A methodology for the digitalization of buildings

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Master of Science in Architecture
Construction and City

MASTER THESIS PROJECT

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To the generation that grows up by taking for granted what it is to defend itself in this world, it will have to study, acculturate and graduate.

To the generation that wants to travel, experiment and discover before thinking about creating a family.

To the generation for which English is an obvious way of communication.

To the generation of Smartphones, Google and Social Networks.

To the generation for which recycling is a daily habit and global warming an imminent problem.

To the generation of Euro, InterRail, Erasmus and #FridaysForTheFuture.

To "our European" generation that believes in our planet and wants to try to safeguard it.

Alla generazione che cresce conscia che per difendersi in questo mondo dovrà studiare, acculturarsi e laurearsi.

Alla generazione che vuole viaggiare, sperimentare e scoprire prima di pensare a mettere su una famiglia.

Alla generazione per cui l'inglese è uno scontato mezzo di comunicazione.

Alla generazione degli Smartphone, di Google e dei Social Network.

Alla generazione per cui la raccolta differenziata è un'abitudine quotidiana ed il riscaldamento globale un problema imminente.

Alla generazione dell'Euro, dell'InterRail, dell'Erasmus e dei #FridaysForTheFuture.

Alla generazione di "noi Europei" che crede nel nostro pianeta e vuole provare a salvaguardarlo.

Abstract

The current generation, called “Generation C” (for “connected”), has grown up in a primarily digital world. Computers, Internet, mobile phones, social networks: the effects of an increasingly digitized society are now reaching every corner of our lives and buildings make no exception.
But in the next future, if from one side we will be dominated by a “Digital Revolution”, on the other hand, the climate changes and our increasingly weak and resourceless planet will no longer be negligible.
“Save our planet” seems to be the new unattainable goal and talking about buildings, the “de-carbonization” should be the ambitious target for the next future. New technologies and instruments are available to increase the buildings performances and ef-

ficiency and to reach the final goal of reducing the buildings CO_2 emissions (that assume a third part of the world total amount).

To help this difficult path, the last year revised European Directive 2018/844/EU (amending the previous Energy Performance Building Directive - EPBD, 2010/31/EU and Energy Efficiency Directive, 2012/27/EU) gives interesting messages to be interpreted in order to push the building performances towards a new era.

New investments, strategies and objectives are presented with a new instrument, still to be studied and developed, which define and try to evaluate the buildings “Intelligence”: The “Smart Readiness Indicator (SRI)”.

This thesis research project starts from the Indicator study and analysis. The aforementioned tool, still under definition and current topic of discussion in Bruxelles, fixes the building concept like interconnected, flexible, automated, highly energy efficient and presented it like an entity who covers its very low energy demand to a large extent by on-site or district-system-driven renewable energy sources. It puts in communication its systems with the grid and in relation with occupants activities and needs. Efficiency, flexibility and Comfort are the three building keywords that through the Digitalization process allows the building to take part in the energy demand response, interacting with the external environment and with the users, guaranteeing comfort and well-being.

The “Building Digitalization”, widely analysed in this work, does not refer only to an Automation procedure using Sensor, Appliances and Actuators but also to a real digital development that exploits data from these systems e gives an Artificial Intelligence (Predictive algorithm, Learning Machine and IoT systems) to buildings. The thesis final objective is to define a “Building Digitalization methodology”.

To reduce emissions, to save consumers money lowering building energy bills and maintenance costs, but also optimize the occupants’ comfort, health and security are the starting objectives, used to classify and list the related instruments needed to define the methodology.

The plan, related for a residential house aims to bring the building closer to the European “Smartness” model, allowing it to reach a high score in the new indicator (SRI) rating.

Making our buildings “smart” must be the new challenge for the next decade, to achieve maximum efficiency of new and existing buildings. In this way, the technology could be the key to improve our lifestyles, but mostly a way to save the planet where we live in.

Thesis key words: *Smart Building, Efficiency, Flexibility, Comfort, Digitalization, Smart Readiness Indicator (SRI), Internet of things (IoT), Artificial Intelligence (Ai), Sensors, Actuators*

Abstract

L' attuale generazione, chiamata "Generation C" (per "connesso"), è cresciuta in un mondo prevalentemente digitale. Computer, Internet, telefoni cellulari, social network: gli effetti di una società sempre più digitalizzata stanno raggiungendo ogni angolo della nostra vita e gli edifici non fanno eccezione.
Nel prossimo futuro, se da una parte saremo dominati da una "Rivoluzione Digitale", dall'altra parte, i cambiamenti climatici e il nostro pianeta sempre più debole e privo di risorse non saranno più trascurabili.
"Salvare il nostro pianeta" sembra essere il nuovo obiettivo irraggiungibile e parlando di edifici, la "de-carbonizzazione" dovrebbe essere l'obiettivo ambizioso per il prossimo futuro. Sono disponibili nuove tecnologie e strumenti per aumentare le pre-

stazioni, massimizzare l'efficienza e per raggiungere l'obiettivo finale di ridurre le emissioni di CO_2 degli edifici (che rappresentano un terzo della quota mondiale).

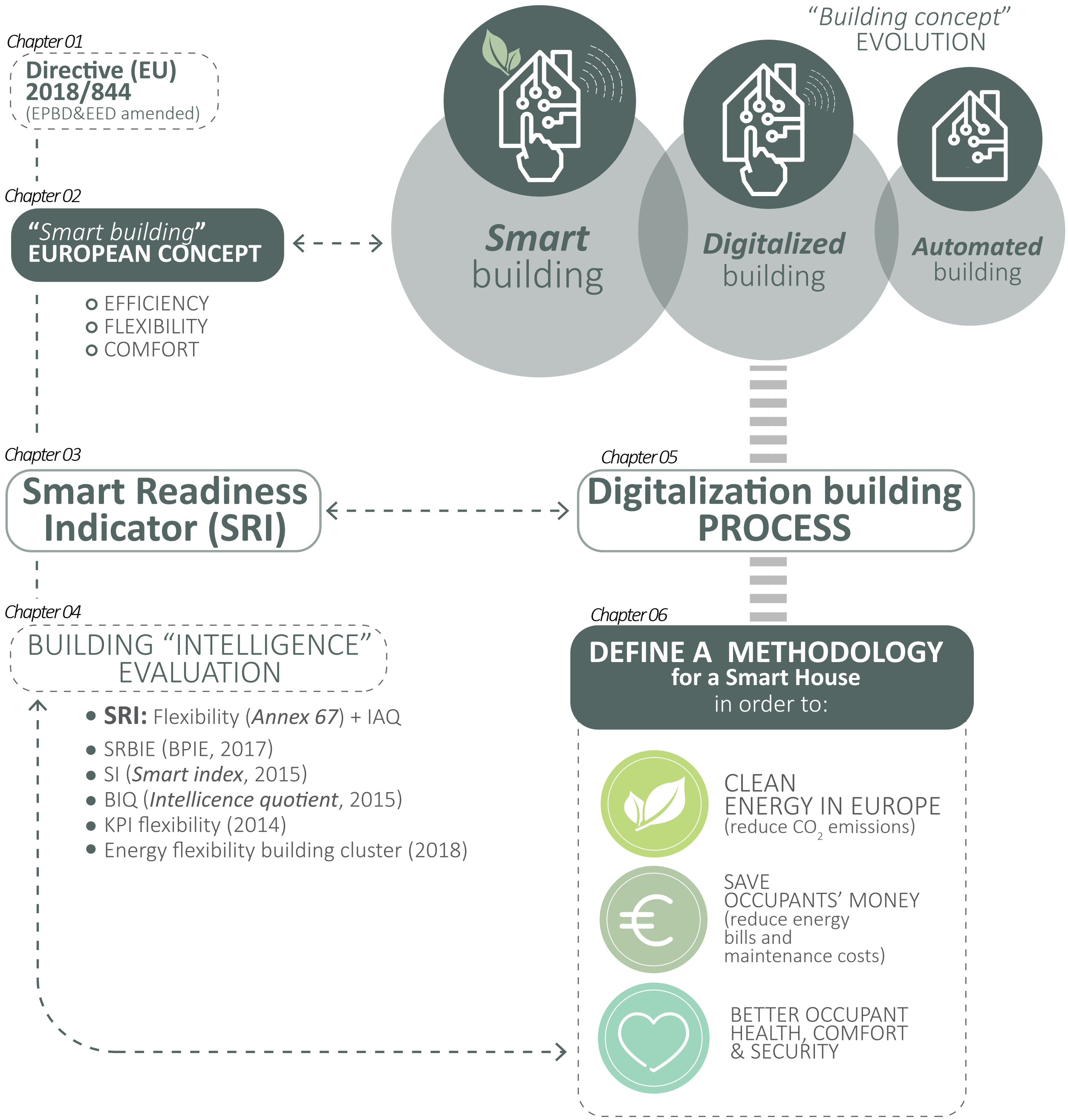
Per aiutare in questo difficile percorso, l'ultima revisione della Direttiva Europea 2018/844/UE (che modifica la precedente direttiva sul rendimento energetico - EPBD, 2010/31/UE e direttiva sull'efficienza energetica, 2012/27/UE) offre interessanti messaggi da interpretare per guidare le performance degli edifici verso una nuova era. Vengono presentati nuovi investimenti, strategie e obiettivi, ma anche un nuovo strumento, ancora da studiare e sviluppare, che definisce e prova a valutare l' "Intelligenza" degli edifici: lo "Smart Readiness Indicator (SRI)".

Questo progetto di ricerca di tesi parte dallo studio e dall'analisi dell'indicatore. Il suddetto strumento, ancora in fase di definizione e attuale argomento di discussione a Bruxelles, fissa un nuovo concetto di edificio come interconnesso, flessibile, automatizzato, altamente efficiente dal punto di vista energetico e che copre la sua bassissima domanda di energia in gran parte da fonti energetiche rinnovabili in loco o alla scala del distretto. Esso mette in comunicazione i suoi impianti con la rete e in relazione con le attività e le esigenze degli occupanti. Efficienza, flessibilità e comfort sono le tre parole chiave dell'edificio che grazie al processo di digitalizzazione risponde della domanda energetica, interagendo con l'ambiente esterno e con gli utenti a cui garantisce comfort e benessere.
La "Digitalizzazione degli edifici", ampiamente analizzata in questo lavoro, non si riferisce solo a una procedura di automazione che utilizza "sensors", "appliances" e "actuators", ma anche a un vero sviluppo digitale che sfrutta i dati provenienti da questi sistemi e fornisce un'intelligenza (Ai, Predictive algorithm, Learning Machine and IoT systems) agli edifici. L'obiettivo finale della tesi è quello di definire una "Metodologia per la digitalizzazione degli edifici".

Ridurre le emissioni, far risparmiare denaro ai consumatori riducendo le bollette e i costi di manutenzione, ma anche ottimizzare il comfort, la salute e la sicurezza degli occupanti sono gli obiettivi iniziali, utilizzati per individuare e classificare gli strumenti necesari per definire la metodologia. Il piano, redatto per una casa residenziale, vuole avvicinare l'edificio al modello "smartness" come definito a livello europeo consentendogli di raggiungere un punteggio alto nel calcolo del nuovo indicatore (SRI).
Rendere i nostri edifici "intelligenti", "smart" deve essere la nuova sfida per il prossimo decennio, per raggiungere la massima efficienza degli edifici nuovi ed esistenti. In questo modo la tecnologia potrebbe essere la chiave per migliorare i nostri stili di vita, ma soprattutto un modo per salvare il pianeta in cui viviamo.

Parole chiave della tesi: Smart Building, Efficienza, Flessibilità, Comfort, Digitalizzazione, Smart Readiness Indicator (SRI), Internet of things (IoT), Artificial Intelligence (Ai), Sensori, Attuatori.

Questa tesi è stampata su carta riciclata, come simbolo di un impegno costante e quotidiano di attenzione all'ambiente, in congruenza con le tematiche trattate in questa ricerca ed i propositi prefissi dall' Unione Europea per il prossimo futuro.


Chapter 01
Directive (EU) 2018/844
(EPBD&EED amended)
Chapter 02
"Smart building"
EUROPEAN CONCEPT
EFFICIENCY
FLEXIBILITY
COMFORT
"Building concept"
EVOLUTION
Smart building
Digitalized building
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SRI: Flexibility (Annex 67) + IAQ
SRBIE (BPIE, 2017)
SI (Smart index, 2015)
BIQ (Intellicence quotient, 2015)
KPI flexibility (2014)
Energy flexibility building cluster (2018)
Chapter 06
DEFINE A METHODOLOGY
for a Smart House
in order to:
CLEAN ENERGY IN EUROPE
(reduce CO_2 emissions)
SAVE OCCUPANTS' MONEY
(reduce energy bills and maintenance costs)
BETTER OCCUPANT HEALTH, COMFORT & SECURITY

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"Europeans spend more than 90% of their lifetime in the buildings." [1]

"Buildings cause 35% of all CO_2 emissions." [2]

“Save the planet” is the goal...

to use “technology”: the solution.

Introduction

Time flows and we do not see it; the earth revolves around itself, but we do not notice it; our beloved planet and the society where we live changes, grows, evolves “under our eyes”, often without giving us the time to realize it.

This process of evolution, once slow and not always perceptible, is now increasingly accelerated. The technology revolution we are living in is the main character. The world becomes more computerized and digitalized day after day, hour after hour at an increasingly urgent pace, so much so that it begins to be visible and perceptible to human perception in its daily existence. New technologies, artificial intelligence are taking over our lives, they will manage our cities and they are entering much faster than we believe inside our homes. The buildings of the future will study and control us, they will know our tastes, habits and how to satisfy our every need even before our brain has time to realize it.

If a total loss of privacy will be the price to pay in exchange for comfort and well-being, on the other hand, we must pay attention to our increasingly weak and resource less planet. Fortunately, nowadays the climate change topic is increasingly "in fashion" and imminent. "Save the planet" seems to be the new unattainable goal, even because terms, strategies and tools to try to achieve this goal are not always clear.
Talking about buildings and architecture, the "**de-carboniza-tion**" should be the ambitious target for the next future."With the growing share of renewable energy by PV and wind, balancing energy supply and energy needs become increasingly important."[3] New instruments are available to increase the buildings performances and efficiency, and to reach the final goal of reduce the buildings CO_2 emissions (that assume a third part of the world total amount).

At the building level itself, smart building design and control technologies can improve indoor climate conditions and at the same time empower building occupants by providing information on energy use and indoor climate conditions. [4] These new technologies and "intelligent" systems already exist and need only to be legislated, applied and evaluated.

To help this difficult path, the last year revised **European Directive 2018/844/EU** (amending the previous Energy Performance Building Directive - EPBD, 2010/31/EU and Energy Efficiency Directive, 2012/27/EU) gives interesting messages to be interpreted in order to push the building performances towards a new era. Keep high comfort, ensuring energy efficiency/flexibility and high indoor environmental quality levels by a new design and operational approach for buildings based on "de-carbonization": this is the ambitious target for the next future and a new vision and new goals for a decarbonised building stock by 2050.
New instruments are needed and the revised EPBD&EED is giving directives to the member states let these become law before march 2020. New investments, strategies and objectives but also new instruments and methodologies to be studied and developed like a new "**smart indicator**" that leave a new path for a "**building digitalization**" process.

Making buildings "smart" must be the new challenge for the next decade, as a tool to achieve maximum efficiency of new and existing buildings in order to reduce their CO_2 emissions as much as possible.

Technology used in the right way can be the key to improve our life styles, but mostly a way to save the planet where we live in.

Thesis objectives

This final thesis objective aims to define a "**Building Digitalization methodology**" to clean Energy in Europe lowering the CO_2 emissions, to save consumers money reducing building energy bills and maintenance costs, but also to optimize the occupants' comfort, health and security. The plan, related for a residential house is organized in order to reach the new European "Smart Building" concept but also to allow the building to get close to the maximum new indicator (SRI) score.

In order to identify the best solution to apply to achieve this objective, extensive researches and bibliographic analysis have been carried out. Starting from European Directives and the "Smart Readiness Indicator project" in-depth analysis and calculation of the new indicator were applied.

An in-depth research and reading of scientific articles has led to an in-depth study of various topics such as: the concept of "Smart Building"; chronological definitions and features of the intelligent buildings; building evaluation systems and tools; indoor air quality and evaluation; concept of flexibility and relative measurement; smart city and examples; digitization processes; the occupant behaviour; IoT and Automation. This investigation was carried out through researches in specific scientific journals such as the REVHA journal following its online publications but also some Scientific articles search engines like "Science Direct" or "Research Gate".

However, the research also covered reports and projects by national, European and international institutions and bodies that are dealing with these issues: in particular, in addition to the European Commission, we can mention the BPIE (Buildings Performance Institute Europe), the EuroACE (European Alliance of Companies for Energy Efficiency in Buildings), ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development) and the IEA (International Energy Agency).

Following this analysis, the definition of the objectives and requirements to draw up the plan was necessary. Some categories and elements of classification are defined in order to list the technologies (devices and process) needed.

A practical application of the methodology presented in this thesis would be interesting to test it and is left for future developments. Following its implementation, a measurement of the building before and after the digitization intervention should be made using the SRI indicator. For its application, specific knowledge regarding then IT systems and solutions developed within the text, but not analyzed in detail could be required. In the concluding chapter, some themes and ideas are also presented for future research and debates always linked to the Building digitalization and the concept of "Smartness" also seen on a larger scale. The most popular question is: "Are we ready for a Smart Revolution?"

Structure of the thesis

The thesis is organized in seven chapters followed by some diagram, schemes and tables attached.

Following this introduction a first **CHAPTER (01_ European directives: EPBD & EED)** presents the starting point for all the work done: the European Legislation. The European directives are analysed from the first one to understand their process and how the building concept has evolved through them. An analysis was carried out highlighting the first articles and quotations referring to the "Smart Buildings" concept. Particular attention is given to the last directive (EPBD2018 - Directive (EU) 2018/844) of which articles and main objectives are catalogued. Obviously the SRI topic is highlighted.

The second **CHAPTER (02_"Smart Building" concept)** aims to define and summarize the "Smartness" European concept, analyzed the "Smart building" features, needs and fundamental principles. Its structure is presented in order to introduce the SRI, to which the third **CHAPTER (03_ Smartness Readiness Indicator)** is dedicated. The ongoing European project and its methodology is explained through the presentation of some case studies. The SRI strengths, weaknesses and future developments are analyze to be compared in the following CHAPTER **(04_Building "Intelligence" evaluation)** with other previous indicators and building intelligence evaluation methods.

The fifth **CHAPTER (05_Building Digitalization)** moves towards the digitalization process, categorizing the subtle differences between Automated, Digitized and Smart Building. For all the phases of this evolving concept, the necessary tools and technologies are defined, including the processes and key points. Particular attention is paid to new technologies (IoT, Ai, Sensors, Actuator and devices) through studies and real applications. Another fundamental point is the Occupant role, analysed through simulated process examples.

The sixth **CHAPTER (06_Digitalization process for a Smart House)** presents through the results obtained from this analysis an application of the concepts studied with the presentation of a methodology for the Digitization of a residential building. Diagrams and tables have been drawing up to define instruments and technologies needed. The role of each individual element is explained by emphasizing the Central Unit main character and the User Interface necessity.

In the seventh and last **CHAPTER (07_Conclusion and future developments)** a critical analysis of the previous methodology is presented, followed by advices and problems in its evaluation through indicators. The building de-carbonization is the final challenge proposed with a technological key solution. It is expanded on a wider context: the city and the European perspective, leaving room for future developments.

In **attachments**, some methodology scheme, official European sheets and some results are reported to approve and clarify some details of the presented work.

Introduzione

Il tempo passa e noi non lo vediamo; la terra ruota intorno a se stessa, ma noi non ce ne accorgiamo; il nostro amato pianeta terra e la società in cui viviamo cambia, cresce, si evolve sotto i nostri occhi, spesso, senza darci il tempo di rendercene conto.

Questo processo di evoluzione, una volta lento e non sempre percepibile, oggigiorno è sempre più accelerato. La rivoluzione tecnologica che stiamo vivendone è l'attore protagonista. Il mondo si informatizza sempe di più giorno dopo giorno, ora dopo ora ad un ritmo che aumenta esponenzialmente tanto da cominciare ad essere, per la prima volta, visibile e riconoscibile alla percezione umana nel suo quotidiano. Le nuove tecnologie, le intelligenze artificiali stanno prendendo il sopravvento sulla nostra vita, gesti-

ranno le nostre città e stanno entrando molto più velocemente di quello che crediamo all'interno delle nostre case. Gli edifici del futuro ci studieranno e ci controlleranno, sapranno i nostri gusti, abitudini e come soddisfare ogni nostra esigenza ancora prima che il nostro cervello abbia il tempo di esternarla.

Se una totale perdita della privacy sarà il prezzo da pagare in cambio di comfort e benessere, dall'altro lato bisogna fare attenzione al nostro pianeta sempre più debole e privo di risorse. Fortunatamente, al giorno d'oggi il tema del cambiamento climatico è sempre più "di moda" ed imminente. "Salvare il pianeta" sembra essere il nuovo obiettivo irraggiungibile, anche perché i termini, le strategie e gli strumenti per raggiungerlo questo obiettivo non sono sempre chiari.

*Parlando di edifici ed architettura, la "***de-carbonization***" dovrebbe essere l'obiettivo ambizioso per il prossimo futuro. "Con la crescente quota di energia rinnovabile dal fotovoltaico all'eolico, il bilanciamento dell'offerta di energia e del fabbisogno energetico diventa sempre più importante." [3] Nuovi strumenti sono disponibili per aumentare le prestazioni e l'efficienza e per raggiungere l'obiettivo finale di ridurre il le emissioni di* CO_2 *degli edifici (che rappresentano un terzo della quota mondiale).*

A livello dell'edificio stesso, la progettazione di edifici con sistemi "intelligenti" possono migliorare le condizioni climatiche interne e allo stesso tempo consapevolizzare gli occupanti fornendo informazioni sull'uso dell'energia e sulle condizioni climatiche interne. [4] Queste nuove tecnologie e sistemi esistono già e devono solo essere legiferati, applicati e valutati.

Per aiutare questo difficile percorso, la **Direttiva Europea 2018/844/UE** *pubblicata l'anno scorso (che modifica la precedente direttiva sul rendimento energetico - EPBD, 2010/31/UE e direttiva sull'efficienza energetica, 2012/27/UE) offre interessanti messaggi da interpretare per incentivare le performance degli edifici verso una nuova era. Mantenere un elevato comfort, garantendo efficienza energetica / flessibilità e alti livelli di qualità dell'ambiente interno con un nuovo approccio progettuale e operativo basato sulla "de-carboniza-tion": questo è l'obiettivo ambizioso per il prossimo futuro e una nuova visione e nuovi obiettivi per un Stock di edifici decarbonizzati entro il 2050.*

*Sono necessari nuovi strumenti e la revisione dell' EPBD&EED ha dato direttive agli stati membri in modo che legiferino prima del marzo 2020. Nuovi investimenti, strategie e obiettivi ma anche nuove metodologie da studiare e sviluppare come un nuovo "***smart indicator***" e un nuovo percorso per un processo di "* **building digitalization***".*

Rendere i gli edifici "intelligenti", "smart" deve essere la nuova sfida per il prossimo decennio, come strumento per raggiungere la massima efficienza delle nuove costruzioni e di quelle esistenti al fine di ridurre il più possibile le loro emissioni di CO_2*.*

La tecnologia usata nel modo corretto potrà essere la chiave per migliorare il nostro stile di vita, ma soprattutto la salvezza del pianeta in cui viviamo.

Obiettivi della tesi

*L' obiettivo finale della tesi mira a definire una "***Metodologia di Digitalizzazione dell'edificio***" per pulire l'energia in Europa riducendo le emissioni di CO_2, per far risparmiare denaro ai consumatori riducendo le bollette ed i costi di manutenzione, ma anche per ottimizzare il comfort, la salute e la sicurezza degli occupanti. Il piano, redatto per una casa residenziale è organizzato per raggiungere il nuovo concetto europeo di "edificio intelligente", ma anche per consentire all'edificio di avvicinarlo al massimo punteggio del indicatore massimo (SRI).*

Al fine di identificare la migliore soluzione da applicare per raggiungere questo obiettivo, sono state condotte ricerche approfondite e analisi bibliografiche. Partendo dalle Direttive Europee e dal "Smart Readiness Indicator" project è stata svolta un'analisi approfondita dell'indicatore e svolto il suo calcolo.

Un'approfondita ricerca e lettura di articoli scientifici ha portato ad uno assimilazione di vari argomenti come: il concetto di "Smart Building"; definizioni cronologiche e caratteristiche degli edifici intelligenti; costruzione di sistemi e strumenti di valutazione degli edifici; qualità e valutazione dell'aria interna; concetto di flessibilità e relativa valutazione; Smart Cities ed esempi; processi di digitalizzazione; il comportamento degli occupanti; IoT ed automazione. Questa indagine è stata condotta attraverso ricerche su specifiche riviste scientifiche come la rivista REVHA dalle la sue pubblicazioni online, ma anche alcuni motori di ricerca di articoli scientifici come "Science Direct" o "Research Gate".

Tuttavia, la ricerca ha riguardato anche relazioni e progetti di istituzioni e organismi nazionali, europei e internazionali che si occupano di questi temi: in particolare, oltre alla Commissione europea, possiamo citare la BPIE (Buildings Performance Institute Europe), l'EuroACE (European Alliance of Aziende per l'efficienza energetica negli edifici), l'ENEA (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile) e l'AIE (Agenzia internazionale dell'energia).

A seguito di questa analisi, è stata necessaria la definizione degli obiettivi e dei requisiti per redigere il piano di Digitalizzazione. Alcune categorie ed elementi di classificazione sono definiti per elencare le tecnologie (dispositivi e processi) necessari.

Una prova pratica della metodologia presentata in questa tesi sarebbe interessante da applicare, ed è lasciata a sviluppi futuri. In seguito alla sua attuazione dovrebbe essere fatta, tramite l'indicatore SRI, una misurazione dell'edificio prima e dopo l'intervento di digitalizzazione. Per la sua applicazione, potrebbero essere richieste conoscenze specifiche riguardanti i sistemi e le soluzioni IT sviluppati all'interno del testo, ma non analizzati in dettaglio all'interno di questo progetto. Nel capitolo conclusivo, alcuni temi e idee sono presentati per ricerche e dibattiti futuri, sempre legati alla digitalizzazione degli edifici e al concetto di "intelligenza" anche su scala più ampia. La domanda conclusiva è: "Siamo pronti per una "Smart revolution"?"

Struttura della tesi

La tesi è organizzata in sette capitoli seguiti da alcuni schemi e tabelle allegate.

A seguito di questa introduzione, un primo **CAPITOLO (01_ Le direttive europee: EPBD e EED)** *presenta il punto di partenza per tutto il lavoro svolto: la*

Legislazione Europea. Le direttive europee vengono analizzate dalla prima all'ultima per comprendere il loro processo di evoluzione e come il concetto di edificio è cambiato nel loro corso. Un'analisi è stata effettuata evidenziando i primi articoli e le citazioni riferiti al concetto di "Smart building". Un'attenzione particolare è riservata all'ultima direttiva (EPBD2018 - Direttiva (UE) 2018/844) di cui sono catalogati gli articoli e gli obiettivi principali. Ovviamente l'argomento SRI è posto in evidenza.

Il secondo **CAPITOLO (02_ concetto di "Smart Building")** *mira a definire e sintetizzare il concetto europeo di "Smartness", ad analizzare le caratteristiche, i bisogni ed i principi fondamentali dello "Smart building". La sua struttura è presentata per introdurre l'SRI, a cui è dedicato il terzo* **CAPITOLO (03_L'indicatore di prontezza di intelligenza)**. *Il progetto europeo in corso e la sua metodologia sono spiegati attraverso la presentazione di alcuni casi studio. I punti di forza, le debolezze e gli sviluppi futuri dell'SRI sono analizzati per essere confrontati nel seguente* **CAPITOLO (04_Costruzione "Intelligenza")** *con altri indicatori e metodi di valutazione dell'edificio intelligente.*

Il quinto **CAPITOLO (05_La digitalizzazione degli edifici)** *si sposta verso il processo di digitalizzazione, categorizzando le sottili differenze tra edificio Automatizzato, Digitalizzato e "Smart". Di tutte le fasi di questo concetto in evoluzione, vengono definiti gli strumenti e le tecnologie necessarie, i processi ed i punti chiave. Particolare attenzione è rivolta alle nuove tecnologie (IoT, Ai, Sensori, Attuatori e dispositivi) attraverso studi e applicazioni reali. Un altro punto fondamentale è il ruolo di Occupante, analizzato attraverso esempi di processi simulati.*

Il sesto **CAPITOLO (06_ Processo di digitalizzazione per una Smart House)** *presenta attraverso i risultati ottenuti da questa analisi un'applicazione dei concetti studiati con la presentazione di una metodologia per la digitalizzazione di un edificio residenziale. Diagrammi e tabelle sono stati elaborati per definire gli strumenti e le tecnologie necessarie. Il ruolo di ogni singolo elemento è spiegato sottolineando il carattere principale della "Central Unit" e la necessità di un'interfaccia con utente.*

Nel settimo e ultimo **CAPITOLO (07_Conclusione e sviluppi futuri)** *viene presentata un'analisi critica della metodologia precedente, seguita da consigli e problematiche nella sua valutazione attraverso indicatori. La de-carbonizzazione dell'edificio è la sfida finale proposta con una soluzione in chiave tecnologica. Si espande su un contesto più ampio: la città e una prospettiva Europea lasciando spazio a sviluppi futuri.*

Negli allegati, alcuni schemi metodologici, file ufficiali dell'Unione Europea e alcuni diagrammi dei risultati sono riportati per verificare e chiarire alcuni dettagli del lavoro presentato.

CHAPTER _01

The European directives

on Energy Performance of Buildings (EPBD) and Energy Efficiency (EED)

1.1. Introduction

Nowadays buildings are responsible for approximately 40% of energy consumption and they produce 35% of CO_2 emissions in Europe. The 35% of the European building stock is over 50 years old and almost 75% is energy inefficient. Their renovation represents each year, depending on the country, only from 0.4% to 1.2%. Increase the renovation of the existing buildings could lead to significant energy savings and potentially reduce by 5-6% the total European energy consumption and the CO_2 emission by 5%.

Improving the energy efficiency of buildings can also generate other economic, social and environmental benefits. Levels of Better performing buildings provide higher comfort and wellbeing for their occupants and improve health by reducing illnesses caused by a poor indoor climate. It also has a major impact on the affordability of housing and on the concept of energy poverty. Improvement of the energy performance of the housing stock and the energy savings it brings would enable many households to escape energy poverty. Investments in energy efficiency also stimulate the economy, in particular, the construction industry, which generates about 9% of Europe's GDP (*Gross Domestic Product*) and directly accounts for 18 million direct jobs. European Member State would particularly benefit from a boosted renovation market, as they contribute more than 70% of the value added in the

EU building sector. [1] For all these reasons a complementary legal instrument is needed to lay down more concrete actions with a view to achieving the great unrealised potential for energy savings and reducing the large differences between Member States' results.[2] Directives on the energy performance of buildings and energy efficiency are related in the last years by the EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION.

"A DIRECTIVE is a legal act of the European Union which requires member states to achieve a particular result without dictating the means of achieving that result. It can be distinguished from regulations, which are self-executing and do not require any implementing measures." [3]

The Energy Performance of Buildings Directive (EPBD) is the European Union's main legislative instrument aiming to promote the improvement of the energy performance of buildings within the Community. It was inspired by the Kyoto Protocol which commits the EU and all its parties by setting binding emission reduction targets.[4] The first EPBD was published the 16 December 2002, introducing a certification process to improve the energy performance taking into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. The following directives are the 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive and their related amending of 30 May 2018.
These directives are the EU's main legislative instruments promoting the improvement of the energy performance of buildings within the EU and providing a stable environment for investment decisions to be taken. As Directives, they needed to be transposed by the Member States into national legislation.

1.2. All the directives

In the following chapters a brief introduction to the directives from the 2002 until today is presented:

- **Directive 2002/91/EC** of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPBD)
- **Directive 2010/31/EU** of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD)
- **Directive 2012/27/EU** of the European Parliament and of the Council of 25 October 2012 on energy efficiency (EE), amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance
- **Proposal for amending 2010/31/EU**, 30.11.2016 'The first introduction of a 'smartness indicator'
- The **2015 Paris Agreement on climate change** following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21)
- **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 (EPBD) and Directive 2012/27/EU on energy efficiency(-DEE).

1.2.1 EPBD 2002

Having regard to the Treaty establishing the European Community and linked with the policies and measures needed to comply with the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), the 16th December 2002 the European Parliament and of the Council published the Directive 2002/91/EC on the energy performance of buildings (EPBD).

The new goal is improving the energy performance of buildings taking into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. [5]
A building certification process is introduced to calculate the energy performance of buildings on the basis of a new methodology, which may be differentiated at the regional level. It includes, in addition to thermal insulation other factors that play an increasingly important role such as heating and air-conditioning installations, application of renewable energy sources and design of the building. [6]

The main goals:

- Minimum energy performance requirements tailored to the local climate (through thermal insulation, heating and air-conditioning, installations, application of renewable energy sources and design of the building)

- Certification process to describe the actual energy-performance situation of the building and maybe revised accordingly (calculation methodology, minimum requirements for new constructions, minimum renovation requirements, regular maintenance of boilers and air-conditioning systems, officially recommended indoor temperatures for thermal comfort and avoid wastes, energy consumption monitoring)

It's the first step in a building performance implementation in an energy efficiency direction. The **Building Certification** introduced by this directive, it's the one nowadays recognized and mandatorily in use in almost all the European countries. It is the first instrument and step, that needed more than a decade to enter in our daily life operation like a real revolution and a building economical evaluation parameter.

1.2.1 EPBD 2010

The 19th May 2010, the Directive 2002/91/EC has been amended with the new Directive 2010/31/EU on the energy performance of buildings (EPBD).
The main purpose is the same: reduce the Union's energy dependency and greenhouse gas (CO_2) emissions, reducing energy consumption and increasing the use of energy from renewable sources.

The objective is reducing by 20% of the Union's energy consumption by 2020, to improve further the energy performance of buildings taking into account climatic and local conditions as well as indoor climate environment and cost-effectiveness.
The energy performance of buildings should be calculated based on a methodology, which may be differentiated at national and regional level. That in-

cludes, in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. [7]

The main instruments are: the minimum requirements for the energy performance of buildings and building elements; energy performance certificates; regular maintenance and inspection of systems reports; long term strategies and national plans for increasing the number of nearly zero-energy buildings.

The focus is on measures which avoid overheating, such as shading and sufficient thermal capacity in the building construction, and further development and application of passive cooling techniques:

(a) decentralized energy supply systems based on energy from renewable sources;
(b) cogeneration;
(c) district or block heating or cooling, particularly where it is based entirely or partially on energy from renewable sources;
(d) heat pumps.

