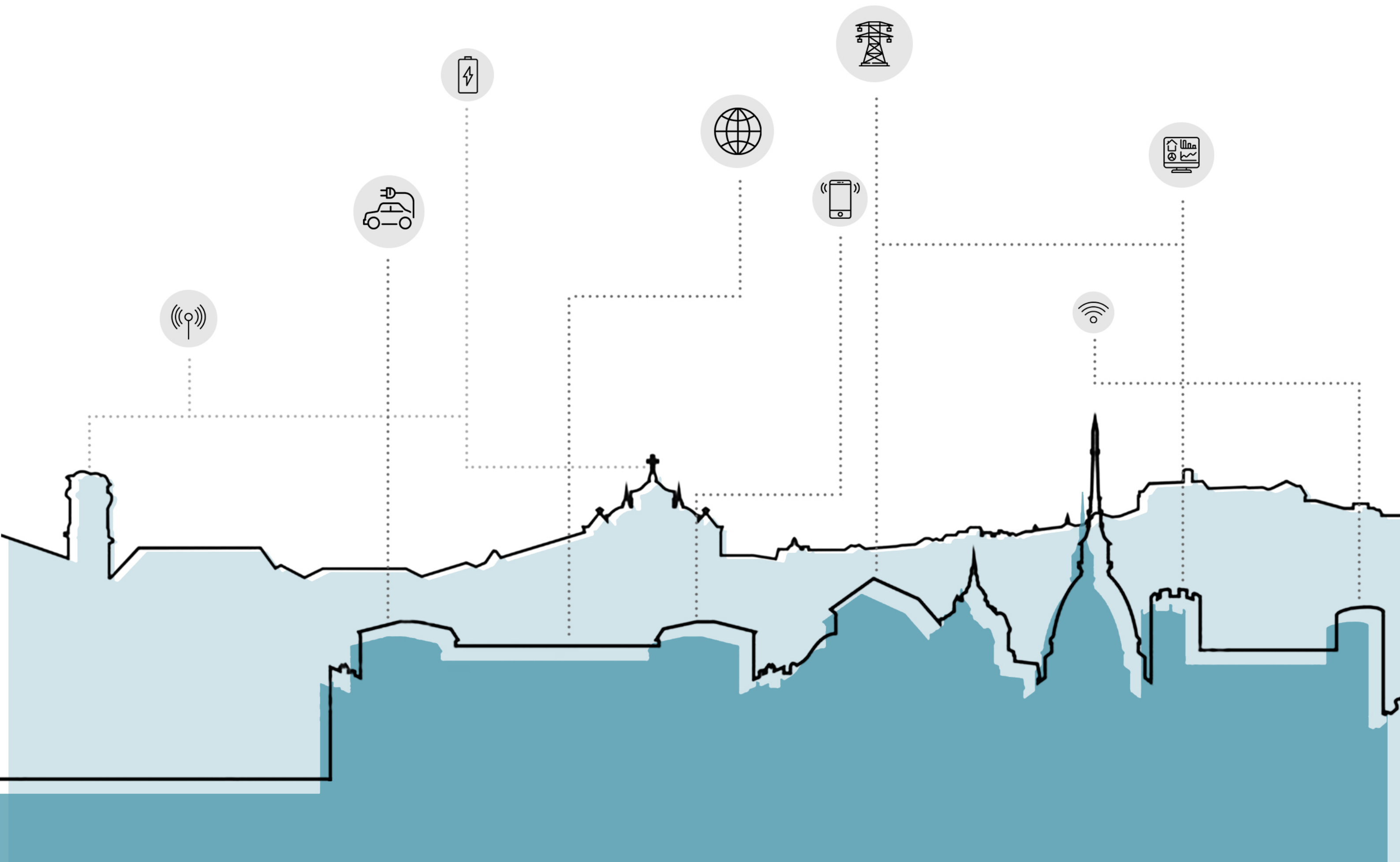
Smart Readiness Indicator and Indoor Environmental Quality:

two case studies in Italy and Portugal

MARIA FEJR POLITECNICO DI TORINO 2019



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Smart Readiness Indicator and Indoor Environmental Quality: two case studies in Italy and Portugal

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Abstract

The use and integration of smart technologies inside buildings in planned renovations is a point addressed in the Directive (EU) 2018/844 that also introduces the Smart Readiness Indicator (SRI), a new indicator to assess the readiness of buildings to adapt itself to users and grid needs. With this new indicator, the Directive aims to communicate more directly to more people (users, owners, etc.) the added value of having ICT technologies in a building. If users understand the value of this transformation, they are more motivated to invest time and money in it.

The indicator is then defined as a tool that provides information about the readiness of buildings to interact with external energy networks and occupants of the buildings themselves to ensure more efficient operation and better energy performance through ICT technologies. The evaluation of the indicator, through the verification of the services present, allows potential investors to understand what to target their resources in a hypothetical retrofit.

To better understand the functioning of this indicator, it was decided to apply it to two case studies, an Italian and a Portuguese one. This experiment allowed in the first case to use a critical approach going not only to assess the level of readiness of the building, but also to identify the shortcomings and difficulties in applying the methodology proposed by the European project.

In the second case, the evaluation of the SRI allowed a comparison of two different approaches in defining the comfort of an indoor environment: one more scientific based on the use of recorded data and indices obtained by them and the other obtained through the calculation of the indicator. In the second application the aim was also to find a hypothetical univocal definition of the weighting coefficients to be applied in the methodology.

Keywords:

EPBD; smartness; Smart Readiness Indicator (SRI); comfort; Indoor Environmental Quality (IEQ)

Abstract

Nella Direttiva (UE) 2018/844 viene affrontato il tema dell'uso e dell'integrazione di tecnologie intelligenti all'interno degli edifici nelle ristrutturazioni programmate con anche l'introduzione di un nuovo indicatore per valutare la prontezza degli edifici ad adattarsi alle esigenze degli utenti e della rete: lo Smart Readiness Indicator. Con questo nuovo indicatore, la direttiva mira a comunicare in maniera più diretta ad un maggior numero di persone (utenti, proprietari, ecc.) il valore aggiunto di avere tecnologie ITC in un edificio. Se gli utenti comprenderanno il valore di questa trasformazione, saranno più motivati a investirci tempo e denaro.

L'indicatore viene quindi definito come uno strumento che fornisce informazioni sulla disponibilità degli edifici ad interagire con le reti energetiche esterne e con gli occupanti degli edifici stessi per garantire un funzionamento più efficiente e una migliore prestazione energetica grazie alle tecnologie ITC. La valutazione dell'indicatore, attraverso la verifica dei servizi presenti, permette ai potenziali investitori di capire come investire le proprie risorse in un ipotetico retrofit dell'edificio.

Per comprendere meglio il funzionamento di questo indicatore, si è deciso di applicarlo a due studi di caso, uno italiano e uno straniero. Questo esperimento ha permesso nel primo caso di utilizzare un approccio critico non solo per valutare il livello di prontezza dell'edificio, ma anche per identificare le carenze e le difficoltà di applicazione della metodologia proposta dal progetto europeo.

Nel secondo caso, la valutazione dell'SRI ha permesso di confrontare due diversi approcci nella definizione del comfort di un ambiente interno: uno più scientifico basato sull'uso di dati registrati e indici ottenuti in seguito e l'altro ottenuto attraverso il calcolo dell'indicatore. Nella seconda applicazione l'obiettivo era anche quello di trovare un'ipotetica definizione univoca dei coefficienti di ponderazione da applicare nella metodologia.

Keywords:

EPBD; smartness; Smart Readiness Indicator (SRI); comfort; Indoor Environmental Quality (IEQ)

Index

Acronyms

BACS - Building & Automation Control System
BREEAM - Building Research Establishment Environmental Assessment Method
EPBD - Energy Performance of Buildings Directive
IAQ – Indoor Air Quality
ICC – Combined Comfort Index
IEQ – Indoor Environmental Quality
LEED - Leadership in Energy and Environmental Design
PMV - Predicted Mean Vote
PPD - Percentage of People Dissatisfied
SRI – Smart Readiness Indicator
TBS – Technical Building System
TC – Thermal Comfort

When we say things like "People don't change" it drives scientists crazy. Because change is literally the only constant in all of science. Energy, matter, it's always changing. Morphing. Merging. Growing. Dying. It's the way people try not to change that's unnatural. The way we cling to what things were instead of letting them be what they are. The way we cling to old memories instead of forming new ones. The way we insist on believing, despite every scientific indication, that anything in this lifetime is permanent. Change is constant. How we experience change, that's up to us.

1 Introduction

The European Union attributes 36% of CO_2 emissions and the 40% of the energy consumption to the building stock. The members of the European Union are constantly researching on this topic and part of the results of this work are partly expressed in the Directive (EU) 2018/844 in which buildings are the main subject of all the proposals made. The main objective to be achieved is to reduce greenhouse gases by at least 40% compared to 1990 levels. The functioning of buildings requires a significant use of energy and reducing the demand for it would have a strong impact on the achievement of the goal by 2030 [1]. The final goal is to transform all the building in nZEB decreasing the energy bill costs and improving the users daily life.
However, the last directive introduces another major challenge: the achievement of the objectives described above, also through the introduction of building automation. The inclusion of technological devices capable of monitoring the daily actions that occur inside the building would be able to provide useful information to complete the building characteristics figure. Knowing the building well would allow the action on its technological deficits and consequently a better response to the needs of those who occupy or manage it. [3]

The objective of this research is in fact to understand, study and subsequently explain one of the major innovations introduced by the Directive (EU) 2018/844: the Smart Readiness Indicator. This work aims to analyse it theoretically and then define its gaps by applying it to real case studies. The result of this path would allow a more targeted search that would lead to the resolution of all the criticisms found. [9]

The main subject of this thesis is the Smart Readiness Indicator, an indicator that measures the smartness of the building. In order to better understand this indicator, initial research work was carried out on the document in which it was introduced for the first time, explaining its objectives and innovations in chapter 2. Subsequently, in chapter 3, the different conetions of smartness present to date, the indicators that measure it and the methodologies to define these indicators were defined. Chapter 4 critically illustrates the methodology for calculating the indicator proposed by the European project as the final result of work produced by a group of technical experts. Chapter 5 describes the application of the indicator to an Italian case study and the relative criticalities found. Among these, the major one refers to the definition of a weighting coefficient table to be used during the calculation. In order to find a solution, in chapter 6, the SRI is related to another aggregate indicator, thus understanding how experts currently behave in defining the weight percentages to be associated with the different quantities that could influence the IEQ. Chapter 7 shows the application of the calculation to the second case study in Portugal and comments the results obtained in terms of comfort, well-being and health, two categories which would be largely affected if the result of the calculation were high. In chapter 8 the quantities influencing the two categories commented on in the previous chapter are measured and verified in the traditional way to demonstrate the absence of a relationship between the results obtained by using the indicator and those measured with a sensor instrument.

In the end, chapter 9 deals with the conclusions and the awareness reached at the end of this research both through the in-depth bibliographic research that has addressed several points and through the application of the indicator on two real case studies.

2 Analysis of the contents of the new Energy Performance Directive (EU) 2018/844

The European Union attributes 36% of CO_2 emissions to the building stock. The members of the European Union are constantly researching on this topic and part of the results of this work are partly expressed in the Directive (EU) 2018/844 in which buildings are the main subject of all the proposals made. The main objective to be achieved is to reduce greenhouse gases by at least 40% compared to 1990 levels. The functioning of buildings requires a significant use of energy and reducing the demand for it would have a strong impact on the achievement of the goal by 2030 [1].

2.1 Directive (EU) 2018/844 objectives

At the end of June, the new EPBD (Energy Performance of Buildings Directive), which amends the previous one - Directive 2010/31/EU - is published in the Official Journal of the European Union. The aim is to transform most of the building stock into nZEB (nearly Zero Energy Building) by 2050. The three main points introduced in this document are the implementation of strategies to make buildings more energy efficient, the introduction of infrastructure for electric vehicles and the implementation of energy performance monitoring.

The current European scenario contains 75% of Europe's building stock that is energy inefficient and needs to speed up renovation times with a focus on smart building technologies [2].

The new Directive focuses on the building, identifying it as the key to achieving the new objectives for the future. The innovations that the new directive presents are:

- long-term renewal strategies to achieve the decarbonisation target by 2050;
- the smart readiness indicator for buildings to assess the smartness of a building called SRI (Smart Readiness Indicator);

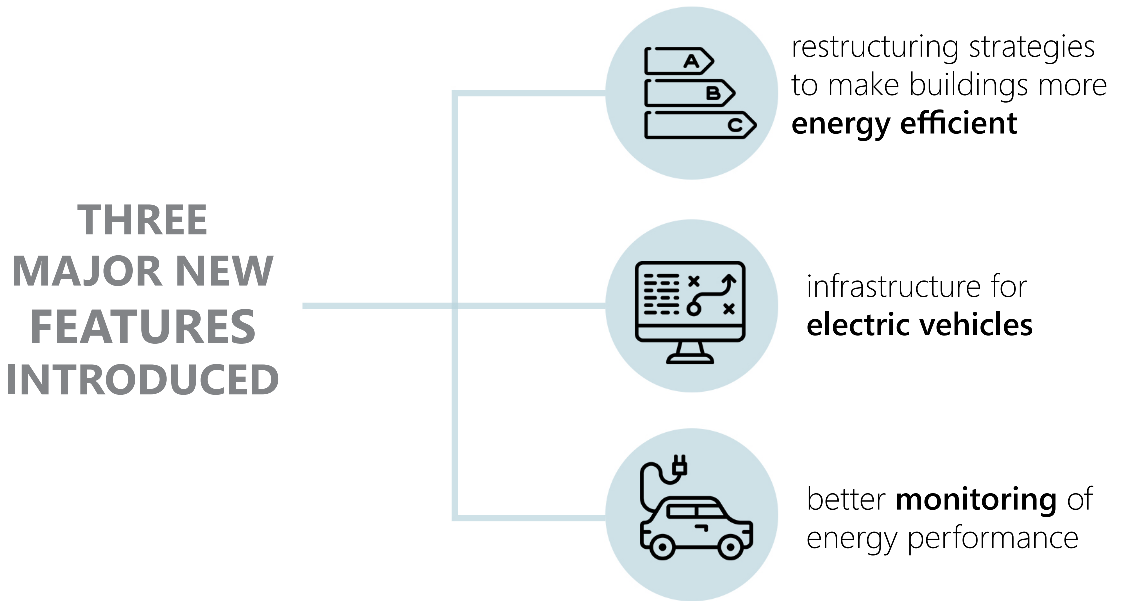


Figure 1. Schematic representation of the major innovations introduced in the Directive (EU) 2018/844.

- support for the development of e-mobility infrastructures in building car parks;
- greater transparency in the procedures for calculating energy efficiency;
- an advancement in building automation through the insertion of devices in everyday life that, for example, are able to control the temperature inside a room.

By introducing long-term strategies, the Directive try to ensure that public funds are actually used and to encourage an active action it creates some requests to Member States. They must aim to have a heritage of buildings decarbonized by 2050, to prepare for an effective transformation of existing buildings into nearly zero energy buildings, but above all they must set indicative milestones to be verified in 2030, 2040 and 2050 [16].

The issue of electro mobility is addressed through the submission of information on the number of car parks according to the type of building: a minimum number of charging points must be placed in all non-residential buildings that have more than 20 car parks by 2025, at least one for every 10 car parks in both new and renovated. Another indication concerns

the simplification of charging points and the provision of economic exemptions for those who will embrace these innovations.

A further recommendation of the Directive is the adoption of building control and automation systems as well as the use of self-regulating devices. This is because, if it is economically feasible in large non-residential buildings, automation and control systems should be in place by 2025 when the effective rated power of 290 kW for combined heating or heating and ventilation systems is exceeded. Another case for which the directive recommends the inclusion of self-regulating devices, to independently control the temperature in a room, is that in which the cost of introducing the device is less than 10% of the total costs incurred for the inclusion of all heat generators replaced.

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" [3].
This means that automation and control systems are a set of elements both concrete (real physical products) and abstract (engineering software) that through their presence are able to contribute to a better success of actions related to energy, economic or security.

Based on how it is defined and explained in the document of the new Directive, a building control and automation system is able to:
- constantly monitor the system allowing the saving and comparison of data to improve the use of energy;
- compare the energy efficiency of multiple buildings, identifying any leaks or system failures and alerting a technician responsible for improving the situation;
- allow communication between the connected technical systems and other devices present in the buildings, but also with technical systems of different membership.

So, these tools help the building's plant system to get closer to having an automatic control and easy monitoring of the system itself. The monitoring and control system must be able to continuously monitor energy consumption data and then analyse it at a later stage. Through

this data it should also be able to detect faults and make comparisons with other systems belonging to the building itself, but also to different buildings.
The EPBD directive does not give many concrete examples of what can be the control and automation systems of a building, in fact it only talks about possible devices that are able to regulate the indoor air temperature and sensors for monitoring the indoor air quality. [3]

2.2 Subjects and instruments

The protagonists of this revolution are the Member States. Each of them will have to find its own retrofit strategy to achieve greater energy efficiency, but also to decarbonize the building stock by 2050. The same retrofit strategy could also be used to improve the security in case of fire or earthquake.

The Member States therefore have a role to play in better defining the guidelines laid down in the Directive. In order to facilitate the implementation of certain necessary retrofit strategies, they will need to draw up a work plan and financing programmes for both new and existing buildings. In order to carry out these programs in the most efficient way, it is necessary to have the technical and theoretical preparation of experienced personnel in the field of construction and energy [1].

Figure 2. Graphical represantion of the 3 main instrument to achieve Member States objectives.

However, three instruments are introduced into the Directive, which can help the Member States in their work, which are:
- the trigger point;
- the one – stop – shop;
- the building renovation passport.

Trigger points can be defined as glimmers of opportunity, certain periods in the life of the building in which it is most appropriate to make interventions. It would therefore be useful to be able to understand the right time to make a deep transformation and the type of intervention to be taken. The aim is to transform reftrofit measures into investments for life. The interventions, in fact, will not deal with the resolution of a single specific problem, but with the identification and resolution of other common problems. All these measures are also aimed at improving energy performance.
The second instrument introduced is the one – stop – shop defined as a sort of information center where people can better understand how retrofit measures and financial tools run. [3]

The attempt to digitise the energy system through the integration of, for example, renewable energies or smart grids allows a transformation at the energy level. This notion has direct connections and consequences on the building landscape that tries to digitize through the attempt to transform buildings into intelligent and connected structures.

These transformations would allow significant energy savings for users by giving them precise information on the trend of their consumption and also allowing technicians to better manage the system by having more data about it. It is therefore necessary to make users aware of the concrete benefits that can be obtained with smart-ready systems and digital solutions, but above all to encourage them by means of economic facilitations in order to obtain greater feedback from them.

The introduction of these techniques can also be of great help in order to better monitor large systems by avoiding continuous on-site inspections. The reflections of these new technologies would affect both consumers and owners through considerable energy savings. [4]

Returning to the tools introduced in the directive mentioned above, the third, the building renovation passport, is defined as a personalized document dedicated to the building that allows the definition of some information about an hypothetical retrofit. In this document it is possible to find details on how can be made a deep retrofit and the stages in which it can be done, but also the duration in years that it may take (for example 15-20 years) [3].

2.3 Art. 8 of the new Directive

The great innovation of this directive, however, is found in Article 8, which talks about a new indicator that can describe the smart readiness of a building, but also about the inclusion of charging points for electric vehicles.

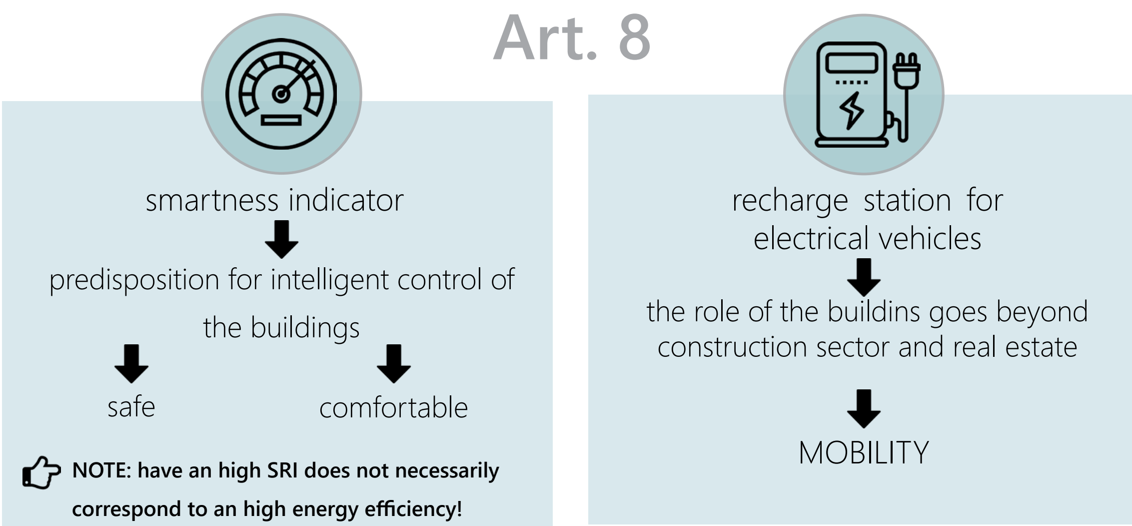


Figure 3. Schematic representation of the major innovations introduced in Art. 8 of the Directive (EU) 2018/844.

The proposed indicator is a real innovation as it not only concerns energy efficiency, but it also touches on aspects related to comfort and safety inside a building. A good indicator result is not directly proportional to the energy performance of the systems and therefore does not ensure high energy efficiency. The indicator will be synonymous with the intelligence of the building, but if, for example, it is poorly insulated it cannot be, however intelligent, energy efficient and comfortable.

The Directive's intention to extend the subject of energy efficiency beyond the building sector is also interesting, introducing also in the mobility area, which still has a strong impact on the global energy aspects.

"The smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The smart readiness indicator should raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and should give confidence to occupants about the actual savings of those new enhanced-functionalities."

The indicator introduced by the Directive is called Smart Readiness Indicator (SRI) and it is defined as a way to measure how well a building can adapt to the needs of its occupants and the grid while improving its energy efficiency and performance.
However, it is also specified that deciding to adopt this indicator is an optional procedure for Member States.

The Directive also refers to the hypothetical calculation methodology that should be followed to obtain the indicator. The procedures to be followed are not directly specified, but directives to be used in the definition of the calculation are explained. The methodology must in fact include a whole series of parameters both individually and allowing communication between them. Some features that must be included are related to building automation and the control of the system: devices able to allow the regulation of the indoor temperature, smart meters, infrastructures for the electrical vehicle charging and the possibility to store the renewable energies produced. All this without, of course, losing sight of the objectives regarding energy efficiency, the improvement of indoor climatic conditions and the performance of the system.

The methodology should refer in particular to three key features present in the building. The first refers to his ability to use renewable energy sources to support energy consumption. The second point is the ability that the building should have to adapt to the needs of the user by creating ideal conditions of internal comfort and allowing him to monitor consumption. Finally, the flexibility that the building can have in the need for electricity by participating both actively and passively in the demand.

As specified in the ANNEX IA of the Directive (UE) 2018/844, the calculation methodology should result in a clear and easy-to-read value for all stakeholders involved in the construction landscape. The important thing is that there is a common agreement of the European

Union to evaluate how much a building is ready through a well-defined indicator and a shared methodology for calculating this. [3]

2.4 Improvements

The revision of this document (EPBD) has been essential in order to improve on some of the aspects and topics already discussed, but also to introduce new ones.

"The EPBD review represents an opportunity to better define the smartness concept, reinforce conditions applicable to BEMS, further promote building automation and use of website platforms and apps, and foresee the introduction of standards to ensure interoperability."

From the previous quotation it can be deduced that this new Directive focuses more attention on aspects related to building automation and the use of technological-informatics systems, recognizing them as a valuable aid in achieving greater energy efficiency of buildings. Paragraph 15 specifies indeed that the building's energy consumption and performance do not depend only on its envelope. It is clear that over the years the envelope aspect has been extended and there has been considerable progress on it. For this reason it is now necessary to focus all the energies on another area in order to try to achieve the various objectives set. The topic of automation would be one of the areas to be explored through the installation of devices that can provide useful information about the building and facilitate its control. The installation of intelligent devices, sensors and control devices would help to carry out different actions on the internal spaces, from the control of the internal air temperature to the connection of these with the external networks. This could provide more specific data on energy consumption and in general on the working of the system. [1]

2.5 Comparison between the two Directives: 2010/31/EU and (UE) 2018/844

The new Directive amends and implements the previous one issued, some years ago, in 2010. The most recent considers the building as an element capable of being part of a process that aims to meet the needs of consumers and the environment. In the past, however, the only objective was to create an entity that would have certain characteristics necessary to satisfy

the energy needs.

