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D2.3 Asset rating calculation methodology of SmartLivingEPC v1

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Deliverable 2.3

Asset rating calculation methodology of SmartLivingEPC v1

Work Package: WP2 Smart Living EPCs Framework Asset Methodology
Task: T2.1 SRI analysis and integration to SmartLivingEPC
T2.2 Energy and non-energy resources analysis and integration to SmartLivingEPC
T2.3 Environmental life-cycle assessment and integration to SmartLivingEPC
T2.4 Technical audits and inspections integration to SmartLivingEPC
T2.5 Building complex assessment asset methodology
T2.6 SmartLivingEPC asset rating calculation methodology
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List of Acronyms, Abbreviations and other Terms used in the document

Term	**Description**
AD	Architectural Design
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ASGE	Assessment Standard for Green Eco-districts
BAC	Building Automation and Control
BIM	Building Information Modelling
CDP	Community Detailed Plan
CEP	Community Energy Planning
CEP	Comprehensive Energy Planning
CESD	Comprehensive Energy System Design
CMP	Community Master Plan
CRP	Community Regulatory Plan
CSP	Community Site Plan
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DHW	Domestic Hot Water
DSM	Demand-side management
ECI	Energy consumption indicator
EeMAP	European Regional Network of the World Green Buildings Council for the Energy Efficient Mortgages Action Plan
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
GIS	Geographic Information System
GTI	Green Township Index
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IRP	Integrated renewable and non-renewable energy resource planning
LCA	Life Cycle Analysis
LP and NLP	Linear Programming (LP) and Non-Linear Programming
MILP	Mixed-integer programming
MP	Municipal facility plans
MSs	Member States
NSA	Neighborhood sustainability assessment
PEP	Primary energy planning
PMV	Predicted Mean Vote
PPD	Percentage of Persons Dissatisfied
SA, GA, TS, ES, ANN, ACO, PSO	Simulated Annealing (SA), Genetic Algorithms (GA), Tabu Search (TS), Evolution Strategies (ES), Artificial Neural Networks (ANN), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO)
SRI	Smart Readiness Indicator

TBS	Technical Building Systems
WHO	World Health Organization
RER	Renewable Energy Ration

The terms and definitions outlined above reflect those used in standardization. ISO and IEC maintain terminological databases at the following addresses:

1. ISO online browsing platform: available at https://www.iso.org/obp
2. IEC Electropedia: available at https://www.electropedia.org/

Executive Summary

The SmartLivingEPC project has a goal of incorporating the key elements of Industry 4.0 into a Smart Energy Performance Certificate. This certificate will be generated using digital tools and will gather essential assessment data for both the structural elements and systems of a building from Building Information Modeling (BIM) knowledge. It will include enriched information pertaining to energy efficiency and sustainability for both the initially designed and the actual performance of the building.

SmartLivingEPC will furnish insights into the operational behavior of a building by introducing a novel rating system. This rating system will be constructed through a balanced consideration of various factors, such as the building's life cycle performance, its level of intelligence, and the performance of its technical systems, which will be assessed through technical audits. These new methodologies will build upon established European standards, while simultaneously spurring the development of fresh technical standards for Smart Energy Performance Certificates. The expanded certification framework will also encompass considerations related to water usage, noise pollution, and acoustics.

The novel elements of the SmartLivingEPC concept are based on:

a) a novel certification rating methodology, which will refer to the actual energy consumption of building systems, integrating actual information from smart sensors and power meters. The methodology will be based on the assessment of different aspects of the building, including the buildings energy performance, sustainability, smartness and condition of technical systems, delivering a novel rating scale. SmartLivingEPC aspires to deliver the next generation rating practices, through an enhanced approach, which will integrate additional energy and sustainability related parameters into the building’s assessment procedure.
b) the synergies with building sustainability relevant instruments: specific sustainability indicators of the Level(s) scheme will be incorporated enhancing the information provided and support a life cycle approach.
c) the enhancement of the digital construction practices and Industry 4.0 building services with the integration of processes compatible with the digitally structured environment. In particular, it will deliver an Energy Performance Certificate (EPC) fully compatible with BIM literacy, which will retrieve information from smart meters and digital twins. Also, SmartLivingEPC steps towards achieving the integration of the SRI rating into the EPC procedure;
d) the compatibility with digital building logbooks, which allows a variety of data, information and documents to be recorded, accessed, enriched and organized under specific categories. It will entail all required elements and features, that will allow its integration into digital building logbooks, facilitating in this manner transparency, trust, informed decision making and information sharing.
e) the integration of the findings of regular building technical systems audits in the process of calculating the energy class of the building; The technical audit literacy has delivered numerous standards and procedures in recent years which deliver significant information on the actual performance of building technical systems. SmartLivingEPC will integrate this information into the buildings energy performance evaluation procedures, both on asset and operational level assessment.
f) Further to that, SmartLivingEPC aims to the development of a new rating scheme for neighborhood scale, based on the assessment of individual building units and on additional building complex parameters.

As we transition to an era where building units can interact energetically through smart grids, and where the systematic link between buildings can demonstrate the energy optimization potential at the neighborhood level, it becomes important to introduce a new energy classification methodology at the building block level. This methodology should consider that energy performance is influenced not only by the individual building, but also by the urban context and the local microclimate.The methodology will consider the energy infrastructure and services on a building block scale, as well as the interaction of buildings allowing the issuance of a certificate at a building complex level.

The project aspires to develop a new rating scheme for neighborhood scale, based on the assessment of individual building units and additional building complex parameters with the aim of energy performance certification of building complexes. The energy infrastructure and services on a building block scale, as well as the interaction of the block buildings, were studied. During this task, the differences that the building had in relation to the neighborhood(street lighting, network services, smart grids, energy communities, etc.) were

determined. Another aspect that was investigated was how buildings interacted with each other at a neighbourhood level and how this interaction affected the energy performance from that perspective. Deliverable D2.2 presents the main aspects of the asset complex EPCs, identifying the required conditions, the calculation input, as well as the prescribed results of building complex EPCs.

1 Introduction

1.1 Work package and Task description

This deliverable belongs inside Work Package 2 (WP2), which focuses on the formulation of strategies for evaluating building performance. D2.3 plays a crucial role in this work package, as its objective is to establish the **computation technique for asset ratings** within the context of SmartLivingEPC. The main aim of D2.3 is to establish a rigorous, all-encompassing, and widely recognized approach for determining asset ratings along with the weighting procedure proposal. The proposed technique aims to incorporate a range of performance metrics, encompassing energy efficiency, environmental sustainability, smart preparedness, as well as non-energy factors such as indoor environmental quality and accessibility. There are a series of tasks to be performed:

Methodological Design: The objective of this assignment is to provide a calculating methodology that considers the diverse performance indicators incorporated into the SmartLivingEPC asset rating. This encompasses the process of establishing precise definitions for the algorithms, models, and weighting factors associated with each indicator. The process will incorporate European standards and technical audits. This measure guarantees that the evaluations of assets are not only precise but also in accordance with established European rules and optimal methodologies. The objective of this assignment is to address the data collection and validation process pertaining to the asset rating calculations in the context of the pilots. The document will delineate the many categories of data that are to be gathered, the origins from which this data will be obtained, and the methods by which its accuracy and reliability will be verified, frequently through the implementation of technical audits.

Methodological Testing: Prior to finalizing the methodology, a validation process will be conducted with real-world data, commonly referred to as pilot data, to ascertain the accuracy and dependability of the proposed approach. This assignment will entail the examination of the pilot structures, the application of the prescribed technique, and the subsequent analysis of the obtained outcomes.

The final step entails the documentation of the approach, encompassing the algorithms employed, the data prerequisites, and the validation procedures. The purpose of this material is to provide a complete guide for stakeholders who will be utilizing the SmartLivingEPC asset rating system.

Every task included in this set aims to provide a valuable contribution towards the advancement of a strong and dependable technique for calculating asset ratings. This objective, referred to as **Deliverable D2.3**, is the central focus of our work. The effective accomplishment of these tasks will yield a methodology that may be employed to evaluate the performance of buildings in a thorough, standardized, and practical manner.

1.2 Scope and objectives of the deliverable

The SmartLivingEPC project requires a methodical and strategic approach in order to achieve its ambitious goal of rethinking energy performance in the built environment. Every individual component of the project is essential in realizing the overarching objective. The deliverable D2.3, entitled "Asset rating calculation methodology of SmartLivingEPC v1," is not an exception. This section provides a comprehensive explanation of the scope and aims of D2.3, aiming to clarify its significance within the larger context of the project. The scope of D2.3 is multifaceted, encompassing both the theoretical and practical aspects of asset rating calculation within the SmartLivingEPC framework. At its core, this deliverable presents the following aspects:

The technique, as outlined in D2.3, offers a thorough explanation of the technique employed for calculating asset ratings. It includes a detailed account of the various procedures, algorithms, and instruments utilized to ascertain energy performance ratings.

To harness the significant impact of Building Information Modelling (BIM), D2.3 places emphasis on the harmonious integration of the asset rating technique with BIM. This ensures that the ratings produced are not only precise but also extensively influenced by the abundant data provided by BIM models.

The built environment encompasses a wide array of building types, encompassing both residential dwellings and tertiary buildings. D2.3 assures that the proposed approach possesses adaptability and applicability across a wide range of building kinds, hence accommodating the distinct requirements of each.

To ensure the accuracy of asset ratings, it is crucial to employ a robust framework for data collection. D2.3 provides a comprehensive overview of the methodologies and recommended approaches for gathering data, with the aim of ensuring that the evaluations are grounded on dependable and pertinent information.

The asset rating calculation approach proposed in D2.3 will be utilized as the fundamental framework for the SmartLivingEPC system. The implementation of a uniform approach to assess building performance will facilitate the comprehension and comparison of asset evaluations among stakeholders. The standardization of SmartLivingEPC is of utmost importance in facilitating its widespread acceptance since it guarantees the ratings' universal applicability and acceptance. Furthermore, the methodology will be created with the intention of being flexible, hence enabling future modifications and enhancements. The necessity of adaptability is paramount in light of the swift progressions in building technology and sustainable practices. The objective of D2.3 is to provide a technique that is both adaptable and resilient, with the purpose of ensuring the longevity of SmartLivingEPC as a tool for evaluating building performance.

Expected Outcomes

The anticipated result of this study is the development of a thorough and all-encompassing system for **calculating asset ratings and proposed scale rating and weighting scheme**. The proposed methodology aims to comprehensively address several dimensions of building performance, encompassing energy efficiency, non-energy related aspects, smart readiness, and environmental sustainability.

A comprehensive guide will be created to provide users with clear instructions on the application of the methodology in a user-friendly manner. The intended audience for this guide comprises diverse stakeholders, encompassing building owners, facility managers, and policy-makers. It will provide comprehensive instructions, presented in a sequential manner, for the computation of asset ratings. In addition to the user guide, comprehensive technical documentation will be generated at v3 of this deliverable to provide detailed information on the algorithms, data requirements, and validation methods (by using pilot buildings). This document will function as a scholarly resource for specialists and academics who are interested in delving into the technical intricacies of this methodology.

The proposed rating methodology will undergo evaluation on a subset of designated pilot buildings, and the ensuing outcomes will be meticulously recorded. The obtained results will serve to confirm the employed methodology and additionally offer valuable insights into its practical applications and limitations. The proposed technique will be specifically developed to ensure smooth integration with pre-existing systems, including Building Information Modeling (BIM) tools and digital building logbook. This integration will facilitate the adoption of SmartLivingEPC by stakeholders, streamlining the implementation process. Thus, the approach employed will adhere to the appropriate European standards, so guaranteeing its suitability and recognition within the European Union. The contribution of Deliverable D2.3 to the overarching goals of the SmartLivingEPC project will be substantial. The use of this instrument will offer a dependable, uniform, and all-encompassing means of evaluating the performance of buildings, therefore encouraging the adoption of more sustainable and efficient building methodologies.

The main objective of this deliverable is:

The development of a new rating scheme for building and neighbourhood scale, based on the assessment of individual building units and additional building complex parameters.

The secondary objectives are:

- Shifting from the unit building scale to the complex building scale,
- Exploring the interaction between buildings,
- Identifying energy-consuming services unique to neighborhoods,
- Creating a neighborhood certificate.

As we move into an era, where building units will be able to interact energetically through smart grids but also through energy communities, energy classification on a neighborhood scale is expected to become particularly important in the coming years. SmartLivingEPC will launch and introduce a new energy classification methodology at the neighborhood level, which on the one hand will be based on the categorization of individual building units, on the other hand, will consider the energy infrastructure and services on a district scale, as well as the interaction of buildings. The result is expected to be a certificate at a complex level, which will allow energy savings at the level of neighborhood energy infrastructure. The SmartLivingEPC complex certification scheme will be demonstrated in the district of Leitza, Spain where 6 buildings nearby have been selected.

1.3 Relations to other tasks and deliverables

This deliverable holds significant importance as a fundamental component of Work Package 2 (WP2). The completion of this deliverable is closely intertwined with various tasks in Work Package 2, establishing a coherent structure for the development of assessment processes.

The present effort, D2.3, is closely linked to the research conducted in **Task T2.1,** which centers on the analysis and integration of Smart Readiness Indicators (SRIs) into the SmartLivingEPC framework. The approaches and classifications that were formulated in Task 2.1 to evaluate smart technology in buildings have been incorporated into the asset rating calculation methodology presented in Deliverable 2.3. This measure guarantees that the evaluations of assets encompass not only energy efficiency but also the building's smart readiness, thereby offering a comprehensive perspective on building performance.

The objective of **task T2.2** is to integrate energy and non-energy considerations into the categorization of buildings under the SmartLivingEPC framework. The approaches that have been created in this study, including those pertaining to the consumption of non-energy resources like as water and noise, have been incorporated into D2.3. The asset rating computation in D2.3 is enhanced to encompass a wider range of building performance indicators, hence increasing its comprehensiveness. The results from this task are to be used in the classification and rating scheme of the methodology.

The relationship between **Task T2.3**, which focuses on Environmental Life-Cycle Assessment (LCA), and its integration into the SmartLivingEPC project is of academic interest. The primary objective of T2.3 is to conduct an environmental life-cycle assessment of buildings, utilizing various methods and standards such as the Level(s) system. The sustainability indicators and calculation techniques outlined in T2.3 have been integrated into the asset rating calculation methodology described in D2.3. This measure guarantees that the evaluations of assets also encompass the environmental sustainability of the building, rendering them more comprehensive and in line with the sustainability objectives set by the European Union.

The connection to **Task 2.4**, which involves technical audits and inspections, is under discussion. The incorporation of a system into the SmartLivingEPC platform. The objective of T2.4 is to include the results obtained from technical audits and inspections into the asset ratings (e.g. based on the data found on-site certain parameters are classified – like water efficiency). The processes and procedures that were created in Task 2.4 for the purpose of incorporating audit findings have been integrated into Deliverable 2.3. The utilization of current and verified data guarantees that the evaluations of assets are founded on the most recent information, hence augmenting their dependability and trustworthiness. The objective of T2.5 is to establish a comprehensive assessment methodology for building complexes, which includes the evaluation of individual building units as well as other relevant factors at the **neighborhood level**. The approaches proposed in Task 2.5 will yield significant insights into the interplay between buildings and their surrounding infrastructure, including smart grids and energy communities. The aforementioned insights will be incorporated into the asset rating calculation process of D2.3 for building complex. This integration will enable a more sophisticated and all-encompassing evaluation, including the building's contextual placement within a broader complex or neighborhood .

Task T2.5 and T2.6 and the SmartLivingEPC Asset Rating Calculation technique is our primary focus. Task 2.6 aims to integrate the findings from many preceding activities, such as the SRI analysis, energy and non-energy assessments, life-cycle evaluations, Level(s) framework, and technical audits. These inputs will be synthesized and incorporated into a **unified rating system known as the SmartLivingEPC rating system**, which will provide weighted ratings. D2.3 is the pinnacle of this endeavor, offering a user-friendly asset rating that can be seamlessly incorporated into digital building logbooks and evaluated inside a Building Information Modeling (BIM) framework.

The primary objective of D2.3 is to consolidate the many approaches and outcomes from these tasks into a cohesive and comprehensive system for calculating asset ratings. The proposed technique possesses the capability to encompass a diverse array of performance metrics, while also exhibiting flexibility in its applicability across various scales, ranging from individual buildings to building complexes and communities.

2 Asset rating calculation methodology – BUILDING EPC

2.1 Indicators derived from SmartLivingEPC asset assessment

The SmartLivingEPC (SLE) asset assessment places significant emphasis on the calculation of a building's primary energy consumption and its indicators. The methodology involves a dual-phase process: firstly, assessing the energy demands of the edifice, encompassing heating, cooling, ventilation, dehumidification/humidification, and domestic hot water (DHW) [1]. The architectural design of a structure can exert a substantial influence on the well-being, satisfaction, and efficiency of its occupants [2]. A diverse array of metrics can be employed to define buildings, extending beyond energy-related indicators such as energy efficiency and carbon emissions [3]. Indicators considered in the SmartLivingEPC concerning non-energy indicators are indoor environmental quality (IEQ) including radon risk assessment, seismic class, and accessibility [4].

The concept of "indoor environmental quality" (IEQ) refers to the overall condition of a building's air quality, temperature, lighting, and ambient noise levels. Inadequate IEQ can give rise to many health issues, such as asthma exacerbations, headaches, and fatigue and thus is considered an important part of the assessment [5-6]. Among the indoor air quality parameters, particular attention was given to the presence of radon as this one poses a significant non-energy-related risk that can potentially severely affect the health of occupants [7]. The accumulation of radon gas has significant health risks, notably an elevated likelihood of developing lung cancer, which has been acknowledged by the World Health Organization (WHO) as the second leading cause of this disease, following smoking [8]. The potential for radon exposure can be influenced by various factors, including the geographical location and geological characteristics of the building site, as well as the construction and ventilation systems employed in the building [9]. The implementation of radon testing and, if deemed necessary, the adoption of radon mitigation measures by building proprietors will effectively mitigate the danger associated with radon exposure [10].

Another non-energy indicator of high importance, especially for countries at higher risk, is the consideration of seismic risk class. Seismic retrofitting is a viable alternative for building proprietors seeking to enhance the earthquake resistance of their structures [11]. A set of retrofitting techniques has been analyzed for their contribution to the reduction of seismic vulnerability in buildings [12]. Hence, a significant non-energy variable might be denoted by the seismic risk class, ranging from SR1 to SR4 [13]. Improved methodologies have been formulated to quantify seismic risk and loss assessment in reinforced concrete buildings [14].

The Smart Readiness Indicator (SRI) is an emerging metric that has been developed with the purpose of assessing a building's ability to accommodate the requirements of its occupants and enhance its energy efficiency. It functions as an indicator of the level of intelligence exhibited by a building, with regards to its capacity to utilize technology in order to enhance performance and promote the well-being of its occupants. One of the primary elements of sustainable and responsible investing (SRI) pertains to the emphasis placed on energy efficiency. This particular aspect has witnessed notable advancements with the integration of Artificial Intelligence (AI) within intelligent buildings [15]. The SRI also includes a quantitative evaluation of the capacity of buildings to change loads, a critical factor in optimizing energy consumption patterns [16].

The adaptability of SRI has been investigated in several climates, including cold climate countries, indicating that its applicability is not restricted to specific climatic conditions [17]. It is anticipated that the indicator will exert a substantial influence on the total energy efficiency of buildings. The metric in question functions as a holistic assessment that not only prioritizes energy efficiency, but also takes into account the adaptability and resilience of the building infrastructure [18].

The SRI, or Smartness Rating Indicator, is a versatile instrument capable of accommodating technological developments and legislative modifications, hence rendering it a resilient metric for evaluating the intelligence of buildings. The anticipated function of this technology is crucial in facilitating the shift towards developing infrastructure that is both sustainable and intelligent.

The LEVEL(S) framework offers a complete methodology for evaluating the sustainability performance of buildings, with a particular emphasis on environmental indicators. These indicators quantify different dimensions, including carbon emissions, material utilization, water usage, and trash production, with the objective of mitigating the substantial environmental impact associated with buildings. As an illustration, it has been observed that buildings account for around 50% of all extracted materials and overall energy consumption, as well as approximately one-third of water consumption and trash creation [19].

