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Application of Smart Readiness Indicator for Mediterranean buildings in retrofitting actions

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Application of Smart Readiness Indicator for Mediterranean buildings in retrofitting actions

Dissertation presented to obtain the master's degree in Engineering in the Energy for Sustainability

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Abstract

In recent years, there is an increasing need to invest in smart, energy-efficient technologies in the buildings to improve health, convenience for occupants and to reduce energy consumption and carbon emission impacts. According to the revised Energy Efficiency Directive (2018/844/EU), the Member States are required to develop the long-term renovation strategies to move towards sustainable, secure and decarbonized energy systems by 2050. As one of the main parts of these strategies, digitalization and developments in the information and communication technology (ICT) sector play a critical role in improving the efficiency of the European energy market and remaining in the current progress of sustainable and renewable energy systems. Therefore, the revision required the Member States to establish an optional common scheme for definition and calculation of the smart readiness indicator (SRI) to assess the capabilities of buildings to adapt its operation to the needs of the occupants and of the electricity grid and to achieve more efficient operation.

This work aims to analyses and apply the SRI calculation methodology proposed by European Commission Directorate-General (DG) Energy in two service buildings in the Mediterranean climate in Portugal. The smart ready services in the buildings were identified and evaluated according to the proposed calculation methodology and the overall SRI score was obtained for the buildings. Also, the possible effects of smart services and retrofit actions on indoor environment quality (IEQ) and energy performance in the buildings were assessed through performing a monitoring campaign and energy simulation for two different rooms in the buildings.

Keywords Smart Readiness Indicator, smart ready technologies, building retrofitting, energy efficiency, thermal comfort, Energy Performance of Building Directive.

Resumo

Nos últimos anos, surgiu uma crescente necessidade de investir em tecnologias inteligentes e energeticamente eficientes nos edifícios para melhorar a saúde, a adaptação aos ocupantes e a reduçãono consumo de energia e reduzir o impacto das emissões de carbono. De acordo com a revisão da nova Diretiva Europeia sobre o Desempenho Energético dos Edifícios (2018/844 / UE), os Estados-Membros devem desenvolver estratégias de mudança a longo prazo, no sentido de adotar medidas que inclua sistemas energéticos sustentáveis, seguros e sem emissões de gases com efeito de estufa até 2050. Como uma das principais partes desta estratégia, a digitalização e o desenvolvimento no setor da tecnologia da informação e comunicação (ICT) desempenhar um papel crítico na melhoria da eficiência do mercado energético Europeu e na manutenção do progresso atual dos sistemas de energia sustentável e renovável. Por conseguinte, a revisão exige aos Estados-Membros a responsabilidade de estabelecer um regime comum opcional para definir e calcular o indicador de aptidão para tecnologias inteligentes (SRI), para avaliar a capacidade dos edifícios em adaptar o seu funcionamento às necessidades dos ocupantes e à rede de energia elétrica pública, para conseguir uma operação mais eficiente.

Este trabalho tem como objetivo analisar e aplicar a metodologia de cálculo do SRI proposta pela Direção-Geral da Comissão Europeia para as Políticas Energéticas, considerando dois edifícios de serviços localizados no clima mediterrâneo em Portugal. Os serviços inteligentes existentes nos edifícios em estudo foram identificados e avaliados de acordo com a metodologia de cálculo proposta, em que a pontuação geral do SRI foi obtida para a totalidade dos edifícios. Além disso, os possíveis efeitos dos serviços inteligentes, as ações de modernização na qualidade do ambiente interior (IEQ) e o desempenho energético dos edifícios foram avaliados através da realização de uma campanha de monitorização e simulação energética para duas salas diferentes nos edifícios.

Palavras-chave: Indicador de aptidão para tecnologias inteligentes, tecnologias inteligentes, reabilitação dos edifícios, eficiência energética, conforto térmico, Diretiva Europeia sobre o Desempenho Energético dos Edifícios.

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Acronyms

CABA – Continental Automated Building Association

CHP – Combined Heat and Power

DE – Dynamic Envelope

DER – Distributed energy Resource

DH – District Heating

DHW – Domestic Hot Water

DSM – Demand Side Management

EG – Energy Generation

EPBD – Energy Performance of Buildings Directive

EPC – Energy Performance Certificate

IAQ – Indoor Air Quality

ICT – Information and Communication Technology

IEQ – Indoor Environment Quality

KPI – Key Performance Indicator

MC – Monitoring and Control

RES – Renewable Energy System

SRI – Smart Readiness Indicator

TABS – Thermally Activated Building system

TBS – Technical Building System

TES – Thermal Energy Storage

VPP – Virtual Power Plant

1. INTRODUCTION

1.1. Context

Access to sustainable energy sources has long been a major concern for developed and industrialized countries, especially the European Union (EU). The European Union is the largest energy consumption market in the world which is highly dependent to the energy import specially from Russia and Middle East. On the other hand, the global environmental concerns are becoming a serious challenge for the world. Housing stock is still majorly energy inefficient in the Europe and is identified as one of the main energy consumers and greenhouse gas emissions producers. According to the EPBD [1], almost half of the final energy consumption in European Union is used for heating and cooling which 80% of that is used in the buildings. Also, the building sector is responsible for approximately 36% of all Co_2 emissions in the EU. Therefore, it seems necessary that Member Sates look for a cost-efficient balance between decarbonizing energy systems and reducing energy consumption in the building which requires accelerating the building renovation rate and tapping the potential of smart buildings. To reach these objectives, EPBD in the latest amended directive (2018/844/EU) required Member States to clarify their expectations for long-term renovation strategies and to set domestic progress indicator according to their national conditions to monitor the developments. Besides, the smart readiness indicator (SRI) for buildings was defined as a measure to assess the level of smartness of a building. These attempts highlight the value of smart services application in buildings especially in retrofitted buildings, in energy conservation and sustainable development. To achieve these goals, EPBD recommends adopting building control and automation systems especially in large non-residential buildings by 2050 and utilizing self-regulating devices to control the indoor temperature independently in case it is economically feasible. According to [1], a “building automation and control system” is defined as “a system comprising all products, software and engineering services that can support energy efficient, economical and safe operation of technical building systems through automatic controls and by facilitating the manual management of those technical building systems”. In another words, automation and control systems are sets of tools and software which can contribute to more monotonous and economic actions for energy performance and security improvements. A constantly monitored system is able to record and analysis the information to energy consumption improvement, diagnosis and alert of system failures and connect building technical systems to other services in the building. However, there is not sufficient detailed definition of control and automation systems of buildings provided by EPBD.

As it was mentioned before, Member States should define the guidelines in the Directive based on their specific needs and conditions (geographically, financially…) and accordingly, implement necessary strategies in the buildings. For this aim, based on the Directive recommendations, Member States should be prepared technically and theoretically regarding construction and energy and utilize three useful tools including trigger points, One-Stop-Shop (OSS) and the building renovation passport to perform in a more efficient way [2]. Trigger points are certain periods in the building's life when the most efficient decisions and appropriate intervention can be made to improve the energy performance of the building. In addition, the One-Stop-Shops for energy renovations of buildings are "transparent and accessible advisory tools from the client perspective and new, innovative business models from the supplier perspective" [3] which is supported also by the "Smart financing for smart buildings" initiative. In order to develop working models and frameworks in which climate mitigation and energy performance of buildings will effectively improve, the European Commission, Joint Research Center (JRC) has effectively involved. The third tool introduced by the Directive is the building renovation passport which is a document (in electronic or paper format) which is a step-by-step road map for a long-term (up to 15-20 years) deep renovation for a specific building [1].

The area of concentration of this Master's thesis is to analyze the smart readiness indicator (SRI) defined by the "new" EPBD directive and assess the proposed calculation methodology by applying it in the building in the Mediterranean climate region and evaluate the effectiveness of possible retrofit actions on SRI, the energy performance of the building and indoor environment quality (IEQ).

1.2. Problem statement

As it was mentioned in the previous section, SRI was introduced by the latest published EPBD directive and it is in the beginning point of its way. Therefore, the methodology of SRI calculation needs to be comprehensively studied, evaluated and examined from different aspects and in various conditions. The lack of researches in this field could hinder the effective implementations and prevent the building owners, occupants and stakeholders to take full advantage of this scheme. This study was carried out to contribute to fill this research gap thorough assessment of the proposed methodology for a specific building in a particular climate condition and investigate the relation of this indicator with building retrofitting.

The area of concentration of this work is the analyzing and implementation of the proposed SRI calculation methodology in two service buildings in the Mediterranean climate in Portugal. One of these buildings has been constructed in 2008 and no energy certification study has been conducted for this building so far. But the building envelope and technical systems in the building have already passed the national regulations. The other one has been constructed in 2015 beside the first building (partially integrated from inside) with the higher energy performance and energy class C. The objective of this work is to analyze the SRI calculation methodology in the Mediterranean climate and to investigate the effect of building renovation on SRI as well as energy-saving and IEQ It is achievable by comparing SRI before and after implementing the possible retrofitting actions. More specific goals of the research were included in the following research questions:

- Which factors are effective on SRI assessment for a building?
- Is there any relation between building retrofitting and SRI improvements?
- Does the higher SRI actually guarantee better energy performance in the building?
- Does the higher SRI really guarantee better IEQ?
- In which ways the SRI in a building can be improved?

1.3. Methodology

The methodology applied in this study is mainly based on the methodology introduced by European Commission Directorate-General (DG) Energy which is a checklist approach filled through site visiting and a sort of calculations based on the data provided in the spreadsheets. This methodology will be explained in chapter 3. Then, two case study buildings were selected and analyzed through an on-site investigation. In order to evaluate the indoor environment quality for the buildings with different SRI and technical building services, a sort of measurements was carried out for two separate rooms in two case buildings. Moreover, two sets of surveys were performed to assist SRI assessment and to evaluate occupants' overall satisfaction of indoor environment quality in the case study buildings. In addition, to analysis the buildings' energy performance under the influence of smartness and energy-efficient actions, the building simulation was carried out using DesignBuilder Software for two separate rooms.

1.4. Thesis structure

This thesis consists of five chapters (besides the introduction and conclusion chapters). Chapter 2 provides an overview of the recent researches on the smart buildings' definitions, SRI assessment and building retrofitting strategies in the Mediterranean climate region. The SRI calculation methodology is introduced and analyzed comprehensively in chapter 3. The case studies are presented in chapter 4 and the SRI calculation is implemented for the buildings. Then the IEQ assessments and energy performance simulations for the case buildings are presented. Lastly, Chapter 5 provides conclusions and recommendations for future work.

2. LITERATURE REVIEW

In this chapter, the recent researches in the field of smart building definitions, SRI methodology assessment and building retrofitting strategies in the Mediterranean climate are presented.

2.1. State-of-the-art on smart buildings

It is evident in the recent studies that the building stock in Europe is just at the beginning point of its smart-ready way [4]. Although there has been a viable concern in different studies to discuss smart buildings, the definition of smart building often varies between the publications. Nevertheless, the most imperative step to developing relevant technologies and systems related to smart-ready buildings is to have a united interpretation of smart buildings as a reference. According to [5], a smart building is defined as a building in which advanced building technology systems are integrated for the efficient performance of the buildings in terms of energy efficiency, occupational health and comfort, security, sustainability, and building marketing. Similarly, Wang et al [6] described the smart building as a building that provides an optimal comfort level and energy consumption as well as sustainability issues by employing intelligent technology and renewable energy resources. In addition, several other studies agree that one of the most indispensable aspects of smart buildings is system synthesis which improves the building functionality and performance. Kiliccote et al [7] described a smart building is a building in which the self-aware, grid-aware end-use systems are combined and are in a monotonous interaction with occupants needs and environmental conditions. Likewise, Buckman et al [8] defined smart buildings as buildings that adaptively integrate entire building systems including smart system, operation, control, material, and construction to improve building performance. In a distinctive prospect, the smart building defined as a building which is integrated into smart grids. As it was described in [9], a building which is integrated to a smart city system with active modules in thermal and electric energy systems and involves actively in energy generation, load shifts and energy-storing can be considered as a smart building. The Buildings Performance Institute Europe (BPIE) defines a smart building as a dynamic micro energy-hub which with energy generation, control, store, demand response and interconnection with electric vehicles improve the flexibility of the energy systems while provides a healthy and comfortable living and working environment for the occupants [10].

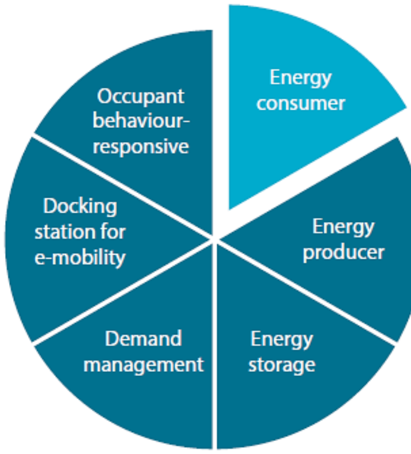


Figure 2.1. New functions of smart buildings [10]

A smart building was also defined as a part of a smart environment that provides more efficient living and working environments for occupants [11]. Moreover, according to the Continental Automated Building Association (CABA) a smart building has the ability to behave in relation to the effects of parameters around it [12].

As it was mentioned before, regarding the smart readiness indicator there has been a few studies carried out so far. In one of this work conducted by Janhunen et al [13], the applicability of the SRI to cold climate countries in Northern Europe was explored. Since most of the buildings in Northern European countries enjoy advanced information and communication technologies with high energy consumption profiles, they were an exceptional test environment for the indicator. The findings implied that this indicator was not able to recognize the specific features of cold climate buildings, specifically those using advanced district heating systems. This research also suggests that the applicability of SRI as a fair rating system across the EU member states is uncertain because of the subjective nature of the proposed methodology for SRI relevant building services selection. In the other study, the smart-readiness metrics were used to determine the smart-readiness level of the current typical Dutch residential building in [14]. The regular Dutch terraced house is the most common type residential building in the Netherlands, so the smart-readiness assessment in the study was focused on typical Dutch terraced house and its design variations that currently available or could be developed in the future. Based on the modeling and simulation results of the tested case studies, the typical Dutch terraced house had significant untapped potential that can be optimized to adjust the current building to be ready in the smart building transformation. It was also shown that the indicators depend on the occupant behavior which could cause the same building to have different smart-readiness levels according to the occupancy pattern.

2.2. State-of-the-art of building strategies in Mediterranean climate

During the last decade, many countries have put significant effort toward energy efficiency improvement in existing buildings. Building retrofitting offers many challenges and opportunities which can vary depending on different circumstances such as climate conditions, building type and economic situation besides many uncertainties such as climate change, energy policy change and human behavior change. All of these factors could be highly effective during building retrofitting technology selection. There have been many studies conducted in this field that examined the building retrofitting in various perspectives. However, the area of concentration in this section is on review the studies have been done regarding the challenges and opportunities of building retrofitting in the Mediterranean climate.

Some studies analyzed different building envelope performance in the Mediterranean region and found that energy demand can be reduced by using proper windows, shading devices and building envelope materials [15-18]. Using passive strategies has been also one of the main areas of interests for the researches in this field. A study on passive cooling techniques was carried out by Imessad et al [19] to evaluate the impact of thermal mass and eaves and night ventilation on energy demand. They showed that cooling energy demand is more affected by thermal transmittance values than by the envelope thermal mass and recommended the optimum overhang length for south-facing windows. Also, it was suggested that the combination of both natural ventilation and horizontal shading devices improves thermal comfort for occupants and significantly reduces cooling energy demand. Accordingly, Gil-Baez et al [20] studied on the effects of passive refurbishment solutions to improve the envelope of school buildings (insulation, shading and glazing) in a building in the Mediterranean climate. The results showed that energy demands reductions are relatively lower compared with those reported in equivalent schools in other climates.

Climate change as one of the main potential challenges of building retrofitting in the Mediterranean region has been studied in [21-23]. It was shown that the demand for cooling and the risk of overheating increase considerably in all the prediction scenarios for climate patterns in the future. While in some studies it was suggested that increased thermal insulation and reductions in infiltration will have a greater effect on global energy demand, in some researches it was proven that the facade improvement is not an effective measure in the Mediterranean climate, and the use of adaptive setpoint temperatures is the most efficient measure.

2.2.1. Conclusion

To sum up, according to several pieces of research have been conducted to define the smart building, it can be said that the main objectives of smart buildings are to optimize the energy consumption and thermal comfort based on different factors such as occupants' behavior and climate using smart technologies integrated with renewable energy sources. However, the indicator which assesses the level of smartness of buildings has been recently introduced with the lack of sufficient and reliable scientific researches. In addition, in order to develop the study for the retrofitted buildings in the Mediterranean region, it seems necessary to identify the main character and effective retrofit actions of the buildings in this region. Based on the several studies, because of the long summers and the intense need for cooling, considering passive measures in retrofit buildings in the Mediterranean climate is the main area of interest of many works in this field.

3. THE SMART READINESS INDICATOR

3.1. Introduction

In the coming years, the world needs to consider digitalization integration into the energy sector more than ever. This would be a key effort in improving efficiency and protecting the environment. Therefore, it was introduced by EPBD as an indispensable support for the European energy market to remain competitive, affordable, and secure in the decentralized and decarbonized network [1]. In addition, investments in the information and communication technology (ICT) integration into the construction sector should be accelerated across Europe to lead the future sustainable and renewable energy systems. Besides, EPBD emphasis of the using ICT in the building sector as one of the main requirements for EU's 2020 target for nearly zero-energy buildings (nZEB), the 2030 long-term energy efficiency and renewable energy targets and the 2050 carbon economy goal [1]. For this aim, an indicator is needed to evaluate the level of readiness of the building services to record and transfer data and interact with occupants and network, or in other words, the level of smartness of building services. Smart readiness indicator (SRI) was defined as a cost-effective measure to help reducing energy consumption and carbon impacts, integration to renewable energy sources (RESs) while providing a healthy and comfortable living condition. Technical studies have been conducted by VITO[1] team under the authority of the European Commission (DG Energy) with the purpose to develop a calculation methodology and potential characteristics of this indicator. The first technical study was published in August 2018 aiming at analyzing the possible scope and characterizing of SRI [24]. The second technical study was conducted in December 2018 with the aim of further investigation on the methodology and features of SRI [25]. Meanwhile, this research has been developing and so far, three interim reports have been launched to present the latest developments and methodological progress. This chapter aims to introduce and analyze the methodology and definitions provided by these references.

[1] https://www.vito.be/en

3.2. SRI definition

The new provision of the amended EPBD requires the establishment of an optional European Smart Readiness Indicator (SRI) scheme as a common language to evaluate the capability of buildings to use ICT and electrical systems. This indicator is a tool to facilitate expected smart building objectives achievements regarding energy production, storage and fault diagnosis improvements as well as healthier, more comfortable and convenient life for occupants. Figure 3.1 shows the expected advantages according to smart readiness indicator catalogue provided by DG Energy [25].

Figure 3.1. Expected advantages from smart readiness indicator implement [25]

According to revised EPBD, SRI is "an assessment of the capabilities of the building or building unit to adapt its operation to the needs of the occupants and the grid and to improve its energy efficiency and overall performance" [1]. This indicator should be a cost-effective measure which support technology innovation in the building sector and raise awareness from ICT and smart technologies. Figure 3.2 shows the main three features of the smart readiness indicator introduced by EPBD.

