, Liechtenstein, Luxemburg, the Netherlands, Switzerland, United Kingdom); (c) Southern Europe (Cyprus, Greece, Italy, Malta, Portugal, Spain); (d) North-Eastern Europe (Czech Republic, Estonia, Latvia, Lithuania, Poland, Slovakia); and (e) South-Eastern Europe (Bulgaria, Croatia, Hungary, Romania, Slovenia). Statistical display of the building stock data allows for the elicitation of default weighting factors based on the following mathematical equation:

$$WF_{ebd} = \left(100\% - \sum(\text{fixed weights})\right) \cdot a_d \qquad (2)$$

Where:

WF_{ebd} stands for the weighting factor of a domain based on the “Energy balance” method,

a_d represents the relative importance of a given “technical domain” in the used energy balance.

If the user of the methodology wishes to use manually defined values for the a_d parameter, the following equations should be used:

$$a_d = \frac{Q_d}{Q_{total}} \qquad (3)$$

$$Q_{total} = Q_{heating} + Q_{domestic\ hot\ water} + Q_{cooling} + Q_{ventilation} + Q_{lighting} + Q_{renewables} \qquad (4)$$

Where:

Q_d is the primary energy use for the domain under examination,

$Q_{heating}$ is the primary energy use for space heating,

$Q_{domestic\ hot\ water}$ is the primary energy use for domestic hot water,

$Q_{cooling}$ is the primary energy use for space cooling,

$Q_{ventilation}$ is the primary energy use for ventilation,

$Q_{lighting}$ is the primary energy use for lighting,

$Q_{renewables}$ is the renewable energy produced on site.

In the final report on the technical support to the development of SRI for buildings [12] where the formal methodology for the SRI assessment is presented, a hybrid weighting approach is employed. Based on this, the “energy balance weighing” method is applied to all “impact criteria” that are considered closely related to energy, namely “Energy savings”, “Maintenance & fault prediction”, and “Energy flexibility & storage”. However, the weights of some “technical domains” such as the “Monitoring and Control” as well as “Dynamic Building Envelope” with regard to these “impact criteria”, cannot be extracted from an “energy balance weighting” approach, and as a consequence fixed weights are assigned to these domains (i.e., 20% for “Monitoring & Control” and 5% for “Dynamic Building Envelope”). The remaining 75% is derived from the “energy balance weighting” method. In the cases where none of the abovementioned weighting methods is used, “equal weighing” is applied. Fig. 6 presents the existing hybrid approach for eliciting the domain weighting factors. The table cells marked in grey are excluded from the weighting process, given that not every “technical domain” is considered relevant to each “impact criterion”.

