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D2.7 Asset rating calculation methodology of SmartLivingEPC v3

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Asset rating calculation methodology of SmartLivingEPC v3

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	T2.2 Energy and non-energy resources analysis and integration to SmartLivingEPC
	T2.3 Environmental life-cycle assessment and integration to SmartLivingEPC
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	T2.5 Building complex assessment asset methodology
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Version History

v	Author	Date	Brief Description
1	**Tiberiu Catalina**	**27.02.2025**	**First draft version of the document**
2	**Tiberiu Catalina**	**05.03.2025**	**Second version revised**
4	**Catalin Lungu**	**08.03.2025**	**Final version for submission**

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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
KPI	Key Performance Indicators

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/

1 Executive Summary

1.1 Overview of SmartLivingEPC objectives

The SmartLivingEPC project wants to change the way Energy Performance Certificates (EPCs) are made by using cutting edge digital tools, Building Information Modeling (BIM), and a method for evaluating buildings that uses more than just standard energy markers. The project is in line with the European Green Deal and the Energy Performance of Buildings Directive (EPBD). This will make sure that EPCs change into flexible, data-driven tools that help with digitalization, smart building adaptation, and sustainability.

1.1.1 Certificate for smart and holistic energy performance

Traditional EPCs only look at how much energy a building uses. The SmartLivingEPC framework adds a more thorough rating method that includes:

Smart Readiness Indicator (SRI) figuring out how well a building can change and use energy efficiently. Non-Energy Indicators, such as comfort levels for temperature, visual perception, and sound, as well as indoor air quality and ease of entry. **Environmental Life Cycle Analysis (LCA)** is a way to figure out how sustainable a building is. **SmartLivingEPC gives a more accurate and complete picture of a building's achievements by including these components.**

1.1.2 Digitalization and merging with BIM

To make EPCs more accurate and useful, SmartLivingEPC uses modern tools like:

Building Information Modeling (BIM) to get info automatically. Digital Twins to model how energy works in real time. Using IoT and smart tools to keep an eye on how the building is really doing. Digital building logbooks make performance data clear and up to date all the time. This method closes the gap between how a building actually works and its theoretical energy grade. This makes EPCs more useful for building owners, investors, and lawmakers.

1.1.3 Bringing EPCs to the level of neighborhoods and building complexes

SmartLivingEPC goes beyond rating individual buildings by adding a method for rating apartment complexes and neighborhoods that considers:

Shared energy supplies and district heating and cooling are two ways that buildings may connect to each other. Local power lines and storage systems (energy communities, smart grids) can store energy. Microclimate and energy economy in cities. This EPC method for neighborhoods helps with better city planning, making better policy choices, and making the best energy-saving plans at the district level.

1.1.4 Standardization and lining up policies

The project makes sure that it fits with both European and state rules, and its goals are:

- The new EPBD and Level(s) sustainability structure can work together.
  Follow the rules set by ISO (ISO 52000-1, ISO 7730, ISO 16798-1, etc.).

- As it was indicated in the Commission Implementing Regulation (EU) 2020/2156, Member States that decide to implement the Smart Readiness Indicator (SRI) scheme may couple the issuing of its certificate with their energy performance certification scheme or with the inspection of heating, air-conditioning and combined heating or air-conditioning and ventilation systems under Directive 2010/31/ EU, or with their scheme for energy audits under Directive 2012/27/EU.

SmartLivingEPC makes sure that the next generation of EPCs is widely accepted and usable in all EU member states by pushing for agreement with EU-wide standards.

Help with the energy transition and lowering carbon emissions SmartLivingEPC's main goal is to help Europe reach its carbon balance goals by:

- Promoting repairs and upgrades that use less energy.
- Giving partners better tools for making decisions.
- Making it easier for smart building systems to be used.

SmartLivingEPC is a key part of reducing carbon emissions in buildings and speeding up the energy shift in the EU. It does this by making EPCs more reliable, useful, and effective.