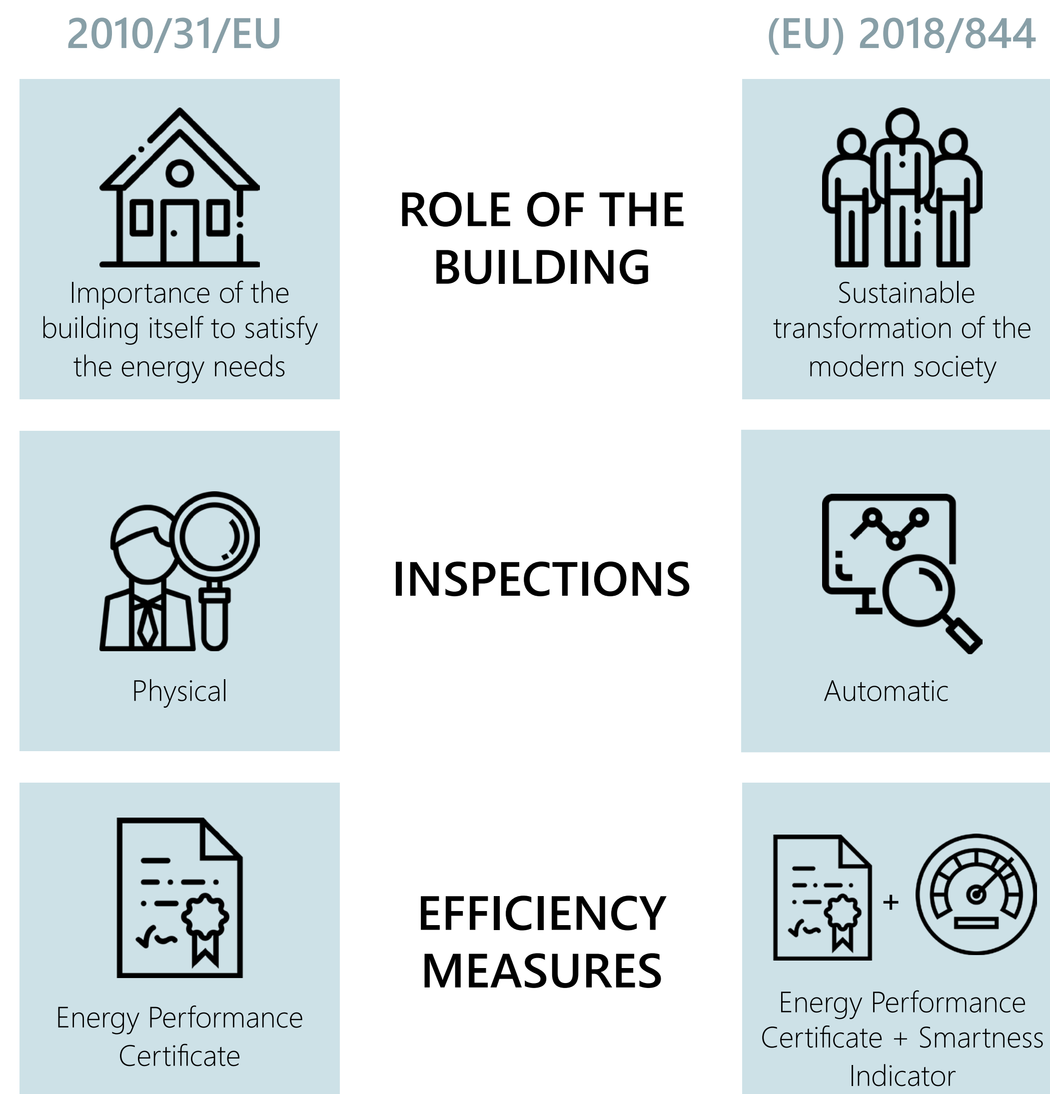


Figure 4. Scheme of the major differences between the Directive 2010/31/EU and the (EU) 2018/844.

Controlling a building has always been a practical operation to be carried out physically. Through physical inspections carried out by expert technicians, it was possible to become aware of faults and, if necessary, resolve them, trace consumption and, in general, have an overview of the values relating to the energy performance of a building. All these features can now be at the fingertips of operators who manage the operation and maintenance of a system, but also of the user who lives directly with it. The insistence in the new Directive on the desire to increase the level of building automation by allowing automatic inspections of its operation in real time, which also bring significant time savings, is therefore fundamental.

Focusing on energy performance, as we know until now, all the information related have always been declared and explained in the certified energy performance (EPC). These documents are intended to provide certain information to users and consumers when a building is to be rented or sold, such as, for example, current legal standards that allow comparisons to be made and the energy performance of the building to be assessed. Within this sheet there are also recommendations on possible actions to be taken to improve energy performance. In fact, some information that is not mandatory but can be added is specific to consumptions, how to reduce them, the cost of any intervention and the hypotetically payback periods.

Today, however, the revision of the directive introduces the Smart Readiness Indicator, previously mentioned, which proves to be a valuable complementary element to the EPC. In fact, this innovation should make stakeholders aware of the power of automation and smart devices on a future improvement in energy performance. This result would be achieved by the ability of the building, through the help of these technological introductions to adapt responding in the most immediate way to the needs of those who live there and the network. Users should gain more confidence in the real power that these innovations can have in achieving real future savings. [5] [6] [7]

2.6 Final critics

Until now, various information regarding the new Directive has been addressed: objectives, innovations, definitions and hopes for the future, and it seems that this document has touched most of the research areas that are fundamental to achieving the goals set by the European community in terms of energy efficiency and reduction of consumption and emissions of harmful gases. But is it actually so complete and specific? Can it give an unequivocal definition of the topics covered?

With a deep reading we can say that there are some gaps in the definition of some aspects or in the development of others.

The most frequently encountered criticisms relate to:

- the role of the occupant, which is not well defined within this strategy of transformation designed for buildings. Will it play an active or passive role?
- the definition of the automation grades at which the building can aspire, perhaps divided according to the characteristics it may or may not have;
- the illustration of a number of examples of what is defined a self-regulation device;
- an unequivocal definition of smartness, a concept that has been cited many times, but never explicitly described;
- a definition of a smart building and the characteristics it should have in order to be smart;
- the lack of a calculation methodology for obtaining the value of SRI, in fact there are only guidelines and requirements to be complied with.
-

In the next chapters the aim is to remedy these shortcomings found in the new directive through a deep bibliographic research. In fact, the goal will be to define the missing aspects by finding answers in other documents to ensure that we can have a complete picture of the energy, economic and innovation landscape in the building sector.

3
Review of the current definitions and interpretations of the concept of smartness

Nowadays, the concept of smartness is beginning to be part of the everyday language of most of the actors in the construction world. It is also addressed in the revision of the EPBD 2018. However, in this content, no univocal definition of the concept is given. In fact, the text could be freely red and interpreted by the readers obtaining hypothetical misunderstandings and different opinions.

The word smart changes its meaning over time and is attributed to different contexts and elements such as "city". In 2006 and 2008, respectively, according to Shapiro and Hollands *"Smarter cities start from the human capital side, rather than blindly believing that ICT can automatically create a smart city"*. A year later Giffinger, Fertner, Kramar Meijers, & Pichler-Milanović define the smart city as *"...a well performing city built on the "smart" combination of endowments and activities of self-decisive, independent and aware citizens"*. In both definitions, the man or the citizen, in the second case, is placed at the centre of this revolution or is considered the principle of transformation when it is aware of the possible advantages and improvements.

A few years later, in 2011, the human figure was merged with new technologies to achieve this innovative vision: *"City tends to be smart when investments in human and social capital and traditional (transport) and modern (ICT) infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."* Subsequently, this definition is integrated with new interesting references for the development of cities and in general for all the things that can become smart over time such as sustainability and security and about this Sansaverino, Vaccaro and Zizzo express themselves as *"The word "smart" includes various features as technological and inter-connected, but also sustainable, comfortable, attractive, safe"*. In the same year for Angelidou *"Smart cities represent a conceptual urban development model based on the utilization of human, collective, and technological capital for the enhancement of development and prosperity in urban agglomerations"*. This definition therefore confirms the importance of collaboration between human and technological resources, which becomes the key combination for the success of this evolution. As Anttiroiko states, having a smarter city could also intervene in the improvement of the local economic and political field. This it would lead to the creation of additional services for citizens thanks to the support of new technologies influencing the whole society [8].

Nowadays, talking about smartness in an architectural context and therefore referring to buildings is defined as *"...the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems or the external environment (including energy grids) and to demands from building occupants"*. [9]

The meaning of smartness can belong to two different interpretations. The first relates the concept only and exclusively to mobile devices without taking into account the environment and its consequences, while the second introduces the concept of community, giving importance to the improvement of well-being and quality of life within it. At this rate, the word smart begins to incorporate inside more aspects no longer related only to innovative technologies, but, for example, also to sustainability, safety and comfort.

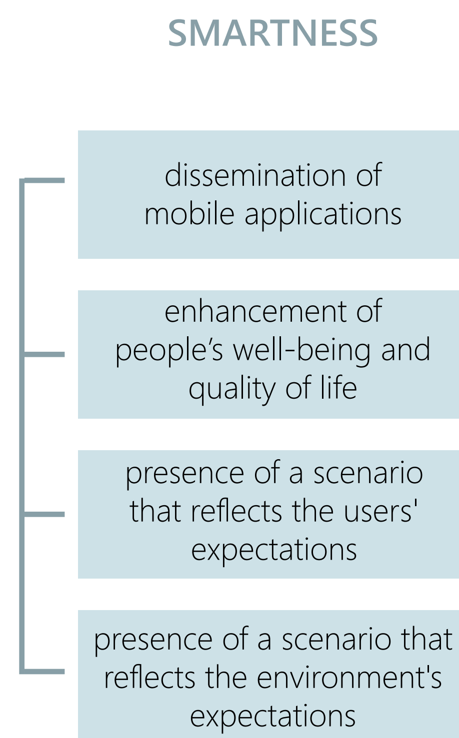


Figure 5. Scheme of the 4 main interpretations of smartness.

The user perceives smartness as something that is easy to use and sustain during the time, healthy and accessible for everyone, that brings improvements both for the environment and for an economic return over time, but above all that is useful. The perception of the environment instead considers this concept with a view to obtaining a phenomenon that adapts to the local climate and does not create harmful gas emissions, that is sustainable, renewable and respects the local characteristics. The thing that accumulates these two points of view is the "green" part of the concept of smartness, the idea that a smart city or building is healthy for both the environment and man. [10]

2.6 Smart building role

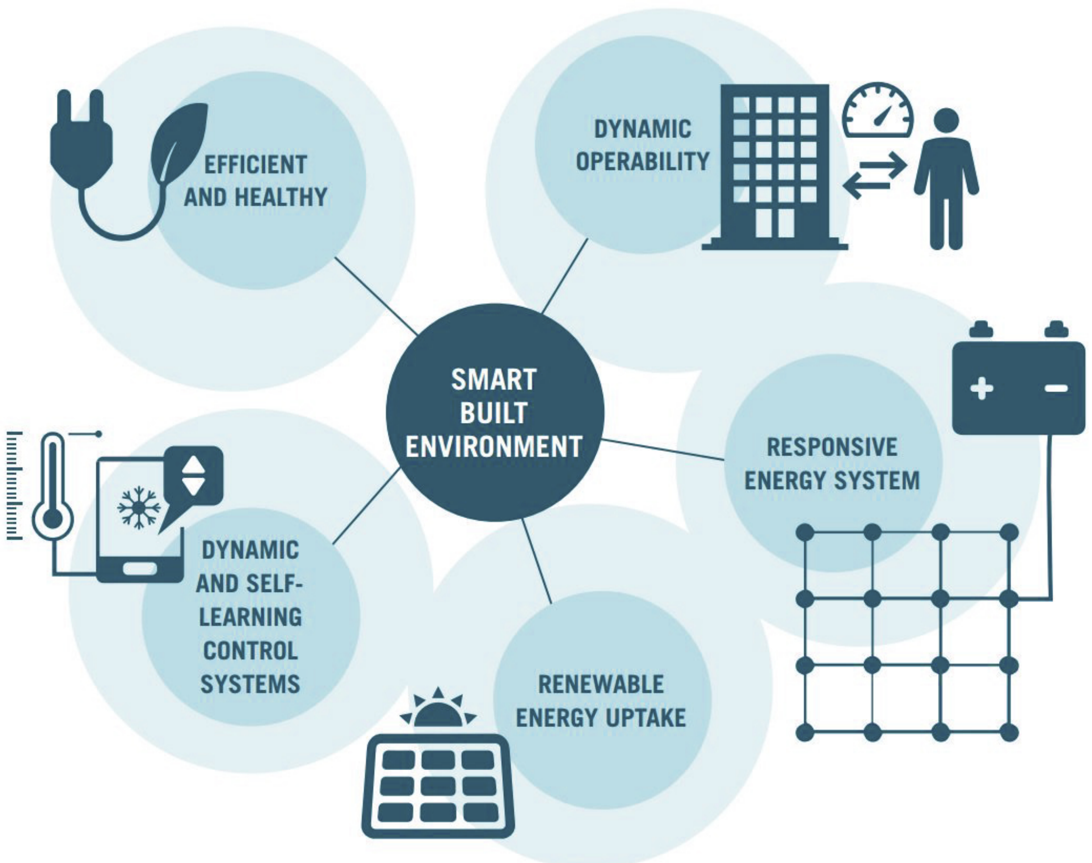


Figure 6. Buildings importance in the definition of a smart built environment. [11]

Nowadays the energy market needs a major transformation in which the role of the building could be relevant and active. Transforming a building into a smart building would enable Europe to create an energy sector that uses renewable, decentralised and interconnected resources and achieve greater efficiency by abandoning an old centralised system based on fossil fuel consumption. This process of improvement would also upgrade the indoor living conditions and working environment of users,
factors that, for example, influence absenteeism and productivity in the workplace. Ensuring a reasonable IEQ is essential to be able to fulfil the initial function established for the building. [22]

Making some improvements to buildings can become the key to a marked increase in energy efficiency. The strategy is to enclose:

- energy storage systems;
- in-situ renewable electricity production;
- and ensure the building's ability to regulate itself according to demand and response from outside.

All these innovations go against the previous conception where the building was seen only as an energy consumer. [11]

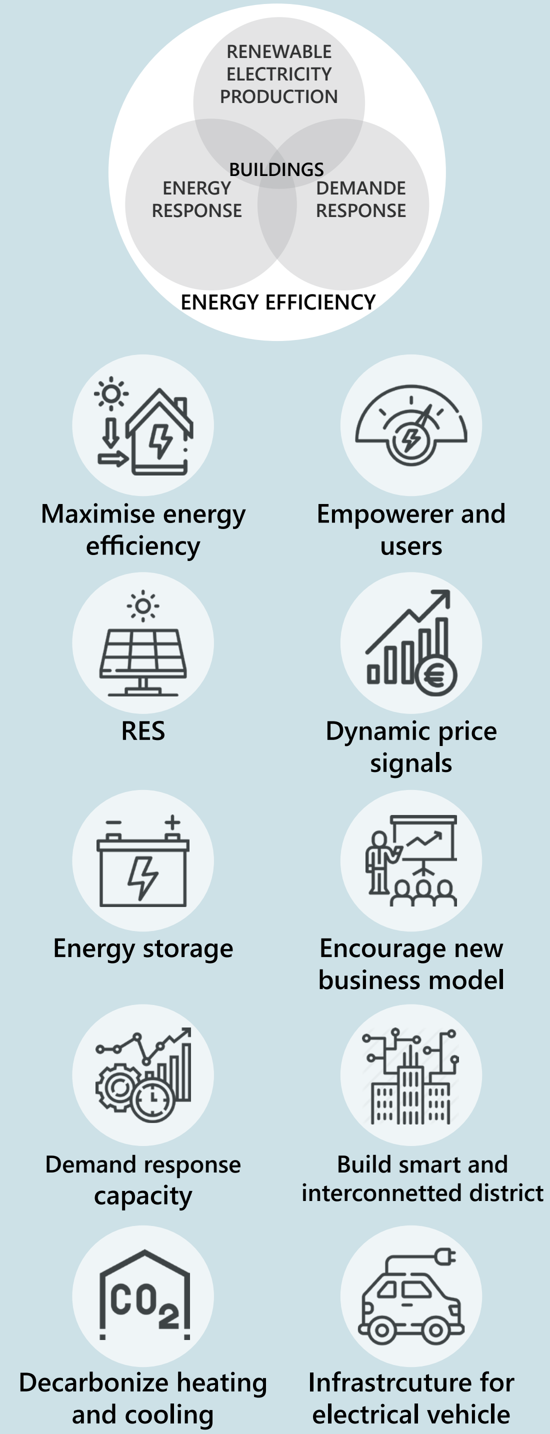


Figure 7. Up: relation between energy efficiency and building flexibility. Down: 10 principles of buildings that work as micro energy-hubs. [4]

A smart building allows his constant monitoring, obtaining essential information to ensure that it best meets the needs of those who occupy it and increasing its energy performance. It is also important his readiness to interfere with electric vehicles. [12]

It is well known that 40% of total energy consumption is due to low energy efficiency buildings. That is also why the 2010 EPBD Directive introduced a requirement for all new buildings to be nZEB at least, so that their energy consumption was very close to zero. The future outlook is for the entire building sector to be transformed into nZEB, which would have a major impact on the entire energy sector. This type of building would allow a reduction in GHG (Greenhouse Gases), a decrease in the value of energy bills as well as a marked improvement in the living conditions of different types of users.

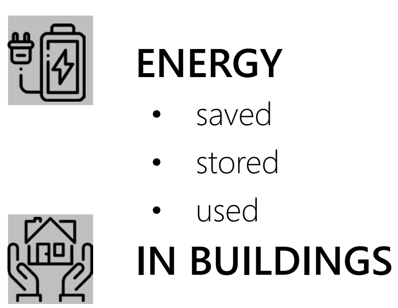


Figure 8. How to treat energy in buldings.

The goal is therefore to make buildings connected to the energy structure, making sure that they are able to produce, store and use energy efficiently. The effect of this action is amplified when as many buildings as possible are involved.

The BPIE (European Institute for Building Performance) has created a document listing 10 useful principles to be followed, individually or in their entirety, to maintain a more effective result, to enable a building to play a key role in the transformation described above. The principles are: increasing the energy efficiency of buildings, increasing the production of renewable energy, ensuring that the building can store the energy produced, improving the response to demand and response, decarbonizing the heating and cooling system, giving greater prominence to end users, having a real update of the variation in prices, encourage investment, build interconnected neighbourhoods and create useful infrastructure for electric vehicles (Figure 7). Once the analysis has been completed in relation to the innovations expected and introduced by the new Directive, it is important for this thesis to examine in depth the role played by the building in the broader definition of this concept and, secondly, the role played by the occupant of the building itself. The building is beginning to be seen as a necessary element to be able to have an upgrade in all areas involved. Firstly, it contributes to the creation of various benefits for the citizens of the European Union, which can be the reduction of energy bills, the formation of new jobs and the construction of more comfortable homes. At the same time, the new building will also be able to make more balanced use of energy flows.

As previously mentioned, the user also enjoys a new role in this progressive transformation of the building through the introduction of technological controls and smart applications. The inclusion of smart meters inside a building allows the user to have a greater awareness and greater control of their energy system and through these devices it can also have a constant measurement of energy consumption that improves the interaction between demand and response. The introduction of these devices aims at reducing energy consumption and creating intelligent links between the different buildings involved, the users and the relevant energy sphere. In fact, the user is able to control his energy consumption according to his preferences and the signals transmitted from outside. The combination and collaboration between constant monitoring and the presence of new technologies allows to obtain relevant results for different figures, professional and not. The collected data allow to know the behaviour of the user who lives inside the building and therefore to have a constant monitoring on its consumption, but also reports about technical defects, failures or elements that need maintenance. Allowing the user to have this technical information in a clear and transparent way will also increase his awareness.

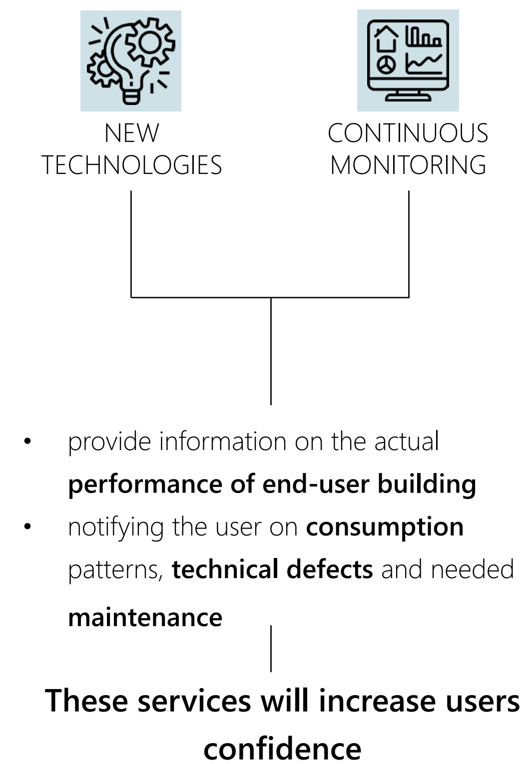


Figure 9. Concequences of the introduction of new technologies and continuos monitoring in the buildings.

Entrusting users with this responsibility and possibility to control the energy consumption of their buildings, will bring them to long-term invest in intelligent and cost-effective solutions. To affirm the idea of buildings that become key elements for an energy transformation they should create great improvements also at the social level. A conscious occupier can simultaneously, thanks to an intellectual maturity, control the production of energy in situ, but also domestic consumption, significantly reduces bills and contributes to the development of a culture in which electric vehicles are the most advanced means of transport . Informing inhabitants about their building and the improvements that can be achieved through constant monitoring and data collection, allows them to enlarge their view of the energy system, under transformation, up to the scale of interconnected neighbourhoods and then smart cities. [4]

2.6 Methodologies to evaluate the smartness

Having intelligent buildings will bring many benefits. Users will be able to know in real time information on the use of energy and explain their needs towards the building for a comfortable lifestyle. This will allow a conscious use of energy, increasingly produced through renewable sources, which follows the requests issued by the building without having waste.

Having an intelligent control of the building also allows a better supervision of the aspects related to the maintenance and repair of this. In order to evaluate all these characteristics that a building can have, it is necessary to introduce an indicator that meets the requirements summarised in the following quotation.

"A smartness indicator will reflect the ability of buildings to:

- *adjust to the needs of the user and empower building occupants providing information on operational energy consumption*
- *ensure efficient and comfortable building operation, signal when systems need maintenance or repair*
- *readiness of the building to participate charge electric vehicles and host energy storage systems."* [13]

Being able to define the level of smartness by means of an indicator is not only a priority at the scale of the building. As we find explained in the study conducted by Dall'O, Bruni, Panza, Sarto and Khayatian also at the scale of the city (small or medium sized), is necessary to be able to assess the index of achievable smartness. Even in cities, by improving smartness, we can obtain progress in the field of energy and environmental sustainability, as well as necessary progress in the technological range.

The methodology considered in this case wants to define the level of smartness of each category and then put them together to realize a single final value. Seven categories are considered in all: smart economy, smart energy, smart environment, smart governance, smart living, smart people and smart mobility (Figure 10). Being able to consider them individually, in an initial analysis, allows to go and act on the lacking areas.