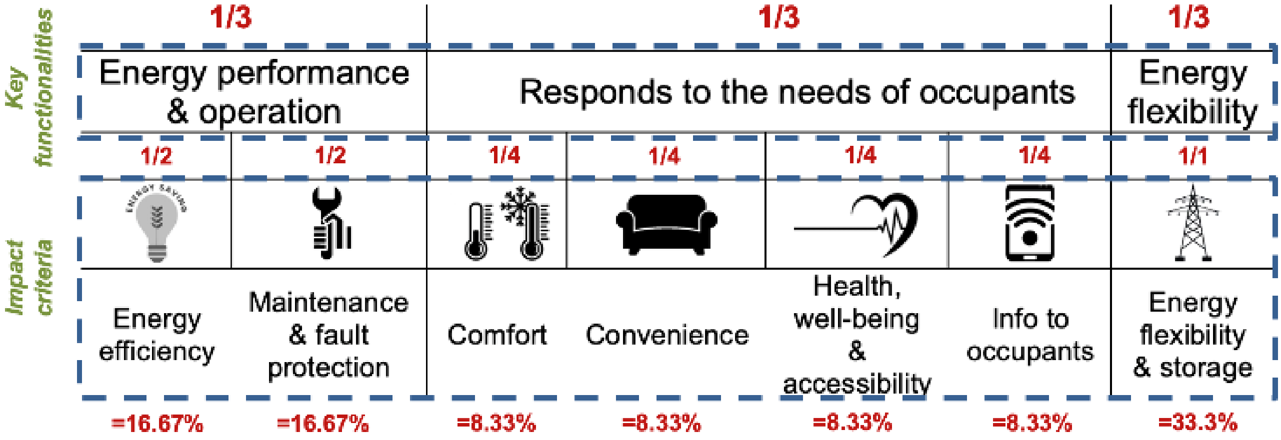

Fig 2. Application of the “equal weighting” method for assigning weights to the “key functionalities” and the “impact criteria” of the SRI assessment process, and final weights assigned.

2.2. “Energy Balance” Weighting Customisation

As elaborated above, the Technical Report of the EC suggests three ways of weighting the service levels for the SRI calculation: “equal weighting”, “fixed weighting”, and “energy balance weighting”. The first method is used for functionality levels related to responding to the needs of the users which can be thus very subjective. This is the reason why the Technical Report suggests using equal weights to avoid the arbitrary ranking of these functionalities. The same strategy can be used in Greece, with the potential exception where functionalities related to convenience/comfort and health and well-being become very important, as in the case of buildings that are mainly intended for the elderly. This possibility can be evaluated by assessing this type of buildings in the testing phase.

The fixed weights method is based on a subjective interpretation of the importance of indicators in the domains of electric vehicle charging, monitoring and control, and the energy-related indicators in the dynamic building envelope domain. Especially for the monitoring domain, the suggested fixed weightings are quite high relative to the other indicators (20%), indicating that the SRI calculation emphasises that monitoring is an important aspect of the smartness of a building. Indeed, monitoring can be used for quality assurance control after construction or renovation and could unlock the future application of Method C of the SRI which is based on real measurements for each functionality level. This recommendation also fits the Greek context, as the projects that are currently monitored are very few. The SRI implementation in Greece is a great opportunity for increasing the data-driven evaluation of the performance of the Greek buildings. A high weight in the SRI class can increase the motivation for monitoring, thus, it is suggested to keep the default fixed weights for the monitoring domain in Greece. For the EV charging domain, the fixed weights relate to the convenience, info provided to the users, and the potential for energy flexibility. While the latter could be potentially very significant in the future where EVs can provide valuable energy storage for the grid, for now it can stay at the level suggested by the EC study. For the dynamic building envelope, the recommended low weights are considered reasonable as the energy use for these kinds of elements are not that high.

The final category is based on the energy balance of the buildings in each country/region and the shares that different domains have there. The Technical Report provides a suggestion of “energy balance weights” for Southern European countries, broken down for residential and non-residential buildings.

The final energy balance weighting vector is heavily dependent on two parameters: (a) the fixed weights that have been assigned to some of the domains against specific impact criteria, and (b) the a_d parameter which represents the relative importance of a given “technical domain” in the used energy balance.

It becomes clear that the fixed weights are up to the user of the methodology to define, and thus are subjective and beyond calculation. However, the a_d parameter can be calculated based on actual data, to better reflect the Greek context. In this respect, we have created a table with tailored a_d numerical figures for all the implicated domains (i.e., space heating, space cooling, domestic hot water, electricity generation from RES, ventilation, and lighting), broken down for each climate zone in Greece. However, it should be pinpointed that these weights have been developed for the residential sector alone, since similar data for non-residential sector are extremely hard-to-retrieve. Nevertheless, the same methodology could be applied once such data become available.

Before moving on to the calculation process, the following assumptions should be considered:

- “Lighting”, “Space cooling” and “Ventilation” use only electricity,
- “Space heating” uses electricity, natural gas, and oil,
- “Domestic Hot Water (DHW)” uses electricity and natural gas,
- The amount of primary energy coming from natural gas is equally allocated between “Space heating” and “Domestic Hot Water”,
- Oil is used exclusively for “Space heating”.