The framework employs a life-cycle perspective, encompassing the environmental consequences spanning from the initial design stage to the ultimate disposal phase of a structure. This is consistent with the overarching objectives of circular economy concepts, which strive for comprehensive environmental monitoring and long-term sustainability [20]. The significance of reversibility and durability as potential indicators for evaluating circular construction technologies is underscored by LEVEL(S), which is essential for ensuring the long-term viability of projects [21].

Additionally, LEVEL(S) demonstrates its potential in facilitating the adaptive reuse of cultural heritage buildings by providing a comprehensive range of environmental impact indicators specifically designed for these distinct contexts [22]. The utilization of the LEVEL(S) framework enables stakeholders to discern areas of high sustainability impact and make well-informed choices aimed at enhancing the ecological efficiency of buildings.

2.1.1 SRI – rating procedure and dedicated output indicators

The final report of the second SRI technical study [8] investigated three potential SRI assessment methods (i.e., Method A, Method B, and Method C). Methods A and B are based on the assessment of the *smart-ready services* that are present, or planned at the design stage, and their *functionality level*. The assessment aims to determine with sufficient reliability what services are present or planned, and if so, the functionality level for each of those services. For this purpose, when available, digital models of buildings, including building information models or digital twins, may be used. The main difference is that Method A considers a reduced **service catalogue**, and thus spans a subset of the *smart-ready services* considered in Method B. Consequently, Method A requires less effort, time, and potentially expertise. By default, Method B would require an on-site inspection of the assessed object. Alternatively, Method C aims to be based on measured data, quantifying the operational *smartness* of in-use buildings.

Method A and B are asset methodologies included in the SRI assessment package produced by the SRI support team, whereas Method C is considered a potential future evolution towards an operational assessment. The generic process of the SRI assessment following Method A or B is outlined in Figure 1.

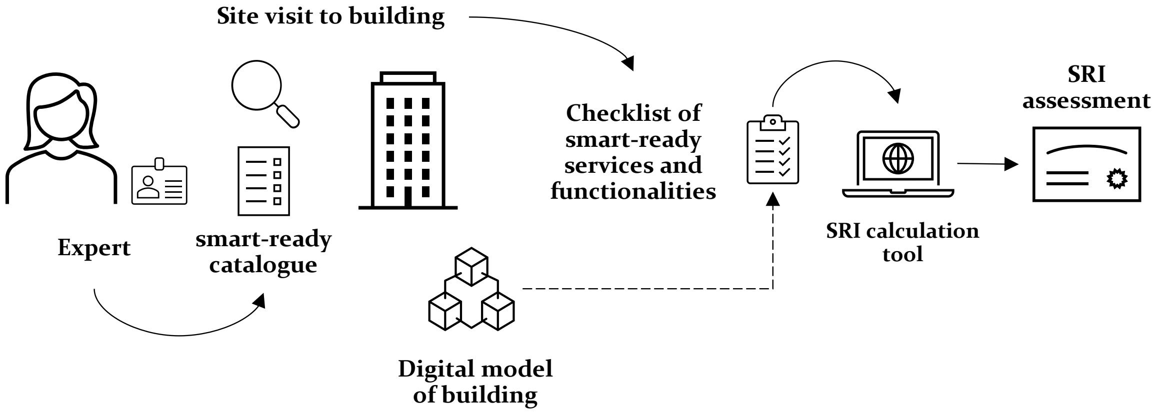


Figure 1: Generic SRI asset assessment process. Method A or B.

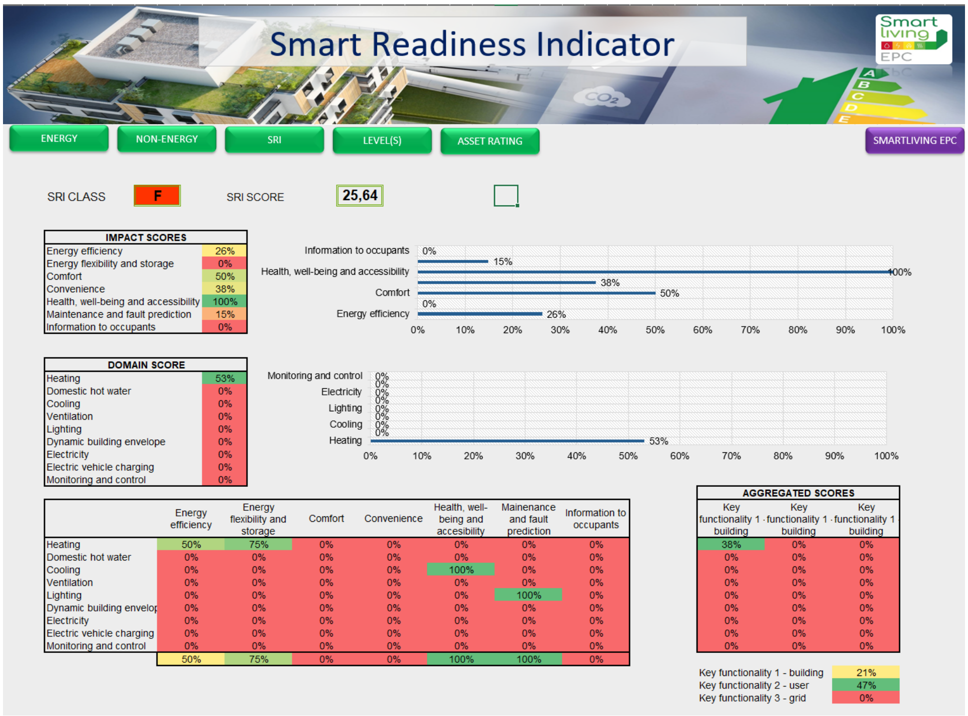
The results of the SRI assessment shall be included in the SRI certificate, as indicated in D2.1. The output data of the calculations is depicted in Table 1.

Table 1: SRI assessment output data

Description	Symbol	Unit
Total smart readiness score	SR	%
Total smart readiness rating	SR_{class}	-
Smart readiness score, per key functionality	SR_f	%

Energy performance and operation Response to user needs Energy flexibility		
Smart readiness score, per impact criterion Energy efficiency Maintenance and fault prediction Comfort Convenience Health, well-being, and accessibility Information to occupants Energy flexibility and storage	SR_{ic}	%
Smart readiness score, per technical domain Heating Domestic hot water Cooling Ventilation Lighting Dynamic building envelope Electricity Electric vehicle charging Monitoring and control	SR_{d}	%

During the rating procedure developed by AIIR-FV in this deliverable, an example is integrated in the general methodology.



SRI CLASS F

SRI SCORE 25,64

IMPACT SCORES	
Energy efficiency	26%
Energy flexibility and storage	0%
Comfort	50%
Convenience	38%
Health, well-being and accessibility	100%
Maintenance and fault prediction	15%
Information to occupants	0%

DOMAIN SCORE	
Heating	53%
Domestic hot water	0%
Cooling	0%
Ventilation	0%
Lighting	0%
Dynamic building envelope	0%
Electricity	0%
Electric vehicle charging	0%
Monitoring and control	0%

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accesibility	Mainenance and fault prediction	Information to occupants
Heating	50%	75%	0%	0%	0%	0%	0%
Domestic hot water	0%	0%	0%	0%	0%	0%	0%
Cooling	0%	0%	0%	0%	100%	0%	0%
Ventilation	0%	0%	0%	0%	0%	0%	0%
Lighting	0%	0%	0%	0%	0%	100%	0%
Dynamic building envelop	0%	0%	0%	0%	0%	0%	0%
Electricity	0%	0%	0%	0%	0%	0%	0%
Electric vehicle charging	0%	0%	0%	0%	0%	0%	0%
Monitoring and control	0%	0%	0%	0%	0%	0%	0%
	50%	75%	0%	0%	100%	100%	0%

AGGREGATED SCORES		
Key functionality 1 - building	Key functionality 1 - building	Key functionality 1 - building
38%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%
0%	0%	0%

Key functionality 1 - building	21%
Key functionality 2 - user	47%
Key functionality 3 - grid	0%

Figure 2: Example of the SRI rating assessment procedure (draft version)

2.1.2 Energy indicators – SmartLivingEPC rating procedure and the dedicated output indicators

The SmartLivingEPC (SLE) asset assessment lays considerable importance on the computation of a building's primary energy usage. The technique entails a two-step procedure: initially, determining the energy requirements of the structure, including heating, cooling, ventilation, dehumidification/humidification, and domestic hot water (DHW) [23]. The aforementioned needs are subject to influence from a multitude of elements, including but not limited to weather conditions, building geometry, orientation and position, envelope features, and occupancy scenarios [24]. The second stage entails the computation of energy losses within the subsystems of the primary Technical Building Systems (TBS). These subsystems encompass heating, domestic hot water (DHW), ventilation, air conditioning, and lighting [25]. The calculation approach primarily relies on the guidelines outlined in the European Performance of Buildings Directive (EPBD) [26].

The energy indicators are summarized in the following table:

Table 2: Energy indicators

No	ENERGY PERFORMANCE INDICATORS at Building Level	MU	ASSET calculation methodology according to:
1,2	Non-Renewable Primary Energy Consumption for the Heating system (Electric vector & Thermal vector)	kWh/m^2,y	EN 52000-1
3,4	Renewable Primary Energy Consumption for the Heating system (Electric vector & Thermal vector)	kWh/m2,y	EN 52000-1
5,6	Non-Renewable Primary Energy Consumption for the DHW system (Electric vector & Thermal vector)	kWh/m2,y	EN 52000-1
7,8	Renewable Primary Energy Consumption for the DHW system (Electric vector & Thermal vector)	kWh/m2,y	EN 52000-1
9,10	Non-Renewable Primary Energy Consumption for the Cooling system (Electric vector & Thermal vector)	kWh/m2,y	EN 52000-1
11,12	Renewable Primary Energy Consumption for the Cooling system (Electric vector & Thermal vector)	kWh/m2,y	EN 52000-1
13	Non-Renewable Primary Energy Consumption for the Ventilation system (Electric vector)	kWh/m2,y	EN 52000-1
14	Renewable Primary Energy Consumption for the Ventilation system (Electric vector)	kWh/m2,y	EN 52000-1
15	Non-Renewable Primary Energy Consumption for the Lighting system (Electric vector)	kWh/m2,y	EN 52000-1
16	Renewable Primary Energy Consumption for the Lighting system (Electric vector)	kWh/m2,y	EN 52000-1
17	Non-Renewable Primary Energy Consumption for the BAC system (Electric vector)	kWh/m2,y	EN 52000-1
18	Renewable Primary Energy Consumption for the BAC system (Electric vector)	kWh/m2,y	EN 52000-1
19	Total Non-Renewable Primary Energy Consumption, Thermal vector	kWh/m2,y	EN 52000-1
20	Total Non-Renewable Primary Energy Consumption, Electric vector	kWh/m2,y	EN 52000-1
21	Total Renewable Primary Energy Consumption, Thermal vector	kWh/m2,y	EN 52000-1
22	Total Renewable Primary Energy Consumption, Electric vector	kWh/m2,y	EN 52000-1
23	Building’s Energy Performance Class for the Heating system	A…G	SLE class
24	Building’s Energy Performance Class for the DHW system	A…G	SLE class
25	Building’s Energy Performance Class for the Cooling system	A…G	SLE class
26	Building’s Energy Performance Class for the Ventilation system	A…G	SLE class

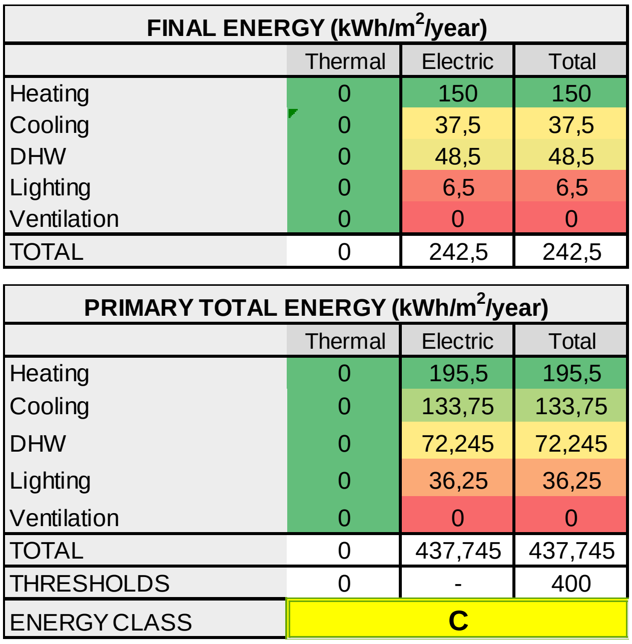
27	Building’s Energy Performance Class for the Lighting system	A...G	SLE class
29	Building’s Energy Overall Performance Class	A...G	SLE class
30	Renewable Energy Ration (RER)	%	EN 52000-1
31-32	Exported Primary Energy, Electric vector & Thermal vector	kWh/m2,y	EN 52000-1

The SLEPC rating incorporates a comprehensive array of intermediary energy characteristics, which have been developed in accordance with the updated EPBD requirements. The **flexibility of the SmartLivingEPC (SLEPC) evaluation system in national contexts** is a notable characteristic. It is noteworthy that each Member Stat (MS) of the European Union (EU) possesses its own defined protocols for assessing the energy performance of buildings, which are frequently customized to suit local circumstances, rules, and energy sources. The SLEPC rating system has been specifically developed to align with national rating systems, functioning as an overlay that can integrate and augment pre-existing approaches.

The SLEPC rating method starts by utilizing the national rating as a baseline benchmark. Subsequently, it integrates supplementary levels of evaluation, including Smart Readiness Indicators (SRI), non-energy performance metrics, and sustainability indicators, among various other measures. This approach guarantees that the SLEPC rating is both comprehensive and in accordance with national standards and procedures. The inclusion of a known country-specific rating system facilitates a smooth transition for stakeholders, enabling them to more readily embrace the SLEPC rating, which offers a more thorough evaluation.

SLEPC provides the adaptability of its methodology to incorporate potential future modifications or revisions in national procedures, by leveraging existing national rating systems. The long-term sustainability and relevance of the SLEPC rating system are of utmost importance due to the dynamic nature of the building performance assessment domain, which undergoes periodic revisions in standards and technologies.

In the context of building performance evaluation, it is imperative to comprehend the differentiation between final energy and primary energy. The term "final energy" pertains to the energy that is utilized by the various end-use systems within a structure, including but not limited to heating, cooling, lighting, and appliances. The energy being referred to is the one that is directly employed within the building for a multitude of purposes. It can be seen from the figure that there is an example of final energy consumption versus primary energy consumption.



FINAL ENERGY (kWh/m^2/year)			
	Thermal	Electric	Total
Heating	0	150	150
Cooling	0	37,5	37,5
DHW	0	48,5	48,5
Lighting	0	6,5	6,5
Ventilation	0	0	0
TOTAL	0	242,5	242,5

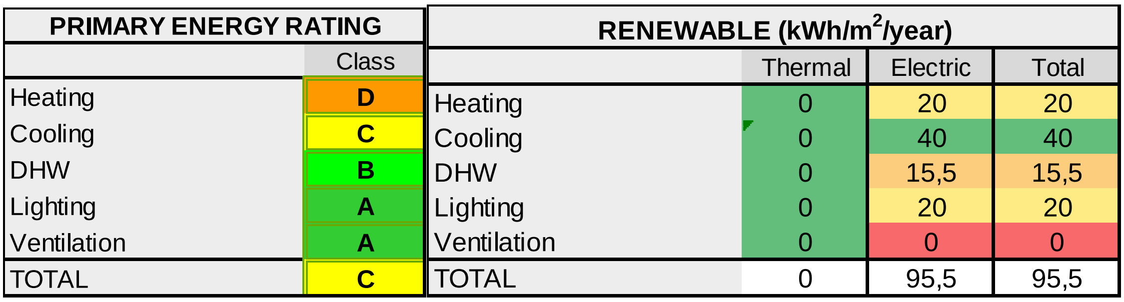
PRIMARY TOTAL ENERGY (kWh/m^2/year)			
	Thermal	Electric	Total
Heating	0	195,5	195,5
Cooling	0	133,75	133,75
DHW	0	72,245	72,245
Lighting	0	36,25	36,25
Ventilation	0	0	0
TOTAL	0	437,745	437,745
THRESHOLDS	0	-	400
ENERGY CLASS	C		

Figure 3: Example of final energy (thermal and electric vectors) and total primary energy

In contrast, primary energy encompasses the complete energy cycle, commencing with the extraction of raw energy resources, followed by their conversion into practical forms, and ultimately their utilization within the building. The processes encompass the dissipation of energy that takes place, notably during the generation, transmission, and distribution of electricity. The concept of primary energy offers a more holistic perspective on the energy consumption of a structure, encompassing the entirety of its environmental consequences resulting from energy utilization.

The utilization of national conversion factors is a crucial element in the computation of primary energy within the SmartLivingEPC (SLEPC) rating framework. The utilization of conversion factors is crucial in the process of converting final energy consumption into primary energy units. It is of utmost significance to note that these elements show variations across different countries, which can be attributed to the distinct energy composition, efficacy of energy conversion and distribution networks, and various other localized circumstances.

The SLEPC rating system integrates national conversion factors into its methodology to ensure that primary energy calculations are harmonized with local circumstances. This aligns with the general strategy of SLEPC, which involves leveraging existing national rating systems and procedures to ensure adaptability and relevance across various EUMSs. SLEPC employs country-specific conversion factors to ensure the accuracy and comparability of its main energy estimates, hence enabling a more nuanced and contextually sensitive evaluation of building performance. We have prepared a tool for the calculation of energy ratings. The figure presents an example of a primary energy rating, but it must be mentioned that not all EU countries have energy ratings for all the consumers like heating/cooling/DHW/lighting/ventilation.



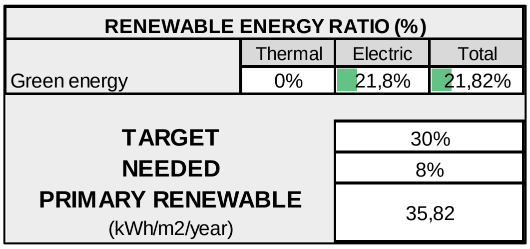
PRIMARY ENERGY RATING	
	Class
Heating	D
Cooling	C
DHW	B
Lighting	A
Ventilation	A
TOTAL	C

RENEWABLE (kWh/m^2/year)			
	Thermal	Electric	Total
Heating	0	20	20
Cooling	0	40	40
DHW	0	15,5	15,5
Lighting	0	20	20
Ventilation	0	0	0
TOTAL	0	95,5	95,5

Figure 4: Example of primary energy rating (including rating for main consumers) along with renewable energy

Another focus of our research work was related to the RER (renewable energy ratio) that is also one of the main energy indicators. The metrics for each system are computed and classified according to their source of energy, distinguishing between renewable and non-renewable sources, as well as differentiating between electric and thermal vectors. The present study examines the consumption of primary energy in both **non-renewable and renewable forms** across many sectors, including heating, domestic hot water (DHW), cooling, ventilation, lighting, and building automation and control (BAC) systems. The primary consumption of non-renewable and renewable energy can be classified into two categories: **thermal and electric vectors (see figure below).**

These indicators, when considered together, offer a holistic perspective on the energy performance of a structure. These assessments not only provide a detailed evaluation of individual systems, but also contribute to a comprehensive performance classification that considers several dimensions of energy efficiency and sustainability. The SLEPC rating demonstrates its efficacy as a strong and comprehensive instrument for assessing building performance, in accordance with European standards, and enabling well-informed decision-making among diverse stakeholders.