Smart index categories

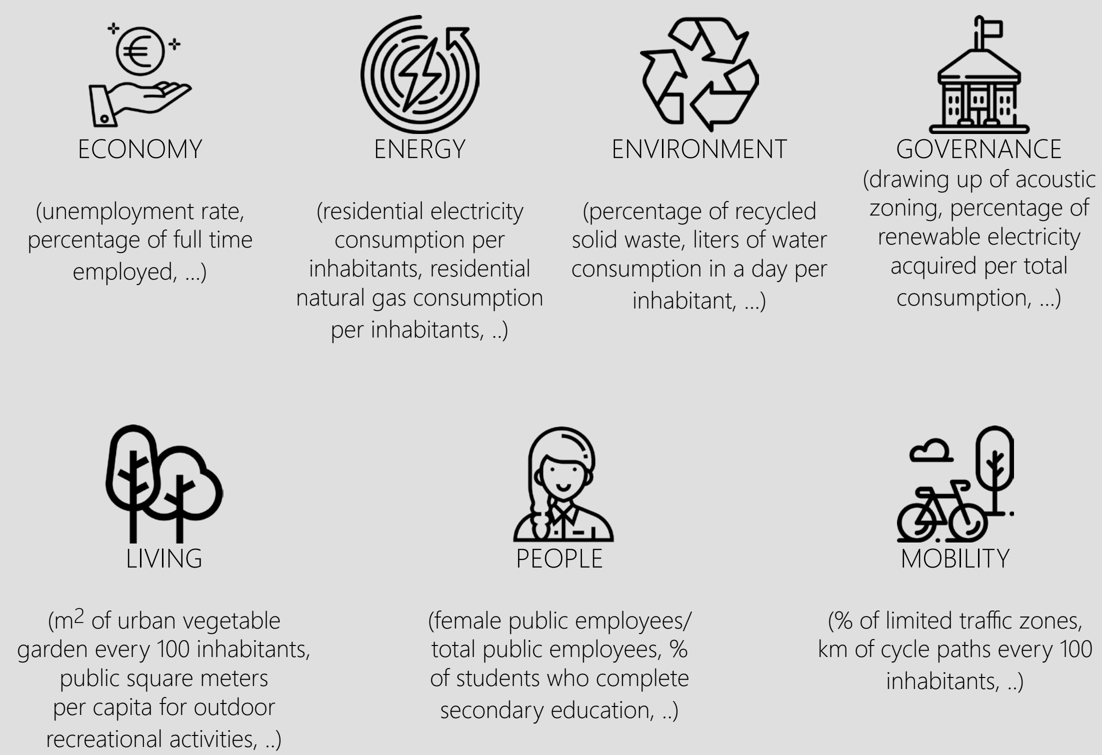


Figure 10. Categories for the evaluation of smart cities and some of the parametres present in each category.

After reading and studying different articles dealing with smartness and smartness indicators (Tables 1 and 2), it was possible to identify different types of indicators present until now and methods for calculating them.

The main smartness indicators identified are:

- energy class;
- SRI;
- related to the n' of gadgets;
- related to the n' of systems that contribute to the internal comfort;
- related to the n' of technical items controlled by BEMS (building energy management system).

Title	Contents	Year
Assessing the smartness	Smartness indicator defined by a survey made by professionals (domains and subdomains)	2014
Evaluation of cities' smartness by means of indicators for small and medium cities and communities: A methodology for Northern Italy	Indicator by a normalization value through the minimum-maximum method on a scale of values from 0 to 10	2017
Evaluation of Sustainability Indicators in Smart Cities for India Using MCDM Approach	Criterias analysed by fuzzy method	2017

Table 1. Scientific article related to smartness indicators

Title	Contents	Year
Assessing the smartness of buildings	Review and methodology	2014
Smart home energy management systems: Concept, configurations, and scheduling strategies	Smart HEMS	2016
Evaluation of cities' smartness by means of indicators for small and medium cities and communities: A methodology for Northern Italy	Review, smart city and indicators related to dimension	2017
Smart mobility in Italian metropolitan cities: A comparative analysis through indicators and actions	Review, smart city and mobility	2018
Using urban environmental policy data to understand the domains of smartness: An analysis of spatial autocorrelation for all the Italian chief towns	Smartness and smart city	2018
Functionality between the size and indicators of smart cities: A research challenge with policy implications	Smartness and review of smart cities	2018

Table 2. Scientific article related to definition of smartness

These kinds of indicators can be calculated with different methodologies: 4 have been identified.

- Survey for professionals: collections of questions to be answered by experienced technicians and professionals. The average of the responses obtained leads to a final value.
- Check list approach: list of elements, systems and functions whose presence must be verified. The more points there are, the better the result will be.
- Indicators to be calculated: this category provides obtaining a numerical or percentage value through mathematical processes and formulas.
- Score assessment: selected people will have to assign scores to certain items or categories in a document or list. Imagine A

In these first two chapters the research dealt with the new EPBD, the objectives it imposes, but also the innovative concepts that it introduces. One of these is the "Smart Readiness Indicator" mentioned in the article 8, which is inserted in order to measure the intelligence of a building in the future. Subsequently it was defined what was meant by smartness and which are now the indicators or systems on the market able to indicate the level of smartness. The next chapter will treats the indicator proposed by the directive, in particular will analyse the first calculation methodology proposed by the European Union to define the value of this indicator for a building.

4

The Smart Readiness Indicator

4.1 Smart technologies

The construction sector in Europe should invest in building renovations to achieve energy improvements, but it should also integrate ICT solutions that make the building smart and allow it the possibility to check the recorded data about the different performance. With the introduction of these devices and these technologies, the building recovers points in terms of energy, but also becomes more comfortable and healthier allowing a better use of space by the occupants. The inclusion of intelligent technologies will allow the building to relate both to its inhabitants and to the external network. Today, the role of the building becomes crucial for this transformation, which should reduce the energy consumption, reduce the carbon production and should increase the availability of renewable energy.

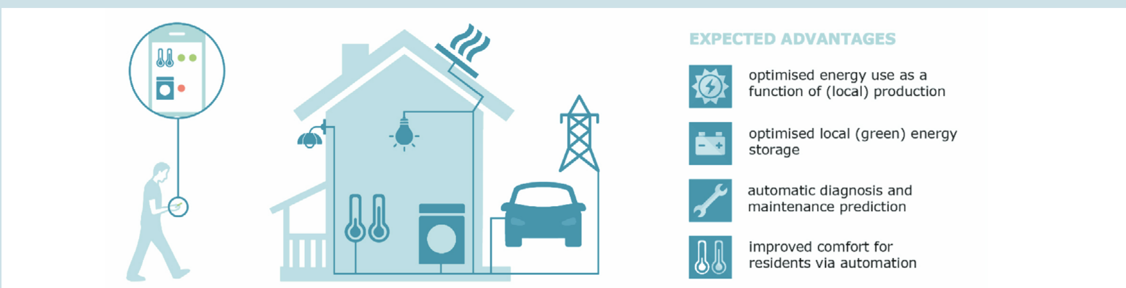


Figure 11. Expected advantages after the introduction of smart technologies in buildings. [9]

The EPBD underlines the need to introduce smart technologies into the buildings but also to try to define the readiness of a building in being smart through the Smart Readiness Indicator (SRI). With this indicator it should be made more explicit the importance of having smart devices inside a building to a greater number of stakeholders (occupants, technicians, owners, etc.). It is appropriate that those who will invest in the introduction of these innovations is aware and well informed [15].

4.2 The definition

"A Smart Readiness Indicator (SRI) for buildings shall thus provide information on the technological readiness of buildings to interact with their occupants and the energy grids, and their capabilities for more efficient operation and better performance through ICT technologies."

Figure 12. Summary of the three main readinesses that the buildings could achieve through the introduction of ICT technologies. [9]

This indicator allows to find a common language between different buildings to evaluate and compare them within the construction market considering both intelligent and low-performing services. These multiple motivations can contribute to the affirmation of technologies and smart devices inside buildings. The aggregation of VITO, Waide Strategic Efficiency, Ecofys and OFFIS was responsible for the study completed in August 2018. Online it is possible to find the final report in which they are summarized and illustrated the main points achieved by the project.

The outcome of the study is a methodology that meets a number of requirements and touches on several points. In fact, the result of the indicator must be a clear method of communication for all actors in the building sector of some features of the building. It should be relevant in achieving the objectives proposed by the EPBD 2018, because it is related to several important issues such as energy resources, health or consumer safety, and it should provide information in order to encourage investments with positive consequences. In addition, the assessment of the indicator must strike a balance between being detailed and having limited costs and duration. The calculation can be carried out by different figures, both specialized technicians and simply the owners of the building in question thanks to the flexibility of the methodology that the study is committed to ensure. [9]

4.2 Why it is introduced?

The introduction of this indicator through the new EPBD Directive born from the desire to assess how much buildings are able to use recorded data and technological systems to transform themselves and meet the needs of the occupants and the network. In this way they could achieve a marked improvement in their performance, in particular in energy efficiency field. This number should have a great responsibility, which is to increase the transparency of the value of the automated and automatically monitored building in the eyes of both the owner and the occupant. The occupants will be able, through the introduction of advanced devices that monitor the performance of the building and record the data, to check daily savings achieved. However, the choice to adopt this type of indicator to get more information from the building remains, for now, an optional choice for Member States that can assess to implement it or not.

In general, the new EPBD Directive often deal with the concept of Building Automation and Controls (BACS), which plays an important role in achieving the smart building concept. These systems are therefore expected to create healthier spaces by reducing harmful gas emissions and energy consumption, which it will be mostly renewable, and above all to help in responding effectively to user demands. The challenge of the Directive is to align the fixed guidelines with those of the indicator in order to achieve the common objectives: the energy efficiency, the quality of the indoor environment and the regulation of demand and response. These are the final results expected for the future buildings and this indicator should be able to represent an added value in this transformation, by showing in a clear and transparent way the potential of the building, to both owners and users. [16]

4.2 Calculation methodology of the SRI launched by the European project

The first steps to be taken in the calculation methodology are:

1. the definition of the smart present services within a building. A series of services goes to compose a domain (e.g. cooling, heating, lighting, etc.)
2. the choice of the level of functionality for each service selected based on the functionalities that it offers

In the following page there is an example of a service present in the lighting domain, the "lighting control", and the different levels of functionality attributable to it.

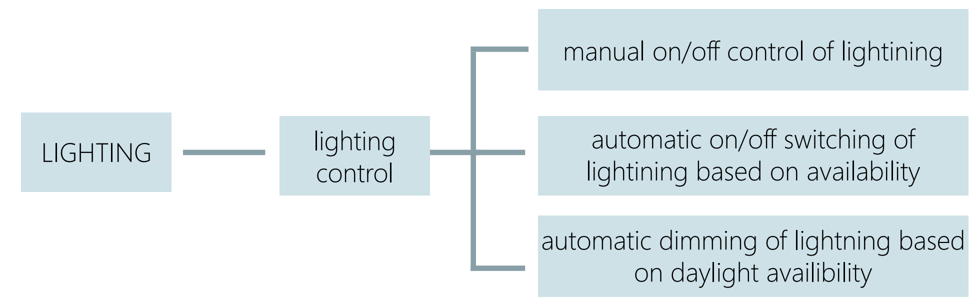


Figure 13. Example of a domain, one of its services and the relative functionality levels.

The next steps to follow are instead:

3. the evaluation of impact criteria (energy savings, comfort, information to occupants, etc.) with the assignment of scores relating to the levels of functionality chosen
4. the definition of the weighting coefficient table related to the impacts
5. the obtaining, through a mathematical operation, of a smart readiness value that brings together domains and impacts. The final result can be presented either in percentage or in energy class. It is also possible to define and read the sub-scores that indicate the percentage of smart readiness for each impact (e.g. 54% on convenience and 78% on wellbeing & health).

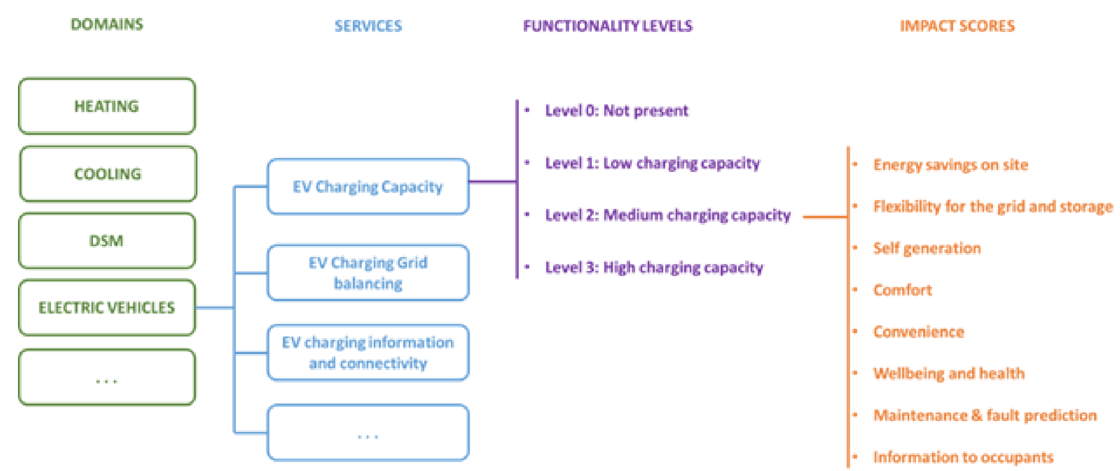


Figure 14. Schematic representation of Smart Readiness Indicator calculation methodology. [9]

If we want to resume brefly the steps needed in the calculation we can define 5 ones.

- **STEP 1**: choose which services are relevant for the building
- **STEP 2**: assess the functionality level of each relevant service
- **STEP 3**: count impact scores related to the impact criteria
- **STEP 4**: definition and application of weightings coefficient
- **STEP 5**: calculate SRI score

4.4.1 STEP 1 -Which services should be asset?

The total of the services that it can be found in the annex are totally 112 (99 if we not consider the "various").

Each one of these services belong to one of the 10 domains and also can have different functionality levels related to how much the element analysed are smart.

The domains presented in the European project for this methodology are ten.

DOMAINS

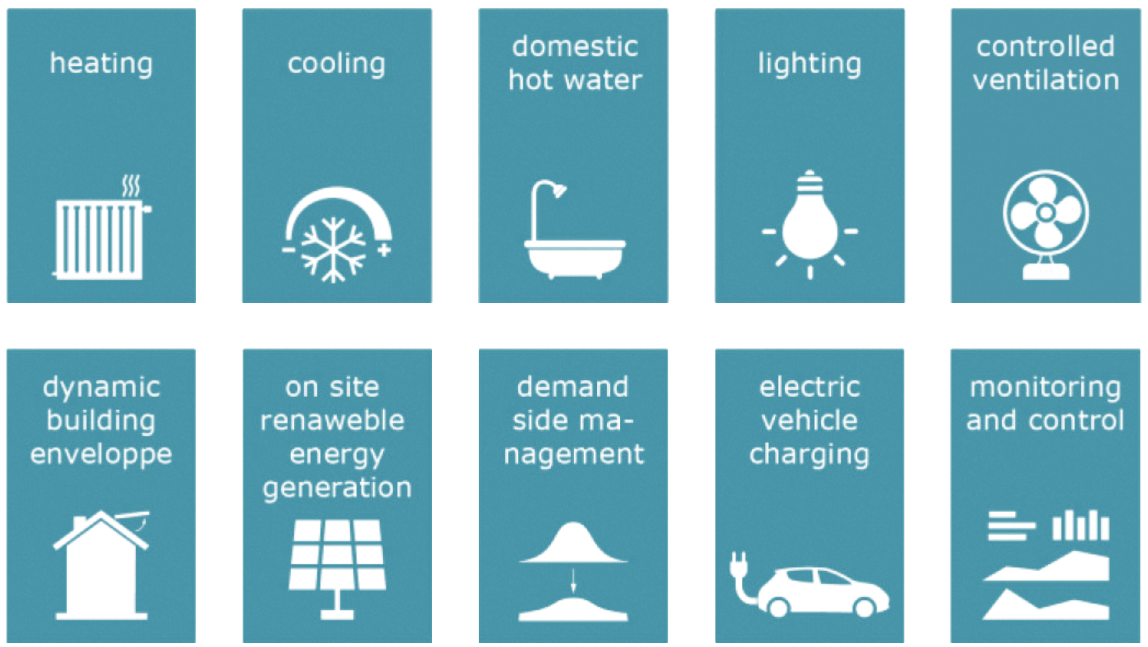


Figure 15. Domains categories considered in the calculation of SRI. [9]

Heating

This domain covers all the services that contribute to improving the performance of systems related to heating, from generation to storage and finally to use. Most of the services present refer to technical automation systems related to the heating of indoor environments.

Cooling

The domain deals with everything related to the energy used to create cooling and the devices to control it. The importance of some services depends on the final use of the space examined, the location, the climate and the occupants who use it.

Domestic Hot Water

This domain contains services that deal with the life cycle of domestic hot water within a building from generation to distribution.

Controlled Ventilation

The domain of controlled ventilation deals with services that relate to the internal temperature of an environment and the flow of air within it. The introduction of automatic systems can be very useful to detect parameters in real time and use them to improve indoor comfort and indoor air quality.

Lighting

In this domain, the services deal with automated lighting according to timetables or detection of people.

Dynamic Building Envelope

This domain deals with the control systems related to the mobile part of the envelope, that is the systems related to the shading and opening of the glass parts. An improvement of these aspects would lead to a real saving on the energy used for heating or cooling, but would also have a positive impact on the comfort of users, both visual and thermal.

Renewable Energy Generation on site

In this domain it is possible to find the services that regulate the mechanism of power generation on site. The steps to be managed are related not only to production, but also to storage and then distribution to the connected grid.

Demand Side Management

The domain has services related to the control of energy demand as a response to requests from the network. It therefore deals with demand management by electricity networks and how they are managed in a more or less smart way.

Electric Vehicle Charging

This domain assesses services related to electric vehicles such as charging points and their functionalities. Storage and consumption capacities are also analysed.

Monitoring and Control

The last domain has services that focus on the characteristics of any sensors present such as the one that detects the occupation. This can have a number of consequences for heating and ventilation, for example.

Various

In this domain there are services that are not directly related to any of the previous domains, but instead are related to themes, such as security, that do not depend on the technical building system. [9,15,17]

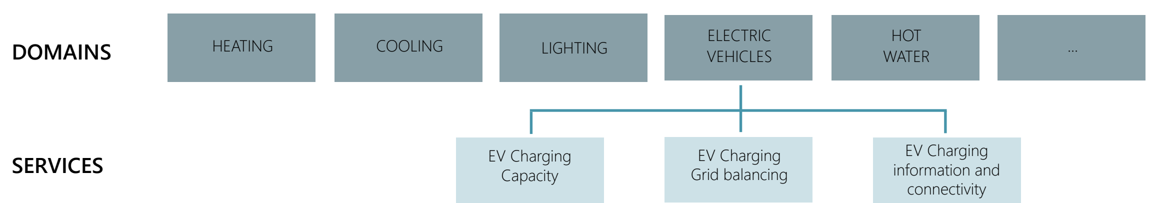


Figure 16. Scheme of some domains and an example of the services included. [9]

The number of the services that would be considered for the evaluation depends from the type of building that we choose for the application of the indicator.

The process in wich it selected the maximum number of services is called "triage". If it considered, for example, a single family house the maximum number of services that must be examined is 49, because maybe some domains and their relative services are not relevant. Obviously, if a less number of services it considered the inspection will need less time to be done but also the value of "maximum obtainable score" will be lower even if one of the factors most highlighted in the methodology is the time needed for the procedure, which in the calculation phase differs very much from the expectation of the document. Anyone intends to perform this calculation, will need to analyze well the installations and the present systems in the building because the descriptions supplied to choose the functionality levels are very specific and to answer

correctly it is needed to know well the system that is valued in the specific service or to read the relative technical card.

Domain	Smart ready service
Heating	Heat emission control
Heating	Report information regarding HEATING system performance
Domestic hot water	Control of DHW storage charging (using hot water generation)
Domestic hot water	Control of DHW circulation pump
Cooling	Control of distribution network chilled water temperature (supply or return)
Cooling	Sequencing of different cooling generators
Controlled ventilation	Supply air flow control at the room level
Controlled ventilation	Heat recovery control: prevention of overheating
Lighting	Occupancy control for indoor lighting
Lighting	Control artificial lighting power based on daylight levels

Domain	Smart ready service
Dynamic building envelope	Window solar shading contro
Dynamic building envelope	Window open/closed control, combined with HVAC system
Energy generation	Amount of on-site renewable energy generation
Energy generation	Optimizing self-consumption of locally generated energy
Demand side management	Services for integrating battery storage systems into energy portfolio
Demand side management	Smart Grid Integration
Electric vehicle charging	EV Charging Capacity
Electric vehicle charging	EV charging information and connectivity
Monitoring and control	Control of thermal exchanges
Monitoring and control	Reporting information regarding current energy consumption

Table 3 and 4. Examples of domains and services proposed in the calculation methodology

4.4.2 STEP 2 and 3 - Functionality level and related impact scores

After choosing the services to be used in the evaluation and understanding which level of functionality to assign to each one of them, based on the systems present in the building in question, we can compare the scores assigned to each level of functionality. These scores can be found in the excel file attached to the methodology proposed by the European project. In this file it is possible to find all the scores assigned to each service and for each level of functionality in relation with the impact criteria.

The total number of impact criteria shown in the document is 8 and they are related to different subjects: building, users and energy grid.

IMPACTS

Figure 17. Impact categories of the SRI calculation. [9]

Energy savings on site

Describes the influence that the chosen services can have on energy savings. Not all the energy used is considered, but the one which can be managed by smart devices.

Flexibility for the grid and storage

It refers to the impact that the services could have on a potential flexibility of the building.

Self-generation

It is related to the services that are related with renewable energy production and storage on site.

Comfort

It describes the effect that the services can have on the occupant comfort (thermal, visual and acoustic).

Convenience

It refers to the services that make the occupants life "easier" by asking for less control of the system.

Well-being and health

It is related to some positive impact that some services could provide to the well-being and health of the users.

Maintenance and fault prediction

It is referred to the positive influence that smart services which allow an automatic fault detection and diagnosis of TBS (Technical Building System) could have.

Information to occupants

It describes the impact of the services that are related to the communication of some information about the building to the users.

Each service has a functionality level that generate an impact scores that can goes from - 4 to +4.

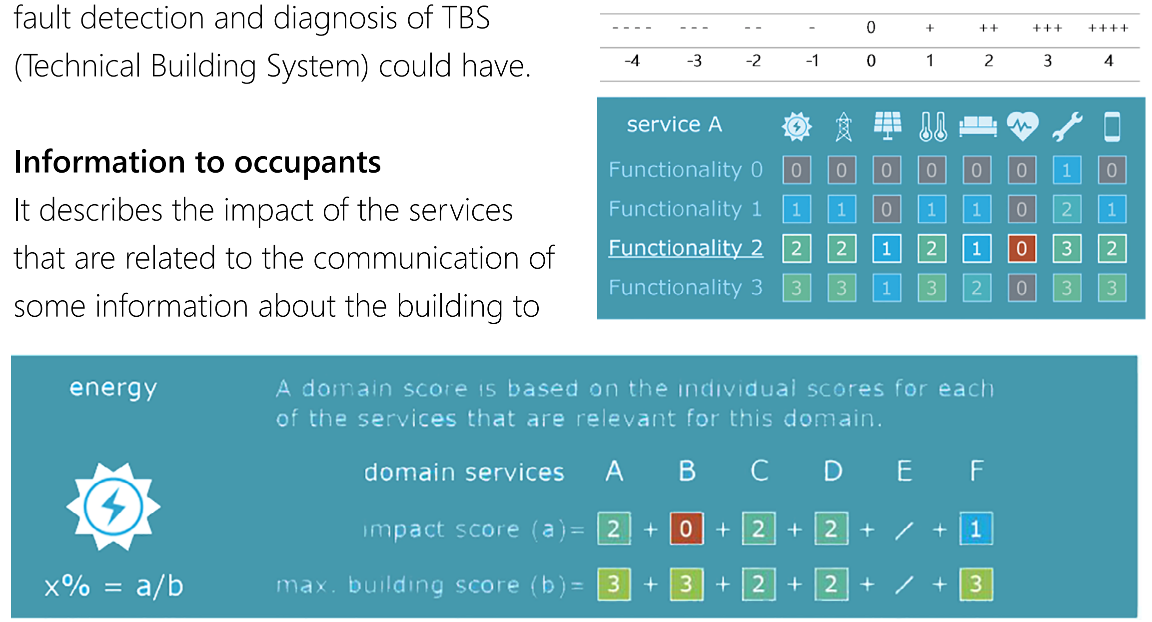


Figure 18. Up: example of the functionality levels and the relative score assigned. Down: example of the relation between the impact score and the maximum score obtainable by the building. [9]

DOMAIN SERVICE (COOLING)	IMPACT SCORE (ENERGY)	MAX. BUILDING SCORE	IMPACT SCORE	MAX. BUILDING SCORE	...
A	2	3	1	2	...
B	0	3	2	3	...
C	2	2	1	2	...
D	2	2	0	2	
E	0	2	3	3	
F	1	3	1	2	
TOT	7	15	8	14	

Domain (HEATING)

- Impact (ENERGY) % = 7/15 = 0,46*100 = 46%
- Impact (2) % = 8/14 = 0,57*100 = 57%
- ...
- Impact (8)

DOMAIN SERVICE (COOLING)	IMPACT SCORE (ENERGY)	MAX. BUILDING SCORE	IMPACT SCORE
A	2	3	...
B	0	3	...
C	3	1	...
D	2	2	...
E	1	3	
F	0	2	
TOT	8	14	

Domain (COOLING)

- Impact (ENERGY) % = 8/14 = =0,57*100 = 57%
- ...
- Impact (8)

Table 5 and 6. Examples of the application of step 3 and 4 of the calculation methodology.

$$\text{Percentage} = \frac{\text{ordinal impact score case study building}}{\text{maximum obtainable score for the case study building}}$$

	Energy	Flexibility	Self-generation	Comfort	Convenience	Wellbeing and Health	Maintenance & fault prediction	Information to occupants
Ordinal impact score case study	54	18	5	34	42	13	16	20
Maximum obtainable score for the case study	73	25	5	45	61	19	23	30
Relative score	**74%**	**72%**	**100%**	**76%**	**69%**	**68%**	**70%**	**67%**

Table 7. Example of the relation between the case study building impact scores, the maximum scores obtainable and the relative scores in percentage. [9]

4.4.3 STEP 4 - Weighting coefficient

There are no references in the European project document to the levels of importance to be assigned to the different domains in relation to the impact criteria. If a domain has little or no influence on an impact, it will have a percentage equal to or close to 0% and then the remaining percentage will be distributed among the various domains until it reaches 100%.