To begin with, the final consumption of electricity, oil, and natural gas in the residential sector of Greece was 1,432.9, 1228.2, and 421.682 ktoe in 2020 respectively. At the same time, the RES electricity amounted to 958 ktoe. Regarding the final electricity consumption and apart from the electricity needed for appliances, 4.9% is used for space heating, 6.4% for lighting, 3% for space cooling, 9.4% for domestic hot water, and 9% for other building-related uses (which for the purpose of this case will be assumed to be used for ventilation). These final energy consumptions of electricity, oil, and natural gas, as well as the RES electricity are then translated into primary energy consumption, based on the following conversion factors:

Electricity: 2.9
Oil: 1.1
Natural gas: 1.1
RES: 1

As a result, the respective primary consumptions are presented in TABLE I:

TABLE I. PRIMARY ENERGY CONSUMPTIONS OF ELECTRICITY, OIL, AND NATURAL GAS

Fuel	Primary energy consumption (TWh)
Electricity	48.33
Space cooling	2.36
Lighting	3.09
Space heating	1.5
Domestic Hot Water	4.54
Ventilation	4.35
Oil	15.71
Natural gas	5.39
RES electricity	11.14

Given the assumptions described above, these primary consumptions need to be allocated to the four climate zones of Greece. This is done by reducing the respective figures to the four climate zones as follows: (a) reduction based on the number of buildings that each climate zone contains for lighting, ventilation, and RES, (b) reduction based on the cooling degree days for space cooling, and (c) reduction based on the heating degree days for space heating and domestic hot water. To elicit the cooling and heating degree days for the four climate zones, an indicative city has been selected for each climate zone, acting as the representative of the climate zone. For Greece, the following cities have been considered [12]:

Climate zone A: Heraklion
Climate zone B: Athens
Climate zone C: Thessaloniki
Climate zone D: Kastoria.

Climate Zone A, known for its temperate Mediterranean climate with mild winters and hot summers; Climate Zone B, characterised by its hot-summer Mediterranean climate; Climate Zone C, with a humid subtropical climate influencing its energy demands; and Climate Zone D, experiencing a continental climate with more pronounced seasonal temperature extremes.

On that reflection, the allocation of primary energy consumption to the four climate zones for all the implicated domains is presented in TABLE II. Then, by applying the applying the above equation $a_d = Q_d/Q_{total}$ on the numerical figures presented in TABLE II, the following a_d values are calculated for each climate zone and presented in TABLE III. Both tables, TABLE II and TABLE III, are provided in the Appendix section.

These values, in turn, could be used in $\mathrm{WF}_{\mathrm{ebd}} = \left(100\% - \sum(\text{fixed weights})\right) \cdot a_d$, based on which the customised final weightings can be calculated and used within the Greek context (TABLE V).

3. CASE STUDY: APPLICATION AND RESULTS

The case is based on a Single-Family House in Greece, the key information of which along with the implicated technical domains are presented on TABLE IV. The SRI calculations were implemented based on the insights laid out in in the study of Apostolopoulos et al. [8], utilising the formal calculation sheet provided by the European Commission. The technical characteristics of the building are detailed as follows:

TABLE IV. KEY CHARACTERISTICS OF THE CASE OF "SINGLE-FAMILY HOUSE" IN GREECE

Building identity	**Characteristics**
Climate Zone	South Europe
Location	Athens, Greece
Greek Climate Zone	B
Construction Year	2011
Floor Area	128 m^2
Technical domains	**Description**
Heating	New noncondensing fuel oil boiler with outdoor temp compensation / central distribution, pipeline mainly inside heated spaces, well insulated
Ventilation	Natural ventilation
DHW	New fuel oil boiler with storage tank and stand-by immersion resistance. Solar collectors for 60% of DHW

For simplicity reasons, it is assumed that the building is located in climate zone B of Greece. This positioning influences the custom domain weightings of the SRI calculation, particularly affecting the domains of energy savings, energy flexibility and storage, and maintenance and fault detection. The remaining weighting factors of each technical domain against the rest of the criteria are the default ones, as rolled out by the European Commission (Fig. 3). The detailed custom domain weights are outlined in TABLE V.