RENEWABLE ENERGY RATIO (%)			
	Thermal	Electric	Total
Green energy	0%	21,8%	21,82%
TARGET	30%		
NEEDED	8%		
PRIMARY RENEWABLE (kWh/m2/year)	35,82		

Figure 5: Example of analysis of RER – based on energy vectors

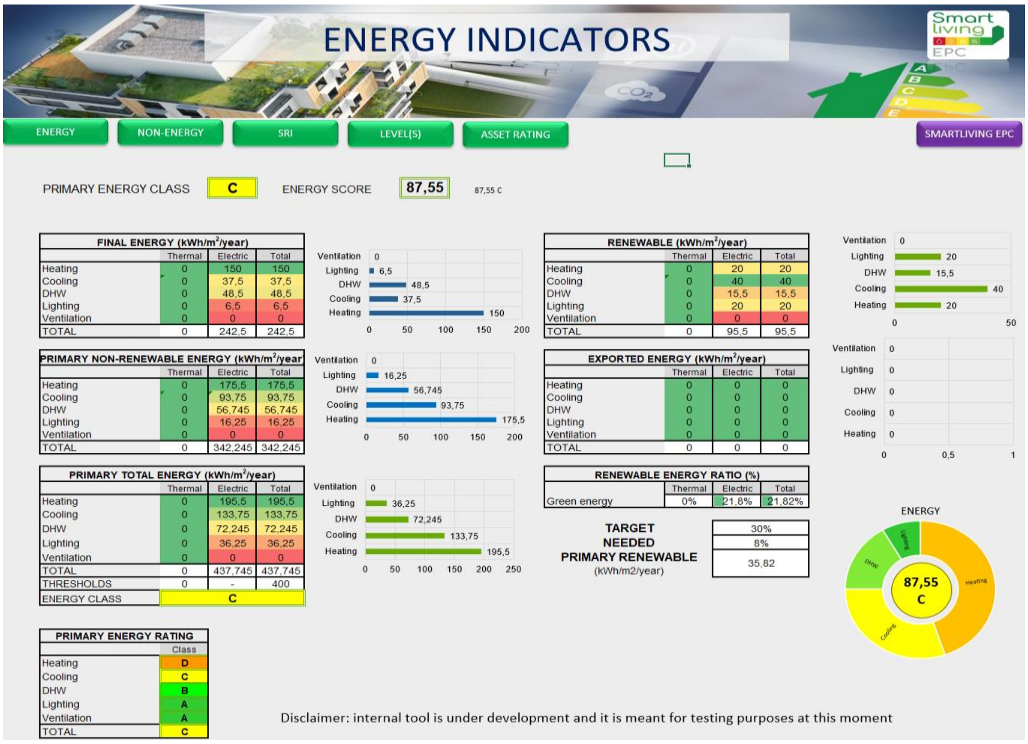
This technique not only strengthens the legitimacy and dependability of the SLEPC rating, but also ensures its consistency with national energy policies and regulations, hence fostering wider acceptance and implementation within the European Union (EU).

The SmartLivingEPC (SLEPC) assessment system utilizes a **scoring method** to convert the computed primary energy consumption into a readily comprehensible and comparative energy performance **classification**. The energy score is quantified as a percentage and thereafter assigned to a performance class ranging from A to G, in accordance with the following mapping. We propose a rating score based on the same rating scale methodology agreed at EU level for SRI. Thus, we have converted the primary energy class to a score similar to that of SRI.

Table 3: Primary energy class to score

Primary energy class	Score
A	90-100%
B	80-90%
C	65-80%
D	50-65%
E	35-50%
F	20-35%
G	0-20%

The process simplifies the intricate calculations and diverse parameters associated with evaluating the energy efficiency of a building into a comprehensible score and classification. The utilization of scores and classifications provides valuable information that can facilitate educated decision-making processes related to energy efficiency enhancements, financial investments, and the development of policies. Moreover, the score is needed later on for the global assessment between energy, non-energy, environmental and SRI values.



PRIMARY ENERGY CLASS **C** ENERGY SCORE **87,55** 87,55 C

FINAL ENERGY (kWh/m²/year)

	Thermal	Electric	Total
Heating	0	150	150
Cooling	0	37,5	37,5
DHW	0	48,5	48,5
Lighting	0	6,5	6,5
Ventilation	0	0	0
TOTAL	0	242,5	242,5

PRIMARY NON-RENEWABLE ENERGY (kWh/m²/year)

	Thermal	Electric	Total
Heating	0	175,5	175,5
Cooling	0	93,75	93,75
DHW	0	56,745	56,745
Lighting	0	16,25	16,25
Ventilation	0	0	0
TOTAL	0	342,245	342,245

PRIMARY TOTAL ENERGY (kWh/m²/year)

	Thermal	Electric	Total
Heating	0	195,5	195,5
Cooling	0	133,75	133,75
DHW	0	72,245	72,245
Lighting	0	36,25	36,25
Ventilation	0	0	0
TOTAL	0	437,745	437,745
THRESHOLDS	0	-	400
ENERGY CLASS	C		

PRIMARY ENERGY RATING

	Class
Heating	D
Cooling	C
DHW	B
Lighting	A
Ventilation	A
TOTAL	C

RENEWABLE (kWh/m²/year)

	Thermal	Electric	Total
Heating	0	20	20
Cooling	0	40	40
DHW	0	15,5	15,5
Lighting	0	20	20
Ventilation	0	0	0
TOTAL	0	95,5	95,5

EXPORTED ENERGY (kWh/m²/year)

	Thermal	Electric	Total
Heating	0	0	0
Cooling	0	0	0
DHW	0	0	0
Lighting	0	0	0
Ventilation	0	0	0
TOTAL	0	0	0

RENEWABLE ENERGY RATIO (%)

	Thermal	Electric	Total
Green energy	0%	21,8%	21,82%

TARGET	30%
NEEDED	8%
PRIMARY RENEWABLE (kWh/m2/year)	35,82

Disclaimer: internal tool is under development and it is meant for testing purposes at this moment

Figure 6: Example of the energy rating assessment procedure (draft version)

In brief, the SLEPC rating system has been developed with the intention of being thorough and flexible. The assessment framework offers a comprehensive evaluation of building performance that surpasses conventional energy performance ratings. Moreover, it exhibits adaptability to harmonize with the varied and dynamic national rating methods within the EU. This feature enhances the tool's effectiveness in promoting energy efficiency and sustainability, not just at the individual building level but also within the wider framework of energy policy and regulation in the EU.

2.1.3 Non-energy indicators - SmartLivingEPC rating procedure and the dedicated outputs indicators

The recognition of non-energy indicators is deemed significant by the SmartLivingEPC (SLEPC) rating system, alongside the crucial consideration of energy performance in building assessment. These factors offer a more thorough perspective on the entire performance of a building and contribute to the holistic aspect of the SLEPC rating. The non-energy indicators are specifically formulated to evaluate different facets of building performance that are not directly linked to energy usage but are of utmost importance for ensuring occupant well-being, health, and environmental sustainability.

The classification of non-energy indicators:

- Indoor Environmental Quality (IEQ) refers to the overall condition of the indoor environment in terms of factors that can affect the health, comfort, and productivity of occupants. These considerations encompass elements such as the purity of air, the level of thermal comfort, and the performance of acoustics. Indoor Environmental Quality (IEQ) plays a crucial role in ensuring the well-being of occupants and can also have a significant influence on productivity within commercial environments.
- The evaluation of water resource utilization efficiency encompasses an analysis of fixtures, appliances, and water recycling systems.
- The assessment of radon risk in buildings involves the evaluation of potential exposure to radon, a naturally occurring radioactive gas that poses health hazards.
- The assessment of the structural integrity of buildings in regions prone to earthquakes is conducted to evaluate the risk associated with seismic activity.
- The Accessibility Index quantifies the level of accessibility of a facility with regards to individuals with disabilities, taking into account several aspects such as the presence of ramps, elevators, and appropriate signage.

The non-energy indicators are summarized in the following table:

Table 4: Non-energy indicators

No	NON-ENERGY INDICATORS at Building Level	MU	ASSET calculation methodology according to
1	Visual comfort – artificial illuminance level	Lux	EN 16798-1:2019/ ISO/CIE 20086:2019(E) + SLE
2	Visual comfort Color rendering (CRI)	-	EN 16798-1:2019/ ISO/CIE 20086:2019(E) + SLE
3	Visual comfort Artificial lighting sources temperature	K	EN 16798-1:2019/ ISO/CIE 20086:2019(E)) + SLE
4	Acoustic comfort – Sound pressure level/frequency	dB	EN 16798-1:2019/ SR EN ISO 717-1 + SLE
5	Acoustic comfort – Global sound pressure level	dB(A)	EN 16798-1:2019/ SR EN ISO 717-1 + SLE
6	Acoustic comfort – Reverberation time RT60	sec	EN 16798-1:2019/ SR EN ISO 11654 + SLE
7	Thermal comfort – Operative temperature	ºC	EN 16798-1:2019/ISO 7730:2005+ SLE
8	Thermal comfort – PMV index	-	EN 16798-1:2019//ISO 7730:2005+ SLE
9	Thermal comfort – PPD	%	EN 16798-1:2019//ISO 7730:2005 + SLE
10	Indoor air quality – CO_2 level	PPM	EN 16798-1:2019 + SLE
11	Indoor air quality - Radon risk rating	-	SLE rating
12	Accessibility index rating	-	SLE rating
13	Water consumption efficiency rating	%	SLE rating
14	Earthquake hazard risk	-	EU standard on earthquake risk assessment from SR1 to SR4 (SR – seismic risk)

2.1.3.1 Building zoning

The SmartLivingEPC (SLEPC) rating system places significant importance on the notion of building zones as a fundamental aspect of evaluating non-energy factors, including Indoor Environmental Quality (IEQ), noise levels, thermal comfort, and lighting conditions. A building typically exhibits variability in terms of its utilization and environmental conditions. Various sections or zones inside the building may possess distinct requirements and characteristics, necessitating a thorough assessment of each zone for a comprehensive appraisal.

The significance of doing zonal analysis lies in the recognition of the inherent variability in outdoor conditions. Specifically, zones in close proximity to crowded streets exhibit various levels of noise and air quality in comparison to zones situated more internally. The functional requirements of various zones differ from one another. As an illustration, it is worth noting that a classroom setting often necessitates particular lighting and acoustic requirements, whilst a library environment would demand distinct settings to provide ideal comfort and functionality.

Occupant behavior can lead to variations in temperature and humidity conditions between different zones inside a building, such as kitchens or restrooms compared to living or sleeping quarters. These variations are driven by the specific activities that occur in each zone.

The energy utilization patterns within a building might exhibit substantial variations between different zones, hence exerting an influence on the overall energy efficiency of the structure.

The methodology employed by the SLEPC rating system involves the utilization of a zonal approach for the assessment of buildings. This technique entails the subdivision of the structure into smaller, separate regions that serve certain functions, which are then evaluated individually. The assessment of each zone is conducted by considering pertinent factors. **The Indoor Environmental Quality (IEQ) of each zone is assessed and evaluated based on measurements and ratings of air quality, thermal comfort, and acoustic circumstances**.

The assessment of lighting levels, both natural and artificial, is conducted to verify that they align with the specific requirements of each zone.

The levels of external and internal noise are assessed and compared to established standards to determine their compliance with the intended purpose of each zone. The assessment of temperature and humidity levels is conducted in relation to the unique requirements of each zone in order to determine thermal comfort.

Zonal scores and overall rating: The building is evaluated based on specific indicators, with each zone being assigned its own set of ratings. These scores are subsequently combined to determine the overall SLEPC rating for the building. The utilization of zonal analysis facilitates a more comprehensive comprehension of building performance, hence facilitating the implementation of focused interventions aimed at enhancing it. The implementation of a zonal approach within the SLEPC rating system enhances the precision and comprehensiveness of evaluating a building's performance. This approach considers the intricate interrelationships among diverse environmental and functional factors, which can exhibit substantial variations across distinct sections within a given building.

The SLEPC rating system not only evaluates the performance indicators of individual zones within a building but also integrates a **weighting mechanism that takes into account the surface area of each zone in relation to the overall surface area of the building**. This stage is of utmost importance in order to achieve a more precise and fair assessment of the building's comprehensive performance.

The significance of zone weighting lies in the principle of proportional representation. It suggests that zones with larger surface areas are expected to have a stronger influence on the overall performance of a building, hence necessitating a proportionally larger impact on the final SLEPC rating.

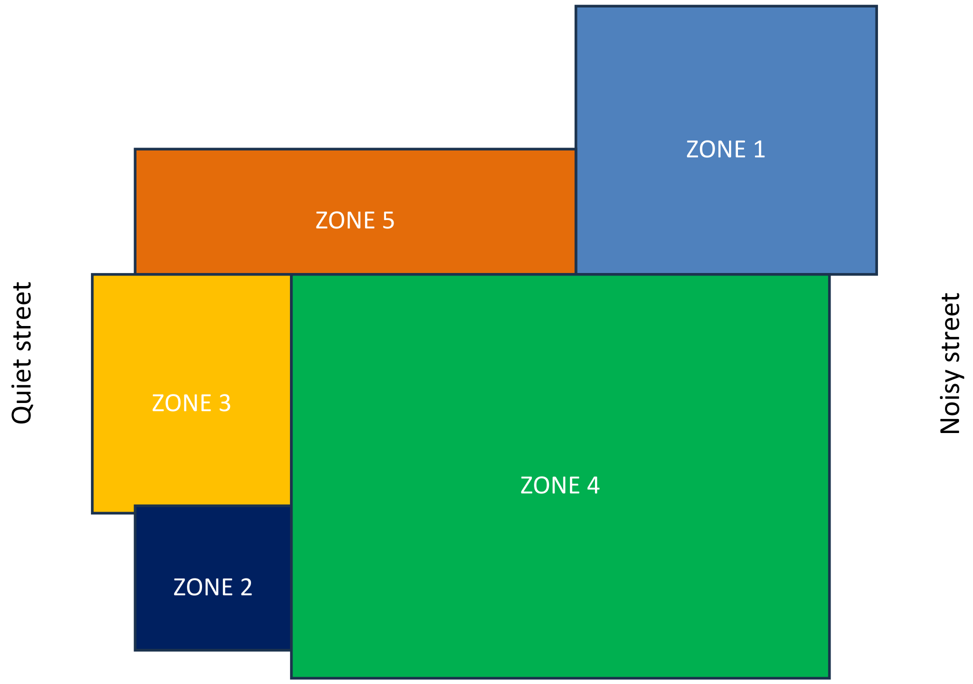


Figure 7: Example of building zoning - based on position/destination

Resource allocation is a crucial aspect of effectively managing interventions and allocating resources for change. One way to enhance this process is by comprehending the weighted relevance of each zone, as it enables **prioritization based on their significance.** The utilization of weighting in the evaluation process guarantees that the total assessment remains unbiased by the performance of smaller, less influential zones.

Methodology for Weighting: The methodology employed involves the calculation of the surface area for each zone, which is then stated as a percentage relative to the overall surface area of the building. The percentage is subsequently employed to assign appropriate weights to the scores of each performance indicator, such as indoor air quality, visual, noise, and thermal comfort, for the designated zone.

2.1.3.2 Indoor air quality rating scheme

The assessment of Indoor Air Quality (IAQ) holds significant importance as a constituent of the evaluation of Indoor Environmental Quality (IEQ) in the SmartLivingEPC (SLEPC) rating system. In order to offer a thorough and precise assessment of indoor air quality (IAQ), the system places emphasis on two primary indicators: carbon dioxide (CO_2) concentrations and the potential danger of radon exposure.

The Significance of Carbon Dioxide Levels and the Risk of Radon

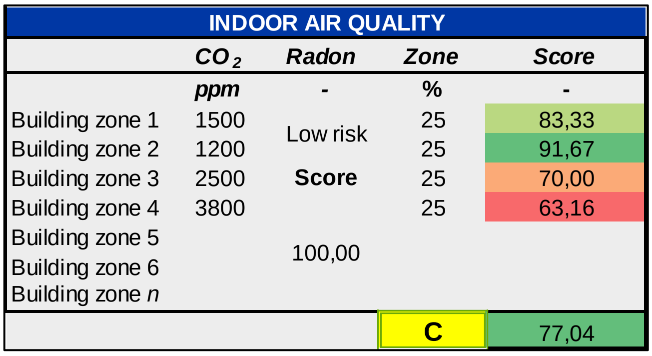
The concentration of carbon dioxide (CO_2) in the atmosphere. High concentrations of carbon dioxide (CO_2) inside indoor environments may serve as ***an indicator of inadequate ventilation, potentially resulting in reduced cognitive performance and discomfort experienced by individuals*** present in such places. The monitoring of carbon dioxide (CO_2) levels is of utmost importance in evaluating the efficacy of a building's ventilation system and guaranteeing the welfare of its occupants.

Radon Risk: Radon, a naturally occurring radioactive gas, has the potential to accumulate within buildings, with a particular propensity for lower levels such as basements. The potential health consequences of prolonged exposure to elevated levels of radon are significant, notably an augmented susceptibility to developing lung cancer. The evaluation of radon risk is of utmost importance in guaranteeing the well-being and security of individuals residing within a building.

The evaluation methodology employed in this study will be discussed in this section.

Carbon dioxide (CO_2) levels are quantified in parts per million (ppm) throughout different areas within the building. Subsequently, these data are assessed in accordance with defined criteria in order to ascertain the sufficiency of ventilation and the overall quality of the air. The method of calculation was developed and presented in Deliverable D2.1.

The assessment of radon risk involves the utilization of specialized detectors to measure the levels of radon. Based on the concentration levels and duration of exposure, the risk is then classified into three categories: 'Low,' 'Medium,' 'High and 'Extreme ' (Low - score 100, Medium – 75, High – 50 and Extreme – 25)

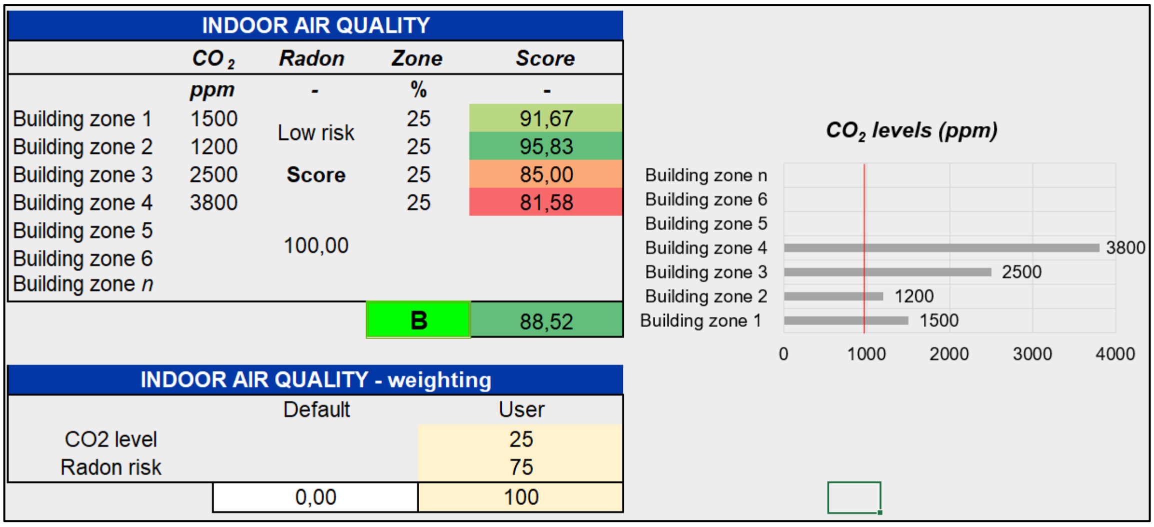


INDOOR AIR QUALITY				
	CO$_2$	***Radon***	***Zone***	***Score***
	ppm	**-**	**%**	**-**
Building zone 1	1500	Low risk	25	83,33
Building zone 2	1200		25	91,67
Building zone 3	2500	**Score**	25	70,00
Building zone 4	3800		25	63,16
Building zone 5		100,00		
Building zone 6				
Building zone *n*				
			C	77,04

Figure 8: Example of scoring for Indoor Air quality (IAQ) for 4 zones

The weighted ratings are subsequently combined across all zones in order to compute the overall performance indicators for the building. This practice guarantees that the performance of each zone is precisely represented in the building's final SLEPC rating, offering a more intricate and all-encompassing evaluation. The SLEPC rating system delivers a balanced and equitable evaluation by including zone weighting that is based on surface area. This approach allows for a more targeted and effective approach to enhancing building performance.

For indoor air quality (IAQ) we have two indicators: **CO$_2$ levels** (a quantitative indicator) and Radon risk (a qualitative indicator).



INDOOR AIR QUALITY				
	CO$_2$	***Radon***	***Zone***	***Score***
	ppm	**-**	**%**	**-**
Building zone 1	1500	Low risk	25	91,67
Building zone 2	1200		25	95,83
Building zone 3	2500	**Score**	25	85,00
Building zone 4	3800		25	81,58
Building zone 5		100,00		
Building zone 6				
Building zone *n*				
			B	88,52

INDOOR AIR QUALITY - weighting		
	Default	User
CO2 level		25
Radon risk		75
	0,00	100

Figure 9: Example of scoring and weighting between the two IAQ indicators

The default values for weigthing are 50 for both indicators but the users have the choice to modify them according to national priorities. In the example above the radon pollutant is considered more important than CO$_2$ level. If we must judge based on the impact on health this approach is valid.