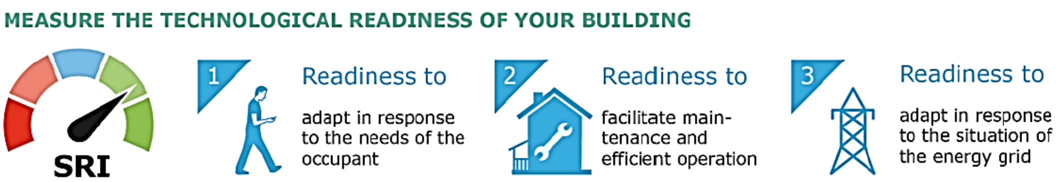


Figure 3.2. Three main features of the smart readiness indicator of the building [25]

3.3. Methodological framework

The SRI framework is based on first and second technical catalogue provided by European Commission DG Energy [24, 25] which should be in an efficient and cost-effective approach, reflect the features and potential of innovative technologies, able to maintain energy performance and operation of the building and complement policy and market initiative such as Energy Performance Certificate (EPC), Eco-design and energy labelling and Building Renovation Passport (BRP). This framework follows a methodological approach in 5 principal tasks including:

Task 1: Technical support for the consolidation of the definition and calculation methodology of the SRI. The objective of this task is to provide a technical guideline for SRI definition and calculation methodology.

Task 2: Investigation of SRI implementation pathways and of the format of the SRI.

Task 3: Guidance for effective SRI implementation.

Task 4: Quantitative modelling and analysis of the impact of the SRI at EU level.

Task 5: Stakeholder consultation and study website.

Task 6: Support to the policy making process.

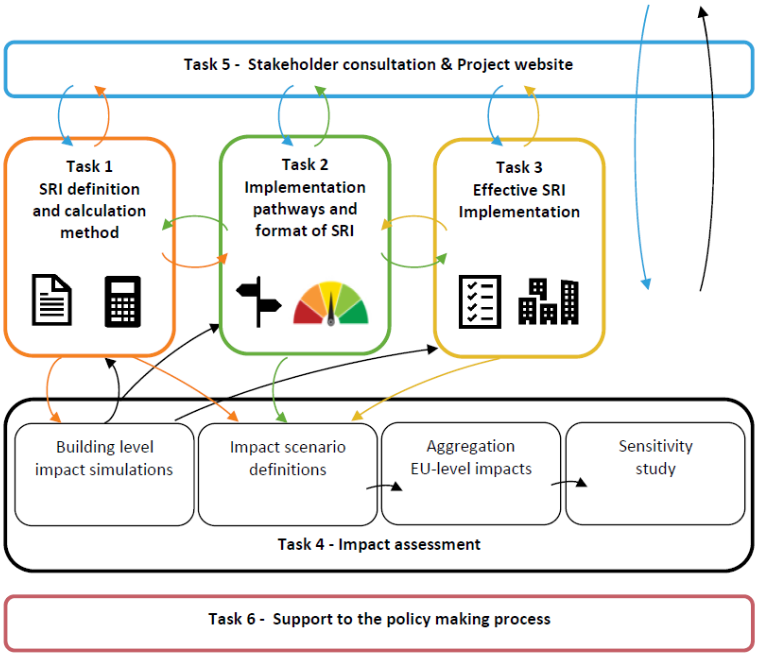


Figure 3.3. the main tasks of SRI methodological framework [25]

As it is depicted in Figure 3.4, the methodology of SRI assessment and implementation can be categorized into three different methods based on stockholders' feedback [26] which are described as follows:

A Simplified online quick-scan	**B** Expert SRI assessment	**C** In-use small building
Checklist approach with limited, simplified services list	Checklist approach, covering catalogue of smart services	Measured/metered data (potentially restricted set of domains)
Online self-assessment by end-user (no certification) Or On-site inspection by third-party qualified expert (formal certification)	Online self-assessment by technical expert (no certification) Or On-site inspection by third-party qualified expert (formal certification)	In-use buildings, metered data, Part of the commissioning? TBS self-reporting their actual performance
Up to one hour	½ day to one day, depending on complexity	Gather data over a long period (e.g. a year)
Restricted to residential buildings and small non-residential building (net surface floor area <500m^2)	Non-residential buildings (and residential buildings if desired)	Residential and non-residential Restricted to occupied buildings (not in design phase)

Figure 3.4. Three potential assessment method [26]

Method A: It is a simplified method with the aim of quick TBS assessment with identifying the main services and then to assess the key functionalities in detail. It was also proposed that the functionality levels of products are provided by manufacturers to make the self- assessment more straightforward [26]. However, it seems that this method cannot be applied properly, especially for the buildings with innovated and complex systems, so the functionality level is assigned for a group of systems, not a particular system individually. Also, self-assessment opens the possibility of manipulation or wrong evaluation so the results cannot be trustworthy.

Method B: This is a detailed assessment that can be applied for all types of buildings and can be implemented for both new constructions and existing or retrofitting buildings. The evaluation process will be a complex task in this method and needs to be performed by a professional third-party assessor. This method is the area of concentration in this work which is described later in this chapter.

Method C: This is a long-term assessment of the functionality level of smart services in the building to evaluate their effectiveness on energy saving, flexibility, comfort improvements, etc. and to distinguish how much these improvements are because of smart controls or other factors such as using retrofit actions and amendments in occupants' behavior.

The methodology introduced in the first technical report contain 112 services (99 services when the "various" domain is excluded) and divides the smart ready services into 10 distinct domains including heating, domestic hot water, cooling, controlled ventilation, lighting, dynamic building envelope, on-site renewable energy generation, demand-side management, electric vehicle charging, monitoring and control. However, during the ongoing study that have been conducted by DG Energy, there have been some changes in the domains and their subset smart services. These domains are described as follows:

Heating: This domain covers all the smart services contribute to improving the performance of the heating systems in the building by optimizing the generation, distribution, storage and end-use consumption. These services introduced in the catalogue are based on the technical standard EN 15232 [28] with some amendments and are mainly related to the automation of the control of technical building systems for heating the indoor environment. The list of smart ready services in the heating domain is presented in **Error! Reference source not found.**.

Table 3.1. Smart ready services in the heating domain

Service group	Smart ready service	Status in the new version
Heat control - demand side	Heat emission control	-
Heat control - demand side	Emission control for TABS (heating mode)	-
Heat control - demand side	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	-
Heat control - demand side	Control of distribution pumps in networks	-
Heat control - demand side	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	⊗
Heat control - demand side	Thermal Energy Storage (TES) for building heating (excluding TABS)	⊗
Heat control - demand side	Building preheating control	⊗
Control heat production facilities	Heat generator control (for combustion and district heating)	-
Control heat production facilities	Heat generator control (for heat pumps)	-
Control heat production facilities	Sequencing of different heat generators	-
Control heat production facilities	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)	⊗
Control heat production facilities	Control of on-site waste heat recovery fed into the heating system (e.g. excess heat from data centers)	⊗
Information to occupants and facility managers	Report information regarding HEATING system performance	-
Flexibility and grid interaction	Flexibility and grid interaction	⊕

Domestic hot water: This is a domain which deals with the smarter control of hot water generation, storage and distributing hot water for the building by independent hot water systems. This domain is of the more importance for the residential buildings and similar to heating domain the technical standard of EN 15232 has been used for the smart services' definition. The list of smart ready services in the domestic hot water domain is presented in Table **Error! Reference source not found.**.

Table 3.2. Smart ready services in the domestic hot water domain

Service group	Smart ready service	Status in the new version
Control DHW production facilities	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	-
Control DHW production facilities	Control of DHW storage charging (using hot water generation)	-
Control DHW production facilities	Control of DHW storage temperature, varying seasonally: with heat generation or integrated electric heating	⊗
Control DHW production facilities	Control of DHW storage charging (with solar collector and supplementary heat generation)	-
DHW control - demand side	Control of DHW circulation pump	⊗
Control DHW production facilities	Sequencing in case of different DHW generators	⊕
Information to occupants and facility	Report information regarding domestic hot water performance	-

Cooling: This domain deals with the smart services which enhance the performance of the thermal storage, emission control systems, generators and energy consumption for cooling the indoor environment. Similarly, technical standard EN 15232 has been used as the main source in defining these services. The list of smart ready services in the cooling domain is presented in Table 3.3.

Table 3.3. Smart ready services in the cooling domain

Service group	Smart ready service	Status in the new version
Cooling control - demand side	Cooling emission control	-
Cooling control - demand side	Emission control for TABS (cooling mode)	-
Cooling control - demand side	Control of distribution network chilled water temperature (supply or return)	-
Cooling control - demand side	Control of distribution pumps in networks	-
Cooling control - demand side	Intermittent control of emission and/or distribution	⊗
Cooling control - demand side	Interlock between heating and cooling control of emission and/or distribution	-
Cooling control - demand side	Control of Thermal Energy Storage (TES) operation	-
Control cooling production facilities	Generator control for cooling	-
Control cooling production facilities	Sequencing of different cooling generators	-
Information to occupants and facility	Report information regarding cooling system performance	-
Flexibility and grid interaction	Flexibility and grid interaction	⊕

Controlled Ventilation: This domain deals with the smart services that control the airflow and temperature of the indoor environment. This domain not only effective in energy consumption but also has a significant value in the indoor air quality and the health of the occupants. Similarly, technical standard EN 15232 has been used as the main source in defining these services. The list of smart ready services in the controlled ventilation domain is presented in Table 3.4.

Table 3.4. Smart ready services in the controlled ventilation domain

Service group	Smart ready service	Status in the new version
Air flow control	Supply air flow control at the room level	-
Air flow control	Adjust the outdoor air flow or exhaust air rate	⊗
Air flow control	Air flow or pressure control at the air handler level	-
Air temperature control	Room air temp. control (all-air systems)	⊗
Air temperature control	Room air temp. control (Combined air-water systems)	⊗
Air temperature control	Heat recovery control: prevention of overheating	-
Air temperature control	Supply air temperature control	-
Free cooling	Free cooling with mechanical ventilation system	-
MV system operation	Heat recovery control: icing protection	⊗
MV system operation	Humidity control	⊗
Feedback - Reporting information	Reporting information regarding IAQ	-

Lighting: The lighting domain covers the services related to manage/control the electric lighting system based on a time schedule or occupancy detection. The initial CEN/464 CENELEC Smart House Roadmap (a project supported by the European Commission and the European Free Trade Association), the market data and analysis from the PPP (Public Private Partnership) Photonics 21 has been mainly used to define the services. The list of smart ready services in the lighting domain is presented in Table 3.5.

Table 3.5. Smart ready services in lighting domain

Service group	Smart ready service	Status in the new version
Artificial lighting control	Occupancy control for indoor lighting	-
Artificial lighting control	Mood and time-based control of lighting in buildings	⊗
Control artificial lighting power based on daylight	Control artificial lighting power based on daylight levels	-

Dynamic Building Envelope: This domain deals with the control of the movable parts of the building envelope, i.e. the openings and sun shading systems. Consideration of these systems is relevant to the SRI because improving the control of operation the shading systems and openings can contribute to reducing the heating and/or cooling needs and indoor air quality. Similarly, these services are based on the standard EN 15232 but with some amendments regarding various types of shading. The list of smart ready services in the dynamic building envelope domain is presented in Table 3.6.

Table 3.6. Smart ready services in dynamic building envelope domain

Service group	Smart ready service	Status in the new version
Windows control	Window solar shading control	-
Window control	Window open/closed control, combined with HVAC system	-
Window control	Changing window spectral properties	⊗
Feedback - Reporting information	Reporting information regarding performance of dynamic building envelope systems	⊕

On-site energy generation: This domain includes services that using for monitoring, forecasting and optimizing the operation of local power generation and the storage or delivery of energy to the connected grid. The services have been defined based on the IEC Smart Grid Standardization Roadmap [29], however, they have been aggregated by the DG energy team to cover more practical perspectives. Some of the features in the standard have been defined for the services in the 'demand-side management' domain of SRI in the previous version of the study. The list of smart ready services in the energy generation domain is presented in Table 3.7.

Table 3.7. Smart ready services in energy generation domain

Service group	Smart ready service	Status in the new version
DER - Generation Control	Amount of on-site renewable energy generation	⊗
Feedback - Reporting information	Reporting information regarding energy generation	-
DER - Storage	Storage of locally generated energy	-
DER- Optimization	Optimizing self-consumption of locally generated energy	-
DER - Generation Control	CHP control	-
DSM- Storage	Support of (micro)grid operation modes	⊕
Feedback - Reporting information	Reporting information regarding local electricity generation	⊕
Feedback - Reporting information	Reporting information regarding electricity consumption	⊕

Demand side management: This domain deals with the control of energy demand flexibility and interaction with both the local smart grid and the national grid. The definition of the services of this domain is based on both the IEC SMB Smart Grid Standardization Roadmap [29] and consolidated information from the Preparatory Study on Smart Appliances [30]. For the services which require more detailed data to be assessed some aggregations have been made. Since some services of the Electric Vehicle can contribute to the storage and flexibility services for the grid, there are some overlaps with the services defined in demand side management domain. The list of smart ready services in the demand-side management domain is presented in Table 3.8. This domain has been removed in the new technical study.

Table 3.8. Smart ready services in demand side management domain

Service group	Smart ready service
DSM- Storage	Services for integration of renewables into the building energy portfolio
DSM- Storage	Services for integrating battery storage systems into energy portfolio
DSM- Grid	Support of microgrid operation modes
DSM- Storage	Integration of smart appliances
DSM- Grid	Power flows measurement and communications
DSM - Local Systems	Energy delivery KPI tracking and calculation
DSM- Grid	Fault location and detection
DSM- Grid	Fault prevention and risk assessment

Service group	Smart ready service
DSM- Grid	Fraud detection and losses calculation
DSM - Local Systems	Neighborhood energy efficiency calculation
DSM- Grid	Demand prediction
DSM- Grid	Information exchange on renewables generation prediction
DSM- Storage	Heat management for a multi-tenant house by aggregator
DSM - Local Systems	Flexible start and switch off of home appliances
DSM - Local Systems	DSM control of a device by an aggregator
DSM- Storage	Energy storage penetration prediction
Smart Grid Integration	Smart Grid Integration
DSM control of equipment	DSM control of equipment
Connecting PV to DSO grid	Connecting PV to DSO grid
Feedback - Reporting information	Reporting information regarding DSM
Override control	Override of DSM control

Electric vehicle charging: This domain covers services for recharging electric vehicles provided by buildings. The well-organized control of the electric storage from electric vehicle charging can contribute to the flexibility of the building and grid. The IEC SG Standardization Roadmap [29] and IEC 15118 (Vehicle to grid communication interface International standard) have been used to define the related services and the domain definition. The list of smart ready services in the electric charging domain is presented in Table 3.9.

Table 3.9. Smart ready services in electric vehicle charging domain

Service group	Smart ready service	Status in the new version
EV Charging - non-Grid sensors	Charging whenever needed at the charging pole of the building ("dumb charging service")	✗
EV Charging - Market	Charging with local, building system-based control (price signal-based charging)	✗
EV Charging - Market	Charging with aggregated control (EV responsible party as VPP balancing responsible party)	✗
EV Charging - Market	Charging with aggregated control (EV responsible party under a balance responsible party)	✗
EV Charging - non-Grid sensors	Grid connected heating for EV in winter time	✗
EV Charging - Grid	Providing system services to DSO operations	✗

Service group	Smart ready service	Status in the new version
EV Charging - non-Grid sensors	Charging for optimization of the EV battery life-cycle	⊗
EV Charging - Grid	Charging at a commercial building site - roaming	⊗
EV Charging - Market	Charging based on DSO price tags - " local wind storage"	⊗
EV Charging - Market and Occupant	Providing the state-of-charge to home display	⊗
EV Charging - Grid	Fast charging services - mode 4	⊗
EV Charging - Grid	Vehicle to grid operation and control	⊗
EV Charging	EV Charging Capacity	-
EV Charging - Grid	EV Charging Grid balancing	-
EV Charging - connectivity	EV charging information and connectivity	-

Monitoring and control: This domain focus on data provided by any sensors using in the multiple technical building systems (TBS). For example, the information from occupancy detectors which can be used by heating, cooling, ventilation or lighting systems. The monitoring and control services which deal with only one domain has been considered under this particular domain for the assessment simplification. The list of smart ready services in the monitoring and control domain is presented in Table 3.10.

Table 3.10. Smart ready services in monitoring and control domain

Service group	Smart ready service	Status in the new version
HVAC interaction control	Heating and cooling set point management	⊗
HVAC interaction control	Control of thermal exchanges	⊗
HVAC interaction control	Run time management of HVAC systems	-
Fault detection	Detecting faults of technical building systems and providing support to the diagnosis of these faults	-
Feedback - Reporting information	Reporting information regarding current energy consumption	⊗
Feedback - Reporting information	Reporting information regarding historical energy consumption	⊗
Feedback - Reporting information	Reporting information regarding predicted energy consumption	⊗
TBS interaction control	Occupancy detection: connected services	-
TBS interaction control	Occupancy detection: space and activity	⊗
Central control of energy consumers	Remote surveillance of building behavior	⊗
Central control of energy consumers	Central off-switch for appliances at home	⊗

Service group	Smart ready service	Status in the new version
Feedback - Reporting information	Central reporting of TBS performance and energy use	-
Smart Grid Integration	Smart Grid Integration	+
Feedback - Reporting information	Reporting information regarding demand side management performance and operation	+
Override control	Override of DSM control	+
Single platform that allows automated control	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and	+

Various (this domain has been removed in the second technical report): The other smart services which are subsequently defined by stockholders and are not directly related to the technical building system in the scope of EPBD can be covered in this domain of the catalogue; for example, the services related to the building security system. The list of smart ready services including in various domain is shown in Table 3.11.

Table 3.11. Smart ready services in various domain

Service group	Smart ready service
Coming home - leaving home functions	Coming home - leaving home functions
Inactivity recognition services	Inactivity recognition services
Multi-tenant access control for buildings without keys	Multi-tenant access control for buildings without keys
Wellbeing and health	Occupants Wellbeing and health status monitoring services
Wellbeing and health	Dementia monitoring
Rain water Collection	Rainwater Collection
Safety & Alerts	Smoke detection
Safety & Alerts	Water leakage detection
Safety & Alerts	Carbon Monoxide detection
Safety & Alerts	Emergency notification services
Safety & Alerts	Smart testing of emergency lighting
Safety & Alerts	Intelligent alerting on building events
Cost allocation	Energy Cost Allocation for heating, cooling and water
Lifts and elevators	Lift and elevator control and dispatching
Lifts and elevators	Lift and elevator monitoring and maintenance
Lifts and elevators	Lift and elevator energy recovery

Regarding the changes in the third interim report of the second technical study, first, the domain "on-site renewable energy generation" became "electricity" because of the following reasons: First, the term "renewable energy generation" can cover centralized energy generation or renewable thermal energy in heating systems, so it cannot be considered technology-neutral as it requires to be according to the smart ready system definition. Second, it was suggested that many renewable energy sources such as solar and wind energy cannot be considered as "smart" according to SRI definition because of the lack of energy-efficient control and direct response to occupants and grids. Also, the term "generation" cannot reflect the services relating to energy storage as well. Moreover, the term "electricity" is more relevant because some services concerning renewable energy generation such as thermal solar panel are already in the heating domain. Finally, some smart services regarding electricity consumption are not already comprised in any domains.

Second, the domain "demand-side management" has been removed in the second technical report because it was suggested that most of the services introduced in this domain are strongly linked to a certain technical building service which can be directly linked to other domains such as heating, cooling or domestic hot water, and remaining services can be categorized in the "monitoring and control" domain. These changes are seen in Figure 3.5.