The allocation of the different percentages can depend on many factors such as the end use of the building, its location or the preferences of the user who lives there.

	Energy saving on site	Flexibility for the grid and storage	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Heating	49	2,5	0	40	10	10	10	7
DHW	10	2,5	0	10	10	10	10	7
Cooling	6	2,5	0	15	10	10	10	6
Controlled ventilation	7	2,5	0	10	10	10	10	6
Light	10	2,5	0	10	10	10	10	7
Dynamic building envelope	7	0	0	5	10	10	10	6
Energy generation	0	2,5	80	0	10	10	10	7
DSM	0	40	10	5	10	10	10	7
Electrical vehicle	0	40	10	0	10	10	10	7
Monitoring and control	11	5	0	5	10	10	10	40
TOT	100	100	100	100	100	100	100	100

Table 8. Example of one of the weighting coefficient table presented in the calculation methodology. [9]

4.4.4 STEP 5 - Calculation of the SRI percentage

To calculate the final value of SRI it is necessary to find the percentage related to each impact criteria and then merge them in a weighted final result.

Another way to present the value of SRI, different than the result in percentage, is according to Table 9 in which at each range of SRI values correspond a class. [9, 15,]

SRI	Class
>86%	A
>72%	B
>58%	C
>44%	D
>30%	E
>16%	F
16% or less	G

Table 9. Relation between SRI result and energy classes. [9]

4.5 A previous application method to rate the smartness: comparison with the SRI

In 2015, Arditi, Mangano and De Marco published the result of a research conducted to define an indicator that could evaluate the smartness of a building. Unlike the existing assessment methods for buildings (for example LEED and BREEAM), this index introduced in their study aims to be in relation not only with energy efficiency, but also with building living costs and user comfort.

Domains and variables	Mean scores < 20 years of experience	20-35 years of experience	> 35 years experienc
Economic issues (X)	4.27	4.11	4.00
Planning and design costs (x_1)	4.59	4.41	4.50
Construction costs (x_2)	3.62	3.75	3.18
Operation and maintenance costs (x_3)	4.19	4.32	4.09
Sustainability costs (x_4)	4.11	3.88	3.68
Energy issues (Y)	4.57	4.36	4.18
Heating system (y_1)	4.62	4.30	4.09
Cooling system (y_2)	4.73	4.41	4.23
Lighting system (y_3)	4.24	4.27	3.77
Water system (y_4)	3.78	3.63	3.05
Occupant comfort issues (Z)	4.05	3.95	3.77
Temperature (z_1)	4.35	4.29	4.05
Humidity (z_2)	3.73	3.82	3.68
Air quality (z_3)	4.16	4.11	4.36
Acoustic comfort (z_4)	3.49	3.61	3.64
Functionality (z_5)	3.92	3.98	3.64
Psychological aspects (z_6)	3.41	3.38	3.09
Security (z_7)	3.43	3.45	3.55
Fire protection (z_8)	3.81	3.93	4.05

Table 10. part of the list in wich the scores are assigned by people of different ages.

The index is given by the combination of a first assignment of values to a list of services made by a technician and weighting coefficient that are the result of a survey. This index allow the knowledge of the building smartness but also the benchmarking with the values obtained from other buildings.

As it was described before, this indicator is in many ways similar to the Smart Readiness Indicator proposed by the new EPBD, but it is possible to see in detail, in the diagram below, the two indicators compared to better understand the differences. [9,18]

SMARTNESS INDEX (2015)

- Variables defined
- Score range 1; 5
- Score range decided by a group of professionals
- Result based on average score

SMART READINESS INDICATOR (2018)

- 112 services
- Score range -4; 4
- Score range defined according to functionality level
- Result based on average percentage

5 Case study 1- Orologio Living Apartments (Torino)

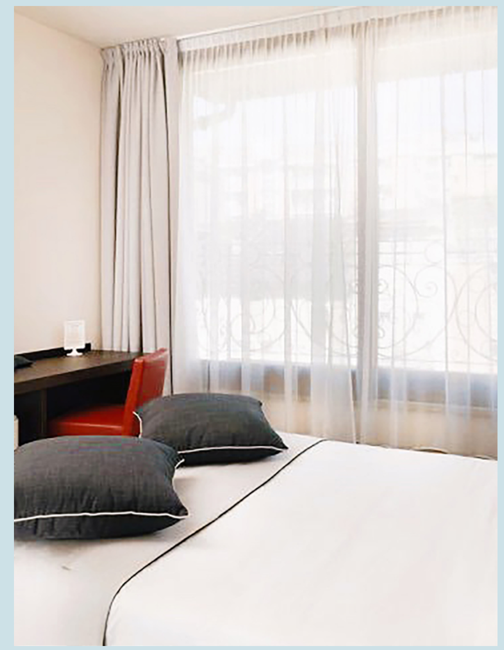



Figure 19 and 20. On the left: photo of the external facade of the hotel. On the right: an example of the interior of a room. [19, 38]

To understand if the methodology described in chapter four works to map the building and to know its characteristics, the following step was the application of it in a critical manner on a case study.
After an analysis of the building characteristics it was possible to choose the services present and start the calculation of the indicator.

5.1 Description of the building

The case study in which the calculation methodology is applied is the hotel Orologio Living Apartments located in Turin near the city centre. The building was built in the early 1900's and between 2004 and 2005 it was renovated to be used as an accommodation facility by the owner.
The building has six floors above ground of which the first 5 are intended for the hotel. On the different floors there are 20 apartments in total with about 78 beds. On the ground floor there is the reception, the office of the director and a green outdoor area for users. Each apartment has a small kitchen and various appliances such as

refrigerator, dishwasher, oven, washing machine, etc. The dimension of each one is about 35-45 m2.

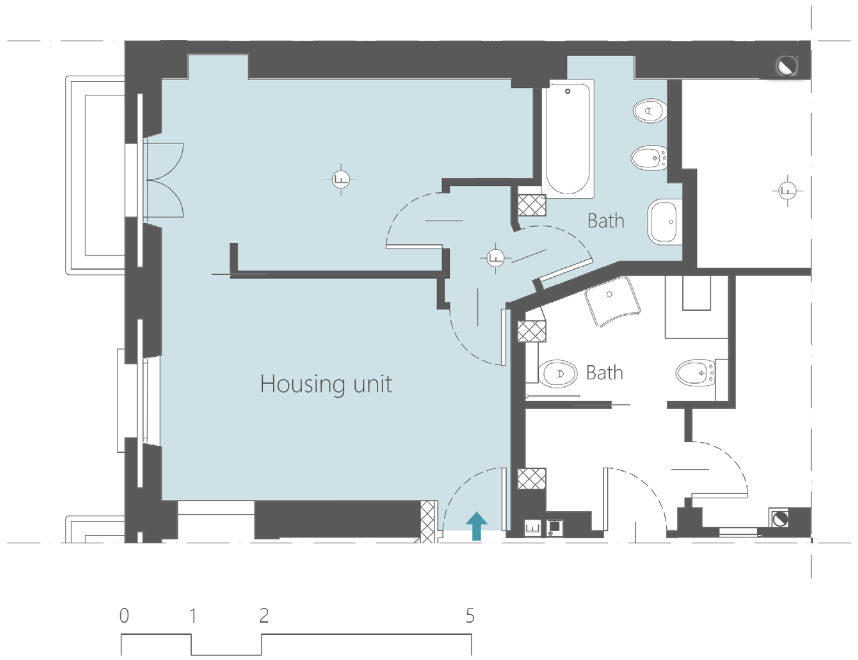


Figure 21. Plan of one of the room of the Orologio Living Apartments.

5.2 The system

The building is equipped with a heating system consisting of two condensing boilers fired with natural gas. Domestic hot water is produced by one of these two boilers. In addition, there is a 300-litre storage tank that keeps the water at a temperature of 46°. The cooling system consists of a refrigerating unit placed outside the building. The terminals in the distribution network are fan coils, installed in the false ceiling or on the floor, for all rooms except bathrooms where there are decorative radiators.

Figure 22. Photo of the case study building boiler room. [19]

5.3 Adhesion to Mobistyle project

The building is also part of a European project called Mobistyle: *Motivating end-users Behavioural change by combined ICT based tools and modular Information services on energy use, indoor environment, health and lifestyle* which aims to increase users' knowledge, in order to decrease energy consumption, and improve IEQ and consequently their health. These results should be achieved through the administration of feedback sent to the occupant daily containing advice to take good behavioural habits. The advice sent to the users would be derived from the analysis of monitoring data of the indoor spaces, subsequently transformed into messages of easy understanding and transmitted through electronic devices such as apps, smart-devices, etc.

In building in which a lot of people are hosted, like for example the hotel, it is necessary to employ experts from different scientific disciplines to develop better the way for giving information to the occupant on their electricity consumption in real time or on the indoor environmental quality through simple messages maybe on the phone. This system could encourage them in having a more reasonable behaviour.

Figure 23. Control system based on KNX connection. [19]

Initially, before participating in the European project Mobistyle, the hotel was already equipped with a monitoring and control system able to communicate the data recorded by the different sensors, connected to each other with the outside through servers, PCs or wireless networks. The entire system was based on the KNX connection standard, which allows management and monitoring networks to be created between different certified devices, even from different companies.

5.4 The building controlled parameters

The system inside the building allowed:

- the doors of the various apartments to be opened and closed through a key cards (even remotely);
- the heating and cooling to be managed with a thermostat;
- the fan coils to be suspended when the windows were opened;
- the occupancy of the apartments to be recognised by the presence of the key card and consequently the power supply to be activated;
- the main access door to be opened by means of an access code to be activated;
- the various services to be managed remotely.

Inside the various rooms, on the other hand, parameters were monitored, such as temperature control via the thermostat and the opening of doors and windows. All the recorded data can be consulted, after being transmitted by KNX bus, through software for pc or app for mobile devices.

With the introduction of the new sensors, following the Mobistyle project, the monitoring focuses on electricity consumption and IEQ characteristics; the parameters monitored are the internal temperature, relative humidity, CO_2 levels, electricity consumption of an entire apartment and then the individual profiles of use of different electrical devices. [19]

5.5 Application of the SRI evaluation

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. In this attached file there is a distinction between services, in fact out of 112 totals

if it considered also the domain of "various", only 52 are considered essential services or services that will have a greater influence on the result.

Controlled ventilation	Ventilation-2a	Air temperature control	Room air temp. control (all-air systems)	✓ 1
Controlled ventilation	Ventilation-2b	Air temperature control	Room air temp. control (Combined air-water systems)	✗ 0

Table 11. Example of two services present in the domani "controlled ventilation". The first one is one of the essentials.

To start, some domains have been eliminated in their entirety according to certain directives given in the European project. For example, for the "domestic hot water" domain it is specified that if it is known that there is no possibility of storage of hot water, the entire domain and the services present in it must ignored.

The domains not taken into account in the calculation of the hotel indicator are marked in grey below also with the reason of the choice specified next.

- **HEATING**
- DHW – *"Is DHW storage present? If not ignore all DHW storage-related services."*
- **COOLING**
- MECHANICAL VENTILATION – *"Is controlled ventilation present? (in any central form) If not ignore all CV services!"*
- **LIGHTING** – "Is important in non-residential buildings."
- **DYNAMIC BUILDING ENVELOPE**
- ENERGY GENERATION – *"If no on-site energy generation (or storage thereof) capabilities omit all EG services."*
- **DEMAND SIDE MANAGEMENT**
- ELECTRIC VEHICLE CHARGING – *"If no EV charging omit all EV services."*
- **MONITORING AND CONTROL**

Below, in Figure 24, are shown the domains used in the calculation in the two options: the standard one and the one after joining the Mobistyle project.

The domains excluded from the calculation are therefore: domestic hot water, mechanical ventilation, energy generation and electrical vehicle charging.

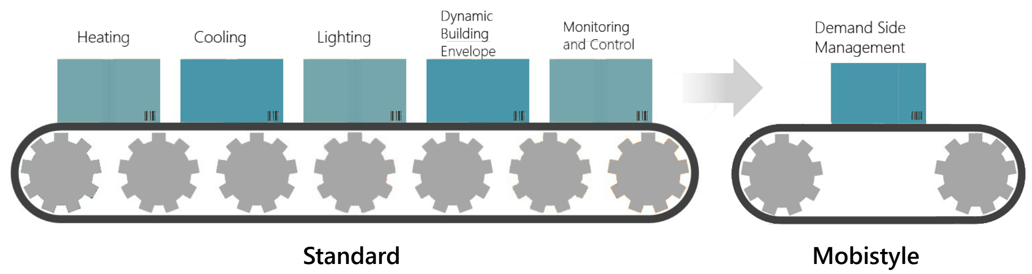


Figure 24. Services considered in the calculation of the Orologio Living Apartments SRI, before and after the Mobistyle project adhesion.

The domain demand side management is considered only with the addition of Mobistyle and not in the standard option. Obviously not considering some domains, the services present in them will be ignored.

The services considered for the evaluation of SRI are resumed in the following tables in which it is possible to find the functionality level assigned.

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
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	On off 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-2a	Heat generator control (for combustion and district heating)	0	Constant temperature control	2
Heating-2c	Sequencing of different heat generators	0	Priorities only based on running time	3

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Cooling-1a	Cooling emission control	2	Individual room control	4
Cooling-1d	Control of distribution pumps in networks	1	On off control	4
Cooling-1f	Interlock between heating and cooling control of emission and/or distribution	0	No interlock	2

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Lighting-1a	Occupancy control for indoor lighting	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)	4

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Dynamic building envelope-1	Window solar shading control	0	No sun shading or only manual operation	4
Dynamic building envelope-2	Window open/closed control, combined with HVAC system	2	Level 1 + Automised mechanical window opening based on room sensor data	3

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Monitoring and control-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	0	No central indication of detected faults and alarms	2
Monitoring and control-9	Occupancy detection: connected services	1	For individual functions, e.g. lighting	2
Monitoring and control-12	Central off-switch for appliances at home	2	off switch with ability for remote operation	3

Tables 12, 13, 14, 15 and 16. Domains, services and level of functionality selected for the Orologio Living Apartments SRI calculation.

The following step was to define the weighting coefficient.

"For step 3 and 4, the weights used for in this study proposed by this study are tentative. They will be discussed and consolidated in subsequent steps."

The European project document does not specify a methodology for assigning weights. For this reason, it was decided to keep the same weights assigned to some impacts in the two case studies presented in the European project.

	Energy saving on site	Flexibility for the grid and storage	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Heating	52	2,5	0	40	10	10	10	7
DHW	14	2,5	0	10	10	10	10	7
Cooling	7	2,5	0	15	10	10	10	6
Controlled ventilation	4	2,5	0	10	10	10	10	6
Light	8	2,5	0	10	10	10	10	7
Dynamic building envelope	5	0	0	5	10	10	10	6
Energy generation	0	2,5	80	0	10	10	10	7
DSM	0	40	10	5	10	10	10	7
Electrical vehicle	0	40	10	0	10	10	10	7
Monitoring and control	10	5	0	5	10	10	10	40
TOT	100	100	100	100	100	100	100	100

Table 17 Weighting coefficient table related to the residential building case study presented in the European project text. [9]

	Energy saving on site	Flexibility for the grid and storage	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Heating	49	2,5	0	40	10	10	10	7
DHW	10	2,5	0	10	10	10	10	7
Cooling	6	2,5	0	15	10	10	10	6
Controlled ventilation	7	2,5	0	10	10	10	10	6
Light	10	2,5	0	10	10	10	10	7
Dynamic building envelope	7	0	0	5	10	10	10	6
Energy generation	0	2,5	80	0	10	10	10	7
DSM	0	40	10	5	10	10	10	7
Electrical vehicle	0	40	10	0	10	10	10	7
Monitoring and control	11	5	0	5	10	10	10	40
TOT	100	100	100	100	100	100	100	100

Table 18. Weighting coefficient table related to the office case study presented in the European project text. [9]

The only column with different values assigned is the one related to the "energy savings on site" that were broken down according to the percentages of consumption of the hotel.

	Energy saving on site
Heating	52
DHW	14
Cooling	7
Controlled ventilation	4
Light	8
Dynamic building envelope	5
Energy generation	0
DSM	0
Electrical vehicle	0
Monitoring and control	10
TOT	100

	Energy saving on site	Flexibility for the grid and	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Heating	38	2,5	0	40	10	10	10	7
DHW	13	2,5	0	10	10	10	10	7
Cooling	10	2,5	0	15	10	10	10	6
Controlled ventilation	0	2,5	0	10	10	10	10	6
Light	10	2,5	0	10	10	10	10	7
Dynamic building envelope	10	0	0	5	10	10	10	6
Energy generation	0	2,5	80	0	10	10	10	7
DSM	7	40	10	5	10	10	10	7
Electrical vehicle	0	40	10	0	10	10	10	7
Monitoring and control	12	5	0	5	10	10	10	40
TOT	100	100	100	100	100	100	100	100

Tables 19 and 20. On the left: a part of the table related to the weighting coefficient in the "energy saving on site" impact. On the right: weighting coefficient table considered for the Orologio Living Apartments SRI calculation.

"Impacts are weighted by the assumed importance of the domain to the impact criteria."

After eliminating the domains that will not be taken into account in the calculation, the weights have been recalculated proportionally.

	Energy saving on site	Flexibility for the grid and	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Heating	48	20	0	53	20	20	20	11
Cooling	13	20	0	20	20	20	20	9
Light	13	20	0	13	20	20	20	11
Dynamic building envelope	13	0	0	7	20	20	20	9
Monitoring and control	15	40	0	7	20	20	20	61
TOT	100	100	100	100	100	100	100	100

Table 21. Weighting coefficient table only for the domains considered in the clculation of the SRI.

Table 22 shows the ordinal impact scores related to this calculation. The impacts that influence mostly the result are the flexibility, the maintenance & fault prediction, but also comfort, energy, convenience and information to occupants. [9]

	Energy	Flexibility	Self-generation	Comfort	Convenience	Wellbeing and Health	Maintenance & fault prediction	Information to occupants
Ordinal impact score case study	11	1	0	7	8	0	3	1
Maximum obtainable score for the case study	41	3	0	26	30	7	10	4
Relative score	**26.8%**	**33%**	**0%**	**26.9%**	**26.7%**	**0%**	**30%**	**25%**

Table 22. Ordinal scores obtained for each impact criteria, relative maximum scores obtainable for the sames services and relative scores in percentage

The result obtained from the calculation of SRI relative to the current situation of the hotel Orologio Living Apartments is 31,2%.

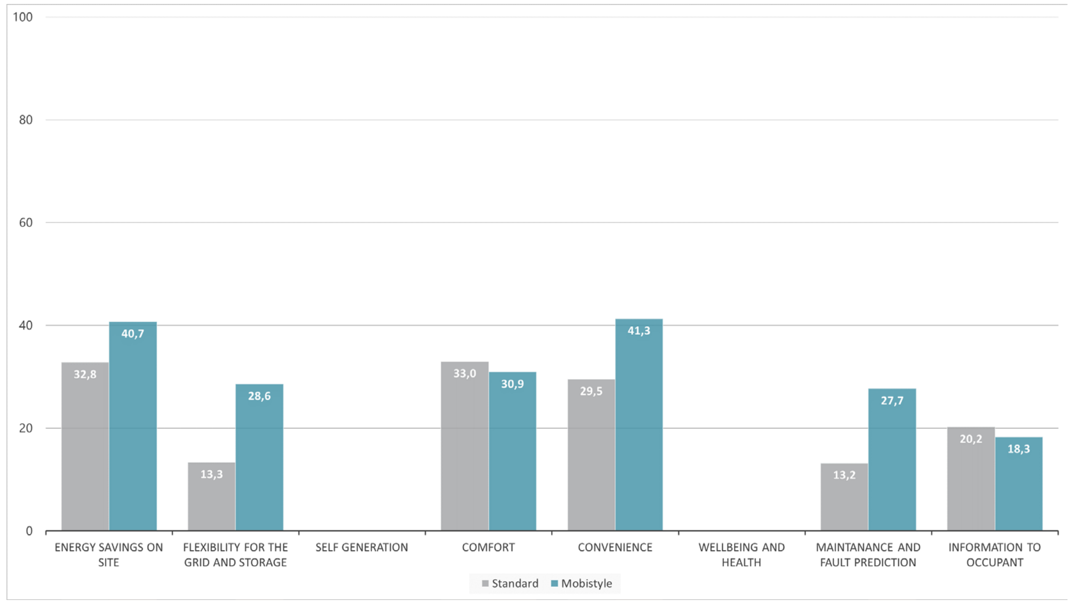


Figure 25. Percentage of influence of each impact criteria in the final SRI result: comparison between the situation before (without DSM domain considered) and after the adhesion to Mobistyle project.

In the bar charts the values of SRI, before and after the application of the Mobistyle project, are shown. In the first one the calculation methodology proposed by the European Project was literally respected. In fact, the demand side management domain is not considered because there are not services related to it. In the second chart the comparison is between the case in which the DSM is considered but with all the functionality levels equal to zero and the one in which the scores are related to the real functionality levels.

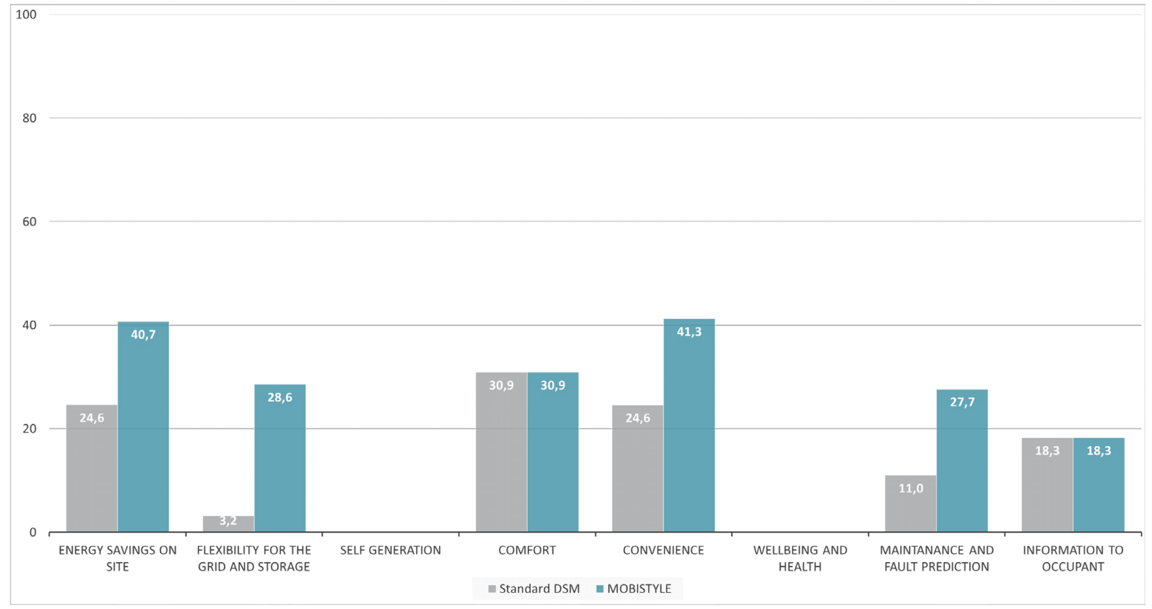


Figure 26. Percentage of influence of each impact criteria in the final SRI result: comparison between the situation before (with all the functionality level od DSM domain equal to zero) and after the adhesion to Mobistyle project.