Member State had to do their national plan maintaining or introducing more stringent measures.

1.2.3 DEE2012

The Directive 2012/27/EU of the European Parliament and of the Council of 25th October 2012 on energy efficiency (DEE), amends the Directives 2009/125/EC and 2010/30/EU and repeal the Directives 2004/8/EC and 2006/32/EC.
Following the "Strategy2020", the new rate of building renovation needs to be increased, as the existing building stock represents the single biggest potential sector for energy savings. Moreover, buildings are crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95 % by 2050 compared to 1990.[8]
Member states are emboldened to new national objectives for exemplary behaviour. New incentives encourage SMEs to undergo energy audits are promoted. To design Energy efficiency improvement are supported by cost-effective technological innovations such as smart meters.
The new main instruments are introduced: "energy audit"; energy performance contracting, cogeneration, **smart metering system** (electronic systems that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication), efficient district heating and cooling (a district heating or cooling system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat).

1.2.4 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21)

The 2015 Paris Agreement on climate change following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) boosts the Union's efforts to decarbonise its building stock. Taking into account that almost 50% of Union's final energy consumption is used for heating and cooling, of which 80% is used in buildings, the achievement of the Union's energy and climate goals is linked to the Union's efforts to renovate its building stock by giving priority to energy efficiency, making use of the 'energy efficiency first' principle as well as considering deployment of renewables. [9]

1.2.5 2016 Proposal

A proposal for a new DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2010/31/EU on the energy performance of buildings is published the 30th November 2016 to simplify really complex regulations.
It was launched, as part of the Clean Energy for All Europeans package, in order to, first of all, direct investment towards the renovation of building existing with economic and societal challenges, but also to introduce for the first time new topics like the concept of a "smart indicator".

The main objectives are:

- integrating long term building renovation strategies, supporting the mobilisation of financing and creating a clear vision for a decarbonised building stock by 2050;
- encouraging the use of ICT and smart technologies to ensure buildings operate efficiently
- streamlining provisions where they have not delivered the expected results. [10]

More specifically, it introduces building automation and control systems as an alternative to physical inspections, encourages the roll-out of the required infrastructure for e-mobility, and **introduces a smartness indicator** to assess the technological readiness of the building to interact with their occupants and the grid and to manage themselves efficiently. This update of the EPBD will also strengthen the links between public funding for building renovation and energy performance certificates and will incentivise tackling energy poverty through building renovation. [11]
Better performing buildings provide higher comfort levels and wellbeing for their occupants and improve health by reducing mortality and morbidity from a poor indoor climate. The energy performance of buildings also has a major impact on the affordability of housing and energy poverty.

"In order to adapt this Directive to the technical progress, the power to adopt acts in accordance with Article 290 of the Treaty on the Functioning of the European Union should be delegated to the Commission to supplement it **by defining the smartness indicator and enabling its implementation**. The smartness indicator should be used to measure buildings' capacity to use ICT and electronic systems to optimise operations and interact with the grid. The smartness indicator will raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and will give confidence to the occupant about the actual savings of these new enhanced-functionalities." [12]
This proposal introduces most of the topics, instru-

ments and objectives related in the following and last Directive, the 2018 amending.

1.2.6 EPBD2018

On 9th July 2018, the revised energy performance of buildings Directive (2018/844/EU) entered into force, amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. The new Directive 2018/844/EU aimed at accelerating the cost-effective renovation of existing buildings, with the vision of a decarbonised building stock by 2050 and the mobilisation of investments. The revision also supports electromobility infrastructure deployment in buildings' car parks and introduces new provisions to enhance smart technologies and technical building systems, including automation. Member States have 20 months to transpose its provisions into national law (namely until 10 March 2020). [13]

1.3 Directive (EU)2018/844 EPBD & EED amended

The Directive 2018/844, published the 19th June in European Official Journal, dated 30th March 2018, amended the previously presented Directive 2010/31/EU on the energy performance of buildings (EPBD) and Directive 2012/27/EU on energy efficiency (DEE).

The measure is the result of the negotiation of the 2016 Proposal, it reinforces and simplifies existing provisions and aims to achieve the Union's energy and climate objectives by 2030.

"By renovating and making our buildings in Europe smarter, we are attaining several simultaneous objectives: lower energy bills, better health, protection of the environment and reduction of our emissions in the EU, given that over a third of these are produced by buildings. And as technology has blurred the distinction between sectors, we are also establishing a link between buildings and e-mobility infrastructure, and helping stabilize the electricity grid. Another building block of the Energy Union has been laid today, let us continue ahead."

Vice-President responsible for the Energy Union Maroš Šefčovič.[14]

"This is the first final agreement on a proposal of the Clean Energy for All Europeans Package, a signal that we are on the right track and we will deliver on our pledge made at the beginning of the mandate. Our ambitious commitment to clean energy in Europe and the Paris Agreement will be made a reality by laws like the one voted today: the revised buildings directive will help create local jobs, save consumers money and improve Europeans' quality of life. It will also help combat energy poverty by reducing the energy bills of older buildings which will be renovated. I now call on the European Parliament and the Council to show leadership and complete the rest of the proposals of the Clean Energy for All Europeans Package."

Commissioner for Climate Action and Energy Miguel Arias Cañete.[15]

1.3.1 The main goals

Like previously analyzed the directive main objective it's always the same, but the stakes increase step by step. The Union is committed to developing a **sustainable, competitive, secure and decarbonised energy system by 2050**.

The main goals are:

CLEAN ENERGY IN EUROPE
Protection of the environment and reduction of CO_2 emissions

BETTER HEALTH & COMFORT
for the occupants

LOWER ENERGY BILL
Save consumers money and combat the energy poverty

To do this, and identify priorities, different kind of objectives are defined. The short-term measures to be satisfied until 2030; mid-term decisions until the 2040 and long-term objectives for the final 2050 purpose.
The 2030 goal is reducing greenhouse gas emissions further by at least 40 % (compared with 1990):

- To increase the proportion of renewable energy consumed
- To make energy savings in accordance with Union level ambitions,
- To improve Europe's energy security, competitiveness and sustainability.

1.3.2 The main topics and instruments

Several new articles and some changes to the previous directive version articles are edits in the last 2018 Directive. The topics taken into consideration from the UE are following presented and classified in order to identify the different ways of action defined by the text. A few topics already introduced in the previous versions are presented and reedited. The economic aspect is trying to be defined, new funding and incentives planned. In addition to the importance that is given to the occupant comfort, to the building performance and efficiency, the new vision is represented by the new "Smart topics".

(Reedited)Topics:

- Fire safety and seismic activity risks (*EU2018/844 – point 8*) which affect energy efficiency renovations and the lifetime of buildings
- Transformation of existing buildings into nearly zero-energy (*EU2018/844 – point 9*)
- Renovation with an average rate of 3 % annually (*EU2018/844 – point 10*)
- Alleviate energy poverty (EU2018/844 – *point 11*)
- Removal of asbestos and other harmful substances (*EU2018/844 – point 14*)
- Preserving cultural heritage (*EU2018/844 – point 18*)

(€)Topics:

- Commission's Smart Finance for Smart Buildings Initiative (Financial mechanisms, incentives and the mobilization of financial institutions)

(*EU2018/844 – point 16*)

- Financial measures related to energy efficiency in building renovation (*EU2018/844 – point 33-35*)

(NEW)Topics:

- Trigger points: opportune moments in the life cycle of a building, for example from a cost-effectiveness or disruption perspective, for carrying out energy efficiency renovations. (*EU2018/844 – point 12*)
- Indoor air quality, better performing buildings provide higher comfort levels and wellbeing for their occupants and improve health (*EU2018/844 – point 13*)
- Improve thermal and visual comfort (*EU2018/844 –point 15*), with relevant elements and technical systems, such as passive elements that participate in passive techniques
- Solutions based on nature, such as well-planned street vegetation, green roofs and walls providing insulation and shade to buildings (*EU2018/844 –point 17*)

(NEW “PERFORMANCE”)Topics:

- High-efficiency alternative systems, (technically, functionally and economically feasible) healthy indoor climate conditions, fire safety and seismic activity risk, (*EU2018/844 – point 19*)
- Transparency of energy performance certificates (ensuring that all necessary parameters for calculations, both for certification and minimum energy performance requirements, are set out and applied consistently.) (*EU2018/844 – point 20*)
- Building automation and electronic monitoring of technical building systems have proven to be an effective replacement for inspections, (provide cost-effective and significant energy savings for both consumers and businesses). (*EU2018/844 – point 36-37*)

(NEW “SMART “)Topics:

- Self-regulating devices in existing buildings for the separate regulation of the temperature in each room. (*EU2018/844 –point 21*)
  Development of the infrastructure for the smart charging of Electric vehicles (*EU2018/844 – point 22-28*)
- Minimum number of recharging points for non-residential buildings with more than 20 parking spaces, (*EU2018/844 –from point 2025*)
- The digitalization of the energy system: integration of renewables to smart grids and smart-ready buildings (*EU2018/844 –point 29*)

(INDICATORS)Topic:

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. (*EU2018/844 –point 30*)

In order to satisfy the purposes previously set out, several plan instruments and technologies are introduced. LTRS, BACs, EV, EPC, EV, SRI are the acronyms that become the labels of this directive. The Long Term Renovation Strategies defines and gives priority to the intervention on the existing building stock; a Building Renovation Passport is presented like a intervention key instruments. The Energy Performance Certification is resubmitted pointing out its importance for the efficiency. But also the new tools are taken into consideration to achieve the same goal. The Electric vehicles and the charging point inside our buildings will increase its economic value and Building Automation control system that will manage the building activities and performance. In order to control, manage and incentive new technologies and smart devices the last and important new tool of this directive is the "**Smart Readiness Indicator**". All the work later presented in this thesis development starts from these new concept and instrument.

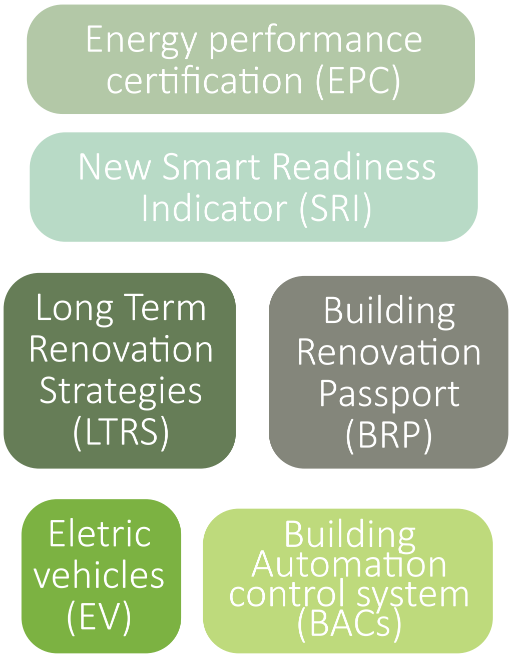


Fig.01 "The Directive (EU) 2018/844 main instruments"

The new SRI takes into consideration new aspects and incentivise new solution, never considered before by previous directives. The "Smart indicator" will be able to measure the ability of buildings to improve their operation and interaction with the network, adapting energy consumption to the real needs of the inhabitants. The European Commission will have to **develop this tool by the end of 2019**.

1.3.3 And the member states? What should they do?

In accordance with the Joint Political Declaration of 28 September 2011 of Member States and the Commission on explanatory documents, Member States have undertaken to accompany, in justified cases, the notification of their transposition measures with one or more documents explaining the relationship between the components of a directive and the corresponding parts of national transposition instruments. With regard to this Directive, the legislator considers the transmission of such documents to be justified. [16]

EU countries will have to implement the directive by **10 March 2020** how explained in the "Article 3".

For the long-term strategies (2050 Objectives) member States and investors should [17]:

1. Integrate and make more effective long-term renovation strategies for an ideally de-carbonized construction sector and a nearly zero-energy park of buildings to 2050, to guide effective policies and mobilize new investments.

2. Encourage the use of smart technologies for the purposes of building efficiency, comfort and flexibility.

3. Promote alternative forms of transport (electric vehicles) in a more holistic view of urban planning.

4. Integrate data already available by virtue of plant inspection and EPA inspections registers, including through new information technologies, smart meters and building automation and control systems.

5. Increase the role of the occupants by informing and protecting them from energy poverty and by sharing them with responsive mechanisms that reduce costs and consumption and benefit the network.

6. Consider the multiple benefits of restructuring, including healthiness, thermal and visual comfort, and seismic safety.

To discuss changes and challenges, but also opportunities, EuroACE (the European Alliance of Companies for Energy Efficiency in Buildings) has written a Guide on the topic.
After several weeks of consultations with stakeholders, including at national level, in summer 2018, EuroACE is now presenting the final version of its **Guide to EPBD Implementation** in a series of webinars in cooperation with BUILD UP. It is be widely explained in the following chapters.

CHAPTER _02

“Smart building” concept

“smart house”
“smart building”
“smart home”
“intelligent building”
“intelligent homes”
“home automation”

Fig.01 “The Directive (EU) 2018/844 main instruments”

Nowadays buildings are more than just stand-alone units using energy from the grid. They are micro-energy hubs consuming, producing, storing and supplying energy more flexible than before. [1] The new buildings are becoming “all-in-one” entities. They could facilitate a shift in the energy system, create “benefit-for-all” conditions and bring multiple positive outcomes, including an increased uptake of renewables and the resultant decarbonisation, energy and cost savings, as well as increased control and comfort for its occupants. [2] Several terms like “smart house”, “smart building”, “smart home”, “intelligent building”, “intelligent homes”, “home automation”, “building automation” has been increasingly common and used interchangeably during the last years.

Only in the last years through a European interest about the topic real definitions and strategies exists. Usually, these terms try to express the kind of building (private or public) level of automation and information services (single devices, interconnected systems, behaviour recognition, prediction, etc.) and of course impression on the customer (intelligent house). [3]

Even if they express the same concept, subtle differences between these terms exist. They will be analyzed in the following chapters. By now, this chapter aims to identify the concept of “Smartness” to describe and define the “intelligent building” model according to the last European studies and Directives.

2.1 What "Smartness" of building is?

Concerning buildings, no universally accepted definition of 'smartness' or 'intelligence' is currently available. In the last 40 years, many authors and organisations have proposed their, sometimes conflicting, definitions of Smart building. The last revised European directive about Energy Performance and Efficiency in Buildings introduce a new smartness definition.

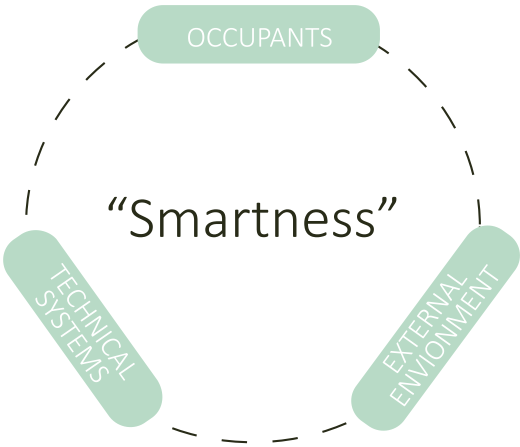


Fig.02 "Smartness triad"

"Smartness of a building refers to the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation the operation of **technical building systems** *or the* **external environment** *(including energy grids) and to demands from building* **occupants***."*

(*Revised EPBD&EE 2018 – Art.2*)

"...a building that can manage itself, interacts with the users and take part in demand response." [4]

The smart building concept is constantly evolving and still not well defined. Almost all the existing definitions share the central ideas of what a smart building is – interconnected, flexible, automated, energy-efficient and comfortable for the occupants. A smart building is highly energy-efficient and covers its very low energy demand to a large extent by on-site or district-system-driven renewable energy sources.

A smart building **(i)** *stabilises and drives a faster decarbonisation of the energy system through energy storage and demand-side* **flexibility***;* **(ii)** *empowers its users and occupants with control over the* **energy flows***;* **(iii)** *recognises and reacts to users' and occupants' needs in terms of* **comfort, health, indoor air quality, safety** *as well as operational requirements. [5]*

Nevertheless, the "Smart Building" concept is elastic in its nature and various actors along the years are inserting different components, functions and preferred outcomes into the concept to fit with their perception. Some "Smart Building" definition from the 90s until today follow below:

"This objective is reached since these buildings "decide" the most efficient way to provide with an appropriate environment for its occupants."
(Loveday, 1997)[6]

“Smart buildings figure out behaviour and behave according to impacts of parameters around it.” (CABA, 2008)[7]

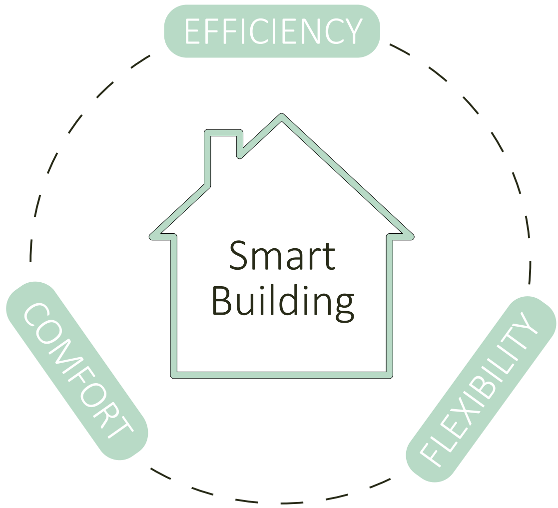


Fig.03 ““Smart Building goals”

“Smart buildings create an environment that maximizes the efficiency of buildingservices, ensuring effective resource management with minimum lite-cycle costs.” (Perumal, 2010) [8]

“Smart buildings involve the usage of design solutions, technology and processes to develop facilities that are comfortable and safe for their occupants while at the same time economical for their owners.”(Katz, 2009) [9]

“Smart Buildings are self-aware and grid-aware, interacting with a smart grid whilst focusing on the real-time demand side response and an increased granularity of controls.” (Kiliccote AIP, 2011) [10]

“A smart building is the integration of building, technology, and energy systems. These systems may include building automation, life safety, telecommunications, user systems and facility management systems.” (Smart Building LLC, 2011) [11]

“Smarter buildings are well managed, integrated physical and digital infrastructures that provide optimal occupancy services in a reliable, cost effective, and sustainable manner.”(IBM, 2012) [12]

“Smart buildings improve the productivity of people and processes by leveraging technology & actionable information to help you & your building make better decisions and become smart, efficient and sustainable.” (Siemens, 2013) [13]

“Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction.” (Buckman, 2014) [14]

“Smart buildings give us unprecedented insight into a building’s performance – at a single site or across an enterprise - by integrating building systems and utilizing advanced analytics in order to monitor, measure and manage the building in the most efficient way.” (Putnam, 2014) [15]

“A Smart Building has a functional, comfortable and healthy indoor environment and its very low energy demand allows for a wide choice of cost-effective, renewable energy sources to be used to fulfil that demand." (EuroACE, 2017) [16]

"A smart home needs to be a comfortable, energy efficient living space in which consumers can benefit from self-generation of electricity and smart and interoperable appliances which have been designed to last and manage consumption through consumer-friendly smart metering systems." (BEUC, 2017) [17]

" [...] the power of buildings to make our bodies healthier, our minds calmer, and our work more efficient. From workplace sensors that continuously monitor air quality to wearables that track your health data, we have more information about the environment and health than ever before." (Fedrizzi, 2017) [18]

2.2 The new "Smart Building" European concept: definition and instruments

As can be confirmed with the previous definitions, the "Smart Building" concept is completely flexible and evolving and can imply different aspects. Only in recent years, attention from the European Union has been demonstrated. In particular, the BPIE (Buildings Performance Institute Europe) is trying to give a definition and analyze the phenomenon. "Directives" from the European Union are coming with the 2018 amendment to the Energy Performance of Buildings and Energy Efficiency directives where the "Smart revolution" begins to take a priority role.

"There is a clear need to accelerate building renovation investments and leverage smart, energy-efficient technologies in the building sector across Europe. Smart buildings integrate cutting edge

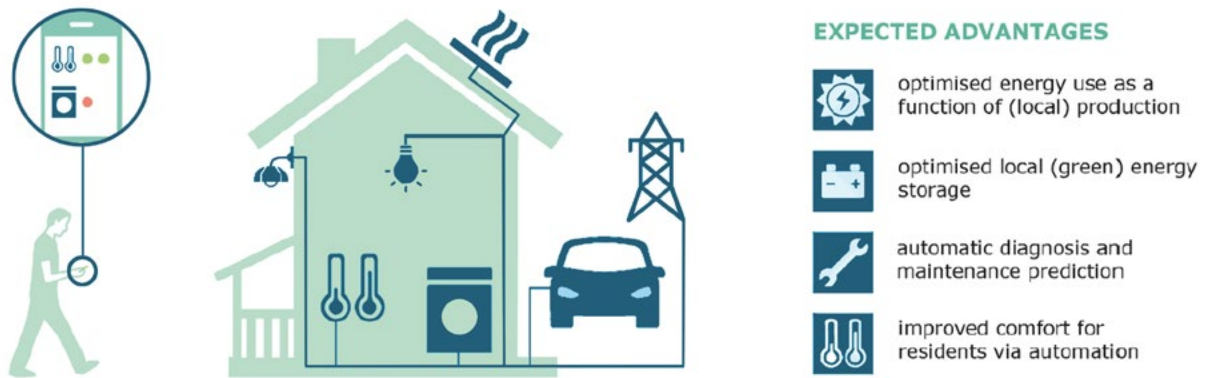


Fig.04 Expected advantages of smart technologies in buildings (SRI PROJECT REPORT, 2018)

ICT-based solutions for controlling energy efficiency and energy flexibility as part of their daily operation. Such smart capabilities can effectively assist in creating healthier and more comfortable buildings, which adjust to the needs of the user and the energy grid while having a lower energy consumption and carbon impact." [19]

Optimization of the energy use as a function of (local) production, optimised local (green) energy storage, automatic diagnosis and maintenance prediction, improved comfort for residents via automation could be considered the main Smart Building features. To better explain the "Smartness" concept the European directive defines in the Annex 1a [20] some **key 'smartness' functionalities**. They are the basic instruments to create a Smart Environment. "Smart ready service" create the relation between building occupant and grid to satisfy their needs; "Smart ready technologies" are the real instruments, devices and IT solutions with the "Technical buil-

Revised EPBD&EED 2018 – Annex1a

"Smart Ready Service" satisfy a need from the user (occupant/owner) of a building or the energy grid it is connected to. The term "ready" indicates that the option to take action exists, but is not necessarily realized. However, the equipment needed to implement the service has to be present in the building.

"Smart Ready Technologies" can either be digital ICT technology (e.g. communication protocols or optimization algorithms) or physical products (e.g. ventilation system with CO2 sensor, cabling for bus systems) or combinations thereof (e.g. smart thermostats).

Smart Ready Services are delivered to the building user or the energy grid through the use of Smart Ready Technologies. The smart ready technologies referenced in this study are considered to be active components which could potentially:

• raise energy efficiency and comfort by increasing the level of controllability of the technical building systems – either by the occupant or a building manager or via a fully automated building control system;
• facilitate the energy management and maintenance of the building including via automated fault detection;
• automate the reporting of the energy performance of buildings and their TBS (automated and real time inspections);
• use advanced methods such as data analytics, self-learning control systems and model predictive control to optimise building operations;
• enable buildings including their TBS, appliances, storage systems and energy generators, to become active operators in a demand response setting.

"Technical Building System" means technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity generation, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit.

"Building Automation and Control System" means 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.

"Interoperability" is the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units. (ISO/IEC 2382-01 on Information Technology Vocabulary, Fundamental Terms).

ding system”, the “Building automation and control system”. “Interoperability” is the last key described and fundamental for the connection between all the elements.

2.3 The Smart Building environment

The European building stock and energy system are at the initial stages of a journey towards becoming smart: moving from a centralised, fossil fuel-based and highly energy-consuming system towards one that is more efficient, decentralised, consumer-focused and powered by renewable energy. [21]
In the preceding paragraphs, the “Smart concept” has always been presented taking about the building. It’s important to define the context and environment where it is settled in because due to the rate of this transition to smart real estate, the process cannot be limited to the construction sector.

“A smart-ready built environment takes advantage of the full potential of ICT and innovative systems to adapt its operation to the needs of the occupant, to improve its energy performance and to interact with the grid.” [22]

As shown in the figure to the side (Fig.05) related by the BPIE (Buildings Performance Institute Europe) the building it’s not only an Energy Consumer, it becomes an Energy producer, Energy storage, it relates with the users and their behaviour and manages its needs.

New market actors which originate from different value chains such as the ICT sector (e.g. Google, Apple), the utility industry (e.g. E.on, British Gas) and the electric vehicle manufacturers (e.g. Mercedes, Tesla) are starting to capture value by entering the buildings market with new products and services. This shift creates simultaneously an opportunity and a threat for providers of HVAC, monitoring systems, appliances and even construction materials to adapt their product offering to this new technological environment. [23].

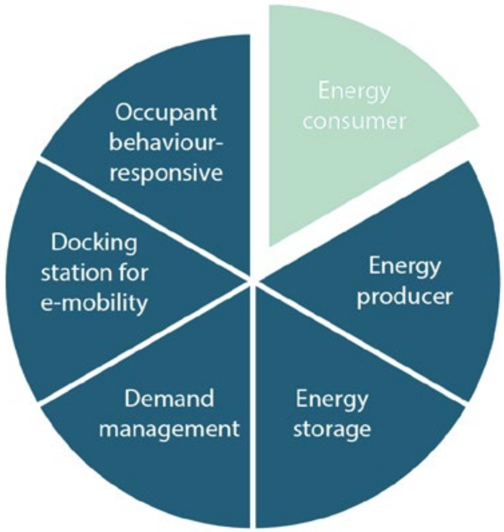


Fig.05 Smart building features (BPIE REPORT, 2017)

Ten interrelated principles have been drawn from BPIE to understand how buildings can effectively function as micro energy-hubs. These principles shown in fig.06 are all important separately, but more effective considered together.
Maximise the buildings’ energy efficiency (1) is the

Fig.06 Smart building 10 PRINCIPLES (BPIE REPORT, 2017)

first important goal that could be realized by deep renovation and efficient new buildings. It brings multiple benefits to demand reduction, but will also enable to integrate the response with volatile renewable energy encouraging the on-site or nearby RES production and self-consumption (2).
Stimulate energy-storage capacities in buildings (3), incorporate demand response capacity in the building stock (4), decarbonise the heating and cooling energy for buildings (5) are the other energy goals. Deepening the fourth principle, it's extremely important to a smart buildings transition is the demand response. DR is the capacity to change energy demand reducing peak consumption or avoiding system emergencies and it could be enabled by adopting energy management systems (EMS) and new technologies such as smart meters, smart thermostats, lighting controls and other load-control technologies with smart end-use devices. Steps in this direction are already being made with the development of new apps allowing consumers to check on the status of their home appliances and thermostats and take control, enabling energy savings with a simple touch on their smartphones.

The relation between Building and users is satisfied by the principle: Empower end-users via smart meters and controls (6), Make dynamic price signals available for all consumers (7).
On the other side the Principle Foster business models aggregating micro energy-hubs (8), underline the need of new building models and private investors. The idea to create a Smart Environment continue talking about Build smart and interconnected districts (9), the Smart city path where Building infrastructure will drive the further market uptake of electric vehicles (10).

Following this evolution process, it's important to underline "the grid" and its communications constantly evolving. The direction is a smart grid to the concept of an integrated Smart City. Fig.07 shows

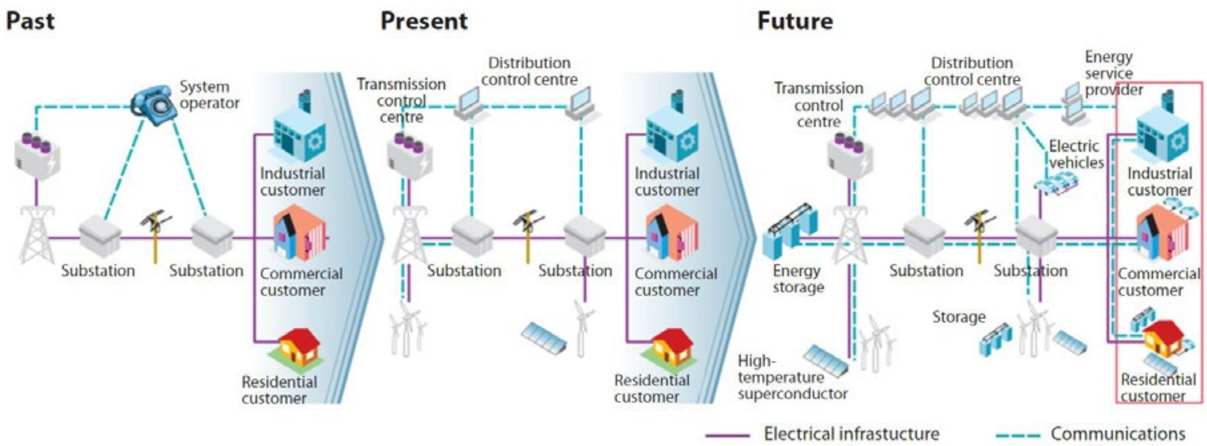


Fig.07 The smartening of the electricity system is an evolutionary process, not a one-time event (IEA, 2011)

the evolution and the “next future forecast” of the relationship between buildings and grid. If in the past the relation with the energy producer and sellers was unidirectional, becoming the building itself energy producer and energy storage the communication between building and grid had to change. Nowadays new elements like electric vehicles or the production of renewable resources onsite further articulate the organization: more substations, bigger distribution control centre, new energy service provider and storage centre.

Some countries have already put in place legislation to take steps towards a smart built environment, such as encouraging the optimisation of the heating system, supporting building energy storage or deploying smart meters. The ongoing review of the EPBD and EED is the prime opportunity to push forward the transition with supportive legislation and embed the principles needed to deliver the benefits of smart buildings to European citizens. [24]

2.4 Smart building characterizing elements

We previously analysed the features and objectives of a Smart Building, but how does it work and what technologies are needed to implement these processes?

Smart meters, building automation and control systems, self-regulating devices for the regulation of indoor air temperature, built-in home appliances, recharging points for electric vehicles, devices for energy storage and detailed functionalities and the interoperability of those features, as well as instruments to guarantee the indoor climate condition, energy efficiency, performance levels and enabled flexibility.[25] The list is quite large, but all these elements can be easily classified.

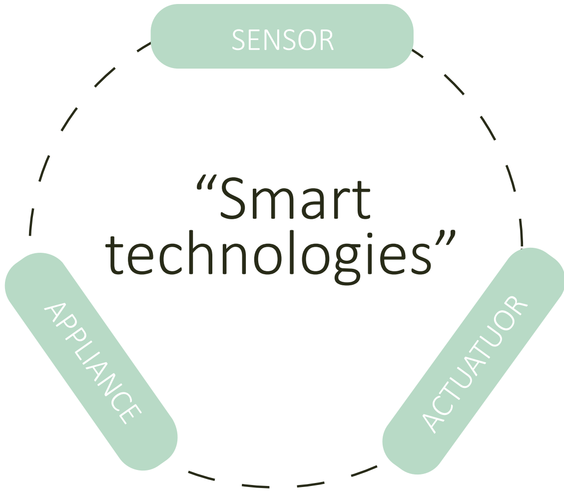


Fig.08 “Smart technologies”

The heart of a Smart Building is the central system, a new element introduced inside it to create the relation and communicant between **Building system, Occupant and grid**. It receives data from **sensors** and smart meters, elaborate and develop it through **artificial intelligence** and send data to **actuators** and **appliances**.

These can be considered the Smart Building active elements that are divided into these three groups according to their functions:

1. Sensor: a device that measures or recognise the status and send it by message (e.g. rain sensor, wind sensor, CO2 sensor); [26]

2. Actuator: a device that receives and carries messages or commands (e.g. dimmer, regulator); [27]

3. Appliance: a device that uses one or more technologies to satisfy one or more specific functions (e.g. central unit, solar systems, shielding). [28]

More than these three elements network is needed to connect these individual active elements (actuators, sensors and appliances) with the central unit that which plays the fundamental role for a building to be considered "Smart".
Through a "User Interface", it communicates with the building occupants to improve its system and give them feedback. The information to the occupants is one of the main goals together with their wellbeing, health and comfort.

As widely explained Energy savings, Flexibility and Self-generation are the huge targets. This is the reason why an HVAC intelligent system is required, but an intelligent building should be able also to relate itself and his envelope with the external environment. To realte itself with the occupant and its needs, to encourage the electric vehicle use through charging points but also to guarantee an automatic diagnosis and maintenance prediction.

CHAPTER _03

Smartness Readiness Indicator (SRI)

Widely introduced and presented by the new 2018 EPBD&EED Directive the new Smart Indicator aims to evaluate the Smart Building features and at the same time, encourage their development.

It will characterize the ability of a building to ***manage itself****, to* ***interact with its occupants****, to* ***take part in demand response and contribute to smooth, safe and optimal operation of connected energy assets*** *(its relation with the grid). [1]*

3.1. The INDICATOR in the directive

The Directive amending is only introducing the concept of new "Smart indicator" like an instrument that still needs to be studied and defined. In the following pages a complete analysis about its requirement and motivation and previous proposals are given to try to analyze it from a complete point of view.

The new indicator is presented with the following article, where it's underline its role of relating the **building**, the **grid** and the **occupants** to evaluate the **efficiency**, the **flexibility** and the **comfort** of the building.

Before the end of 2019, the SRI concept should be clear and well defined to become a nominator (or set of nominators) expected to be included in the Energy Performance Certificate of buildings.
The indicator rank of action is wide and include really different building aspects. As explained in Annex I bis, the smart readiness indicator shall cover features for enhanced energy savings, benchmarking and flexibility, enhanced functionalities and capabilities resulting from more interconnected and intelligent devices. [2]

The difficulty in defining it is the breadth and heterogeneity of the different concepts that are included within it. Generally, different user needs cannot be summed to one indicator, because for example, good air quality will not compensate bad thermal comfort and vice versa. Therefore, a set of users' needs indicators is needed [3] and their combination is the real challenge.

Finding a common unit of measure between purely scientific and objective aspects with subjective and variable perceptions/demands of a human individual is the challenge that, through this chapter, has been faced and presented in a technical and critical manner.

EPBD2018- Article 14 p.10

The Commission shall, by **31 December 2019**, adopt a delegated act in accordance with Article 23, supplementing this Directive by establishing an optional common Union scheme for rating the smart readiness of buildings.

The rating shall be based on an assessment of the capabilities of a building or building unit to adapt its operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance.

In accordance with Annex Ia, the optional common Union scheme for rating the smart readiness of buildings shall:

(a) establish the **definition** of the smart readiness indicator

(b) establish a **methodology** by which it is to be calculated.[1]

Information Technology Vocabulary, Fundamental Terms).