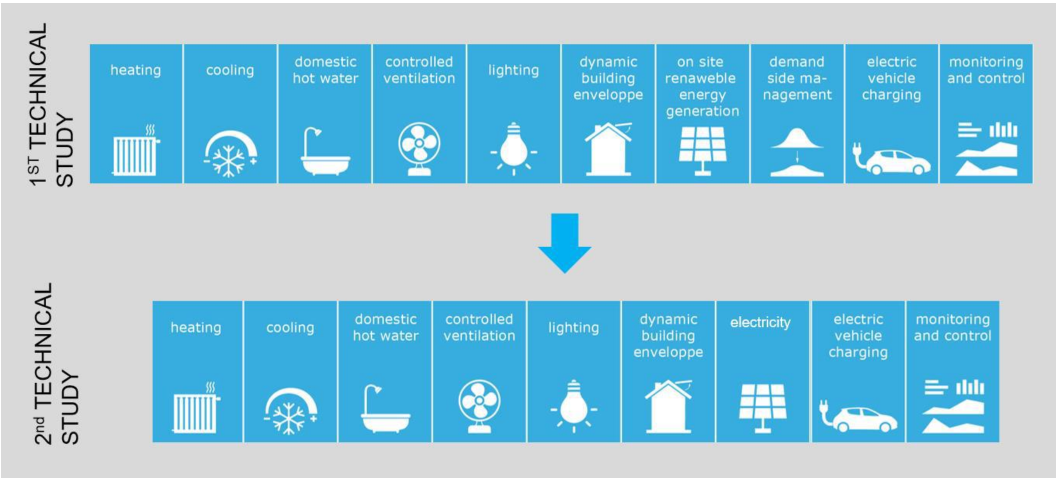


Figure 3.5. Domain categories defined by [26]

In the catalogue, the overall number of 52 smart ready services have been defined and each service can be evaluated based on a specific functionality level ranging from 0 which indicated a non-smart service and maximum of 4 (varies for different services) which refers to maximum smartness of that service. The evaluation of the smart ready services is based on their impact on the occupants, building and the grid which can be assessed according to eight distinct criteria defined in the catalogue including energy savings on-site, flexibility for the grid and storage, self-generation, comfort, convenience, well-being and health, maintenance and fault prediction, and information available to occupants which are described as follow:

Energy saving on site: This criterion demonstrates the impacts of services on energy saving in the building. This impacts not only refers to the direct effects of building services on energy saving, but also covers the contributions from all control systems on reducing the energy needs and finally saving energy.

Flexibility for grid and storage: This criterion represents the impacts of services on the energy flexibility potential of the building.

Self-generation: Refers to the impacts of services on local renewable energy generation and distribution capabilities and the management quality of consumption and storage of the on-site generated energy regarding pick hours, loads, climate, etc. This criterion has been omitted in the new report.

Comfort: Refers to the capabilities of services to provide environment comfort for occupants including thermal comfort, acoustic comfort and visual comfort.

Convenience: Refers to the impacts of services on reducing the occupants' manual control of the technical building system and consequently the easier and more convenient life.

Well-being and health: Refers to the impacts of services on improving health condition for living, e.g. the indoor air quality improvement.

Maintenance and fault prediction, detection and diagnosis: It demonstrates the impacts of the services on technical building services' maintenance and operation by automatic fault detection which can consequently contribute to the energy performance improvements.

Information to occupants: Refers to the impacts of services on providing occupants with information regarding the quality of building service operation

In the new report, the “self-generation” impact criterion has been removed because of the overlaps with “energy flexibility and storage” which concentrate on the benefits for energy grid and “convenience” which covers autonomy in terms of security of supply. Recent changes in the impact criteria are presented in Figure 3.6.

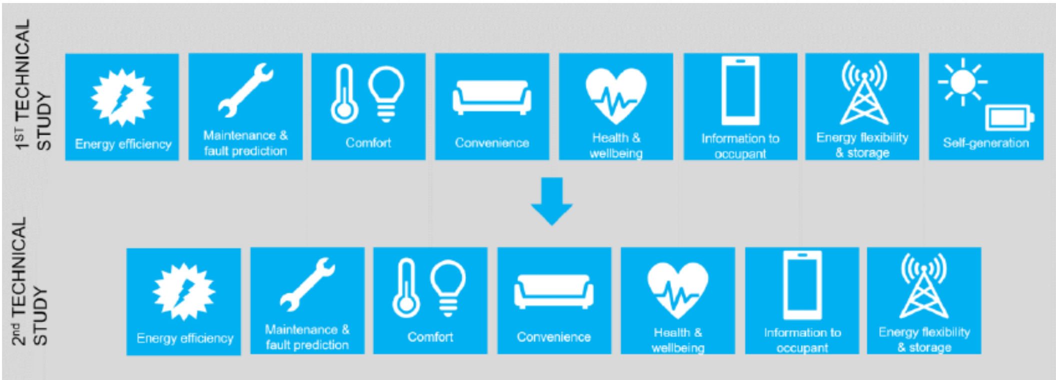


Figure 3.6. Impact criteria defined by [26]

3.4. Calculation Methodology

The proposed SRI calculation by the European Commission is based on a multi-criteria assessment to deal with multiple domains and impact criteria. The overall SRI score indicates how the building’s performance is close to or far from its maximum level of smartness. This methodology can be implemented through on-site inspections by building owners or third-party external assessors. As technology develops, the assessment can be done by intelligent equipment in a less intrusive and costly way. This methodology aims to define a straightforward way to obtain a simple indicator which clearly represents the tangible information regarding the overall smartness level of technical building systems in a cost-effectively way. The ongoing calculation developments try to make the methodology flexible enough to adapt with different building type, climate, culture and even all the updates for the innovative services. To have a simple approach into the calculation methodology, it can be divided into 5 steps which are explained as follows:

Step1: Relevant Service Selection

In the first step, the relevant smart ready services in the building are detected through a triage process. Depending on the building type or other factors some services defined in the catalogue that are not relevant can be easily removed from the calculation procedure.

Step2: Functionality Level Assessment

The functionality level is assessed for each of the applicable services in the building based on the defined impact criteria. This can be done based on information gathered from a visual inspection during a walk-through visiting of the building, an interview with the building owner or facility manager and the review of documentation of the technical building systems. Figure 3.7 illustrates the framework for the functionality level assessment. Each functionality level for each smart service is attributed by a predefined score in the calculation tool (currently a spreadsheet) in each of the eight impact criteria.

Figure 3.7. Example of functionality levels assigned for smart services in a specific domain [24]

The functionality levels are defined in the spreadsheet provided by the European Commission and with the range from -4 to 4. The functionality level of each service is selected based on the description provided for each level in the spreadsheet. Table 3.12 presents an example of functionality levels together with relative impact scores provided in the spreadsheet.

Table 3.12. Example of spreadsheet provided by [24] with functionality levels and impact scores for a specific service

Code	service	
Heating-1a	**Heat emission control**	Heat control - demand side

Functionality levels		Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Wellbeing and health	Maintenance & fault prediction	Information to occupants
		IMPACTS						
Level 0	No automatic control	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Level 1	Central automatic control (e.g. central thermostat)	**1**	**0**	**1**	**1**	**0**	**0**	**0**
Level 2	Individual room control (e.g. thermostatic valves, or electronic controller)	**2**	**0**	**2**	**2**	**0**	**0**	**0**
Level 3	Individual room control with communication between controllers and to BACS	**2**	**0**	**2**	**3**	**0**	**1**	**0**
Level 4	Individual room control with communication and presence control	**3**	**0**	**2**	**3**	**0**	**1**	**0**

Step3: Impact Score Calculation

After filling the calculation tool, for each domain the actual impact score is calculated by summing up the scores of all relevant services and the maximum possible impact score is obtained by summing up the maximum obtainable scores based on the highest functionality level for all relevant services for that specific domain. The relative score for each impact criteria in a particular domain is the ratio of the actual impact score and the maximum achievable impact score. If applicable, the domains which do not exist in a building are omitted. The score of one impact criterion is the weighted average of 10 domain scores. For each impact criterion, the overall score is expressed as a per cent of the maximum score that is achievable for the building type that is evaluated. Figure 3.8 shows how an impact score is calculated for a specific domain. For more clarification, an example of one impact criterion (energy saving) score calculation for heating domain regarding the scores obtained by services according to their functionality levels in relation to the maximum achievable score for the building is presented in Table 3.12.

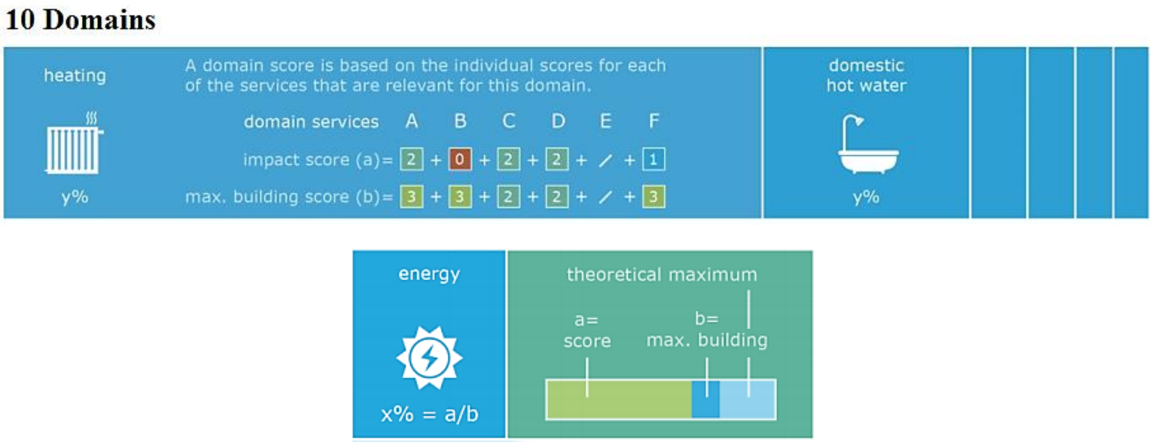


Figure 3.8. Impact score calculation example [24]

Table 3.13. An example of energy saving impact criterion score calculation for heating domain

Smart ready service (Domain: Heating)	Impact score (Energy saving)	Maximum building score (Energy saving)
A	2	3
B	0	2
C	1	3
D	0	3
E	1	2
…	…	…
Sum	4	13
Domain: Heating **Impact: Energy saving=4/13=0.307*100=30.7%**		

Step4: Definition and Implementation of Weighting Coefficients

In order to obtain the impact score for each impact criterion, it is important to calculate the weighted average of the domains' impact score to consider the effects of different factors such as building type, climate and consumption pattern on the SRI calculation. Therefore, defining the weighting coefficients remained a challenge which can affect the final SRI score in a tangible way. The approach to defining the weighting coefficients will be explained in section 3.4.1.

Step5: Overall SRI Calculation

According to the technical studies and based on the feedback from stakeholders, European Commission and the Member States, the final SRI impact score can be calculated through three suggested methods:

Proposal 1: A simple average of the calculated scores of impact criteria. In this method, each impact criterion is of equal importance (14.3%) that was suggested in the first technical study [24]. The critics of this method believe that the high number of the impact criteria hinders a clear communication and increase the complexity of information that should be conveyed to the end-users.

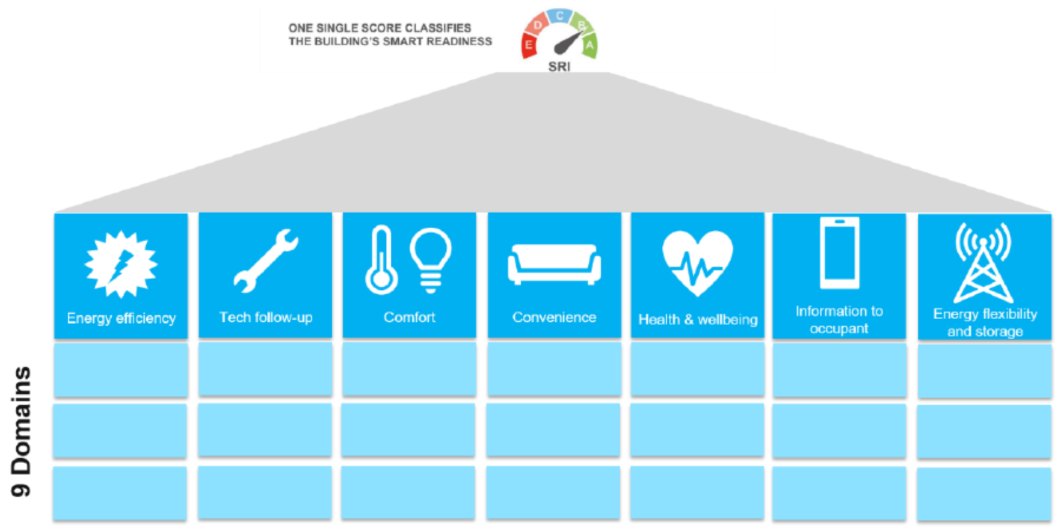


Figure 3.9. Calculation of SRI based on the equal weighting of seven impact criteria [26]

Proposal 2: Equal weight for only three impact criteria that address three targets of SRI calculations defined by EPBD which are energy performance and operation, respond to user needs and respond to needs of the grid. Reducing the number of impact criteria into three to present the level of smartness would be more effective to transfer useful information to end-users. However, the unclear scope of these new impact criteria still remains an issue which should be investigated in the next stages of the study.

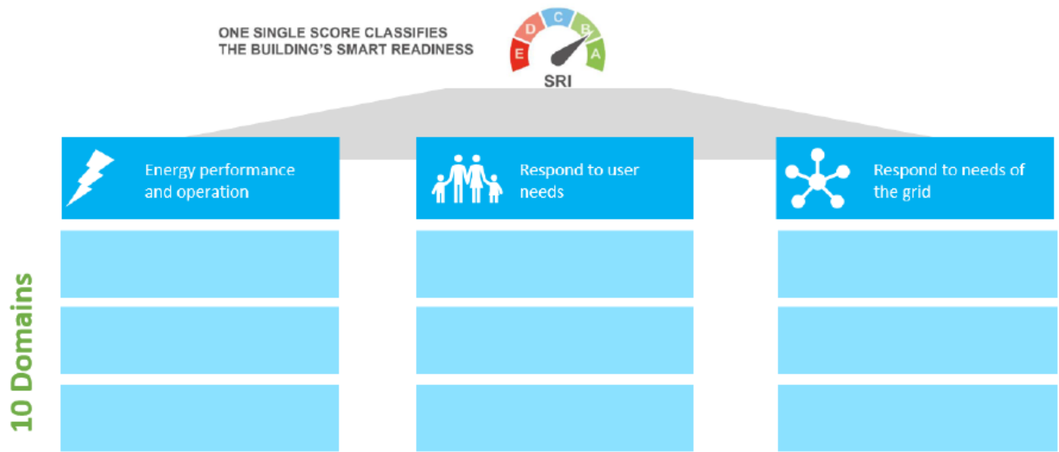


Figure 3.10. Three impact criteria according to EPBD scopes [26]

Proposal 3: Equal weight for the EPBD impact criteria (33.3%) mentioned in proposal 2, with different weights for each seven impact criteria as follows: 33.3% for energy saving and operation which is divided into two impact criteria with equal weight (16.7% energy savings and 16.7% maintenance and fault prediction). 33.3% for responding to user needs including four impact criteria (comfort, convenience, information to occupants and health and well-being) with equal of 8.3% weight. And finally, 33.3% for energy demand flexibility which is a separate impact criterion itself. This method has the benefit of transfer the information in two levels, summarized three equal impact criteria aligned with EPBD and seven individual impact criteria.

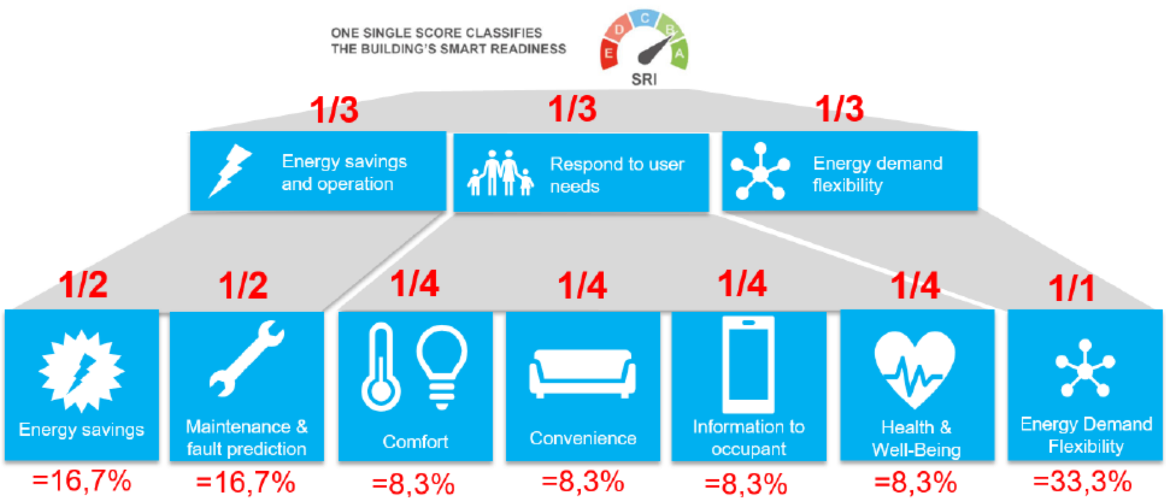


Figure 3.11. Aggregation of final SRI score based on the weighted impact criteria [26]

The way that this indicator will be presented to the end-users is very important to be clear and sufficiently convey useful information regarding overall SRI, scores per domain and per impact criterion as well as aggregated scores per impact criterion. The mnemonics that are currently used (not yet officially) to simply present the SRI level are shown in Figure 3.12. The study team is still working to develop ideas for designing a way for the best visual presentation. It is important to note that the designing should be easily recognizable from current energy label. Also, the related information should communicate to users in a printed document including a certificate with the potential guidance to improve SRI as well as a physical mnemonic and logo with scores.

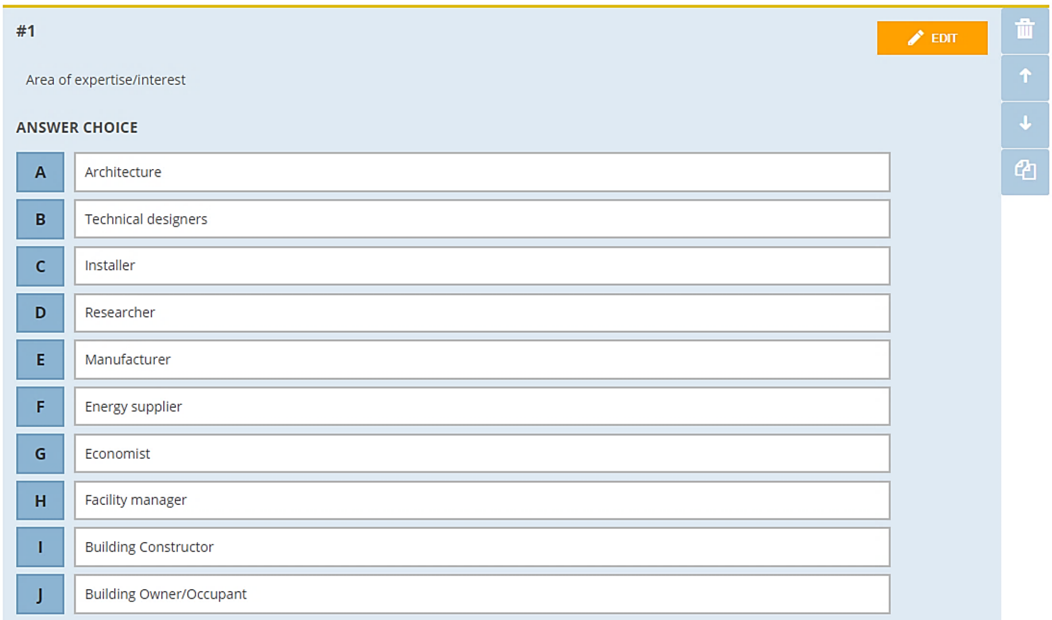
Figure 3.12. Current proposed mnemonics [25]

3.4.1. Weighting coefficient definition in multi-criteria assessment

As it was mentioned before, the calculated scores for domains and impact criteria need to be aggregated to cover all possible impacts of different factors regarding building type and climate conditions. For this aim, the weighting factors should be determined and apply in the SRI assessment process. Before the recent report published on 21st of February 2020 [26], there was not any structured methodology for obtaining the weighting coefficient. Therefore, a survey was conducted as an alternative to define the weighting factors. This survey and the recent methodology developed by the study team will be described in the next sections.