5.6 Sensitivity analysis

The European project states that the domains of demand side management and electrical vehicle charging can be considered key points in the calculation. These domains, in fact, with their presence could bring benefits. Clearly, deep studies are needed to define which domains should or should not be present with certainty in the calculation, assuming certain conditions of localization for example. The consideration of the above-mentioned domains in the calculation should therefore considerably influence the final result, for this reason it was chosen to apply a sensitivity analysis that would measure the stability of the result in different situations. [9]

- **OPTION 1**

The first comparison is between the situation before Mobistyle (DSM=0) and the one after the application of the Mobistyle project (DSM). In both cases the domains considered are: heating, cooling, lighting, dynamic building envelope, demand side management and monitoring and control. In the first case, all the functionality levels of the demand side management services considered are zero, while in the second case, with Mobistyle, the values of the functionality levels considered are the real ones.

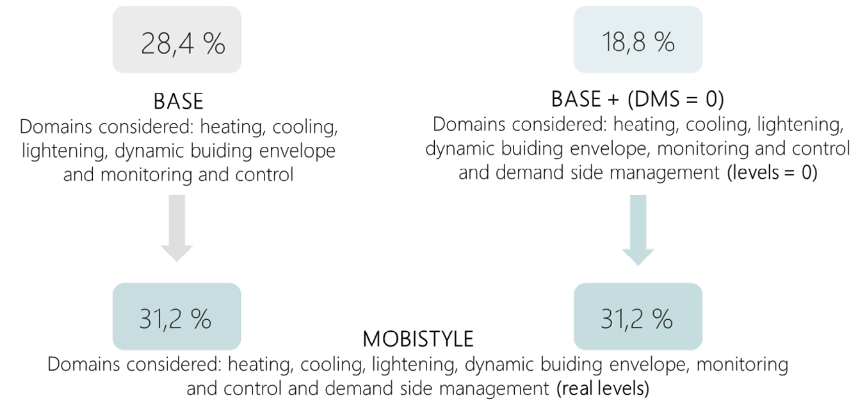


Figure 27. Schematic representation of the result related to OPTION 1.

The methodology of the European project explains that in the absence of certain services, the entire domain to which they belong must be excluded and, as a result, services that are actually present are sometimes excluded. To be able to make a comparison between the cases, however, it is necessary to force the methodology, also trying to see what happens considering these domains, initially excluded.
For this reason, the analysis started from the current basic situation of the hotel with Mobistyle and added these domains to verify the stability of the calculation.
All of the following graphic diagrams respect this logic.

- **OPTION 2**

The second option considered the same services with Mobistyle plus the addition of the domain electrical vehicle charging, in the first case with levels of functionality equal to zero and then using real values.

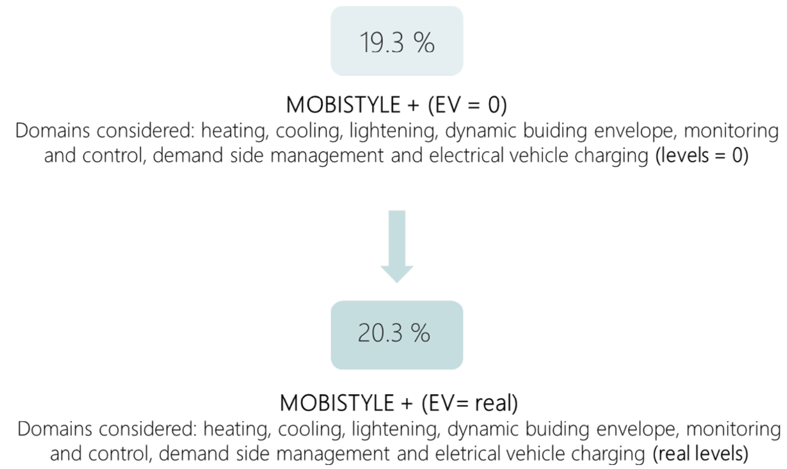


Figure 28. Schematic representation of the result related to OPTION 2.

- **OPTION 3**

In the third hypothesis, the services related to the controlled ventilation domain have been added.

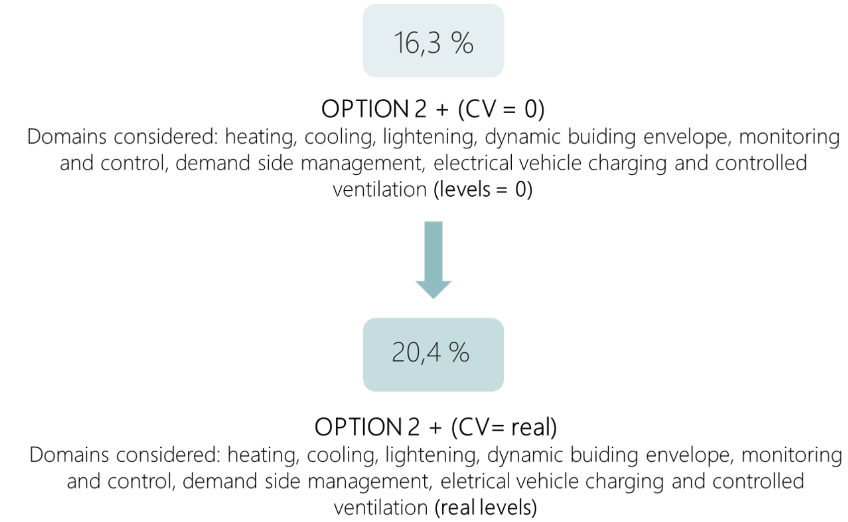


Figure 29. Schematic representation of the result related to OPTION 3.

- **OPTION 4**

And then, in the last option it was always considers the controlled ventilation domain, but excludes the electrical vehicle charging domain (otherwise it would be the same as option c), a characteristic domain since it is the only one that contemplates negative values relating to the levels of functionality.

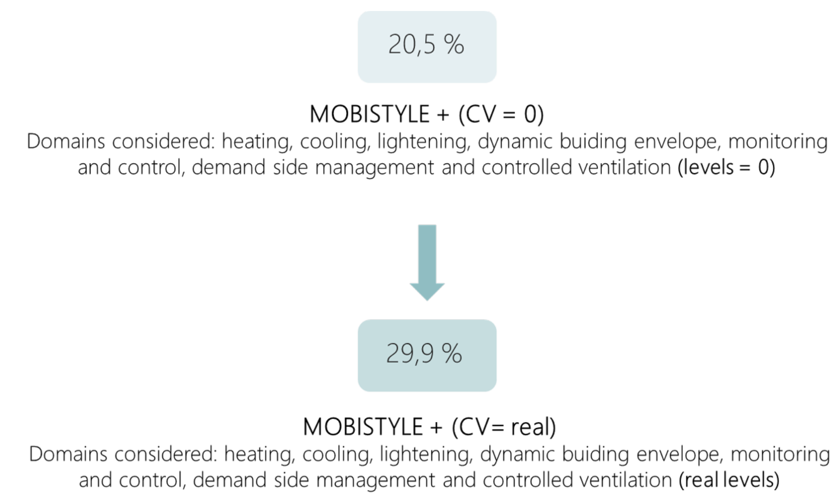


Figure 30. Schematic representation of the result related to OPTION 4.

In the bar graph below all the final result of SRI obtained in the sensitivity analysis are resumed. Each two bars of the different options analysed represent the version “a” in which the domain choose considers all the functionality level equal to zero, and the version “b” in which the functionality level selected are the real one.

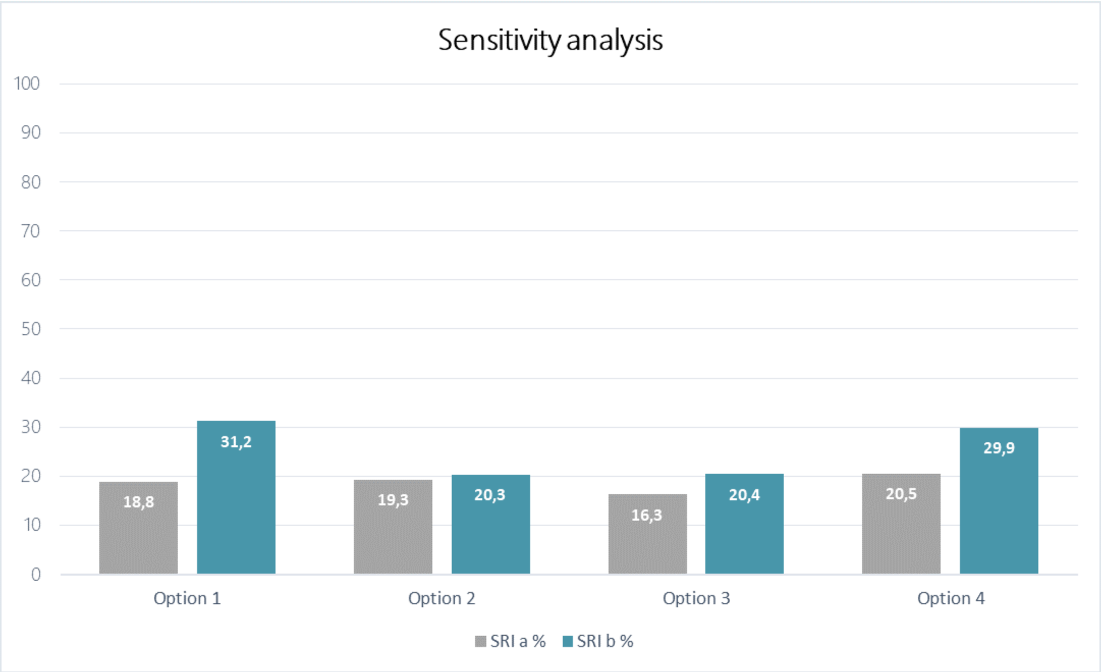


Figure 31. Smart Readiness Indicator results in the different options considered.

In the bar chart it is possible to see how the result of the SRI changes in the different assumptions considered. In option one, the value grows by 66% when the actual functionality levels are considered. In option number 2 the variation between the case a and the case b is minimal, in fact it grows only by about 5.2%. However, considering that only one service has changed its functionality level scores, it can be deduced that the electrical vehicle domain, if implemented even just a minimum, can make improvements. Options 3 and 4 confirm the hypothesis that even a single additional service, if considered in the calculation, can increase the final value of the indicator. In fact, in both options the value of the indicator in case b, where the actual functionality levels are considered, grows.

6 SRI weighting coefficient table definition: a solution based on the research on IEQ factors and weighting coefficient theories used to combine them

One of the main problem founded during the application of the calculation methodology to the case study described in chapter 5 is the weighting coefficient table used to define the result of the SRI. In this chapter the aim is to describe the result of the search on the weighting coeffient and on how different people are weighting the different criteria actually. This could be compared then with what it is possible to get from the physical measurement.

The first literature research is about what exist when factors are combined. For example in comfort this comparison already exist because, when it is evaluated, a set of factors are considered: thermal environment, noise and ligting. There are already a few works in which experts have been investigating the effect of combinig stressers. In fact, when these measurement are made, usually, there is an index to rate thermal comfort, a few indoor air quality indices but also evaluation regarding noise or lighting.

When an evaluation about thermal comfort, about noise and about IAQ (these last two regarding not only comfort but also health) is made, how the weights to this factors are given?

So, one of the main problems is: how will we combine the factors?

With the anlysis of the existing work it was possible to have an idea about the hypothetical subdivision of the weighting coefficients between the stressers.

6.1 IEQ and its importance

“Indoor Environment Comfort results on the combination of four major environmental factors, such as Thermal Comfort (TC), Indoor Air Quality (IAQ), Acoustic Comfort (AC) and Visual Comfort (VC)”. [20]

It has also been affirmed that the Indoor Environmental Quality (IEQ) of a building plays an important role in the performance of the occupants during their activities and has

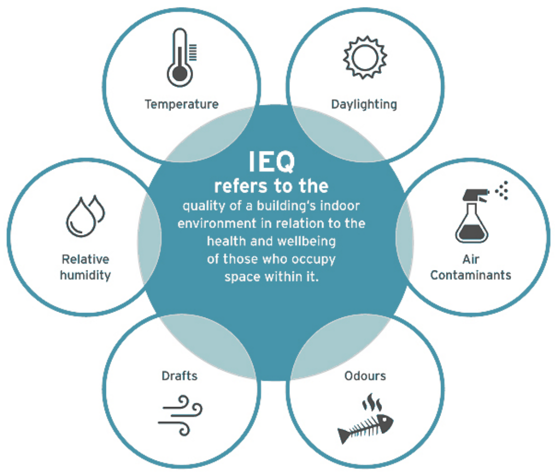


Figure 32. Aspects involved in the determination of the IEQ.

consequences on energy consumption.
In recent years people have begun to understand that the quality of their lives also depends by the energy used in the buildings, which has consequences for the man and not only for the environment. An high percentage of the population, about 75%, lives in cities and every day is a victim of the pollution and the continuous urbanization in growth, but it is also a cause of consumption of natural resources.
To try to achieve the European target of reducing carbon emissions, all buildings should reduce their energy consumption. Buildings should at least meet the minimum energy efficiency requirements set in order to be able to transform themselves during the time into nearly Zero Energy Building (nZEB).
These changes, depending on the energy consumed, often worsen the situation regarding the quality of the internal environment and consequently also affect the health of the occupants and the predisposition to productivity at work. [20,21]
The research that tries to find a balance between these two aspects is constantly developing. One of the most popular solutions is the one that takes into account the possibility of monitoring energy consumption and physical variables related to the quality of the indoor environment. [22]
In order to have a complete picture of the condition of an indoor space, it is advisable to consider both the values that can be obtained during the evaluation of thermal comfort (TC) and the factors that can be obtained by doing the necessary research on Indoor Air Quality (IAQ). [20][21]

6.2 The relation between the SRI and the EPBD (EU) 2018/844

With the definition of IEQ it is possible to prove the presence and ifluence of different stressers. The concept of IEQ is important because the 85% of people pass their time in indoor space and this lead to an high conditioning on the health and productivity of people. This concept is strongly linked with the SRI index in fact as da Silva, Carrilho, Van Cappellen, Van Putten and Smid affirm that if building renovation is done it is possible to improve some qualities of the building that allow a better air quality. With the new revision of the EPBD, the SRI is introduced as a new indicator of the smartness of a building. This value is also synonymous of improving energy efficiency and the quality of the indoor environment. [22]
The SRI weighting coefficient cannot be the same for each calculation, it depends from different reasons and the one showed in the European project document are only to start the discussion. One of the main aspect that really influence the weights is the task of the building in case. For example light may be very important or not, or even noise, in some cases if it is need to be very much concentrated the indoor environment should be more silent while in other task is not necessary to be so silent...
So, what rules we have now about applying weighting factors?
On of the suggestions is to use the Facility Condition Index (FCI) that describe how building have some losses related to the charasteristics like, for example, smoking, gas stoves or water lakes and also to consider the outdoor data related to pollution or vehicle emission. The index can have a value between zero and 100. The lower is the value, the better are the condition of the building. [23]

6.3 The definition of Indoor Environmental Comfort

The indoor environmental comfort can be described as the combination of the physical and physiological sensations of people that live in an indoor space and the physical factors that it is possible to measure for example with sensors or other instruments. All this have a relation with the wellbeing and health, for both adults and children and if we consider the main features of Indoor Air Quality and the external air pollutants we will obtain serious health conseqeuces. Children are usually more susceptible when exposed to air pollutants because they spend between 65% and 90% of their time indoors, especially in schools. These conditions have consequences in the sphere of health, but also in terms of concentration.
The indoor pollution described in these lines is highly generated, for example, by outdoor air, smoke, humidity, gas

emissions, but also by any presence of industrial buildings. [23]
Trying to give the right weightings to the different criteria the evaluators must consider the different people than can live in the buildings and their needs but also the physical measurement and data that can be registred.

Figure 33. Main elements that influence the definition of the weighting coefficients.

Some experts use an approach in which they combine the two different types of data: they consider the values that they obtain by the sensors and a survey questionnaire. In this way they merge objective and subjective perceptions to obtain a thermal comfort evaluation. While others calculate PMV and PPD indices to have a different estimation of indoor thermal comfort.
Buratti, Belloni, Merli, Ricciardi in their research they start calculating the indices related to acoustic, thermal and visual comfort and next they combine these three values at which they gave different weights and mix them with the questionnary results released by people. All indices, including the final index that unites them all, have values in a range from zero to one. The closer the value is to 1, the better the comfort conditions are, but if the value is closer to zero, this means that the internal comfort conditions are worse.
Then, the questionnaire demonstrate, with the results obtained, that even if usually people believe that thermal comfort is the most important parametre, it actually has the more or less the same relevance as acoustic comfort. The questionnaire used is divided in 5 parts and ask first of all for personal data (age and sex) and then there are question related to thermal, acoustic and lighting factors and finally others related on how much importance each one gives to these three categories. From the questionarry results it become possible to divide the different weighting coefficients in percentage to obtain at the end a weighted average value (ICC). [24]

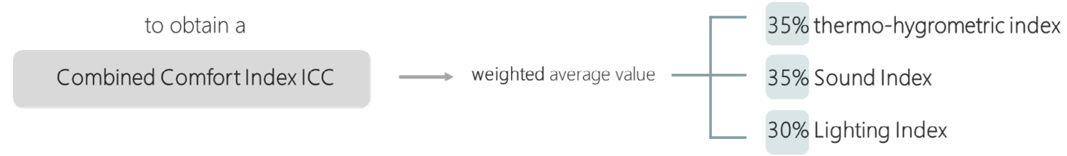


Figure 34. Weighting coefficients to calculate the ICC.

An important role it could be given to the position of the building in the city during the comfort evaluation. In fact, if the building considered is near major roads or industrial facilieties it will have negative influences on the final comfort value.
Kwon, Remøy, van den Dobbelsteen and Knaack add that also the users have a part in this topic: when people can personally control the sensoristic system inside the building they feel more comfortable and satisfied even if, hypotetically, they were to measure the data scientifically they would notice that are out of the standars and the system are not well-performing as in an automated system. [25]
Finally, it can be said that all these parameters are strongly influenced and it depends by the type of building and the needs of the people who live there. It is possible to have dfferent answers for the same building but from different users that live there.

6.4 Weighting coefficient definition

A way for difining the weighting coefficient is the filling of the "comfort" impact column by percentage values that depend in the case of heating, domestic hot water and cooling domains from the thermal comfort indices, for the lighting is appropriate to refer to visual comfort while in energy generation, electrical vehicle charging and monitoring and control domains is proper to consider the indoor environmental comfort.
Accordingly, as has been said before, the idea of comfort can be explained as the set of factors that concerning the thermal conditions, the acoustic and luminous perceptions and finally also the indoor air quality. These factors are then defined by relative indices which, combined, answer the question: what is the most general conception of the

comfort? Clearly the final result could change, because each of the factors mentioned above can be attributed a different weight coefficient and this affects the final sum. This subjectivity in the assignment of weights arises from the different perception of the same place and of the same condition that different people could have. For example if the building studied it is near a noisy area (highway, industries, ...) but it need the opening of its windows to allow natural ventilation: how this problem could be solved? Would it be better to open the windows, withstanding the noise, or prefer the warm indoor condition just to rest in a quiete situation? [26]

		Energy saving on site	Flexibility for the grid and storage	Self generation	Comfort	Convenience	Health and well-being	Maintenance & fault prediction	Information to occupants
Thermal comfort	Heating	52	2,5	0	40	10	10	10	7
	DHW	14	2,5	0	10	10	10	10	7
	Cooling	7	2,5	0	15	10	10	10	6
	Controlled ventilation	4	2,5	0	10	10	10	10	6
Visual comfort	Light	8	2,5	0	10	10	10	10	7
	Dynamic building envelope	5	0	0	5	10	10	10	6
Indoor environmental comfort	Energy generation	0	2,5	80	0	10	10	10	7
	DSM	0	40	10	5	10	10	10	7
Indoor environmental comfort	Electrical vehicle	0	40	10	0	10	10	10	7
	Monitoring and control	10	5	0	5	10	10	10	40
	TOT	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 23. Types of comfort related to the domains that could influence the weighting coefficients definition.

Also in ventilation there are different tipologies like natural, hybrid and mechanical. Sometimes the weightings gived depends on the location of the building and the geometry of it, how it looks, because if a highrise building in a polluted area in the city is considered there will be no chances with natural ventilation because the air would need to be filtered out, particles and some compound need to be removed and also wind velocity that cannot be controlled. In fact in the top part of the building the velocity it's to high to be used in natural ventilation. Some of the weighting coefficient are sometimes somehow related with these aspects: where the building is located and how it looks like.

The comfort is not an easy issue, scientific data collected during measurements, responses and perceptions of people living indoor environments should be considered. The users should also have the opportunity to manage the parameters that regulate comfort in order to obtain a greater awareness and a personal satisfaction.

"We design for the average, we design for standard people."
Prof. Manuel Carlos Gameiro da Silva

Almost everything in nature follow the Gaussian distribution curve and the majority, the standard stay in the middle. It is very difficult to satisfy the desires of all types of occupants, for this reason we try to find a balance between the different positions taken, mediating between the best situation of IEQ and that of energy consumption. [21] [25]

6.5A survey to solve the weighting coefficient definition

The problem of the weighting coefficient is really important in this calculation. In the European project it's not explained how they can be justified the values choosen. The weights can be different depending from the type of work and use of the building. For example an hospital building usually needs high requirements in term of heath because the people hosted are considered sensitive about it. Therefore to verify if there are good health conditions, the impact of wellbeing and health should have an higher percentage of weighting in the table.

Finding a solution to the weight issue could take several years of study and research.

But if it is necessary to choose and to think about a school building planning for example, what should be considered more important between the criteria? If there is the 100% to be distributed among the different criteria: what could be the right approach to have?

If there aren't scientific papers that treat these kind of informations and categories, a possibility to be considered to find a rule for the determination of the weighting coefficient could be the creation of a survey in which experts can contribute with their knowledges. After the preparation of it, it must be launched to a group of professionals asking them to give their own opinion. It must be explained that there are eight criteria to be taken into account and that at each criterion should be assigned its percentage of importance. There are 100 points to be awarded, which must be divided between the different criteria.

Then, after the collection of people answers it will be possible to calculate what is the average obtained for each criterion and finally, through small corrections, the sum of

100% might be ensured. Clearly, the greater the number of experts who will answer the questionnaire, the better the final table obtained will be.
It was decided to create through the program called SOCRATIVE a sort of test or questionnaire that experts can perform through the use of the computer and connecting to a link that is forwarded to them once ready.
The use of this program makes the procedure for involving experts more immediate and facilitates the collection of data processed in real time automatically.
This system was preferred to the compilation of a PDF since, involving an interesting number of people, it is more instantaneous to get in touch with them by sending the link they need to go back to the quiz via a simple email.
A virtual room is created where experts will "enter" to take the test. It is possible to choose whether to give experts the opportunity to respond anonymously or not. For this job it was not necessary to know who exactly was doing the test, as much as to have information about his work specialization, the age and the country of provenance.
The software allows different formats, to choose from, to submit questions: true/false, multiple choice and short answer.
To ask questions about impact percentages, short answer format was used. The question was formulated so that the answer could be a sequence of numbers indicating the assigned percentages.

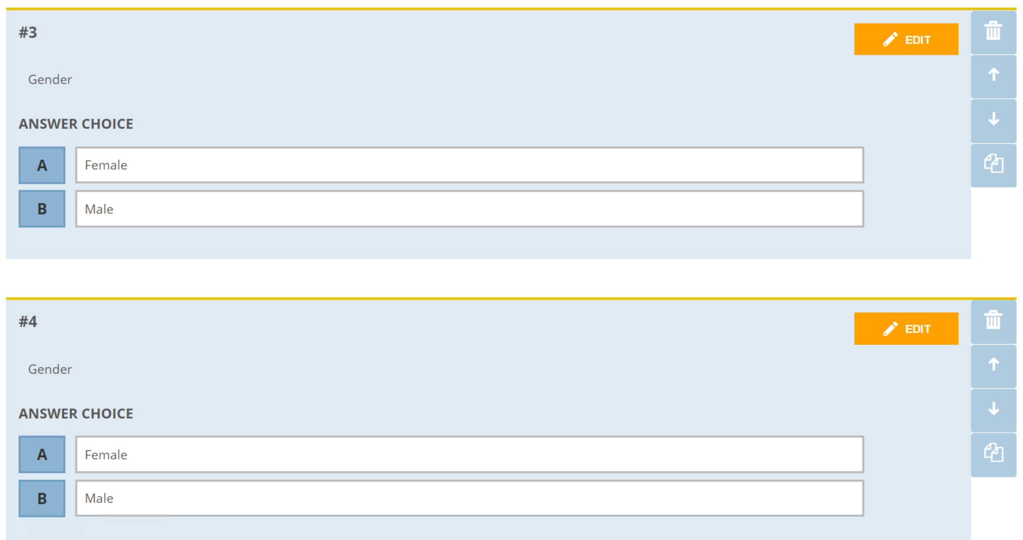


Figure 35. Example of two survey questions related to the personal data.