1.2 Key updates from previous versions

The **third version (V3) of the SmartLivingEPC Asset Rating Calculation Methodology** builds upon the foundation established in **Version 1 (V1)** and **Version 2 (V2)** by incorporating refinements, expanded methodologies, and improved integration with European energy policies and digital tools. Below is a summary of the key updates introduced in **V2** compared to **V1**, along with further refinements introduced in **V3**.

Refinement of the Asset Rating Calculation Methodology

- **V1:** Introduced the **general framework** for SmartLivingEPC, covering energy performance, non-energy indicators, and environmental assessments.
- **V2:** Provided a **more structured approach to rating calculations**, including:
- **Detailed assessment methodologies** for Smart Readiness Indicator (SRI), energy efficiency, and environmental factors.
- **New weighting and aggregation schemes** for rating **buildings** and **building complexes**.
- **Expanded integration of Level(s) sustainability indicators**, ensuring alignment with **Life Cycle Assessment (LCA) frameworks**.
- **V3 refines and streamlines content** to avoid redundancy while **preserving essential details**.
- Clearer **rating methodology documentation**, making it easier for stakeholders to implement.
- **Optimized calculations** based on findings from pilot testing in version V3

1.3 Integration of energy, non-energy, environmental, and smart indicators

The **SmartLivingEPC framework** introduces a **comprehensive and multi-dimensional approach** to building performance assessment by integrating four key categories of indicators: **energy, non-energy, environmental, and smart readiness**. This holistic methodology ensures a **balanced and accurate representation** of a building’s efficiency, sustainability, and adaptability to smart technologies.

1.3.1 Energy Indicators

Energy indicators remain **a core component** of the SmartLivingEPC rating system, ensuring **compliance with EU energy performance policies** and driving **decarbonization efforts** in the building sector.

- **Primary Energy Consumption:** Measurement of non-renewable and renewable energy use in heating, cooling, domestic hot water (DHW), ventilation, and lighting.
- **Renewable Energy Ratio (RER):** Percentage of a building's energy demand met by renewable energy sources.
- **Final vs. Primary Energy Consumption:** Evaluation of the efficiency of energy conversion and distribution.
- **Energy Export Capability:** Quantification of energy fed back into the grid from on-site renewable generation (e.g., PV systems).
- **Building Energy Performance Class (A-G):** Overall classification of a building's energy efficiency, in alignment with ISO 52000-1 and EPBD regulations.

1.3.2 Non-Energy Indicators

Beyond energy consumption, SmartLivingEPC evaluates **indoor comfort, accessibility, and safety parameters**, recognizing their importance in **building quality** and **occupant well-being**.

- **Thermal Comfort:** Assessed using Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD) based on ISO 7730.
- **Indoor Air Quality (IAQ):**
    - CO_2 concentration as a measure of ventilation efficiency.
    - Radon risk assessment, addressing health concerns.
- **Visual Comfort:** Evaluating illuminance levels, color rendering index (CRI), and artificial light temperature based on EN 16798-1.
- **Acoustic Comfort:** Assessment of reverberation time (RT60), background noise levels, and sound insulation based on ISO 717-1.
- **Accessibility Index:** Evaluation of barrier-free design to ensure compliance with inclusive design standards.
- **Earthquake Risk Assessment**
- **Water consumption Index**

1.3.3 Environmental Indicators

Incorporating **Life Cycle Assessment (LCA) methodologies**, SmartLivingEPC quantifies the **environmental impact** of buildings beyond operational energy use.

- Carbon Footprint (Global Warming Potential - GWP): Measurement of CO_2 emissions per square meter over the building's lifecycle.
- Ozone Depletion and Acidification Potential: Evaluating the environmental impact of building materials and energy sources.
- Eutrophication and Water Efficiency: Assessment of water consumption and pollution impact.
- Material Circularity and Waste Management:
- Recyclability of building materials.
- Design for deconstruction and reusability.