2.1.3.3 Thermal comfort rating scheme

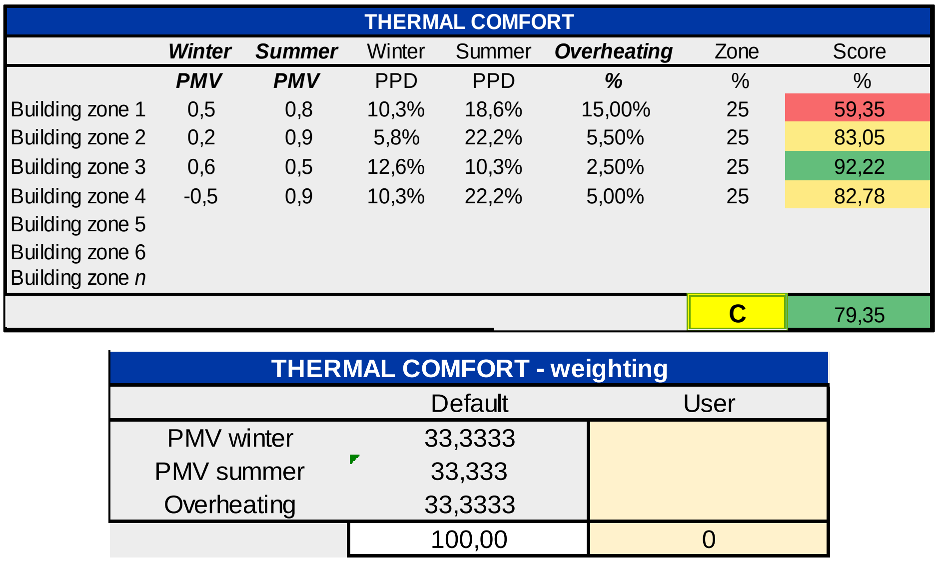
The evaluation of thermal comfort is an essential component of the SmartLivingEPC (SLEPC) assessment system, which focuses on Indoor Environmental Quality (IEQ). The optimization of thermal conditions is not solely an issue of energy efficiency, but it also has a substantial impact on the well-being and productivity of individuals occupying a building. The SLEPC method **employs two primary metrics for evaluating thermal comfort: the Predicted Mean Vote (PMV) for both winter and summer seasons, and the quantification of Overheating as a proportion of hours of overheating.**

The PMV is an index used to forecast the average thermal sensation ratings, ranging from cold to hot, that would be given by a significant number of individuals when exposed to a uniform environment. The calculation of PMV is conducted for both the winter and summer seasons to assure comfort throughout the entire year.

The indicator of overheating quantifies the proportion of time during which indoor air temperatures surpass 26°C, resulting in a state of discomfort. The problem of overheating can pose a considerable concern, particularly in structures characterized by insufficient airflow or inadequate cooling mechanisms.

Assessment Methodology: The PMV is determined by the consideration of various elements, including air temperature, mean radiant temperature, air velocity, humidity, garment insulation, and metabolic rate. The PMV score is a numerical scale that limits from -3 to +3, with values closer to zero indicating an optimal level of thermal comfort. Distinct computations are conducted for the winter and summer periods to accommodate fluctuations that occur due to seasonal changes.

The calculation of the proportion of hours during which the temperature is above 26°C is then conducted in order to evaluate the potential for overheating. Weighting and integration are employed to incorporate the PMV and overheating signs into the overall SLEPC rating, with consideration given to the surface area of each zone. This approach ensures that these crucial measures of thermal comfort are adequately represented in a proportional manner.



THERMAL COMFORT

	Winter	***Summer***	Winter	Summer	***Overheating***	Zone	Score
	PMV	***PMV***	PPD	PPD	***%***	%	%
Building zone 1	0,5	0,8	10,3%	18,6%	15,00%	25	59,35
Building zone 2	0,2	0,9	5,8%	22,2%	5,50%	25	83,05
Building zone 3	0,6	0,5	12,6%	10,3%	2,50%	25	92,22
Building zone 4	-0,5	0,9	10,3%	22,2%	5,00%	25	82,78
Building zone 5							
Building zone 6							
Building zone *n*							
						C	79,35

THERMAL COMFORT - weighting

	Default	User
PMV winter	33,3333	
PMV summer	33,333	
Overheating	33,3333	
	100,00	0

Figure 10: Example of scoring and weighting between the thermal comfort indicators

The SLEPC rating method offers a thorough evaluation of a building's thermal environment by integrating **PMV and Overheating as significant indications of thermal comfort**. This approach gives a nuanced assessment of the building's thermal conditions. This factor contributes to the comprehensive IEQ assessment and provides practical insights for specific activities aimed at enhancing thermal comfort. It is important to mention that the calculation and rating procedure are based on EN 16798-1:2019//ISO 7730:2005**.** The weighting between the three indicators is equal but there is the possibility of user-defined values.

2.1.3.4 Visual comfort rating scheme

The aspect of visual comfort holds great importance within the realm of Indoor Environmental Quality (IEQ), since it has a major impact on the well-being, productivity, and overall happiness of occupants. The SmartLivingEPC (SLEPC) rating system utilizes a comprehensive methodology to evaluate visual comfort, with a specific emphasis on four primary factors: *Illuminance, Daylight Factor, Color Rendering, and Color Temperature of artificial lighting sources*.

The Significance of Visual Comfort Indicators

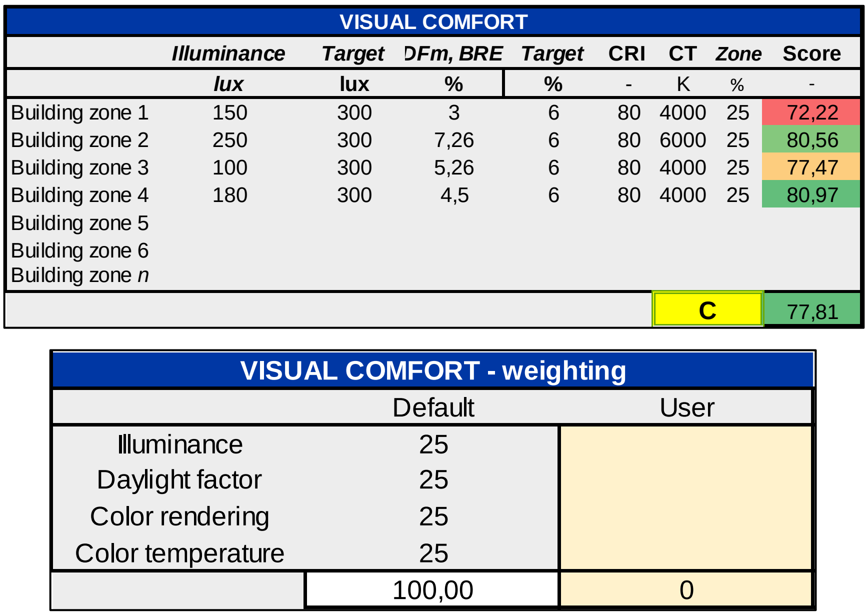
The concept of **illuminance** refers to the measurement of the amount of light that falls on a Illuminance, quantified in lux, refers to the quantity of light that is incident upon a certain surface. Ensuring appropriate levels of illuminance is essential for optimizing task performance, promoting comfort, and minimizing ocular strain and tiredness.

The Daylight Factor is a metric used to quantify the extent to which natural illumination is present in a given area. It is represented as a percentage of the outside illuminance. The impact of natural light on mood and productivity has been extensively demonstrated, therefore establishing its significance as a crucial element in the evaluation of building performance.

Color rendering is a term used to describe the degree to which artificial illumination sources accurately depict the colors of objects. The presence of high color rendering is of utmost importance in environments such as art studios, retail businesses, and medical facilities, where the accurate discernment of colors holds significant importance.

Color temperature is a metric measured in Kelvin (K) that characterizes the degree of warmth or coolness exhibited by artificial illumination. The influence of different color temperatures on mood and focus renders it a significant factor to be considered in diverse building zones.

Weighting and Integration: The visual comfort indicators are assigned weights according to the surface area of the corresponding zone, so assuring a proportional representation in the total SLEPC rating.



VISUAL COMFORT								
	Illuminance	*Target*	*DFm, BRE*	*Target*	**CRI**	**CT**	*Zone*	**Score**
	lux	**lux**	**%**	**%**	-	K	%	-
Building zone 1	150	300	3	6	80	4000	25	72,22
Building zone 2	250	300	7,26	6	80	6000	25	80,56
Building zone 3	100	300	5,26	6	80	4000	25	77,47
Building zone 4	180	300	4,5	6	80	4000	25	80,97
Building zone 5								
Building zone 6								
Building zone *n*								
							C	77,81

VISUAL COMFORT - weighting		
	Default	User
Illuminance	25	
Daylight factor	25	
Color rendering	25	
Color temperature	25	
	100,00	0

Figure 11: Example of scoring and weighting between the thermal comfort indicators

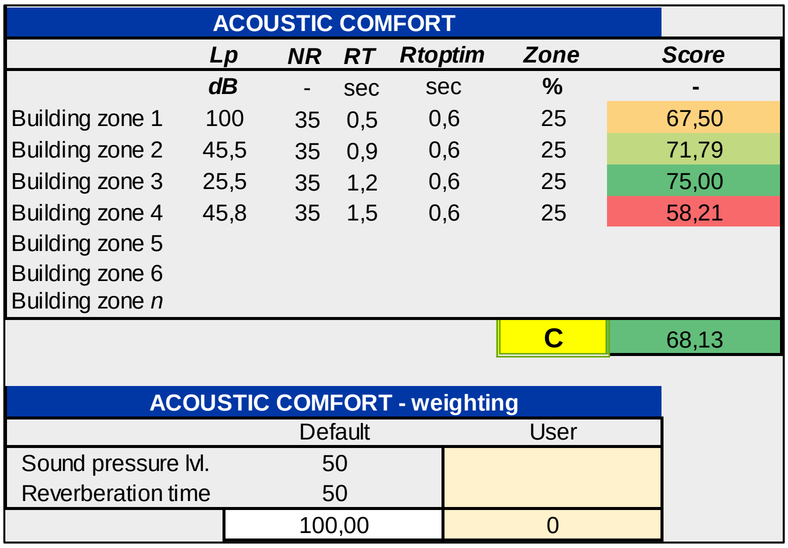
1.1.1.1 Acoustic comfort rating scheme

The acoustic comfort of a building is a crucial component of Indoor Environmental Quality (IEQ) that has a substantial impact on the physical and mental well-being, concentration levels, and overall pleasure of individuals occupying the space. The SmartLivingEPC (SLEPC) rating system utilizes a focused methodology to evaluate acoustic comfort, with specific emphasis on two primary metrics: Sound Pressure Level (Global) and Reverberation Time.

The Significance of Acoustic Comfort Indicators:

The **global sound pressure level** is a measure of the acoustic intensity of sound in the environment. The measurement of sound intensity in a certain setting is quantified using decibels (dB(A), where A represents the A-weighting filter), as the sound pressure level. Elevated sound pressure levels have the potential to induce feelings of discomfort, tension, and diminished productivity, rendering them a vital consideration in the evaluation of acoustic comfort.

The **reverberation time** is a metric that quantifies the period it takes for sound to attenuate in an enclosed environment, typically measured in seconds. Extended reverberation durations have the potential to impede speech intelligibility and diminish the aesthetic appeal of music, so exerting an influence on the acoustic characteristics of a given environment.



ACOUSTIC COMFORT

	Lp	*NR*	*RT*	*Rtoptim*	*Zone*	*Score*
	dB	-	sec	sec	%	-
Building zone 1	100	35	0,5	0,6	25	67,50
Building zone 2	45,5	35	0,9	0,6	25	71,79
Building zone 3	25,5	35	1,2	0,6	25	75,00
Building zone 4	45,8	35	1,5	0,6	25	58,21
Building zone 5						
Building zone 6						
Building zone *n*						
					C	68,13

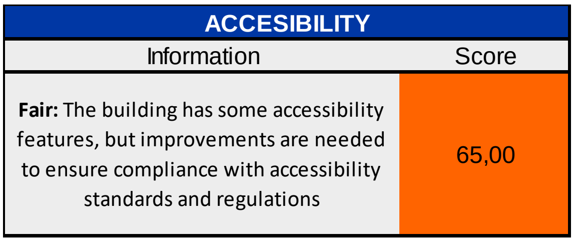
ACOUSTIC COMFORT - weighting

	Default	User
Sound pressure lvl.	50	
Reverberation time	50	
	100,00	0

Figure 12: Example of scoring and weighting between the acoustic comfort indicators

1.1.1.1 *Other non-energy qualitative indicators*

The assessment of accessibility is a fundamental component within the SmartLivingEPC (SLEPC) rating system. The assessment encompasses a spectrum of ratings, ranging from 'Poor' to 'Excellent,' which gauges the level of accessibility and navigability for individuals with disabilities within the premises. This assessment takes into account various factors, including the presence of ramps, elevators, signage, and the dimensions of doors and corridors.



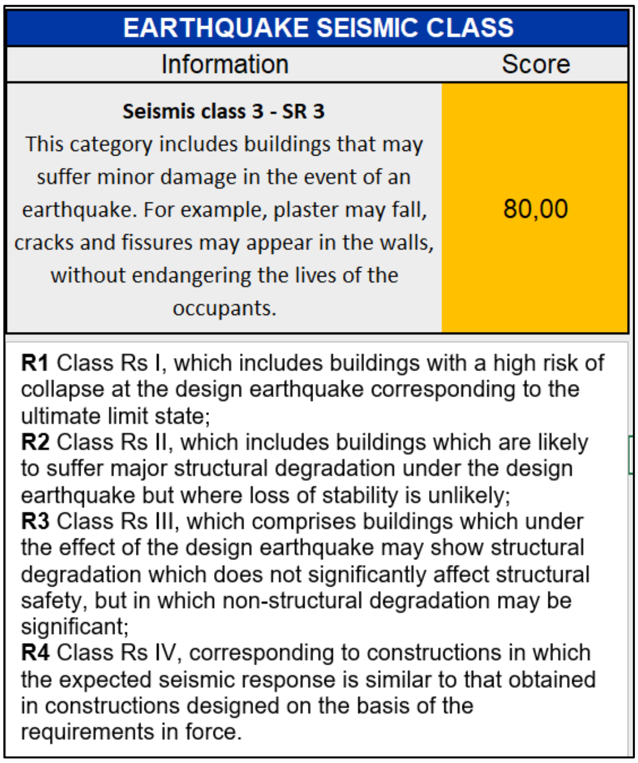
ACCESIBILITY

Information	Score
Fair: The building has some accessibility features, but improvements are needed to ensure compliance with accessibility standards and regulations	65,00

Figure 13: Example of scoring for accessibility indicator

The SLEPC approach also evaluates the potential for **earthquakes**, classifying structures into four distinct categories based on their level of risk.

- SR1 (Seismic Risk Level I): Structures that possess a significant vulnerability to structural failure in the event of a seismic event that meets the criteria for the ultimate limit state.
- Structures falling under the classification of SR2 (Seismic Risk Class Rs II) are characterized as buildings that are prone to significant structural deterioration when subjected to the design earthquake. However, it is improbable for these structures to experience a loss of stability.
- SR3 (Class Rs III): Structures that have the potential to exhibit structural deterioration following a seismic event, without posing a considerable risk to overall structural integrity, but with the potential for substantial non-structural degradation.
- SR4 (Seismic Response Class IV): projects anticipated to exhibit a seismic response comparable to that achieved in projects planned in accordance with existing regulations.



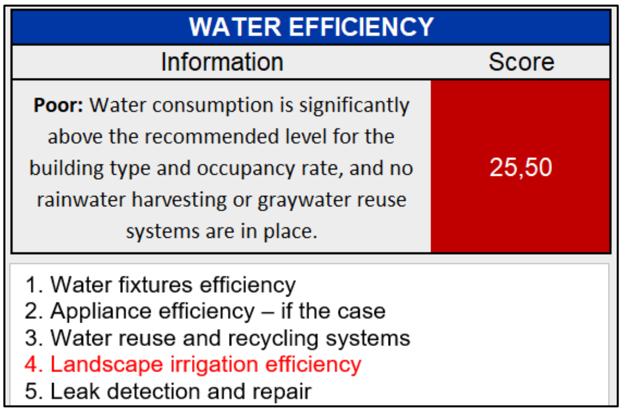
EARTHQUAKE SEISMIC CLASS	
Information	Score
Seismis class 3 - SR 3 This category includes buildings that may suffer minor damage in the event of an earthquake. For example, plaster may fall, cracks and fissures may appear in the walls, without endangering the lives of the occupants.	80,00

R1 Class Rs I, which includes buildings with a high risk of collapse at the design earthquake corresponding to the ultimate limit state;
R2 Class Rs II, which includes buildings which are likely to suffer major structural degradation under the design earthquake but where loss of stability is unlikely;
R3 Class Rs III, which comprises buildings which under the effect of the design earthquake may show structural degradation which does not significantly affect structural safety, but in which non-structural degradation may be significant;
R4 Class Rs IV, corresponding to constructions in which the expected seismic response is similar to that obtained in constructions designed on the basis of the requirements in force.

Figure 14: Example of scoring for earthquake risk

Water efficiency is evaluated by considering the following factors:

- Water Fixture Efficiency: An examination of the effectiveness of faucets, showerheads, and toilets in the conservation of water.
- The topic of discussion pertains to the efficiency of appliances, namely in terms of their water usage, with a focus on dishwashers and washing machines, where relevant.
- The examination of water reuse and recycling systems encompasses an analysis of the prevalence and efficacy of technologies such as greywater recycling and rainwater gathering.
- The topic of discussion pertains to the effectiveness of landscape irrigation systems, namely those utilized in outdoor spaces such as gardens and lawns.
- The implementation of leak detection and repair systems is crucial to ensuring water efficiency due to its ability to identify and rectify water leaks.



WATER EFFICIENCY

Information	Score
Poor: Water consumption is significantly above the recommended level for the building type and occupancy rate, and no rainwater harvesting or graywater reuse systems are in place.	25,50

1. Water fixtures efficiency
2. Appliance efficiency – if the case
3. Water reuse and recycling systems
4. Landscape irrigation efficiency
5. Leak detection and repair

Figure 15: Example of scoring for water efficiency

The SLEPC rating system incorporates each of these variables, assigning weights to them according to their respective influence on the overall performance of the building. The SLEPC rating system provides a detailed and practical evaluation of a building's overall performance and safety characteristics by integrating comprehensive indicators for accessibility, earthquake risk, and water efficiency. This factor adds to the comprehensive Indoor Environmental Quality (IEQ) assessment score and offers significant insights for implementing focused actions aimed at enhancing building quality.

2.1.3.5 Weighting scheme and rating

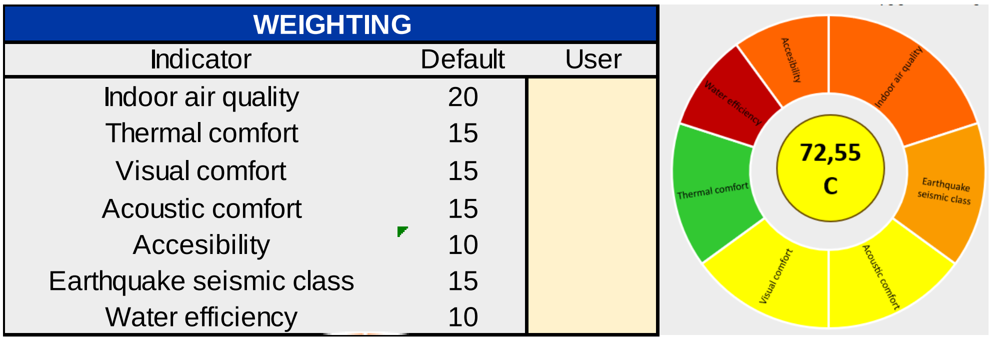
The SmartLivingEPC (SLEPC) rating system has been developed with the intention of being comprehensive and adaptable, enabling modifications to accommodate individual user requirements or geographical factors. The system assesses the performance of a building across various dimensions, which encompass:

- Indoor Air Quality (IAQ)
- Thermal Comfort
- Visual Comfort
- Acoustic Comfort
- Accessibility
- Earthquake Seismic Class
- Water Efficiency

The default weight for each of these indications in the overall SLEPC rating is determined based on established best practices and expert recommendations. However, it is important to acknowledge that various areas and users may possess distinct priorities. To accommodate this diversity, the SLEPC system offers the flexibility to adjust the weighting of these indicators according to individual preferences.