The rules stipulated that the numbers should be separated from each other by the use of a semicolon (;) and that the sum of all the values relating to an impact should be equal to 100%.

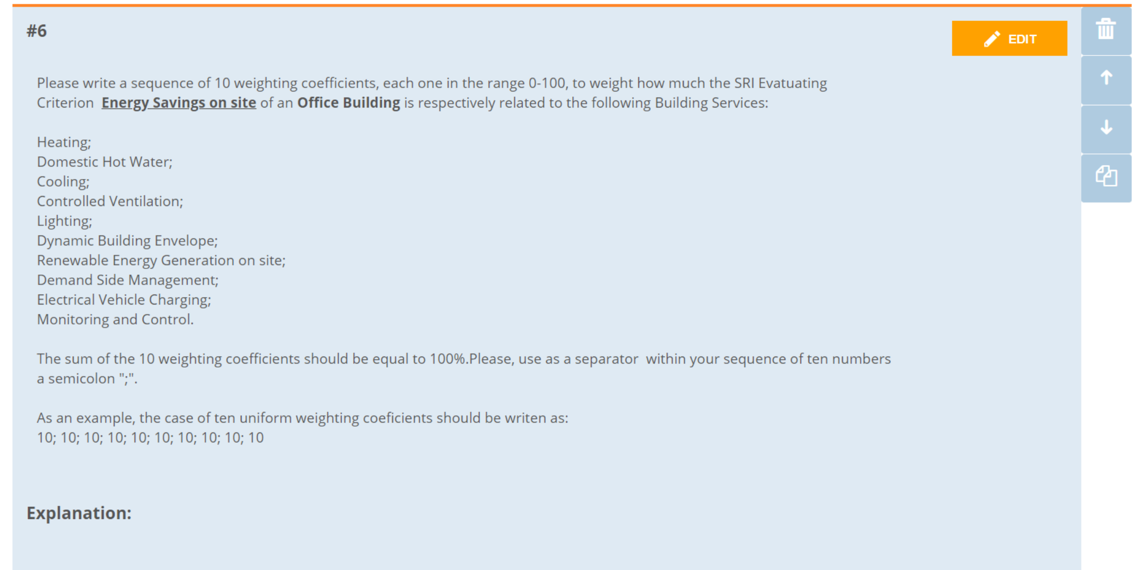


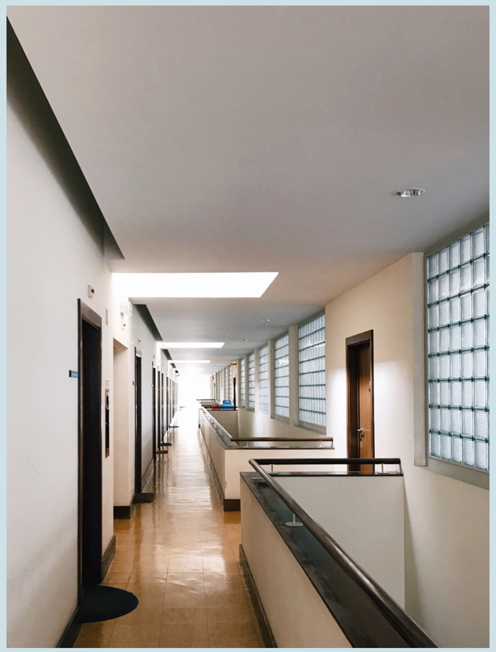
Figure 36. Example of a question related to the definition of the weighting coefficient of an impact criteria.

Has been chosen to dedicate a question for each impact and in the Figure 36 is shown an example of a short answer typology made in SOCRATIVE site.
The questionnaire was composed by a set of short answers.
The steps for this work were:

- create the quiz
- create an email to explain the objective of the research and the instructions to make the test
- launch the test online
- send the email with the link in which it the questionnaire is available (user name=reference of the room)
- wait for the esperts answers
- collect the data
- evaluate the average values to create the weighting coefficient table
- re-calculate the SRI of the building.

Case study 2 - Departamento de Engenharia Mecânica (Coimbra)

This chapter describes the second case study chosen for the application of the calculation merhodology. After the assessment of the services present and the definition of the weighting coefficient it was possible to define the SRI result. The calculation is repeated also using the weighting coefficient obtained by the survey answers.

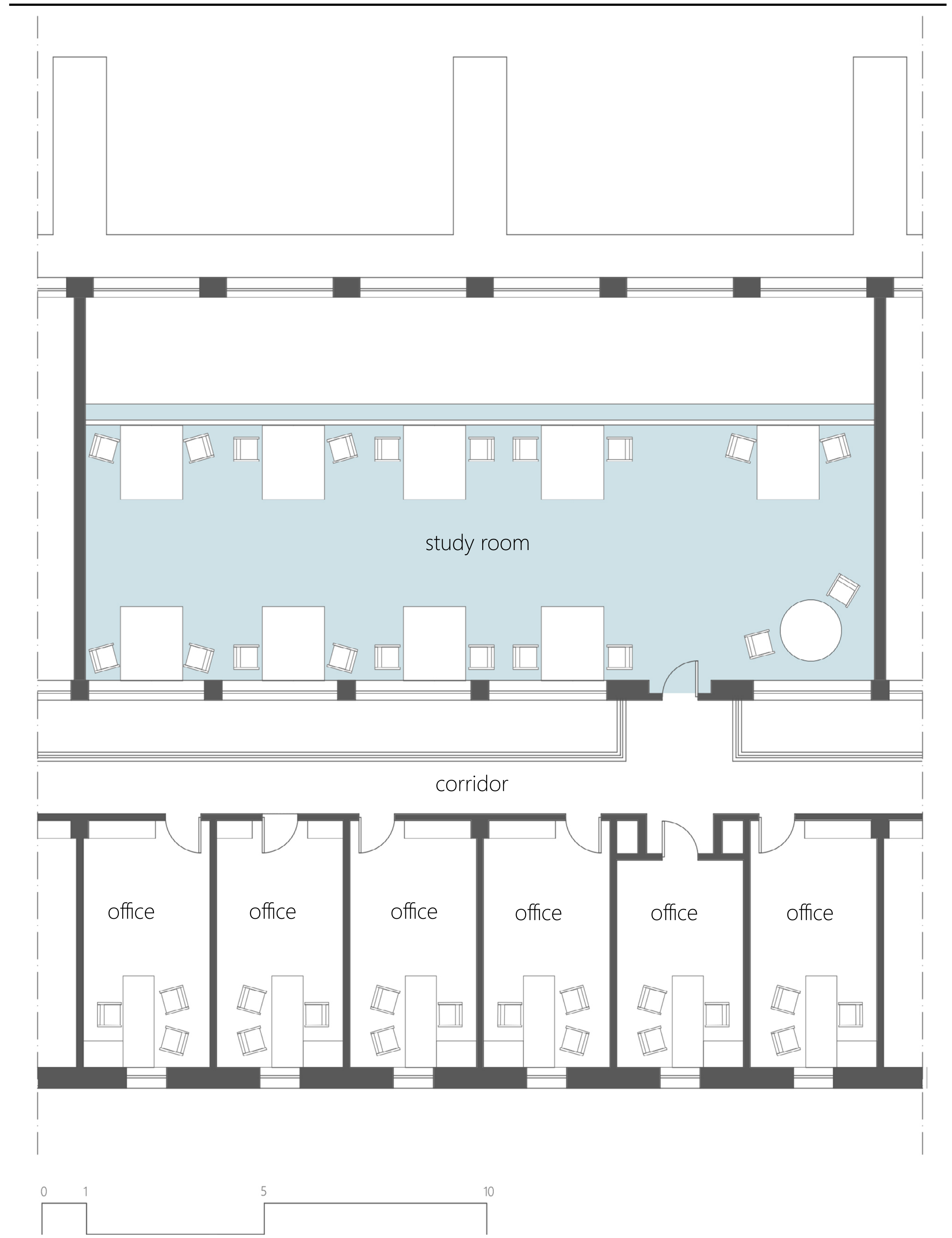


Figures 37 and 38. On the left: photo of the interior space of the DEM block. On the right: photo the external facades of the case study building.

5.1 Description of the building

This chapter applies the methodology for calculating the SRI proposed by the European project and described above.

The case study chosen is one of the buildings that are part of the mechanical engineering complex of the University of Coimbra. The choice fell on this building because it was easy to explore and reach, but also because the information about the systems and services present were more. The building in question consists of a single wing that develops longitudinally. It is reached by two entrances at opposite ends of the building connected by a long corridor.



After crossing the door threshold, there are a series of consecutive rooms, all arranged on one side, dedicated respectively to the offices of individual professors, the secretariat and toilets for women and men. On the other side of the corridor there are two stairs in opposite positions at the two entrances, described above, that allow the possibility to reach the basement. This space is dedicated to various workshops, work and meeting rooms and again to the toilets. In a central position with respect to the stairs described is located, on the main floor, the study room in which the monitoring is carried out with the multifunction key.

The case study examined is a typical office building. All individual work areas are equipped with large windows for optimum natural lighting.

Figures 39 and 40. On the left: case study building entrance. On the right: DEM block corridor.

All professors' rooms have thermostatic valves and some of them have air conditioning system. The hot water that pass in the pumps has a static temperature related to the one chosen in the boiler and doesn't have any mechanism to regulate the temperature in pumps, it's only in the boiler. The control of the pumps it is "on/off" based and there is a digital clock that in the night shut down the pumps, so they work all day and stop at night (automatic control with fixed time program).

There isn't a storage of thermal energy, it is only produced to be used immediately with no possibility to preheat the spaces from home. The digital timer gives the possibility to select the hour in which the system starts to function, in this case the time prefixed is 7 am. It is also possible to understand which is the temperature of hot water that is produced by the boiler with the mini display on it, but this not have any relation with outside temperature: it is a fixed value decided by the technical expert. The boilers present in the site are two and they function both at the same time, but if the weather outside is so hot one of them is switched off.

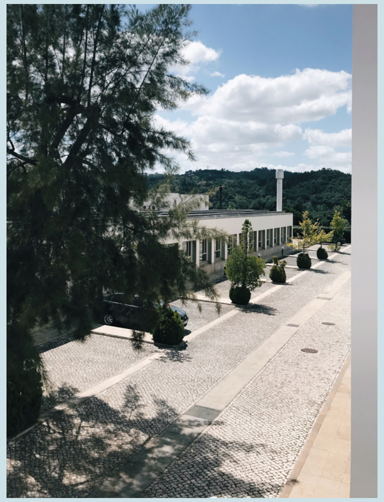
Figures 41 and 42. Building boiler room of the DEM block.

Now there is the idea to implement the functions present in the building and related to it and the next step is to apply a continuous monitoring system even if the system is really old and have to be renewed.

The block doesn't have domestic hot water inside even if the pipes are present, they don't work.

Only in some rooms there is air conditioning system. There are also big chillers but are located in other places in the University complex like the library and the auditorium.

All the light system is not based on automatic detection, but it works only if it is switched by the interrupter with the exception for the corridor in which there is a timer.



Figures 43 and 44. On the left: DEM block roof with photovoltaic panels and inverters. On the right: DEM block.

The building has on the roof a set of photovoltaic panels and there is a monitoring system from where it is possible to know how much energy they produce currently, but also data registered in the previous day. The software is also able to make comparison with the data related to the other buildings of the faculty.
There are seven inverters, three are in the building studied for this calculation and four in another one. It is possible to see one inverter for time or all together and this allow to check the information related to each one but also to make analogies. If one of the panels brakes the current collected is lower and the other ones don't work because they are connected in series. The entire energy produced on site is made for own consumption and it is not possible to store it.

The building doesn't have smart appliances inside and it isn't possible to know the presence of fault in real-time.

In the building there is a place when it is possible to charge the electrical vehicle that is the garage. This recharge point can be used only by people who work inside this University department in any time, one per time. On the charging stop there is a light that is different in relation with the recharge status: "green" that means recharge complete and "red" that means that is discharge.

The building hasn't monitoring system and

Figures 45 and 46. On the left: detail of the electrical vehicle charging point. On the right: electrical vehicle charging point.

control. All the systems are mechanically controlled except for the data related to the current and historical energy consumption. The software that monitor all the data is still in a development mode and it is in program the possibility that it will create graphs and allow the chance to use the data to make benchmarking.

7.2 Application of the SRI evaluation

7.2.1 Assessment of the building services

It was possible to make all the precious part related to the assessment in about 30 minutes thanks to the organization of a meeting with the responsible of the technical system of the building. In this meeting it was possible to consult the technical data sheets and have access to the technical rooms.
Before starting to check whether or not there was a single service, the presence of the following domains proposed by the European project was checked:

- Heating
- Cooling
- Domestic Hot Water
- Controlled ventilation
- Lighting
- Dynamic building envelope
- Self-generation
- Demand Side Management
- Electric vehicle charging
- Monitoring and control

The lack of some services leads to the disregard of some domains that are immediately excluded from the process: domestic hot water, controlled ventilation, dynamic

building envelope and demand side management.
The triage process brings to the consideration of a total of 23 services for the calculation process.

Below are listed in tables all services considered within their respective domains and the assigned levels of functionality.

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
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	On off control	4
Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	1	Automatic control with fixed time program	3
Heating-1g	Building preheating control	1	Program heating schedule in advance	2
Heating-2a	Heat generator control (for combustion and district heating)	0	Constant temperature control	2
Heating-2c	Sequencing of different heat generators	0	Priorities only based on running time	3

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Cooling-1a	Cooling emission control	2	Individual room control	4
Cooling-1d	Control of distribution pumps in networks	1	On off control	4
Cooling-1e	Intermittent control of emission and/or distribution	2	Automatic control with optimum start/stop	3

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Lighting-1a	Occupancy control for indoor lighting	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)	4

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
EG-1	Amount of on-site renewable energy generation	1	Limited amount of PV or CHP production	2
EG-2	Local energy generation information	3	Performance evaluation including forecasting and/or benchmarking	4

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
EV-15	EV Charging Capacity	1	Low charging capacity	3
EV-16	EV Charging Grid balancing	1	1 way (controlled charging)	2
EV-17	EV charging information and connectivity	1	Reporting information on EV charging status to occupant	2

Code	Service name	Functionality level selected	Description of the level	Maximum functionality level
Monitoring and control-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	0	No central indication of detected faults and alarms	2
Monitoring and control-5	Reporting information regarding current energy consumption	1	Indication of actual values only (e.g. temperatures, meter values)	3
Monitoring and control-6	Reporting information regarding historical energy consumption	2	Trending functions and consumption determination	3

Monitoring and control-7	Reporting information regarding predicted energy consumption	3	Analysing, performance evaluation, benchmarking	3
Monitoring and control-13	Central reporting of TBS performance and energy use	1	Real time indication of energy use per energy carrier	3

Tables 24, 25, 26, 27, 28 and 29. Domains, services and level of functionality selected for the DEM block SRI calculation.

7.2.2 Weighting factors: SRI score before and after the survey answers

The table of weighting related to the impacts used in this calculation was the same applied in the analysis of the office case study of the European project. The choice to use this table proved to be the most reasonable to give the right importance to the different domains and services included according to the final use of the building.

	Energy saving on site	Flexibility for the grid and	Self generation	Comfort	Convenience	Health and well-being	Maintenanc e & fault prediction	Information to occupants
Heating	49	6	2	25	10	21	13	6
DHW	10	1	2	11	8	11	8	4
Cooling	6	6	2	19	7	21	10	4
Controlled ventilation	7	3	2	7	6	9	8	2
Light	10	3	2	18	13	14	15	7
Dynamic building envelope	7	1	8	4	15	4	7	6
Energy generation	0	28	42	3	20	5	14	7
DSM	0	22	21	5	6	2	4	11
Electrical vehicle	0	22	7	4	9	3	9	13
Monitoring and control	11	8	12	5	8	10	12	38
TOT	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 30. Weighting coefficient table related to the Office building of the European project used for the first DEM block SRI evaluation.

The impact weights by domains in the table are sometimes arbitrary because, as the final document of the European project said, the technicians need to do more researches to find the correct values. In some impact columns the values assigned are totally equal and this choice means that the experts are still searching for the correct mode to set them.

The weights for the impacts in the calculation of the final result are distributed equally so all the domains have the same importance in the definition to SRI score, but it is also possible to give them different weight.

ORDINAL IMPACT SCORES								
	Energy	**Flexibility**	**Self-generation**	**Comfort**	**Convenience**	**Health and well-being**	**Maintenance & fault prediction**	**Information to occupants**
Case study values	14	2	2	8	11	0	2	13
Case study maximum	38	6	3	21	31	5	9	21
Relative score	36.80%	33%	67%	38%	35%	0%	22%	62%

Table 31. Relation between the case study building impact scores, the maximum scores obtainable and the relative scores in percentage.

Energy is the impact that has the greatest influence on the percentage, as well as comfort, convenience and information to the occupant. This result reflects the number of smart services present that have a strict correlation with these impacts. Instead, the impacts that least affect the final result are flexibility, on-site generation, health and well-being and maintenance and fault prediction.

Following the steps proposed by the European project for the calculation of the indicator, the result obtained is 41.6 %.

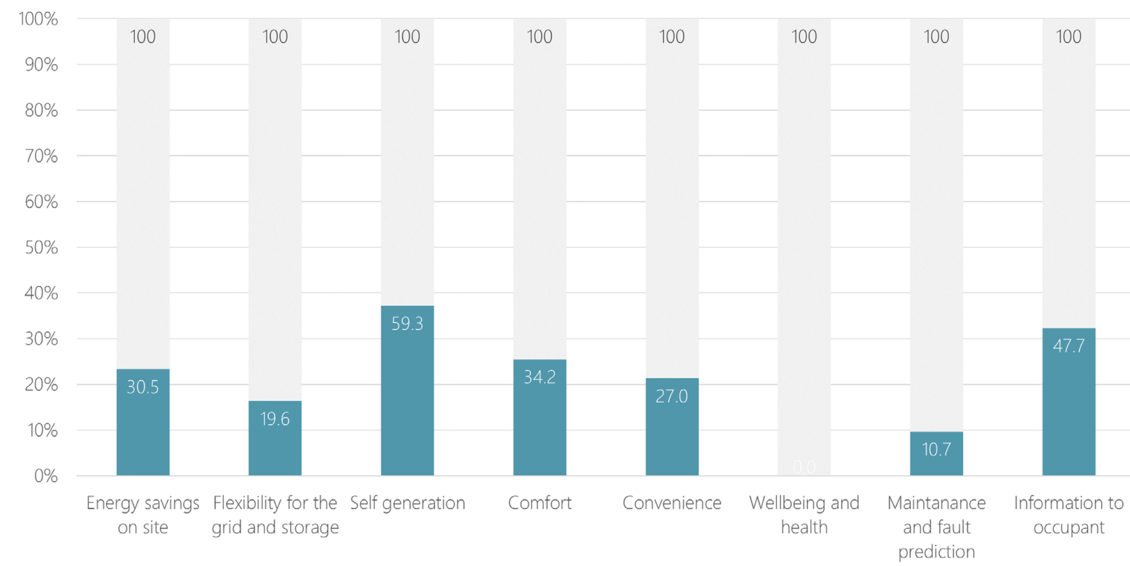


Figure 47. Influence of the different impact criteria on the SRI final result using the Table 30 in the calculation.

This final result is influenced by the different percentages of impacts as shown in the bar chart below. The most important impact category on the result is the self generation, followed by the information to occupant. While it is highlighted that the services present do not allow the category of well-being and health to have any influence on the result.

	Energy saving on site	Flexibility for the grid and	Self generation	Comfort	Convenience	Health and well-being	Maintenanc e & fault prediction	Information to occupants
Heating	41	6	2	25	10	21	13	6
DHW	7	1	2	11	8	11	8	4
Cooling	12	6	2	19	7	21	10	4
Controlled ventilation	4	3	2	7	6	9	8	2
Light	8	3	2	18	13	14	15	7
Dynamic building envelope	7	1	8	4	15	4	7	6
Energy generation	5	28	42	3	20	5	14	7
DSM	5	22	21	5	6	2	4	11
Electrical vehicle	2	22	7	4	9	3	9	13
Monitoring and control	10	8	12	5	8	10	12	38
TOT	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 32. Weighting coefficient table related to the survey answers used for the second DEM block SRI evaluation.

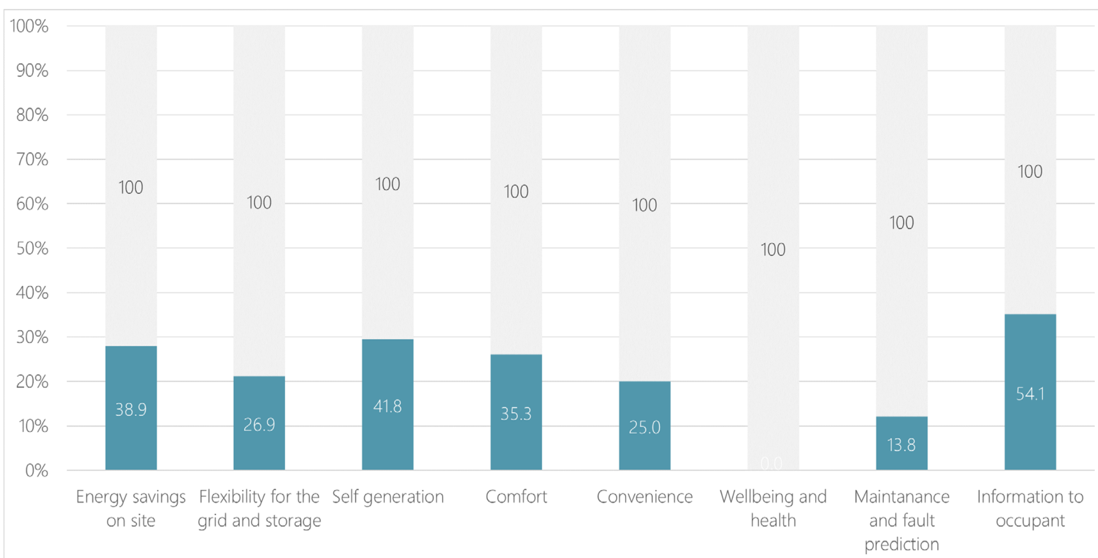


Figure 48. Influence of the different impact criteria on the SRI final result using the Table 32 in the calculaation.

Subsequently, the calculation was carried forward using a new table of weights obtained from the answers to the questionnaire described in paragraph 6. 5. The result obtained in this case is equal to 39.3%.

The bar graph shows how a change in weight coefficients in the impact *monitoring and control* changes the contribution of this category in the final result, in fact this category is the most influent. Also in the self genereation impact is there an important change, that decrease the effect of this category on the SRI final value.

Looking at this result of SRI it is possible to say that it is not an indicator of how good the building is in term of energy efficiency. According to it, a better building is a building where consumptions are maybe high but the building is comunicating a lot so if there are many information about the building the SRI will be better.

In fact, the building analyzed, for example, has some monitoring but it is not yet connected to the control system or it is not present yet so much broadcasting. But one of the problem of the SRI evaluation is that it is only wondered if the services are there or not and not if they performing well or bad. Sometimes, for some services, to be considered in the calculation could bring positive, but also negative consequences on the result. For example, some buildings, efficiently connected in the city mobility system, do not need to have charging points for electric vehicles nearby, but if this domain is not considered in the calculation it makes the value of the indicator worse. [28]

8 A monitoring campaign to evaluate IEQ parameters

Figure 49. Multiprobe usb and its sutain.

In this chapter all the monitoring phases carried out into the chosen building will be described. The collected data will also be explained.

8.1 The work instruments

The monitoring campaign was realized by two main instruments. The first and most important one is the usb device. This multiprobe element allow people to evaluate the IEQ and it was conceived more for public spaces, especially for office buildings.