A new METHODOLOGY is introduced with the purpose of evaluating the building:

- **EFFICIENCY**: the ability to maintain energy performance and operation of the building through the adaptation of energy consumption for example through the use of energy from renewable sources;[4]

- **COMFORT**: the ability to adapt its operation mode in response to the needs of the occupant while paying due attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and the ability to report on energy use; [5]

- **FLEXIBILITY**: the flexibility of a building's overall electricity demand, including its ability to enable participation in active and passive as well as implicit and explicit demand response, in relation to the grid, for example through flexibility and load shifting capacities.[6]

It's also underlined that the new indicator methodology should be **simple, transparent, and easily understandable** for consumers, owners, investors and demand-response market participants.

Its introduction 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, but that the use of the scheme for rating the smart readiness of buildings is currently optional for the Member States. It is "An optional common Union scheme for rating the smart readiness of buildings". [7]

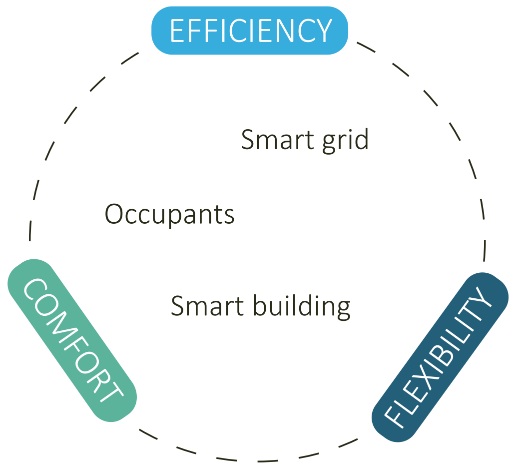


Fig.01 "Smartness features"

3.2. The European Project

"Support for Developing a Smart Readiness Indicator for Buildings" (https://smartreadinessindicator.eu/) is commissioned by EC Directorate-General for Energy. The purpose of the project, launched in February 2017 is helping the directive to **summarized as to provide technical support to feed decision processes and deriving a viable harmonized SRI calculation methodology**.[8]

The main components of the project are:

- **Quantify** and assess the impacts of smart technologies in buildings
- **Propose** a harmonised methodology to calculate and present the SRI of a building
- **Compare** policy options by an impact analysis [9]

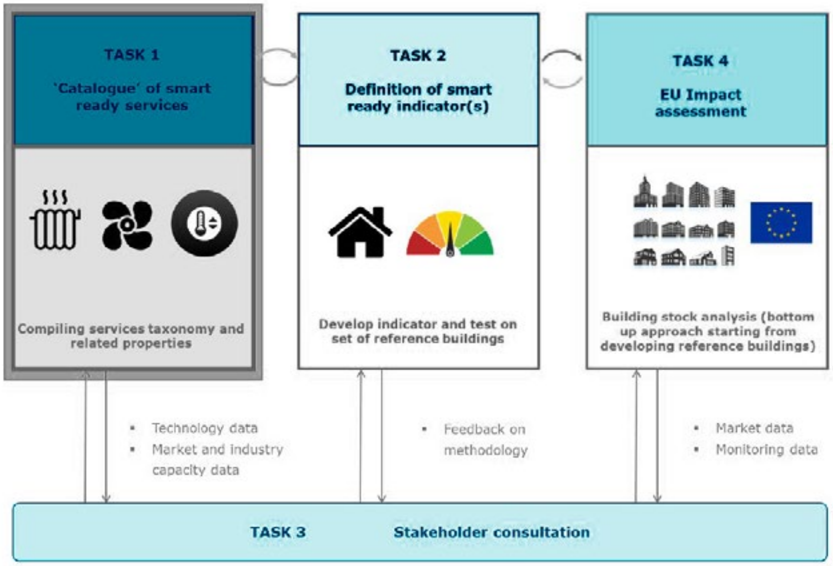
The study is carried out by a consortium that spans a broad spectrum of expertise including information and communication technologies (ICT), building physics, economic and environmental assessment, market and consumer analysis, and worldwide contacts, thus guaranteeing a proper scientific performance of the foreseen tasks. [10] VITO and Waide Strategic Efficiency Europe are the coordinators of this project and several sponsors following showed are supporting it.
A First technical study is commissioned in March 2017 in order to define the "**scope and characteristics of such an indicator**". Until August 2018, through three stakeholder meetings and some feedback monitoring session, the SRI methodology for a first, still hybrid SRI calculation has been defined. It has been applied in two ideal casa study and in two real one (a single-family house and an office building). During this period the study was organized as shown in the following diagram with the relatives' objectives.

Fig.02 Project sponsor and partners (SRI project)

<u>1 st technical study (March 2017 – August 2018):</u>

• Task 1: Characterization of smart ready technologies (SRT) and services;
• Task 2: Establishment of a robust methodology for the harmonised calculation at EU level of the SRI of buildings;
• Task 3: Consultation with stakeholders;
• Task 4: An impact assessment of the SRI and its component SRTs on the performance of EU buildings;
• Task 5: Consultancy to support the Commission's poli cymaking process.

End of December 2018, a second technical support study was launched with the aim to provide further technical input to feed the establishment of the SRI scheme. This second study is carried out by a consortium that spans a broad spectrum of expertise including information and communication technologies (ICT), building physics, economic and environmental assessment, market and consumer analysis, and worldwide contacts, thus guaranteeing a proper scientific performance of the foreseen tasks. [11]



The diagram on the side, from the last 26th August 2018 report, shows the phases defined for development by the first technical study.

It can be seen that all the interconnected phases take into consideration the stakeholder consultation.

Fig.03 1st technical study schedule (SRI project)

From the first study results, it will deliver inputs to refine and finalize the SRI definition and its calculation methodology.

At the same time, it explores the possible options for an implementation, evaluating the impact for a technical and effective application at the EU level.

2nd technical study (December 2018 – Ongoing):

- Task 1: Technical support for the consolidation of the definition and the calculation methodology of the SRI.
- Task 2: Investigation of SRI implementation pathways and of the format of the SRI.
- Task 3: Guidance for effective SRI implementation.
- Task 4: Quantitative modelling and analysis of the impact of the SRI at EU level.
- Task 5: Stakeholder consultation and study website.Understanding and challenges.
- Task 6: Support for the policymaking process.

During this part, the consortium partners are consulting with relevant stakeholders and use their feedback to inform the analysis helping to create awareness and consensus to the best approach to establish the SRI. The end of this second phase is scheduled for July 2020.

A 1st stakeholder meeting settled down the 26th of March where, through a “Stakeholder registration”, it was possible real-time participation with Brussels commission and intervene with online questions. Other two meetings have been fixed for the 9th of October and for the next march, reason why the Indicator still to be defined and improved will probably change and to better satisfy the needs request.

3.3. The SRI concept and calculation methodology

Fig.04 Graphical representation of linkages of the SRI to other policy initiatives (SRI project)

The definition of a "Smart Building" evaluation system is created to implement the instruments already defined and in use to evaluate buildings. The objective, like was created with the Building Energy Certification in 2002 to promote the sustainability and the renewable energy sources, is to open the Digital Market and incentivize the technologies used for a good purpose.

The "Smart Ready Indicator" aims to promote the building smartness to building users, owners, tenants and smart service providers.

The indicator is intended to [12]:

- raise awareness about the **benefits of smart technologies and ICT in buildings** (from an energy perspective, in particular),
- motivate consumers to **accelerate investments in smart building technologies and support the uptake of technology innovation** in the building sector.

The indicator could:

- contribute to enhancing the **energy efficiency, comfort and well-being** in buildings
- **improve policy linkages** between energy, buildings and other policy segments, in particular in the ICT area
- contribute to the **integration** of the buildings sector into future energy systems and markets.

The SRI will give a common language for its stakeholders reason why it aims to involve the interest of the building Occupant/Owner/Investor directed interested but also professional roles like the Facility

Fig.05 Three key functionalities of smart readiness in buildings (SRI project)

Fig.06 Target audience for the SRI (SRI project)

manager and smart services provider from IT and industry worlds: network operators, manufacturers of technical building systems, design and engineering companies etc.

The SRI aims to evaluate the features previously described to define the “Smart Building” characteristics. For this reason Occupants, Building system and grid continue to be the key functionalities. In accordance with the revised EPBD, will be evaluated:

1. The **ability to adapt its operation mode in response to the needs of the occupant** paying due attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and the ability to report on energy use.

2. The ability to maintain **energy efficiency performance and operation of the building** through the adaptation of energy consumption for example through the use of energy from renewable sources.

3. The **flexibility of a building’s overall electricity demand**, including its ability to enable participation in active and passive as well as implicit and explicit demand-response, **in relation to the grid**, for example through flexibility and load shifting capacities. [13]

A **multi-criteria assessment** method is proposed for calculating the smart readiness indicator. The evaluation methodology is based on the “**Smart Ready Services**” list present in a building and its related “**Functionality level**”. Each service could be implemented in various degrees of smartness. Each implementation refers to a functionality level. For example, evaluating lighting control, it may vary from a Level 1, “manual on/off control of lighting” to the maximum functionality level with “automatic on/off switching of lighting based on daylight availability” [14] or even “automatic dimming of lighting based on daylight availability” [15]. Indeed, evaluating the SRI will in fact consist in assigning the right functional level to each parameter who describe the building.

In total, the catalogue of smart services currently contains **112 services** that are actually **52 actionable** smart ready services after streamlining focussing on the services which can be practically assessed on-site and which are expected to bring about the most important impacts.

Not all of them are equally viable or pertinent for inclusion in a practical SRI methodology. Many of the services listed in the catalogue are based on international technical standards, for example, BACS control functions (EN 15232-1:2017), lighting control systems (EN 15193-1:2017) and Smart Grid Use cases (IEC 62559-2:2015).

The provisional impacts in the catalogue are based on expert assessment and, where possible, on applicable standards. [16] For the streamlining the parameter considers are the usual triad Efficiency, Comfort and Flexibility. They are still provisional and could change in different case studies. The services are organized in **10 domains**. Not always all the domains are presented inside the building and the multi-criteria evaluation is done giving a weight according to its specific importance in each case.

Fig.07 Ten domains structuring the SRI catalogue

Heating
This domain include the operation of the heating systems (storage, generation, distribution and emission of heat).These services are mainly related to the automation of the control of technical building systems for space heating. (EN 15232)

Cooling
This domain focuses on thermal storage, emission control systems, generators and energy consumption for space cooling.
The relative share of cooling energy consumption in the energy demand of a building will depend on climate and building usage, alongside the technical and geometrical properties of the building envelope, its technical installations and shading devices and the occupant behavior. (EN 15232)

Domestic hot water
The domain of domestic hot water includes services dealing with the smarter control of generating, storing and distributing potable hot water in a building. (EN 15232)

Controlled ventilation
This domain covers services for air flow control and indoor temperature control.
The ventilation rate and temperature control are important drivers for the energy demand of a building, and are equally important in relation to human health and thermal comfort. Smart controls can balance the contrasting demands. (EN 15232)

Lighting
This domain focuses on electric lighting managed/controlled by a lighting system based on, for instance, time, daylight, and occupancy. (CEN/CENELEC Smart House Roadmap)

Dynamic building envelope
This domain focuses on the control of openings and sun shading systems. It tries to optimize control of lighting and HVAC systems. Services in this domain can affect the heating and cooling demand by controlling the amount of solar heat gains. (EN 15232)

On-site renewable energy generation
This domain includes services that monitor, forecast and optimize the operation of decentralized power generation and control the storage or delivery of energy to the connected grid. (2010 IEC Smart Grid Standardization Roadmap)

Demand Side management
This domain focuses on the control of energy demand in response to implicit or explicit signals from the grid (i.e. energy flexibility). The scope includes both explicit and implicit demand-response and both local smart grids (e.g. on a campus or urban level) and (supra)national grid. (IEC SMB Smart Grid Standardization Roadmap)

Electric vehicle charging
This domain covers technical services provided by buildings to electric vehicles (EV) through recharging points. (IEC 15118)

Monitoring and control
This domain focuses on sensor data which can be provided by TBS in buildings and can be used by other services, and/or be combined into one overarching system such as a Home Energy Management System (HEMS). This for example includes occupancy detection functionalities, which can be used by multiple TBS such as heating, ventilation and lighting systems. This can also encompass services regarding the capability of the building occupants/managers to verify that the SRTs in place are operating as intended. [17]

An additional domain '**Various**' contains services out of scope but that might be considered in future SRI methodology development. For each functional level and Ready Service that belong to a Domain is given a different score for **8 Impact criteria**.

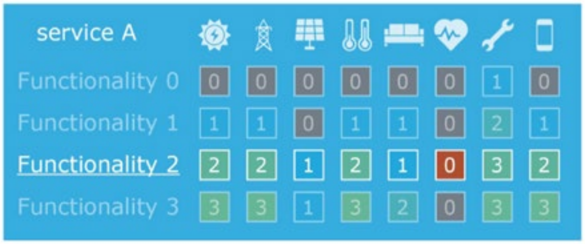


Fig.08 Eight impact criteria defined in the study

4 Functionality levels decide the Impact scores for each service. They give for each of the smart ready services in the catalogue, provisional impact scores according with a ordinary scale (----,---,--,-, 0, +, ++, +++,++++) from **-4 to 4**. Most of the impacts are positive but the scale also provides the opportunity to ascribe negative impacts. The negatives scores are used for examples for the Electric Vehicles parameters whose presence is considered so important to be penalized in case of absence.

Under the proposed SRI methodology, the smart readiness score of a building is a **percentage (0%-100%)** that expresses how close (or far) the building is from maximal smart readiness.

The following diagram (fig. 10, p. 64) shows the evaluation process to define a score per each service and relative criteria. The European project attached to the last SRI report "SUPPORT FOR SETTING UP A SMART READINESS INDICATOR FOR BUILDINGS AND RELATED IMPACT ASSESSMENT" related the last 26th of August, an excel file to calculate the score. The Smart Ready Services listed in this file are attached (Table 3.B).

Fig.08 Eight impact criteria defined in the study

Energy savings on site
This impact category refers to the impacts of the smart ready services on energy saving capabilities. It is not the whole energy performance of buildings that is considered, but only the contribution made to this by smart ready technologies, e.g. energy savings resulting from better control of room temperature settings.

Flexibility for grid and storage
This impact category refers to the impacts of services on the energy flexibility potential of the building.

Self-generation
This impact category refers to the impacts of services on the amount and share of renewable energy generation by on-site assets and the control of self-consumption or storage of generated energy.

Comfort
This impact category refers to the impacts of services on occupants' comfort. Comfort refers to conscious and unconscious perception of the physical environment, including thermal comfort, acoustic comfort and visual performance (e.g. provision of sufficient lighting levels without glare).

Convenience
This impact category refers to the impacts of services on convenience for occupants, i.e. the extent to which services "make the life easier" for the occupant, e.g. by requiring fewer manual interactions to control technical building systems.

Well-being and health
This impact category refers to the impacts of services on the well-being and health of occupants. For instance, smarter controls can deliver an improved indoor air quality compared to traditional controls, thus raising occupants' well-being, with a commensurate impact on their health.

Maintenance and fault prediction, detection and diagnosis
Automated fault detection and diagnosis has the potential to significantly improve maintenance and operation of technical building systems. It also has potential impacts on the energy performance of the technical building systems by detecting and diagnosing inefficient operation.

Information to occupants
This impact category refers to the impacts of services on the provision of information on building operation to occupants. [18]

EXAMPLE CASE: THE BUILDING HAS A MEDIUM CHARGING CAPACITY FOR ELECTRICAL VEHICLES

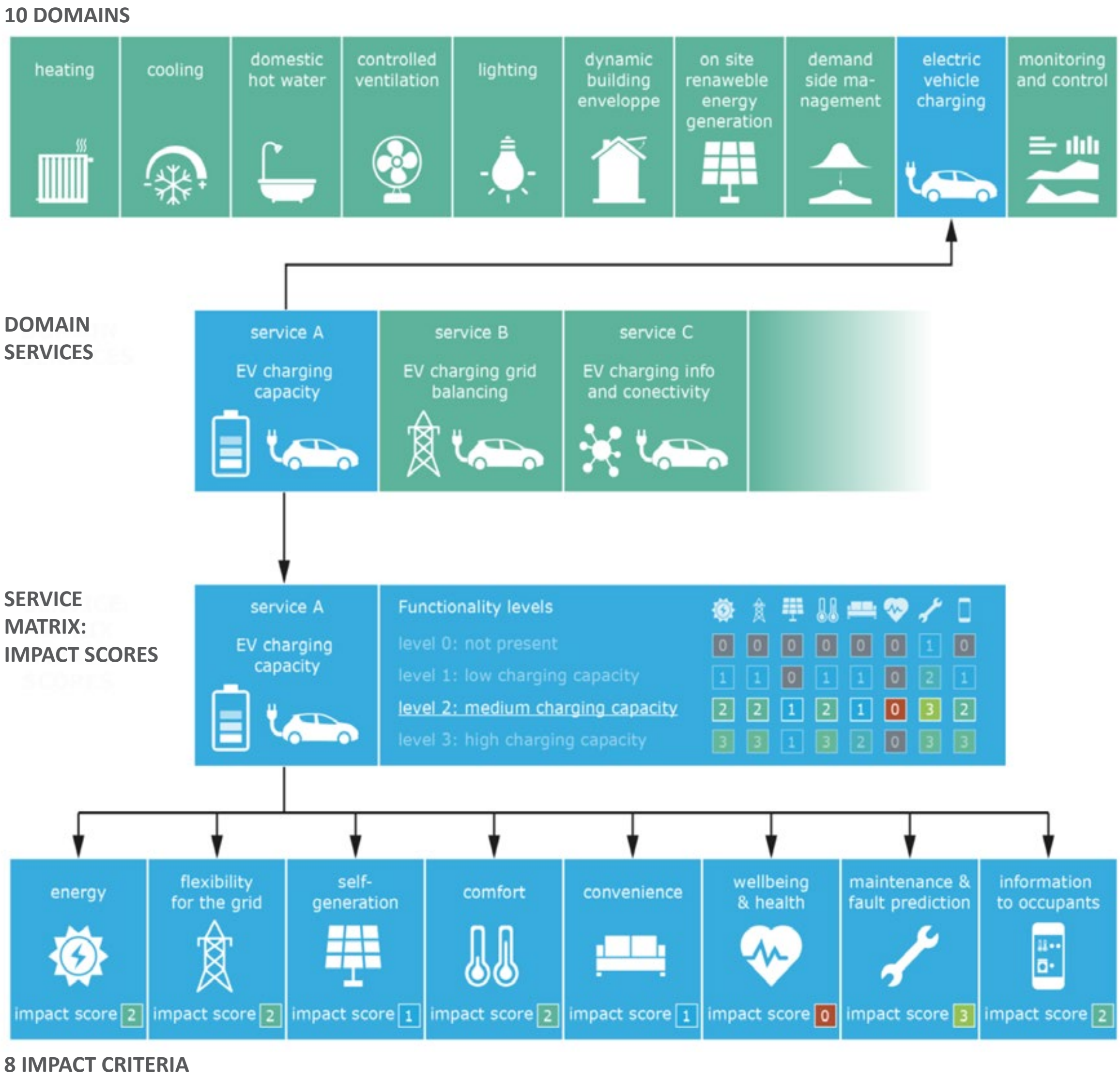


Fig.10 SRI methodology diagram

The process to calculate this global score is the following:

1. Assessment of a score for the available smart-ready services: what services are available and their smartness level (functionality level). A score is given for each impact criteria.

2. This domain impact score is calculated as the ratio (expressed as a percentage) between individual scores of the domains' services and theoretical maximum individual scores (maximum score for the maximum level possible in the relative case study).

3. For each impact criteria, the total impact score is calculated as a weighted sum of the single domain impact scores. For this calculation, the domain weight will depend on its relative importance for the considered impact.

4. The SRI score is then derived as a weighted sum of the 8 total impact scores. Again, the weight allocated to each impact will depend on its relative importance for the smart readiness of the building (weights).

For point 3 and 4 the weighing procedure is still in a definition phase. The ones proposed are tentative and now in a discussion phase.
The methodology has the flexibility to be practically implemented in various ways, e.g. through on site-inspections by external SRI assessors, self-assessment by building owners, a blend of check-lists and self-reporting by intelligent equipment, etc. Due to different factors, in any real building, the amount of services to be inspected as part of an SRI assessment will be much lower than the 52 smart ready services listed in the streamlined catalogue. [19]

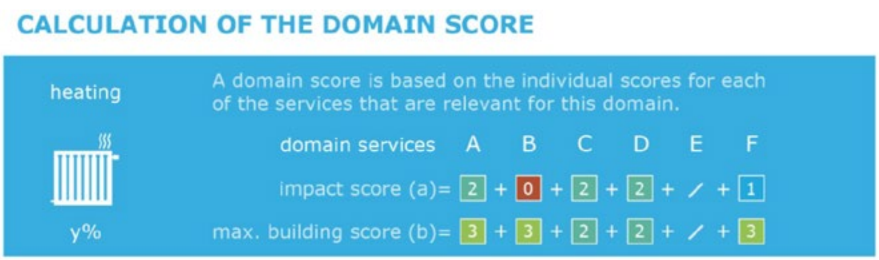


Fig.11 Summing the scores of all relevant services in a domain for a specific impact category

3.4. Case study calculation

The streamlined methodology was tested in four field case studies. Two of them are ideal case study (a single-family house and an office building) the others are real ones: a traditional single-family house located in Manchester, UK and the contemporary EnergyVille office building located in Genk, Belgium. They are fully illustrated in the “Support for Developing a Smart Readiness Indicator for Buildings, Final Report, 26 August 2018” and three of them following illustrated.

3.4.1 CASE STUDY 1: Hypothetical single-familiy house

The first case study analysed is a hypothetical semi-smart single family house with a 165 m² floor area and a 9% of window area.
The building is a partly refurbished, i.e. the insulation of roofs and walls have been improved to a moderate level, and modern double-glazed windows have been installed.

Reference buildings		External building component	Area [23] [m²]	U-Value [W/m²K]	Thermal bridge [W/m²K]	A/V [24] [m⁻¹]
Semi-detached house	 View Southeast	Facade north	0	0.34	0.1	0.52
		Facade west	30			
		Facade south	71			
		Facade east	30			
		Roof / upper floor ceiling	100	0.25		
		Ground plate	86	0.52		
		Windows	22	1.3		

Fig.12 First case study description (SRI project)

Heating is provided by a gas boiler with radiators, which is the case for more than 40% of the residential space heating consumption of the EU28 building stock (with a heating system exchange rate of about 3.6% per year at EU level, gas fired heating systems will still remain the norm in the near future). Do-

Domain	Energy savings on site	Flexibility for the grid and storage	Self generation	Comfort	Convenience	Health and well-being	maintenance & fault	information to occupants
Heating	52%	2.5%	0%	40%	10%	10%	10%	7%
Domestic hot water	14%	2.5%	0%	10%	10%	10%	10%	7%
Cooling	7%	2.5%	0%	15%	10%	10%	10%	7%
Controlled ventilation	4%	2.5%	0%	10%	10%	10%	10%	7%
Lighting	8%	2.5%	0%	10%	10%	10%	10%	7%
Dynamic building envelope	4%	0.0%	0%	5%	10%	10%	10%	7%
Energy generation	0%	2.5%	80%	0%	10%	10%	10%	7%
Demand side management	0%	40%	10%	5%	10%	10%	10%	7%
Electric vehicle charging	0%	40%	10%	0%	10%	10%	10%	7%
Monitoring and control	10%	5.0%	0%	5%	10%	10%	10%	40%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Fig.13 First case study weights (SRI project)

INDICATOR RESULT

SRI 53%

INSPECTION TIME

30 min
(with document)

47 min
(without document)

mestic hot water is provided by the heating system without a circulation system. The building has no space cooling and uses natural ventilation. [20]

Through a 30 min inspection, the following tables (Fig.14) have been produced. For each existing "Smart ready services" a functional level is defined. Through the scores assigned to each impact for each service, a ratio between the assigned score and the maximum obtainable generates a score subsequently weighted through the weights defined for this specific case in fig.13.
The final result obtained through this calculation for this hypothetical case study is 53%.

Code	Service	Case study functionality level	Functionality level	Maximum functionality level
Heating-1 Heat control on the demand side				
Heating-1a	Heat emission control	Individual room control (e.g. thermostatic valves, or electronic controller)	2	4
Heating-1b	Emission control for TABS (heating mode)	NA	0	0
Heating-1c	Control of distribution network hot water temperature (supply or return) - Similar function can be applied to the control of direct electric heating networks	Outside temperature compensated control	1	2
Heating-1d	Control of distribution pumps in networks	Variable speed pump control (pump unit (internal) estimations)	3	4
Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	Automatic control with optimum start/stop	2	3
Heating-1f	Thermal Energy Storage (TES) for building heating	NA	0	0
Heating-1g	Building preheating control	Program heating schedule in advance	1	2
Heating-2 Heat control on the supply side				
Heating-2a	Heat generator control (for combustion and district heating)	Variable temperature control depending on the load (depending on supply water temperature set point)	2	3
Heating-2b	Heat generator control (for heat pumps)	NA	0	3
Heating-2c	Sequencing of different heat generators	NA	0	3
Heating-3 Reporting information				
Heating-3	Report information regarding heating system performance	NA	1	4
Lighting-1a	Occupancy control for indoor lighting	Manual on/off switch	1	3
Lighting-2	Control artificial lighting power based on daylight levels	Manual (per room / zone)	1	4
EG-2	Local energy generation information	None	0	4
EG-3	Storage of locally generated energy	None	0	3
DSM-18	Smart Grid Integration	None	0	1
DSM-19	DSM control of equipment	None	0	4
DSM-21	Reporting information regarding DSM	None	0	2
DSM-22	Override of DSM control	None	0	3
EV-15	EV charging capacity	Low charging capacity	1	3
EV-16	EV grid balancing	None	0	2
EV-17	EV charging information and connectivity	None	0	2
MC-3	Run time management of HVAC systems	Individual setting following a predefined time schedule including fixed preconditioning phases	1	3
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	No central indication of detected faults and alarms	0	2
MC-9	Occupancy detection: connected services	Remote control of main TBS	1	3
MC-13	Central reporting of TBS performance and energy use	Real time indication of energy use per energy carrier	1	3

Fig.14 First case study smart ready funcitional levels (SRI project)

3.4.2 CASE STUDY 2: Hypothetical office building

This second case study presented is a hypothetical office building.

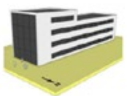
Reference buildings		External building component	Area[35] [m²]	U-Value [W/(m²K)][36]	Thermal bridge (W/m² K)	A/V[37] [m⁻¹]	Reference surface [m²]	Share of window area[38] [%]
Office building	 View Northeast	Facade north	576	0.60	0.1	0.37	1,676	22
		Facade west	187					
		Facade south	598					
		Facade east	234					
		Roof / upper floor ceiling	591	0.40				
		Ground plate	591	0.60				
		Windows	611	1.3				

Fig.15 Second case study description (SRI project)

The building has a gas-fired boiler and hydronic heat distribution via radiator emitters. Space cooling is provided by a chiller that distributes coolth via a hydronic system using fan-coils. Domestic hot water is via localised instantaneous heaters and does not have storage. Controlled ventilation is supplied via an air handling unit but does not use heat recovery. [21]

The study estimates a 2.5 hours with all the documents needed inspection or 4.3 hours in absence of documents in order to produce the following tables (Fig.17). For each existing "Smart ready services" a functional level is defined. The services, not presents are not taken into consideration. Through the scores assigned to each impact for each service, a ratio between the assigned score and the maximum obtainable generates a score subsequently weighted through the weights defined for this specific case (fig.14). This table is different from the previous one and waited for the specific case study.

The final result obtained through this calculation for this second hypothetical case study is 64%.

Domain	Energy savings 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%
Domestic hot water	10%	2.5%	0%	10%	10%	10%	10%	7%
Cooling	6%	2.5%	0%	15%	10%	10%	10%	7%
Controlled ventilation	7%	2.5%	0%	10%	10%	10%	10%	7%
Lighting	10%	2.5%	0%	10%	10%	10%	10%	7%
Dynamic building envelope	7%	0.0%	0%	5%	10%	10%	10%	7%
Energy generation	0%	2.5%	80%	0%	10%	10%	10%	7%
Demand side management	0%	40%	10%	5%	10%	10%	10%	7%
Electric vehicle charging	0%	40%	10%	0%	10%	10%	10%	7%
Monitoring and control	11%	5.0%	0%	5%	10%	10%	10%	40%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Fig.16 Second case study weights (SRI project)

INDICATOR RESULT

64%

INSPECTION TIME

2,5 hrs
(with document)

4.3 hrs
(without document)

Code	Service	Case study functionality level	Functionality level	Maximum functionality level
Heating-1 Heat control on the demand side				
Heating-1a	Heat emission control	Individual room control with communication and presence control	4	4
Heating-1b	Emission control for TABS (heating mode)	NA	0	0
Heating-1c	Control of distribution network hot water temperature (supply or return) - Similar function can be applied to the control of direct electric heating networks	Outside temperature compensated control	1	2
Heating-1d	Control of distribution pumps in networks	Variable speed pump control (pump unit (internal) estimations)	3	4
Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	Automatic control with optimum start/stop	2	3
Heating-1f	Thermal Energy Storage (TES) for building heating	NA	0	0
Heating-1g	Building preheating control	Thermostat self-learning user behaviour (presence, setpoint)	2	2
Heating-2 Heat control on the supply side				
Heating-2a	Heat generator control (for combustion and district heating)	Variable temperature control depending on the load (depending on supply water temperature set point)	2	3
Heating-2b	Heat generator control (for heat pumps)	NA	0	0
Heating-2c	Sequencing of different heat generators	NA	0	0
Heating-3 Reporting information				
Heating-3	Report information regarding heating system performance	Actual values and historical data	2	4
Cooling-1 *Cooling control on the demand side*				
Cooling-1a	Cooling emission control	Individual room control with communication and presence control	4	4
Cooling-1b	Emission control for TABS (cooling mode)	NA	0	0
Cooling-1c	Control of distribution network chilled water temperature (supply or return)	Outside temperature compensated control	1	3
Cooling-1d	Control of distribution pumps in networks	Variable speed pump control (pump unit (internal) estimations)	3	4
Cooling-1e	Intermittent control of emission and/or distribution	Automatic control with optimum start/stop	2	3
Cooling-1f	Interlock between heating and cooling control of emission and/or distribution	Total interlock	2	2
Cooling-1g	Control of Thermal Energy Storage (TES) operation	NA	0	0
Cooling-2 *Cooling control on the supply side*				
Cooling-2a	Generator control for cooling	Variable temperature control depending on outdoor temperature	1	3
Cooling-2b	Sequencing of different cooling generators	NA	0	0
Cooling-3 *Reporting information*				
Cooling-3	Report information regarding Cooling system performance	Actual values and historical data	2	4

Fig.17 Second case study smart ready funcitional levels (SRI project)

Code	Service	Case study functionality level	Functionality level	Maximum functionality level
CV-1 *Air Flow Control*				
CV-1a	Supply air flow control at the room level	NA	0	0
CV-1b	Adjust the outdoor air flow rate	NA	0	0
CV-1c	Air flow or pressure control at the air handler level	NA	0	0
CV-2 *Air Temperature Control*				
CV-2a	Room air temp. control (all-air systems)	NA	0	0
CV-2c	Heat recovery control: prevention of overheating	NA	0	0
CV-2d	Supply air temperature control	NA	0	0
CV-3	Free cooling	NA	0	3
CV-6 *Reporting information*				
CV-6	Reporting information regarding IAQ	NA	0	3
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	NA	0	0
DHW-1b	Control of DHW storage charging (using heat generation)	NA	0	0
DHW-1d	Control of DHW storage charging (with solar collector and supplementary heat generation)	NA	0	0
DHW-3	Report information regarding domestic hot water performance	NA	0	0
Lighting-1a	Occupancy control for indoor lighting	Automatic detection (manual on / dimmed or auto off)	3	3
Lighting-2	Control artificial lighting power based on daylight levels	Automatic dimming	4	4
EG-2	Local energy generation information	None	0	4
EG-3	Storage of locally generated energy	None	0	3
DSM-18	Smart Grid Integration	None	0	1
DSM-19	DSM control of equipment	None	0	4
DSM-21	Reporting information regarding DSM	None	0	2
DSM-22	Override of DSM control	None	0	3
EV-15	EV charging capacity	Low charging capacity	1	3
EV-16	EV grid balancing	None	0	2
EV-17	EV charging information and connectivity	None	0	2
MC-3	Run time management of HVAC systems	Adaptation from a central room	2	3
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	Individual setting following a predefined time schedule including fixed preconditioning phases	2	2
MC-9	Occupancy detection: connected services	None	0	3
MC-13	Central reporting of TBS performance and energy use	Real time indication of energy use per energy carrier	1	3

Fig.17 Second case study smart ready funcitional levels (SRI project)

3.4.3 CASE STUDY 3: Traditional single family house

This is the first real case study presented in the last SRI report. The house is sited in Manchester (UK) and it was built in 1902. It has a over 250 m^2 floor area: three story detached house with parking areas and with a garage. The walls had been insulated 15 years previously with insulation injected into the cavities between the interior and exterior brick layers, but more recently underfloor insulation had been added to the whole ground floor, and many rooms as well as all the top roof area of the house had had interior solid insulation applied. The back of property had a recently constructed conservatory/kitchen space and an adjacent office area.

Fig.18 Traditional single-family house case study picture (SRI project)

Fig.19 Traditional single-family house case study picture (SRI project)

The windows were all renovated with modern double glazing made in keeping with the original window aesthetic. As a result the property is well insulated. [22]

Main features to define the functional level were analysed talking with the occupants:

- No cooling benefit
- Self-generation system planned in the future (PV panel) currently not feasible
- DSM services not present
- No controlled ventilation, manually operated extractor fans in each of the bathroom and toilets and within the kitchen hood over the hob.

• Solar control provided by manualy operated blinds, shutters and curtains (in all relevant rooms and were certainly sufficient to address glare, thermal comfort and privacy needs).

• Interestingly, the conservatory had an automatically dual sensor (interior temperature and external rain) controlled motorised top vent (fig. 20) that the user programmed to open as a function of the conservatory temperature (it shuts automatically if its rain). This is a smart ventilation/solar control technology, however, it does not feature in the streamlined methodology service list.

• Lighting all manually controlled with either on-off switches or dimmer switches. Only one downstairs toilet have a occupancy sensor which controlled the lighting. The exterior of the property has motion sensor controlled security lighting with manual override. All the lighting are energy efficient, with most being LED but a few fluorescent lights too.

• Heating provided by two heat generators (one gas condensing combi-boiler and one gas system boiler) with the condensing boiler.