3.4.1.1. Survey-based method

A possibility to obtain the weighting factors is to collect the experts' opinion in various fields through conducting a survey. The professionals can be selected from different field of studies or expertise including architecture, technical designing, manufacturing, energy supplement, economy, building facility, construction. After determining the geographical location of participants (to take into account the climate factor), they are asked to evaluate the effect of each impact score on 10 domains by scoring them ranging from 0-100 which must be divided between different domains. The average score obtaining from all participants will determine the weighting coefficient for each impact criteria. A greater number of participants from various field of expertise will lead to more precise results. The SOCRATIVE platform which is a cloud-based system developed in 2010 by Boston-based graduate school students has been used for this survey. It allows creating simple tests that everyone can take quickly on laptops or their smartphones. The use of this platform makes the survey procedure for involving experts more immediate and facilitates and the possibility of real-time collection data for the researchers. The participants were asked to determine their field of expertise or interest, their age, gender and their living country and city. Then, they are asked about impact percentages in the short answer questions. The questions were designed so that the answers could be a sequence of numbers indicating the assigned percentages. The question was formulated so that the answer could be a sequence of numbers indicating the assigned percentages. Some questions presented in the survey in Socrative platform are shown in Figure 3.13.



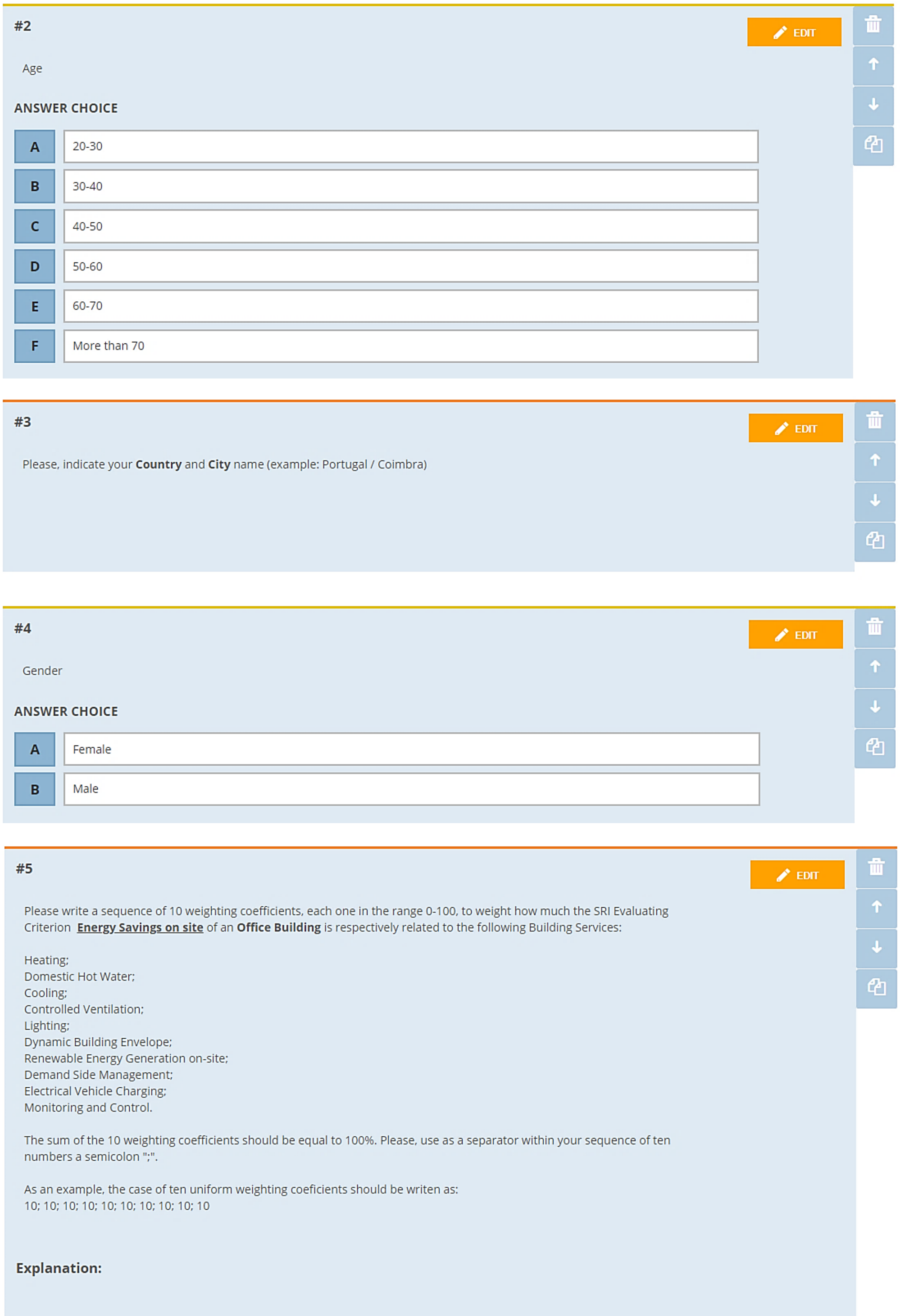


Figure 3.13. Examples of questions presented in the survey in Socrative platform

3.4.1.2. Proposed method in the technical study

This methodology for the definition of the weighting factors was proposed in the recent report by the study team and it was tested by several stakeholders with the positive feedback. However, there were some arguments to give more weight towards some impact criterion. As it is shown in Figure 3.14, three types of weighting factors are defined in this methodology: fixed weights, equal weights and energy balance weights. Step 1 considers 20% weighting for the domain “monitoring and control” for all impact criteria, 5% weighting for the domain “dynamic envelope” for energy savings, maintenance and fault prediction and energy demand flexibility impact criteria. If no service exists for a certain domain, it is considered as zero. In step 2, the impact criteria “comfort”, “convenience”, “information to occupants” and “health and well-being” have the equal weighting coefficients which are obtained by dividing the remaining scores (excluding fixed weight) by the number of relevant domains in the given impact criterion. In setp3, for the impact criteria “energy savings”, “maintenance and fault prediction” and “energy demand flexibility” the energy balance weights are assigned based on the building type (residential and non-residential) and the climate zones.

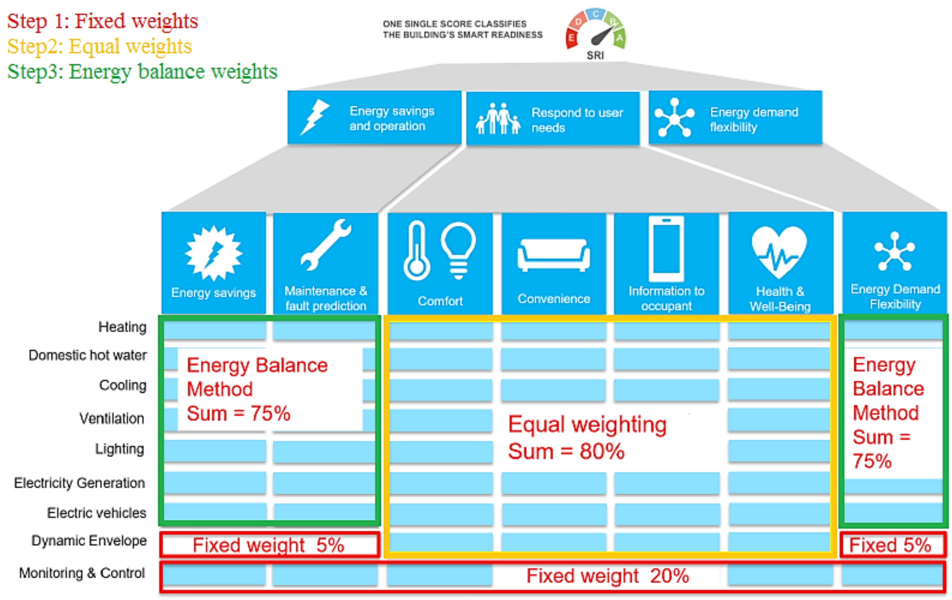


Figure 3.14. Proposed approach for weighting factors [26]

This value is obtained by multiplying the remaining weight for the given impact criterion (excluding fixed weights) by the relative importance of the domain in the energy balance defined by the study team for different building types and climate zones (Table 3.14).

Table 3.14. Proposed relative importance of domains based on the building types and climate zones [26]

Residential					
	North	West	South	North-East	South-East
Heating	39.9	45.3	42.2	40.5	27.5
DHW	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

Non-residential					
	North	West	South	North-East	South-East
Heating	41.8	36.4	40.3	39.0	38.3
DHW	7.2	11.0	14.3	12.5	15.4
Cooling	12.5	16.9	15.7	11.2	9.9
Ventilation	26.2	19.1	11.7	24.4	20.1
Lighting	10.4	13.8	16.0	9.7	11.9
Electricity	2.0	2.8	2.1	3.1	4.4

A building-specific energy balance should be defined based on the primary energy uses for space heating, domestic hot water, space cooling, controlled ventilation, lighting and production of on-site renewable electricity [26]. The correction factor for each domain is calculated by dividing the primary energy use of the given domain by the sum of the six primary energy consumption which can be obtained from EPC calculations. Considering these steps, the final weighting matrix for different building types and climate zones are provided in [26]. Table 3.16Table 3.15 represents an example of these matrices for a non-residential building in southern Europe climate zone. Also, the suggested climate zones for European countries is shown in Table 3.16 in which Portugal is located in the southern Europe climate zone.

Table 3.15. Weighting matrix for non-residential buildings in southern Europe [26]

Southern Europe	Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Health & Wellbeing	Maintenance & fault prediction	Information to occupants
Heating system	0.30	0.42	0.16	0.1	0.2	0.36	0.11
Domestic Hot Water	0.11	0.15	0.00	0.1	0	0.13	0.11
Cooling system	0.12	0.16	0.16	0.1	0.2	0.14	0.11
Controlled ventilation	0.09	0.00	0.16	0.1	0.20	0.10	0.11
Lighting	0.12	0.00	0.16	0.1	0.00	0.00	0.00
Electricity: renewables & storage	0.02	0.02	0.00	0.1	0.00	0.02	0.11
Dynamic Envelope	0.05	0	0.16	0.1	0.20	0.05	0.11
Electric Vehicle Charging	0	0.05	0	0.1	0	0	0.11
Monitoring & Control	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 3.16. Climate zones defined for weighting factor calculations [26]

Country	Climate zone
Iceland	North Europe
Norway	North Europe
Sweden	North Europe
Denmark	North Europe
Finland	North Europe
Czech Republic	North-East Europe
Estonia	North-East Europe
Latvia	North-East Europe
Lithuania	North-East Europe
Poland	North-East Europe
Slovakia	North-East Europe
Cyprus	South Europe
Greece	South Europe
Italy	South Europe
Malta	South Europe
Portugal	South Europe
Spain	South Europe
Bulgaria	South-East Europe
Croatia	South-East Europe
Hungary	South-East Europe
Romania	South-East Europe

Country	Climate zone
Slovenia	South-East Europe
Austria	West Europe
Belgium	West Europe
France	West Europe
Germany	West Europe
Ireland	West Europe
Liechtenstein	West Europe
Luxembourg	West Europe
Netherlands	West Europe
Switzerland	West Europe
United Kingdom	West Europe

3.5. Conclusion

The SRI calculation framework proposed in the first and second technical studies by DG energy was presented and analyzed in this chapter. In the latest study, the DSM domain and the self-generation impact criterion was omitted. Therefore, the number of domains reduced to nine and the number of impact criteria reduced to seven. Also, for all domains, some smart services were removed, and some new services were added. Furthermore, the methodology to obtain weighting coefficient was unclear in the previous technical studies which it was developed and introduced with more details considering the building type and climate zones in the recent study. Besides, an aggregation was conducted to calculate the overall SRI based on the weighted average of the relevant impact criteria. This methodology will be examined in the case study buildings in the next chapter.

4. CASE STUDY PRESENTATION

4.1. Introduction

After introducing the SRI calculation methodology in the previous chapters, this method will be implemented in two case study buildings (non-residential buildings) which are located in the same climate zone. So, it provides the opportunity to compare the SRI and its effect on the energy performance and thermal comfort in two similar buildings with different services. To assess the possible impacts, a sort of IEQ measurements and energy simulation will be done and the results will be analyzed in this chapter.

4.2. Climatic data of the study area

The case study buildings are located in the city of Coimbra (latitude 40.2033° N, longitude 8.4103° W) on the center of Portugal. According to Portugal climate zones provided by "Regulamento das Características de Comportamento Térmico de Edifícios (RCCTE, 2006)" [31], Coimbra is located in the climatic zone I1; V2 (see Figure 4.1) with number of heating degree days (based 20˚C) equal to 1460 days, duration of heating season of 6 months, summer project outdoor temperature of 33 ˚C and average daily thermal amplitude of the hottest month 13 ˚C. The monthly average of temperature, rainfall, relative humidity and global radiation in Coimbra are presented in Figure 4.2.

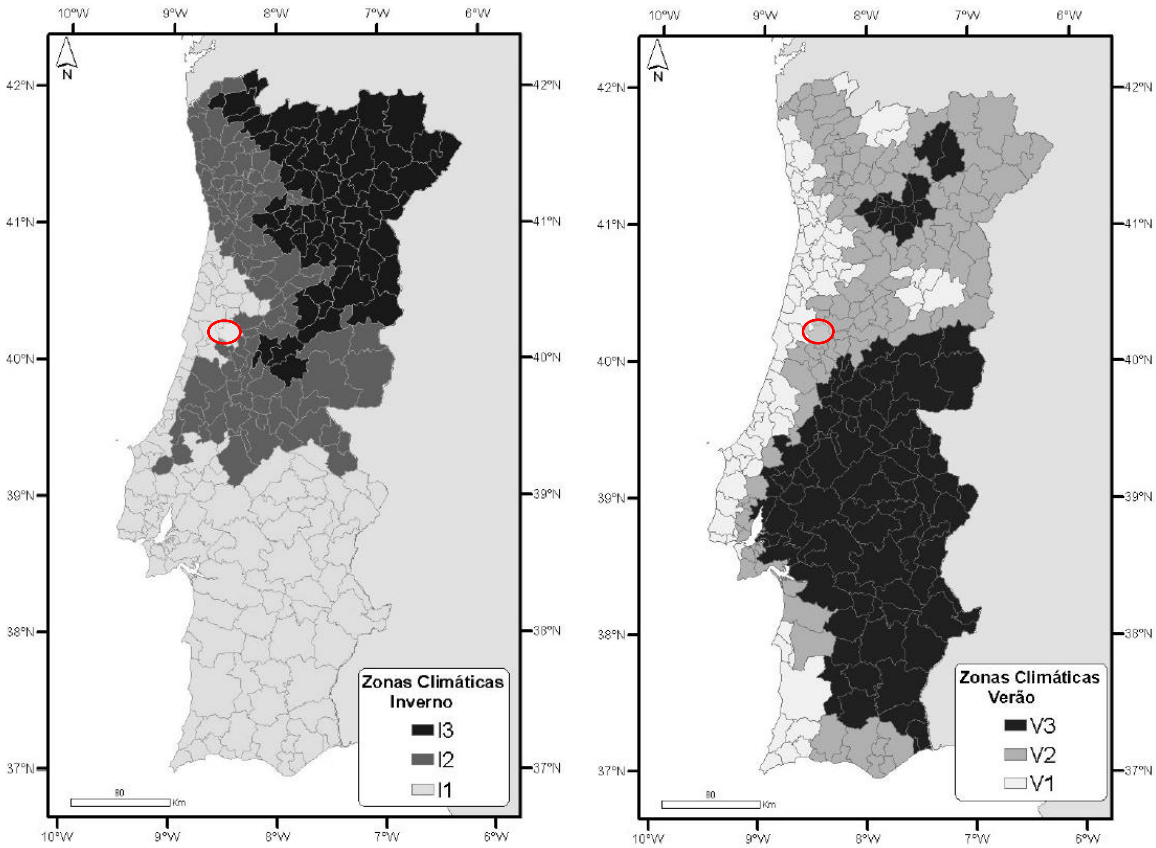


Figure 4.1. Climate zones and location of the city of Coimbra in Portugal

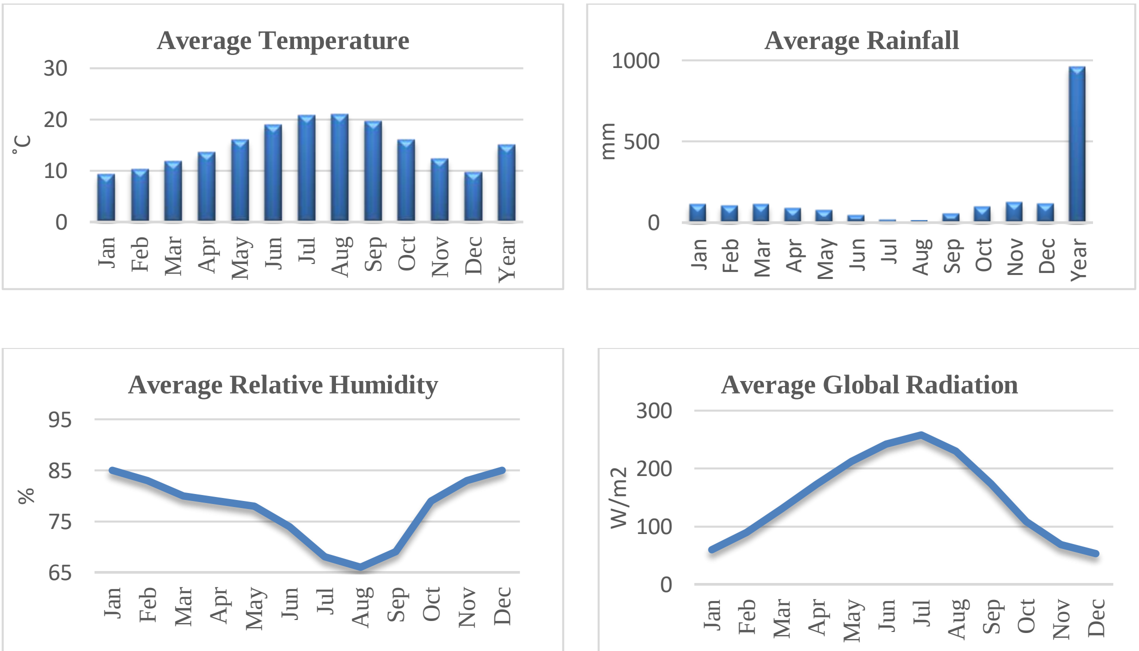


Figure 4.2. Monthly average of temperature, rainfall, relative humidity and global radiation of Coimbra [www.worldclimate.com, www.portaldoclima.pt]

4.3. Description of the buildings

The case study buildings are two buildings with separate building technology systems and are partially connected internally. The construction is the Institute for Research and Technological Development for Construction, Energy, Environment and Sustainability (Itecons). The building structure consists of two partially separate building (Itecons1 and Itecons2) which are constructed in different years (2008 and 2015).

4.3.1. Case study1: Itecons1

The Itecons1 building consists of three floors which comprise of laboratory and administrative blocks. The structure of this block is in reinforced concrete, with several solutions for the opaque zone of facades: brick masonry with sheet metal covering; double wall with an armed concrete and brick masonry. A laboratory is located on floor 0 and the office rooms, auditorium and corridors/lobby are on the two upper floors. The key features of this building are presented in Figure 4.3.