This small object includes different sensors that can measure:

- the temperature
- the relative humidity
- the CO2 concentration
- the atmospheric pression
- the illuminance
- and the VOCs.

All these components are inserted inside an usb stick that can be easily connected to a computer.

With this small element, the creator also thought about a sustain, equipped with an extension cord, that allow who is taking the measurement to put the device far from the work position and the direct emission of heat and CO2 that could interfere with the perception of the quantities considered.

This instrument has a related software that allows the users to read all the data recorded. The software is called AURA IEQ DISCOVERER ® and it is fundamental to permit the communication between the usb device and the personal computer, to show in preview the data that are collected in real time by numbers and graphs, to control the measurement process and also to categorize the indoor condition in relation with the EN 16798-1 and the level of one of the IAQ Index that is related to VOCs concentration in the air.

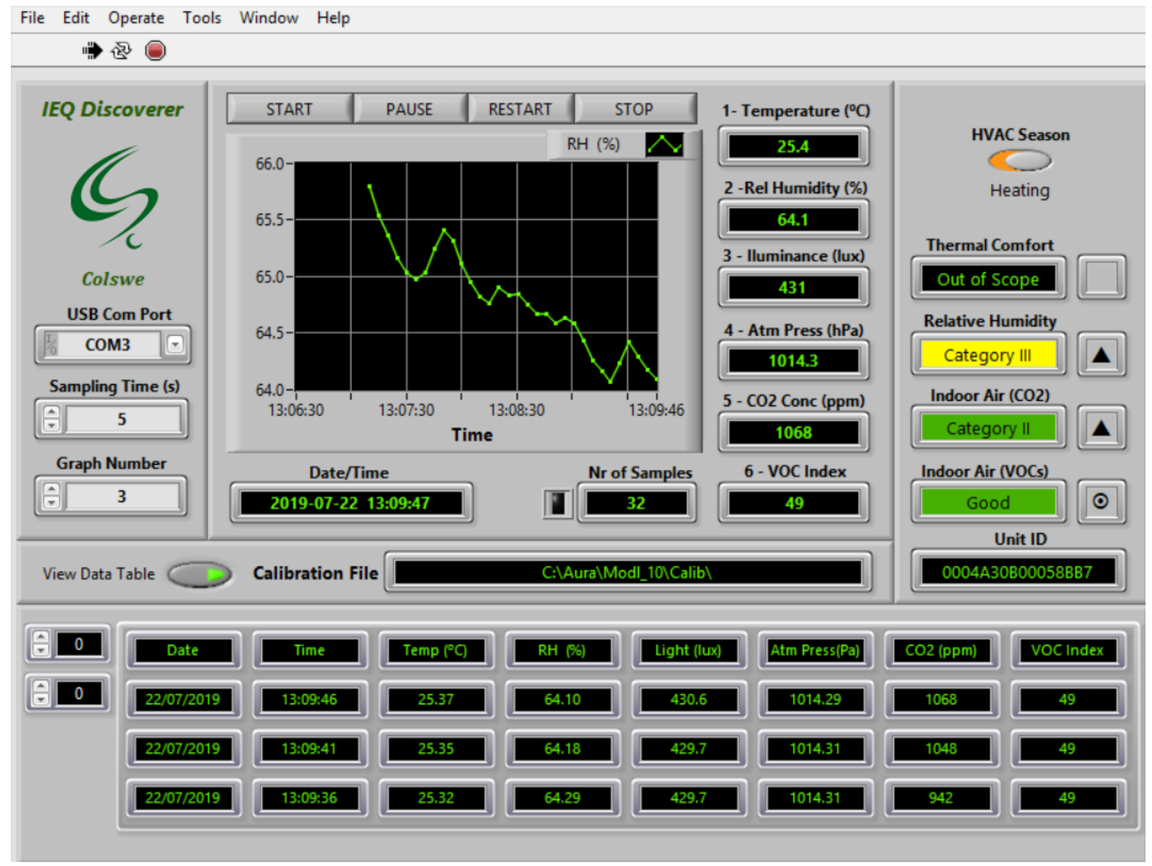
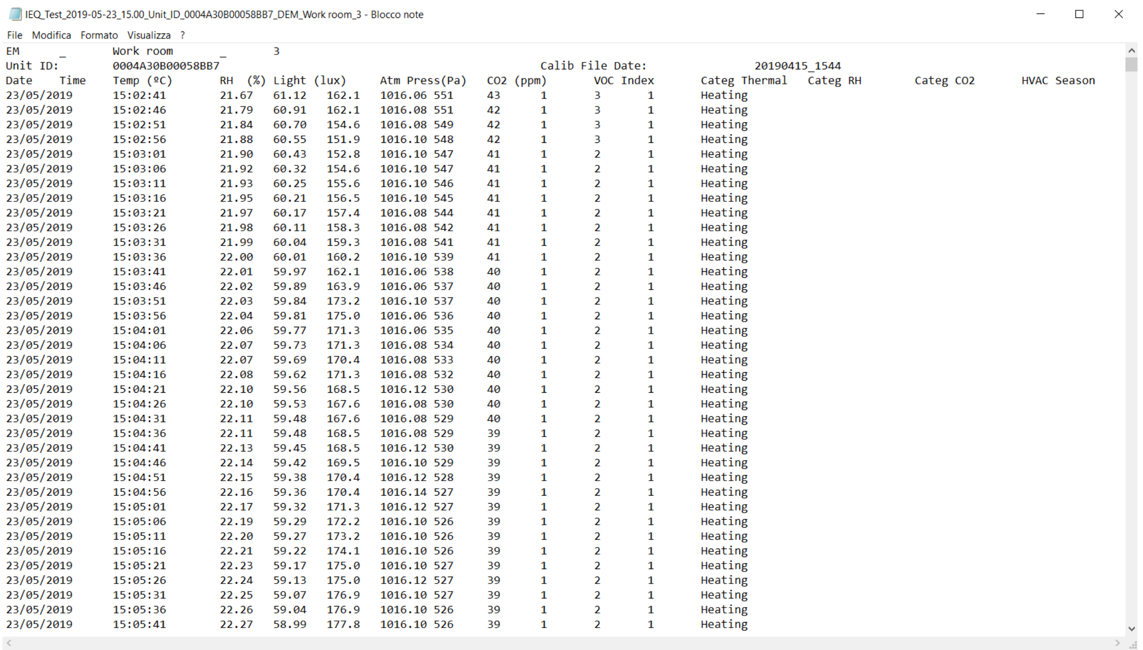


Figure 50. Capture of the software during its functioning - relative humidity graph.

After the connection of the usb tool with the computer, the software can be launched. The first thing to select after the software opening is the name of the usb port then it

is possible to press “start” and then select “run”. The next operations that must be done are the selection of the calibration file for that measurement session, the filling of the spaces related to the building in which the monitoring is done, the name of the room and the point of reference inside the location and finally the measurement will start.
At the end of each measurement session the software create a .txt file (Figure 51) in which all the data are saved in a folder previously created. [27]



IEQ_Test_2019-05-23_15.00_Unit_ID_0004A30B00058BB7_DEM_Work room_3 - Blocco note

File Modifica Formato Visualizza ?

EM _ Work room _ 3
Unit ID: 0004A30B00058BB7 Calib File Date: 20190415_1544

Date	Time	Temp (ºC)	RH (%)	Light (lux)	Atm Press(Pa)	CO2 (ppm)	VOC Index	Categ Thermal	Categ RH	Categ CO2	HVAC Season
23/05/2019	15:02:41	21.67	61.12	162.1	1016.06	551	43	1	3	1	Heating
23/05/2019	15:02:46	21.79	60.91	162.1	1016.08	551	42	1	3	1	Heating
23/05/2019	15:02:51	21.84	60.70	154.6	1016.08	549	42	1	3	1	Heating
23/05/2019	15:02:56	21.88	60.55	151.9	1016.10	548	42	1	3	1	Heating
23/05/2019	15:03:01	21.90	60.43	152.8	1016.10	547	41	1	2	1	Heating
23/05/2019	15:03:06	21.92	60.32	154.6	1016.10	547	41	1	2	1	Heating
23/05/2019	15:03:11	21.93	60.25	155.6	1016.10	546	41	1	2	1	Heating
23/05/2019	15:03:16	21.95	60.21	156.5	1016.10	545	41	1	2	1	Heating
23/05/2019	15:03:21	21.97	60.17	157.4	1016.08	544	41	1	2	1	Heating
23/05/2019	15:03:26	21.98	60.11	158.3	1016.08	542	41	1	2	1	Heating
23/05/2019	15:03:31	21.99	60.04	159.3	1016.08	541	41	1	2	1	Heating
23/05/2019	15:03:36	22.00	60.01	160.2	1016.10	539	41	1	2	1	Heating
23/05/2019	15:03:41	22.01	59.97	162.1	1016.06	538	40	1	2	1	Heating
23/05/2019	15:03:46	22.02	59.89	163.9	1016.06	537	40	1	2	1	Heating
23/05/2019	15:03:51	22.03	59.84	173.2	1016.10	537	40	1	2	1	Heating
23/05/2019	15:03:56	22.04	59.81	175.0	1016.06	536	40	1	2	1	Heating
23/05/2019	15:04:01	22.06	59.77	171.3	1016.06	535	40	1	2	1	Heating
23/05/2019	15:04:06	22.07	59.73	171.3	1016.08	534	40	1	2	1	Heating
23/05/2019	15:04:11	22.07	59.69	170.4	1016.08	533	40	1	2	1	Heating
23/05/2019	15:04:16	22.08	59.62	171.3	1016.08	532	40	1	2	1	Heating
23/05/2019	15:04:21	22.10	59.56	168.5	1016.12	530	40	1	2	1	Heating
23/05/2019	15:04:26	22.10	59.53	167.6	1016.08	530	40	1	2	1	Heating
23/05/2019	15:04:31	22.11	59.48	167.6	1016.08	529	40	1	2	1	Heating
23/05/2019	15:04:36	22.11	59.48	168.5	1016.08	529	39	1	2	1	Heating
23/05/2019	15:04:41	22.13	59.45	168.5	1016.12	530	39	1	2	1	Heating
23/05/2019	15:04:46	22.14	59.42	169.5	1016.10	529	39	1	2	1	Heating
23/05/2019	15:04:51	22.15	59.38	170.4	1016.12	528	39	1	2	1	Heating
23/05/2019	15:04:56	22.16	59.36	170.4	1016.14	527	39	1	2	1	Heating
23/05/2019	15:05:01	22.17	59.32	171.3	1016.12	527	39	1	2	1	Heating
23/05/2019	15:05:06	22.19	59.29	172.2	1016.10	526	39	1	2	1	Heating
23/05/2019	15:05:11	22.20	59.27	173.2	1016.10	526	39	1	2	1	Heating
23/05/2019	15:05:16	22.21	59.22	174.1	1016.10	526	39	1	2	1	Heating
23/05/2019	15:05:21	22.23	59.17	175.0	1016.10	527	39	1	2	1	Heating
23/05/2019	15:05:26	22.24	59.13	175.0	1016.12	527	39	1	2	1	Heating
23/05/2019	15:05:31	22.25	59.07	176.9	1016.10	527	39	1	2	1	Heating
23/05/2019	15:05:36	22.26	59.04	176.9	1016.10	526	39	1	2	1	Heating
23/05/2019	15:05:41	22.27	58.99	177.8	1016.10	526	39	1	2	1	Heating

Figure 51. Result of the monitoring in .txt file.

8.2 The characteristic of the monitored room

Measurement were conducted in one of the study rooms in DEM (department of mechanical engineer) of the university of Coimbra (Portugal). The process began the 23rd of May 2019 and ended the 7th of June (weekends were not included). The usb pen full of sensors was always placed not near the personal computer, thanks to its own sustain, to not affect the result by the CO2 emitted by the pc user. The measures were taken in different hours of the day to better understand the changes of the values.
The area of the study room is 101.5 m2, and has different work places with desk and chairs: it can host at least 20 people inside. The room seems really bright thanks to the white walls and to the big windows present that give a lot of natural light inside. During the measurement the room was never completely occupied and sometimes there was only one person inside. It is located in the first floor of the building and it have a balcony on the room downstairs which have an air conditioning system.
In the measurement period the climate change, different times, from a similar spring one to a really summer one and this allows some comparisons.

Figure 52. Interior monitored room.

Figure 53. Interior monitored room - windows.

All the data were taken with the same usb, located in same position and by the same personal computer. The information collected were saved in .txt format in a specific folder and then passed on Excel to better work on it, to create graphs and well understand all the numbers.
In the measurement period the climate change, different times, from a similar autumn one to a really summer one and this allows some comparisons.

8.3 The collected data

The monitoring campaign conducted for more than a week has allowed the collection of a considerable amount of data that could be used for various related research.

The first step was the comparison between the data measured inside the room, where the measurements were conducted, and those perceived by the weather station located outside the engineering faculty.

External weather conditions clearly affect people's daily clothing. As Matos de Carvalho, Gameiro da Silva and Esteves Ramos demonstrate, the weather for the seven days before the day in question can affect people's outfits. The percentage of engraving can be plotted as a decreasing curve toward the actual reference day. Regarding the discourse of clothing, it was appropriate to calculate the clothing insulation [clo], whose value, if greater or less than 0.7 respectively, allowed us to determine whether we are in a heating or cooling condition.

The determination of this additional unit, together with those defined above, allows the calculation of the PMV and PPD indices, both values that refer to thermal comfort.

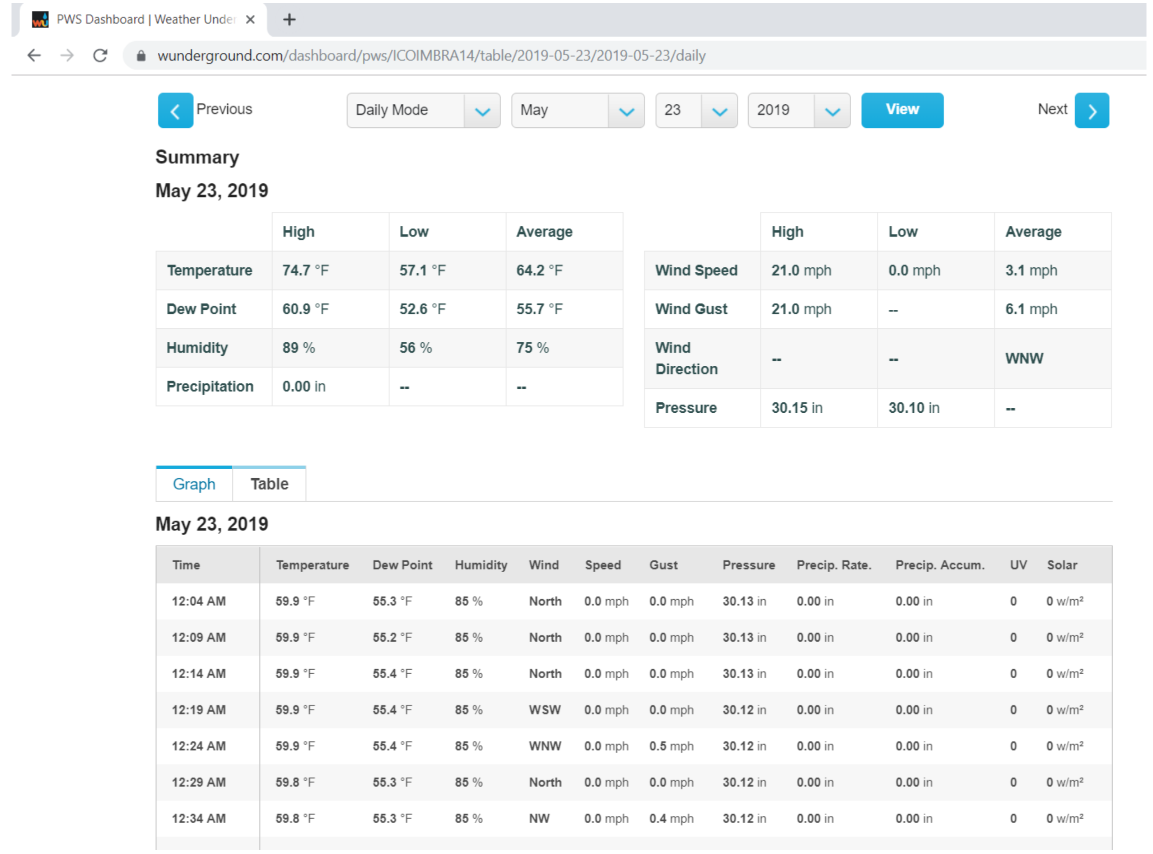
Subsequently, with the VOC values recorded internally, it was possible to define the quality of the indoor air by comparing them with the different ranges present in the colour table with values from 0 to 500.

The next step was to verify, with the help of the reference standards, whether the lighting conditions within the monitoring space were appropriate and enough for the activities carried out in the room. The verification of all these reference indices allows to try to define a single general index that includes them all.

8.3.1 Indoor vs outdoor

The first step to start the work on the data collected was to choose if it was necessary to use all the data measured in the different days or if it was better to select some of them. In relation with the idea of the following steps to do, the decision was to select only two days that had different characteristics. In fact, the days chosen had to represent two models of typical days, one with more spring like characteristics and the other that seems a typically summer day. The indoor data used are the one registered by the multiprobe usb inside the building while the outdoor one was taken by the weather station online site, which refers to the weather station located outside the building considered. In the site used, called "wunderground" it was possible to choose

the correct weather station and to have information about the temperature measured outside, but also about the relative humidity. The data are collected in the website in ranges of 5 minutes and that allows to know deeply the instantaneous climatic variation (even if it less precise than the internal measurement).



PWS Dashboard | Weather Under

wunderground.com/dashboard/pws/ICOIMBRA14/table/2019-05-23/2019-05-23/daily

Previous Daily Mode May 23 2019 View Next

Summary

May 23, 2019

	High	Low	Average
Temperature	74.7 °F	57.1 °F	64.2 °F
Dew Point	60.9 °F	52.6 °F	55.7 °F
Humidity	89 %	56 %	75 %
Precipitation	0.00 in	--	--

	High	Low	Average
Wind Speed	21.0 mph	0.0 mph	3.1 mph
Wind Gust	21.0 mph	--	6.1 mph
Wind Direction	--	--	WNW
Pressure	30.15 in	30.10 in	--

Graph Table

May 23, 2019

Time	Temperature	Dew Point	Humidity	Wind	Speed	Gust	Pressure	Precip. Rate.	Precip. Accum.	UV	Solar
12:04 AM	59.9 °F	55.3 °F	85 %	North	0.0 mph	0.0 mph	30.13 in	0.00 in	0.00 in	0	0 w/m²
12:09 AM	59.9 °F	55.2 °F	85 %	North	0.0 mph	0.0 mph	30.13 in	0.00 in	0.00 in	0	0 w/m²
12:14 AM	59.9 °F	55.4 °F	85 %	North	0.0 mph	0.0 mph	30.13 in	0.00 in	0.00 in	0	0 w/m²
12:19 AM	59.9 °F	55.4 °F	85 %	WSW	0.0 mph	0.0 mph	30.12 in	0.00 in	0.00 in	0	0 w/m²
12:24 AM	59.9 °F	55.4 °F	85 %	WNW	0.0 mph	0.5 mph	30.12 in	0.00 in	0.00 in	0	0 w/m²
12:29 AM	59.8 °F	55.3 °F	85 %	North	0.0 mph	0.0 mph	30.12 in	0.00 in	0.00 in	0	0 w/m²
12:34 AM	59.8 °F	55.3 °F	85 %	NW	0.0 mph	0.4 mph	30.12 in	0.00 in	0.00 in	0	0 w/m²

Figure 54. Capture of the weather station data web page.

In relation to this topic of the temporal scans it must be said that the data recorded by the pen are of 5 seconds in 5, therefore in order to allow the comparison it has been assumed, for the external condition, the variation of the climatic station. This has caused a less fluid graphic representation given by the lack of data very close in time as it is shown in Figures 57 and 58.

The first day was the 23rd of May and his average indoor temperature measured was 23.3° while the outdoor one, in the same range of hours, was 22.0°. For the second day the temperatures were respectively 26.5° and 33.1°.

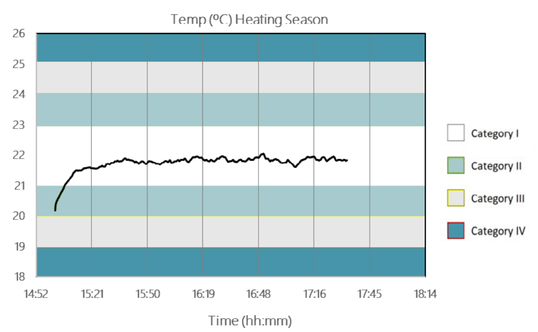
Category	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility.
II	Normal level of expectation
III	An acceptable,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

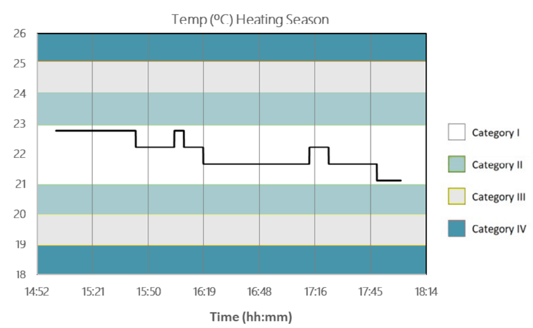
Table 33. Categories definition. [28]

According to the prEN 16798-1 standard four classes are explained. They refer not only to thermal comfort, but also to lighting, acoustic and IAQ. For acoustic and lighting is difficult to apply these categories because it depends a lot from the task of the building. So, the categories are defined for every stressers. [28]

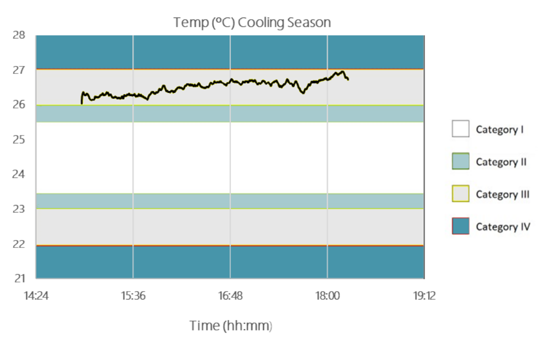
In the graphs below the Indoor Environmental Quality are categorized. If the curve in the graph is located in category I the IEQ is on target, while if it is in category 4 means that is not so comfortable.

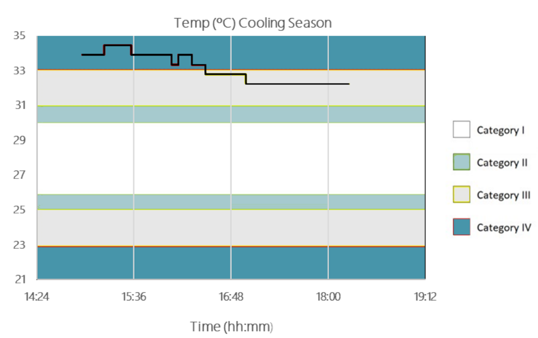
23rd May





31st May

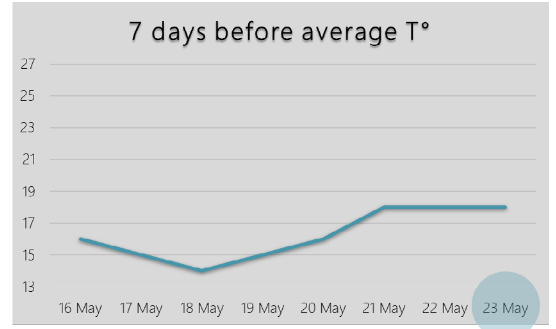


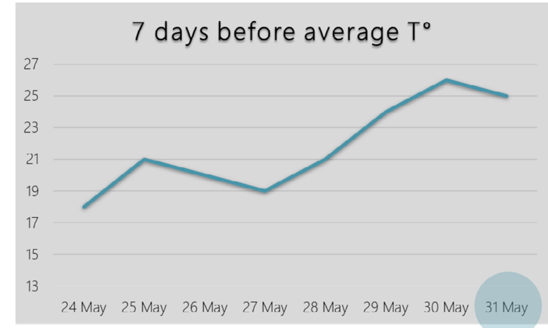


Figures 55 and 56. Indoor air temperature.

Figures 57 and 58. Outdoor air temperature.

To better justify and understand how the previous temperature influence people outfit two graphs that show the trend of the outdoor temperature in the seven days preceding the two reference days were done.





Figures 59 and 60. The average temperature changing during the 7 days before the 23rd and the 31st of May.