Ground floor the large kitchen, the conservatory area and the office are both heated by underfloor hydronic heating.
The rest of the ground floor rooms (two reception rooms, a utility room, a toilet and hallway) and the middle floor bathroom are heated by radiators. Control of the heating is split into 3 zones (the kitchen/conservatory, office and rest of the ground floor) each with their own central thermostat and programming. The condensing boiler services these zones on separate hydronic loops, each operating at their own temperature and supplied through a manifold.
The system boiler feeds a hot water storage tank and the upstairs heating circuit. In total it supplies heat to six bedrooms, two bathrooms and the stairwells and landings. All of the heating in these areas is via radiators. [23]

There are a number of **smart features in the control and management of the heating and hot water**:

• programmable temperatures scheduled by hour,

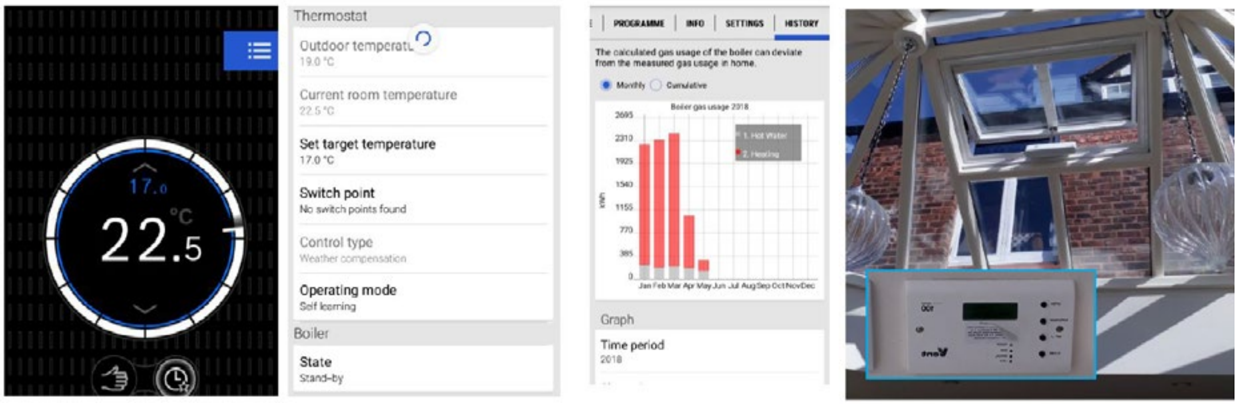


Fig.20 Smart controls for the heating and hot water - Automatic smart conservatory top vent (SRI project)

day, and day of week/year in each of the 4 control zones
• weather compensation
• self-learning optimum stop/start
• TRVs on all emitters - linked to room temperature sensors or occupancy sensors (excluding the under-floor heating)
• VSD controlled distribution pumps (flow within each zone is fully adjustable so the pump energy consumption is optimised)
• remote management of all heating and hot water via smart phone app (via smart home tracking)
• occupant (smart-phone) presence detection option
• historical record and display of heating and hot-water consumption

The self-learning system determines the thermal response rate of the room (by a period of progressively more refined iterative heating to the set-point as a function of the interior to exterior temperature difference) the system learns when the heating needs to be activated at what temperature to achieve a given temperature lift within a given period. Critically, combined with the weather compensation system linked to local weather forecasting, this allows the smart controls to raise or decrease the temperature in an energetically optimal manner to meet the user comfort needs, and thus saves significant amounts of energy while optimising comfort. [24]

This case study took **35 minutes to assess** (including occupant discussion time and spreadsheet tool data filling). It was given an SRI **score of 45%** under the streamlined methodology. It scored 0% for the missing domains or the domains where there was no smart functionality recognised within the streamlined methodology. These domains were excluded from the calculation of the overall score. The results are following (fig.21) reported by domain and by impact parameter. The specific calculations made are shown attached in Table 3.C.

	Energy	Flexibility	Self generation	Comfort	Convenience	Well-being and health	Maintenance & fault prediction	Information to occupants	SRI
Overall	71%	0%	0%	77%	33%	17%	20%	19%	45%
Heating	75%	0%	0%	85%	64%	0%	25%	75%	
DHW	100%	0%	0%	0%	0%	0%	50%	67%	
Cooling	0%	0%	0%	0%	0%	0%	0%	0%	
Ventilation	0%	0%	0%	0%	0%	0%	0%	0%	
Lighting	0%	0%	0%	0%	0%	0%	0%	0%	
Dynamic envelope	0%	0%	0%	0%	0%	0%	0%	0%	
Self generation	0%	0%	0%	0%	0%	0%	0%	0%	
DSM	0%	0%	0%	0%	0%	0%	0%	0%	
Electric Vehicles	0%	0%	0%	0%	20%	0%	0%	0%	
Monitoring & control	60%	100%	0%	67%	38%	33%	17%	14%	

Fig.21 Traditional single-family house case study weights (SRI project)

3.5. Who talks about SRI and Smart Buildings?

If the "Smartness of buildings" topic has been a source of discussion and research in the last years, addressed by various universities and institutions, with the latest European Directive revision, numerous agencies and projects have been created parallel deal with the issue. In addition to an awareness and research campaign, some of these bodies try to offer help to member states for the work they will have to do to transport it on a national scale.

3.5.1 BPIE (The Buildings Performance Institute Europe)

The Buildings Performance Institute Europe (BPIE) is a **non-profit policy research institute** located in Brussels founded in 2010. It's dedicated to improve the energy performance of buildings across Europe.

BPIE aims to **support European objectives and the EPBD/EED directives** by developing new initiatives and a variety of projects, both at EU and Member State levels, enabling policy-makers and stakeholders to agree on effective programmes. These projects include analysing progress on nearly-Zero Energy Buildings, monitoring the building stock, developing energy-saving strategies for shopping malls and innovative retrofitting approaches and more. [25]
The past and current projects focus mainly on key challenges linked to efficient policy implementation. In line with our mission and objectives, our work concentrates on the following areas:

- New buildings
- Renovating the EU building stock
- Supporting policies and instruments
- Buildings data

In the last two years, BPIE publications have widely developed the Smart topic: from trying to decode a Smart building definition to the EPBD 2018 directive analysis; from decarbonised energy systems to smart cities. "Is Europe ready for a smart buildings revolution?" is the question at issue. Also, a "Smart-Ready Built Environment Indicator" is presented from BPIE in 2017. Its characteristics and calculation methods are described in the following chapter (4.2.1) where it is presented and compared with the SRI.

3.5.2 EuroACE (European Alliance of Companies for Energy Efficiency in Buildings)

The European Alliance of Companies for Energy Efficiency in Buildings was formed in 1998 by Europe's **leading companies involved with the manufacture, distribution and installation of a variety of energy-saving goods and services** (2018 – Saint Gobain, Velux, Ursa, United technologies, Rockwool, Armacel).
EuroACE works together with the European institutions to help Europe move towards efficient use of energy in buildings, thereby contributing to the EU's commitments on job creation, energy security, and sustainability.
It aims to promote efficient use of energy in buil-

dings by working with the EU Institutions and other stakeholders to incorporate energy efficiency in all relevant EU policies, in particular, it engages with institutions and stakeholders in advocacy activities, with a focus on the EPBD and EED.

Therefore, EuroACE is committed to help the EU deliver better-performing buildings, with a view to achieve by 2050, at EU level, a building stock at nearly zero energy performance level.
The objective of EuroACE is to help the EU move towards more efficient use of energy in buildings. One of the key dimensions of the Energy Union, energy efficiency is the number one solution for the EU to achieve its energy security, economic competitiveness and sustainability goals. [26]

EuroACE organises, twice a year, national implementation workshops in order to foster transposition and application of buildings-related EU Directives (EPBD and EED) and it relates in October 2018 an interesting report related is "**A guide to THE IMPLEMENTATION OF THE AMENDED ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE (EPBD)**". It's a guide for the member state to understand and interpret the new directive: the smart topic is considerable and the SRI mentioned.
In order to promote the Guide, EuroACE partners in 2018/2019 with the platform BUILD UP (The European Portal For Energy Efficiency In Buildings), to present the EPBD Guide in thematic webinars. [27]
The third webinar of the series took place on 13th February and discussed the topic of 'Smart and Technology Equipped Buildings – new features from the amended EPBD'.

The webinar was moderated by Hélène SIBILEAU, Senior EU Affairs Manager, who also introduced an overview of EuroACE Guide to EPBD Implementation.

It has been talked about the SRI like a concept that may have a positive effect on the market, that needs to be transparent, simple and meaningful to ensure that end-user get value. It's highlighted the importance of a calculation relied on performance-based criteria and indicators that can be simulated/measured. Existing energy calculation methods and EN standards can be used. However, also EuroACE is waiting for new developments and directions from the second SRI technical study. (These informations belong to the online 13th February 2019 Web-seminar discussion).

3.5.3 IEA-EBC International Energy Agency (Energy in buildings and community programme)

The IEA (International Energy Agency) was born in 1973 and it works to ensure reliable, affordable and clean energy for its 30 member countries and beyond. Their mission is guided by four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide.

In recognition of the significance of energy use in buildings, in 1977 the International Energy Agency has established an Implementing Agreement on Energy in Buildings and Communities (EBC-formerly known as ECBCS). The function of EBC is to undertake research and provide an international focus for building energy efficiency. Tasks are undertaken through a series of 'Annexes', so-called because they are legally established as annexes to the EBC Implementing Agreement. [28]

Their High Priority Research Themes are:
- Integrated planning and building design
- Building energy systems
- Building envelope
- Community-scale methods
- Real building energy use

The Annex taken into consideration by us is the **67 about Energy Flexibility** analysed in the following chapter (4.1.1) to present the flexibility concept and better explain the SRI impact criteria and its functionalities.

3.5.4 REHVA (Federation of European Heating, Ventilation and Air Conditioning Associations)

REHVA is the Federation of European Heating, Ventilation and Air Conditioning Associations is the leading European professional organization whose main activity is to develop and disseminate technology and information for mechanical services of buildings. It represents a network of more than 100.000 engineers from 27 countries. REHVA's mission is to develop and disseminate economical, energy-efficient, safe and healthy technology for mechanical services of buildings; to serve its members and the field of building engineering (heating, ventilation and air conditioning) by facilitating knowledge exchange, supporting the development of related EU policies and their national-level implementation. [29]

The Smart Buildings, the SRI, the building digitalization are the main topics of the last REHVA publications (often cited as a bibliography of this thesis): these imminent themes arouse particular interest in the federation.

3.5.5 ENEA (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile)

ENEA is the National Agency for New Technologies, Energy and Sustainable Economic Development, is the Italian body governed by public law that aims at research, technological innovation and the provision of advanced services to businesses, the public administration and citizens in the energy, environment and sustainable economic development sectors. [30]
The areas of specialization are energy technologies (renewable sources, accumulations, smart grids) where the Agency is also the coordinator of the National Energy Technology Cluster, nuclear fusion and safety, energy efficiency (with the National Agency for 'efficiency), technologies for cultural heritage, seismic protection, food security, pollution, life sciences, strategic raw materials, climate change. [31]

Enea actively participates with some projects like "Azione concentrate EPBD (2015-2017)" to support the transposition and implementation of the Energy Performance of Buildings Directive (EPBD) through the exchange of good practices and ideas.

It also dealt with presenting and discussing the new directives presented by the EU: In the last RAEE (**Rapporto Annuale sull'Efficienza Energetica 2018**), the new directive is one of the main topics. It will have to legislate like member state about the amending 2018 EPBD/EED. The SRI topic is presented by ENEA but still like an ongoing project, more attention is given to the "Building renovation passport".

3.5.6 SBA (Smart Building Alliance for Smart cities)

Smart Building Alliance for Smart cities is a French Association Created in 2012 that federates to date 253 organizations representing all building-related trades and Smart City stakeholders, to think and define the Smart Building. SBA provides support to the building industry, helping it to quickly adapt to the changes arising from the wide-spread introduction of digital technology in the Smart Building and the Smart City. It offers a global view shared by pooled infrastructures to promote new services, focussing on uses, that generate efficiency and better social cohesion. SBA promotes the use of interoperable solutions based on open standards. In this way, products and services can be developed that offer the various users real added value, with sustainable business models. SBA's objective is to promote the field of Smart Buildings in Smart Cities by bringing on board all the stakeholders in the construction industry. [32]

They developed a lot of projects about these topics the most relevant for us "Smart building for smart cities" and "Ready2Services"-"Ready2Grids". These are two prerequisites for smart buildings and smart cities that define their standards and could be integrated into other standards (like the previous HQE and BREEAM).

3.6. Strengths, weaknesses and future developments

Following this wide investigation, a critical analysis is necessary. Considering that SRI is a new tool, **not yet defined and approved** in all its aspects, but still subjected to tests, modifications and current topic of discussion, its potential need to be highlighted. It was launched by the European Council certainly also with the purpose to **open the building market** towards new areas and development tools as well as **improving the concept of sustainability and energy efficiency**, enriching it with technologies that would have in any case dominated this area.

It should not be forgotten, however, that the SRI is now presented as a tool that can be used in a completely **optional** manner.

(**STRENGTHS**)

It is a **flexible** tool that can vary and adapt to each case and circumstance. As previously mentioned, it contains very different aspects and **creates a unique measurement unit** between qualitative and quantitative aspects through the functionality level classification. It's noticeable how a subjective parameter like the "Convenience" has been quantified.

Since the Indicator score is currently expressed as a total percentage (%), its convenience is that the different **Domains scores (%) are visible separately.** This function is useful to understand where the building has a good level of "smartness" and in which aspects it instead has a margin of improvement.

Another important feature is that the SRI **evaluate just what the building owns**. The services not present are automatically eliminated and not taken into account, thus not negatively affecting the total score. The only exception is for vehicles considered so important to give a negative score to the domain in case of lack of dedicated recharging points.

(**WEAKNESSES AND PROBLEMS**)

Perhaps due to the fact that its elaboration is still in progress, there are numerous problems and weaknesses encountered. First of all, the **"Ready services catalogue" skimmed** to speed up the calculation procedure, does not always include all the necessary parameters and some aspects who risk not being take into consideration. The other major problems concern the **calibration of the weight**, whose balancing method in absence of some fields is not always completely clear. Some problems in this regard have also been found when retracing the case studies.

A problem with a larger scale concerns the **creation of weight tables**. The percentages, in fact, will not be able to have the same values between buildings with different functions, with different architectural types, if placed in different countries or in heterogeneous contexts. Cataloguing systems will have to be created, but parameters and features to do it are yet to be defined.

(**FUTURE DEVELOPMENTS**)

Definitely to be left to future developments is the creation of different weight tables, but also of differentiation for **building typologies and location** in the different member states.

Another important issue will concern the execution time to carry out the evaluation. The study has already estimated times for a competent operator with all the necessary information to assign the right functionality levels. A potential solution to facilitate the evaluation process could be the use of “Building Information Models” or the establishment of standardized labels to be applied to “SmartReady” products.

(**26th march stakeholder meeting**)

Many of the reflections reported are the result of a bibliographical analysis, but also a reflection of what emerged during the discussion from the first stakeholder of the second technical study on the 26th of March 2019. During the meeting, the progress of the study of the indicator was presented, reminding the outcomes of the first study. The next steps in the policymaking process, in view of the adoption of the SRI legal acts by mid-2020 have been explained. In conclusion, the stakeholders took part in a discussion about the SRI value proposition and implementation pathways and the consolidation of the SRI calculation methodology.

(**COST-BENEFITS IMPACT ASSESSMENT**)

The technical study elaborates also an impact assessment in order to analyse the cost and benefits due to Smart ready technologies in buildings spread inside the European Union.

The first part of this analysis consists of modelling the European building stock in the five geographical areas (defined by the new EPBD). Two scenarios were taken from this survey to represent the possible paths of the building sector, the first is called “Agreed Amendments” and corresponds to an application of the EPBD without additional measures, while the second is “Agreed Amendments + Ambitious Implementation” which considers a more ambitious implementation EPBD. The second part of the impact assessment is based on evaluating the effects that the spread of smart ready technologies (SRT) and SRI would bring.

The analysis is conducted in three ways depending on weather and the building system (heating, cooling or both) and three different scenarios are taken into consideration:

- SRT_BAU: No implementation of SRI, there are only incentives for
smart technologies, or rather the autonomous evolution that can be observed in the current market.
- SRT_Moderate implementation: Voluntary implementation of the SRI, measures of moderate accompaniment and mid-level introduction in member states.
- SRT_High implementation: involuntary implementation of SRI, measures of strong accompaniment and high introduction in member states.

The working hypothesis is based on the following assumptions: SRI will bring a classification system common in the European Union in such a way that smart technology or service providers they could position themselves according to the SRI level they offer. This will create a common structure that will be encouraged the adoption and dissemination of these technologies.

The rate of adoption of smart services and their connection with the SRI will be strongly influenced by the adoption and support policies that member countries will decide to have. The impact will also be time-dependent, the more the use of the indicator will become consolidated over time, the market will become familiar to it.
For this evaluation, it's used a model with SRI divided into 4 levels (I to IV) where the value higher corresponds to a building with more improvements translated into CO_2 emission savings.

An annual growth rate of smart ready technologies is determined for each scenario. For each one, it's also determined (for example from I to II) the relative potential savings in terms of thermal and electrical energy as a percentage compared to real demand and the investment cost per m^2 of the surface.
The combination of the development rate with the potential improvement of the SRI results in overall savings and cost investment (CAPEX) implementation in the construction sector.
As regards CO_2 emissions, a 61% reduction is estimated from current levels by 2050 under the condition of "Agreed Amendments" and 67% in "Agreed Amendments + Ambitious Implementation ".
While taking into consideration the different scenarios obtained by the spread of smart ready technologies, as regards energy saving, a saving of around 150 TWh / a is considered in 2050 in the SRT_BAU scenario, while for the SRT_Medium and SRT_High scenarios they consider the implementation of the SRI and of the regulatory measures associated

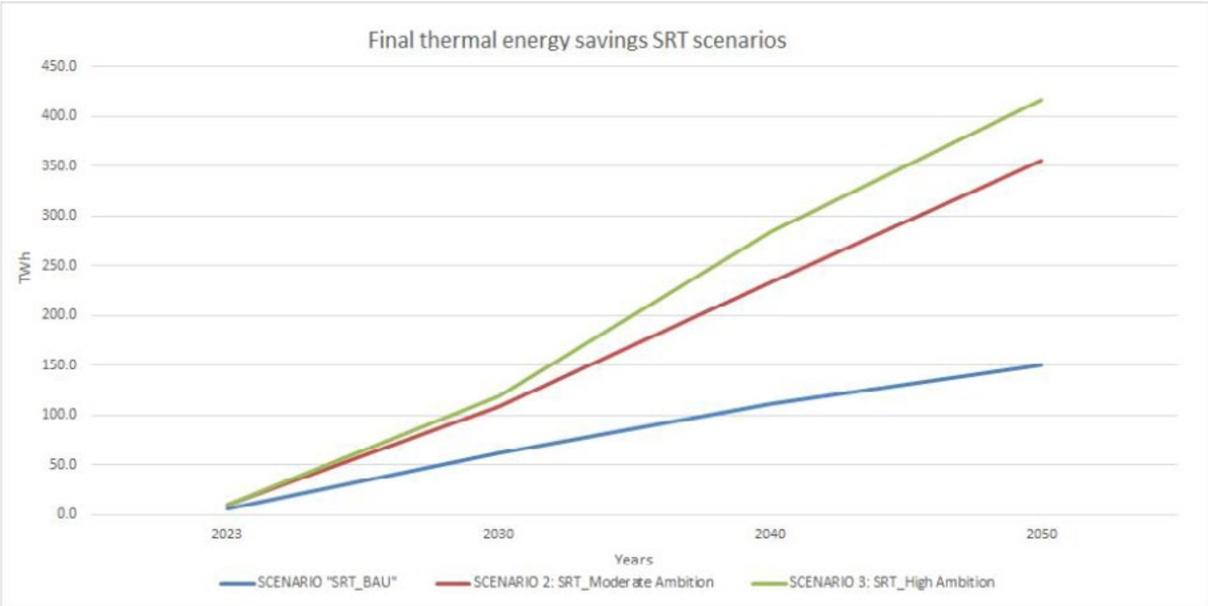


Fig.22 Final thermal energy savings SRT scenarios (SRI project)

with it savings is respectively of approximately 350 TWh/a and 420 TWh/a (see Figure 22).
The average economic return of smart ready technologies considering annual investments and previously cited savings is between 2 and 6 years.

(**SRI RATING vs EPC RATING**)
There is a potential synergy between the SRI and the "Energy Performance Certificate (EPC)" (in Italy known as "Attestato di Prestazione Energetica (APE)") which includes the future possibility of a single assessment process for both, in order to reduce significantly the costs and to stimulate more intervention on the updating of the building's capacities and functions or the possibility of a communication platform between the two so that potentially useful information is accessible from one to the other.
The distinction that remains clear between the two is that the SRI has a voluntary nature while the EPC is mandatory and also the services and functionalities can be significantly different both in the definition and in the invasiveness of the updating interventions.

The clear relationship between the two could be the goal of a subsequent investigation, an evaluation would be necessary that clearly clarifies the overlap as regards methodology and wealth of information, coming to establish the criteria with which to build eventual communication platforms or the possible sharing of assessment methods.

CHAPTER _04

Building "Intelligence" evaluation

SRI can be considered the first official tool to assess the building “Intelligence” as appointed by a European directive. In the past years other studies, projects or simple articles have already been carried out and presented the aim to measure the “Smartness” or other closely related and connected parameters. The following chapter aims to present some of these tools found through bibliographic research and to compare them. The parameters and methodologies used are the most varied. Some of these measurement systems will be the same ones used by the SRI and cited by the indicator that includes them in its concept. In this first paragraph, two evaluation parameters contained in the SRI are presented, while in the following several other indicators are compared.

4.1. Parametres related with the SRI

Continuing to talk about the new EPBD indicator, it's noticeable how the new "Smart Readiness Indicator" introduces and connects different Smart building features never joined by previous building evaluation systems in a unique value. In fact, the SRI officially combine 8 criteria area to evaluate the following 3 building key scope we have already seen [1]:

(a) Adaption of energy consumption to more re-new¬able sources; (ENERGY)

(b) Adaptation in response to user needs; (COMFORT)

(c) Flexibility of electricity demand in relation to the grid. (FLEXIBILITY)

But this key scope of SRI can be broken down into two indicators.
(a) and (c) may be combined in a **Flexibility/demand response indicator**: A flexibility indicator basically will indicate how much electric power can be shifted and for how long time, typically from electricity high price situation to low price situation.[2]

(b) (comfort, air quality, lighting, convenience,...) **Adaptation to user needs indicator** may be described with wellbeing, convenience as well as relevant information to occupants. These features can be measured with indoor air quality, thermal and visual comfort (acoustic comfort may also be an issue through equipment noise) generally describing occupant satisfaction with the building. [3]

The other important difference between these two kinds of criteria is the assessment system. The Flexibility/demand response indicator should use quantitative criteria while the user needs indicator could be solved only with a qualitative one.
For this reason, a set of users' needs indicators is needed with a common classification using the functionality levels.

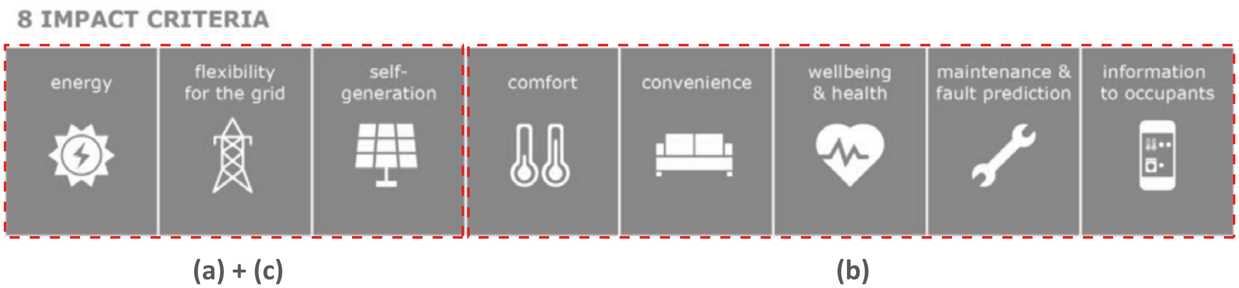


Fig.01 Modify SRI Impact Criteria (SRI project)

4.1.1 Flexibility Indicator (Annex 67)

The Energy Flexibility of a building is the **ability to manage its energy demand and generation according to local climate conditions, user needs and grid requirements**. [4]
It will play an important role in facilitating energy systems based entirely on renewable energy sources. Flexibility is necessary to control energy consumption to match the actual energy generation from various energy sources such as solar and wind power.

A few indicators are used to evaluate the building flexibility, some will be presented in the following chapter with the "KPIs of energy flexibility (2014-16)" (4.2.4) with a few mathematical definitions, but this new concept was also recently studied and analyzed by **Annex67-Energy Flexible Building**.

Fig.02 Annex67: Energy Flexible Buildings Logo (EBC-IEA)

It is a project launched by the **International Energy Agency - Energy in buildings and community programme** with the aim of gaining increased knowledge on the benefits and services the utilization of the Energy Flexibility in buildings may provide to the future energy networks. The IEA-EBC is an international energy research and innovation programme in the buildings and communities field to provide high-quality scientific reports and summary information for policymakers.
This EBC project about the "Energy Flexible Buildings", started in 2014 and still ongoing for this year. They want to demonstrate how energy flexibility in buildings can provide generating capacity for energy grids, and to identify critical aspects and possible solutions to manage such flexibility. The member states involved in the project are Austria, Belgium, Denmark, France, Italy, Netherlands, Norway, Portugal, Spain, Switzerland, United Kingdom. [5]

The project objectives are [6]:

- the development of a common terminology, a defini¬tion of 'energy flexibility in buildings' and a classification method,
- investigation of user comfort, motivation and accept¬ance associated with the introduction of energy flexibility in buildings,
- investigation of the energy flexibility potential in different buildings and contexts, and development of design examples, control strategies and algorithms,
- investigation of the aggregated energy flexibility of buildings and the potential effect on energy grids,
- demonstration of energy flexibility through experimental and field studies.

This studies could involve all the SRI energy-self generation-flexibility part but with a different approach. The SRI parameters to be relate with the others parameters (IEQ etc.) have to choose a qualitative approach, according to the number and type of services provided by his components while the IEA Flexible Buildings evaluation is a quantitative and physical evaluation based using data or results from

simulation studies based on optimization methods including predictive control.
Annex 67 has written a Position Paper explaining the view of Annex 67 regarding how to consider Energy Flexibility – also in the Smart Readiness Indicator.

There is a need for an approach that takes in to account the dynamic behaviour of buildings rather than a static counting and rating of control devices. [7]
For the annex67 studies, the IEA indicator will be better than the SRI evaluation because for them isn't only the results of the available technologies in a building, but it significantly depends also on the way these technologies are used and controlled.

This indicator should facilitate the design and operational decision on both building and energy system level, taking into account the complex interactions between building, energy system, occupants and other boundary conditions [8]. It doesn't consider a current single building evaluation but a wider perspective of building clusters and offers options for extended data processing in the surroundings energy networks.
It evaluates three proprieties of flexibility: capacity, time aspects, costs. [9]
The methodology introduced by the IEA EBC Annex

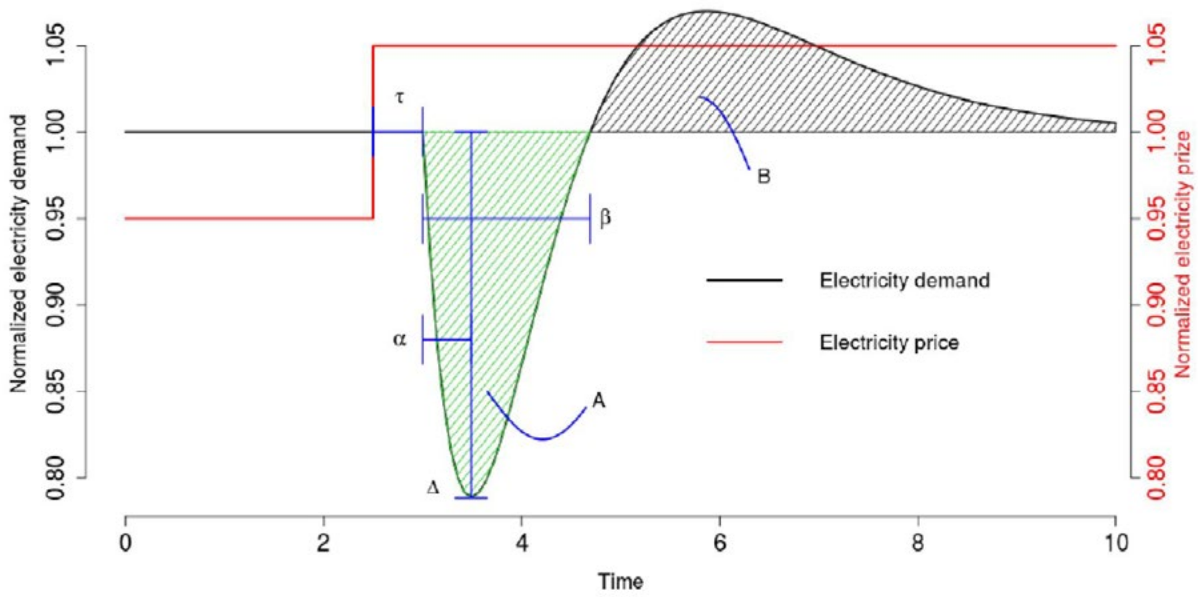


Fig.03 Annex67 – Example of response of a building's electricity demand to a penalty signal (where τ is the time from the signal is submitted to an action starts, α is the period from start of the response to the max response, Δ is the maximum response, β is the duration of the response, A is the shifted amount of energy, B is the rebound effect for returning the situation back to "reference")

67, represents Energy Flexibility in this manner, by quantifying the amount of energy a building can shift according to external forcing factors, without compromising the occupant comfort conditions and taking into account the technical constraints of the building and of its HVAC system. In that, it acknowledges that forcing factors act as boundary conditions, which can change over the lifetime of a building and with different levels of frequency:
Low-frequency factors: climate change, macro-economic factors, technology improvements, energy costs, use of the building.
High-frequency factors: energy mix/RES availability, energy prices, internal/solar gains, user behaviour, hourly energy prices, ambient temperature.
Consequently, the Energy Flexibility of a building is not a fixed static value, but varies according to such forcing factors and control signals (in the following called) penalty signal), which induce a system response (see Fig.03). Hence, a building is able to shift and move the instantaneous energy demand minimizing the effect of the penalty signal. The penalty signal could be designed to: 1) minimize the energy consumption, 2) minimize the cost, or 3) minimize the CO_2 footprint f the building – or a combination of those criteria. Different penalty signals may also represent different (ancillary) services needed by the grid. [10]

4.1.2 Indoor Environmental Quality (IEQ)

The concept of Indoor Environmental Quality (IEQ), usually defined as the set of conditions associated with **the thermal environment, the indoor air quality, the acoustic envi-ronment and the visual environment**, is normally used to assess the extent to which this objective is achieved in a given building.
Relevant physical variables together with the calculation of the suitable indices are used to assess the indoor environment in the different aspects composing IEQ as the most adequate solution. [11]
The EN 16798-1 - EPB standard, CEN/TC 156 – Ventilation of building published by CEN (European Committee for standardization) define the specifies requirements for indoor environmental parameters for thermal environment, indoor air quality, lighting and acoustics and specifies how to establish these parameters for building system design and energy performance calculations. It is the same use from the SRI to help the functionality level definition. [12]

The prof. Gameiro da Silva and his research group (University of Coimbra, Department of Mechanical Engineering, Portugal) with the Dutch consulting company Van Cappellen Advies presented two case studies where the IEQ is improved and evaluated.
The renewal of a substantial part of the HVAC systems in these buildings implied the writing of a set of IEQ performance and systems concept specifications and in the process of drafting these, the requirements alone were considered to be inadequate in terms of quality assurance. Thus, has been added to the scope of work a two-year Soft Landings program for objectively assessing and evaluating the real IEQ achievements before a final and formal completion could be established. [13]
To do this the evaluation sensors are needed to measure the following variables in the indoor station:
mean radiant temperature (black globe); air velocity/temperature/barometric pressure, at the neck

position; air velocity/temperature, at the ankle position; surface temperature distributions of floor/ceiling/wall-window; relative humidity; sound pressure level (A weighted); Luminance level; Concentrations of CO_2, VOCs, and particle matter (PM10, PM2.5 and PM1.0).

And in the outdoor station: air temperature; relative humidity; barometric pressure; wind velocity/direction; solar irradiance; concentration of CO_2 and fine particle matter PM10, PM2,5, PM1.0.

Other variables are: Operative room temperature (OT), Running Mean Outdoor Temperature (RMOT), Wind Chill (WC); Thermal Comfort – Perceived Mean Vote (TC-PMV); Thermal Comfort – Perceived Percentage Dissatis fied (TC-PPD); Vertical Air Temperature Gradient – Percentage; Dissatisfied (VATG-PD); Room Air Temperature Fluctuation (ATF); Indoor Dew Point (IDP); Outdoor Dew Point (ODP); Draught Rate – Perceived Percentage Dissatisfied (DR-PPD); Indoor Absolute Humidity (IAH). [14]

This project is autonomous from the calculation of the SRI, but certainly useful to understand the new smartness indicator.

4.2 Other Indicators examples and definitions

A brief review of the other buildings/smart buildings/energy performance indicators or set of indicators are presented. From the most official ones like the proposed by agencies like the BPIE to single studies from scientific articles.

4.2.1 Smart-Ready Built Environment Indicators - SRBEI (2017)

The Smart Built Environment Indicator (SBEI) developed by the Buildings Performance Institute Europe (BPIE) in 2017 supports the assessment of EU countries' readiness to transition to smart buildings. It's a first European proposal of a smart indicator. Future versions of the Smart Built Environment Indicator should aim to incorporate data on dynamic and self-learning control systems, in order to provide a more complete picture. [15]

The key aspects considered by the SBEI to describe how smart-ready built environment is related to the energy performance of the building stock, the share of energy from renewable sources, the smart meter deployment, the development of a dynamic energy market, the improvement of the access to demand response, the rollout of building energy storage and the market penetration of electric vehicles. [16]

The equation for calculating the indicator and the description of its parameters is here presented.

A full description can be read at page 8 in the BPIE report of 2017 “Is Europe Ready for a Smart Revolution?” [17]

$$SBEI = \frac{\left(\left(\frac{BEP+FEC}{2}\right) + CMF + IAQ\right) + \left(SM + \left(\frac{DP+FLX}{2}\right) + CON\right) + (DR+BES+EV) + \left(RES+PV+\left(\left(HP+\frac{DH}{2}\right)\right)\right)}{12}$$

BEP = Building envelope performance; **FEC** = Final energy consumption; **CMF** = Ability to keep adequately warm/cool; **IAQ** = Healthy living and working environment; **RES** = Renewables energy consumption; **PV** = Photovoltaics; **HP** = Heat pumps; **DH** = District heating; **SM** = Smart meter deployment; **DP** = Dynamic pricing; **RES** = Renewables energy consumption; **FLX** = Flexible market; **CON** = Connectivity; **DR** = Demand response; **BES** = Building energy storage; **EV** = Electric vehicles.