Project data	
Building Name	Itecons1
Type	Service
Year of construction	2008
Energy Class	N/A

Building element/system	Specifications
External Walls	20 cm perforated brick, 2cm plastered (inside), 5 cm polyurethane foam (outside), metal plate finishing. U=0.54 W / m^{2}ºC.
Internal Walls	11 cm brick, 2 cm plastered (inside), 5 cm rock wool, U=0.58 W / m^{2}ºC
Glazing	Single glazing, U=3.9 W / m^{2}ºC, solar factor=0.42 (0.279 with shading)
Roof	25cm light-weight concrete slab, 8cm extruded polystyrene, U=0.38 W / m2ºC (upward), 0.37 W / m2ºC (downward)
Air handling unit (only for auditorium)	Fresh air flow=3500m3/h Extract air flow=1700m3/h
Heating and cooling systems	Heat pump, COP (4), EER (3)

Figure 4.3. Key features of the case study building (Itecons1)

Itecons2 building with facades in the north, south, east and west has a strong thermal inertia class. It consists of a three-floor administrative body intended for offices and for an adjacent building, in which laboratories, workshops and technical areas are inserted for technical and laboratory activities of Itecons2. This administrative body consists of offices, laboratory, staff room, meeting room, computer room as well as sanitary installations, storage and corridors/lobbies. The key features of this building are presented in Figure 4.4.

Project data	
Building name	Itecons2
Type	Service
Year of construction	2015
Energy Class	C

Building element/system	**Specifications**
External walls	North and south orientation: 15 cm concrete, 6 cm expanded cork, 3 cm double plasterboard, U= 0.49 W/m2ºC West orientation: 25 cm concrete, 6 cm expanded cork, 3 cm double plasterboard, U= 0.52 W/m2ºC South orientation: 20 cm concrete, 6 cm expanded cork, 11 cm perforated ceramic brick, 2 cm plaster, U= 0.44 W/m2ºC North, south and west oriented, floor2,3: 0.75cm metal plate, 6 cm expanded cork, 24cm brick, 3cm double plasterboard, U= 0.31 W/m2ºC South and east, offices: 0.75cm metal plate, 6 cm expanded cork, 24cm brick, 2cm plaster, U= 0.34 W/m2ºC
Internal walls	15 cm perforated ceramic brick, 2 cm plaster, U= 1.47 W/m2ºC
Glazing	Double glazing, U= 3.54 W/m2ºC, solar factor=0.27
Roof	4 cm Sandwich panel, 6 cm cork, 25 cm slab, U= 0.55 W/m2ºC
Hot water system	Solar collector, storage volume: 200L, Rated thermal output (kW)=1.5
Heating and cooling system	VRV, Cooling power (kW)=85, Heating power (kW)=95, COP=3.19, EER=3.68

Figure 4.4. Key features of the case study building (Itecons2)

4.4. Methodology application in the case building

The first step to take in order to start calculating the indicator is to study the building and its characteristics well in order to be able to choose the services present in it.

With the consultation of the technical sheets and a subsequent inspection of the building, it was possible to select the services present in it from those proposed in the catalogue attached to the European project document.

As it was described in the chapter3, in order to find weighting coefficient for the case study building a survey was conducted and experts from different area of interest and expertise were asked to evaluate the effects of each impact criterion on 10 proposed domains according to their knowledge and experience. The results of the survey conducted in Coimbra, Portugal for a service building is shown in Table 4.1.

Table 4.1. The survey result for weighting coefficients identification

	Energy savings on site	Flexibility for the grid and storage	Self-generation	Comfort	Convenience	Wellbeing and health	maintenance & fault prediction	information to occupants
Heating	14.3%	11.3%	12.8%	16.9%	12.3%	16.0%	12.4%	12.0%
DHW	12.9%	10.6%	11.3%	9.9%	9.6%	8.9%	9.2%	9.0%
Cooling	13.3%	10.8%	12.4%	17.2%	11.8%	16.0%	12.4%	12.0%
Controlled Ventilation	8.8%	6.7%	9.0%	13.1%	9.6%	15.3%	9.4%	9.6%
Lighting	9.3%	7.9%	9.9%	10.1%	9.3%	12.2%	9.1%	9.4%
Dynamic building envelope	10.0%	9.2%	7.6%	10.2%	8.2%	9.7%	8.4%	5.8%
Energy Generation	9.0%	14.5%	14.1%	4.6%	8.8%	4.6%	9.1%	8.9%
DSM	8.1%	9.7%	8.4%	3.7%	11.3%	5.1%	10.4%	8.3%
Eclectic Vehicle	5.0%	9.0%	7.2%	6.1%	8.6%	4.6%	6.9%	8.3%
Monitoring and Control	9.5%	10.3%	7.2%	8.2%	10.5%	8.0%	12.4%	16.7%
Sum	100%	100%	100%	100%	100%	100%	100%	100%

4.4.1. SRI calculation for Itecons1

In the triage process, some domains have been eliminated according to certain directives given in the European project and the building characteristics. The domains not taken into account in the calculation of the Itecons1 indicator are identified in bellow:

- Controlled ventilation
- Electrical vehicle charging
- On-site generation

The services considered for the evaluation of SRI are resumed in the Table 4.2 in which it is possible to find the functionality level assigned and the changes in the recent study.

Table 4.2. Relevant smart ready services and their functionality level in the Itecons1 building

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Heating-1a	Heat emission control	2	Individual room control (e.g. thermostatic valves, or electronic controller)	4	-
Heating-1c	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	0	No automatic control	2	-
Heating-1d	Control of distribution pumps in networks	1	No automatic control	4	-
Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	0	No automatic control	3	⊗
Heating-1g	Building preheating control	0	No automatic control	2	⊗
Heating-2b	Heat generator control (for heat pumps)	0	On/Off-control of heat generator	3	-
Heating-2d	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)	0	No automatic control based on external signals	2	-
Heating-2e	Control of on-site waste heat recovery fed into the heating system (e.g. excess heat from data centers)	0	No heat recovery control	3	-
Heating-3	Report information regarding HEATING system performance	0	None	4	-
Heating-4	Flexibility and grid interaction	0	No automatic control	3	⊕

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DHW-2	Control of DHW circulation pump	0	No control	2	⊗
DHW-3	Report information regarding domestic hot water performance	0	None	3	-

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Cooling-1a	Cooling emission control	2	Individual room control REF	4	-
Cooling-1d	Control of distribution pumps in networks	1	On off control	4	-
Cooling-1e	Intermittent control of emission and/or distribution	0	No automatic control	3	⊗
Cooling-1f	Interlock between heating and cooling control of emission and/or distribution	0	No interlock	2	-
Cooling-2a	Generator control for cooling	1	Variable temperature control depending on outdoor temperature	2	-
Cooling-3	Report information regarding cooling system performance	0	None	4	-
Cooling-4	Flexibility and grid interaction	0	No automatic control	3	⊕

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Lighting-1a	Occupancy control for indoor lighting (bathrooms)	2	Automatic detection (auto on / dimmed or auto off)	3	-
Lighting-1a	Occupancy control for indoor lighting (common area)	3	Automatic detection (manual on / dimmed or auto off)	3	-
Lighting-1a	Occupancy control for indoor lighting (rooms)	0	Manual on/off switch	3	-
Lighting-1b	Mood and time-based control of lighting in buildings	0	Manual on/off	2	⊗
Lighting-2	Control artificial lighting power based on daylight levels	1	Manual (per room / zone)	3	-

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DE-1	Window solar shading control	0	No sun shading or only manual operation	3	-
DE-2	Window open/closed control, combined with HVAC system	0	Manual operation or only fixed windows	2	-
DE-4	Reporting information regarding performance of dynamic building envelope systems	0	No reporting	3	+

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DSM-5	Power flows measurement and communications	1	local use of sensor data	3	×
DSM-6	Energy delivery KPI tracking and calculation	1	local optimization	1	×
DSM-7	Fault location and detection	1	local based detection of errors	2	×
DSM-8	Fault prevention and risk assessment	0	None	2	×
DSM-9	Fraud detection and losses calculation	0	None	2	×
DSM-10	Neighborhood energy efficiency calculation	0	None	3	×
DSM-11	Demand prediction	0	None	2	×
DSM-15	DSM control of a device by an aggregator	0	None	2	×
DSM-19	DSM control of equipment	0	Not present	4	×
DSM-21	Reporting information regarding DSM	0	None	2	×

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
MC-1	Heating and cooling set point management	1	Adaptation from distributed / decentralized plant rooms only	3	×
MC-2	Control of thermal exchanges	0	None	2	×
MC-3	Run time management of HVAC systems	2	Individual setting following a predefined time schedule; adaptation from a central room; variable preconditioning phases	3	-
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	1	With central indication of detected faults and alarms	2	-
MC-5	Reporting information regarding current energy consumption	1	Indication of actual values only (e.g. temperatures, meter values)	3	×
MC-6	Reporting information regarding historical energy consumption	1	Indication of actual values only (e.g. temperatures, meter values)	3	×
MC-7	Reporting information regarding predicted energy consumption	0	None	3	×
MC-9	Occupancy detection: connected services	1	For individual functions, e.g. lighting	2	-
MC-10	Occupancy detection: space and activity	0	No occupancy detection present	4	×
MC-11	Remote surveillance of building behavior	0	Not present	3	×
MC-12	Central off-switch for appliances at home	0	None	3	×
MC-13	Central reporting of TBS performance and energy use	0	None	3	-
MC-25	Smart Grid Integration	0	None - No harmonization between grid and TBS; building is operated independently from the grid load	3	+
MC-28	Reporting information regarding demand side management performance and operation	0	Reporting information on current DSM status, including managed energy flows	3	+
MC-29	Override of DSM control	0	No DSM control	3	+
MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	0	None	3	+

For the lighting domain, the services for occupancy control were in different functionality levels for bathrooms, offices and common area. Since there was no guidance in the technical study for such situations, the relevant scores were defined based on the area percentage of that particular space.

Table 4.3 and Table 4.4 represent the ordinal impact scores with the weighted coefficient consideration based on the first technical study with survey-based weighting factors and the second technical study considering building type and climate zones. According to the methodology provided in the first technical study that was described in chapter3, the overall SRI for this building is 25.3%. Considering the calculation methodology introduced in the second technical study, the overall scores obtained in two different ways. It is equal to 23% if the SRI obtained by simple averaging the impact scores or it is 18% when the aggregated factors considered for each impact criterion (as it was explained in chapter 3).

Table 4.3. Relative scores for impact criteria according to first technical study methodology for Itecons1 (survey-based weighting coefficients)

	Energy savings on site	Flexibility for the grid and storage	Self-generation	Comfort	Convenience	Wellbeing and health	maintenance & fault prediction	information to occupants
case study values	1.90	0.34	0.00	1.78	1.64	0.54	0.55	1.13
case study maximum	9.05	1.25	0.00	6.23	5.13	1.12	1.46	3.13
relative score	21%	27%	0%	29%	32%	48%	37%	36%

Table 4.4. Relative scores for impact criteria according to second technical study methodology for Itecons1

	Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Wellbeing and health	maintenance & fault prediction	information to occupants
case study values	2.24	0.2	1.61	1.69	0.6	0.6	0.4
case study maximum	8.59	3.02	4.92	6.12	1.66	3.84	3
relative score	26%	7%	33%	28%	36%	16%	13%

4.4.2. SRI calculation for Itecons2

In the building Itecons2, the domains can be excluded from calculation is just "electric vehicle charging" domain and the other defined domains are involved in the calculation process. The services considered for the evaluation of SRI are presented in Table 4.5 in which it is possible to find the functionality level assigned.

Table 4.5. Relevant smart ready services and their functionality level in the Itecons2 building

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Heating-1a	Heat emission control	2	Individual room control (e.g. thermostatic valves, or electronic controller)	4	-
Heating-1c	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	0	No automatic control	2	-
Heating-1d	Control of distribution pumps in networks	1	No automatic control	4	-
Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	0	No automatic control	3	⊗
Heating-1g	Building preheating control	1	Program heating schedule in advance	2	⊗
Heating-2b	Heat generator control (for heat pumps)	1	Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)	3	-
Heating-2d	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)	0	No automatic control based on external signals	2	-
Heating-2e	Control of on-site waste heat recovery fed into the heating system (e.g. excess heat from data centers)	1	Heat recovery on/off control based on availability	3	-
Heating-3	Report information regarding HEATING system performance	0	None	4	-
Heating-4	Flexibility and grid interaction	0	No automatic control	3	⊕

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DHW-2	Control of DHW circulation pump	2	Demand-oriented control	2	⊗
DHW-3	Report information regarding domestic hot water performance	0	None	4	-

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Cooling-1a	Cooling emission control	2	Individual room control REF	4	-
Cooling-1d	Control of distribution pumps in networks	1	On off control	4	-
Cooling-1e	Intermittent control of emission and/or distribution	0	No automatic control	3	(x)
Cooling-1f	Interlock between heating and cooling control of emission and/or distribution	0	No interlock	2	-
Cooling-2a	Generator control for cooling	1	Variable temperature control depending on outdoor temperature	2	-
Cooling-3	Report information regarding cooling system performance	0	None	4	-
Cooling-4	Flexibility and grid interaction	0	No automatic control	3	(+)

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Ventilation-1a	Supply air flow control at the room level	0	No ventilation system or no automatic control	3	-
Ventilation-1b	Adjust the outdoor air flow or exhaust air rate	1	Staged (low/high) OA ratio / OA flow (time schedule)	3	(x)
Ventilation-1c	Air flow or pressure control at the air handler level	2	Multi-stage control	4	-
Ventilation-2c	heat recovery control: prevention of overheating	0	Without overheating control	2	-
Ventilation-2a	Room air temp. control (all-air systems)	0	on-off capacity control	2	(x)
Ventilation-2d	Supply air temperature control	1	Constant set point	3	-
Ventilation-3	Free cooling with mechanical ventilation system	2	Free cooling	3	-
Ventilation-5	Humidity control	0	No automatic control	2	(x)
Ventilation-6	Reporting information regarding IAQ	2	Real time information of IAQ available to occupants	3	-

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
Lighting-1a	Occupancy control for indoor lighting (bathrooms)	2	Automatic detection (auto on / dimmed or auto off)	3	-
Lighting-1a	Occupancy control for indoor lighting (common area)	3	Automatic detection (manual on / dimmed or auto off)	3	-
Lighting-1a	Occupancy control for indoor lighting (rooms)	0	Manual on/off switch	3	-
Lighting-1b	Mood and time-based control of lighting in buildings	0	Manual on/off	2	(x)
Lighting-2	Control artificial lighting power based on daylight levels	1	Manual (per room / zone)	3	(+)

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DE-1	Window solar shading control	2	Motorized operation with automatic control based on sensor data	4	-
DE-2	Window open/closed control, combined with HVAC system	0	Manual operation or only fixed windows	3	-
DE-4	Reporting information regarding performance of dynamic building envelope systems	0	No reporting	3	⊕

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
EG-1	Amount of on-site renewable energy generation	1	Limited amount of PV or CHP production	2	⊗
EG-2	Local energy generation information	4	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	4	-
EG-3	Storage of locally generated energy	0	None	3	-
EG-4	Optimizing self-consumption of locally generated energy	0	None	2	-
electricity-8	Support of (micro)grid operation modes	0	None	3	⊕
electricity-11	Reporting information regarding energy storage	4	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	3	⊕
electricity-12	Reporting information regarding electricity consumption	1	reporting on current electricity consumption on building level	3	⊕

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
DSM-5	Power flows measurement and communications	1	local use of sensor data	3	⊗
DSM-6	Energy delivery KPI tracking and calculation	1	local optimization	1	⊗
DSM-7	Fault location and detection	1	local based detection of errors	2	⊗
DSM-8	Fault prevention and risk assessment	0	None	2	⊗
DSM-9	Fraud detection and losses calculation	0	None	2	⊗
DSM-10	Neighborhood energy efficiency calculation	0	None	3	⊗
DSM-11	Demand prediction	0	None	2	⊗
DSM-15	DSM control of a device by an aggregator	0	None	2	⊗
DSM-19	DSM control of equipment	0	Not present	4	⊗
DSM-21	Reporting information regarding DSM	0	None	2	⊗

code	service	Functionality level	Description of the Level	Maximum functionality level	Status in new version
MC-1	Heating and cooling set point management	1	Adaptation from distributed / decentralized plant rooms only	3	⊗
MC-2	Control of thermal exchanges	0	None	2	⊗
MC-3	Run time management of HVAC systems	2	Individual setting following a predefined time schedule; adaptation from a central room; variable preconditioning phases	3	-
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	1	With central indication of detected faults and alarms	2	-
MC-5	Reporting information regarding current energy consumption	1	Indication of actual values only (e.g. temperatures, meter values)	3	⊗
MC-6	Reporting information regarding historical energy consumption	1	Indication of actual values only (e.g. temperatures, meter values)	3	⊗
MC-7	Reporting information regarding predicted energy consumption	0	None	3	⊗
MC-9	Occupancy detection: connected services	1	For individual functions, e.g. lighting	2	-
MC-10	Occupancy detection: space and activity	0	No occupancy detection present	4	⊗
MC-11	Remote surveillance of building behavior	0	Not present	3	⊗
MC-12	Central off-switch for appliances at home	0	None	3	⊗
MC-13	Central reporting of TBS performance and energy use	0	None	3	–
MC-25	Smart Grid Integration	0	None - No harmonization between grid and TBS; building is operated independently from the grid load	3	⊕
MC-28	Reporting information regarding demand side management performance and operation	0	Reporting information on current DSM status, including managed energy flows	3	⊕
MC-29	Override of DSM control	0	No DSM control	3	⊕
MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	0	None	3	⊕

Table 4.6 and Table 4.7 represent the ordinal impact scores with the weighted coefficient consideration based on the first technical study with survey-based weighting factors and the second technical study considering building type and climate zones. According to the methodology provided in the first technical study that was described in chapter3, the overall SRI for this building is 34%. Considering the calculation methodology introduced in the second technical study, the overall scores obtained in two different ways. It is equal to 33% if the SRI obtained by simple averaging the impact scores or it is 26% when the aggregated factors considered for each impact criterion (as it was explained in chapter 3).

Table 4.6. Relative scores for impact criteria according to first technical study methodology for Itecons2 (survey-based weighting coefficients)

	Energy savings on site	Flexibility for the grid and storage	Self-generation	Comfort	Convenience	Wellbeing and health	maintenance & fault prediction	information to occupants
case study values	3.35	0.64	0.37	2.74	2.38	1.03	0.77	1.58
case study maximum	9.22	3.10	1.38	6.65	5.98	2.82	2.66	4.08
relative score	36%	21%	27%	41%	40%	37%	29%	39%

Table 4.7. Relative scores for impact criteria according to second technical study methodology for Itecons2

	Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Wellbeing and health	maintenance & fault prediction	information to occupants
case study values	3.02	0.20	2.25	2.30	1.24	0.74	1.60
case study maximum	8.80	2.29	5.37	6.46	2.68	3.68	3.80
relative score	34%	9%	42%	36%	46%	20%	42%

As it was mentioned before, an approach to present the calculation outcomes is to show the relative scores of the impact criteria compare with the ideal scores of the building which indicate how far is the building from its ideal point and what are the strengths and weaknesses of the building in terms of smartness. Figure 4.5 shows the relative scores of impact criteria for Itecons1 and Itecons 2. From this chart, it can be seen that the relative scores of all impact criteria for Itecons2 are higher than that of for Itecons1 owing to employing smarter control system in heating and cooling systems and utilizing ventilation system and electricity generation. However, this difference is much higher for the "Information to occupants" impact criterion which is mainly because of employing a system in the building providing real-time and historical information regarding indoor air quality. This system uses and presents the data from the sensors which are installed in both buildings, but as this service is introduced in the controlled ventilation domain, which is not applicable for Itecons1 building, this building is excluded from the scores related to this service that could be one of the weak points of this methodology which should be solved in the next studies. The other point is that in both buildings there is a severe lack of services which manage the flexibility for grid and storage. Therefore, one of the main possible improvement of smartness in the buildings would be utilizing storage for the energy generation, management and optimization energy supply and consumption.