By integrating these environmental factors, SmartLivingEPC aligns with EU Green Deal objectives, Level(s) framework, and EPBD sustainability goals, fostering the transition to low-carbon and resource-efficient buildings.

1.3.4 Smart readiness

Incorporating **Smart Readiness Assessment**, SmartLivingEPC quantifies the **smart readiness** of buildings and building units, both overall as well as on various key functionalities, impact criterion and technical domains. 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 Energy performance and operation Response to user needs Energy flexibility	SR_f	%
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	%

2 Introduction

2.1 General description

The building sector plays a pivotal role in advancing the European Union's (EU) climate neutrality objectives. Recognizing that both operational and embodied carbon emissions must be addressed to meet these goals, the EU's Energy Performance of Buildings Directive (EPBD) has evolved to encompass a more holistic view of building sustainability. The recently adopted Directive (EU) 2024/1275 (the recast EPBD) marks a significant step in this direction by mandating, for the first time, the calculation and disclosure of buildings' life-cycle Global Warming Potential (GWP). Under this legislative framework, Member States will be required to incorporate a standardized methodology—aligned with EN 15978 and the EU's Level(s) initiative—into national building codes and Energy Performance Certificates (EPCs). However, while Directive 2024/1275 signals a clear intent to integrate Life Cycle Assessment (LCA) into mainstream practice, critical challenges remain. Chief among them is the absence of established reference values or benchmarks to contextualize GWP data. Without such benchmarks, developers, designers, and policymakers may find it difficult to gauge whether a building's embodied carbon performance is "good" or "poor," thereby hindering the establishment of meaningful reduction targets. The Directive attempts to address this shortfall through transitional measures: requiring transparent reporting of GWP data to build robust evidence base and obliging Member States to set out national roadmaps by 2027 for introducing eventual limit values. Until then, voluntary reference scales and ongoing research efforts seek to provide interim guidance. In doing so, Directive 2024/1275 underscores the broader shift toward fully incorporating life-cycle carbon analyses in building regulations—an essential move if Europe is to meet its climate commitments in a sector responsible for a substantial share of total greenhouse gas emissions.

Created under WP2, Deliverable D2.7 centers on establishing performance assessment techniques. D2.7 is crucial in this work package as, in the framework of SmartLivingEPC, it defines the mechanism of asset rating computation. This deliverable main objective is to provide a thorough and globally approved technique for awarding asset ratings together with the suggested weighting methodology. The proposed approach comprised a range of performance criteria including energy efficiency, environmental sustainability, smart preparedness, non-energy factors including interior environmental quality and accessability.

2.2 Scope and objectives of the deliverable

The SmartLivingEPC project uses a methodical, scientific methodology to assess built environment energy performance. Emphasizing its relevance inside the larger project framework, the present deliverable reflects the range and objectives of WP2.

Comprising a continuation of D2.3 and D2.6, **D2.7 provides a comprehensive overview of the asset rating calculation technique of the SmartLiving EPC framework.** It guarantees the inclusion of Building Information Modeling (BIM) for accurate and thorough evaluations by outlining the essential stages and assumptions required in computing energy performance ratings.

The ability of the technique to accommodate several building forms—including residential and tertiary structures—ensures wide applicability.

The major outcomes are a computation process for grading assets at single building or building complex level including energy efficiency, non-energy aspects, smart readiness, and environmental sustainability.

The SLEPC rating system was tested using SLEPC pilot building – Frederick University Limasol; the results will be noted to confirm the effectiveness of the method as well as offer details on its constraints and practical applications. By being compatible with present technology, including digital building logbooks and BIM tools, the approach guarantees integration and compliance with European standards.

SmartLivingEPC aimed also to create a new energy classification system at the neighborhood level by considering the energy infrastructure and linkages at the district level as well as the building units.

3 Methodology overview

3.1 General framework of the SmartLivingEPC rating system

In order to develop more sustainable and energy-efficient building that are in line with the EU requirements it is important to analyze the building from multiple angles. The proposed procedure takes into account multiple kpi-s from building smartness to earthquake seismic risk.