People clothes can really allow them to stay in most indoor and outdoor spaces, they provide to create a barrier between human body and the environment, and it is highly influenced by the outdoor average temperature. The clothing insulation, obtained by the information relative to the clothes, is not only influenced by the daily outdoor temperature but also by the seven days before as we said before. This "thermal memory" sometimes, when they are different weather conditions during a week confuses people and leads them to wear clothing that is not suitable for the current day. [29]

8.3.2 Clothing insulation – CLO

One of the most obvious people attitudes is to adapt their selves to the thermal condition (indoor or outdoor) regulating the amount of clothing worn. Wear different types of clothes have influence on the thermal feeling and on the acceptability of certain conditions. [30]

The clothing insulation (Icl) is the value that show the concept explained before and it is estimated by a sum of the different parameters present in the following tables. This units express the clothing insulation that a person could have in an indoor space with an air temperature equal to 21° and a perceived relative humidity with a value under 50%.

There are two kind of approach: the first one is related to a table with a set of possible usual combination of clothes (work clothing or daily wear clothing) while the second is a list of the singular element of clothing with their relative partial values of insulation.

Garment	I_{clu}		Change of optimum operative temperature, °C
	clo	$m^2 \cdot K/W$	
Underwear			
Panties	0,03	0,005	0,2
Underpants with long legs	0,10	0,016	0,6
Singlet	0,04	0,006	0,3
T-shirt	0,09	0,014	0,6
Shirt with long sleeves	0,12	0,019	0,8
Panties and bra	0,03	0,005	0,2
Shirts/Blouses			
Short sleeves	0,15	0,023	0,9
Light-weight, long sleeves	0,20	0,031	1,3
Normal, long sleeves	0,25	0,039	1,6
Flannel shirt, long sleeves	0,30	0,047	1,9
Light-weight blouse, long sleeves	0,15	0,023	0,9
Trousers			
Shorts	0,06	0,009	0,4
Light-weight	0,20	0,031	1,3
Normal	0,25	0,039	1,6
Flannel	0,28	0,043	1,7
Dresses/Skirts			
Light skirts (summer)	0,15	0,023	0,9
Heavy skirt (winter)	0,25	0,039	1,6
Light dress, short sleeves	0,20	0,031	1,3
Winter dress, long sleeves	0,40	0,062	2,5
Boiler suit	0,55	0,085	3,4
Sweaters			
Sleeveless vest	0,12	0,019	0,8
Thin sweater	0,20	0,031	1,3
Sweater	0,28	0,043	1,7
Thick sweater	0,35	0,054	2,2
Jackets			
Light, summer jacket	0,25	0,039	1,6
Jacket	0,35	0,054	2,2
Smock	0,30	0,047	1,9
High-insulative, fibre-pelt			
Boiler suit	0,90	0,140	5,6
Trousers	0,35	0,054	2,2
Jacket	0,40	0,062	2,5
Vest	0,20	0,031	1,3
Outdoor clothing			
Coat	0,60	0,093	3,7
Down jacket	0,55	0,085	3,4
Parka	0,70	0,109	4,3
Fibre-pelt overalls	0,55	0,085	3,4
Sundries			
Socks	0,02	0,003	0,1
Thick, ankle socks	0,05	0,008	0,3
Thick, long socks	0,10	0,016	0,6
Nylon stockings	0,03	0,005	0,2
Shoes (thin soled)	0,02	0,003	0,1
Shoes (thick soled)	0,04	0,006	0,3
Boots	0,10	0,016	0,6
Gloves	0,05	0,008	0,3

Table 34. Clo value for the different clothes. [33]

In relation to the choice of considering only two days with different climatic condition in the analysis conducted, also the CLO was only calculated for these cases. Table 35 shows the final value related to the 23rd of May that was 0.81 while the one of the 31st of May was. The first refers to an outfit composed by the basic underwear, a top, a shirt, a pair of pants, a summer jacket and also to a pair of socks and thatshoes. The sum of all these singular values was 0,81 that is higher the fixed value of 0,7. This result demonstrates that there was a heating condition and outside it was not really warm.
In the second sum the element considered were always the basic underwear, a summer long dress, a pair of socks and also a pair of shoes. The final value resulted 0.31 that is less than 0.7 and it proves the cooling condition needed inside the room to react at the hot climate condition noticed outside.

23rd May	underwear	0.05	**0.81** > 0.7 heating
	top	0.06	
	shirt	0.15	
	pants	0.26	
	summer jacket	0.25	
	socks	0.02	
	shoes	0.02	
31st May	underwear	0.05	**0.31** < 0.7 cooling
	socks	0.02	
	shoes	0.04	
	dress	0.20	

Table 35. Values selected related to the choosen clothes and the results of CLO evaluation.

8.3.3 PMV and PPD

With the collection of all the previous value it is possible to calculate two of the main important thermal comfort indices: the PMV and the PPD. The PMV, as his name tell, is the “Predicted Mean Vote” and it is considered a worldwide standard since the 1980s. It represents what is people reaction to the thermal environment in relation to heat transfer. The variables that affect people responses are the activity level, the clothing insulation, the temperature of the air and the air velocity. If these different variables are mixed in various way, different conditions at which people can react are obtained. Users reaction is expressed by a vote that can be classified in a standard scale. [31]
Usually this indicator is used to understand how much discomfort is present inside an

environment. The scale of evaluation goes by "-3" to "+3" (middle values included). The lower value means "cold" and the higher means "hot". The values in the middle are in sequence from the lower: "cool", "slightly cool", "neutral", "slightly warm" and "warm". These ranges have corrispondent thermal comfort zones called "A,B and C classes" and they are relative exactly to the values from -0.2 to +0.2, -0.5 to +0.5 and -0.7 to +0.7.

To calculate this index it is necessary to know the values of the metabolic rate, the clothing insulation, the air temperature, the mean radiant temperature, the air humidity and the air velocity. If the value obtained is equale to "0" means that the perception of the thermal sensation inside an environment is neutral. [32] [33] [34]

The evaluation by different people in the same space that are wearing the same clothes and working with the same efforts always will be different and to better understand how much people are insatisfied in a precise space heated the PPD that means "Predicted Percentage of Dissatisfied" is used. While with the PMV it is possible to know the mean value of a large number of people, whit this index the number of people that will not feel confortable (hot or cold) is shown. The final value is expressed in percentage. Also for the PPD there are the same classes "A, B and C" mentioned before and in this case they correspond to value under 6, 10 and 15%.

Figure 61 shows the relationship between the two indices. In the thermal neutrality position on the curve, when PMV is equal to zero, the percentage of insatisfied people still corresponds to a minimum of insatisfied people that is the 5%. This means that 2.5% will feel cold and the other 2.5% will feel warm. [33] [34]

These two indices help to answer at questions like how much an indoor environment is far from a perfect situation and it has the right balance between air temperature and relative humidity.

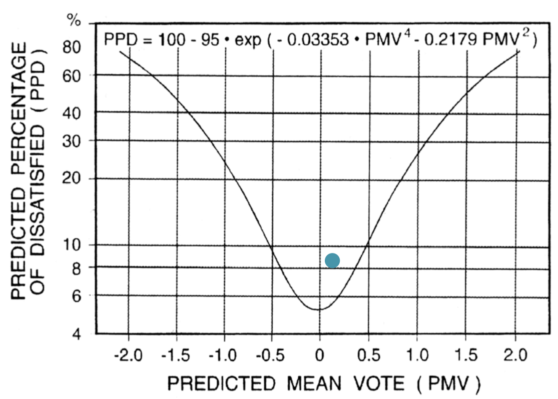


Figure 61. Position of PMV and PPD values obtained. [33]

To calculate these two indices starting from the values obtained by the monitoring session it was used a simplified spreadsheet in Excel. Graphically the table for the calculation is divided in three column: the first one from the left must be filled by the user with the informations needed, the second has the intermediate values and the third and last one show the final result of the two indices. After the insertion of the data is just necesarry to click the "Run" button and in no more than one second the result will apear. The data insert must be included in the ranges defined by ISO 7730.

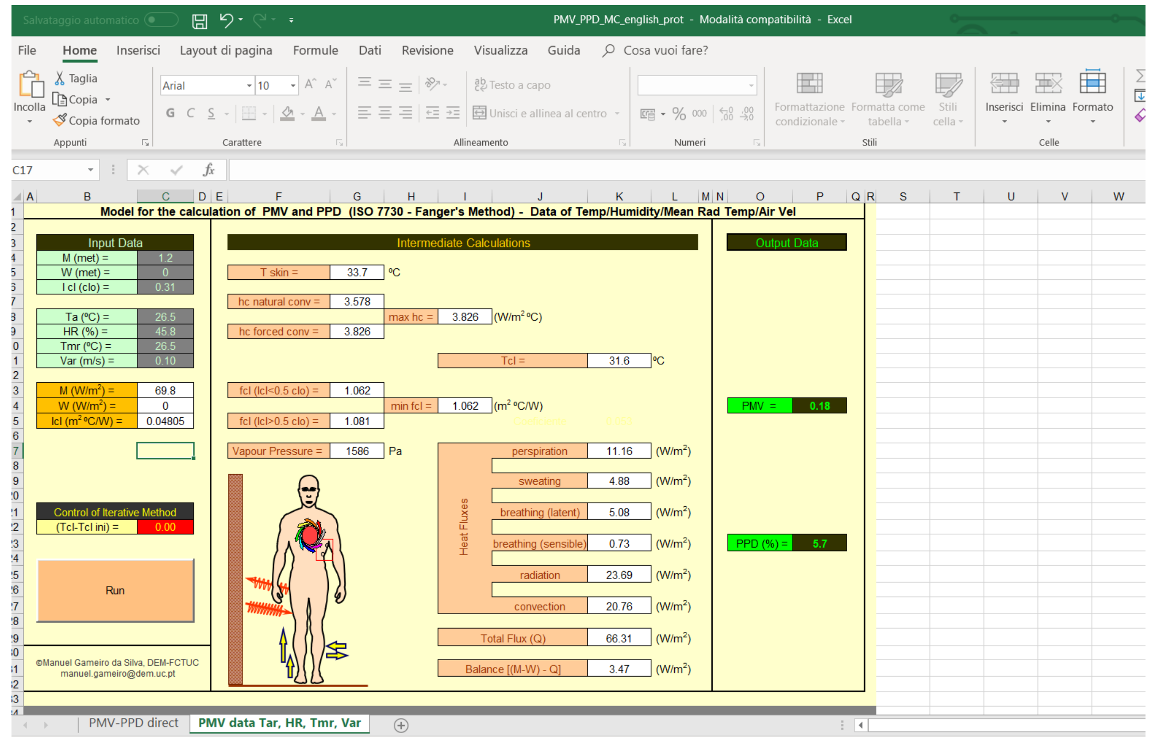


Figure 62. Capture of the Excel table for the calculation of the PMV and PPD values.

For the 23rd of May the data inserted were respectively 23.3° for the average temperature, 55.6% for the relative humidity and 0.81 for the clo. Instead the values enetered for the 31st of May were in order 26.5° [C°], 45.8 [%] and 0.31 [clo]. For both cases the values considered for the methabolic rate and the air velocity were respectively 1.2 [met] and 0.1 [m/s].

The results of the calculation of PMV for the two days were 0.17 in the first case and 0.18 in the second one so they can be placed in the range between 0 (neutral) and 1

(slightly warm). However, the values are much closer to the zero and it means that the indoor condition was almost neutral and not far from the optimal comfort sensation.
The image X shows how the spreadsheet that appears once the users open the excel file and it is refered to the calculation of the 31st of May.
Meanwhile, with the same spreadsheet and the same data entered was also obtained the PPD value. In the first day the percentage of people dissatisfied was 5.6% while in the second was 5.7%. This means that the results correspond to A class with a percentage less than 6%.

8.3.4 VOCs

The following step was to classify the VOC in relation to the coloured table. The VOC (Volatile Organic Compounds) are basically the gases that some substances could emitt. A lot of some ours daily element used contain VOCs like for esample parfumes, ckeanser, paints and also some building materials or elements that contain glues. All this component create air pollution.
Usually there are more emissions in the internal spaces than the external and they create effects on the health occupant and his work efficancy. The easier and natural way to reduce these effects is the ventilation increase but it is clearly that it would be better to reduce or avoid the emissions. [35]

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
301 to 500	Hazardous	Maroon

Table 36. AQI categories. [36]

If there are values of VOC it is possible to define the range of air quality in accordance with the colour of Table 36. Usually to find the range an average between the main pollutants (CO, SO2, O3, ...) is done but it is also allowed to use just one of them. The measurement taken in both the days chosen for this research gave values of VOCs under 50. The first day values range was between 30 and 43 while the 31st of May the range was between 9 and 13. This can be explained because in the second day there was more ventilation due to the high temperature and in fact, it reduced the VOC concentration. The range between 0 and 50 corresponds to the green colour and it means that the AQI is "good" or "healthy". This category certifies that the pollution detected doesn't create risks, or in case they are small ones. [36]

8.3.5 Illuminance

The information related to the lights are all contained in the European Standard UNI EN 12464-1, in which all the minimum illuminance requires for indoor work places to guarantee the visual comfort are defined. The minimum lux required for school rooms are from 300 to 500. In the first day chosen, the 23rd of may the average of lux data was 310.2 while the ones related to the 31st was 341.5. These values are only related to natural light because during the monitoring session no type of artificial light was used. The difference between the two days are always influenced by the weather that was definitely more sunny the 31st. [37]
Once they are all these different indices it is appropriate to try to think about a unique index that puts them all together. Buratti, Belloni, Merli and Ricciardi try to do this creating an index called ICC (Combined Comfort Index). They start obtaining the single indices: thermo-hygrometric, acoustic, and visual one. After the weighting of each of them they obtained the final index. [24]

9 Conclusions

With the application of the calculation methodology proposed by the European project different criticalities have emerged in the logic of this indicator. The SRI calculation in based on a check-list approach, including a set of 112 services (52 of which are considered the commonest) to which the analyst has to define a smart readiness score (from -4 until +4). The calculation process does not provide a least number of obligatory services to be considered. For this reason, it becomes difficult to compare different cases study in objective way, because it seems that each technician has the freedom of choosing in subjective way the number of services to be considered in the calculation.

The logic of calculation relative to the choice of the domain adopts a system that consists in non-considering the whole domain if it does not match a preselection. This involves the exclusion of some hypothetically present services inside the domain due to a superficial selection of which domain is considered. This logic, which is not clearly defined at the moment, implies a possible manipulation of the final result since to obtain the percentage of SRI it is then necessary to subdivide the value obtained by the number of domains considered in the calculation. Consequently, if a smaller number of domains containing services with a higher level of functionality is chosen to evaluate, a higher value of the indicator is obtained than if the actual number of domains present is considered, even if with services with a lower level of functionality or even not present. This choice of domains to be considered is at the discretion of the technician who will perform the calculation.

The calculation methodology needs to define a table of the weights that could be able to lead the comparison, in an objective way, of different buildings assessable in term of SRI. This is not allowed since the technician has freedom of decision based on factors he will choose to consider or not for the purposes of the calculation. This involves the probable obtaining of different values of the indicator relative to the same building but processed by different experts.

Finally, the document provided is already lacking in the first phase of the calculation because some of the 112 services in the list are not well explained, or sometimes it is not very clear the definition of the different levels of functionality and the difference between them. Some of the services are also repeated in multiple domains because they are inherent to both, but in that case would it be appropriate to consider them only once? Or two?

The illustration of the calculation in the document of the European project is shown step by step only for a single case study, while in the others the result is simply reported in percentage without an explanation of the passages. The in-depth case study is not completed with clear passages until the conclusion of the procedure, but it lacks precise and specific explanations in the fundamental step in which weights are assigned to the different categories. These lacks in the description makes the rest of the methodology misunderstood and inaccurate.

The criticism descripted could be solved and clarified with an implementation of the document of the European project. This calculation methodology should be tested on several buildings in order to refine all the steps. For example, by carrying out more tests on different buildings with different locations, it might be possible to establish univocal table of weights that can be used by different technicians. The same applies to the choice of services to be considered in the calculation: it would be suitable that in accordance to the final use of the building considered in the calculation there was an order of priority to be followed in the selection of services. These improvements in the description of the methodology would allow Member States, that choose to adopt this indicator, to carry out the calculation precisely, obtaining an objective result.

In conclusion, it can be said that the indicator actually respects the definition with which it was introduced and its evaluation gives an idea of how intelligent the building is, how ready it is to be flexible in adapting to continuous changes in order to meet the needs of the user and the network. With the introduction of automation systems it would be possible to have a large amount of data and information useful to make the building ready to react and to obtain consequently also improvements in terms of energy efficiency. However, this tool should not be seen as a substitute, but rather as complementary to the existing and widely established evaluation procedures used to describe the building from other points of view.

References

[1] Enocean-alliance, Analysis of EPBD 2018 regarding re-quirements for building automation, https://www.enoceanalliance.org/wpcontent/uploads/2019/03/EPBD_EN.pdf

[2] Mariangiola Fabbri, Maarten De Groote, Oliver Rapf, Building renovation passports – Customized roadmaps towards deep renovation and better homes, BPIE, 2016.

[3] THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Official Journal of the European Union, 2018.

[4] Maarten De Groote, Mariangiola Fabbri, Jonathan Volt, Oliver Rapf, Smart buildings in a decarbonised energy system - 10 principles to deliver real benefits for europe's citizens, BPIE (2016).

[5] Nesen Sürmeli-Anac, Andreas H. Hermelink, The Smart Readiness Indicator: A potential, forward-looking Energy Performance Certificate complement?, ECOFYS, 2018.

[6] BPIE (Buildings Performance Institute Europe), ENERGY PERFORMANCE CERTIFICATES ACROSS THE EU - A MAPPING OF NATIONAL APPROACHES, October 2014.

[7] THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, Official Journal of the European Union, 2010.

[8] Kamila Borsekova, Samuel Koróny, Anna Vaňová, Katarína Vitálišová, Functionality between the size and indicators of smart cities: A research challenge with policy implications, Cities 78 (2018), 17–26.

[9] Verbeke S., Waide P., Bettgenhäuser K., Uslar M.; Bogaert S. et al., SUPPORT FOR SETTING UP A SMART READINESS INDICATOR FOR BUILDINGS AND RELATED IMPACT ASSESSMENT FINAL REPORT, VITO, 2018.

[10] Clara Benevolo, Paola Dameri, La smart city come strumento di green development. Il caso di Genova Smart City, Impresa Progetto - Electronic Journal of Management n°3, 2013.

[11] Maarten De Groote, Jonathan Volt, Frances Bean, Is Europe ready for the smart buildings revolution? Mapping smart-readiness and innovative case studies, BPIE (2017).

[12] European commission, Evaluation of the Energy Performance of Buildings Directive 2010/31/EU (2015).

[13] Peter Wouters, Jens Laustsen, The smartness indicator, REHVA Journal April (2017), 19-22.

[14] Giuliano Dall'O', Elisa Bruni, Angela Panza, Luca Sarto, Fazel Khayatian, Evaluation of cities' smartness by means of indicators for small and medium cities and communities: A methodology for Northern Italy, Sustainable Cities and Society 34 (2017), 193-202.

[15] Verbeke S., Waide P., Bettgenhäuser K., Uslar M.; Bogaert S. et al., SUPPORT FOR SETTING UP A SMART READINESS INDICATOR FOR BUILDINGS AND RELATED IMPACT ASSESSMENT EXECUTIVE SUMMARY of FINAL REPORT, VITO, 2018.

[16] The European Alliance of Companies for Energy Efficiency in Buildings, A Guide to the Implementation of the Amended Energy Performance of Buildings Directive (EPBD) 2018, EuroACE (2018).

[17] Jarek Kurnitski, Jaap Hogeling, Smart Readiness Indicator (SRI) for buildings not so smart as expected, REHVA Journal August (2018), 6-9.

[18] David Arditi, Giulio Mangano, Alberto De Marco, Assessing the smartness of buildings, Facilities Vol 33 No. 9/10 (2015), 553-572.

[19] Riccardo Sanna, Sviluppo di una metodologia per la realizzazione di un sistema ICT finalizzato a stimolare il cambiamento comportamentale tramite l'utilizzo di dati sull'uso dell'energia, IEQ e salute, POLITECNICO DI TORINO (2016/2017).

[20] Luísa Dias Pereira, Daniela Raimondo, Stefano Paolo Corgnati, Manuel Gameiro da Silva, Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: Methodology and results, Building and Environment 81

(2014), 69-80.

[21] Luísa Dias Pereira, João Dias Carrilho, Nelson Silva Brito, Maria Rocheta Gomes, Mário Mateus, Behrang Chenari, Manuel Gameiro da Silva, Teaching and researching the indoor environment: From traditional experimental techniques towards web-enabled practices, Sustainable Cities and Society 26 (2016), 543–554.

[22] Manuel Gameiro da Silva, João Dias Carrilho, Leo Van Cappellen, John Van Putten, Bart Smid, Gemeentehuis Horst aan de Maas: A Case of Excellence in Indoor Environmental Quality, REHVA Journal (2018), 40-50.

[23] Ehsan Majd, Meredith McCormack, Meghan Davis, Frank Curriero, Jesse Berman, Faith Connolly, Philip Leaf, Ana Rule, Timothy Green, Dorothy Clemons-Erby, Christine Gummerson, Kirsten Koehler, Indoor air quality in inner-city schools and its associations with building characteristics and environmental factors, Environmental Research 170 (2019), 83–91.

[24] C. Buratti, E. Belloni, F. Merli, P. Ricciardi, A new index combining thermal, acoustic, and visual comfort of moderate environments in temperate climates, Building and Environment 139 (2018), 27–37.

[25] Minyoung Kwon, Hilde Remøy, Andy van den Dobbelsteen, Ulrich Knaack, Personal control and environmental user satisfaction in office buildings: Results of case studies in the Netherlands, Building and Environment 149 (2019), 428–435.

[26] Wonyoung Yang, Hyeun Jun Moon, Combined effects of acoustic, thermal, and illumination conditions on the comfort of discrete senses and overall indoor environment, Building and Environment 148 (2019), 623–633.

[27] Manuel Carlos Gameiro da Silva, L.W. van Cappellen, Eduardo Sanjuanello, Assessing and Communicating Indoor Environmental Quality, REHVA Journal April (2019), 14-18.

[28] UNI EN 16798-1: 2019, Prestazione energetica degli edifici - Ventilazione per gli edifici - Parte 1: Parametri di ingresso dell'ambiente interno per la progettazione e la valutazione della prestazione energetica degli edifici in relazione alla qualità dell'aria interna, all'ambiente termico, all'illuminazione e all'acustica - Modulo M1-6

[29] Paulo Matos de Carvalho, Manuel Gameiro da Silva, João Esteves Ramos, Influence of weather and indoor climate on clothing of occupants in naturally ventilated school buildings, Building and Environment (2012), 1-9.

[30] Rajan Rawal, Sanyogita Manu, Yash Shukla, Leena E. Thomas, Richard de Dear, Clothing insulation as a behavioural adaptation for thermal comfort in Indian office buildings, Windsor Conference 2016 - Making Comfort Relevant April (2016), 403-415.

[31] Runming Yao, Baizhan, Jing Liu, A theoretical adaptive model of thermal comfort – Adaptive Predicted Mean Vote (aPMV), Building and Environment 44 (2009), 2089–2096.

[32] UNI EN ISO 7726: 2002, Ergonomia degli ambienti termici - Strumenti per la misurazione delle grandezze fisiche

[33] UNI EN ISO 7730: 2006, Ergonomia degli ambienti termici - Determinazione analitica e interpretazione del benessere termico mediante il calcolo degli indici PMV e PPD e dei criteri di benessere termico locale https://www.academia.edu/33766999/Ergonomics_of_the_thermal_environment_Analytical_determination_and_interpretation_of_thermal_comfort_using_calculation_of_the_PMV_and_PPD_indices_and_local_thermal_comfort_criteria

[34] Manuel Carlos Gameiro da Silva, SPREADSHEETS FOR THE CALCULATION OF THERMAL COMFORT INDICES PMV AND PPD, August (2013).

[35] EPA, AQI Air Quality Index – A Guide to Air Quality Your Health, February (2014). https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

[36] Sarath Guttikunda, Air Quality Index (AQI): Methodology & Applications for Public Awareness in Cities, SIM series 34 (2010), 1-13.

[37] UNI EN 12464-1:2011, Luce e illuminazione - Illuminazione dei posti di lavoro - Parte 1: Posti di lavoro in interni

[38] OROLOGIO LIVING APARTMENTS TORINO: https://www.orologio-residence.com/appartamenti/