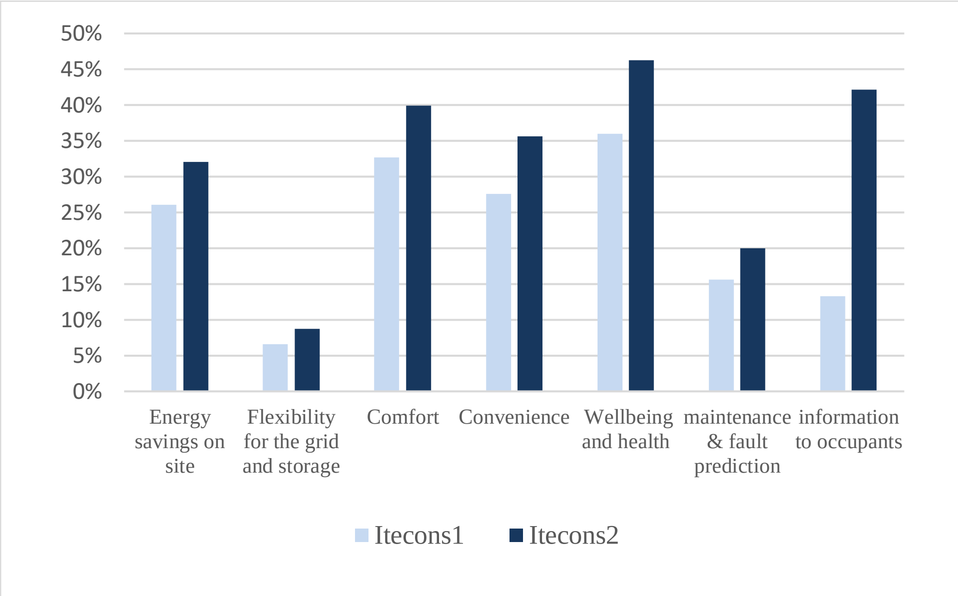


Figure 4.5. Comparison of the relative scores of impact criteria for Itecons1 and Itecons2

4.5. Potential actions for SRI improvement

One of the positive points of the methodological approach for SRI calculation proposed by DG Energy is that in each study, a specific building is compares with its ideal situation. This idea assists to recognize the potential improvements to make the level of smartness of a building as close as possible to its maximum smartness level. Table 4.8 and Table 4.9 show the relative scores for the impact criteria for each relevant domain in Itecons1 and Itecons2 buildings respectively. From these tables, the following points can be considered:

Although there are services to supply hot water in both buildings, the lack of control systems for storage charging and systems for report hot water generation performance to occupants causes this domain obtains no score in any impact criterion. Therefore, one possible action for SRI improvement could be installing controllers for automated storage charging based on external signals (temperature, demand...) and controllers for performance evaluation, predictive management and fault prediction. However, regarding the type of buildings, investment in this domain seems irrational.

Scores in heating and cooling domains are relatively low for both buildings, even for the one with implemented retrofit actions, which shows that the applied measures were not supposed to improve smartness. The role of the smart services in these two domains is mainly to improve energy savings, comfort and convenience in the building. The scores of these domains can be improved by using sensors for occupancy detection for demand-side management, advanced central temperature control, manage the distribution parts by installing variable speed pump control, variable control of heat pumps' capacity depending on the load and external signals from the grid, systems to report the information regarding performance evaluation of heating and cooling systems and predictive management and fault predictions controllers.

Table 4.8. Relative scores of the impact criteria for each relevant domain in Itecons1

	Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Well-being and health	Maintenance & fault prediction	Information to occupants
Heating	0.23	0.00	0.27	0.22	0.00	0.00	0.00
DHW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	0.21	0.00	0.29	0.14	0.00	0.00	0.00
Lighting	0.33	0.00	0.33	0.33	0.00	0.00	0.00
DE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MC	0.50	1.00	1.00	0.56	1.00	0.50	0.67

Table 4.9. Relative scores of the impact criteria for each relevant domain in Itecons2

	Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Well-being and health	Maintenance & fault prediction	Information to occupants
Heating	0.31	0.00	0.36	0.22	0.00	0.00	0.00
DHW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	0.29	0.00	0.43	0.14	0.00	0.00	0.00
Ventilation	0.38	0.00	0.33	0.44	0.33	1.00	1.00
Lighting	0.37	0.00	0.37	0.37	0.00	0.00	0.00
DE	0.40	0.00	0.20	0.33	0.50	0.00	0.00
Electricity	0.40	0.00	0.00	0.20	0.00	0.50	0.67
MC	0.50	1.00	1.00	0.56	1.00	0.50	0.67

The other possible action that can be effectively used to improve SRI is to heighten scores in ventilation domain in Itecons2 by adopting advanced demand and supply flow control using air quality sensors, advanced modulate heat recovery control which controls multiple rooms and using outside air to minimize mechanical cooling. This domain is already being of high scores in “Maintenance and fault prediction” and “Information to occupants” owing to the existing advanced monitoring system for real-time and historical information regarding IAQ.

Although there is already the motorized operation for solar shading control in Itecons2 building, a possibility is to link this system with the HVAC control based on the data collected from temperature sensors. Also, using automated operable windows to help HVAC systems, e.g. to control free natural night cooling is an option to improve SRI.

Another potential is to strengthen the control operation of the electricity generation system in Itecons2 by providing a storage system for locally generated electricity, consumption optimization by using systems to predict the electricity needs in the building. This system with the combination of the current forecast system of solar electricity generation could effectively enhance the score of this domain.

Concerning the growing interest of the construction sector in using smart technologies in buildings, there has been an intense competition between relevant manufacturers to offer more advanced services. Some of the leading companies in this area are **Siemens, Schneider Electric, Honeywell, Cisco, Hitachi, IBM, Johnson Controls, Legrand and Panasonic**. Regarding the proposed solution to improve SRI in the case study buildings, the following smart services can be found in the market. It is important to note that these services would be more efficent if the installation is customised for each specific building (based on its needs and specific condition) and be integrated to building automation system. For example, a control system has been designed by Siemens to control comfort temperature, fresh air flow, natural and artificial lighting in the individual rooms based on communication and occupancy detection (Figure 4.6).

Figure 4.6. Individual room controling systems for controling heating, ventilation, lighting and shading [32]

4.6. Indoor environmental quality assessment

The indoor environment is an important element which has a significant impact on the occupant's comfort, health and productivity. Indoor Environmental Quality includes various parameters such as noise, indoor temperature, humidity, lighting. One of the main factors to evaluate the effects implementation retrofit actions and level of smart readiness is to assess the indoor environment quality. The assessment has been done in two individual rooms in Itecons1 and Itecons2 buildings which are located in a similar position and with almost similar envelope characteristics. The main difference between the two rooms is the size of the glazing area which is more in the room in Itecons1. The indoor environment assessment has been done in two stages. First, a survey was conducted to ask people to express their opinion and feelings about the different effective parameters on the indoor environment quality. In the next stage, a monitoring campaign was performed to measure the effective parameters on the indoor environment quality and thermal comfort.

Step1: Indoor environment quality survey

The format of the questionnaire used in this work is based on the CBE Occupant Indoor Environmental Quality Survey administered by the Center for the Built Environment, the University of California Berkeley which is a proven and effective tool to appraise occupant satisfaction. A general description of the CBE database is reported in [33]. The survey uses a 7-point ordered scale to rate occupant satisfaction with the building, workspace, and parameters of indoor environmental quality (IEQ), ranging from ‘very satisfied’ (+3) to ‘very dissatisfied’ (-3), with a neutral midpoint (0). In the cases that respondents indicate dissatisfaction with a particular air quality parameter of their work environment, they are directly asked a set of follow-up questions to provide more information regarding the reasons for their dissatisfaction. The satisfaction level is categorized into three-point scores: top three points for “satisfied”, middle point for “neutral” and the bottom three points for “dissatisfied”.

The questions included 3 main parts. Part1 included the questions about the participant’s gender, location of their office and the time duration of the work in that particular office. Part 2 of questionnaire consisted of the questions about the participants’ overall level of satisfaction/dissatisfaction with noise level, lighting (in summer and winter), visual comfort, temperature (in summer and winter), air circulation (in summer and winter), level of odor, level of pollutants and air quality in terms of humidity and dryness (in summer and winter).

Finally, in part 3 participants were asked to express their opinion on the level of their control over temperature, ventilation and lighting in their workplace. Some of the examples of the questions in the survey are shown in Figure 4.7.

How satisfied are you with the Noise level in your workplace? *

- Very Satisfied
- Satisfied
- Partially Satisfied
- Not Satisfied/Dissatisfied
- Partially dissatisfied
- Dissatisfied
- Very Dissatisfied

Which of the following contribute to your dissatisfaction with the acoustic? (If applicable)

- People talking on the phone
- People talking in surrounding offices
- People talking in the corridor
- Telephones ringing
- Office equipment
- Other...

Which of the following contribute to your dissatisfaction with the temperature? (If applicable)

- Thermostat is inaccessible
- My area is hotter/colder than other area
- Thermostat is adjusted by other people
- Air movement is too low
- Air movement is too high
- Drafts from vents
- Heating/cooling system does not respond
- Incoming sun
- Humidity too high (damp)
- Humidity too low (dry)
- Hot/cold surrounding surfaces (floor, etc.)
- Drafts from windows
- Heat from office equipment
- Heating/cooling capacity is insufficient
- Other...

Figure 4.7. Examples of the questions in the IEQ survey assessment

The final result from the survey is shown in Figure 4.8 which shows that people working in Itecons 2 building are more satisfied with the indoor environment quality in their office. People working in the office in Itecons1 are more satisfied with the lighting level and visual comfort which it refers to the very low glazing area in the office in Itecons2 which is not able to provide an acceptable level of lighting required for tasks and office works.

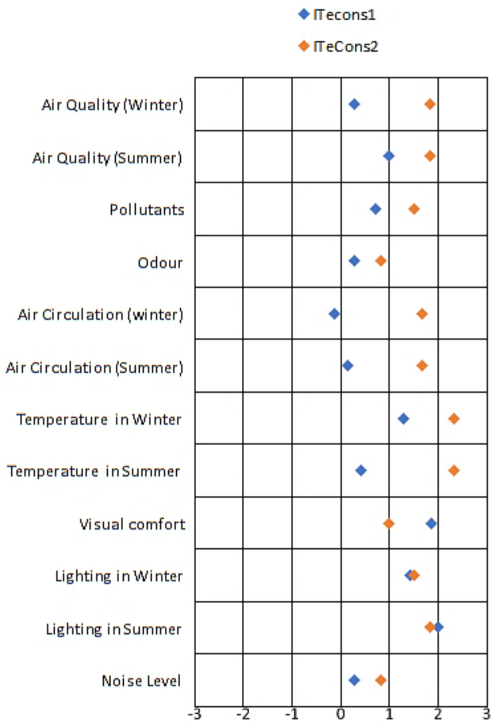


Figure 4.8. IEQ survey results (range between 'very satisfied' (+3) to 'very dissatisfied' (-3))

Step2: Evaluate Indoor Environment parameters through measurements

The monitoring campaign was performed by two main instruments. The first one is the multi-probe USB device which allows evaluating the IEQ especially for office buildings (Figure 4.9). This object includes different sensors that can measure:

- Temperature
- CO_2 concentration
- Illuminance
- Relative humidity
- Atmospheric pressure and
- Volatile organic compounds (VOCs).

Figure 4.9. IEQ measurement device

All these elements are installed inside a USB that can be easily connected to a computer. Also, a sustain equipped with an extension cord allows the inspector to put the device far from the experiment environment and to prevent the immediate heat and CO2 emission to interfere with the perception of the quantities considered.

The accompanied software allows the users to read the recorded data. The software is IEQ DISCOVERER ® which is necessary for communication between the USB device and the personal computer, for real-time data monitoring through numbers and graphs and for classification the indoor condition in relation with the EN 16798-1 and the level of VOCs concentration in the air (Figure 4.10).

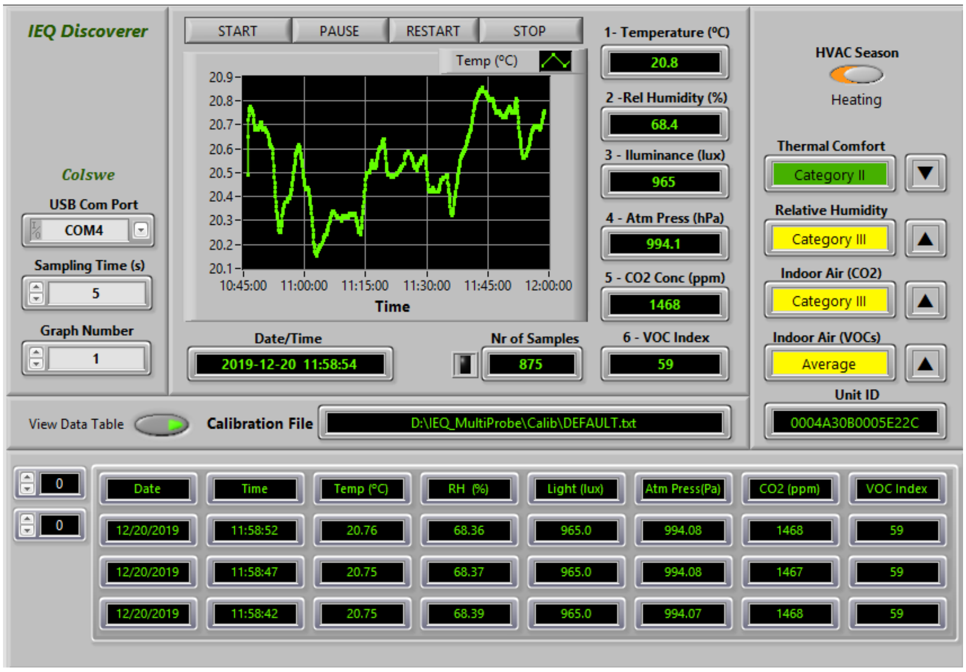


Figure 4.10. IEQ measurement device software screen during its functioning

The software can be launched after the connection of the USB tool to the computer. At the end of each measurement session, the software creates a .txt file in which all the data are saved in a folder previously created.

4.6.1. IEQ assessment of the monitored rooms

Measurements were conducted in one room in Itecons1 and Itecons2. The process began on 6th and ended on 15th of January 2020 (weekends were not included). The USB pen with sensors was always placed not near the personal computer, thanks to its own sustain, to not affect the result by the CO_2 emitted by the PC user. The measures were taken during the day (working hours) to better understand the changes in the values.

The area of the monitored room in Itecons1 is 75.4m^2 on the first floor with the glazing area oriented to west and south (Figure 4.11). The number of 10 people work inside with PCs. Thanks to the large glazing area, the room is bright and people can use the daylight in most parts a day. The room always was completely occupied (except lunchtime) during the measurement. All the data were taken with the same USB, located in the same position in the almost center of the room and by the same personal computer. The information collected was saved in .txt format in a specific folder and then passed on Excel for analyzing.

Figure 4.11. The monitored room in the Itecons1 building

The other monitored room was the room located on the ground floor of Itecons2, with the area of 104m^2 and the glazing area oriented to east and south (Figure 4.12). 9 people work at the room with PCs. The room always was completely occupied (except lunchtime) during the measurement. All the data were taken with the same USB, located in the same position in the almost center of the room and by the same personal computer.

Figure 4.12. The monitored room in the Itecons2 building

First, the indoor measured data compared with the data perceived by the weather station. The indoor data used was obtained by the multi-probe USB inside the building while the outdoor weather data was achieved from the weather station web site (wunderground.com). In this web site, it is possible to choose the nearby weather station with climatic information of the area.

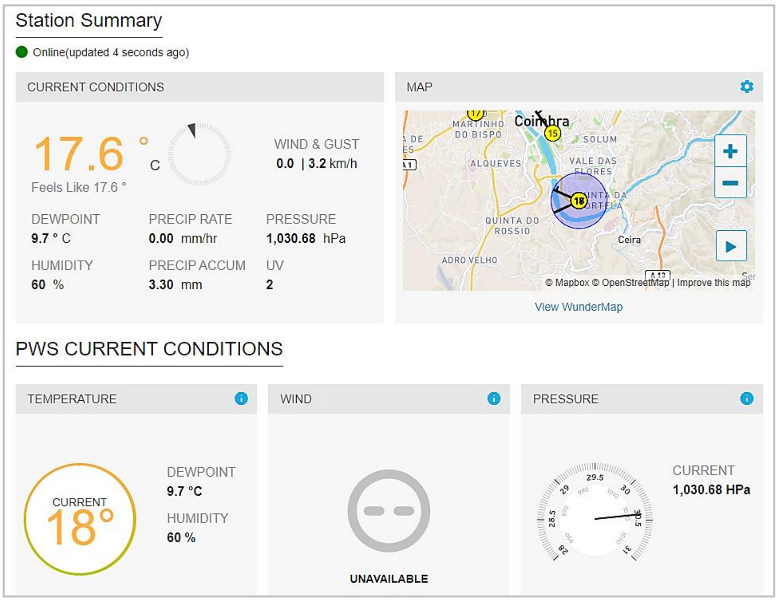


Figure 4.13. Weather station summary information [www.wunderground.com]

The first day was the 6th of Jan and the average indoor temperature measured was 20° in the room in Itecons1 and 20.7° in the room in Itecons2 while the average outdoor temperature, in the same range of hours, was 7.4°. The last day of measurement was 15th of Jan with the average indoor temperature of 20.3° in the room in Itecons1 and 22.3° in the room in Itecons2 while the average outdoor temperature, in the same range of hours, was 15.5°. The outdoor temperature on 6th and 15h of January are presented in Figure 4.13.

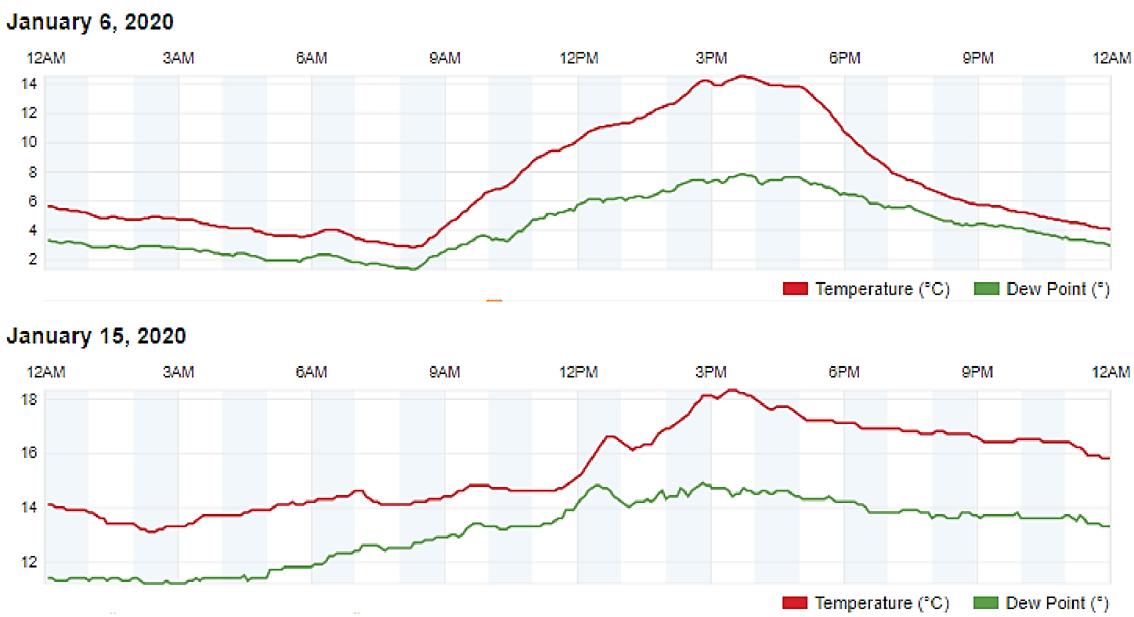


Figure 4.14. Outdoor temperature in Coimbra on 6th and 15th of January [https://www.wunderground.com/]

The measurement outputs for temperature, relative humidity and Co_2 concentration are shown for the case study buildings for 6th and 15th of January in Figure 4.15 and Figure 4.16 respectively. In these figures, the Indoor Environmental Quality is classified. If the curve in the graph is located in category I the IEQ is on target, while if it is in category 4 means that it is not in the comfort zone. As it is shown in the figures, in most hours during a day IEQ is in the range of high level and normal level of quality in the room in Itecons2. Also, owing to monitoring systems provided in Itecons 2, the temperature reaches the set point quickly (only about one hour later than the beginning of the working day). Furthermore, the high Co2 concentration (more than 1800ppm in some hours) indicates the necessity of ventilation system installed in the room in Itecons1.