The basic principles of the SmartLivingEPC project's indicator system revolve around thorough and integrated evaluations that take into account environmental sustainability, energy efficiency, and smart readiness. The approach places a strong emphasis on the necessity of precise data gathering and analysis, enhancing accuracy with the use of Building Information Modeling (BIM) and other digital tools. It also places a high priority on flexibility and adaptability, which enables the evaluation method to take into account different building types as well as upcoming developments in building technology. The project seeks to develop a rigorous and globally applicable system for assessing and improving building performance, eventually supporting more sustainable and efficient built environments. It does this by combining several performance measurements and adhering to established European standards.

3.2 Data collected from technical audits

3.2.1 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.

3.2.1.1 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

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.

3.2.1.2 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.

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.

3.2.1.3 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).

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.

3.2.1.4 Integration of audit data into the SmartLivingEPC 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 2: Mapping of SmartLivingEPC KPIs to findings from HVAC audits

ENERGY PARAMETERS						Asset (retro active)	Operational (periodically)
1	1 - energy rating 2 - Level(s) 3 - Other (non-energy/on-site audit) - 4 - SRI	1	2	3	4	Calculated	Measured
2	Heating consumption [kWh]			X		YES	YES
3	Specific heating consumption [kWh/m²]			X		YES	NO
4	DHW consumption [kWh]			X		YES	YES
5	Specific DHW consumption [kWh/m²]			X		YES	NO
6	Ventilation consumption [kWh]			X		YES	YES
7	Specific ventilation consumption [kWh/m²]			X		YES	NO
8	Cooling consumption [kWh]			X		YES	YES
9	Specific cooling consumption [kWh/m²]			X		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.

3.2.1.5 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.

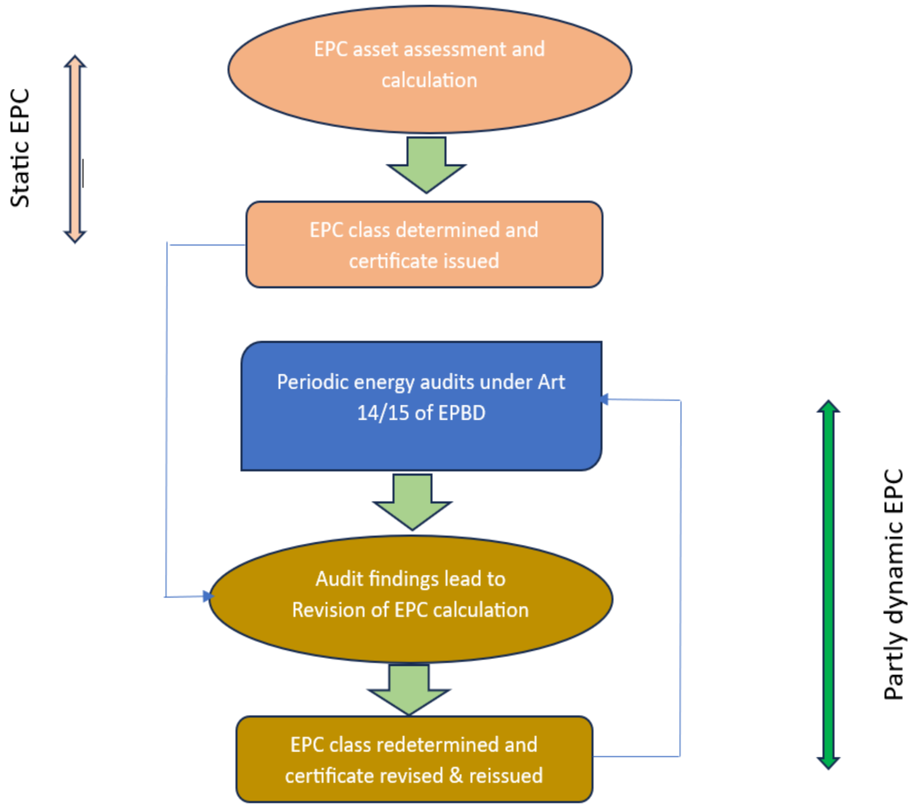


Figure 1: Energy calculation: General structure of heating and DHW standards - EN 15316 – series

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.