For each indicator factor, the countries are given a score between **1 (not smart-ready) to 5 (smart-ready)**. Indicator data has primarily been gathered from the EU Building Stock Observatory3 and Eurostat. The specific application of this indicator is intended for entire countries, but the characteristics considered are scalable also to a small cluster context and useful to evaluate the flexibility also at an aggregated level.

4.2.2 Smartness Index – SI (2015)

A Smartness Index (SI) to capture the level of smartness of a building was developed by a study related by the Politecnico di Torino with the Illinois Institute of Technology and published in the article “Assessing the smartness of buildings” in July 2015. For each domain and variable, the mean value of the importance has been computed based on the answers to the survey. SI has been calculated as the mean value of the importance ascribed by the respondents to each domain and sub-domains. Then, domains and sub-domains have been weighted through a normalization. [18] It’s following presented a resume of the equations and parameter considered.

SI = (WX × X) + (WY × Y) + (WZ × Z)

X = (WX1 × X1) + (WX2 × X2) + (WX3 × X3)

Y = (WY1 × Y1) + (WY2 × Y2) + (WY3 × Y3) + (WY4 × Y4)

Z = (WZ1 × Z1) + (WZ2 × Z2) + (WZ3 × Z3) + (WZ4 × Z4) + (WZ5 × Z5) + (WZ6 × Z6)

Economic Issues (X): products (structure, equipment, facilities, materials), people (users, owners, occupants), and processes (construction, facility management, maintenance)

- Planning and design costs (X1)
- Construction costs (X2)
- Operation and maintenance costs (X3)
- Sustainability costs (X4)

Energy Issues (Y) : HVAC control, security and access control, fire security, building transportation control,etc

- Heating system (Y1)
- Cooling system (Y2)
- Lighting system (Y3)
- Water system (Y4)

Occupant Comfort Issues (Z) : thermal comfort, visual comfort and indoor air quality

- Temperature (Z1)
- Humidity (Z2)
- Air quality (Z3)
- Acoustic comfort (Z4)
- Functionality (Z5)
- Psychological aspects (Z6)
- Security (Z7)
- Fire protection (Z8)

The weights (W) were obtained through normalization of the following equation:

$$W_i = \frac{\sum_{j=1}^{j=n} x_{ij}}{n}$$

where n is the number of respondents for variable i.

A **Likert-scale scoring** system was used, where 1 = Not important, 2 = Moderately important, 3 = Important, 4= Very important, and 5 = Extremely important. Also the final result of the SI will be from 1-5.
This study is a marked departure from the current building certification models such as LEED and BREAM that assess overall building performance. The contribution of this study is that it pushes to the forefront the “smartness” of a building as a standalone concept that is defined in terms of energy efficiency, life-cycle costs, and user comfort. [19]

4.2.3 Building Intelligence Quotient (2015)

Prof. Volkov introduced a formal definition of an “intelligent” building and formula (building intelligence quotient- BIQ) that can be used as a measure of building “intelligence”. [20] The BIQ shows also the difference between building “intelligence” and building automation because it’s calculated by the comparison of the two different equation. [21]
To estimate automation level of a building the equation (Eq.1) is calculated with a set of all processes that change values of the building parameters while to estimate “intelligence” level of a building the equation (Eq.2) is calculated with a set of all controlling processes over changes of values of the observed building parameters.

$$BIQ = \frac{Q(P_2)}{Q(P_1)}$$

Eq.1

$$BIQ = \frac{Q(R_1)}{Q(R)}$$

Eq.2

X - a set of all parameters of the building. Might be anything, for example, temperature, light intensity in any building zone.

X1 - a subset of the observed building parameters. Observed, in the context of our task, means parameters that can be measured automatically by "smart" building's sensors and meters and acknowledged by building AI. Obviously that amount of observed parameters dramatically fewer than amount of all building parameters.

P - a set of all processes that change values of the building parameters. It is a huge set of processes that includes: natural processes, for example, outside temperature changes and, as consequence, temperature change in particular building zones; and technical processes, for example, operation of a HVAC system that also causes temperature change in particular building zones.

P1 - a subset of processes which change the values of observed building parameters (P1-P). In other words, processes that change the parameters that can be measured automatically by "smart" building sensors and meters and acknowledged by building AI.

P2 - a subset of controlled processes which change the values of observed building parameters (P2-P1).Controlled, in the context of our task, means that inhabitants can control this process. For example, inhabitants can't control outside temperature changes, but can control a HVAC system using thermostat.

R - a set of all controlling processes over changes of values of the observed building parameters.

R1- a subset of processes that control changes of the observed building parameters which are functionally adaptive to the own state space X1 (R1-R). In the context of our task it means that such processes are initiated by building AI and change values of building parameters using "smart" building devices and actuators.

The closer BIQ to 1, the better "smart" building solution. The BIQ formula is very simple itself, the biggest challenge is to get an input for the formula. As "smart" building solutions are based on Artificial Intelligence, obviously, different products have a difference in accuracy. Accuracy depends on a system itself, on a particular building, on a building's functional purpose and on an inhabitants' behavioral patterns. Accuracy might change during the building's life-cycle depending on the amount of accumulated data. Interestingly, increasing the amount of data might as improve accuracy (the more statistic the better, law of large numbers) as make it worse (for example, overfitting in algorithms based on neural networks).
This evidence suggests that BIQ can't be calculated analytically, without simulating building processes (environmental changes and inhabitants activities) to see how "smart" building solution will cope with it. [22]

4.2.4 KPIs of energy flexibility (2014)

In order to evaluate the Flexibility concept, explained through the Annex 69 in the previous chapter (4.1.1), a list of key performance indicators (KPIs) it's presented by the article "Control strategies for building energy systems to unlock demand side flexibility" related in 2017 by J. Clauß, C. Finck, P. Vogler-Finck, P. Beagon to describe the physical characteristics of a building.
Conventional key performance indicators (KPI) measures how the building interacts with the grid and its energy flexibility.

The following list is a overview of specific energy flexibility performance indicators, together with supporting control strategies, their formal mathematical definition and context of application. If applied correctly, the indicators help improving the building performance in terms of energy flexibility and can enable minimization of operational energy costs. [23]

1. Self-generation (load cover factor)
2. Self-consumption (also supply cover factor)
3. Peak power generation
4. Peak power load
5. Flexibility (optimum cost)
6. Flexibility factor FFPC (costs)
7. Flexibility factor FFshift (volume)
8. Flexibility factor (FF)
9. Load shift for CO2
10. Energy flexibility
11. Available structure storage capacity
12. Storage efficiency
13. Shifting efficiency
14. Loss of load probability (LOLP)
15. Power shifting capability
16. Grid feed-in
17. Demand recovery ratio

Flexibility indicators can describe physical characteristics of a building (e.g. storage capacity) or quantify the magnitude of the building´s reaction to external signals (e.g. electricity price) within the context of the power grid. Load matching and grid interaction indicators (e.g. equations 1-4, 14, 16) give a coarse overview of the ratio of the building energy load vs. on-site electricity generation as well as identify the load and generation peak periods. Energy flexibility indicators (e.g. equations 7-9) are often price-based and show whether energy/electricity is consumed during high- or low-price periods. Their generic nature allows their application to various building types, climates and energy systems. All this parameters can be used for determining the energy flexibility (or related characteristics) of a building and can either be calculated during post processing of the building simulation results or be included into a model-based control algorithm directly. Limitations of the indicators include the availability of the data used to compute them, so that the simulation software must be able to provide the data.[24]

4.2.5 Energy Flexible Building Cluster Indicators (2018)

This research study related by the "EURAC research, Institute for Renewable Energy" with "Politecnico di Milano", identifies a set of potential key performance indicators that could be adapted to the cluster scale and used to characterize Energy Flexible Building Clusters. The selected indicators have been classified into five different categories:

Costs: Specific Cost of Flexibility, Spark Spread, Total Supply Spread, Flexibility Factor
Thermal level: Available Storage Capacity, Comfort Index
Electric level: Grid Control Level, Load Matching Index, Grid Interaction Index
Thermal-Electric level: On-site Energy Ratio, Annual Mismatch Ratio, Maximum Hourly Surplus, Maximum Hourly Deficit, Ratio of Peak Hourly Demand to Lowest Hourly Demand
Other relevant indicators: Homogeneity Index, Smart-ready Built Environment Indicator

The reviewed indicators can contribute to the definition of the Smart Readiness Indicator, introduced in the European Commission proposal for the EPBD revision, in order to test a building's technological readiness to adapt to the needs of the occupants and the energy environment, as well as to operate more efficiently.[25]

4.2.6 Others examples and summary

In history other innumerable proposals and attempts to measure the "building modus operandi" have been carried out using evaluation as a system to bring important performance improvements. Several evaluation attempts are made, approaching the parameters required for the evaluation of "smartness".

Yang and Peng [26] in 2001 proposed to measure the performance of a building by looking into its organizational flexibility, technological adaptability, individual comfort, and environmental performance. Gonzàlez et al. [27] in 2011 proposed an Energy Efficiency Index: a ratio between the performance (energy consumption/ CO2 emissions) of an actual building and the performance of a reference building. Wong, et al. in 2008 [28] propose eight building control systems, typical of a smart building: Integrated building management system for overall monitoring; Heating, ventilation, and air-conditioning control system for comfort control and the quality of the indoor air; Addressable fire detection and alarm system for fire prevention and annunciation; Telecom and data system for communication network; Security monitoring and access system for surveillance and access control; Smart/energy efficient lift system; Digital addressable lighting control for light design; Computerized maintenance management system.

Wong and Jan in 2003 [29] proposed performance measures in spatial comfort, indoor air quality, visual comfort, thermal comfort, and acoustic comfort while Morsy in 2007 [30] measured the psychological aspects that influence building users' comfort and the smart buildings' performance in adapting to the psychological needs of the occupants. According to Kleissl and Agarwal in 2010 [31], buildings were evaluated like subsystems associated with airflow, water, safety, access, and security that run together and share information. These examples are all presented in the "Assessing the smartness of buildings" article. [32]

It can still be cited the Building Intelligence Quotient (BIQ) proposed by the Continental Automated Building Association (CABA) makes use of communication systems, building automation, annunciation, security and control systems, facility management applications, and building structures and systems. [33]

As building evaluations are to be mentioned also the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK and Leadership in Energy and Environmental Design (LEED, 2008) in the U. These evaluation certification are really famous and coveted in the architectural design world but they basically focus on the many sustainability issues not paying attention to the smart technologies or human needs.

In order to summarize the analysis carried out, the indicators previously presented in this chapter are then reported and compared in the following table.

Indicator	Author	Year	Description	Score
Smart Readiness Indicator (SRI)	European Union	2018	Energy savings on site; Flexibility for grid and storage; Self-generation; Comfort; Convenience; Well-being and health; Maintenance and fault prediction; Information to occupants	0-100%
Energy Flexible Building Cluster Indicators	/	2018	Costs, Thermal level, Electric level, Thermal-Electric level	Values
Smart-Ready Built Environment Indicators (SRBEI)	BPIE	2017	Energy performance, renewable sources, smart meter deployment, dynamic energy market, access to demand response, energy storage, electric vehicles.	0-5
Building Intelligence Quotient (BIQ)	Valkov	2015	"Automated building" related with "Intelligent building"	0-1
Smartness Index (SI)	Arditi	2015	Economic iusssues, Energy Iussues, Occupant comfort Issues	0-5
KPIs of energy flexibility	/	2014-16	Flexibility factors, Grid feed-in, Self Generation, Self-consumption, Peak power, Efficiency factors etc.	Values

Fig.03 Indicators features summary

Following all the research carried out, it can be seen that the new European indicator is undoubtedly the most eclectic and complete, succeeding in synthesizing different types of assessment with a common unit of evaluation (the scores applied to the different functional levels).
Comparing it with the only other tool presented by a European body, it's noticeable the official and practical nature of the SRI not abandoned to a simple study, but combined with a process of testing, experimentation and comparison with stakeholders. Furthermore, the SRBEI tends to focus on a vision of "Smartness" closely linked to an environment rather than an evaluation of the effects on the Building-Grid-Occupant system.

To conclude the SRI is also the only indicator, compared to the others analyzed to use a percentage score and seems to contain in itself also the parameters described by the other evaluation tools mentioned.

CHAPTER _05

The Digitalized building

By the year 2020, an entire generation, Generation C (for "connected"), will have grown up in a primarily digital world. Computers, the Internet, mobile phones, social networking — all are second nature to members of this group. The **phenomenon of digitization** is reaching an inflexion point. The effects of an increasingly digitized world are now reaching into every corner of our lives and building services make no exception. The futuristic perceived concept of "smart home" is already a reality today in many buildings across the globe. [1] But a digital transformation thought a new digital life will need a building digitalized stock.

Several words are used to describe this phenomenon but we have to consider the differences between digitization, digitalization and digital transformation. The "**digitization**"is the process of making information available and accessible in a digital format, moving to "**digitalization**" we talk about the process of considering how best to apply digitized information to simplify specific operations while with "**digital transformation**" the process of devising new business applications that integrate all the digitized data and digitalized applications. [2]

We can, therefore, consider the "Building Digitalization process" like a monitoring and data analysis useful not only to characterize the building in its individual behaviour but also to open opportunities of interaction among buildings as parts of an energy communities. [3] A data acquisition, processing, and storage it's critical like the user experience, behaviour and response [4]. The "Digitalized Building" will take part in the process of devising new business applications that integrate all the digitized data and digitalized applications called "Digital transformation"[5]

5.1. Automation, Digitalization and Smartness

Today we are on the verge of the era of the smart world where everything is supposed to be done automated and proactively without or minimal human intervention. [6]

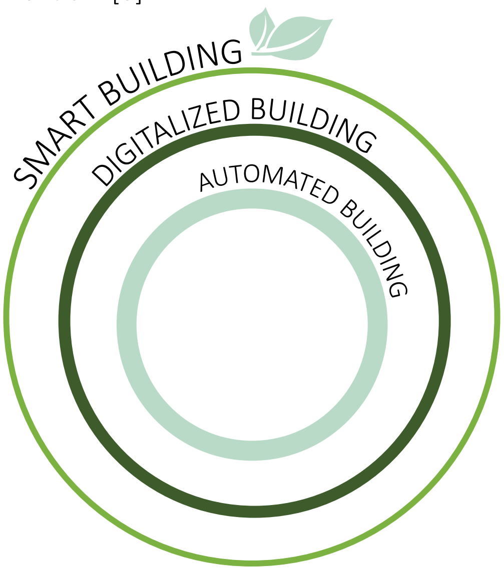


Fig.01 "Smart, Digitalized, Automated Buildings hierarchy"

"*For example, while returning home from office you can contact your home on the Internet to make sure the central heating is on, the curtains are drawn, and a gas fire is roaring in the grate when you get home.[7] We can instruct our micro oven, through our Smartphone, to warm up the pizza; or a wearable gizmo that has an embedded sensor for checking sugar level can remind us to take the insulin dose when the sugar level is high. But we want more. For instance, the room light will be off when we say good night; or on the way to our office, our car radio should brief the morning headlines on its own. Moreover, if the morning flight is delayed, the alarm clock will adjust itself accordingly, allowing us to slumber a bit longer.* [8]"

A "**Smart home**" can do this being perceived by interpreting the data collected from different sensors planted at the house [9] But is it enough to call it "Smart"?

When we talked about "a home equipped with lighting, heating, and electronic devices that can be controlled remotely by Smartphone or computer"[10]we are talking about an "**Automated Building**". Sensor, contacts, smart meters capture and share data in an automated and pervasive manner, but this is not enough. As widely discussed above the "**Smartness of a building** refers to the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation the operation of technical building systems or the external environment (including energy grids) and to demands from building occupants" [11]. In an **Intelligent building**" the house essentially programs itself by monitoring the environment and sensing actions performed by the inhabitants. For example, turning lights on and off, adjusting the thermostat, observing the occupancy and behaviour patterns of the inhabitants, and learning to predict future states of the house."[12]

To reach the "Smart Building" goals the "**Building Digitalization process**" is essential to interpret

the “users & building” complex systems. Sensors, smart meter, devices and actuators are the building **HARDWARE**. They know the building temperature, humidity, airflow, water level, gas leaks, if there is the presence of smoke, earthquakes, recognize the face, lip print or voice of the person and can control the energy and gas consume or the intensity of solar radiation. They **AUTOMATED** the BUILDING.
But in order to **DIGITALIZED** it the data acquisition, processing, and storage issues need to be solved. A **SOFTWARE** is needed for the data transition, formatting, data cleaning and consistency checking. It introduces a **building’s artificial intelligence. IoT (Internet of things) AI, Learning Machine** could learn the pattern and behaviour of an applied system automatically, enhance the user experience, identify anomalies and conflicting situation.

A few things are missing to talk about a **SMART BUILDING** that include, first of all, a **NETWORK** to connects parts of “smart“ building with each other but also several features before presented: relation with the external environment; maintenance and fault detection, user information and sensitization, electric vehicles promotion, fault prediction and maintenance. So even if a Smart Building can be considered a Digitalized building, its definition includes more.

And so, “**When a building could be consider smart?**”. While the difference between an automated and an intelligent building is essential and well-defined, the limits between a digitalized and a smart building is fluid and sometimes interchangeable. A level of intelligence classification was already given in 2003 byR. Harper book, [13] that define “5 building rate of intelligent”.

1. **Homes which contain intelligent objects** – a building containing individual intelligent devices and systems operating independently. For example, a light sensor that turns on when it detects motion or insufficient outdoor lighting.

2. **Homes which contain intelligent, communicating objects** – a building with intelligent devices and systems, which are able to provide information to others. An example can be a situation where the system after locking the front door activates a security alarm, turn off all lights, and turn off electrical socket at household appliances and other activities.

3. **Connected homes** – individual devices and systems of the building are interconnected and at the same time can be controlled from the building or outside – remotely. For example, we have a situation where a person illegally enters the secure building. If the building falls into this degree, then the system calls automatically a security service, notifies owner of the building intrusion and adapts its behaviour (turn on lights, pull up the blinds and other predefined activities).

4. **Learning homes** – the building records normal activities of residents and makes efforts to predict behaviour from the collected data. Subsequently it automates the repetitive activities. A common example can be activation of

the heating feature or light of the building at a certain time. Initially we have to perform necessary operations manually, but then they will be executed automatically after some time.

5 **Attentive homes** – the last degree of the building is based on the previous degree with the difference that it does not work with historical data, but it works with the data in real time. At this degree, are often applied sensors detect motion and activity of the inhabitants of the building. On the base of the information from the sensors are the individual elements of the building operated according to anticipated of needs.
Individual degrees of buildings follow one another and a higher degree includes activities and abilities from all lower degrees. Currently commercially available technologies cover degree 1-3 starting to spread out into higher degree 4 and 5. These higher levels can be seen as a part of research projects.

Another classification of the Building intelligence evolution is given in 2017 by the BPIE in its report "Smart Building Decoded" [14] that, with a different terminology classification expressed the same concepts as above, drawing a historical evolution of the "Smart building" meanings.
This evolving concept is traced back to the early 80s where in the USA, the Intelligent Building Institution describes an Intelligent Building as "one which integrates various systems to effectively manage resources in a coordinated mode to maximise: technical performance; investment and operating cost savings; flexibility" [15]

The first concept of "Smart Home" is presented like our AUTOMATED HOUSE concept, focused on "lifestyle" in-house control. With the Internet of Things

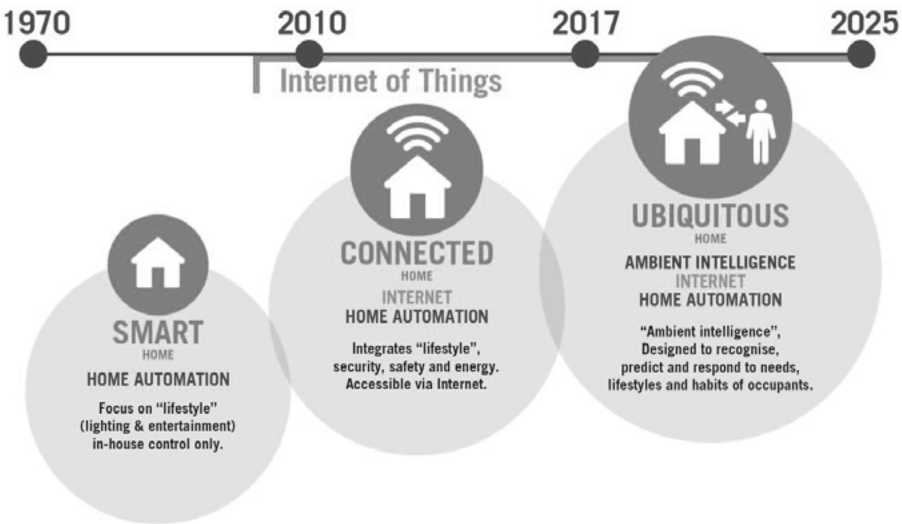


Fig.02 "Evolution of connected and smart homes" (BSRIA)

appearance, the House become “connected” (DIGITALISED). The next step is ambient intelligence, referring to the notion that the building is sensitive and responsive to the needs of occupants and the energy system. [16] The “Ubiquitous home” is what it’s here define like SMART.

An ambient-intelligent building is also a human-centric building. It recognises and automatically adapts to itself according to the occupants’ behaviour and preferences, and thereby optimises comfort, security, energy use and well-being. The progressing level of intelligence is growing up.

The intelligence is much more sophisticated in today’s (smart) buildings. This analysis gives the most complete definition of this evolving concept according with the EPBD and SRI concept.

5.2. The automation instruments

As previously mentioned, the brain of an intelligent building is the **central system**, which helps automate the operation of the building thanks to the necessary central control system and the individual active components: sensors, network and actuators. [18]

Sensors are in buildings to measures quantities, to collect and elaborate data, to analyse and investigate indicators, to give information to the building manager and to give feedbacks to occupants.[19]. The sensors provide information to the control system that influences decisions about development activities.

In the Smart Building can be found mainly those categories of sensors:

- To control the operation of the Smart Building is needed to monitor temperature sensors, humidity, airflow, water level, gas leaks and other. For the safety of the building used sensors that indicate the presence of smoke, flammable gases, earthquakes, temperature control, reco-

Fig.03 “Automated, Smart, Digitalized building classification ”

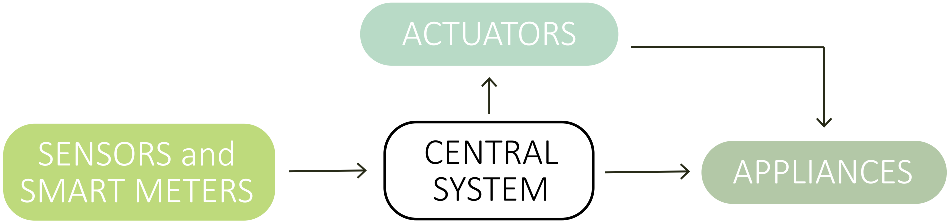


Fig.04 “The automated building instruments”

gnize the face, lip print or voice of the person.

- To control the energy are used sensors: electric power, voltage, current, flow of water and gas, temperature, intensity of solar radiation and leaks. [20]

Actuators receive and carry messages from the sensor (smartphone, dimmer, etc.) for the implementation phase, by adjusting or changing appliances settings or the building components status. In the meanwhile, the **network** connects individual active elements with a central unit (cable – star or bus, Wi-Fi [21]

Some examples of appliances, sensors and actuators are given in the following list:

- Appliances: solar systems, shielding, recovery ventilation, heating, sauna, lighting, audio, TV & Multimedia, swimming pool system, garage doors,etc.

- Sensors: temperature sensor, rain sensor, wind sensor, CO2 sensor, humidity sensor, motion sensor, electricity meter, water leak sensor, flow sensor, pressure sensor, microphone, smoke sensor, sensor breaking of window, windows and doors contacts,

- Actuator: dimmer, regulator, selflearning devices, smartphone, central unit, remote control panel. [22]

5.3. The building digitalization structure

The “Building Digitalization” run out an important role in the transition from Automation to a “Smart” solution. As previously explained, this transition takes place through technologies and devices that provide “Intelligence” to our system.
Among these technologies, one of the trending areas is the development of **Internet of Things (IoT)**.
As one of the challenges of smart buildings is to deal with a complex web of interconnected functional entities in different aspects of a building [23] the essence of IoT is to make any information available to anyone and anytime across all the barriers. [24]
Its architecture is crafted to equip all objects with **identifying, sensing, networking, and processing**

capabilities, so that these objects could exchange and share information with each other and develop advanced services over the Internet. [25]
IoT has taken us to the new possibilities of a smart world for smart living, but this is not enough, the object could be even more "intelligent". It's possible to impulse cognition to the IoT as such that it becomes the extended version of a human. For that, it's required infusing IoT with **Artificial Intelligence (AI)**.
The AI which goes beyond normal machine intelligence to cognitive reasoning and **rationalizing problem solutions like human intelligence** is cognitive AI.[26] It is defined as "An area of computer science that deals with giving machines the ability to seem like they have human intelligence."[27]

But the final purpose of AI is to program the machines such a way so that they can take decisions independently without any human intervention as such that they have their own intelligence to think and reason necessary for taking decisions. So, the emphasis in IoT is the 'connection' whereas, in AI, it is the 'intelligence'. In the perspective of Computer Science studies, AI is a stream of study having many sub-branches such as Machine Learning (ML), Neural Networks, Fuzzy Systems, Genetic Algorithm, Natural Language Processing (NLP) and much more. [28]
The last fundamental element to talk about a digitized building is the **Occupant Profile**. His **behaviour, habits, needs and demands** are fundamental for the purpose of making the machines work at their maximum performance. The Occupants is studied and analysed by the Artificial Intelligence and it's given to him the possibility to have real-time feedback, in addition to a report on the state of the building over time. His communication with the central system ta-

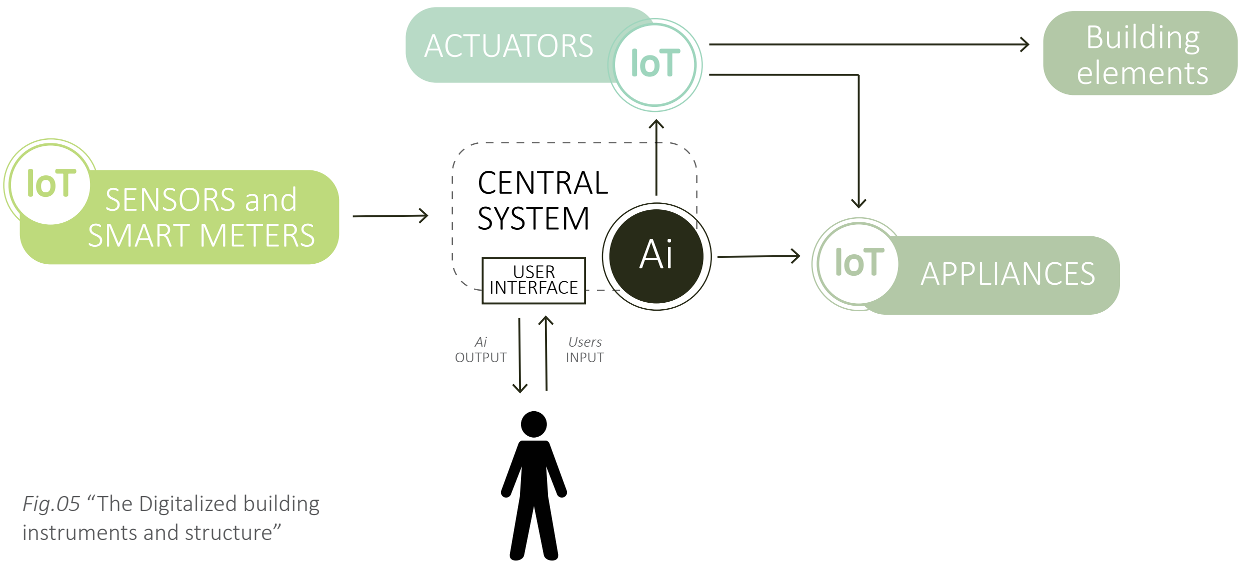


Fig.05 "The Digitalized building instruments and structure"

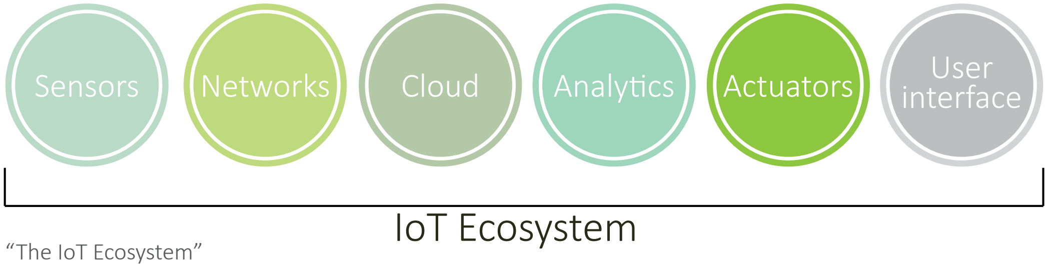


Fig.06 "The IoT Ecosystem"

kes place through a graphic interface, which allows him to manually adjust the functionalities in case of particular needs.

5.3.1 IoT, Ai and learning machine: a digitalization methodology and examples

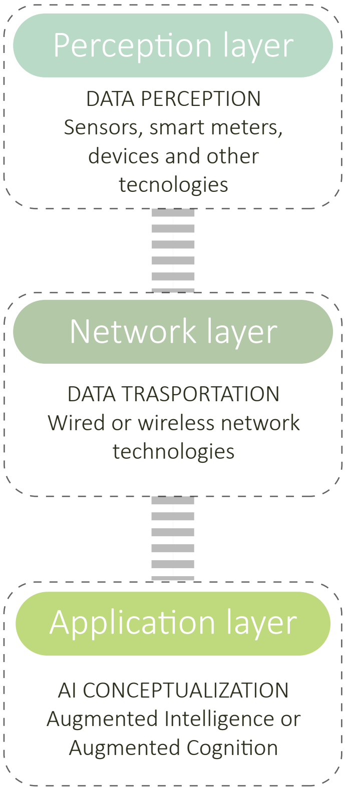
The IoT is being defined as a "Network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment."[29] The primary object of IoT is to connect the objects which are connectable. Here the 'intelligence' (to be technically correct, we should state it as knowledge) come from the sharing of data and streamlining these data to the proper channel. (...) The common factor is that every object is consisting of some type of sensors (e.g. temperature, light, motion, etc.), actuators (e.g. displays, sound, motors, etc.), computing resources (to process the sensed data locally or remotely) and a communication medium (Bluetooth, ZigBee, RFID, etc.).[30]

The IoT system is composed, in fact, by elements that according to different function and contribution can be classified in (1) Devices or sensor, the terminal part; (2) Networks, the communication;(3) the Cloud, the data repository and data processing infrastructure, (4) the Analytics, computational and data mining algorithm, and (5) Actuators and (6) User interfaces.[31]

In the article "Adopting Internet of Things for the development of smart buildings: Are view of enabling technologies and applications" related this year by University of Florida members [32], these components organization, is structured in a three-layer architecture: a Perception layer (1), a Network layer (2) and an application layer (3).

The **perception layer** which includes the perception nodes and perception networks is integrated into the target and is responsible for sensing and data collection. It includes technologies like Wireless Sensor Networks (WSN), Video cameras, Radio frequency identification (RFID), near field communication (NFC) devices, GPS, two-dimensional code, ambient sensors (e.g. temperature, humidity, CO_2), passive infrared (PIR), ultra-wide-band (UWB), and smart meters etc.
The **network layer** is responsible for data transportation, as it is the convergence of various devices

(e.g. gateway) and communication infrastructure. These technologies used could be wired like the USB system or wireless communications like Wi-Fi, Bluetooth, Zigbee, Long-Term Evolution (LTE), Z-Wave, RFID, WAVE, IrDA. Finally, the **application layer** is the top layer which end users interact with.
We are talking about the Artificial Intelligence classify in "Augmented Intelligence" (capability to describe, predict and use relationships among phenomena, conceptualization of artificial intelligence: Predictive Analytics & Machine Learning, Computer vision, Natural Language Processing (NLP), Speech Recognition) and "Augmented Cognition" (a research task that focuses on environments where human-computer interaction exists: Big Data, Cloud Computing, Cognitive Technologies).
This classification is presented to underline like in every phase of the digitalization process the IoT connection is needed. A more precise and accurate description of the possible technologies is presented in the article mentioned in the bibliography.
Moreover, this new American study (2019) presented [33] following this classification, proposes a "Digitalisation methodology "classifying a few final goals to define the **Major IoT application areas**:



1. **Indoor localization - occupants' localization and behaviour**: micro-location is a geo-fence with high certainty, providing the ability to position and track any object inside the building, and consequently used for better and more efficient service provision (e.g. thermal comfort, lighting, preference-based services, etc.)

2. **Energy efficiency**: maximize the use of building energy, with the ideal condition to be a Net Zero Building (NZB), while keeping a high level of service at the same time. Environment and occupants play a key role in how a smart building should operate.

3. Proactive building equipment' maintenance (**facility management**): preventive maintenance and organized operation and control of building facilities and equipment to reduce operations and maintenance time and cost.

4. **Indoor occupant comfort**: Optimize ambient environmental conditions according to occupants' preferences for improving health and productivity.

Fig.07 "Three-layer IoT architecture."

For each of these categories and the **Related building systems** (HVAC, Lighting, Alarm, Auxiliary facilities (e.g. elevator, parking, door), Structure) have been defined sensing devices (for the Perception layer), communication technologies and middleware (for the Network layer) and the analytic, processing and kind of interaction with users (for the application layer). A "Building Digitalization application" is proposed and studies like a interesting methodology. However, due to the in-depth level of the building Intelligence concept previously developed, this structure is not applicable as it lacks systems and operations fundamental.
However, the case reported has been fundamental to understanding the approach to the methodology needed to relate a similar scheme. This example is used to understand how instruments, process and building components are interconnected trying to transform the building in a thinking mind.