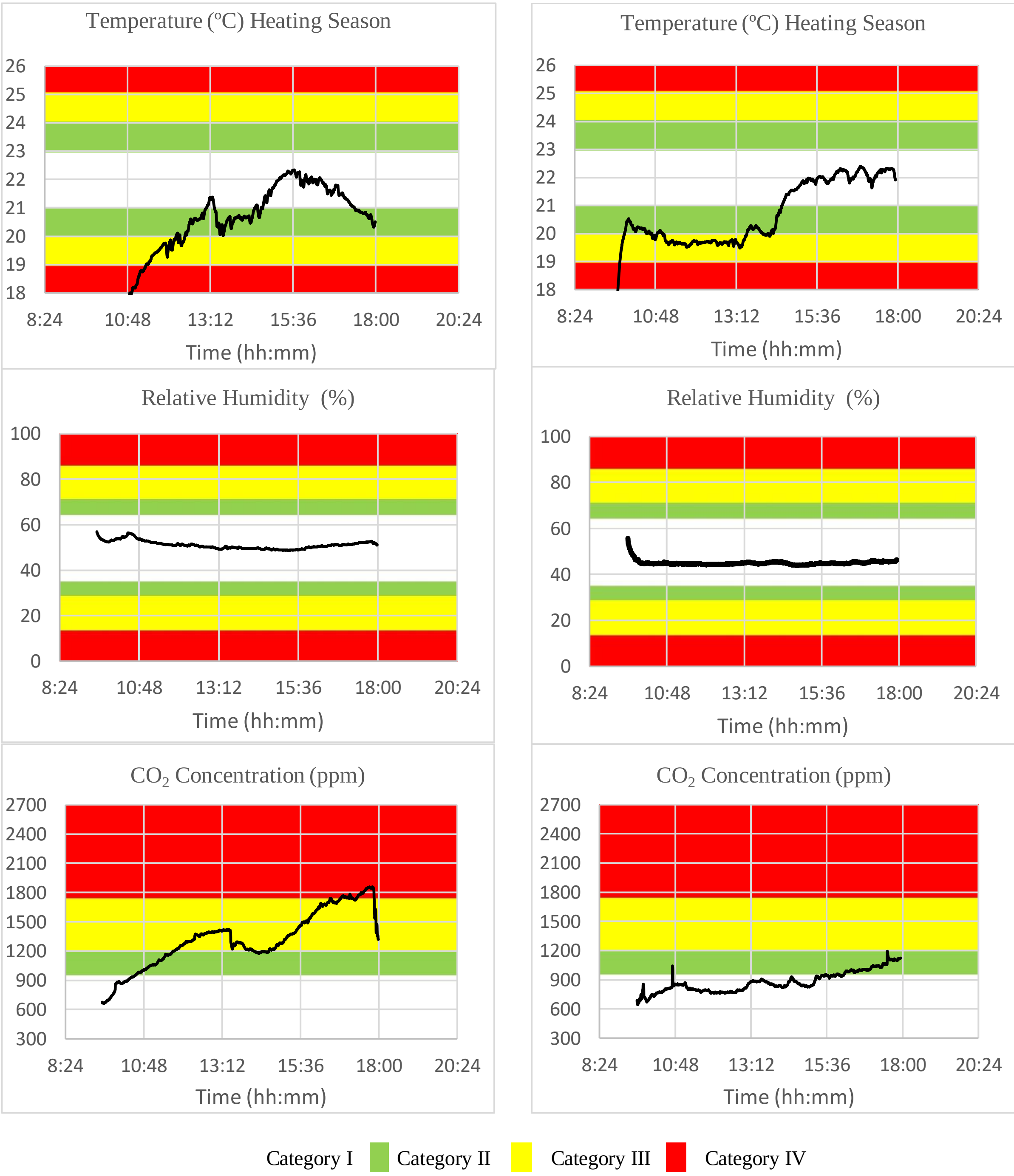


Figure 4.15. The temperature, humidity and Co2 concentration variation on 6 of Jan for the rooms in Itecon1 (left) and Itecons2 (right)

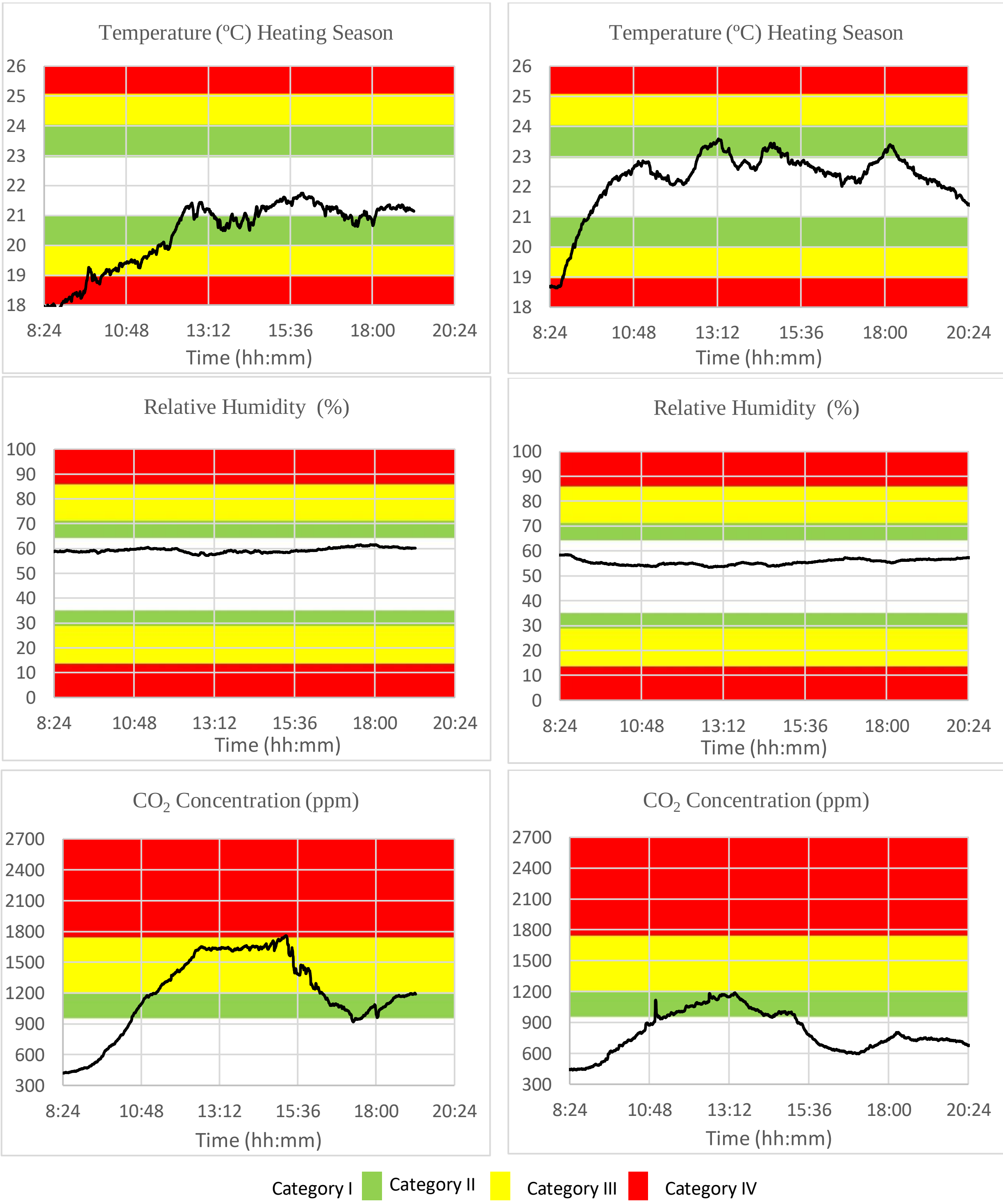


Figure 4.16. The temperature, humidity and Co2 concentration variation on 15 of Jan for the rooms in Itecon1 (left) and Itecons2 (right)

The EN 16798-1 [34] standard explained four classes for the indoor environment quality. They refer to levels of satisfaction with indoor environmental quality factors including thermal comfort, lighting, acoustic and indoor air quality. For acoustic and lighting is difficult to apply these categories as it depends on the building's type.

Table 4.10. Indoor environment quality categories definition [34]

Category	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick very young children and elderly persons, to increase accessibility.
II	Normal level of expectation
III	An acceptable, moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

The other measured parameter to assess IEQ is the amount of VOCs in the air. Many elements used in everyday life emit VOCs for example perfumes, cleanser, paints and also some building materials or elements that contain glues. The most effective way to reduce the negative impacts of pollutants in the indoor air is using ventilation system or it would be better to reduce or avoid the emissions [35]. The level of VOCs can be assessed using air quality index (AQI) which is presented in Table 4.11.

Table 4.11. AQI categories [36]

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	..air quality conditions are:	…as symbolized by this color:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301to 500	Hazardous	Maroon (Gray)

The measurement taken in both days chosen for this research gave values of VOCs between 33 and 43 for the room in Itecns1 and between 30 and 40 for the room in Itecons2. The range between 0 and 50 corresponds to the green color and it means that the

AQI is "good" or "healthy". This category certifies that the pollution detected does not create risks, or in case they are small ones [36].

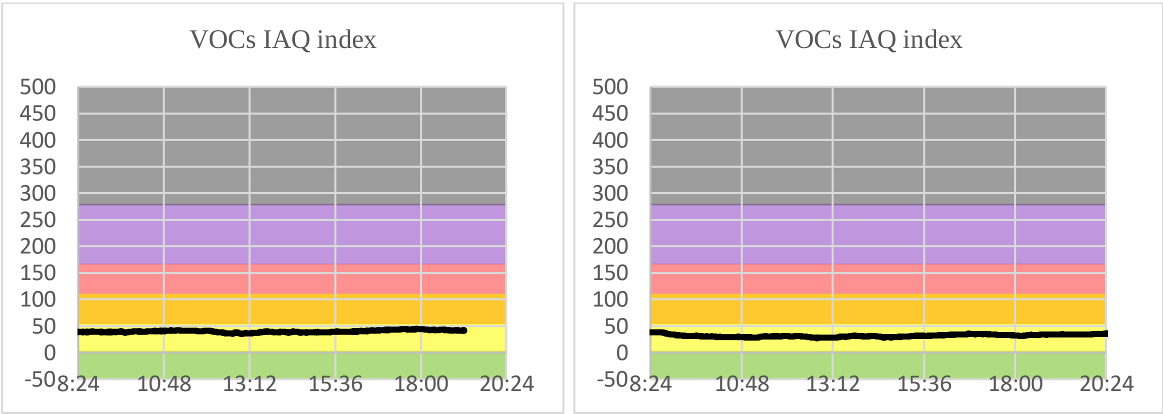


Figure 4.17. The VOC variation on 15 of Jan for the rooms in Itecon1 (left) and Itecons2 (right)

The information related to the lights is all contained in the European Standard UNI EN 12464-1 [37], in which all the minimum illuminance requires for indoor workplaces to guarantee the visual comfort are defined. The minimum lux required for offices for the normal works writing, typing, reading, data processing is 500. In the last day chosen, the 16 of Jan the average of lux data was 1013 for the room in Itecons1 and while for the room in Itecons2 it was 382. These high difference between values are only related to natural light difference transmitted from the larger glazing area.

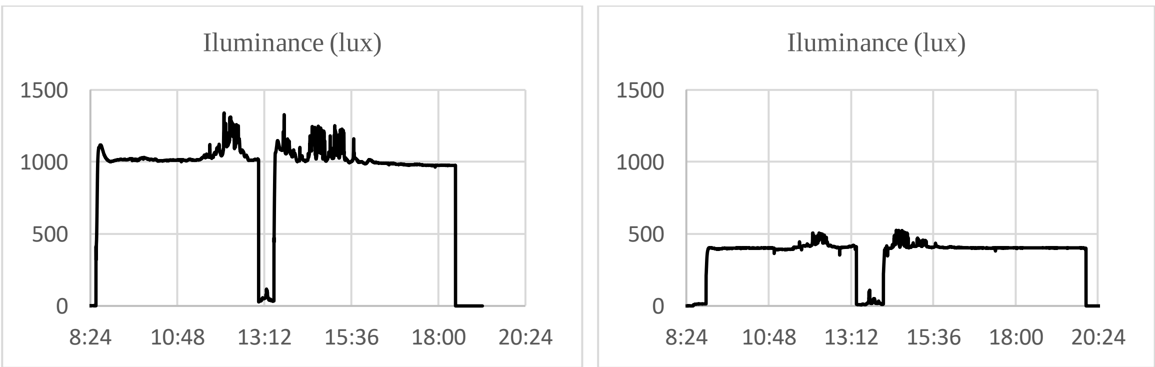


Figure 4.18. The illumination on 15 of Jan for the rooms in Itecon1 (left) and Itecons2 (right)

Another measurement device was used to evaluate the thermal comfort in the monitored rooms (Figure 4.19). In this device, three sensors are installed to measure the temperature of the three points in different height which indicate the temperature of the air around the head, the center of gravity of body and feet of a seated person on the chair. A humidity sensor and a probe attached in the middle measure the humidity and operative temperature respectively.

Figure 4.19. The thermal comfort measurement device

This device is connected to a computer and there is a possibility for real-time monitoring the temperature variations. The measurement should be done in the minimum of 10-15 minutes' time period to have more precise and stable results.

Figure 4.20. Thermal comfort measurement software screen during its functioning

Similar to the USB measurement device, the measured data is in a text file that can be imported to the excel file for better analysis. The measurement outputs are shown in Figure 4.21 which clearly represents the better thermal comfort in the monitored room in Itecons2 building.

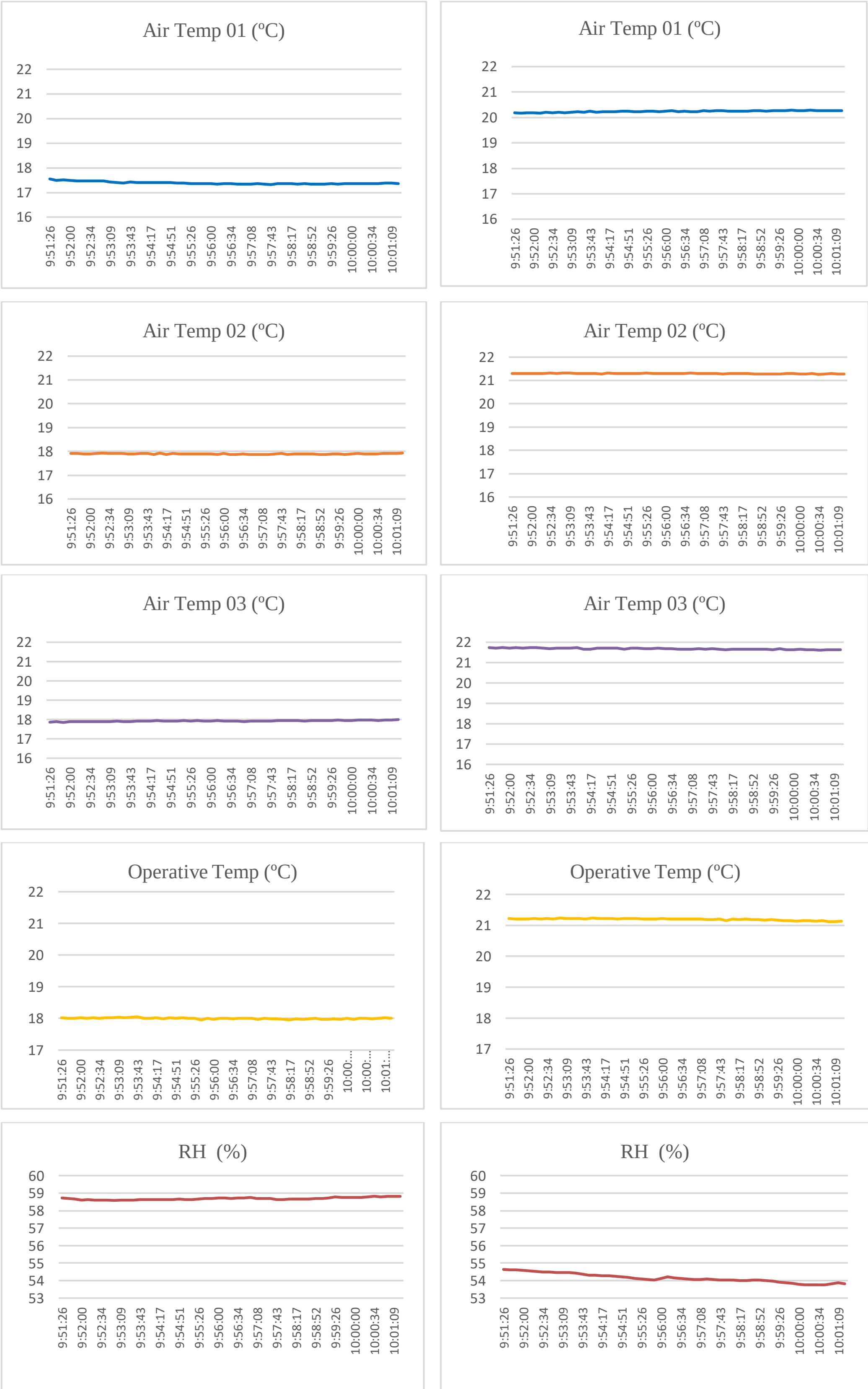


Figure 4.21. Three points temperature, operative temperature and relative humidity in the rooms in Itecons1 (left) and Itecons2 (right)

4.7. Building retrofitting actions

The major possible retrofit technology types that can be used in building applications can be categorized into three groups [38]; supply-side management, demand-side management, and change of energy consumption patterns (human factor). These technologies are listed in Figure 4.1.

Heating and cooling demand reduction (Demand side management)	Human factors (Energy consumption patterns)
• Building fabric insulation (i.e. roof, wall, etc.) • Windows retrofits (i.e. multiple glazing, low-E coatings, shading systems, etc.) • Cool roof and cool coatings • Air tightness, etc.	• Comfort requirements • Occupancy regimes • Management and maintenance • Occupant activities • Access to controls, etc.
Energy efficient equipment and low energy technologies (Demand side management)	**Renewable energy technologies and electrical system retrofits (Supply side management)**
• Control upgrade • Natural ventilation • Lighting upgrade • Thermal storage • Energy efficient equipment and appliances • Heat recovery, etc.	• Solar thermal systems • Solar PV/PVT systems • Wind power systems • Biomass systems • Geothermal power systems • Electric system retrofits, etc.

Figure 4.22. Main categories of building retrofit technologies [38]

Selection among the retrofit technologies is not an easy task and needed to be in line with energy efficiency, indoor environment quality and global environment improvement in a cost-effective way. In other words, the main objective of a retrofit project is to implement a set of optimum solutions for energy demands and CO_2 emissions minimization, while maximization of the economic efficiency and indoor environmental quality. It is also important to consider the tradeoff between different goals that can be achieved by implementing different retrofit actions and beyond that, optimizing one of the achievements can subsequently compromise other goals which can be optimized by using a multi-objective strategy [39]. More specifically, technologies are utilized in building retrofitting in order to reduce heating and cooling loads, annual energy consumption, annual emission effective on global warming, life-cycle environmental impact, water consumption, while increase the thermal sensation, visual comfort, indoor air quality, and acoustic comfort [40]. In terms of financial objectives, the direct and initial costs, the ongoing cost, life cycle costs (LCC) and the energy-saving cost need to be evaluated during a building retrofit strategy.