Customizable Weighting: Individuals are provided with the opportunity to modify the predetermined weights assigned to each indication in accordance with their requirements or considerations. As an example, in areas characterized by a significant susceptibility to seismic activity, auditors may opt to assign a greater level of importance to the Earthquake Seismic Class indicator. In regions where the availability of water is limited, the Water Efficiency indicator may be assigned greater importance. In educational or healthcare environments, there is often a prioritization of IAQ and Acoustic Comfort.

The Enhancement of the SLEPC System by Customizable Weighting



WEIGHTING

Indicator	Default	User
Indoor air quality	20	
Thermal comfort	15	
Visual comfort	15	
Acoustic comfort	15	
Accesibility	10	
Earthquake seismic class	15	
Water efficiency	10	

Figure 16: Example of weighting and class/score calculation for non-energy

The Significance of the Region: Enables the SLEPC rating to be better calibrated with regional vulnerabilities and preferences, such as places prone to seismic activity or regions experiencing water scarcity.

User-Centric: This feature allows users to customize the SLEPC rating according to their individual requirements and concerns, hence enhancing the practicality and applicability of the rating.

The holistic assessment approach employed by the SLEPC system guarantees a well-rounded and thorough evaluation, even when using customized weighting. This is achieved by the inclusion of a predefined set of key indicators. The inclusion of customizable weighting enables users to enhance their decision-making process by obtaining more comprehensive information regarding building enhancements, investments, and policy planning. The SLEPC rating system, with its provision of extensive customization options, not only facilitates a thorough evaluation of a building's performance but also enables the accommodation of individual user requirements and geographical factors.

2.1.4 Environmental analysis - SmartLivingEPC rating procedure and the dedicated outputs indicators

The integration of environmental sustainability is a fundamental principle within the SmartLivingEPC (SLEPC) rating system. The primary objective of the system is to offer a thorough assessment of the environmental impact of a building, encompassing a range of indicators that evaluate the building's ecological footprint and its overall performance. The indicators have been specifically developed to conform to the Level(s) framework, which is a European methodology utilized for evaluating and disclosing the sustainability aspects of buildings. The indicators are the following:

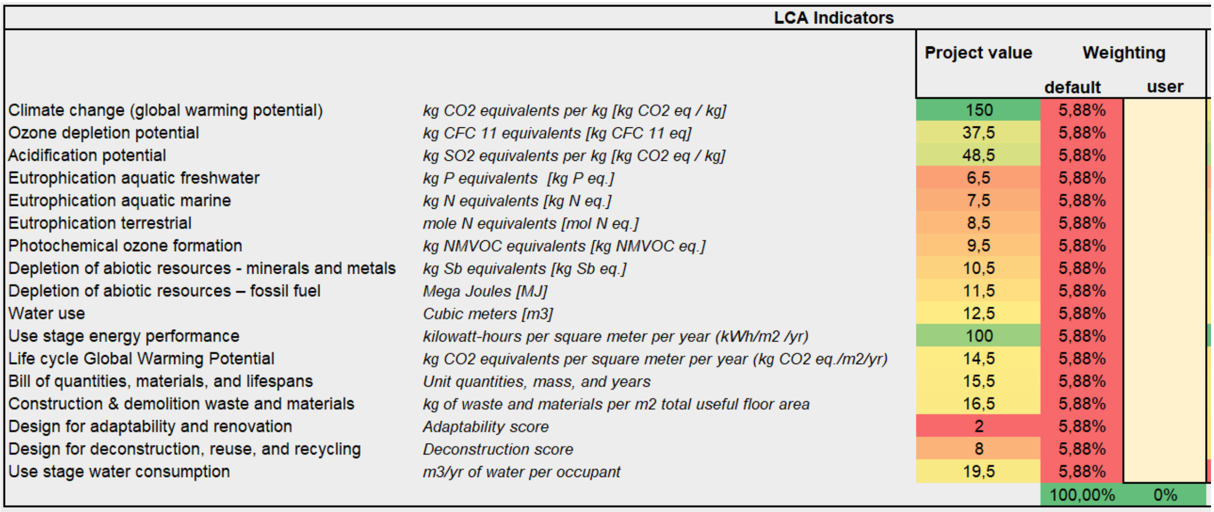
Table 5: Environmental indicators

Indicator Name	**Indicator Description**	**Units**
limate change (global warming potential)	Indicator denoting the potential global warming resulting from the discharge of greenhouse gases into the atmosphere. Climate change is the consequence of human-induced emissions on atmospheric radiative forcing, specifically heat radiation absorption, which has been identified as a subject of paramount concern. Subsequently, this phenomenon may yield adverse ramifications on vital components such as ecosystem health, human well-being, and material welfare. The majority of these emissions have been observed to accentuate radiative forcing, leading to an elevation in surface temperatures on Earth, commonly acknowledged as the greenhouse effect. Consequently, this indicator emphasizes the imperative areas of safeguarding, namely human health, the natural environment, and the built environment.	kg CO_2 equivalents per kg [kg CO_2 eq / kg]
Ozone depletion potential	Indicator of emissions to air that causes the destruction of the stratospheric ozone layer.	kg CFC 11 equivalents [kg CFC 11 eq]
Acidification potential	In the realm of environmental phenomena, a reduction in the pH level of rainwater and fog measurements ensues, subsequently eliciting adverse consequences for ecosystems. Such effects manifest in the leaching of soil nutrients and heightened metal solubility into the soil matrix. The ramifications of acidifying pollutants extend across diverse domains, including soil quality, groundwater, surface waters, living organisms, ecosystems, and even the integrity of constructed materials such as buildings. Among the chief contributors to acidification are emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), and ammonia compounds (NHx). Areas warranting particular concern and protection encompass both the natural environment and the constructed urban landscape, as well as human health and the safeguarding of vital natural resources.	mole H+ equivalents [mol H+ eq.] kg SO_2 equivalents per kg [kg CO_2 eq / kg]
Eutrophication aquatic freshwater	In the realm of freshwater ecosystems, an observable phenomenon emerges in the form of amplified growth measurements of aquatic plants or the proliferation of algal blooms, both of which can be attributed to the elevated presence of nutrients. This influx of nutrients contributes to a state of excessive enrichment, resulting in the exacerbation of aquatic plant growth or the burgeoning of algal populations.	kg P equivalents [kg P eq.]

Indicator Name	Indicator Description	Units
	Such a scenario warrants scholarly attention, as it pertains to the subject of freshwater ecotoxicity, which delves into the repercussions of toxic substances on the delicate balance and functionality of these vital aquatic environments.	
Eutrophication aquatic marine	Marine ecosystem reaction measurement to excessive availability of a limiting nutrient.	kg N equivalents [kg N eq.]
Eutrophication terrestrial	Enhanced quantification of nutrient accessibility within the soil consequent to the infusion of botanical fertilizers.	mole N equivalents [mol N eq.]
Photochemical ozone formation	Indicator delving into the measurement and subsequent effects of nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) on the domains of 'Human Health' and 'Terrestrial Ecosystems' protection. Emphasizing photo-oxidant formation, which engenders the generation of reactive chemical species such as ozone through solar irradiation on specific primary air pollutants, the research explores the potential deleterious consequences of these reactive compounds on human health and the environment, including detrimental effects on crops. The pertinent areas of protection under scrutiny encompass human health, the built environment, the natural habitat, and essential natural resources.	kg NMVOC equivalents [kg NMVOC eq.]
Depletion of abiotic resources - minerals and metals	Indicator delving into the concept of "abiotic resource depletion," an essential metric for measuring the exhaustion of natural non-fossil resources. Abiotic resources encompass diverse natural sources, such as iron ore, crude oil, and wind energy, which are characterized by their non-living origin. This indicator holds significant prominence within sustainability discussions, and consequently, various methodologies have emerged to characterize contributions to this domain. The divergent approaches adopted in these methodologies often stem from disparities in problem definitions. As a result, the scope of this indicator may encompass solely natural resources or extend to encompass human health and the natural environment, thereby warranting comprehensive consideration.	kg Sb equivalents [kg Sb eq.]
Depletion of abiotic resources – fossil fuel	Indicator of the depletion of natural fossil fuel resources.	Mega Joules [MJ]
Water use	Indicator of the amount of water required to dilute toxic elements emitted into water or soil.	Cubic meters [m^3]
Use stage energy performance	“Operational energy consumption”: primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.	kilowatt-hours per square meter per year [$kWh/m^2/yr$]
Life cycle Global Warming Potential	“Carbon footprint assessment” or “whole life carbon measurement”: building’s contribution to greenhouse gas (GHG) emissions measurement associated with earth’s global warming or climate change.	kg CO_2 equivalents per square meter per year [kg CO_2 eq./m^2/yr]

Indicator Name	**Indicator Description**	**Units**
Bill of quantities, materials, and lifespans	The quantities and mass of construction products and materials, as well as estimation of the lifespans measurement necessary to complete defined parts of the building.	Unit quantities, mass, and years
Construction & demolition waste and materials	In the context of construction, renovation, and demolition activities, the aggregate volume of waste and materials produced serves as the basis for computing the diversion rate pertaining to reuse and recycling, adhering to the principles outlined in the waste hierarchy.	kg of waste and materials per m^2 total useful floor area
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.	Adaptability score
Design for deconstruction, reuse, and recycling	In the realm of architectural design, the evaluation of the potential for future material recovery and reuse, encompassing disassembly considerations to optimize the ease of deconstructing essential building components, is imperative. This entails a comprehensive assessment of the feasibility of reutilizing and recycling said components, along with their associated sub-assemblies and constituent materials.	Deconstruction score
Use stage water consumption	The comprehensive quantification of water utilization for an average building inhabitant, encompassing the ability to distinguish between potable and non-potable water supplies, as well as facilitating the identification of regions facing water scarcity.	m^3/yr of water per occupant

Each of these indicators is computed using defined techniques to assure precision and comparability. Within the SLEPC rating scheme, the allocation of weights for each indicator is initially established as equal, with each indicator being assigned a weight of 5.88. Consequently, the cumulative weight of all indicators amounts to 100. This technique maintains equilibrium by assigning equal significance to every facet of environmental impact and sustainability within the comprehensive evaluation. Nevertheless, it is important to acknowledge that the weighting of each indication can be altered, allowing for adjustments to the value of 5.88 if deemed appropriate by an energy auditor. In places characterized by a notable degree of water shortage, the 'Water Use' indicator may be accorded greater significance in the evaluation process. The inherent flexibility of the SLEPC rating system enables it to effectively accommodate and respond to unique environmental circumstances and individual priorities. To calculate the score for the LEVEL(S) reference values must be proposed during the project. Based on these references a score/environmental class can be computed.



LCA Indicators		Project value	Weighting default	Weighting user
Climate change (global warming potential)	*kg CO2 equivalents per kg [kg CO2 eq / kg]*	150	5,88%	
Ozone depletion potential	*kg CFC 11 equivalents [kg CFC 11 eq]*	37,5	5,88%	
Acidification potential	*kg SO2 equivalents per kg [kg CO2 eq / kg]*	48,5	5,88%	
Eutrophication aquatic freshwater	*kg P equivalents [kg P eq.]*	6,5	5,88%	
Eutrophication aquatic marine	*kg N equivalents [kg N eq.]*	7,5	5,88%	
Eutrophication terrestrial	*mole N equivalents [mol N eq.]*	8,5	5,88%	
Photochemical ozone formation	*kg NMVOC equivalents [kg NMVOC eq.]*	9,5	5,88%	
Depletion of abiotic resources - minerals and metals	*kg Sb equivalents [kg Sb eq.]*	10,5	5,88%	
Depletion of abiotic resources – fossil fuel	*Mega Joules [MJ]*	11,5	5,88%	
Water use	*Cubic meters [m3]*	12,5	5,88%	
Use stage energy performance	*kilowatt-hours per square meter per year (kWh/m2 /yr)*	100	5,88%	
Life cycle Global Warming Potential	*kg CO2 equivalents per square meter per year (kg CO2 eq./m2/yr)*	14,5	5,88%	
Bill of quantities, materials, and lifespans	*Unit quantities, mass, and years*	15,5	5,88%	
Construction & demolition waste and materials	*kg of waste and materials per m2 total useful floor area*	16,5	5,88%	
Design for adaptability and renovation	*Adaptability score*	2	5,88%	
Design for deconstruction, reuse, and recycling	*Deconstruction score*	8	5,88%	
Use stage water consumption	*m3/yr of water per occupant*	19,5	5,88%	
			100,00%	0%

Figure 17: Example of LCA indicators with default weighting

2.1.5 Data collected from technical audits

2.1.5.1 Nature of audit data

As explained in D2.1 under the EPBD inspections audit data is produced for HVAC systems for eligible buildings. The two key parameters produced are the actual system efficiency and the extent to which the system is correctly sized to provide the required service. The specific outputs depend on the MS specifications and the audit level but invariably include the above parameters. The subsections below provide some concrete examples by HVAC type but more details are included in D2.1.

2.1.5.2 Mapping audit outputs with EPC inputs for heating systems and hot water

The key space energy heater performance aspects are:

- Sizing of the space heat generator (specifically the degree of oversizing in relation to the need)
- Seasonal efficiency of the space heat generator
- Correct positioning of the heat emitters
- Quality of insulation of the distribution system piping
- Information on the characteristics/energy performance of the pumping system
- Information on the spatial resolution of the control of the heat emitters
- Information on the appropriateness of the positioning off the sensors
- Information on the amount and appropriate sizing of the hot water storage
- Information on the insulation quality of the hot water storage

For the DHW system:

- type and size of heat generator used for domestic hot water production
- sizing, thermal insulation, temperature levels and control strategy of any storage vessel
- sizing, performance (including fouling and scaling), thermal insulation and temperature control of heat exchanger
- auxiliary energy requirements (e.g. circulation pump)
- temperature levels, operation timing and control strategy of circulation lines

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards which will be shown in the M20 version of this report. Thus, they can be used to adjust and improve the accuracy of heating and hot water energy performance calculations used to generate EPCs providing the EPCs are generated in accordance to the EPB calculation standards.

2.1.5.3 Mapping audit outputs with EPC inputs for cooling systems

The key air conditioner system energy performance aspects can be reported (depending on the level of inspection adopted) can be:

- The specific cooling load
- The specific cooling capacity
- Assessment of the air-conditioning efficiency
- Assessment of the sizing compared to the cooling and ventilation requirements of the building
- Assessment of the system efficiency including maintenance and controls
- Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations
- Information on any parameters suspected to be useful to measure concerning energy efficiency of the refrigerator.

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards which will be shown in the M20 version of this report. Thus, they can be used to adjust and improve the accuracy of air conditioning energy performance calculations used to generate EPCs providing the EPCs are generated in accordance to the EPB calculation standards.

Furthermore, the following advice that may improve the system energy performance:

- Advice on location, function and settings of controls, sensors and indicators
- Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment in not running in accordance with the use of the building
- Advice to record meter readings on regular basis if meters are installed but no consumption records are available
- Advice on the use of shading devices.

2.1.5.4 Mapping audit outputs with EPC inputs for ventilation systems

The key ventilation system energy performance aspects can be reported (depending on the level of inspection adopted) can be:

- Assessment of the size compared to the cooling and ventilation requirements of the building
- Assessment of the system's efficiency including maintenance and controls
- Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations
- Electrical power consumed by the fan(s).

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards which will be shown in the M20 version of this report. Thus, they can be used to adjust and improve the accuracy of heating and hot water energy performance calculations used to generate EPCs providing the EPCs are generated in accordance with the EPB calculation standards.

Furthermore, the following advice may improve the system's energy performance:

- Proposals to improve the results in terms of energy impact, including
- possible replacement of the system, subsystems or components and the economic justification of choices
- Advice on the location, function and settings of controls, sensors and indicators
- Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment is not running in accordance with the use of the building

- Advice to record meter readings on a regular basis if meters are installed but no consumption records are available
- Advice on the use of shading devices.

In addition, the following aspects have relevance for the IAQ and IEQ of the ventilation system:

- State, integrity and cleanliness of the ductwork (including observations)
- Total air flow rate extracted and/or supplied by the air handling unit
- In case of presence of specific ventilation systems for the reduction in the concentration of specific gas (e.g. radon), the operation or not of these specific ventilation systems during the inspection
- In case of a central system, the pressure before and after the unit and the air filter
- Missing, blocked or damaged air filters and blanking plates in place
- Frequency of air filter changing or cleaning, and time elapsed since the last change or cleaning as well as discrepancies between written records of air filter changes and visual evidence
- Any evidence that occupants find the air delivery arrangement unacceptable
- Cleanliness and correct functioning of the air inlets and outlets.

Furthermore, the following advice may improve the IAQ/IEQ:

- Advice regarding the cleaning of exhaust and supply systems to ensure a good air quality
- Advice for improvement includes the adjustments to be made to ensure that it agrees with the design.

1.1.1.1 Audit data from inspections of Building Automation and Control Systems

This will be added following the M20 version of D2.1.

1.1.1.1 Integration of audit data into the SmartLivingEPC asset methodology

In principle HVAC audit data, gathered through audits implemented under Articles 14 and 15 of the EPBD, could help to inform the energy parameters for the SLEPC asset methodology listed in the table below.

Table 6: Mapping of SmartLivingEPC KPIs to findings from HVAC audits

Energy parameters					Asset (retroactive)	Operational (periodically)
1 -energy rating 2 – Level(s) 3 – Other (non-energy/on-site audit) - 4 - SRI	1	2	3	4	Calculated	Measured
Heating consumption [kWh]			√		YES	YES
Specific heating consumption [kWh/m^2]			√		YES	NO
DHW consumption [kWh]			√		YES	YES
Specific DWH consumption [kWh/m^2]			√		YES	NO
Ventilation consumption [kWh]			√		YES	YES
Specific ventilation consumption [kWh/m^2]			√		YES	NO
Cooling consumption [kWh]			√		YES	YES
Specific cooling consumption [kWh/m^2]			√		YES	NO

The audits would return information on the actual sizing and efficiency of heating and ventilation systems, as operated, in the buildings subject to inspection and hence would tend to occur in a different sequence to a conventional EPC assessment and calculation.

2.1.5.5 Procedures for the use of audit data within SLEPC

HVAC audits are currently required under Articles 14/15 of the EPBD for buildings with certain characteristics. The frequency with which mandatory HVAC audits are conducted is set at the Member State level but they are likely to be more frequent than the issuance of an EPC in most cases. Nor do the audits generally occur at the same time as an EPC assessment, calculation and certificate is issued. In part for this reason the audit information is not currently made use of in EPCs. This is a waste as in principle the information these audits contain could be used to refine the EPC HVAC performance calculations. Doing so would make the audit information more salient as it could affect the EPC rating and building owners (and the market in general) are known to place value on higher EPC ratings.

For the above to happen from a procedural perspective the EPC would need to be amendable in the light of the information gathered from the audit as shown in the following figure.