4 Asset Rating Calculation for Buildings

4.1 Energy indicators

The SmartLivingEPC project assesses the main energy consumption of both renewable and non-renewable energy sources for a number of building systems, including heating, cooling, ventilation, lighting, and building automation and, eventually, control (BAC) systems. Every system has its energy consumption assessed for both thermal and electric vectors. These indicators promote the shift, wherever possible, to renewable energy by ensuring a thorough assessment of energy sources and their efficiency of use. The SmartLivingEPC calculation approach provides a comprehensive view of a building's energy profile in addition to determining primary energy consumption for both thermal and electric vectors, both renewable and non-renewable. Determining a building's primary energy usage and associated indications is a key component of the SmartLivingEPC (SLE) asset evaluation. The approach consists of two steps: first, determining the building's energy requirements, including those for heating, cooling, ventilation, dehumidification/humidification, and domestic hot water (DHW) [1]. The well-being, contentment, and productivity of a building's inhabitants can be significantly impacted by its architectural design [2].

The SmartLivingEPC project evaluates the building's overall energy performance class as well as the energy performance class of each system, including lighting, ventilation, heating, cooling, and DHW, in addition to energy consumption data. This classification encourages a comprehensive approach to energy efficiency and assists in identifying areas that require upgrading and restoration. The Renewable Energy Ratio (RER), which determines the proportion of energy from renewable sources, and the quantity of exported primary energy, for both electric and thermal vectors, are indicators that show the building's ability to return excess energy to the grid. The necessity of moving to sustainable energy sources and improving the energy efficiency of all building systems is emphasized by these guiding principles.

The energy indicators are summarized in the following table:

Table 3: Energy indicators

No	ENERGY PERFORMANCE INDICATORS at Building Level	MU	ASSET calculation methodology according to:
1	Non-Renewable Primary Energy Consumption, Thermal vector	kWh/m2,y	EN ISO 52000-1
2	Non-Renewable Primary Energy Consumption, Electric vector	kWh/m2,y	EN ISO 52000-1
3	Renewable Primary Energy Consumption, Thermal vector	kWh/m2,y	EN ISO 52000-1
4	Renewable Primary Energy Consumption, Electric vector	kWh/m2,y	EN ISO 52000-1
5	Total primary energy consumption	kWh/m2,y	EN 52000-1
6	Building’s Energy Overall Performance Class	A…G	SLE class, EN ISO 52003-1
7	Renewable Energy Ration (RER)	%	EN ISO 52000-1
8-9	Exported Primary Energy, Electric vector & Thermal vector	kWh/m2,y	EN ISO 52000-1

The calculation methodology for all 9 indicators was detailed in D2.4. The total primary energy includes both renewable and non-renewable primary energy, as stated in the new EPBD.

According to EPBD standards, delivered energy—that is, energy supplied via the assessment boundary—should be used to compute total primary energy. It is suggested that EPC-values be determined using the total primary energy from provided energy to the construction site (the same is true for CO_2 emissions) in order to standardize the primary energy calculation and to make the assessment boundary definition clearer. This method makes sure that ambient energy and renewable electricity produced and utilized on-site—which are not considered delivered energy—do not raise the EP-value. The SLE calculation uses different parameters but is based on the same energy flows for total primary energy and non-renewable energy. This approach supports the EPBD goal of a high proportion of energy derived from renewable sources and extremely low energy use. Figure 2 depicts the suggested assessment border for the SLE calculation process, which adheres to the EN ISO 52000-1 building assessment boundary. A building site boundary is added to this example in order to calculate primary energy. Since minimizing total primary energy from the energy networks is the aim, ambient energy and on-site generated renewable energy are not included in the total primary energy indication.