A source of inspiration from another point of view is the Turin Start-Up "Enerbrain". It is a enterprise born in 2014 that works to improve financial performance and comfort of large buildings (like offices, schools, hospital etc.). It aims to reduce the CO_2 buildings emissions, to improve the occupants and their wellbeing and to save owners money improving the buildings energy efficiency.[34]

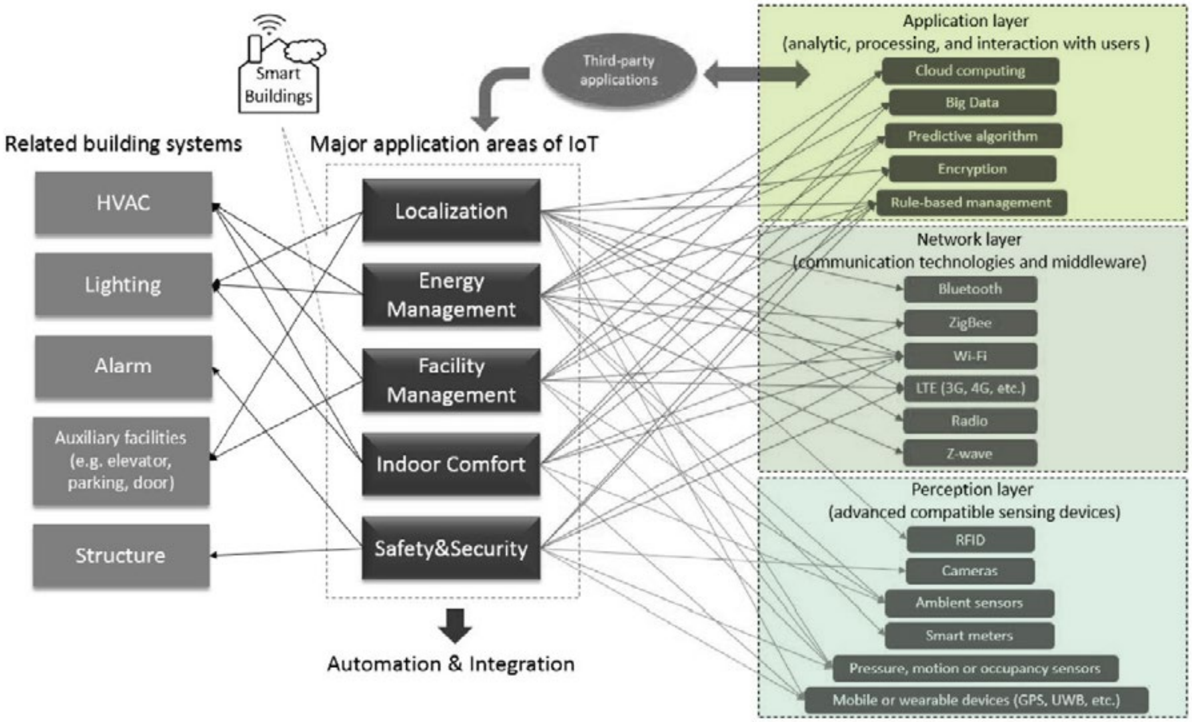


Fig.08 "Summary of application of IoT on smart buildings (goals, technologies, and related building systems)" (Jia, 2019)

Sustainability, Comfort and Efficiency: these are the shared research objectives that brought this research focus on this interesting project. The Enerbrain field of intervention, in fact, could be considered limited in comparison with these thesis goals, which aim to digitize and improve the building under multiple points of view in order to satisfy the SRI parametres. Nevertheless the innovative technologies and the methodology proposed is useful to understand the application process of this analysis.

Fig.09 Enerbrain goals (Enerbrain)

The patent created by this young start-up for a system applicable in all circumstances is innovative. Indoor air quality and energy efficiency are the two main aspects taking into consideration using smart intelligence and devices.

Fig.10 Enerbrain digitalization technologies (Enerbrain)

Sensors are installed non-invasively within the environment. An intelligent algorithm based on the learning machine intelligence analyses these data and sends a command to actuators directly installed to control the system without any modifications to the instalation.

Enerbrain has a regulation system for HVAC systems (heating, cooling and ventilation) that allows to improve the comfort and reduce consumption for air conditioning. It is not only a guarantee of machine learning, but it is also an implementation of data monitoring and data synthesis. This system could simplify maintenance and extends the systems life. A control panel with a dashboard allows the user to monitor and interview to modify the Artificial Intelligence decisions. The system is also designed for facility managers and for the big non-residential buildings management.

Over the interesting use of these technologies in a practical and marketable manner, Enerbrain also emphasizes the importance of the last piece of this process: the communication with the user must be clear and easily accessible in order to obtain his direct collaboration: the Occupant role should take place among the priorities. Also this last one is crucial point of this research.

5.3.2 The communication between building and Occupant: solution and simulated process

Moreover, hardware, software and networks; sensors, devices and actuators; comfort, efficiency and flexibility, an intelligent building learns from its inhabitants, adapts to their life cycle and initiates decisions about changing states of various engineering systems itself. [35] The "Digitalization process" and in particular the AI system take an import role to put the "Occupant" in a lead position. It's important first of all understand his behaviour for correct building automation, but also his implication & response. For this last reason, the participation and the building feed-back should relate with the users in a simple and immediate way. The user interface can be a app on his Smartphone, a customized devices, a website/dashboard or computer program, etc.

The functions that it performs are innumerable: the output data from the Ai of the central Unit and the input from the requests of the user concern the majority of the categories managed by the central unit. Predictive algorithms study the user behaviour and activity, his preferences and response to the system, to anticipate it. The Ai will choice between user request and the optimal choice from an efficiency point of view, advising eventually a different kind of intervention. The communication can be through a screen on site but it's also important its remote control.

In this direction, Mobistyle is a European project focused on motivation end users' behavioural change through ICT based personalized information on user's energy usage, indoor environment and health. In order to achieve this overall aim, MOBISTYLE is built on the following five qualitative objectives:

1. To present understandable information and indicators, related to energy use and energy efficiency, in an easy to handle and attractive way for users.

2. To provide understandable personalized information for users by combining energy monitoring with monitoring of indoor environmental quality, behaviour parameters and daily habits.

3. To motivate a prolonged change of users' habits and daily practices on energy use by combined modular personalized information on individual energy use, health and lifestyle.

4. To foster new business models and applications for future engagements of developers. [36]

Fig.11 The Mobistyle project vision (MOBISTYE project)

This project creates a game applied on two case study a Polish and a Danish one, through a Mobile Android application that gives tips to change user behaviour based on the building sensors.
The other project is a web application developed in Html and Javascript used primarily to configure rooms and give suggestions the objective is improving indoor environmental conditions and energy consumption through alerts/push messages recommends. In this case, there are two different roles the building occupant and the building manager. It is validated in a Slovenian and an Italian case study.

The aspects to be highlighted in this project do not simply concern the focus on the occupant, but the approach with which it is taken into consideration. The data monitoring, the cloud, building sensor and the user wearable are the main elements, but also the type of approach with the user is never underestimated. A joke, an attractive graphic, a simple and direct system convinces the occupant to relate to the building.

Through the Mobistyle project we understood how artificial intelligence can be put in communication with a human being, but how does the communication process between the two parties work?

As previously mentioned for the "Digitalization" process the AI need to collect Data about the Building environment (internal and external) but also about the inhabitants' activities, environmental changes and inhabitants preferences.

In article [37] a simulation process aims to create a dynamic building model for a Smart Building "digita-

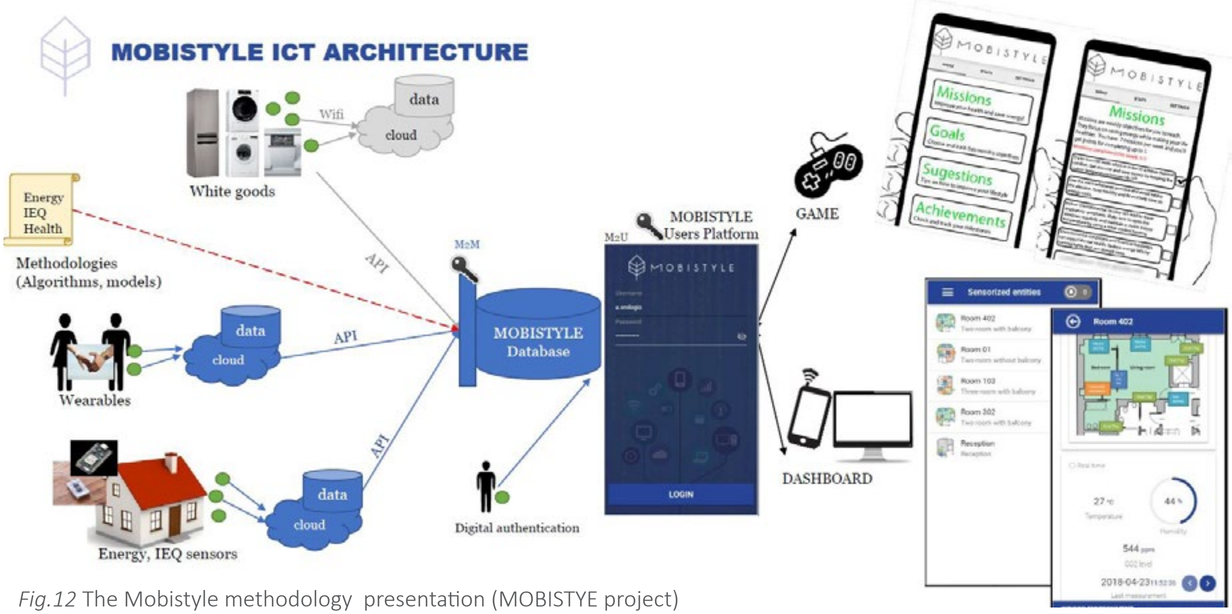


Fig.12 The Mobistyle methodology presentation (MOBISTYE project)

lization". The Fig.13 explains the simulated process where the Data collected by sensors will be processed by an AI.

The environment and inhabitants generate events that will be registered by sensors. They will send the Data collected to the AI component, which does decision making, to modify the state according to the original settings. If it's required for decision making it can pull additional data from other sensors. Once the decision has been made, AI can change a state of the building model using model actuators and devices. The decision taken by the user will be regulating in according to his reaction but leaving the possibility of his direct intervention on the devices. Data and reactions will be collected by the AI

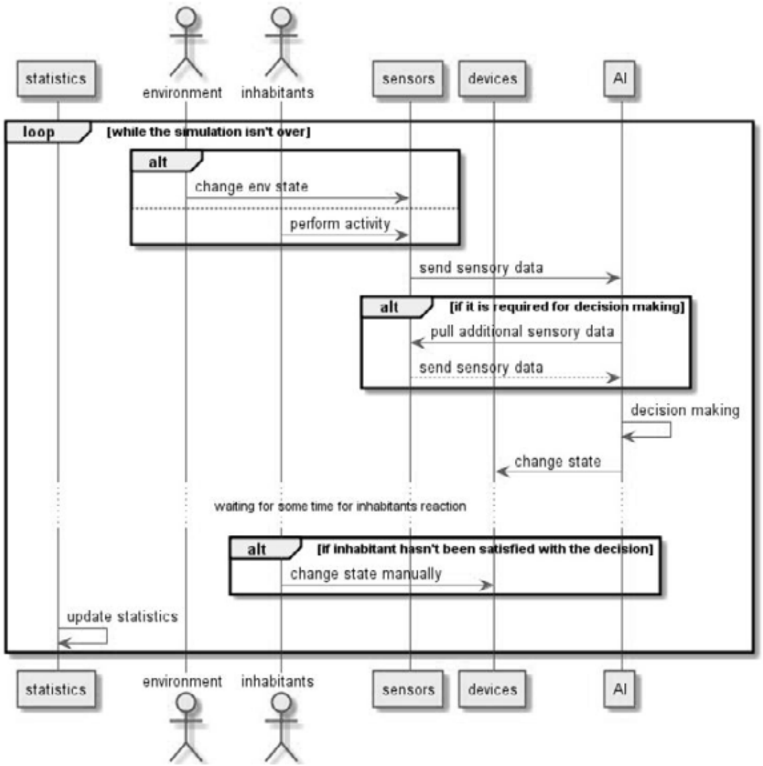


Fig.13 The Mobistyle methodology presentation (MOBISTYE project)

in order to create statistics and algorithms for the best behaviour according to the environmental situation and user choices.

This simulation process was done in 2015 by the Moscow University in order to create an evaluation tool for calculating a Building Intelligence Quotient (BIQ) which could be used as a measure for choosing "smart" building solution. It was used to translate the BIQ theoretical concept into a tool appropriate for engineering practice.

Changing point of view, and speaking about the detriment of this "Digitalization process", it's to underline that if the user is monitored by the building that saves every kind of data in its database in order to give him comfort, benefits and allows him to save money, on the other side an increasing loss of his privacy is inevitable. The continuous monitoring and the collecting and scheduling of his behaviour and habits data need to be registered and stored.

5.4. Benefits and goals

Digitalized buildings encompass a wide variety of sensors, actuators, devices, and control systems that are interconnected and jointly function to improve the service for its occupants. A part of the concept of smart buildings involves integrating a communication network within the buildings' elements so that they can be manipulated or monitored remotely. [38] Several benefits are given by adopting some automated, intelligent solution, a few are listed in the following script:

- Inhabitants comfort: learn from inhabitants behaviour and tries to maximize their comfort
- Energy savings: reduce energy consumption. It is profitable for building owners as it leads to costs cut.
- Time-saving: save a lot of time by automating daily routines.
- Safety: detect fire, water and gas leaks, have a self-diagnostic system and warns inhabitants when equipment becomes faulty or performance starts to decrease.
- Expert systems: Embedded expert systems could contain knowledge about any domestic or industrial area.
- Health and care: decisions health of inhabitants has the highest priority. It is reflected in the appropriate temperature, light intensity, air-condition parameters, etc.
- Assistive domotics: improve the quality of life of the elderly and the disabled living alone by providing a safe and comfortable environment. Homes assist in daily routines, alerts social services and relatives if emergency help is required, reduce a sense of isolation by connecting with other people through the internet and so on. [21]

Following the previous detailed analysis, the aspects and technologies to be taken into consideration for the digitization of a building are certainly clearer. The importance of the types of devices and their classification based on the function assumed in the process is now clear, as the relationships between the various elements. The possible technologies have been described and the possible stakeholders taken into consideration.

To realized the innumerable categories and aspects and the relationships between the various digitalization factors, it's important for the definition of a digitization methodology starts from a listing of the objectives to be achieved. The field of action is extremely high, which is why the choice of the final objectives and the parameters to be taken into consideration is very important.

CHAPTER _06

Digitalization process for a Smart House

Following the technical and bibliographical analysis, dealt with in the previous chapters, an attempt is made to propose a methodology to give, Intelligence to a building. A **method for a "Digitalization plan" for a residential building** is proposed and elaborated following specific practical objectives to be achieved and taking into consideration the capability and limits of existing technologies.
The final purposes to follow for the final result of this more experimental part, as in reality for the whole thesis, are the same ones carried out in the European campaign that led to the drafting of the directive and the definition of the SRI. The building stock "De-carbonization" is the final objective. On the other hand, building efficiency will enable the occupant to reduce his energy bills and its building maintenance costs but it's also taken into consideration the occupant health, security and comfort optimization.

Fig.01 Building digitalization methodology final goals

6.1. The methodology

The methodology study for the realization of this action plan for the “Digitalization of a residential building” is organized in three principal phases:

1. Define the main objectives and relatives needs
2. Listing the elements in order to satisfy that needs and organize it in three main categories
3. Define for each element the relative technologies

In attachment is reported a methodology resume with all the process steps. (Table 1: Methodology process resume)
The plan of intervention on a building for its Digitalization is made for two FINAL PURPOSE:

TO BE “SMART”: Plan of intervention in order to reach a “Level of Intelligence” that satisfies the features and properties, presented and widely discussed in the previous chapters, to be defined as “Smart Building”.

SRI MAX SCORE: Plan of intervention in order to, through a subsequent evaluation, get close to the maximum score of the indicator. The objective is get the maximum functional level for each “Smart ready service” that the building is equipped.

(**METHODOLOGY CONDITIONS**)
The building is considered for its existing features. The plan does not aim to intervene architecturally, to modify the systems or to insert new appliances or devices, but to digitize and make the system intelligent with Sensors, Actuators, Automation system or other devices putting existing elements in connection through Artificial Intelligences and algorithms. The evaluation of the “Smart Readiness Indicator” as well as this methodology does not aim to evaluate the efficiency of the existing building systems, but their Intelligence, Readiness, their ability to learn and manage themselves without human intervention, but always placing themselves in relation with him.

Successful results from this methodology application will be obtained if it’s applied to buildings that are already highly efficient and performing, like the N-Zeb buildings probably already equipped with a high-performance wrapping, renewable systems, shielding systems, water collection, heat pumps etc. The only element whose structure and insertion is taken into consideration with this intervention plan are the electric vehicles charging points. Electric vehicles, considered a fundamental point for the smart society development, are in fact a fundamental point at European level both for the directive and for calculating the indicator. In the SRI, it is the only parameter that can assume negative values and therefore negatively influences the final score.

6.1.1 Needs and categories

The starting point for the drawing up of this plan is the definition of precise objectives that the building must reach: **EFFICIENCY, FLEXIBILITY, COMFORT**.

These are the European goals several cited, but also the keywords for our buildings in the next future.

These objectives are collated with the respective and more specific NEEDS to be satisfied through the evaluation and improvement of the BUILDING ELEMENTS and through some specific BUILDING PROCESS.
These objectives are collated with the respective and more specific NEEDS to be satisfied through the evaluation and improvement of the BUILDING ELEMENTS and through some specific BUILDING PROCESS.

EFFICIENCY

- Reduce consume: Systems optimization according to the building envelope, the internal and the external environment and the occupant behaviour.
- Facility management: Predictive and optimized facility management plan for all the PHYSICAL BUILDING (system, envelope, appliances) components according to the internal and the external environment and the occupant behaviour.

FLEXIBILITY

- Resources optimization: Resources optimization and consume control evaluating the use of renewable sources and according to with the system and appliances optimization, renewable energy sources availability and the internal and the external environment, the occupant behaviour and his COMFORT AND NEEDS.
- Facility management: Predictive and optimized facility management plan for all the PHYSICAL BUILDING (system, envelope, appliances) components according to the internal and the external environment and the occupant behaviour.

Fig.02 "Building digitalization methodology objectives"

COMFORT & OCCUPANTS NEEDS

- Optimize thermal comfort: Optimize thermal comfort according to PHYSICAL BUILDING (system, envelope, appliances) components, the internal and the external environment and the occupant behaviour.
- Optimize light comfort: Optimize light comfort according to PHYSICAL BUILDING (system, envelope, appliances) components, the internal and the external environment and the occupant behaviour.
- Optimize acoustic comfort: Optimize acoustic comfort according to PHYSICAL BUILDING (system, envelope, appliances) components and the internal and the external environment and the occupant behaviour.
- Optimize air quality comfort: Optimize air quality comfort according to PHYSICAL BUILDING (system, envelope, appliances) components, the internal and the external environment and the occupant behaviour.
- Guarantee occupant security: Guarantee occupant security according to PHYSICAL BUILDING envelope, the internal and the external environment and the occupant behaviour.
- Convenience: Consider the occupant convenience and evaluate its importance in relation to the other parameters.

This last point belongs to the SRI impact area where it is defined as "the extent to which services "make the life easier" for the occupant" [1]. This point is fundamental since when, talking about automation, some functions, that may not be efficiently fundamental, could significantly improve the occupant life quality and therefore considered as a type of comfort.

In order to list and classify all the instruments (elements to measure, acting components or intelligent process) needed a three categories organization has been done:

The **BUILDING STATUS and BEHAVIOUR** contains all the elements that can be detected or measured to describe the building environment. All the data of what happens in the environment inside the building is collected (from the temperature to the noisy level) also the occupants' moves and actions and all the data from external input. The external environment category does not only include data measured outside the building and useful for weather detection, but also any necessary information is taken from the web (like a timer and a calendar scheduling, fundamental for the building management).

The **BUILDING** detects, measured and control all the elements that make it up. They are divided for convenience in Systems (all kind of systems, from the HVAC to the RES installation, from the Security to the Electrical installation), Envelope (all the components that allow intervening to modify it) and Appliances (all the devices present in the building).

The **BUILDING MANAGEMENT** contains all the processes for the operation and optimization of the building, deciding functions and parameters by coordinating and managing data and parameters of the other two categories.

These three categories are always connected. In fact, even if they contain very different characteristics, they often combine tools that are complementary and necessary for more functions.

BUILDING STATUS and BEHAVIOUR

- OCCUPANTS: *Presence, Activity*
- EXTERNAL ENVIRONMENT: *Weather, Web data*
- INTERNAL ENVIRONMENT: *Temperature, IAQ, Natural Ventilation, Acoustic, Light*

BUILDING

- SYSTEMS: *Heating system, Cooling system, Mechanical ventilation system, Domestic Water system, Domestic hot water system, STP/other system to produce DHW (including the use of RES), Rain collector system, Lighting system, Electrical system, PV panel and other systems to produce Electricity (including the use of RES), Gas distribution system, Security system, Fault alert system.*
- ENVELOPE: *Windows and doors, Shading*
- APPLIANCES: *Lifts, Devices (household appliance, technology, IT appliance: washing machine, oven, microwave, dishwasher, music system, etc.), Electric Vehicles charging points.*

BUILDING MANAGEMENT

- FACILITY MANAGEMENT: *Ordinary facility, Fault management*
- RESOURCES MANAGEMENT: *Domestic Water, Domestic hot water (with relative Res), Electricity (with relative Res and Energy Storage for energy optimization), Gas*
- SECURITY MANAGEMENT: *Alarms*
- COMFORT OPTIMIZATION: *Thermal, Light, Acoustic, Air quality, Convenience*

The building management resume all the needs and connect through processes the building status with the real building components.

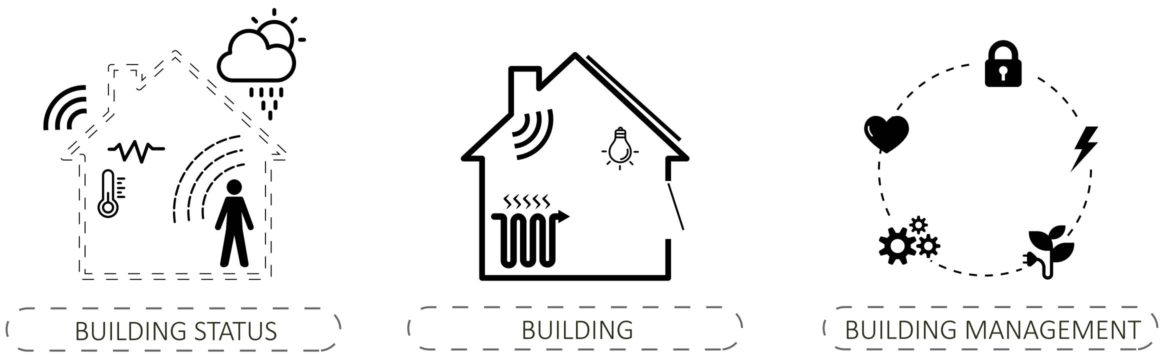


Fig.03 "Building digitalization methodology objectives"

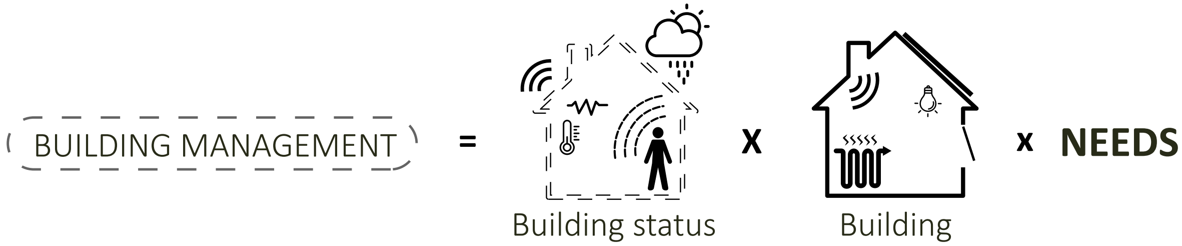


Fig.04 "Building management"

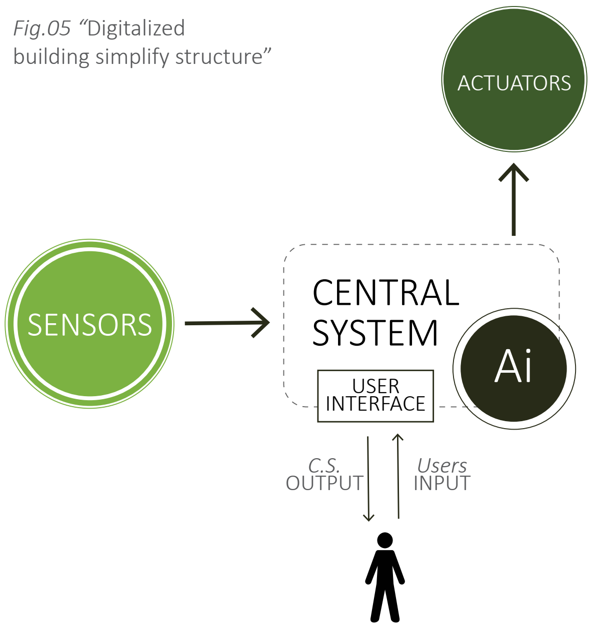
6.1.2 Sensor, Actuators, Ai

Once defined categories and therefore the relative elements/components to be measured or controlled, it will be necessary to define the necessary relative technologies to associate with each one.
As already widely discussed in the previous chapter, there are different types of technologies required for a digitalization process. Fig. 05 shows how the process inside our building is conceived and simplified.

For this digitalization plan, technologies will be categorized into Sensors for the devices needed to measure, Actuators for the devices that act in some way to change status and Artificial Intelligence when we talk about processes. For each element of the sub-categories, these three instruments will be listed. Not all the three functions are always present in the whole of a macro category.

Not for all the categories, the three technologies will be defined. In order to define the "Building status" we need Sensors and the relatives Artificial intelligence algorithms.
The "Building" category technologies will measure, actuate and process its main components. Here are listed the Ai process exclusively related to the building element.
All the process that connects the building with a central function or that need some "Building status" to be process are resume in the last category.
In fact, Building management will resume the Building Ai Process the defined Central Unit algorithms.

Fig.05 "Digitalized building simplify structure"



6.1.3 Technologies list development

Intervention categories, tools and typologies of inserted technologies are studied with the help functional levels of the SRI. The maximum level has been taken into account for each category in order to help to complete the ELEMENTS list. Attached In Table 6.B are presented the SRI maximum functional level considered for each ready service.
As we can see from the following simplify diagrams (Fig. 07,08) the elements are all interconnected and central systems operates all the building management functions elaborating all the sensors data belonging from the environment and from the building components.
Here following, in addition to the schemes to better understand the methodology are reported the tables where all the technologies (sensors, actuators and Ai) are listed organized in the three different main-categories.

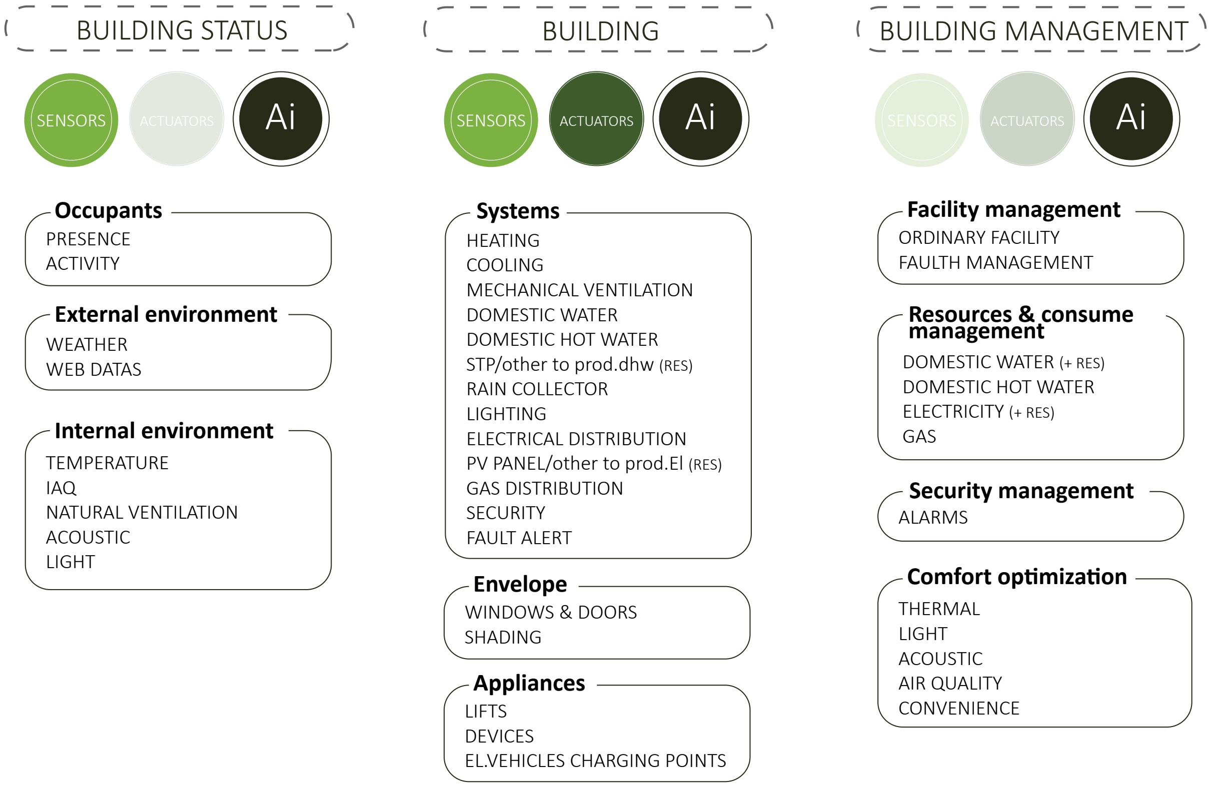


Fig.06 “Categories and relative instruments ”

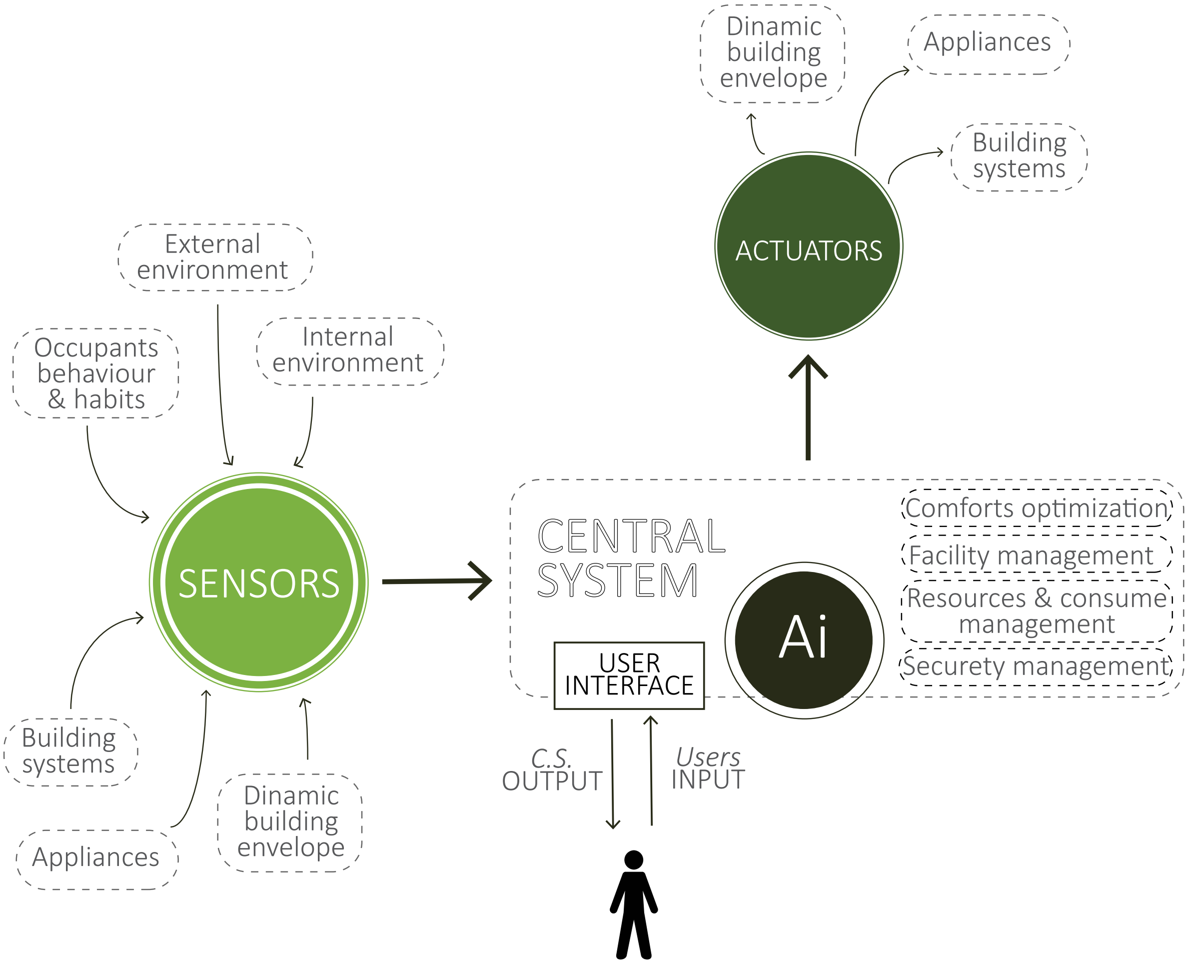


Fig.07 Digitalized building simplify structure with relatives categories

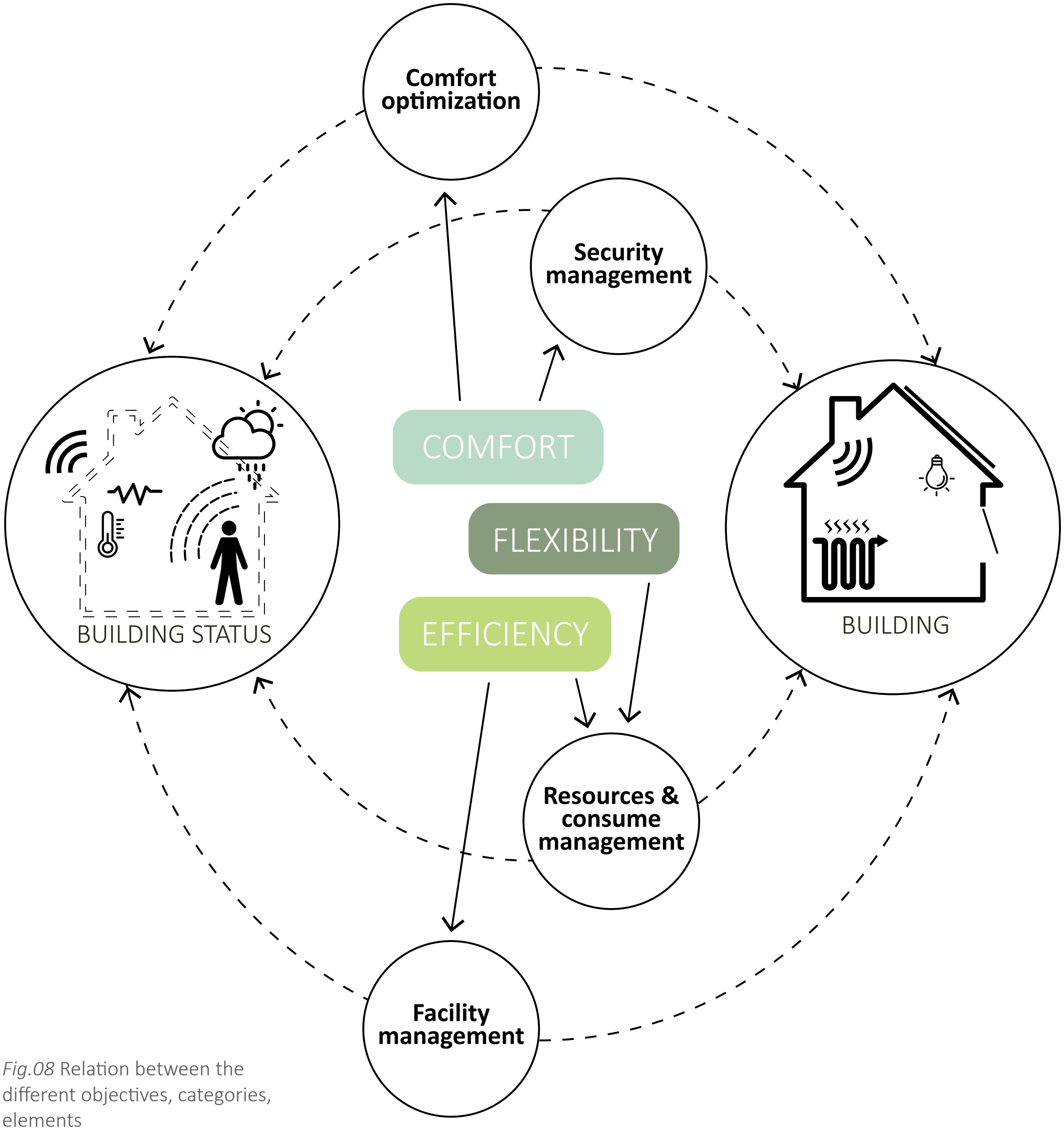


Fig.08 Relation between the different objectives, categories, elements

“Building status” digitalization instruments

CATHEGORIES	COMPONENTS	SENSORS (Device)	Ai (Process)
OCCUPANTS	Presence	Coming home-living home functions/ Access detector Occupancy sensor (ER/area) - position	*Data elaboration* User localization and activities deduction
	Activity	Motion sensor (ER/area)	Occupant activity monitoring in relation with the physical building elements (create habits algorithm)
EXTERNAL ENVIRONMENT	Weather	Wind sensor Rain sensor Light sensor Temperature sensor Pressure sensor CO_2 sensor Glare / solar intake meter Humidity sensor	*Data analysis and predictions* Comparing weather station data with weather forecast data
	Web data	*Connection with WEB/external data IN-PUT* *IN-PUT from external factors*	Timer function Weather forecast data access Calendar scheduling access Other data needed (web access)
INTERNAL ENVIRONMENT	Temperature	Temperature sensor (ER)	*Data elaboration*
	IAQ	Humidity sensor (ER) CO_2 (ER) VOC (Volatile organic compounds) (ER)	*Data elaboration*
	Natural Ventilation	Natural Ventilation Flow (ER)	*Data elaboration*
	Acoustic	Noisy level (ER)	*Data elaboration*
	Light	Internal light sensor (ER)	*Data elaboration*