According to European commission [41], the Mediterranean biogeographical region includes the Mediterranean see and seven member states, France, Portugal, Italy, Spain (partially) and Greece, Malta, Cyprus (completely). The climate is characterized by hot dry summers and humid, cool winters, sudden heavy rain or bouts of high winds such as the Sirocco and Mistral. It includes high mountains and rocky shores, thick scrub and semi-arid steppes, coastal wetlands and sandy beaches as well as a myriad of islands dotted across the sea.

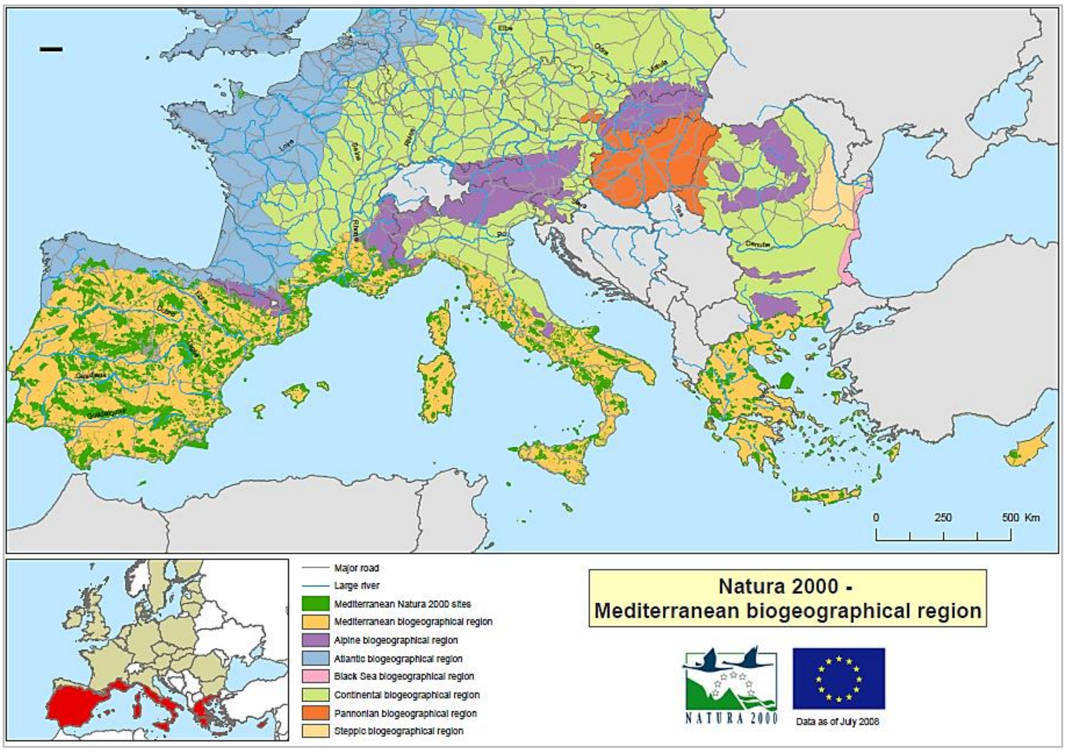


Figure 4.23. European climate zones in Europe [41]

The most outstanding difference of building behavior in the Mediterranean region compared to the rest of Europe is the higher cooling demand of buildings in the hot and long summers of Mediterranean climate. Therefore, one of the main concentrations of building retrofitting in the Mediterranean area seems to be implementing effective technologies to reduce the cooling demand, improve indoor air quality and provide thermal comfort for occupants. Moreover, utilizing of passive cooling opportunities such as natural ventilation, effective shading and high thermal mass building envelope material, is also applicable in the Mediterranean building which can effectively contribute to reducing energy consumption in the cooling seasons.

As it was mentioned before, a sort of energy-efficient technologies has been implemented in one of the case study buildings (Itecons2) which leads to a better energy performance compared with the other one. Since both buildings are located in the same location and have almost same architectural characteristics, the energy-efficient technologies applied in the Itecons2 can be considered as the retrofitted actions that can be implemented in the same building (Itecons1). Therefore, these technologies will be introduced in this section and their actual effects on energy performance and SRI improvements will be described in the next sections.

To reduce the energy dependence to the grid, the photovoltaic solar system is used for mini energy production, installed in building roof, composed of 92 Open PQ60 collectors (240 Wp power class) along in two lines, with a nominal power of 22.08 kW. The system is installed on the roof, in the south orientation and with an inclination of 30º. Air renewal system installed in the building roof guarantees the indoor air quality and reducing energy consumption through heat recovery. It is equipped with a ventilation module with plug-fun fans, a filter module, a rotary heat recovery unit and a direct expansion battery for heating and cooling (thermal correction) of the outside air. The supply power and the extraction power are 3 kW and 2.2 kW respectively. The motorized window shading which is categorized as the dynamic building envelope system enables the building facade to adjust the solar lighting transmitting into the indoor space based on the information it receives from inside sensors. As this technology applied to the south orientation windows, it would be an effective way to reduce the energy demand of both heating and cooling.

4.8. Energy performance simulation

Building simulation is an effective tool to model the energy behavior and estimate the heating and cooling of a building. Energy simulation provides an overview of the quality of energy performance in a building. For this purpose, Design builder software was used to model the internal gains, thermal comfort and heating and cooling loads in two monitored room in Itescons1 (area=75.4 m^2) and Itecons2 (area=104 m^2) buildings. The glazing area for the monitored room in Itecons 1 is equal to 45.8 m^2 and for the room in Itecons 2 is equal to 9.3 m^2. For better comparison, the glazing area for the room in Itecons1 was reduced in the software's input to be equal to the glazing area for the room in Itecons2. Figure 4.24 illustrates the sun path over the case buildings. It shows that the glazing area of the building Itecons2 is constantly on the exposure of sunlight during the day. Therefore, utilizing the window shading seems an effective way to reduce loads especially on cooling seasons.

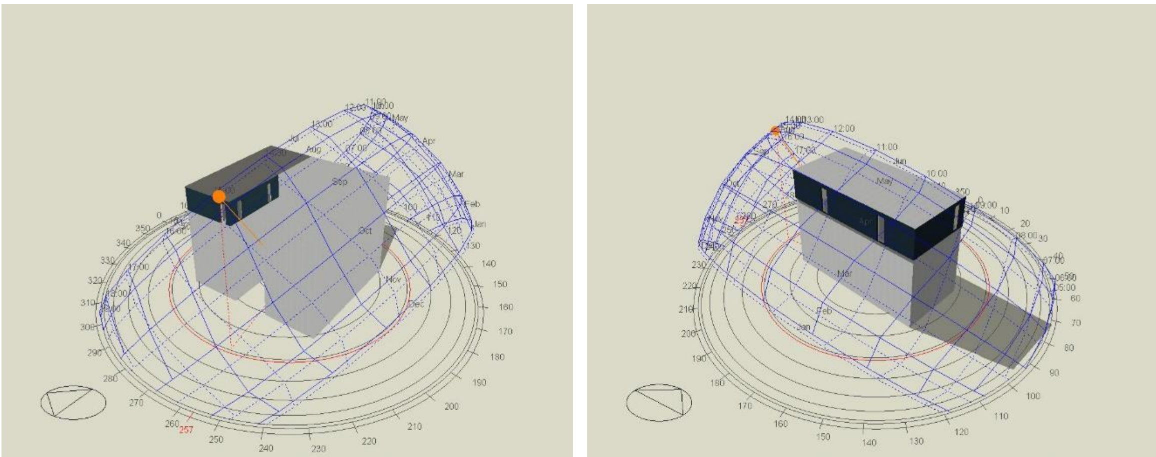


Figure 4.24. Sun path over the Itecons 1 (left) and Itecons2 (right), [Design builder]

Figure 4.25 shows the effect of using the ventilation system with economizer in reducing cooling demand and improving indoor air quality in the room in Itecons2. Comparing the indoor temperature of two rooms indicates that the free cooling system during the night decreases the indoor air temperature and consequently the cooling system needs less energy to cool down the indoor space during the day. Also, as it was shown in the environment quality measurement results, the total fresh air based on the air exchange per hour in the room without ventilation (Itecons 1) constantly decrease during the working hours, while it remains constant for the room with ventilation (Itecons2). The operative temperature and radiant temperature which are effective in indoor thermal comfort are also remained constant in the room in Itecons 2 (with motorized shading). However, as it is illustrated in the sun path over the buildings (Figure 4.24), in summer after late hours in the morning and continuously in the afternoon the sunlight is transmitted through the south and west-facing windows of the Itecons1 building which causes the rising in the operative and radiant temperature in the indoor space.

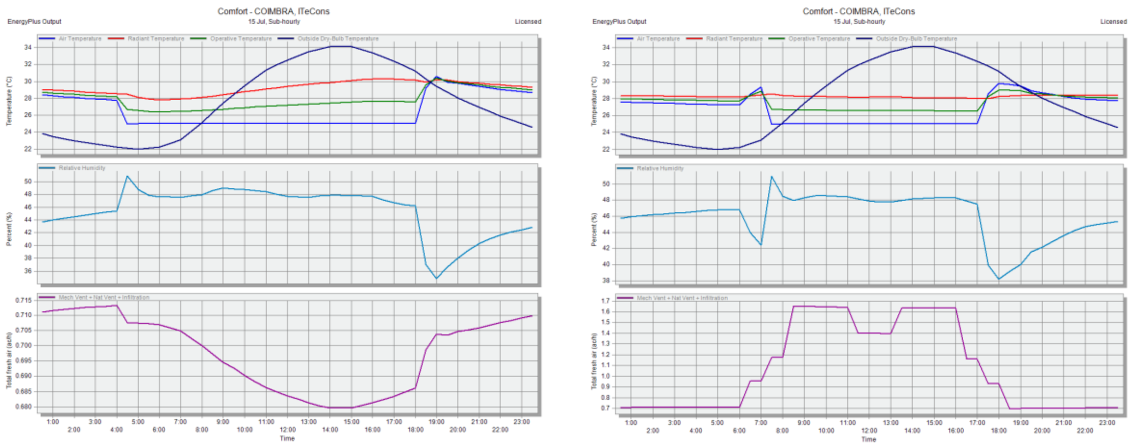


Figure 4.25. Comfort condition in the rooms in Itecons1 (left) and Itecons2 (right)

The heating and cooling loads for the monitored rooms were obtained as 3.85 kW (0.051kW/m^2) and 6.35 kW (0.084kW/m^2) for the room in Itecons1, 5.97 kW (0.057kW/m2) and 5.9 kW (0.056kW/m2) for the room in Itecons2. Thus, the sensible heating and cooling in the room in Itecons2 are 24.7% and 26.7% less than the sensible heating and cooling in the room in Itecons1 (Figure 4.26). Although some part of this amount is because of extra loads imposed through the external roof in the room in Itecons1 which is not applicable for the room in Itecons2 (it is not located in the top floor of the building), implementation the retrofit actions in the building combined with smart services is also effective in the energy consumption reduction for cooling and heating in the building.

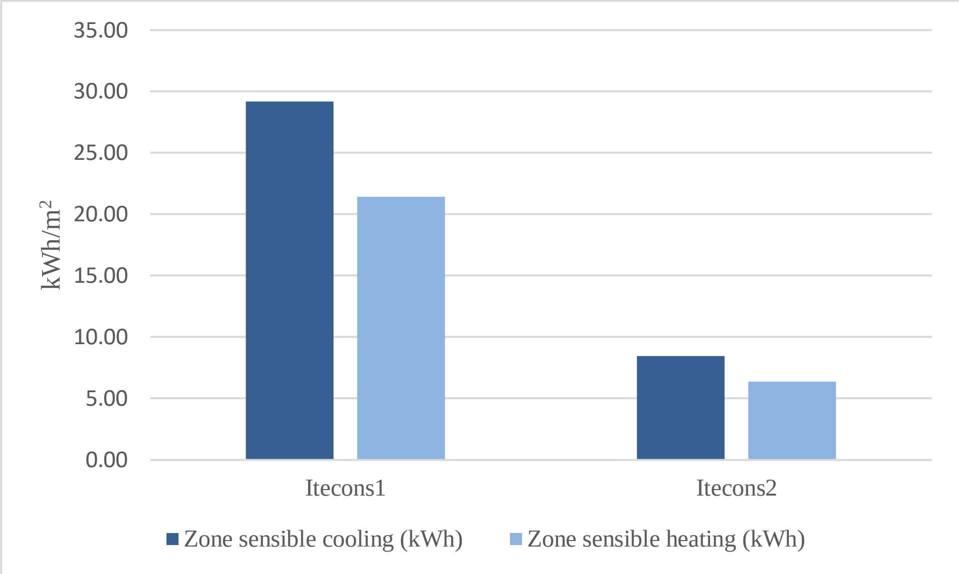


Figure 4.26. Zone sensible cooling and heating values in the rooms in Itecons1 and Itecons2

The annual amount of the internal gains in the monitored rooms of the case study buildings shows that using the motorized shading for windows in the room in Itecons2 able to adjust the solar gains transmitting into the indoor space in summer and assist in reducing cooling loads (Figure 4.27). It is also shown that the main energy consumer in both buildings is electrical appliances and lighting system.

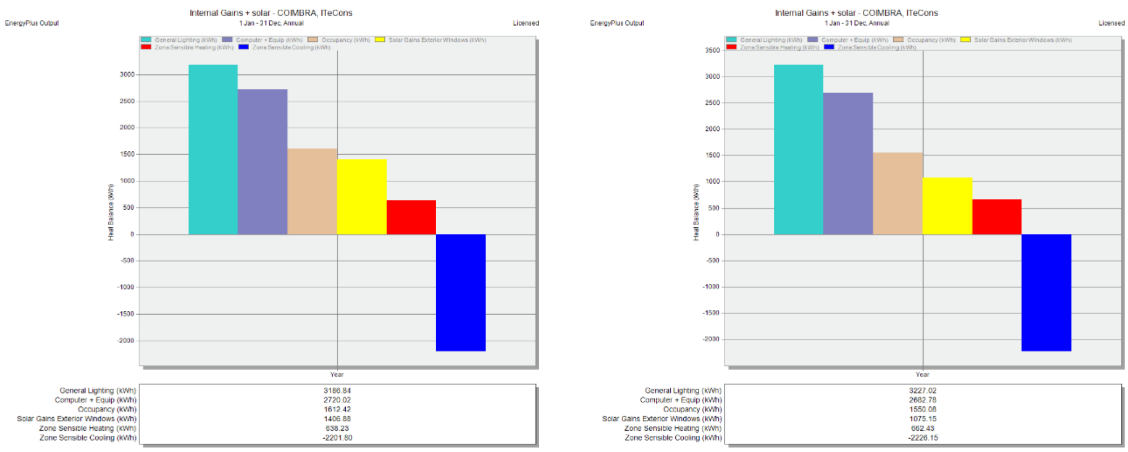


Figure 4.27. Internal gains of the rooms in Itecons1 (left) and Itecons2 (right)

4.9. Conclusion

In this chapter, the SRI calculation methodology was analyzed and implemented in the case study buildings. Also, the relation between building smartness, thermal comfort and energy consumption was evaluated using IEQ and thermal comfort assessment and energy simulation. The effects of retrofit actions on thermal comfort, energy-saving and SRI improvement are summarized in Table 4.12. The main retrofitting actions and their effects on thermal comfort, energy-saving and SRI are as follows:

- Heating domain: Multi-stage control of heat generator capacity depending on load or demand which mainly contribute to SRI, thermal comfort and energy-saving improvement in Itecons2.
- Cooling domain: Variable control of cooling production capacity depending on load or demand which effectively contribute to SRI, energy-saving and thermal comfort improvements.
- Ventilation domain: Using ventilation system together with real-time monitoring and historical data of IAQ in the Itecons2 not only improves the thermal comfort and IEQ in the spaces but also enhances SRI and contribute to energy-saving.
- Building envelope domain: Using motorized control of window shading in Itecons2 which is mainly effective on reducing cooling loads and consequently energy consumption for cooling.
- Electricity generation domain: Photovoltaic panels in the Itecons2 with reporting information services with the ability to performance evaluation and forecasting which mainly contribute to SRI improvement through increased interaction with occupants.

Table 4.12. The relation between retrofit actions implemented the case study building and thermal comfort, energy saving and SRI

Retrofit actions	Domain	Thermal comfort	Energy Saving	SRI
Multi-stage control of heat generator capacity depending on load or demand	Heating	✓	✓	✓
Variable control of cooling production capacity depending on load or demand	Cooling	✓	✓	✓
Multi-stage of air flow control at air handler level	Ventilation	-	✓	✓
Constant setpoint: A control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action	Ventilation	✓	✓	✓
Free cooling: air flows modulated during all periods of time to minimize the amount of mechanical cooling	Ventilation	✓	✓	✓
Real time monitoring & historical information of IAQ available to occupants	Ventilation	-	-	✓
Double glazing windows	DE	✓	✓	-
Motorized operation with automatic control based on sensor data	DE	✓	✓	✓
Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	Elecricity	-	✓	✓

5. CONCLUSION AND FUTURE WORKS

The main focus of this work was presenting, analyzing and implementing the smart readiness indicator (SRI) which has been recently introduced by the revised EPBD. The methodological framework for SRI calculation is still under development by DG Energy using the active and ongoing feedback from stakeholders and the Member States. Then, the proposed SRI calculation methodology was analyzed and implemented in two case study buildings in Portugal. Also, in one of the buildings a sort of retrofit actions was implemented so because of the similar structure of the buildings it was possible to evaluate the effects of some common building retrofitting actions on the level of smartness specifically in the Mediterranean climate region.

To summarize, some issues have been observed during the analysis calculation methodology which needs more studies and investigations. First, identifying the functionality levels of the smart ready services needs a group of experts who have access to the technical documents of the building services. However, even in some cases the functionality levels should be more clarified to minimize the personal judgment on the selection and scoring the services. Second, in some buildings, such as service buildings, the same services are assigned for different functionality levels in different zones. For example, manual or automatic control of lighting system in rooms or common areas of a non-residential building. In these cases, it was not clarified how the overall functionality level for that service can be calculated. The other issue is that in some cases a building cannot receive scores for a certain service because it is defined in a domain that does not exist in the building. For instance, although one of the case study buildings in this work has a monitoring service to receive IAQ data, it cannot be scored by this because this service was defined in the “ventilation” domain category which does not exist in the building. The other issue which needs to be analyzed is that the existence of some services is not of importance in some types of buildings, such as DHW services in the office or services buildings. So, as these services are not used frequently, their level of smartness is not effective and the investments will be with low payback. On the other hand, the relative scores of these services are usually too low or equal to zero which negatively affects the overall SRI score of the building. Finally, it should be noted that to have an optimal outcome of digitalization the technical building services, it is more effective to use of all smart services with the maximum functionality level in all domains to minimize the occupants' interference as much as it is possible. For example, if the windows operate manually, not automatically integrated with an HVAC system, in a room in which the heat emission controlled with the maximum functionality level, the occupants' choice in opening or closing the window will reduce the effectiveness of the heating control system.

Regarding the effects of possible retrofit actions, it can be concluded that if the retrofit actions are selected not only based on the building retrofitting objectives but also based on the functionality level enhancement of smart services, they would also contribute to SRI improvement. However, this improvement would be related to responding to occupants' needs but is not necessarily effective to adapt in response to the building operation and energy grid.

Thus, the introduced methodological framework of SRI needs more studies and development to consider all possible aspects and resolve the current issues. Furthermore, regarding building retrofitting, SRI improvement can be considered as one of the retrofitting objectives besides energy saving, thermal comfort, environmental impacts and cost. Therefore, by developing a multi-objective selection approach, the possible building retrofit actions will be chosen based on their effectiveness on SRI together with the other improvements.

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