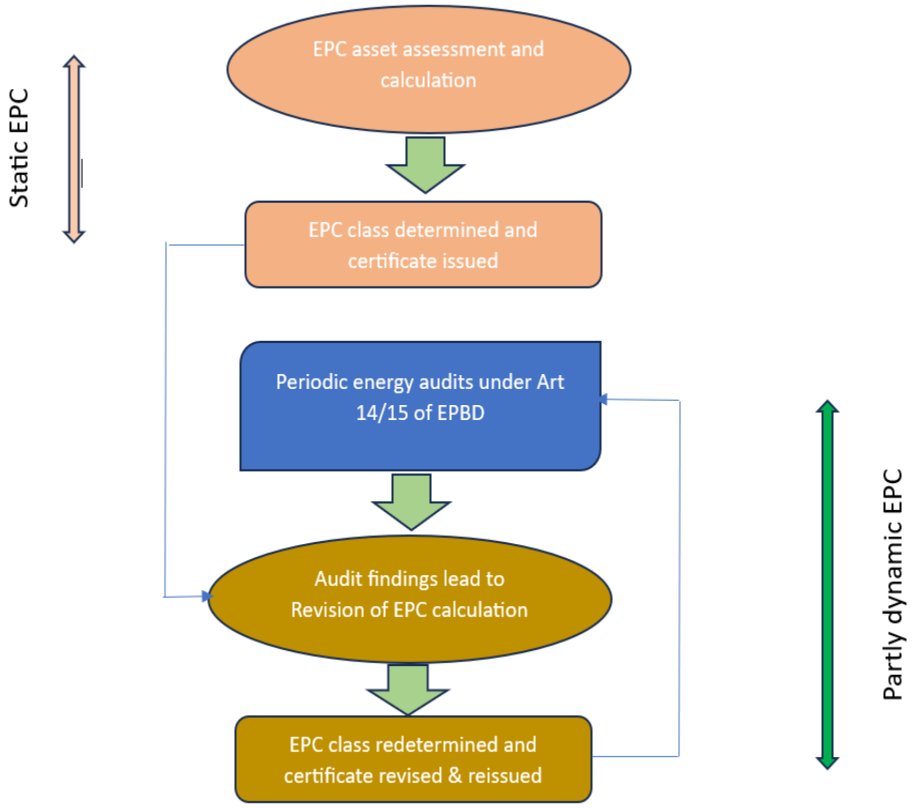


Figure 18: Energy calculation: General structure of heating and DHW standards - EN 15316 – series

Under this schematic, if an EPC has been calculated using a standard asset calculation methodology (e.g. aligned with the EN ISO asset calculation methodology for the energy performance of buildings), then the EPC would need to be capable of being updated each time an HVAC energy performance audit is conducted to reflect the additional information contained within the audit.

Permitting this to happen would be beneficial for the following reasons:

- The HVAC is the dominant part of almost all building’s energy use and thus EPC ratings are sensitive to the performance attributed to it
- The EPBD asset methodology makes a number of assumptions about how the HVAC is operated that may be inaccurate – inclusion of the HVAC audit data would allow the actual performance characteristic to be captured leading to more accurate EPC
- HVAC systems performance can be adjusted (especially in response to audit recommendations) which would alter the real energy efficiency of the building

- HVAC systems are likely to be upgraded or replaced much more rapidly than the building fabric and thus are inherently more dynamic – significant changes in the HVAC characteristics can lead to significant changes in the real energy efficiency of a building and EPCs ought to be better at reflecting (and hence encouraging) upgrades
- Such upgrades or replacements should also be subject to EPBD Article 8(1) and 8(9) requirements regarding the energy performance of technical building systems, thus the audit could both serve as a means of determining the impact that such measures have had while acting as a means of verifying that they have been respected
- Electronic EPC registration systems are already in use in some MSs and in principle such systems could be structured to allow EPCs to be recalculated and reissued (electronically) every time significant changes in the building energy performance are reported in the system
- Were such systems to already include the default EPC asset information for the HVAC systems then it would be possible to adapt the data in the system to reflect the audit findings each time an audit is conducted – this would encourage building owners/managers to act upon audit recommendations as doing so would lead to an improved EPC rating
- Such a system would also encourage the owners/managers of buildings subject to periodic HVAC audits to consider uprating the HVAC system (perhaps through a replacement of all or part of the system) faster than may otherwise be the case as the impact on the EPC rating would be reported at the frequency of the audit. This could be an important stimulus for building owners looking to upgrade the performance to meet minimum EPC rating requirements (now under consideration in the EPBD recast proposals), or simply to demonstrate faster progress in the energy performance of a portfolio of buildings.

For all of the above reasons it makes sense to leverage the value of the HVAC audits and to use them to both enable a more dynamic (and hence valuable) EPC rating and also to allow audits and EPCs to support the critical Article 8 objectives which are one of the key mechanisms to accelerate the transformation of Europe's buildings to higher energy efficiency levels. On top of this, the potential value of such audits in reflecting real service delivered and in particular informing insights into the quality of ventilation delivered can also be leveraged through the SmartLivingEPC IAQ/IEQ KPIs. The experience of the Covid-19 pandemic has demonstrated how critical IAQ is to minimizing transmission of viruses and hence to health and productivity, and hence the value of this aspect alone is very significant and should be a big motivating factor towards both more common and frequent audits and dynamic EPCs.

2.2 Inputs for buildings – SLE & BIM integration

2.2.1 SmartLivingEPC assessment with a BIM environment

The incorporation of Building Information Modeling (BIM) into the SLEPC evaluation process signifies a noteworthy progression in the digitalization of building performance assessments. Building Information Modeling (BIM) functions as an all-encompassing digital depiction of a building's physical and functional attributes, serving as a dependable repository for the necessary data needed for SmartLivingEPC evaluations. The interconnection between BIM and SLEPC can be observed through the utilization of BIM as a source of input data for the computation of diverse indicators.

For the calculation of energy demand BIM has the capability to provide comprehensive geometric information, encompassing building orientation, surface areas, and thermal characteristics of materials, which can be utilized in the computation of energy demand. The data is of utmost importance in the determination of the heating and cooling requirements of the structure. An instance of this is when the Building Information Modeling (BIM) model incorporates data pertaining to the U-values of walls, windows, and roofs. This data can then be inputted directly into the SLEPC assessment tool, enabling the calculation of the Building's Energy Performance Class for Heating, Cooling, and other systems.

As concerns of non-energy indicators BIM has the capability to supply pertinent data concerning IAQ, specifically with regards to HVAC systems. This includes comprehensive details such as system specifications, precise locations, and operational schedules. The provided data possesses the potential to facilitate the computation of carbon dioxide (CO_2) concentrations and radon hazard (qualitative based on EU radon map), both of which serve as pivotal metrics for evaluating the IAQ the SLEPC grading system.

The use of Building Information Modeling (BIM) can moreover provide valuable information regarding the materials employed in the construction of a building, encompassing their thermal characteristics, as well as the building's orientation. The provided data can be utilized for the computation of the Predicted Mean Vote (PMV) throughout both winter and summer periods, along with determining the proportion of hours characterized by discomfort caused by excessive heat. It can also be used to provide data concerning visual comfort indicators such as illuminance and daylight factor. This includes information on window dimensions and orientation, glazing materials, and even the reflectivity of internal surfaces. The provided data can be utilized for the purpose of quantifying the availability of natural light as well as evaluating the efficiency of artificial lighting systems. For noise evaluation it is also a good way to gather information regarding the composition of walls, floors, and ceilings or their acoustic proprieties (e.g. density, sound insulation, etc.). This data may be leveraged to assess sound pressure levels and reverberation times, which serve as crucial metrics for evaluating acoustic comfort.

BIM is also useful to calculate sustainability indicators like global warming potential and water use. This includes information on the specific materials employed, their quantities, and the corresponding environmental impact factors associated with them. The provided data is suitable for direct utilization in Life Cycle Assessment (LCA) computations.

In brief, Building Information Modeling (BIM) functions as a comprehensive data store that has the potential to optimize and augment the assessment procedure of SmartLivingEPC. The incorporation of this technology enables a more precise, effective, and all-encompassing assessment, which is in line with the goals of the SLPC initiative aimed at advancing energy-efficient and ecologically conscious constructions.

2.2.2 Retrieving input data from BIM documents

Building Information Modelling (BIM) functions as a comprehensive digital depiction of a building's physical and functional attributes. A Building Information Modelling (BIM) project commonly encompasses a substantial amount of data that can be promptly used for SLEPC evaluations. The BIM project encompasses several essential categories of information that relevant to SLEPC.

2.2.3 BIM for accurate and comprehensive asset evaluation

This chapter will be completed up to M22, for the next version of this deliverable.

2.3 SmartLivingEPC rating procedure for asset assessment of buildings

The primary objective of the SLEPC rating technique is to offer a thorough assessment of a building's performance by incorporating multiple indicators into a unified rating system. The technique can be categorized into four primary groups, namely Smart Readiness Indicators (SRI), Energy Indicators, Non-Energy Indicators, and LEVEL(S) Indicators. Each category possesses a distinct collection of specific indications, and each indicator is allocated a score according to predetermined criteria.

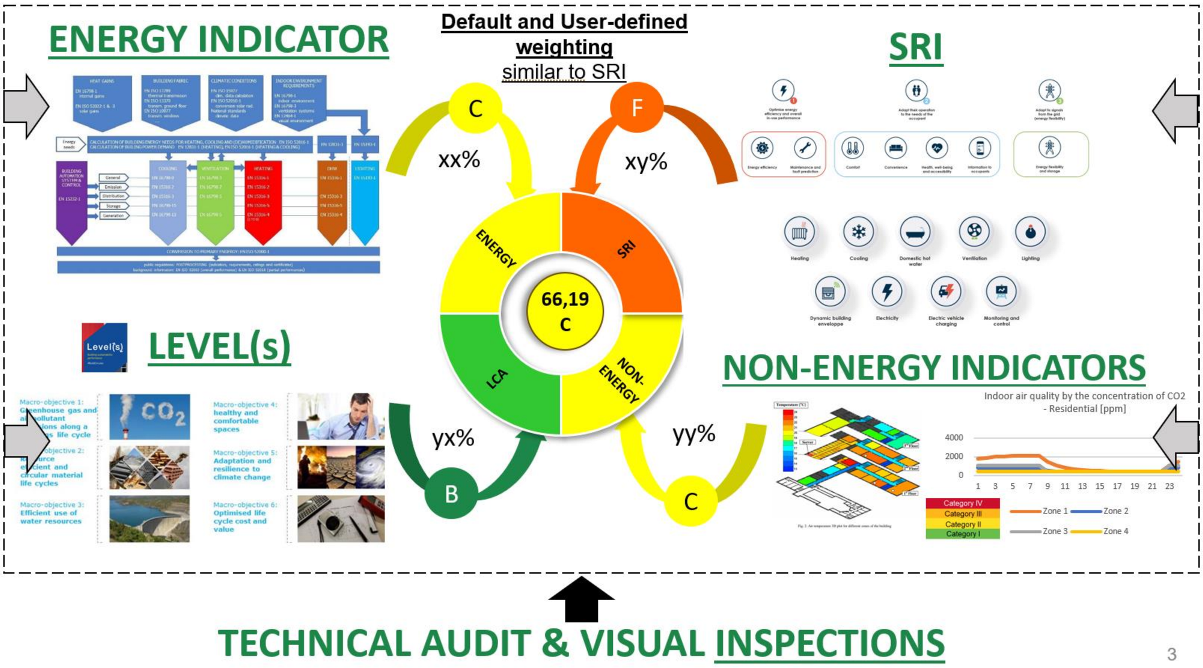


Figure 19: Visual representation of the connections between KPI’s

The rating procedure operates as follows:

First step - The first step involves the identification of individual indicators. Scoring in the context of this discussion refers to the process of evaluating or assigning numerical values to SRI indicators. SRI indicators assess the smart readiness of the building by considering its ability to accommodate inhabitants' requirements, optimize energy usage, and demonstrate satisfactory overall performance. Each component of the SRI is assigned a score. Energy indicators are utilized to evaluate the energy efficiency of a building by considering various aspects such as heating, cooling, lighting, and ventilation. A score is assigned to each parameter, often ranging from A to G. Non-energy indicators encompass a comprehensive evaluation of various factors, including IAQ, thermal comfort, visual comfort, acoustic comfort, accessibility, seismic risk, and water efficiency. Each element is evaluated according to certain parameters. Assess the environmental impact of the building using LEVEL(S) techniques, which encompass several elements such as global warming potential, water consumption, and life cycle analysis. The scoring of each component is determined by its environmental impact.

Second step – The second step involves the implementation of a weighting scheme. The distribution of weights to various variables in a sustainability assessment is a crucial factor that can have a substantial impact on the ultimate evaluation of a structure. Numerous techniques have been suggested to tackle this intricate matter. The Analytic Hierarchy Process (AHP) is a frequently employed approach that facilitates a methodical and organized approach to addressing many criteria within decision-making procedures [27]. The Analytic Hierarchy Process (AHP) has been utilized within the realm of urban sustainability to effectively prioritize and assign weights to sustainability indicators. This approach offers decision-makers a reliable and comprehensive framework [28].

An alternative strategy that has garnered considerable interest is the application of fuzzy multi-criteria decision-making techniques, exemplified by the Decision-Making Trial and Evaluation Laboratory (DEMATEL). The approach described enables the prioritization of sustainability indicators in a manner that is adaptable, considering the inherent uncertainties and ambiguity associated with human judgment [29].

Within the realm of building refurbishment, particularly in developing nations, the Analytic Hierarchy Process (AHP) has been utilized to construct a system of assigning relative importance that is customized to address the distinct requirements and obstacles present within the local environment [30]. This methodology guarantees that the weighing system is both pertinent and suitable for the prevailing circumstances.

Building assessment systems are progressively incorporating social sustainability indices. The significance of social sustainability, which includes factors like accessibility, health, and well-being, is currently acknowledged as a fundamental element of comprehensive sustainability evaluations.

It is important to acknowledge that the selection of a weighting scheme can significantly influence the ultimate evaluation and, as such, should be chosen with great consideration. The transparency of the scheme, its scientific validity, and its alignment with the values and priorities of the stakeholders should be ensured. Various schemes may exhibit varying degrees of suitability depending on the specific characteristics of buildings or the particular phases within a building's life cycle.

As concerns the non-energy indicators it is mentioned the IEQ as one of the critical indicators. The weighting within the framework of SLEPC holds significant importance in evaluating the sustainability of a building. The idea of Indoor Environmental Quality (IEQ) is multifaceted, encompassing several sub-components including air quality, thermal comfort, lighting, and acoustic circumstances. The significance of each of these sub-components may fluctuate based on the requirements and preferences of the tenants of the building, as well as the building's purpose and geographical position.

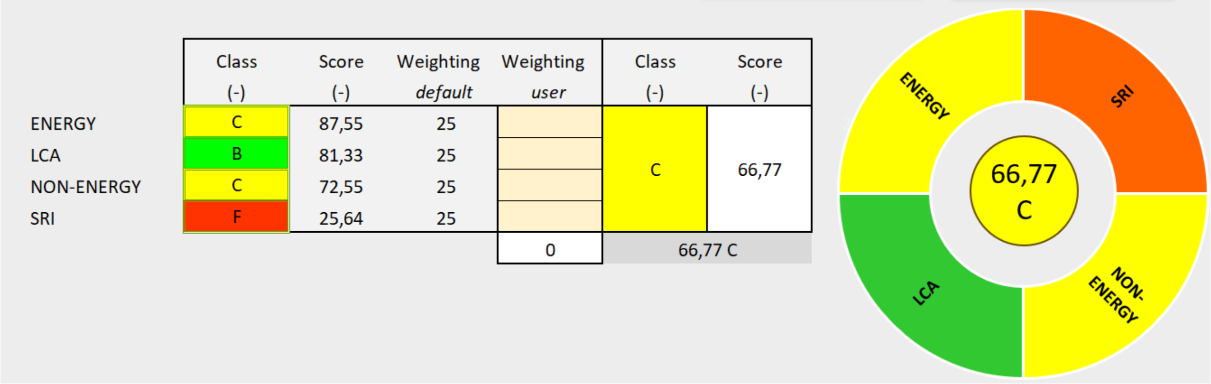
An effective strategy for assigning weights to Indoor Environmental Quality (IEQ) indicators involves the utilization of a classification and scoring system that incorporates both objective and subjective evaluation techniques.

In their study, Heinzerling et al. [31] put out a weighting and categorization scheme to assess and analyze the literature pertaining to models for evaluating IEQ, with a specific emphasis on commercial buildings. Lai and Yik conducted a study utilizing the Analytical Hierarchy Process (AHP) to evaluate the perceived significance of Indoor Environmental Quality (IEQ) through interviews conducted with both end-users and building experts [32].

Furthermore, Piasecki et al. conducted a comprehensive analysis of different models pertaining to indoor environmental quality (IEQ), specifically focusing on thermal and acoustic comfort, indoor air quality, and lighting quality. The authors also examined the effects of various weighting strategies on the overall index IEQ [33]. Although the studies offer significant insights into the intricacies of assessing Indoor Environmental Quality (IEQ), it is crucial to tailor these overarching frameworks to meet the specific needs of the SLEPC project. In essence, the weighting scheme for IEQ should possess the necessary adaptability to cater to the varying requirements of different buildings, while also exhibiting resilience to yield significant and valid comparisons. The concept has the potential to be modified in accordance with empirical evidence or input from stakeholders, so assuring its alignment with the overarching objectives of improving sustainability and promoting the well-being of occupants in the built environment.

The weight assigned to each category (SRI, Energy, Non-Energy, LEVEL(S)) is determined based on its significance within the overall assessment. The default weighting scheme has the flexibility to be modified according to individual requirements or regional considerations. In regions susceptible to earthquakes, greater emphasis may be placed on evaluating the risk associated with seismic activity.

Extended research must be conducted in this direction.



	Class (-)	Score (-)	Weighting *default*	Weighting *user*	Class (-)	Score (-)
ENERGY	C	87,55	25		C	66,77
LCA	B	81,33	25			
NON-ENERGY	C	72,55	25			
SRI	F	25,64	25			
				0	66,77 C	

Figure 20: Example of SMARTLIVING EPC rating

Third step - Computation of the SmartLivingEPC Final Score

The ultimate score of the SLEPC is determined by aggregating the scores from each category according to the designated weighting scheme. The score is a quantifiable measure that signifies the comprehensive functioning of the structure.

Fourth step - SmartLivingEPC Final Class

The SLEPC class of a building is determined based on the final result, which falls within the range of A to G. A higher score corresponds to a higher performance, while a lower number indicates worse performance.

3 Asset rating calculation methodology – COMPLEX EPC

3.1 General description of the assessment methology

Developing the SLEPC asset rating procedure for a building community involves creating a system to evaluate and rate the various assets that a community possesses. In general, community assets can be physical (like infrastructure, natural resources), social (like community cohesion, cultural heritage), economic (like local businesses, employment rates), or environmental (like green spaces, clean air).

SLEPC asset rating calculation methodology is conceived following a step-by-step approach.

Step 1 – Identify the objective of the SLEPC procedure, its purpose and the involved stakeholders (who will use the ratings and for what ?)

Step 2 - Identify and categorize all the possible assets into categories such as by function (residences, schools, hospitals, parks, historical landmarks, community organizations), type (physical, social, economic, environmental), or importance (levels) and then decide on the range of assets to be assessed (public infrastructure, cultural assets, community services, environmental conditions) and included in the SLEPC rating.

Step 3 - Set the boundaries for the assessment such as geographical or administrative boundaries and then develop criteria for evaluating each asset, reflecting community values and goals, such as sustainability, inclusivity, accessibility and propose measurable indicators for each criterion (for instance energy consumption for inside comfort, energy consumption for night lighting, green space per capita for environmental health or the number of accessible public spaces for the criterion of inclusivity etc.; SLEPC selected criteria and indicators must be relevant to the community's specific context and needs, ensuring relevance of the assessment procedure for the building complex level.

Step 4: Based on the input from different experts of the SLEPC consortium (or other experts), weights are assigned to different categories and indicators based on their importance or relevance to the community's goals; an overall scoring system will be then conceived for each indicator with defined benchmarks (class) for each score.

Step 5: Data Collection for each indicator (BIM files, audits etc.), using ethical and effective data collection methods and Analysis Use statistical methods or qualitative analysis to interpret the data and assign scores to each indicator

Step 6: Assign a final rating to the community based on the aggregated scores (rating) and compare these ratings against past ratings or ratings of similar communities for context (benchmarking) Use the ratings to highlight areas of strength and areas needing improvement

The final SLEPC complex level procedure will also include a feedback mechanism for community members and stakeholders to respond to the ratings.

In the following, six already existing methodologies for the assessment of the community energy efficiency and sustainability are shortly introduced, according to the step-by-step procedure presented before.

1. LEED for Neighborhood Development (LEED-ND)
Purpose: To rate neighborhoods based on sustainable development.
Criteria: Includes smart location and linkage to public transportation, neighborhood design and land use, green infrastructure and buildings, and innovation in design.
Data Collection: Through planning documents, site visits, stakeholder interviews.

Rating: Certified, Silver, Gold, or Platinum based on points achieved.

2. STAR Community Rating System

Purpose: To measure sustainability at the community level.

Criteria: Evaluation of built environment, climate and energy, economy and jobs, education, arts and community, equity and empowerment, health and safety, and natural systems.

Data Collection: Community surveys, government reports, and direct measurements.

Rating: Certified, 3-STAR, 4-STAR, 5-STAR based on performance measures.

3. The WELL Community Standard

Purpose: Focuses on health and wellness within sustainability.