Legend: [EI] = different device for each Installation, [ER] = different device for each Room

"Building" digitalization instruments

CATHEGORIES		COMPONENTS	SENSORS (Device)	ACTUATORS (Device)	Ai (Process)	*Related process*
SYSTEMS	HVAC	HVAC (general)	/	Central self learning thermostat	Self-learning Central thermostat intelligent algorithm according with external environment and USER HABITS monitoring for predictive plan	*CONSUME MANAGEMENT* *THERMAL COMFORT*
		Heating	Pump meter (EI) Heat Individual room status control device (ER) (on/off/feedback temperature sensor) Heating system consume meter (monitoring recovery) Heat cost allocators (HCA) / meters (M) - remote reading continuous information Heating Fault detector	Heat automated ON/OFF (ER) Heat individual room temperature self-regulator (ER) Speed pump control device (EI) Temperature system control device (EI) Emission e/o distribution control device (ER) Self-learning heating consume regulator device (Recovery/Energy storage-RES)	Demand evaluation Load prediction storage operation Pre-heating algorithms (self learning thermostat*) Heat generator load prediction based sequencing Heat system control according to external signals combined with internal signals (presence-activity control/temperature)	*CONSUME MANAGEMENT* *THERMAL COMFORT* *FACILITY MANAGEMENT*
		Cooling	Pump meter (EI) Cooling Individual room control device (ER) (on/off/feedback temperature sensor) Cooling system consume meter (monitoring recovery) Cooling cost allocators (HCA) / meters (M) - remote reading continuous information Cooling Fault detector	Cooling automated ON/OFF (ER) Cooling individual room temperature self-regulator (ER) Speed pump control device (EI) Temperature system control device (EI) Emission e/o distribution control device (ER) Self-learning cooling consume regulator device (Recovery/Energy storage-RES) Load prediction based sequencing actuator	Demand evaluation Relation with heating system Load prediction storage operation Cooling system control according to external signals combined with internal signals (presence-activity control/temperature)	*CONSUME MANAGEMENT* *THERMAL COMFORT* *FACILITY MANAGEMENT*
		Mechanical ventilation	Supply air temperature meter Automatic flow/pressure control Icing protection sensor Mechanical ventilation fault detector	MV automated ON/OFF (ER) Automatic/self-learning flow regulator/pressure control device (ER)	Predictive (+ sensor data) heat recovery control algorithm Set point with outdoor temperature + load dependant compensation	*CONSUME MANAGEMENT* *IAQ COMFORT* *FACILITY MANAGEMENT*

CATHEGORIES		COMPONENTS	SENSORS (Device)	ACTUATORS (Device)	Ai (Process)	*Related process*
SYSTEMS	WATER	Domestic water	Flow (velocity) sensor Water consume meters (grid) Leakage detectors	Automated Pump On/Off	On/off related with facility management and user habits/request	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.*
		Domestic hot water	DHW supply and return temperature meter DHW storage level meter Leakage detectors	DHW temperature control device DHW pump actuator and control device DHW storage level control device	Multi-sensors storage management algorithm Intelligent dhw demand predictive algorithm	*CONSUME MANAG.* *FACILITY MANAG.*
		STP/HP/Other systems to produce HW	System working status detector (temperature, res storage level meter) Heat pump/STP/others meters (production/consume) Res system fault detector		Predictive system according with external data, DHW system and HVAC	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.*
		Rain collector	Rain water collector level meter Leakage detectors	Rain water collector control device	Predictive demand/availability connected with the weather forecast	*RESOURCES MANAG.* *FACILITY MANAG.*
	ELETRICAL	Lighting system	Light devices status detection (manual on / dimmed or auto off) [EI] Broken device detector	Light control [EI] - On /Off / Dimmer	Self learning algorithm based also in the user habits and preferences combined with weather detection, timing and internal light (during time intervals, dynamic and adapted lighting scenes are set)	*FACILITY MANAG.* *LIGHT COMFORT*
		Electrical distribution system	Electricity consume meters (grid) El. System fault detector	Central electric system ON/OFF (electricity counter)	On/off related with facility management and user habits/request Multi-sensors storage management algorithm Intelligent dhw demand predictive algorithm	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.* *LIGHT COMFORT*
		PV panels /Other systems to cover El.Demand	PV panel (/other res) energy monitoring device RES working status detector (temperature, res storage level meter) System fault detector		Predictive system according with external data, systems and appliances	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.*

Legend: [EI] = different device for each Installation, [ER] = different device for each Room

Brown colour: the systems devices that works with the FACILITY MANGEMENT process.

CATHEGORIES		COMPONENTS	SENSORS (Device)	ACTUATORS (Device)	Ai (Process)	*Related process*
SYSTEMS	GAS	Gas distribution system	Gas consume meters (grid) Gas leak sensor	Gas Remote/ Automated switch On/Off	Fault detection/solution/alarm algorithm On/off related with facility management and user habits/request	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.*
SYSTEMS	ALARM	Security system	Alarm status detection (system on/off) Devices fault detector	System activator	Automated security system activation (presence sensors) Intelligent Alarm alert (sound, light, central and remote notification), problem solving (call, user notification)	*FACILITY MANAG.* *SECURITY MANAG.*
SYSTEMS	ALARM	Fault alert	Fault detection alert (users and central unit)		Intelligent Alarm alert (sound, light, central and remote notification), problem solving (command, user notification)	*FACILITY MANAG.* *SECURITY MANG.*
ENVELOPE		Windows and doors	Window and doors status detector (Each panel - OPEN/CLOSE - regulation) [EI] Broken window sensor [EI]	WINDOW REGULATOR (Each panel - OPEN/CLOSE - regulation) [EI] WINDOWS Spectral proprieties regulator DOORS Open/Close	Self-learning Regulation with HVAC, internal IAQ, light and User request/presence, external data	*CONSUME MANAG.* *FACILITY MANAG.* *LIGHT, IAQ, ACOUSTIC COMFORT*
ENVELOPE		Shading	Window and doors status detector (Each panel - OPEN/CLOSE - regulation) [EI]	SHADING REGULATOR (Each panel - OPEN/CLOSE - regulation)	Self-learning Regulation with weather and internal light sensors + User request/behavior, external data	*CONSUME MANAG.* *FACILITY MANAG.* *LIGHT, ACOUSTIC COMFORT*
APPLIANCES		Lifts	System fault detector	Lift and elevator calling (actuator)	Lift and elevator predictive call (user presence sensor)	*CONSUME MANAG.* *FACILITY MANAG.* *CONVENIENCE*
APPLIANCES		Devices	APPLIANCE STATUS MONITORING (Every machine) On/Off/Regulator/Timer - Intelligent Start APPLIANCE CONSUME MONITORING (Every machine) chronology, status, performance, predictive	APPLIANCE REGULATION (Every machine) - On/Off/Regulator/Timer-Intelligent Start	Self-learning Household appliances regulated by occupants predictive behavior, needs, directives and Energy management optimization User habits monitoring to detect User habits (for other functions)	*CONSUME MANAG.* *FACILITY MANAG.* *ACOUSTIC COMFORT* *CONVENIENCE*
APPLIANCES		Vehicles charging point	EV grid sensor based charging	Intelligent EV charging point (connected with the energy management and flexibility (using RES)	Grid and battery lifecycle optimizations Best charging timing with flexible energy avaibility	*CONSUME MANAG.* *RESOURCES MANAG.* *FACILITY MANAG.*

Legend: [EI] = different device for each Installation, [ER] = different device for each Room

Brown colour: the systems devices that works with the FACILITY MANGEMENT process.

“Building management” digitalization instruments

CATHEGORIES	COMPONENTS	Ai (Process)	*Related categories*
FACILITY MANAGEMENT	Ordinary facility	FM intelligent planning	*All the BUILDING categories (systems, envelope, appliances)*
	Fault management	Predictive fault detection/intelligent problem solving/alarm algorithm	*All the BUILDING categories (systems, envelope, appliances)*
SECURITY MANAGEMENT	Alarms	Intelligent Alarm alert	*Occupant presence, building even elope*
RESOURCES & CONSUME MANAGEMENT	D.WATER	Predictive availability/demands - STORAGE CONTROL - COMSUPTION OPTIMIZATION	*Users needs and habits (consume) - DH system, Rain collector, External environment*
	DHW	Predictive availability/demands - STORAGE CONTROL - COMSUPTION OPTIMIZATION according with the relative RES (STP, HP...)	*Users needs and habits (consume), External environment, STP/HP/Other systems to produce HW, HVAC system, DHW system, appliances*
	ELECTRICITY	Predictive availability/demands - STORAGE CONTROL - COMSUPTION OPTIMIZATION according with the relative RES (PV panel,..)	*Users needs and habits (consume), External environment, PV panel / Other systems to produce El, all the BUILDING categories (systems, appliances, envelope), user behaviour*
	GAS	Predictive generation/demands - STORAGE CONTROL - COMSUPTION OPTIMIZATION according with the relative RES	*Users needs and habits (consume), External environment, HVAC system, Appliances*

Legend: [EI] = different device for each Installation, [ER] = different device for each Room

CATHEGORIES	COMPONENTS	Ai (Process)	*Related categories*
COMFORT OPTIMIZATION	THERMAL	Intelligent, predictive and self-learning algorithm to use the HVAC system and the BUILDING ENVELOPE to guarantee the best Thermal condition according with defined parameters and USER REQUEST (through interface) in different scenarios	*HVAC system, Building envelope (window and shading), Internal environment temperature sensors, external environment (temperature sensor + forecast), occupant presence and activity, appliances*
	LIGHT	Automated (light, user activity), predictive and self-learning (user habits/request) light appliances On-Off-Dimmer to guarantee the best light condition in different scenarios according with defined parameters and USER REQUEST (through interface) Shading automated (light, user activity), predictive (weather/user habits)) and self-learning (user habits/request) regulation to guarantee the best light condition in different scenarios according with defined parameters and USER REQUEST (through interface)	*External environment (light, solar intake, glare sensor + forecast), Internal environment light sensors, Occupant presence, occupant activity, Building envelope, Light appliances*
	ACOUSTIC	Appliances automated and self-learning (user habits) On-Off-Dimmer according with the real time user activity and the scheduling to guarantee the best acoustic condition in different scenarios Building envelope automated and self-learning (user habits) regulation according with the external environment situation and the internal scenario request. System automated and self-learning (user habits) operation to guarantee the least disturbance according with the real time user activity and the scheduling.	*External environment (wind, noisy sensor), Internal environment noisy sensors, Occupant presence, occupant activity, Building envelope, Appliances, Systems*
	IAQ	Intelligent, predictive and self-learning algorithm to use the HVAC system and the BUILDING ENVELOPE to guarantee the best IAQ condition according with defined parameters and USER REQUEST (through interface) in different scenarios	*HVAC system, Building envelope (windows), IAQ Internal environment sensors, external environment (Humidity, Wind + forecast), occupant presence and activity, appliances*
	CONVENIENCE	Lift predictive call with Occupants sensor data Appliances automated and self-learning (user habits) On-Off Other process request from the user	*Lifts, Appliances, Occupant activity and presence*

Legend: [EI] = different device for each Installation, [ER] = different device for each Room

In order to better explain the process two examples are explained.
In a first case, the "External environment sensors" with the "Weather forecast data" expect a rainfall, the C.U. elaborate the algorithm to regulate the envelope. Windows and shading will be accommodated through their actuators and consequently, the lighting system will be regulated according to the light variation, the same for the HVAC systems that will change regulation according to the change of temperature and air quality data already foreseen following the envelope adjustment. This second part will be activated only according to the occupant, his presence (which room and when) measured through "presence sensors" and the ongoing or planned/predicted activities through "activity sensors" with the relatives cloud data. In the same time, the "rainwater collector actuator" activate the device, the C.U. it's also ready to activate the building functions that were waiting for its water. Due to rain, the possibility of irrigation of the planned garden is automatically cancelled.

A second scenario: a user suddenly leaves his smart apartment. The "Coming home-living home functions/ Access detector" recognize it. The lift is automatically called to be ready in the right floor, the television and the lights that the user left on it's automatically switched off and the security system activated. The "Self-regulating thermostat" will change modes, and the building envelope according to the "external environment station" will be regulated to guarantee the best IAQ condition when he will be back.

6.2. Central Unit functionalities and Users interfaces

The central unit can be considered the building brain. All the data received are elaborated through complex algorithms, widely listed in the previous tables where they are categorized like Artificial Intelligence process. The results of these processes are converted into commands for the building actuators.

Machine learning process uses the data collected and saved in the cloud to elaborate predictive algorithms. The "Building History Data" from the cloud collect all the information about the building during its life-cycle.

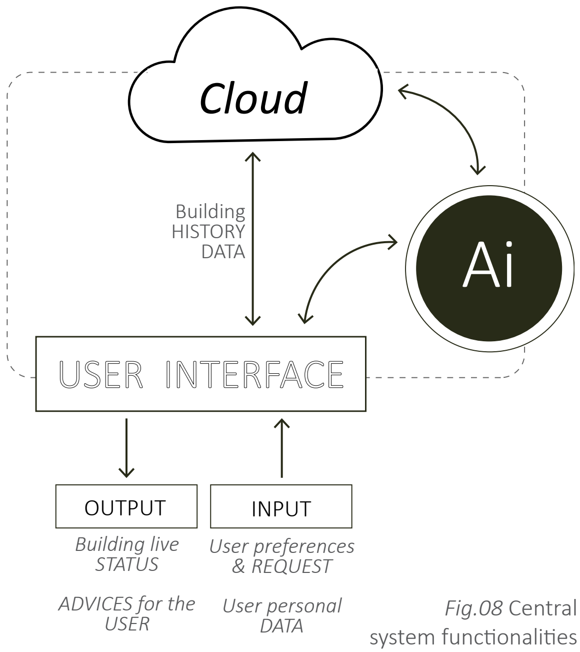


Fig.08 Central system functionalities

The Cloud data are also available to the user that through the "User Interface" receive all the building information.
The "User Interface" allows the occupant also to intervene in the building management process. He can modify the C.U. decisions adapting it to his preferences and needs.
In every case, the Ai will advise him the best solution from an efficiency point of view that considers also his comfort. The Ai analyzes the User interventions in order to accord its command with his wills for future decisions.

User interface functionalities in the three different "Macro-categories"

CATHEGORY	ELEMENTS	OUT-PUT DATA		IN-PUT DATA	
BUILDING STATUS			*type of data*		*type of data*
OCCUPANTS	Presence	OCCUPANCY DETECTION, positions and activities (for security, lighting, HVAC, building envelope, home appliances etc.)	*REAL TIME (House Map)*		
	Activity	PREDICTIVE USERS ACTIVITY (for security, lighting, HVAC, building envelope, home appliances etc.)	*REAL TIME + REPORT + FORECAST*	Add habits, building response for determinate action	*REQUEST*
EXTERNAL ENVIRONMENT	Weather	Weather situation	*REAL TIME + REPORT + FORECAST*		
		External environment condition	*REAL TIME + REPORT + FORECAST*		
	Web data	Time schedule (planning)	*REAL TIME + FORECAST*	Add preference, needs in the time schedule	*REQUEST*
		Weather forecast (sensor + web)	*FORECAST*	Add preference, needs in case of determinate weather	*REQUEST*
INTERNAL ENVIRONMENT	Temperature	Internal environment conditions	*REAL TIME (House Map) + REPORT*		
	IAQ				
	Natural Ventilation				
	Acoustic				
	Light				

CATHEGORY	ELEMENTS	OUT-PUT DATA		IN-PUT DATA	
BUILDING			*type of data*		*type of data*
HVAC SYSTEM	HVAC (general)	HVAC system RUN TIME MANAGEMENT	*REAL TIME + PLANNING*	HVAC system preferences and user directives	*REQUEST*
	Heating	HEATING SYSTEM status and Performance evaluation predictive management	*REAL TIME + REPORT + PLANNING*	HEATING regulation - USERS INPUT	*COMMAND*
	Cooling	COOLING SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT + PLANNING*	COOLING regulation - USERS INPUT	*COMMAND*
	Mechanical ventilation	MV SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT + PLANNING*	MV regulation - USERS INPUT	*COMMAND*
WATER SYSTEM	Domestic water/DHW	DW SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT + PLANNING*	DHW temperature preferences DW manual ON/OFF	*REQUEST* *COMMAND*
	STP/HP/others RES to produce HW	SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT*		
	Rain collector	Rain storage report (Stored, in use)	*REAL TIME + REPORT + FORECAST*		
ELETRICAL SYTEM	Lighting system	Ongoing on/off lights devices status	*REAL TIME (House map)*	Manual ON/OFF/DIMMER regulation	*COMMAND*
	Electrical distribution system	DW SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT*		
	PV panels/other RES to cover El.Demand	SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT*		
GAS SYSTEM	Gas distribution system	USERS' DW SYSTEM status and Performance evaluation including predictive management	*REAL TIME + REPORT*		
ENVELOPE	Windows and doors	Windows and doors status	*REAL TIME (House map) +PREDICTIVE*	Manual OPEN/CLOSE/REGUALTION	*COMMAND*
	Shading	Shading status	*REAL TIME (House map) +PREDICTIVE*	Manual OPEN/CLOSE/REGUALTION	*COMMAND*
APPLIANCES	Lifts	LIFT position	REAL TIME (House map)	Calling function	*COMMAND*
	Devices	Ongoing on/off devices status	REAL TIME (House map) +PREDICTIVE		
	Vehicles charging point	EV charging status (USER INTERFACE)	REAL TIME	Charging ON/OFF	*COMMAND*

CATHEGORY	ELEMENTS	OUT-PUT DATA		IN-PUT DATA	
BUILDING MANAGEMENT			*type of data*		*type of data*
FACILITY MANAGEMENT	Ordinary facility	Intervention needed (real time + planning) Facility management appliances status	*ALARM!* *REAL TIME (House map)*		
	Fault management	Fault detection and alarm	*ALERT + REAL TIME + PREDICTIVE*	Manual command to the Central Unit (HOW SOLVE IT)	*COMMAND*
SECURETY MANAGEMENT	Alarms	House security status	*ALARM!*	Manual alert call	*COMMAND*
SOURCES MANAGEMENT	WATER	WATER consume STATUS(Analyzing, performance evaluation, benchmarking of total and partial values for functions) HW production/demand (recovery, stored, in use) - related RES values Info to optimize WATER consumption	*REAL TIME + REPORT + PREDICTIVE* *REAL TIME + REPORT + PREDICTIVE* *ADVICE!*		
	ELECTRICITY	ELECTRICITY consume STATUS (Analyzing, performance evaluation, benchmarking of total and partial values for functions) Info to optimize ELECTRICITY consumption ENERGY production/demand (recovery, stored, in use, back to the grid) - related RES value (PV panels ...)	*REAL TIME + REPORT + PREDICTIVE* *ADVICE!* *REAL TIME + REPORT + PREDICTIVE*	CENTRAL EL. SYSTEM manual ON/OFF Energy management USER preferences	*COMMAND* *REQUEST*
	GAS	GAS consume STATUS (Analyzing, performance evaluation, benchmarking of total and partial values for functions) Info to optimize GAS consumption	*REAL TIME + REPORT + PREDICTIVE* *ADVICE!*	CENTRAL EL. SYSTEM manual ON/OFF	*COMMAND*
COMFORT OPTIMIZATION	THERMAL	Thermal comfort satisfaction level Info to optimize thermal comfort BUILD HEAT/COLD EXCHANGE (between different areas)	*REAL TIME + REPORT + PREDICTIVE* *ADVICE!* *REAL TIME + REPORT*	Add thermal comfort management preferences, needs	*REQUEST*
	LIGHT	Light comfort satisfy level Info to optimize light comfort	*REAL TIME + REPORT + PREDICTIVE* *ADVICE!*	Add light comfort management preferences, needs	*REQUEST*
	ACOUSTIC	Info to optimize acoustic comfort Acoustic comfort satisfaction level	*ADVICE!* *REAL TIME + REPORT + PREDICTIVE*	Add acoustic comfort management preferences, needs	*REQUEST*
	IAQ	IAQ comfort satisfaction level Info to optimize IAQ comfort	*REAL TIME + REPORT + PREDICTIVE* *ADVICE!*	Add thermal preference, needs	*REQUEST*
	CONVENIENCE			Other user management needs	*REQUEST*

OUT-PUT DATA TYPE (C.U. -> USER)

• *Real time*: real time building data
• *Report*: historical data saving, possibility of consultation and comparison
• *House Map*: A building map is hypothesized to display information about the building in real time
• *Advices*! : Artificial intelligence advices to the users
• *Forecast*: forecast data
• *Alarm*! : Alert notification to catch the users attention
• *Planning/Predictive(?)*: predictive data studied by historical data

IN-PUT DATA TYPE (USER -> C.U.)

• *Request*: user request/needs to the Ai
• *Command*: user intervention to modify automated commands (remote regulation)
• *Info*: user gives needs useful for the system

There are some possible solutions designed to allow the building to relate to the occupant. The previously analyzed "Mobistyle" project is an example. In all cases, simplicity in using the chosen instrument is very important. A clear graphics must help the user by simplifying his operations.
A control panel through a dashboard placed inside the building can be a good solution if postponed with remote control through an app for the phone or a tablet dedicated. The possibility of remote control of the building is fundamental in the smart building context, as well as the messages that the building sends to the user to advise him in his behaviours energy related with the energy system.

Fig.09 User interface typologies

6.3. Relation with the SRI

Due to the need to interconnect most of the digitized building processes and devices, the proposed methodology is complex and organized on multiple levels like the SRI. In the European indicator, different parameters are compared. The different domains and impact criteria allow a complete evaluation while the different ready services through functional levels developed a list of necessary technologies/systems. They are identified as "Smart ready technologies". The Smarter ones (belonged to the max functional levels) are used to define the Sensors, Actuators and Artificial Intelligence process needed to digitalize a building.
The plan proposed is organized in a different way than the SRI. As widely explained, we speak of management processes, that works on various types of scenarios, through the combination of internal, external and occupant environment data and components of the building to be measured, evaluated and managed. The methodology, despite strengths and weaknesses, is a first approach for a complete intervention on a building to be, in the European way, "smart". In both cases, despite different functions and developments, the keyword is "Interoperability".

CHAPTER _07

Conclusions and future developments

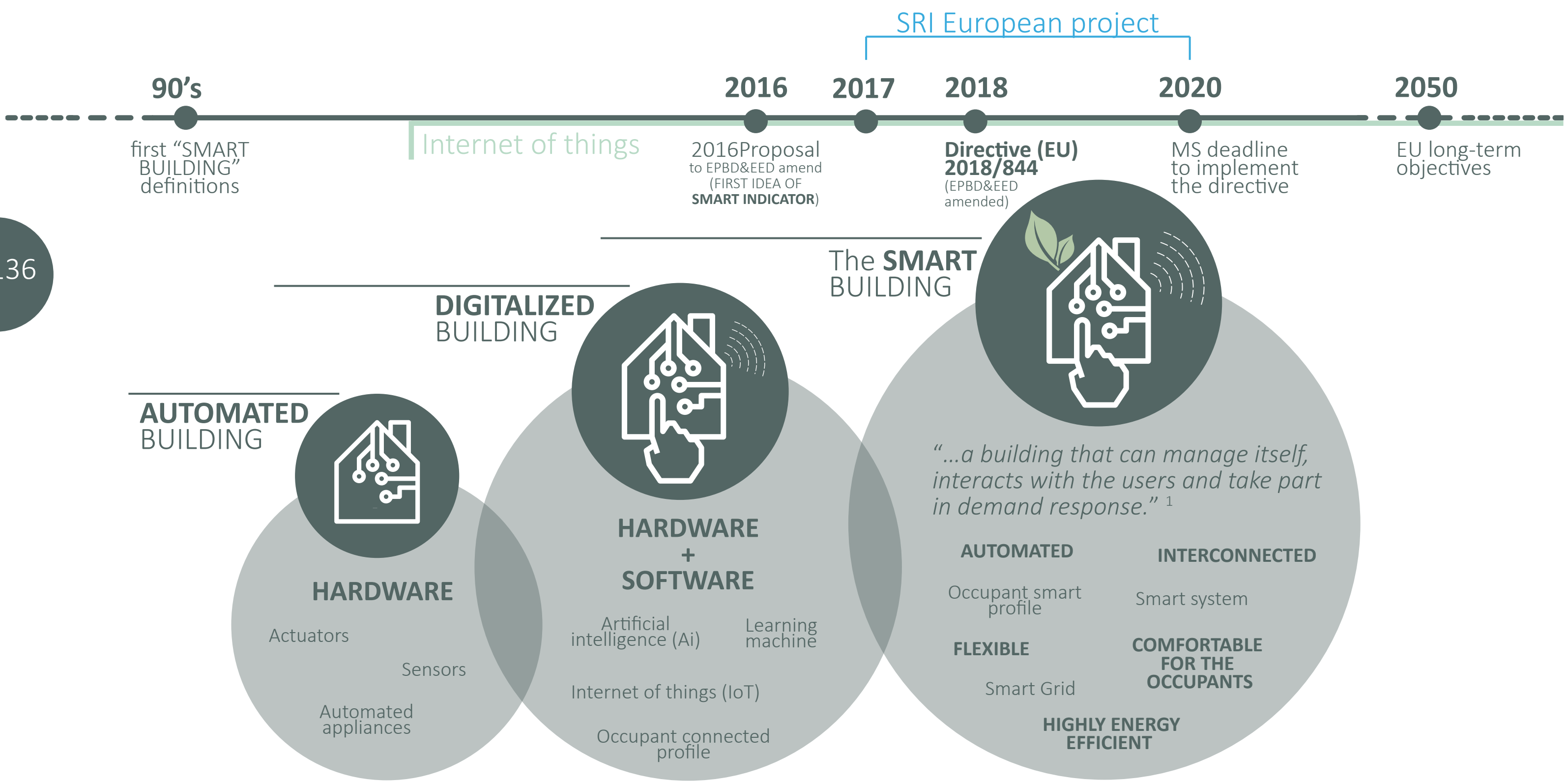


Fig.01 "Building concept evolution"

This research explores "The building concept" development during the phase of the "Digital revolution" that we are living in. The following picture (*Fig.01*) resume the analysis done in the previous chapters showing how the concept has improved during the years, and how, from a legal point of view the phenomenon has been supported and accelerated with the last multi-cited directives and projects. New technologies increased this process and the new "Smart readiness indicator" has the requisites to impose, for the next years, a building stock renovation to a "Smart" direction.

The digitalization process involved different building factors and aspects, often not discounted but all related and interconnected. The building is broken down, measured in all its parts, as well as the User. The proposed methodology is an organized list of the technologies and process required, in order to make the building "Smart" and reach the SRI evaluation parameters. The realization of this methodology has highlighted the need to relate the large amount of data and collected them with the different building components because the variation of each factor can activate a chain of related processes.The results obtained also highlight the occupant role importance in the process, of how it can be monitored, studied, but also trained in order to make the building more efficient. This methodology observes the building efficiency from another perspective: the renovation is no longer conceived as an intervention on the building by modifying it, but as an implementation of himself.

Like previously explained, successful results from this methodology application will be obtained if it's applied to buildings that are already highly efficient and performing, like the N-Zeb probably already equipped with high-performance systems and appliances. It's left for future developments the application of the methodology to one or more case studies to verify its operation and to test the SRI before and after the "Digitalization" process. The possible application of the new indicator and the achievement of a good score is considered fundamental since the SRI, even if still in the definition phase, could become a new evaluation system for our European building stock.

The SRI study project will end in 2020 and hereafter the member states will have to act accordingly.
This could be the first official step for a consequently market revolution. Possible costs and benefits of this change have been highly studied from the EU parties and briefly presented in the previous chapters.

Always thinking about a future European vision, it's important to underline the reason why are introduced, in the methodology proposed, the electric vehicles charging points although they can be considered as an intervention on the building itself. The decision was taken thanks to its considerable importance in the SRI calculation. In fact, this building aspect can be considered its evolution in a broader view of the "Smart concept". In fact, changing scale, it's easy to pass to a district or a city size where the mobility topic is fundamental.
Nowadays the **"Smart city"** can be considered another of the warm and forthcoming topics. It represents an innovative concept that encourages economic development, living quality enhancement and environment preservation based on intelligent and dynamic infrastructures. [1] Also, in this case, we talk about an integrated vision whose evaluation it is composed of numerous factors and variables. Numerous studies and projects are being developed in this direction too. In this case, six fundamental domains can be listed: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. [2]

But the questions are **"Are we able to deal with this change?" , "Is Europe ready for Smart buildings?".**
The answer from the BPIE is a clear NO. Or at least, no country is fully ready to take advantage of the benefits the smart revolution will entail, including greener, healthier and more flexible energy use.
The map (Fig.02) is the result of a precise study presented from BPIE (in its report of 2017 "Is Europe ready for a Smart building revolution?") done evaluating the member states with the Smart-Ready Built Environment Indicators (previously presented – 4.2.1). These are the result of the sum of the different indicator scores for each SRBEI parameter in

each country.
However, progressive legislative measures covering different sectors in different countries are paving the way for smarter building stock.

Fig.02 "Building concept evolution"

For example, Germany has launched a scheme to increase the number of batteries in buildings, while Sweden, Finland and Italy have already completed their roll-out of smart meters. The United Kingdom and France encourage demand response activities, and Denmark is leading to green district heating activities. Electric vehicles are not solely for the early-adopters in the Netherlands.
Finland has also invested significantly in generating renewable energy from heat pumps. [3]
So, if Europe it's not ready, it is preparing to be.

Completely changing scale and returning to the digitization methodology, issues of readiness can also reflect the human individual in this situation with the role of users. In fact, this digitalization phenomenon certainly carries with it a people life-style alteration. Better light, acoustic, thermal and IAQ comfort are in the objective list with a "simplified" life thanks to the "convenience" parameter. So, if a lifestyle improvement it's guaranteed, a loss of decision-making power and privacy will be inevitable. For example, a parameter that we decided to not consider in this plan but that could be a starting point for future developments is the "Occupant Healthy Optimization".
The smart home in the near future will know data on the occupant himself. In addition to his actions and habits within the building, the user will be monitored on his health, appointments, habits to satisfy or anticipate his needs and to advice him. This step probably less impacting with the building efficiency will be a remarkable life change. The buildings will act in an ever more efficient and autonomous way satisfying user needs and desires in a way so perfect as to let him forget actions now taken for granted.

However, due to the increasing evolution of technology, this process is irreversible. The only thing that is still possible to do is direct and exploit this development in order to guarantee an improvement in the human lifestyle and on the other hand to use technologies to reduce the building CO_2 emission and safeguard the planet in which we live in.