TABLE V.CUSTOMISED DOMAIN WEIGHTS FOR SRI CALCULATION

Domain	**Energy Savings**	**Energy Flexibility and Storage**	**Maintenance and Fault Detection**
Heating	0,1705	0,2255	0,1897
DHW	0,0621	0,0822	0,0691
Cooling	0,0603	0,0797	0,0671
Ventilation	0,1069	0	0,1190
Lighting	0,0760	0	0
Electricity	0,2739	0,3624	0,3048

The SRI was calculated using both Method A and Method B for the building under examination. These calculations were performed with the default and customised weights. The total SRI scores obtained, are illustrated in Fig. 3. Additionally, the individual impact scores are depicted in Fig. 4. Notably, the graph does not include scores for "Maintenance and Fault Detection" and "Information to Occupants" as the building scored 0% in these categories.

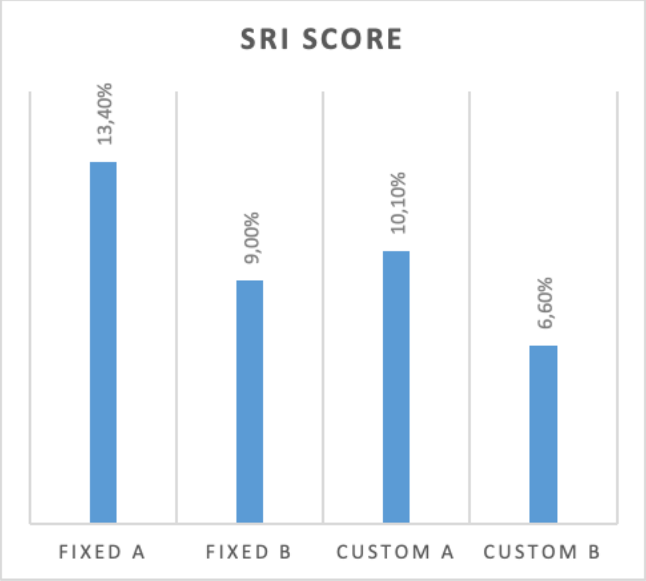

Fig 3. Total SRI Scores with Default and Custom Weightings

Fig 4. Individual Impact Scores with Default and Custom Weightings

Fig. 5 presents the corresponding domain scores, which indicate that only the domains of Heating and Domestic Hot Water are present in the examined building. The other domains, including Cooling, Ventilation, Lighting, Dynamic Building Envelope, Electricity, Electric Vehicle Charging

(EVC), and Monitoring & Control, were declared as not present but mandatory during the assessment. This resulted in the building scoring very low in all four assessments.

This case study underscores the challenges and limitations associated with applying a standardised SRI calculation method to a building with specific regional and climatic characteristics. By comparing the results from Method A and Method B, the study provides valuable insights into the effectiveness of tailored assessment frameworks in accurately reflecting the smart readiness and energy efficiency of residential buildings.

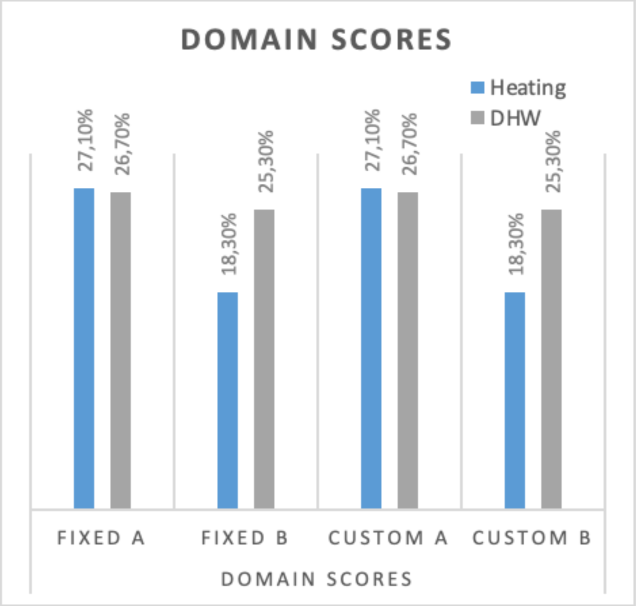

Fig 5. Domain Scores with Default and Custom Weightings

4. CONCLUSIONS

The present study underscores the critical importance of tailoring the SRI methodology to account for specific regional and climatic characteristics, demonstrated through the case study of a typical Greek single-family house. By customizing the weighting factors of different technical domains utilizing the energy balance method, the study highlights significant differences from the standard methodology, thereby illustrating the necessity for such adaptations to yield more accurate and context-relevant assessments.