Criteria: Includes air, water, nourishment, light, fitness, temperature, sound, materials, mind, and community aspects.

Data Collection: Site assessments, policy reviews, and performance metrics.

Rating: Certification based on adherence to WELL requirements.

4. EcoDistricts Protocol

Purpose: Focuses on neighborhood-scale sustainability.

Criteria: Three imperatives – Equity, Resilience, and Climate Protection; and six priorities – Place, Prosperity, Health + Wellbeing, Connectivity, Living Infrastructure, and Resource Restoration.

Data Collection: Community engagement, local data, and policy analysis.

Rating: Certification based on project performance and continuous improvement.

5. ISO 37120: Sustainable Development of Communities – Indicators for City Services and Quality of Life

Purpose: Provides a set of standardized indicators for city services and quality of life, applicable to communities.

Criteria: Wide range of indicators covering economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunications, transportation, urban planning, wastewater, water, and sanitation.

Data Collection: Data is gathered from municipal records, surveys, and other sources.

Rating: Not a rating system but provides benchmarks for comparison and improvement.

6. Community Energy Planning

Purpose: Specifically for assessing and planning a community's energy use and sustainability.

Criteria: Energy consumption patterns, renewable energy potential, energy efficiency opportunities, greenhouse gas emissions.

Data Collection: Energy audits, local energy data, stakeholder consultations.

Rating: Typically not a rating but a strategic plan for improving community energy use and sustainability.

Implementation Considerations:

Stakeholder Engagement: Involve community members, local businesses, and government officials in the assessment process.

Data Accuracy: Ensure accurate and current data collection for reliable assessments.

Customization: Tailor the methodology to the specific context and needs of the community.

Continuous Improvement: Use the results for setting targets, tracking progress, and continuous improvement in sustainability practices.

Integration: Consider how the energy and sustainability goals integrate with other community objectives like economic development and public health.

All these methodologies provide structured frameworks for assessing and improving the sustainability and energy efficiency of communities. They emphasize not just environmental aspects but also economic, social, and governance factors, leading to holistic community development.

3.1 Indicators of the building complex SLEPC

This chapter will be completed up to M22, for the next version of this deliverable.

3.2 Rating assessment and benchmarking procedures of the SLEPC building complex

This chapter will be completed up to M22, for the next version of this deliverable.

4 SmartLivingEPC outcomes

4.1 SmartLivingEPC certificate

The SmartLivingEPC (SLEPC) Certificate aims to be a comprehensive document that encapsulates various aspects of a building's performance, from energy efficiency to environmental impact and smart readiness. The certificate is designed to be user-friendly and informative, providing a holistic view of the building's attributes and performance metrics. Here's a breakdown of the proposed models for the certificate:

Basic Information

Building Address and Geolocation: The certificate starts by providing the building's address along with its latitude and longitude, offering a geographical context.

- **Type of Building and Physical Characteristics:** Information about the type of building (e.g., residential, commercial), its total floor area, volume, and year of construction are included to give a snapshot of the building's physical attributes.
- **Climate:** The climate of the building's location is also mentioned, as it has a significant impact on various performance metrics.

Performance Summary

- **Overall Rating and Sub-Categories:** A short text summarizes the building's overall rating, breaking it down into categories like smart readiness, energy consumption, and comfort. This provides a quick overview of where the building excels and where it needs improvement.
- **Potential for Improvement:** Another section outlines the building's potential to reach a higher class, based on proposed solutions detailed in an annex. This encourages building owners to take actionable steps for improvement.

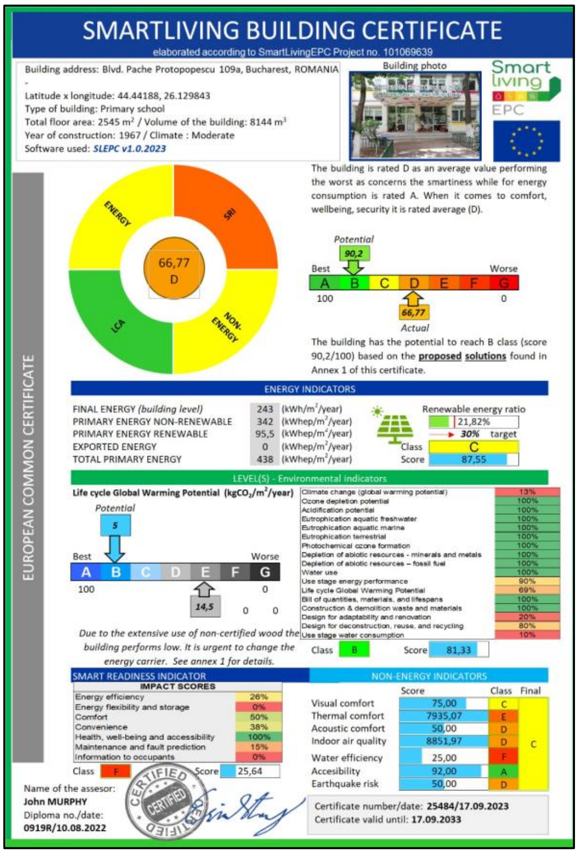
Detailed Metrics

- **Energy Indicators:** This section provides a detailed breakdown of the building's energy performance, including metrics like final energy, primary non-renewable and renewable energy, and exported energy. Each metric is presented in kWh/m2, along with its corresponding energy class and renewable energy ratio.
- **Environmental Indicators:** Metrics like Life Cycle Global Warming Potential are included, along with their values and classes, to give an idea of the building's environmental impact.
- **Smart Readiness and Non-Energy Indicators:** These sections delve into the building's smart readiness capabilities and other non-energy performance metrics like indoor air quality, thermal comfort, and water efficiency. Each sub-category is scored and classified to provide a comprehensive view.

Administrative Details

Certificate Number, Date, and Validity: The certificate concludes with administrative details like the certificate number, date of issue, and validity period, along with the signature of the energy assessor for authentication.

In the following figure there are some examples of graphical representations of these certificates.



SMARTLIVING BUILDING CERTIFICATE

elaborated according to SmartLivingEPC Project no. 101069639

Building address: Blvd. Pache Protopopescu 109a, Bucharest, ROMANIA
-
Latitude x longitude: 44.44188, 26.129843
Type of building: Primary school
Total floor area: 2545 m² / Volume of the building: 8144 m³
Year of construction: 1967 / Climate : Moderate
Software used: *SLEPC v1.0.2023*

Building photo

The building is rated D as an average value performing the worst as concerns the smartiness while for energy consumption is rated A. When it comes to comfort, wellbeing, security it is rated average (D).

Potential 90,2 — Best A B C D E F G Worse — 100 … 0 — 66,77 Actual

The building has the potential to reach B class (score 90,2/100) based on the **proposed solutions** found in Annex 1 of this certificate.

ENERGY INDICATORS

FINAL ENERGY *(building level)*	243	(kWh/m²/year)
PRIMARY ENERGY NON-RENEWABLE	342	(kWhep/m²/year)
PRIMARY ENERGY RENEWABLE	95,5	(kWhep/m²/year)
EXPORTED ENERGY	0	(kWhep/m²/year)
TOTAL PRIMARY ENERGY	438	(kWhep/m²/year)

Renewable energy ratio: 21,82%
30% target
Class: C
Score: 87,55

LEVEL(S) - Environmental indicators

Life cycle Global Warming Potential (kgCO$_2$/m²/year)

Potential 5 — Best A B C D E F G Worse — 100 … 0 — 14,5 — 0 0

Due to the extensive use of non-certified wood the building performs low. It is urgent to change the energy carrier. See annex 1 for details.

Climate change (global warming potential)	13%
Ozone depletion potential	100%
Acidification potential	100%
Eutrophication aquatic freshwater	100%
Eutrophication aquatic marine	100%
Eutrophication terrestrial	100%
Photochemical ozone formation	100%
Depletion of abiotic resources - minerals and metals	100%
Depletion of abiotic resources – fossil fuel	100%
Water use	100%
Use stage energy performance	90%
Life cycle Global Warming Potential	69%
Bill of quantities, materials, and lifespans	100%
Construction & demolition waste and materials	100%
Design for adaptability and renovation	20%
Design for deconstruction, reuse, and recycling	80%
Use stage water consumption	10%

Class: B
Score: 81,33

SMART READINESS INDICATOR

IMPACT SCORES	
Energy efficiency	26%
Energy flexibility and storage	0%
Comfort	50%
Convenience	38%
Health, well-being and accessibility	100%
Maintenance and fault prediction	15%
Information to occupants	0%

Class: F
Score: 25,64

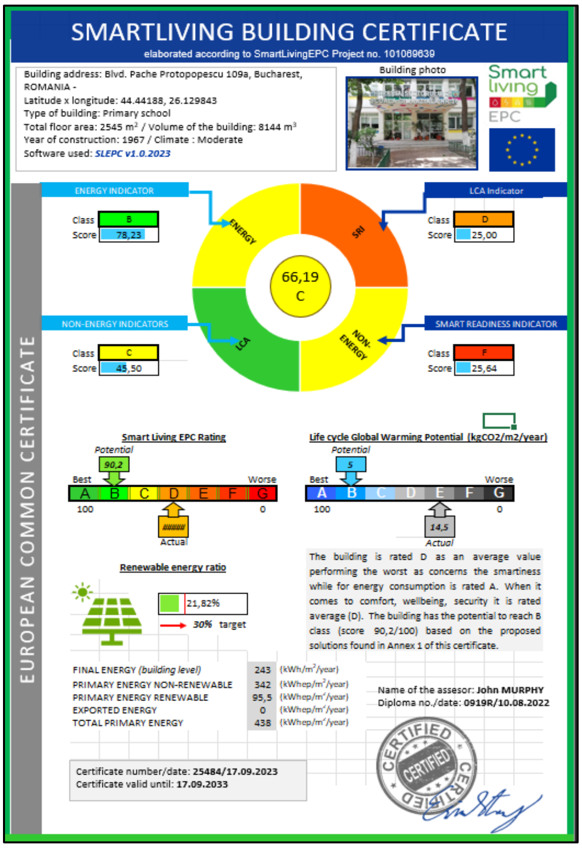
NON-ENERGY INDICATORS

	Score	Class	Final
Visual comfort	75,00	C	C
Thermal comfort	7935,07	E	
Acoustic comfort	50,00	D	
Indoor air quality	8851,97	D	
Water efficiency	25,00	F	
Accesibility	92,00	A	
Earthquake risk	50,00	D	

Name of the assesor:
John MURPHY
Diploma no./date:
0919R/10.08.2022

CERTIFIED

Certificate number/date: **25484/17.09.2023**
Certificate valid until: **17.09.2033**



SMARTLIVING BUILDING CERTIFICATE

elaborated according to SmartLivingEPC Project no. 101069639

Building address: Blvd. Pache Protopopescu 109a, Bucharest, ROMANIA -
Latitude x longitude: 44.44188, 26.129843
Type of building: Primary school
Total floor area: 2545 m² / Volume of the building: 8144 m³
Year of construction: 1967 / Climate : Moderate
Software used: *SLEPC v1.0.2023*

Building photo

ENERGY INDICATOR — Class: B — Score: 78,23

LCA Indicator — Class: D — Score: 25,00

NON-ENERGY INDICATORS — Class: C — Score: 45,50

SMART READINESS INDICATOR — Class: F — Score: 25,64

Smart Living EPC Rating

Potential 90,2 — Best A B C D E F G Worse — 100 … 0 — ###### Actual

Life cycle Global Warming Potential (kgCO2/m2/year)

Potential 5 — Best A B C D E F G Worse — 100 … 0 — 14,5 Actual

Renewable energy ratio

21,82%
30% target

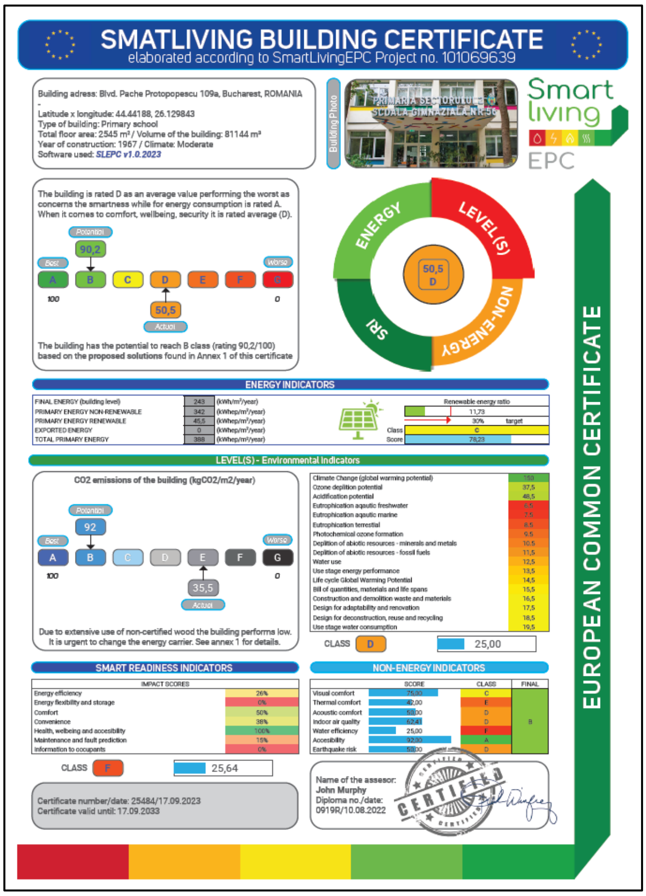
The building is rated D as an average value performing the worst as concerns the smartiness while for energy consumption is rated A. When it comes to comfort, wellbeing, security it is rated average (D). The building has the potential to reach B class (score 90,2/100) based on the proposed solutions found in Annex 1 of this certificate.

FINAL ENERGY *(building level)*	243	(kWh/m²/year)
PRIMARY ENERGY NON-RENEWABLE	342	(kWhep/m²/year)
PRIMARY ENERGY RENEWABLE	95,5	(kWhep/m²/year)
EXPORTED ENERGY	0	(kWhep/m²/year)
TOTAL PRIMARY ENERGY	438	(kWhep/m²/year)

Name of the assesor: **John MURPHY**
Diploma no./date: **0919R/10.08.2022**

CERTIFIED

Certificate number/date: **25484/17.09.2023**
Certificate valid until: **17.09.2033**



SMATLIVING BUILDING CERTIFICATE

elaborated according to SmartLivingEPC Project no. 101069639

Building adress: Blvd. Pache Protopopescu 109a, Bucharest, ROMANIA
-
Latitude x longitude: 44.44188, 26.129843
Type of building: Primary school
Total floor area: 2545 m² / Volume of the building: 81144 m³
Year of construction: 1967 / Climate: Moderate
Software used: *SLEPC v1.0.2023*

The building is rated D as an average value performing the worst as concerns the smartness while for energy consumption is rated A. When it comes to comfort, wellbeing, security it is rated average (D).

Potential 90,2 — Best A B C D E F G Worse — 100 … 0 — 50,5 Actual

The building has the potential to reach B class (rating 90,2/100) based on the proposed solutions found in Annex 1 of this certificate

ENERGY INDICATORS

FINAL ENERGY (building level)	243	(kWh/m²/year)
PRIMARY ENERGY NON-RENEWABLE	342	(kWhep/m²/year)
PRIMARY ENERGY RENEWABLE	45,5	(kWhep/m²/year)
EXPORTED ENERGY	0	(kWhep/m²/year)
TOTAL PRIMARY ENERGY	388	(kWhep/m²/year)

Renewable energy ratio: 11,73
30% target
Class: C
Score: 78,23

LEVEL(S) - Environmental Indicators

CO2 emissions of the building (kgCO2/m2/year)

Potential 92 — Best A B C D E F G Worse — 100 … 0 — 35,5 Actual

Due to extensive use of non-certified wood the building performs low. It is urgent to change the energy carrier. See annex 1 for details.

Climate Change (global warming potential)	150
Ozone deplition potential	37,5
Acidification potential	48,5
Eutrophication aqautic freshwater	6,5
Eutrophication aqautic marine	7,5
Eutrophication terrestial	8,5
Photochemical ozone formation	9,5
Deplition of abiotic resources - minerals and metals	10,5
Deplition of abiotic resources - fossil fuels	11,5
Water use	12,5
Use stage energy performance	13,5
Life cycle Global Warming Potential	14,5
Bill of quantities, materials and life spans	15,5
Construction and demolition waste and materials	16,5
Design for adaptability and renovation	17,5
Design for deconstruction, reuse and recycling	18,5
Use stage water consumption	19,5

CLASS: D
25,00

SMART READINESS INDICATORS

IMPACT SCORES	
Energy efficiency	26%
Energy flexibility and storage	0%
Comfort	50%
Convenience	38%
Health, welbeing and accesibility	100%
Maintenance and fault prediction	15%
Information to occupants	0%

CLASS: F
25,64

NON-ENERGY INDICATORS

	SCORE	CLASS	FINAL
Visual comfort	75,00	C	B
Thermal comfort	42,00	E	
Acoustic comfort	50,00	D	
Indoor air quality	62,41	D	
Water efficiency	25,00	F	
Accesibility	92,00	A	
Earthquake risk	50,00	D	

Certificate number/date: 25484/17.09.2023
Certificate valid until: 17.09.2033

Name of the assesor:
John Murphy
Diploma no./date:
0919R/10.08.2022

CERTIFIED

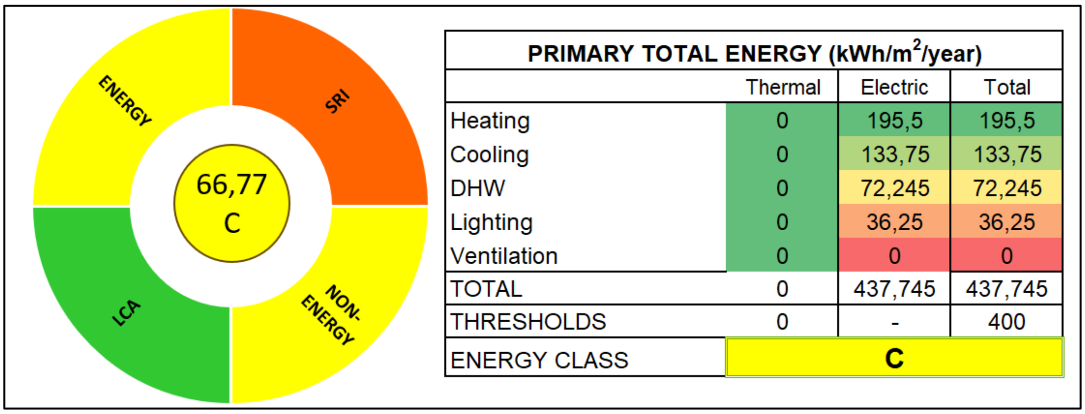
Figure 21: Example of SLE EPC model #1 to 3

The SLEPC Certificate is designed to serve as a comprehensive assessment tool for evaluating the performance of buildings. It provides a multifaceted evaluation that surpasses the scope of conventional energy certificates. The primary objective of this initiative is to enhance building performance and contribute to broader sustainability objectives by incorporating a diverse set of indicators and practical insights.

4.2 SmartLivingEPC labelling and performance classes

The SmartLivingEPC incorporates a system of labeling and performance classification, denoted by letters A to G, together with a number score ranging from 0 to 100. This approach provides a complete and clearly comprehensible means of assessing a building's performance across various aspects. The application of a combined methodology involving alphabetic and numeric grading facilitates a comprehensive evaluation of a building's performance, offering both a concise overview (A to G) and a more intricate comprehension (0 to 100). The inclusion of a color scheme that transitions from red to green enhances the intuitive comprehension of the information, hence increasing its accessibility to individuals who may lack familiarity with building performance measures.

The alphabetic grading system has been widely employed in diverse contexts, ranging from the categorization of energy efficiency in appliances to the evaluation of academic performance. It offers an instantaneous and readily comprehensible indication of the level of excellence or effectiveness. In contrast, the numerical score provides a more detailed comprehension of the building's performance. As an illustration, consider two buildings that are both assigned a 'B' grade. However, their respective numeric scores of 85 and 89 suggest a marginal yet potentially significant variance in their performance.