With building site boundary on Figure 2, total primary energy indicator is calculated from delivered energy to building site, i.e. from delivered energy with nearby and distant origin.

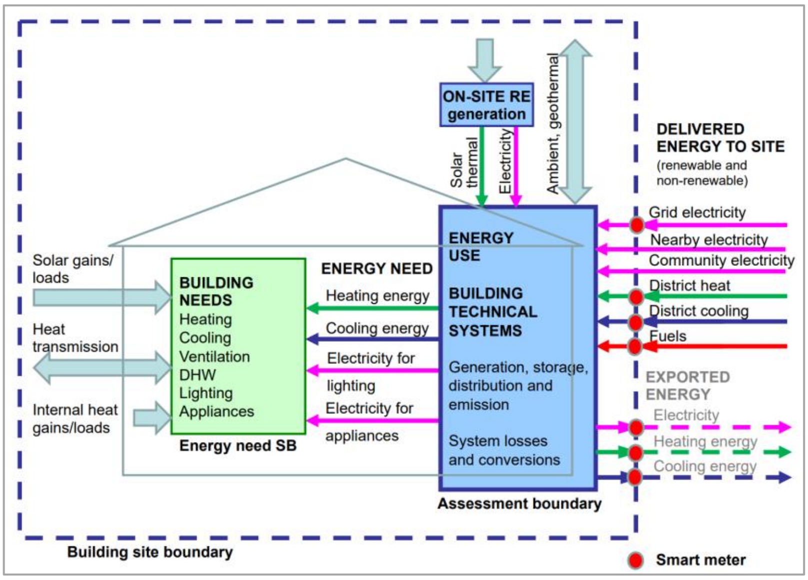


Figure 2: Building site boundary for primary energy calculation that complements building assessment boundary of EN ISO 52000-1 [1]

The SmartLivingEPC (SLEPC) assessment system provides a scoring technique to translate the computed primary energy consumption into a readily accessible and comparative energy performance classification. The energy score is quantified as a percentage and afterward allocated to a performance class ranging from A to G, in line with the following mapping. We propose a rating score based on the same grading scale methodology adopted at EU level for SRI. Thus, we have changed the primary energy class to a score similar to that of SRI.

The SmartLivingEPC methodology has transitioned from the traditional A-G primary energy classification to a numerical scoring system, like the Smart Readiness Indicator (SRI). This shift allows for a more refined and continuous assessment of a building's energy performance, addressing limitations of the discrete letter-based scale. The new approach ensures better differentiation of efficiency levels. By adopting a 0-100 score, the primary energy score now reflects total energy consumption, renewable energy production, and flexibility measures. The new rating system benefits stakeholders by providing greater transparency and flexibility in assessing building improvements. Unlike the rigid A-G scale, where small energy upgrades may not change the class, the score-based approach enables incremental tracking of energy improvements. This is particularly beneficial for renovation planning, as building owners and investors can assess the impact of retrofits in real time and prioritize cost-effective energy efficiency measures. Overall, the shift to a numerical scoring system marks a major advancement in energy performance certification, aligning EPCs with modern energy policies and digital transformation trends.
The approach simplifies the difficult calculations and diverse parameters connected with measuring the energy efficiency of a building into a comprehensible score and categorization. The application of scores and classifications provides valuable information that can help educated decision-making processes connected to energy efficiency increases, financial investments, and the formulation of regulations. Moreover, the score is needed later on for the assessment between energy, non-energy, environmental and SRI values.

The methodology to set the energy performance building class [A to G] follows the indications in EN ISO 52003-1, i.e. stepped scale option with geometric series to express the upper limits of the energy classes,

[1] REHVA Technical Guidance for EPBD Implementation, https://www.rehva.eu/fileadmin/user_upload/2024/EPBD_Guidance_2024.pdf

$$Y = \sqrt{2}^{(n - n_{ref})}$$ [equation 1]

where:

- Y is the index computed for the case of 7 classes (see Table 4)
- n is the position of energy class on the scale and
- n_{ref} is the position of the energy class for reference point on the scale.