The use of customized weights in the SRI calculation revealed notable variations in both total SRI scores ad individual impact scores compared to default weights of the whole South Europe region. These differences underscore the importance of regional characteristics in determining the effectiveness of smart readiness measures, advocating for localized adaptations to the SRI framework.

Continued research is essential to further refine the SRI methodology. Future studies should aim to: a) expand the scope of SRI customisation to include a wider variety of building types; b) integrate real-world data from post-implementation evaluations to validate and refine the weighting factors; and c) explore the long-term impacts of SRI-adapted buildings on energy consumption and occupant comfort.

The implications of these findings are significant for both policy and implementation. The research advocates for the adoption of tailored SRI methodologies at the national level, particularly in countries with diverse climatic conditions. Policymakers are encouraged to consider these tailored approaches to enhance the accuracy and relevance of SRI assessments. Beyond policy makers, other key stakeholders might be impacted. Indicatively:

- Building Designers benefit from knowing how smart readiness can increase a building's value and operational efficiency. This understanding can drive investment in smart technologies during construction and renovation phases.
- Energy Consultants and Assessors: Professionals in the building industry can use the findings to advise their clients more accurately on achieving higher SRI scores, leading to better energy performance and reduced operational costs.

In conclusion, the customisation of the SRI methodological framework, as demonstrated in this study, offers a promising path towards more accurate and meaningful assessments. By aligning SRI calculations with regional and climatic specificities, stakeholders can better address the unique energy challenges and opportunities withing their contexts, ultimately contributing to the broader goals of energy efficiency and sustainable development.

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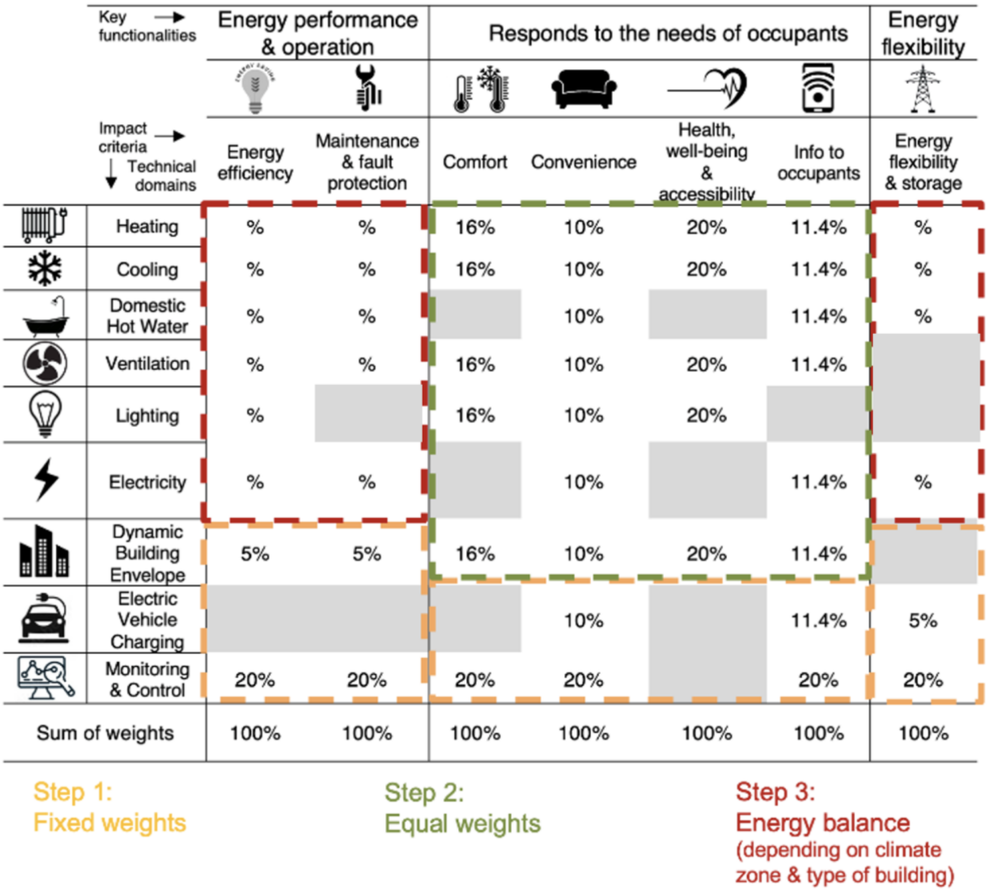
APPENDIX