PRIMARY TOTAL ENERGY (kWh/m²/year)			
	Thermal	Electric	Total
Heating	0	195,5	195,5
Cooling	0	133,75	133,75
DHW	0	72,245	72,245
Lighting	0	36,25	36,25
Ventilation	0	0	0
TOTAL	0	437,745	437,745
THRESHOLDS	0	-	400
ENERGY CLASS	C		

Figure 22: Example of labeling and scoring for the SLEPC Certificate

The utilization of a color-coding scheme proves to be highly successful as a visual signal. Colors are widely recognized as symbols of caution or safety, and the progression from red to green serves as an efficient means of conveying performance levels in a simple manner. This feature is particularly advantageous for stakeholders who may be constrained by time or lack the necessary skills to thoroughly examine the intricacies, yet desire a concise comprehension of a building's sustainability and efficiency.

This multifaceted methodology of categorization has significant efficacy for several reasons:

- **Inclusivity** refers to the ability of a system or approaches to accommodate a wide range of individuals, including both experts who possess the capacity to discern subtle variations in numerical scores, and laypersons who can readily comprehend alphabetic and color-coded ratings.
- **Actionability:** The inclusion of a comprehensive numerical score provides a framework for implementing targeted strategies aimed at enhancing performance. As an illustration, a structure with a numerical rating

of 89 may necessitate minor adjustments to attain the classification of 'A', whereas a building with a rating of 81 may demand more significant modifications.

- The **marketability** of a building can be enhanced by a high rating, which has the potential to positively impact property value.
- **Policy Alignment:** The aforementioned labeling system demonstrates a strong congruence with policy objectives, as it offers a uniform metric that can effectively facilitate regulatory adherence and incentivize desired behaviors.
- The utilization of **color schemes** in behavioral economics aims to leverage behavior cues that can incentivize building owners to enhance their rating. This approach is reminiscent to the impact observed in consumer choices through the implementation of health "star ratings" on food packaging \

4.3 SmartLivingEPC certificate validity

The SmartLivingEPC (SLEPC) Certificate demonstrates a strong and comprehensive capability for evaluating several facets of building performance. The approach employed is multifaceted, surpassing conventional Energy Performance Certificates (EPCs) by encompassing not just energy efficiency but also environmental effects, smart readiness, and additional indicators related to non-energy performance. This is in line with the increasing focus on comprehensive building evaluation frameworks, such as BREEAM or LEED.

The certificate's validity is enhanced through the incorporation of various indications, each accompanied by its own score and categorization framework. This facilitates a more intricate comprehension of a building's functionality. The use of Building Information Modelling (BIM) and digital twins for data collection adds a layer of accuracy and reliability to the certificate. Studies have shown that BIM can significantly improve the quality of the data used for building assessments.

The SLEPC Certificate could serve multiple stakeholders:

- **Decision-Making:** For building owners and occupants, the certificate can serve as a roadmap for improvements, supported by the "potential to reach" scores and proposed solutions. This aligns with studies that highlight the importance of actionable insights in building assessments.
- **Financial Risk Assessment:** For financial institutions, the comprehensive nature of the certificate can serve as a risk mitigation tool, aligning with the growing importance of ESG criteria in investment decisions.
- **Policy and Regulation:** For public authorities, the certificate can serve as a data-driven tool for policy formulation, especially in the context of EU directives like Fit for 55 and the revised EPBD.
- **Construction and Design:** The certificate's compatibility with BIM and digital twins can streamline the construction process, making it more efficient and sustainable.

5 Using SmartLivingEPC assessment methodology for Pilots

Figure 23: The 9 SLEPC pilots

The SmartLivingEPC project offers an extensive variety of pilot cases, which serve as an optimal setting to showcase the adaptability and utility of the asset rating methodology that was developed as part of the project.

The methodical development and proof of data, which serves as the foundation of the asset assessment process, is fundamental to the methodology. This process entails the collection of comprehensive data pertaining to energy usage, indoor environmental conditions, and building designs. The selection of data sources is wide, including technical audits and Building Information Modelling (BIM) in addition to IoT technologies. By employing this comprehensive strategy, a robust and dependable dataset is obtained in preparation for analysis. The verification of data via technical examinations is of the utmost importance, as it guarantees not only precision but also adherence to European standards. The implementation of this stringent procedure ensures that asset evaluations are accurate and comply to well-established standards.

The methodology's applicability to real-world scenarios is verified through the utilization of data obtained from the pilot cases. The utilization of real performance data in this iterative process of testing and refinement is critical in order to guarantee the methodology's practical applicability and dependability. The knowledge acquired from these pilot cases will be of great worth in the process of enhancing the methodology and showcasing its efficacy in various building classifications and utilization situations.

In each pilot case, the methodology involves a detailed calculation of both energy and non-energy indicators:

- Energy related set of indicators include parameters like heating, cooling, ventilation, lighting, and renewable energy usage. The methodology calculates the total energy needs, taking into account the specific characteristics of each building, such as installed load, HVAC systems, and renewable energy installations. For instance, in residential buildings, the focus might be on heating and hot water efficiency, while in educational institutions, lighting and ventilation might be more prominent.

- Non-Energy related set of indicators encompass aspects such as indoor environmental quality, including air quality (like CO_2 levels and radon risk), thermal comfort (operative temperature, PMV index), visual comfort (illuminance level, color rendering index), and acoustic comfort (sound pressure level, reverberation time). Additionally, factors like accessibility and seismic risk are also considered, ensuring a comprehensive understanding of the building's performance beyond energy consumption.

This dual-focus approach is crucial for a holistic assessment of building performance.

The SmartLivingEPC project, with its array of pilot cases, showcases a robust and comprehensive approach to asset rating, emphasizing the significance of both energy and non-energy indicators. This methodology is designed to be applied across various building types, ensuring a standardized yet adaptable framework that aligns with European standards for accuracy and applicability.

Each pilot case presents unique challenges and requirements, requiring a tailored application of the methodology:

- In residential structures like the CERTH/ITI nZEB Smart House and the detached dwelling, the focus might be on optimizing energy usage while ensuring high indoor environmental quality for occupant comfort.
- For educational and public buildings like Frederick University and the Leitza Town Hall, the methodology will assess energy efficiency in heating, cooling, and lighting, alongside ensuring optimal conditions for learning and public services.

By analyzing data from these diverse buildings, the project can fine-tune its approach, ensuring that the methodology is not only theoretically sound but also practically viable. This iterative process of testing with actual performance data from the pilot cases is essential for confirming the methodology's effectiveness and adaptability.

The Smart Readiness Indicator (SRI) plays a pivotal role in the SmartLivingEPC project, particularly in the context of the diverse pilot cases. In each pilot case, the SRI will be used to evaluate the presence and effectiveness of smart technologies. This includes IoT systems, intelligent HVAC controls, smart lighting, and energy management systems. By applying the SRI in the pilot cases, this element of the SmartLivingEPC methodology can be confirmed and enhanced on an ongoing basis. Through the review of empirical data, the project can enhance the ease of use of the SRI, thereby guaranteeing that it precisely characterizes the intelligent readiness of buildings and successfully contributes to their comprehensive evaluation of sustainability.

In the pilot cases, LCA will be used to identify key areas where environmental impacts can be reduced. This could involve selecting more sustainable materials, improving energy efficiency, or implementing waste reduction strategies.

Through the implementation of this approach across a wide variety of buildings, the SmartLivingEPC initiative intends to illustrate the efficacy of its asset rating system in practical situations. The knowledge acquired from these pilot cases will be of significant worth in enhancing the methodology and demonstrating its feasibility in various building types and utilization scenarios.

6 Conclusions and future work

The goal of this deliverable is to depict the brand-new methodology for calculating asset ratings as part of the SmartLivingEPC project. This involves developing a novel system for assessing the energy and environmental performance of buildings, taking into account ratings from smartness, energy, sustainability, and technical audits. The new system will integrate results from WP2 tasks, including SRI, energy and non-energy analysis, LCA, Levels(s), and building systems energy auditing, into a unified, weighted rating system.

The deliverable laid the foundation for the development of an asset methodology for building and building complex scale. A comprehensive analysis of the existing assessment schemes was carried out, with a particular focus on urban sustainability frameworks and neighborhood sustainability assessment tools. The findings reveal that urban sustainability frameworks are organized into three dimensions: environmental, economic, and social, with an additional institutional dimension. However, it was observed that the institutional dimension of sustainability was inadequately represented. The neighborhood sustainability assessment tools also demonstrated an underrepresentation of the social and institutional dimensions. Furthermore, significant progress was made in the identification and classification of energy-consuming services at the neighborhood scale. The analysis indicated that infrastructure for transportation and street lighting, followed by urban forests and drinking water provision, were the most prominent energy-consuming services.

The deliverable explored and analyzed the most advanced discussions as well surrounding the concepts of Energy Communities, Smart Grids, and Building Units' Interaction. This comprehensive analysis contributed to the foundational understanding of these concepts. Building upon this work, collaborative discussions were held with project partners to determine the most appropriate criteria for delimiting the energy performance evaluation areas. This determination is one of the bases for issuing energy efficiency certificates at the neighborhood level, ensuring accurate and effective evaluation. Future work for the development of energy efficiency certificates at the neighborhood level includes the validation of the indicators detected through the implementation of surveys according to the Delphi method. Focusing on methodologies to assess energy and sustainability in communities involves evaluating how efficiently communities use energy, manage resources, and implement sustainable practices.

This new asset EPC is intended to be more user-friendly, incorporating all necessary elements and features for integration into digital building logbooks. This integration will enhance transparency, trust, and information sharing, aiding decision-making in the construction sector among building owners, occupants, financial institutions, and public authorities. A key aspect of the SmartLivingEPC is its assessment within a BIM environment, where all required input data is sourced from BIM documents. The ultimate outcome of this task is to establish a methodology for calculating asset ratings at the building level, specifically for Building EPCs.

Future work
Chapters 2.2, 3.2 and 3.3 will be filled with relevant information.

This deliverable will be continuously completed, improved, reviewed and updated on the course of the project ripening. The assessment methodologies for the holistic certification of single buildings (building EPC) or for building complex level (complex EPC) will be also improved and adapted based on new data from other similar projects, updated or new standards, or additional feedback from consortium partners, to ensure they remains relevant, effective. At utmost importance is also the practical implementation of the rating procedures for the pilot buildings. That is why one of the main future preoccupations will be the testing phase of the SLEPC.

We will ensure practical implementation, transparency of the entire process, data sources, and results, sensitivity (ensuring that assessments covers as much as possible European countries, communities types etc.), and efficiency in terms of time and resources.

By enhancing each step with these detailed considerations and examples, the asset rating methodology becomes more robust, inclusive, and tailored to the specific needs and context of the users.

7 References

[1] I. Petri et al., "Optimizing Energy Efficiency in Operating Built Environment Assets through Building Information Modeling: A Case Study," Energies, vol. 10, no. 8, 2017.

[2] S. Azhar, J. Brown, and A. Sattineni, "A Case Study of Building Performance Analyses Using Building Information Modeling," ISARC, 2010.

[3] T. E. Seghier et al., "Building Envelope Thermal Performance Assessment Using Visual Programming and BIM, based on ETTV requirement of Green Mark and GreenRE," IJBES, vol. 4, no. 3, 2017. PDF

[4] Z. Alwan and B. J. Gledson, "Towards green building performance evaluation using asset information modelling," BEPAM, vol. 5, no. 2, 2015.

[5] J. Milner, C. Shrubsole, P. Das, B. Jones, I. Ridley, Z. Chalabi, I. Hamilton, B. Armstrong, M. Davies, P. Wilkinson, "Home energy efficiency and radon related risk of lung cancer: modelling study," BMJ, vol. 348, pp. f7493, January 2014.

[6] T. Maung, Jack E. Bishop, E. Holt, A. Turner, C. Pfrang, "Indoor Air Pollution and the Health of Vulnerable Groups: A Systematic Review Focused on Particulate Matter (PM), Volatile Organic Compounds (VOCs) and Their Effects on Children and People with Pre-Existing Lung Disease," IJERPH, vol. 19, no. 14, pp. 8752, July 2022.

[7] I. G. A. Ratnawati, G. N. Sutapa, N. Ratini, "The concentration of radon gas in air-conditioned indoor," IJPSE, vol. 2, no. 2, pp. 169, August 2018.

[8] R. Glass, J. Rosenthal, "International Approach to Environmental and Lung Health. A Perspective from the Fogarty International Center," AnnalsATS, vol. 201708-685MG, April 2018.

[9] J. Milner, C. Shrubsole, P. Das, B. Jones, I. Ridley, Z. Chalabi, I. Hamilton, B. Armstrong, M. Davies, P. Wilkinson, "Home energy efficiency and radon related risk of lung cancer: modelling study," BMJ, vol. 348, pp. f7493, January 2014.

[10] T. Maung, Jack E. Bishop, E. Holt, A. Turner, C. Pfrang, "Indoor Air Pollution and the Health of Vulnerable Groups: A Systematic Review Focused on Particulate Matter (PM), Volatile Organic Compounds (VOCs) and Their Effects on Children and People with Pre-Existing Lung Disease," IJERPH, vol. 19, no. 14, pp. 8752, July 2022.

[11] N. Chieffo, A. Formisano, T. M. Ferreira, "Damage scenario-based approach and retrofitting strategies for seismic risk mitigation: an application to the historical Centre of Sant'Antimo (Italy)," European Journal of Environmental and Civil Engineering, vol. 24, pp. 1-23, 2019.

[12] M. Kassem, F. M. Nazri, E. N. Farsangi, B. Ozturk, "Improved Vulnerability Index Methodology to Quantify Seismic Risk and Loss Assessment in Reinforced Concrete Buildings," Structure and Infrastructure Engineering, vol. 17, pp. 1-20, 2021.

[13] P. A. Pelizari, C. Geiss, P. Aguirre, H. S. María, Y. M. Peña, H. Taubenböck, "Automated building characterization for seismic risk assessment using street-level imagery and deep learning," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 181, pp. 103-115, 2021.

[14] M. Orlando, M. Betti, P. Spinelli, "Assessment of structural behaviour and seismic retrofitting for an Italian monumental masonry building," Journal of Building Engineering, vol. 26, pp. 1-20, 2020.

[15] H. Farzaneh et al., "Artificial Intelligence Evolution in Smart Buildings for Energy Efficiency," Applied Sciences, vol. 11, no. 2, 2021.

[16] T. Märzinger and D. Österreicher, "Supporting the Smart Readiness Indicator—A Methodology to Integrate A Quantitative Assessment of the Load Shifting Potential of Smart Buildings," Energies, vol. 12, no. 10, 2019.

[17] E. Janhunen et al., "Applicability of the Smart Readiness Indicator for Cold Climate Countries," Buildings, vol. 9, no. 4, 2019.

[18] P. Fokaides et al., "How Are the Smart Readiness Indicators Expected to Affect the Energy Performance of Buildings: First Evidence and Perspectives," Sustainability, vol. 12, no. 22, 2020.

[19] JiYoung Park, Jungwon Yoon, and Kwang-hyun Kim, "Critical Review of the Material Criteria of Building Sustainability Assessment Tools," Sustainability, vol. 9, no. 2, 2017.

[20] A. Bodini, "Building a systemic environmental monitoring and indicators for sustainability: What has the ecological network approach to offer?" Ecological Indicators, vol. 23, pp. 536-547, 2012.

[21] E. Antonini, A. Boeri, M. Lauria, and F. Giglio, "Reversibility and Durability as Potential Indicators for Circular Building Technologies," Sustainability, vol. 12, no. 18, 2020.

[22] G. Foster and Halliki Kreinin, "A review of environmental impact indicators of cultural heritage buildings: a circular economy perspective," Environmental Research Letters, vol. 15, no. 4, 2020.

[23] M. Santamouris, "Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions," Science of the Total Environment, vol. 512, pp. 582-598, 2015.

[24] M. Santamouris, C. Cartalis, A. Synnefa, and D. Kolokotsa, "On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review," Energy and Buildings, vol. 98, pp. 119-124, 2015.

[25] J. A. Clarke, C. Johnstone, N. Kelly, P. Strachan, and P. Tuohy, "The role of built environment energy efficiency in a sustainable UK energy economy," Energy Policy, vol. 36, no. 12, pp. 4605-4609, 2008.

[26] D. Ürge-Vorsatz, N. Eyre, P. Graham, D. Harvey, E. Hertwich, Y. Jiang, and C. Kornevall, "Energy End-Use: Buildings," in Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 649-760, 2012.

[27] R. Ameen and M. Mourshed, "Urban sustainability assessment framework development: The ranking and weighting of sustainability indicators using analytic hierarchy process," Sustainable Cities and Society, vol. 43, pp. 141-153, February 2019.

[28] S. Kamaruzzaman, E. Lou, P. F. Wong, R. Wood, A. Che-Ani, "Developing weighting system for refurbishment building assessment scheme in Malaysia through analytic hierarchy process (AHP) approach," Energy Policy, vol. 112, pp. 280-290, January 2018.

[29] E. Yadegaridehkordi, M. Hourmand, M. Nilashi, and others, "Assessment of sustainability indicators for green building manufacturing using fuzzy multi-criteria decision making approach," Journal of Cleaner Production, vol. 261, pp. 121-135, July 2020. DOI: 10.1016/j.jclepro.2020.122905.

[30] M. Stender and A. Walter, "The role of social sustainability in building assessment," Building Research & Information, vol. 47, no. 5, pp. 610-625, 2019.

[31] D. Heinzerling, S. Schiavon, T. Webster, E. Arens, "Indoor environmental quality assessment models: A literature review and a proposed weighting and classification scheme," Building and Environment, vol. 70, pp. 210-222, December 2013.

[32] J. Lai, F. Yik, "Perceived Importance of the Quality of the Indoor Environment in Commercial Buildings," Indoor and Built Environment, vol. 16, no. 5, pp. 430-441, August 2007.

[33] M. Piasecki, K. Kostyrko, Sławomir Pykacz, "Indoor environmental quality assessment: Part 1: Choice of the indoor environmental quality sub-component models," Indoor and Built Environment, vol. 26, no. 6, pp. 801-813, July 2017.

[34] Michalina, D., Mederly, P., Diefenbaher, H., & Held, B. (2021). Sustainable Urban Development: a review of Urban Susutainability Indicator Frameworks. Sustainability 2021, 13, 9348.

[35] Sharifi, A., Dawodu, A., & Cheshmehzangi, A. (2021). Neighborhood sustainability assessment tools: A review of success factors. Journal of Cleaner Production, 293, 125912.

[36] Dang, X., Zhang, Y., Feng, W., Zhou, N., Wang, Y., Meng, C., Ginsberg, M., 2020. Comparative study of city-level sustainability assessment standards in China and the United States. Journal of Cleaner Production 251, 119622

[37]Siew, R.Y.J., 2018. Green Township Index: Malaysia's sustainable township rating tool. Proc. Inst. Civ. Eng.Eng. Sustain. 171(4), 169-177

[38]European Parliament and Council Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, L 153, 18 June 2010, pp. 13-35.

[39] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

[40] ISO 52000-1 https://epb.center/support/documents/iso-52000-1/

[41] ISO 52003-1 https://epb.center/support/documents/iso-52003-1/

[42]ISO 52010-1 https://epb.center/support/documents/iso-52010-1/

[43] ISO 52016-1 https://epb.center/support/documents/iso-52016-1/

[44] ISO 52018-1 https://epb.center/support/documents/iso-52018-1/

[45] Department for Communities and Local Government, UK (2017), A Guide To Energy Performance Certificates For The Marketing, Sale And Let Of Dwellings; ISBN: 978-1-4098-4216-3, online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671018/A_guide_to_energy_performance_certificates_for_the_marketing__sale_and_let_of_dwellings.pdf, accessed May 2023

[46]Directive (EU) 2019/944 - (Electricity cover)

[47] Directive (EU) 2018/2001 – (Renewable energy cover)

[48] Vakulenko, I., Saher, L., Lyulyov, O., & Pimonenko, T.V. (2021). A systematic literature review of smart grids. E3S Web of Conferences.

[49] Zishuo Huang, Hang Yu, Zhenwei Peng, Mei Zhao, Methods and tools for community energy planning: A review, Renewable and Sustainable Energy Reviews, Volume 42, 2015, Pages 1335-1348, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2014.11.042.

[50] Goldstein , D.B., Eley, C. A classification of building energy performance indices. Energy Efficiency 7, 353–375 (2014). https://doi.org/10.1007/s12053-013-9248-0

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https://www.linkedin.com/company/smartlivingepc/

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https://www.youtube.com/channel/UC0SKa-20tiSabuwjtYDqRrQ

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