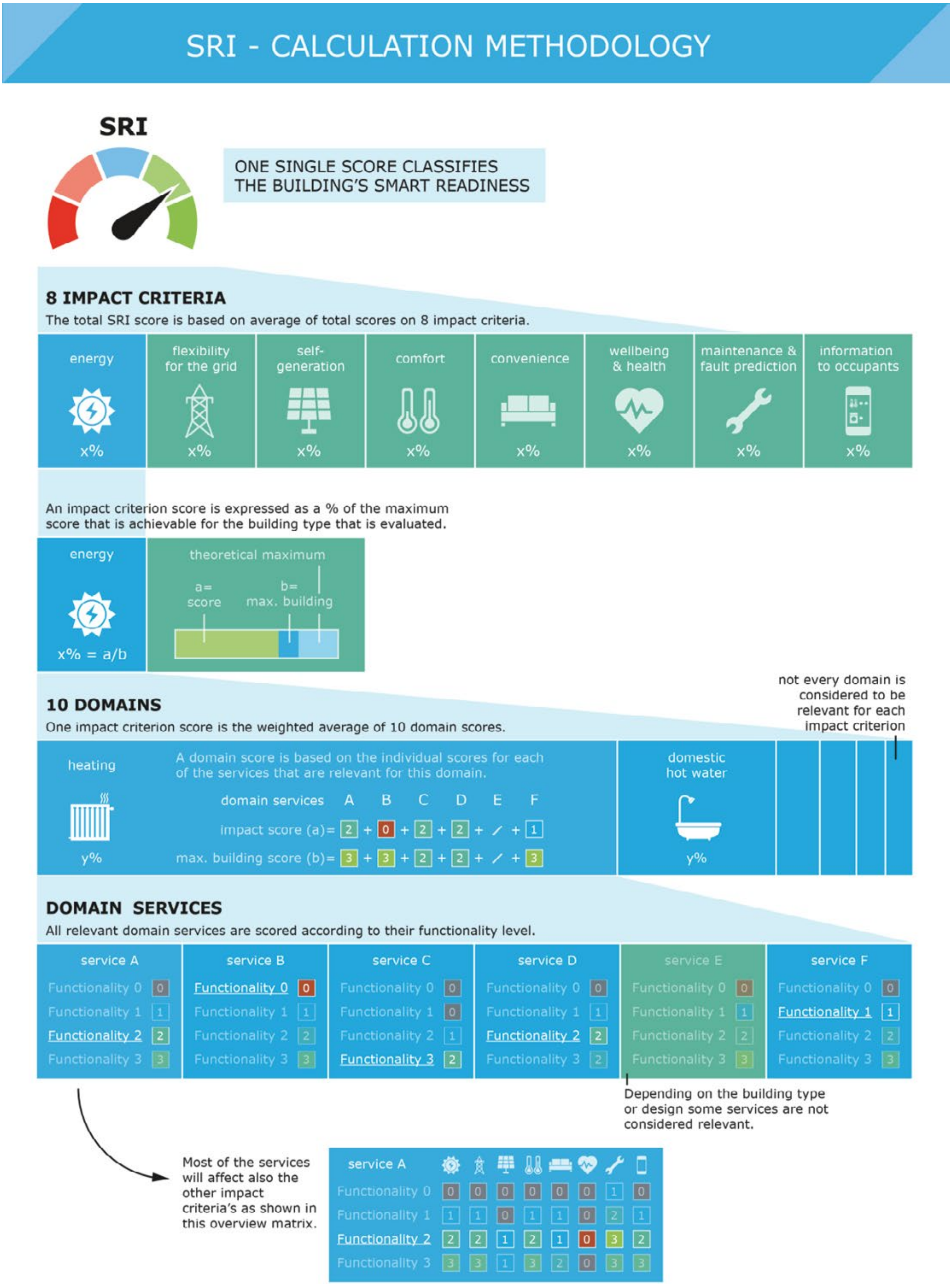
Attachements

CHAPTER 3: Smart Readiness indicator (SRI)

- Table 3.A: SRI Methodology process official resume
- Table 3.B: “Smart Ready services” list
- Table 3.C: 3th case study calculation tables

CHAPTER 6: Digitalization plan methodology

- Table 6.A: Methodology process resume
- Table 6.B: SRI max functional level for each ready service



EUROPEAN COMMISSION DG ENERGY (2018), "Support for Developing a Smart Readiness Indicator for Buildings" project, Support for setting up a Smart Readiness Indicator for buildings and related impact assessment FINAL REPORT, 2018.08.26

Table 3.B: “Smart ready services” list

EUROPEAN COMMISSION DG ENERGY (2018), Annex A, “Support for Developing a Smart Readiness Indicator for Buildings” project, Support for setting up a Smart Readiness Indicator for buildings and related impact assessment FINAL REPORT, 2018.08.26

Domain	Code	Smart ready service	Part of the proposed simplified indicator
Heating	Heating-1a	Heat emission control	yes
Heating	Heating-1b	Emission control for TABS (heating mode)	yes
Heating	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	yes
Heating	Heating-1d	Control of distribution pumps in networks	yes
Heating	Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	yes
Heating	Heating-1f	Thermal Energy Storage (TES) for building heating (excluding TABS)	yes
Heating	Heating-1g	Building preheating control	yes
Heating	Heating-2a	Heat generator control (for combustion and district heating)	yes
Heating	Heating-2b	Heat generator control (for heat pumps)	yes
Heating	Heating-2c	Sequencing of different heat generators	yes
Heating	Heating-2d	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)	no
Heating	Heating-2e	Control of on-site waste heat recovery fed into the heating system (e.g. excess heat from data centers)	no
Heating	Heating-3	Report information regarding HEATING system performance	yes
Domestic hot water	DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	yes
Domestic hot water	DHW-1b	Control of DHW storage charging (using hot water generation)	yes
Domestic hot water	DHW-1c	Control of DHW storage temperature, varying seasonally: with heat generation or integrated electric heating	no

Domestic hot water	DHW-1d	Control of DHW storage charging (with solar collector and supplymentary heat generation)	yes
Domestic hot water	DHW-2	Control of DHW circulation pump	no
Domestic hot water	DHW-3	Report information regarding domestic hot water performance	yes
Cooling	Cooling-1a	Cooling emission control	yes
Cooling	Cooling-1b	Emission control for TABS (cooling mode)	yes
Cooling	Cooling-1c	Control of distribution network chilled water temperature (supply or return)	yes
Cooling	Cooling-1d	Control of distribution pumps in networks	yes
Cooling	Cooling-1e	Intermittent control of emission and/or distribution	yes
Cooling	Cooling-1f	Interlock between heating and cooling control of emission and/or distribution	yes
Cooling	Cooling-1g	Control of Thermal Energy Storage (TES) operation	yes
Cooling	Cooling-2a	Generator control for cooling	yes
Cooling	Cooling-2b	Sequencing of different cooling generators	yes
Cooling	Cooling-3	Report information regarding cooling system performance	Yes
Controlled ventilation	Ventilation-1a	Supply air flow control at the room level	yes
Controlled ventilation	Ventilation-1b	Adjust the outdoor air flow rate	yes
Controlled ventilation	Ventilation-1c	Air flow or pressure control at the air handler level	yes
Controlled ventilation	Ventilation-2a	Room air temp. control (all-air systems)	yes
Controlled ventilation	Ventilation-2b	Room air temp. control (Combined air-water systems)	no
Controlled ventilation	Ventilation-2c	Heat recovery control: prevention of overheating	yes
Controlled ventilation	Ventilation-2d	Supply air temperature control	yes
Controlled ventilation	Ventilation-3	Free cooling with mechanical ventilation system	yes
Controlled ventilation	Ventilation-4	Heat recovery control: icing protection	no
Controlled ventilation	Ventilation-5	Humidity control	no
Controlled ventilation	Ventilation-6	Reporting information regarding IAQ	yes
Lighting	Lighting-1a	Occupancy control for indoor lighting	yes
LIghting	Lighting-1b	Mood and time based control of lighting in buildings	no
Lighting	Lighting-2	Control artificial lighting power based on daylight levels	yes
Dynamic building envelope	DE-1	Window solar shading control	yes
Dynamic building envelope	DE-2	Window open/closed control, combined with HVAC system	yes
Dynamic building envelope	DE-3	Changing window spectral properties	no
Energy generation	EG-1	Amount of on-site renewable energy generation	no

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Energy generation	EG-2	Reporting information regarding energy generation	yes
Energy generation	EG-3	Storage of locally generated energy	yes
Energy generation	EG-4	Optimizing self-consumption of locally generated energy	yes
Energy generation	EG-5	CHP control	yes
Demand side management	DSM-1	Services for integration of renewables into the building energy portfolio	no
Demand side management	DSM-2	Services for integrating battery storage systems into energy portfolio	no
Demand side management	DSM-3	Support of microgrid operation modes	no
Demand side management	DSM-4	Integration of smart appliances	no
Demand side management	DSM-5	Power flows measurement and communications	no
Demand side management	DSM-6	Energy delivery KPI tracking and calculation	no
Demand side management	DSM-7	Fault location and detection	no
Demand side management	DSM-8	Fault prevention and risk assessment	no
Demand side management	DSM-9	Fraud detection and losses calculation	no
Demand side management	DSM-10	Neighbourhood energy efficiency calculation	no
Demand side management	DSM-11	Demand prediction	no
Demand side management	DSM-12	Information exchange on renewables generation prediction	no
Demand side management	DSM-13	Heat management for a multi-tenant house by aggregator	no
Demand side management	DSM-14	Flexible start and switch off of home appliances	no
Demand side management	DSM-15	DSM control of a device by an aggregator	no
Demand side management	DSM-17	Energy storage penetration prediction	no
Demand side management	DSM-18	Smart Grid Integration	yes
Demand side management	DSM-19	DSM control of equipment	yes
Demand side management	DSM-20	Connecting PV to DSO grid	no
Demand side management	DSM-21	Reporting information regarding DSM	yes
Demand side management	DSM-22	Override of DSM control	yes
Electric vehicle charging	EV-1	Charging whenever needed at the charging pole of the building ("dumb charging service")	no
Electric vehicle charging	EV-3	Charging with local, building system based control (price signal based charging)	no

Electric vehicle charging	EV-4	Charging with aggregated control (EV responsible party as VPP balancing responsible party)	no
Electric vehicle charging	EV-5	Charging with aggregated control (EV resposible party under a balance responsible party)	no
Electric vehicle charging	EV-7	Grid connected heating for EV in winter time	no
Electric vehicle charging	EV-8	Providing system services to DSO operations	no
Electric vehicle charging	EV-9	Charging for optimisation of the EV battery life-cycle	no
Electric vehicle charging	EV-10	Charging at a commercial building site - roaming	no
Electric vehicle charging	EV-11	Charging based on DSO price tags - " local wind storage"	no
Electric vehicle charging	EV-12	Providing the state-of-charge to home display	no
Electric vehicle charging	EV-13	Fast charging services - mode 4	no
Electric vehicle charging	EV-14	Vehicle to grid operation and control	no
Electric vehicle charging	EV-15	EV Charging Capacity	yes
Electric vehicle charging	EV-16	EV Charging Grid balancing	yes
Electric vehicle charging	EV-17	EV charging information and connectivity	yes
Monitoring and control	MC-1	Heating and cooling set point management	no
Monitoring and control	MC-2	Control of thermal exchanges	no
Monitoring and control	MC-3	Run time management of HVAC systems	yes
Monitoring and control	MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	yes
Monitoring and control	MC-5	Reporting information regarding current energy consumption	no
Monitoring and control	MC-6	Reporting information regarding historical energy consumption	no
Monitoring and control	MC-7	Reporting information regarding predicted energy consumption	no
Monitoring and control	MC-9	Occupancy detection: connected services	yes
Monitoring and control	MC-10	Occupancy detection: space and activity	no
Monitoring and control	MC-11	Remote surveillance of building behaviour	no
Monitoring and control	MC-12	Central off-switch for appliances at home	no
Monitoring and control	MC-13	Central reporting of TBS performance and energy use	yes
Various	VA-1	Coming home - leaving home functions	no

Various	VA-2	Inactivity recognition services	no
Various	VA-3	Multi-tenant access control for buildings without keys	no
Various	VA-4	Occupants Wellbeing and health status monitoring services	no
Various	VA-5	Dementia monitoring	no
Various	VA-8	Rain water Collection	no
Various	VA-9	Smoke detection	no
Various	VA-10	Water leakage detection	no
Various	VA-11	Carbon Monoxide detecion	no
Various	VA-12	Emergency notification services	no
Various	VA-13	Smart testing of emergency lighting	no
Various	VA-14	Intelligent alerting on building events	no
Various	VA-18	Energy Cost Allocation for heating, cooling and water	no
Various	VA-19	Lifts and elevators: Control and dispatching	no
Various	VA-20	Lift and elevator monitoring and maintenance	no
Various	VA-21	Lift and elevator energy recovery management	no

Table 3.C: 3th case study calculation tables

SR fields						ORDINAL IMPACT SCORES							
Domain	Code	Service	Functionality level for this building	Max possible functionality level	Max functionality level in this building	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Heating	Heating-1a	Heat emission control	2	4	4	2	0	0	2	2	0	0	0
Heating	Heating-1b	Emission control for TABS (heating mode)	0	3	0	0	0	0	0	0	0	0	0
Heating	Heating-1c	Control of distribution network hot water temperature (supply or return) - Similar function can be applied to the control of direct electric heating networks	1	2	2	1	0	0	1	1	0	0	0
Heating	Heating-1d	Control of distribution pumps in networks	3	4	4	3	0	0	3	0	0	0	0
Heating	Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	2	3	3	2	0	0	2	2	0	0	0
Heating	Heating-1f	Thermal Energy Storage (TES) for building heating	0	2	0	0	0	0	0	0	0	0	0
Heating	Heating-1g	Building preheating control	2	2	2	2	0	0	2	2	0	0	1
Heating	Heating-2a	Heat generator control (for combustion and district heating)	1	2	2	1	0	0	1	0	0	0	0
Heating	Heating-2b	Heat generator control (for heat pumps)	0	3	0	0	0	0	0	0	0	0	0
Heating	Heating-2c	Sequencing of different heat generators	0	3	0	0	0	0	0	0	0	0	0
Heating	Heating-3	Report information regarding HEATING system performance	2	4	4	1	0	0	0	0	0	1	2

SR fields			ORDINAL IMPACT SCORES								MAXIMUM POSSIBLE ORDINAL IMPACT SCORES							
Domain	Code	Service	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Heating	Heating-1a	Heat emission control	2	0	0	2	2	0	0	0	3	0	0	2	3	0	1	0
Heating	Heating-1b	Emission control for TABS (heating mode)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	Heating-1c	Control of distribution network hot water temperature (supply or return) - Similar function can be applied to the control of direct electric heating networks	1	0	0	1	1	0	0	0	2	0	0	1	2	0	1	0
Heating	Heating-1d	Control of distribution pumps in networks	3	0	0	3	0	0	0	0	3	0	0	3	0	0	0	0
Heating	Heating-1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	2	0	0	2	2	0	0	0	3	0	0	3	3	0	0	0
Heating	Heating-1f	Thermal Energy Storage (TES) for building heating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	Heating-1g	Building preheating control	2	0	0	2	2	0	0	1	2	0	0	2	2	0	0	1
Heating	Heating-2a	Heat generator control (for combustion and district heating)	1	0	0	1	0	0	0	0	2	0	0	2	0	0	0	0
Heating	Heating-2b	Heat generator control (for heat pumps)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	Heating-2c	Sequencing of different heat generators	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	Heating-3	Report information regarding HEATING system performance	1	0	0	0	0	0	1	2	1	0	0	0	1	0	2	3

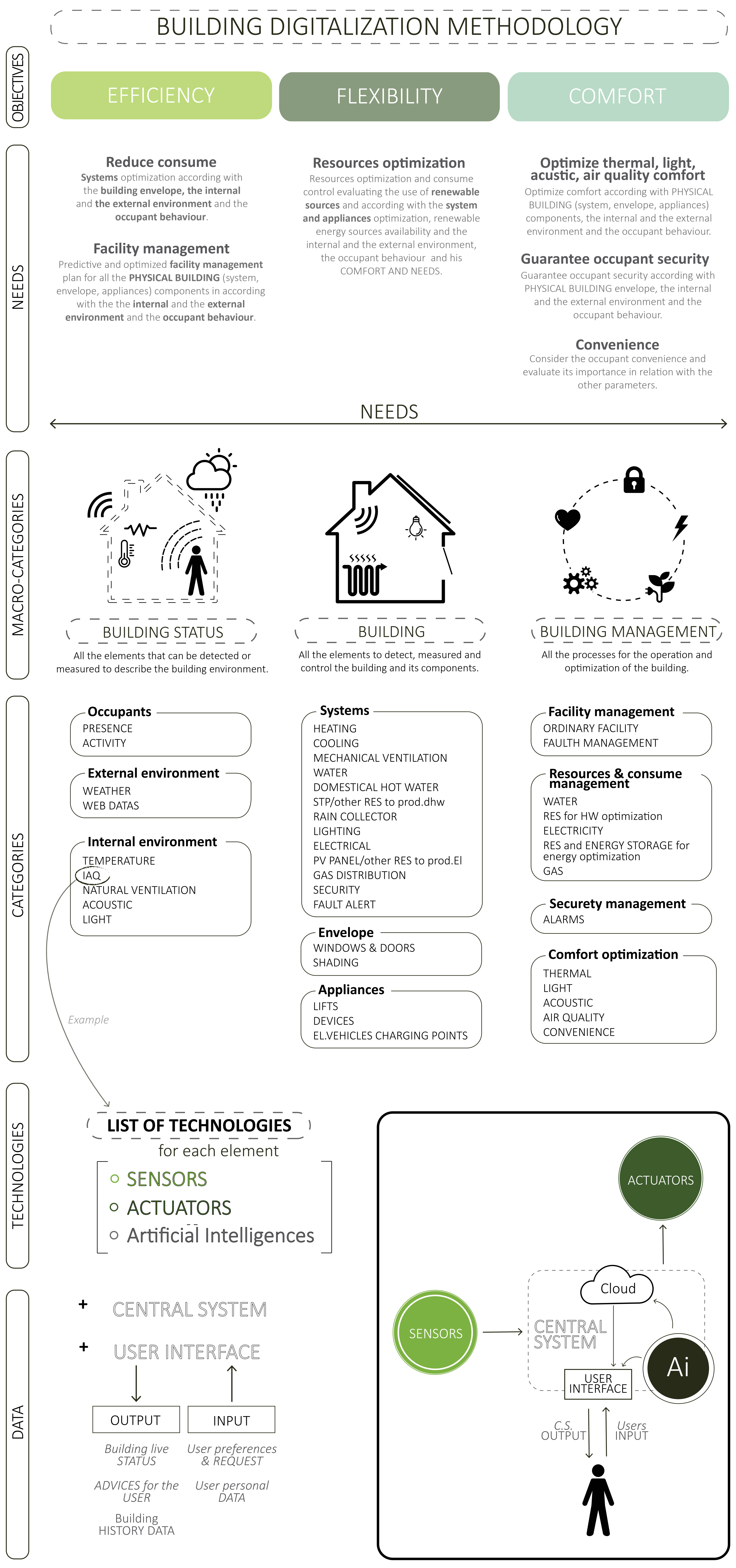
SR fields						ORDINAL IMPACT SCORES							
Domain	Code	Service	Functionality level for this building	Max possible functionality level	Max functionality level in this building	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Domestic hot water	DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	0	3	0	0	0	0	0	0	0	0	0
Domestic hot water	DHW-1b	Control of DHW storage charging (using heat generation)	0	3	0	0	0	0	0	0	0	0	0
Domestic hot water	DHW-1d	Control of DHW storage charging (with solar collector and supplymentary heat generation)	0	3	0	0	0	0	0	0	0	0	0
	DHW-3	Report information regarding domestic hot water performance	2	4	4	1	0	0	0	0	0	1	2

SR fields			ORDINAL IMPACT SCORES								MAXIMUM POSSIBLE ORDINAL IMPACT SCORES							
Domain	Code	Service	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Domestic hot water	DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic hot water	DHW-1b	Control of DHW storage charging (using heat generation)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic hot water	DHW-1d	Control of DHW storage charging (with solar collector and supplymentary heat generation)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DHW-3	Report information regarding domestic hot water performance	1	0	0	0	0	0	1	2	1	0	0	0	1	0	2	3

SR fields						ORDINAL IMPACT SCORES							
Domain	Code	Service	Functionality level for this building	Max possible functionality level	Max functionality level in this building	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Lighting	Lighting-1a	Occupancy control for indoor lighting	0	3	3	0	0	0	0	0	0	0	0
Lighting	Lighting-2	Control artificial lighting power based on daylight levels	0	4	4	0	0	0	0	0	0	0	0
Demand side management	DSM-18	Smart Grid Integration	0	1	1	0	0	0	0	0	0	0	0
Demand side management	DSM-19	DSM control of equipment	0	4	4	0	0	0	0	0	0	0	0
	DSM-21	Reporting information regarding DSM	0	2	2	0	0	0	0	0	0	0	0
	DSM-22	Override of DSM control	0	3	3	0	0	0	0	0	0	0	0
Monitoring and control	MC-3	Run time management of HVAC systems	2	3	3	2	1	0	2	2	1	0	0
Monitoring and control	MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	0	2	2	0	0	0	0	0	0	0	0

SR fields			ORDINAL IMPACT SCORES								MAXIMUM POSSIBLE ORDINAL IMPACT SCORES							
Domain	Code	Service	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants	Energy	Flexibility	Self-gen	Comfort	Convenience	Health	Maintenance & fault prediction	Information to occupants
Lighting	Lighting-1a	Occupancy control for indoor lighting	0	0	0	0	0	0	0	0	2	0	0	2	2	0	0	0
Lighting	Lighting-2	Control artificial lighting power based on daylight levels	0	0	0	0	0	0	0	0	3	0	0	3	3	3	0	0
Demand side management	DSM-18	Smart Grid Integration	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Demand side management	DSM-19	DSM control of equipment	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
	DSM-21	Reporting information regarding DSM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	3
	DSM-22	Override of DSM control	0	0	0	0	0	0	0	0	0	2	0	0	3	0	2	2
Monitoring and control	MC-3	Run time management of HVAC systems	2	1	0	2	2	1	0	0	3	1	0	2	3	1	0	1
Monitoring and control	MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	2
Monitoring and control	MC-9	Occupancy detection: connected services	0	0	0	0	0	0	0	0	1	0	0	1	1	0	2	1
	MC-13	Central reporting of TBS performance and energy use	1	0	0	0	1	0	1	1	1	0	0	0	2	0	1	3

EUROPEAN COMMISSION DG ENERGY (2018), Annex I, "Support for Developing a Smart Readiness Indicator for Buildings" project, Support for setting up a Smart Readiness Indicator for buildings and related impact assessment FINAL REPORT, 2018.08.26



BUILDING DIGITALIZATION METHODOLOGY
OBJECTIVES
EFFICIENCY
FLEXIBILITY
COMFORT
NEEDS
Reduce consume
Systems optimization according with the building envelope, the internal and the external environment and the occupant behaviour.
Facility management
Predictive and optimized facility management plan for all the PHYSICAL BUILDING (system, envelope, appliances) components in according with the the internal and the external environment and the occupant behaviour.
Resources optimization
Resources optimization and consume control evaluating the use of renewable sources and according with the system and appliances optimization, renewable energy sources availability and the internal and the external environment, the occupant behaviour and his COMFORT AND NEEDS.
Optimize thermal, light, acustic, air quality comfort
Optimize comfort according with PHYSICAL BUILDING (system, envelope, appliances) components, the internal and the external environment and the occupant behaviour.
Guarantee occupant security
Guarantee occupant security according with PHYSICAL BUILDING envelope, the internal and the external environment and the occupant behaviour.
Convenience
Consider the occupant convenience and evaluate its importance in relation with the other parameters.
NEEDS
MACRO-CATEGORIES
BUILDING STATUS
All the elements that can be detected or measured to describe the building environment.
BUILDING
All the elements to detect, measured and control the building and its components.
BUILDING MANAGEMENT
All the processes for the operation and optimization of the building.
CATEGORIES
Occupants
PRESENCE
ACTIVITY
External environment
WEATHER
WEB DATAS
Internal environment
TEMPERATURE
IAQ
NATURAL VENTILATION
ACOUSTIC
LIGHT
Example
Systems
HEATING
COOLING
MECHANICAL VENTILATION
WATER
DOMESTICAL HOT WATER
STP/other RES to prod.dhw
RAIN COLLECTOR
LIGHTING
ELECTRICAL
PV PANEL/other RES to prod.El
GAS DISTRIBUTION
SECURITY
FAULT ALERT
Envelope
WINDOWS & DOORS
SHADING
Appliances
LIFTS
DEVICES
EL.VEHICLES CHARGING POINTS
Facility management
ORDINARY FACILITY
FAULTH MANAGEMENT
Resources & consume management
WATER
RES for HW optimization
ELECTRICITY
RES and ENERGY STORAGE for energy optimization
GAS
Securety management
ALARMS
Comfort optimization
THERMAL
LIGHT
ACOUSTIC
AIR QUALITY
CONVENIENCE
TECHNOLOGIES
LIST OF TECHNOLOGIES
for each element
SENSORS
ACTUATORS
Artificial Intelligences
DATA
+ CENTRAL SYSTEM
+ USER INTERFACE
OUTPUT
INPUT
Building live STATUS
ADVICES for the USER
Building HISTORY DATA
User preferences & REQUEST
User personal DATA
ACTUATORS
SENSORS
Cloud
CENTRAL SYSTEM
Ai
USER INTERFACE
C.S. OUTPUT
Users INPUT

Table 6.B: SRI max functional level for each ready service

EUROPEAN COMMISSION DG ENERGY (2018), “sri_1st_technical_study_-_annex_a_catalogue” project, Support for setting up a Smart Readiness Indicator for buildings and related impact assessment FINAL REPORT, 2018.08.26

HEATING

1a	Heat emission control	Individual room control with communication and presence control
1b	Emission control for TABS (heating mode)	Advanced central automatic control with intermittent operation and/or room temperature feedback control
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	Demand based control
1d	Control of distribution pumps in networks	Variable speed pump control (external demand signal)
1e	Intermittent control of emission and/or distribution - One controller can control different rooms/zones having same occupancy patterns	Automatic control with demand evaluation
1f	Thermal Energy Storage (TES) for building heating (excluding TABS)	Load prediction based storage operation
1g	Building preheating control	Thermostat self-learning user behavior (presence, setpoint)
2a	Heat generator control (for combustion and district heating)	Variable temperature control depending on the load (e.g. depending on supply water temperature set point)
2b	Heat generator control (for heat pumps)	Variable control of heat generator capacity depending on the load AND external signals from grid
2c	Sequencing of different heat generators	Load prediction based sequencing
2d	Heat system control according to external signal (e.g. electricity tariff, gas pricing, load shedding signal etc.)	Heat system control according to external signals combined with internal signals (predicted demand, temperature etc.)
2e	Control of on-site waste heat recovery fed into the heating system (e.g. excess heat from data centers)	Variable control of waste heat recovery with possibility to store excess heat or time shift heat recovery
3	Report information regarding HEATING system performance	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

DHW

1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	Automatic charging control based on local availability of renewables or information from electricity grid (DR, DSM)
1b	Control of DHW storage charging (using hot water generation)	Automatic charging control based on signals from district heating grid (DR, DSM)
1c	Control of DHW storage temperature, varying seasonally: with heat generation or integrated electric heating	Automatic selected control with heat generation, demand-oriented supply and return temperature control or electric heating, charging time release and multi-sensor storage management
1d	Control of DHW storage charging (with solar collector and supplymentary heat generation)	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge, demand-oriented supply and return temperature control and multi-sensor storage management
2	Control of DHW circulation pump	Demand-oriented control
3	Report information regarding domestic hot water performance	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

MECHANICAL VENTILATION

1a	Supply air flow control at the room level	Demand control based on air quality sensors (CO2, VOC,RH,…)
1b	Adjust the outdoor air flow or exhaust air rate	Variable control
1c	Air flow or pressure control at the air handler level	Automatic flow or pressure control (with reset)
2a	Room air temp. control (all-air systems)	Demand control
2b	Room air temp. control (Combined air-water systems)	Coordination
2c	Heat recovery control:prevention of overheating	Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control
2d	Supply air temperature control	Variable set point with load dependant compensation
3	Free cooling with mechanical ventilation system	H,x- directed control
4	Heat recovery control:icing protection	With icing protection control
5	Humidity control	Direct humidity control
6	Reporting information regarding IAQ	Real time information of IAQ available to occupants + suggesting triggers to action

COOLING

1a	Cooling emission control	Individual room control with communication and presence control
1b	Emission control for TABS (cooling mode)	Advanced central automatic control with intermittent operation and/or room temperature feedback control
1c	Control of distribution network chilled water temperature (supply or return)	Demand based control
1d	Control of distribution pumps in networks	Variable speed pump control (external demand signal)
1e	Intermittent control of emission and/or distribution	Automatic control with demand evaluation
1f	Interlock between heating and cooling control of emission and/or distribution	Total interlock
1g	Control of Thermal Energy Storage (TES) operation	Load prediction based storage operation
2a	Generator control for cooling	Variable temperature control depending on the load
2b	Sequencing of different cooling generators	Load prediction based sequencing
3	Report information regarding cooling system performance	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

ENERGY GENERATION (RES-CHP)

1	Amount of on-site renewable energy generation	PV or CHP capacity able to cover average needs
2	Local energy generation information	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
3	Storage of locally generated energy	Dynamically operated storage which can also feed back into the grid.
4	Optimizing self-consumption of locally generated energy	long term optimization including predicted generation and/or demand
5	CHP control	Coordination of local RES and CHP with regard to local energy demand profile including energy storage management; Optimization of own consumption

DEMAND SIDE MANAGEMENT

1	Services for integration of renewables into the building energy portfolio	VPP integration
2	Services for integrating battery storage systems into energy portfolio	grid based optimization
3	Support of microgrid operation modes	autonmous energy consumption control
4	Integration of smart appliances	grid based optimization
5	Power flows measurement and communications	(use of sensor data in microgrid operations +) DSO based use of sensor data
6	Energy delivery KPI tracking and calculation	local optimisation
7	Fault location and detection	(local based detection of errors) + DSO optimised operations
8	Fault prevention and risk assessment	(local based detection of errors) + DSO optimised operations
9	Fraud detection and losses calculation	(local based detection of errors) + DSO optimised operations
10	Neighbourhood energy efficiency calculation	data exchange for local swarm and optimization for DSP vpp control
11	Demand prediction	(local optimization +) adaptive load forecast
12	Renewables generation prediction	(local optimization +) adaptive load forecast
13	Heat management for a multi-tenant house by aggregator	(occupant +) building best-effort
14	Flexible start and switch off of home appliances	grid condition based
15	DSM control of a device by an aggregator	VPP operations (price based)
17	Energy storage penetration prediction	microgrid based forecast
18	Smart Grid Integration	Building energy systems are managed and operated depending on grid load; demand side management is used for load shifting
19	DSM control of equipment	Smart appliances, DHW, heating and cooling subject to DSM control
20	Connecting PV to DSO grid	DSO controls
21	Reporting information regarding DSM	Reporting information on current, historical and predicted DSM flows and controls
22	Override of DSM control	Scheduled override of DSM control and reactivation with artificial intelligence

ELECTRIC VEHICLE CHARGING

1	Charging whenever needed at the charging pole of the building ("dumb charging service")	adaptive time charging
3	Charging with local, building system based control (price signal based charging)	adaptive tariffs structures with remote access
4	Charging with aggregated control (EV responsible party as VPP balancing responsible party)	local and grid optimization
5	Charging with aggregated control (EV resposible party under a balance responsible party)	local and grid optimization
7	Grid connected heating for EV in winter time	grid-sensor based charging
8	Providing system services to DSO operations	grid and battery lifecycle optimized behaviour
9	Charging for optimisation of the EV battery life-cycle	car and grid lifecycle optimization
10	Charging at a commercial building site - roaming	charging in different country and regulatory regime
11	Charging based on DSO price tags - " local wind storage"	storage and feed-in to grid
12	Providing the state-of-charge to home display	integrating the information into BEMS
13	Fast charging services - mode 4	dumb
14	Vehicle to grid operation and control	exists
15	EV Charging Capacity	High charging capacity
16	EV Charging Grid balancing	2 way (also EV to grid)
17	EV charging information and connectivity	(Reporting information on EV charging status to occupant +) Communication with a back-office compliant to ISO 15118

LIGHTING

1a	Occupancy control for indoor lighting	Automatic detection (manual on / dimmed or auto off)
1b	Mood and time based control of lighting in buildings	Automated or mobile triggered detection
2	Control artificial lighting power based on daylight levels	Scene-based light control (during time intervals, dynamic andadapted lighting scenes are set, for example, in terms ofilluminance level, different correlated colour temperature (CCT)and the possibility to change the light distribution within the spaceaccording to e. g. design, human needs, visual tasks)

MONITORING AND CONTROL

1	Heating and cooling set point management	Adaptation from a central room with frequent set back of user inputs
2	Control of thermal exchanges	All occupied area has management of heat/cold exchange among zones within one building or among different buildings
3	Run time management of HVAC systems	Control of run time management by artificial intelligence
4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	With central indication of detected faults and alarms / diagnosing functions
5	Reporting information regarding current energy consumption	Analysing, performance evaluation, benchmarking
6	Reporting information regarding historical energy consumption	Analysing, performance evaluation, benchmarking
7	Reporting information regarding predicted energy consumption	Analysing, performance evaluation, benchmarking
9	Occupancy detection: connected services	Centralised detection which feeds in to several TBS such as lighting and heating
10	Occupancy detection: space and activity	Occupancy detection can determine position of people in space (e.g. behind desk)
11	Remote surveillance of building behaviour	Remote control of main TBS with centralised occupancy detection, automatic non-occupancy default settings and user alerts
12	Central off-switch for appliances at home	secquence of deactivation for load optimisation
13	Central reporting of TBS performance and energy use	Real time indication of sub-metererd energy use or other performance metrics for all main TBS

DYNAMIC BUILDING ENVELOPE

1 **2**	Window solar shading control Window open/closed control, combined with HVAC system	Predictive blind control (e.g. based on weather forecast) Open/closed detection to shut down heating or cooling systems + Centralized coordination of operable windows, e.g. to control free natural night cooling
3	Changing window spectral properties	Integrated control with other systems such as heating and lighting

VARIOUS

1	Coming home - leaving home functions	(mobile based +) RFID based (Radio-Frequency Identification)
2	Inactivity recognition services	electricity sensor based (behaviour)
3	Multi-tenant access control for buildings without keys	(mobile based +) RFID based (Radio-Frequency Identification)
4	Occupants Wellbeing and health status monitoring services	Functionality levels to be defined
5	Dementia monitoring	Functionality levels to be defined, e.g. Appliance and person monitoring
8	Rain water Collection	Re-use to prevent waste fo freshwater resources
9	Smoke detection	smoke detectors, cross-linked
10	Water leakage detection	leakage detection , cross-linked
11	Carbon Monoxide detecion	CO detection, cross-linked to other TBS, e.g. warning signals through lighting
12	Emergency notification services	alarm with remote notification
13	Smart testing of emergency lighting	Emergency lighting with automatic testing, connected to a centralised reporting system
14	Intelligent alerting on building events	Artificial Intelligence
18	Energy Cost Allocation for heating, cooling and water	heat cost allocators (HCA) / meters (M) - remote reading continuous information
19	Lift and elevator control and dispatching	forecasting

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13th February 2019 – EuroAce/BUILD UP Webinar– "*Smart & Technology-Equipped Buildings*"

12th March 2019 – SitPolito – "*Enerbrain: Ai e IoT per edifici sempre più smart*"

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POLITECNICO DI TORINO
Master of Science in Architecture Construction and City

MASTER THESIS PROJECT

Tutor: Prof. Stefano Paolo Corgnati
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