Key functionalities →	Energy performance & operation		Responds to the needs of occupants				Energy flexibility
Impact criteria → / Technical domains ↓	Energy efficiency	Maintenance & fault protection	Comfort	Convenience	Health, well-being & accessibility	Info to occupants	Energy flexibility & storage
Heating	%	%	16%	10%	20%	11.4%	%
Cooling	%	%	16%	10%	20%	11.4%	%
Domestic Hot Water	%	%		10%		11.4%	%
Ventilation	%	%	16%	10%	20%	11.4%	
Lighting	%		16%	10%	20%		
Electricity	%	%		10%		11.4%	%
Dynamic Building Envelope	5%	5%	16%	10%	20%	11.4%	
Electric Vehicle Charging				10%		11.4%	5%
Monitoring & Control	20%	20%	20%	20%		20%	20%
Sum of weights	100%	100%	100%	100%	100%	100%	100%

Step 1:
Fixed weights

Step 2:
Equal weights

Step 3:
Energy balance
(depending on climate zone & type of building)

Fig 6. Hybrid approach for weighting the "technical domains".

TABLE II. PRIMARY ENERGY CONSUMPTION OF EACH IMPLICATED TECHNICAL DOMAIN TO THE ENERGY BALANCE WEIGHTING, ALLOCATED TO THE FOUR CLIMATE ZONES OF GREECE

Climate zone	**Primary energy consumption (TWh)**					
	Lighting	***Space cooling***	***Space heating***	***DHW***	***Ventilation***	***RES***
A	0.65	0.32	2.43	0.88	0.91	2.34
B	1.46	1.16	3.27	1.19	2.05	5.26
C	0.84	0.67	5.80	2.11	1.18	3.03
D	0.14	0.22	8.36	3.05	0.20	0.51

TABLE III. TAILORED AD VALUES FOR EACH CLIMATE ZONE OF GREECE

Relative importance (%) for residential buildings	**Climate zone A**	**Climate zone B**	**Climate zone C**	**Climate zone D**
Heating	32.2	27.7	42.5	67.0
DHW	11.7	8.3	15.5	24.4
Cooling	4.2	8.0	4.9	1.8
Ventilation	12.1	14.3	8.7	1.6

Lighting	8.6	10.1	6.2	1.1
Electricity (RES generation)	31.1	36.5	22.2	4.1

TABLE IV. Overview of Technical Domains, Impact Criteria and Key Functionalities Included in the SRI Methodology

Technical domains	
1. Heating 2. Cooling 3. Domestic Hot Water 4. Ventilation 5. Lighting 6. Dynamic Building Envelope 7. Electricity 8. Electric Vehicle Charging 9. Monitoring & Control	
Impact criteria	**Key functionalities**
1. Energy efficiency 2. Maintenance & fault protection	1. Energy performance & operation
3. Comfort 4. Convenience 5. Health, well–being & accessibility 6. Information to occupants	2. Response to the needs of occupants
7. Energy flexibility & storage	3. Energy flexibility