It has been proposed to place the reference point on the limit of classes 4 and 5 (n_{ref} = 4)

Table 4: Primary energy class to score

Primary energy class	Multiplication index [according to EN ISO 52003-1]	Score
	0,00	100
A		…
	0,35	82,5
B		…
	0,50	75,0
C		…
	0,71	64,5
D		…
	1,00 **(reference building)**	50,0
E		…
	1,411	29,45
F		…
	2,00	0
G		

The equation to compute the energy score for a building is

$$y = -1{,}5833x^2 - 2{,}7298x + 99{,}936$$ [Equation 2]

Where:

- y is the building energy score (between 100 and 0) and
- x is the relative primary energy index (between 0 and 2), the same Y in the [equation 1]

The SmartLivingEPC project evaluates asset building energy usage using provided and primary energy. Delivered energy is the energy lighting, heating, ventilation, DHW, and cooling systems directly utilize. The building needs this energy to function. Primary energy includes the whole energy cycle, from extracting primary energy resources to transforming them into building-useable forms. This broad perspective shows a facility's energy use's environmental impact, including production, transmission, and distribution losses.

The SmartLivingEPC project evaluates building performance utilizing several energy sub-indicators in D2.4 (energy demands, supplied energy, etc.). SLE energy indicators **distinguish electric, thermal, and renewable/non-renewable vectors.** Primary energy consumption was assessed for renewable and non-renewable sources.
These indicators give a complete picture of a building's energy efficiency. Along with rigorous system

assessments, they contribute to a comprehensive performance classification that considers sustainability and energy efficiency. The SmartLivingEPC grading system effectively assesses building performance according to EN ISO 52000 series criteria, helping stakeholders make informed decisions. National conversion variables are crucial to SmartLivingEPC basic energy estimation.

The energy mix, conversion efficiency, and efficacy of each nation's distribution networks are needed to convert given energy into primary energy units. To ensure accurate primary energy estimations, the SmartLivingEPC rating system will handle these country-specific conversion factors. SmartLivingEPC provides sophisticated and adaptable building performance assessments in numerous EU member states by complying with national grading systems and regulations. The major energy rating graphic shows a technique for computing energy ratings, however not all EU nations have energy ratings for heating, cooling, DHW, lighting, and ventilation.

4.2 Non-Energy indicators

The SmartLivingEPC (SLEPC) rating system recognizes **non-energy indicators** as essential alongside energy performance in building assessments. These indicators provide a holistic view of a building's overall performance, ensuring occupant well-being, health, and environmental sustainability.

Beyond energy-related measures like carbon emissions and energy efficiency, a wide range of metrics may be used to describe buildings [3]. The SmartLivingEPC takes into account non-energy factors like as accessibility, seismic class, and indoor environmental quality (IEQ), which includes radon risk assessment [4].

The term "indoor environmental quality" (IEQ) describes the general state of a building's lighting, temperature, ambient noise levels, and air quality. Since low IEQ can result in a variety of health problems, including headaches, exhaustion, and exacerbations of asthma, it is regarded as a crucial component of the evaluation [5–6]. The presence of radon was given special consideration among the indoor air quality indicators since it presents a substantial non-energy-related danger that may have a serious negative impact on occupiers' health [7]. Radon gas buildup poses serious health hazards, including an increased risk of lung cancer, which the World Health Organization (WHO) has identified as the second most common cause of the illness after smoking [8]. The building site's geology and geographic location, as well as the structure's construction and ventilation systems, can all have an impact on the risk of radon exposure [9]. The risk of radon exposure can be successfully reduced by building owners conducting radon testing and, if required, implementing radon mitigation measures [10].

The assessment of seismic risk class is another crucial non-energy metric, particularly for high-risk nations. For building owners looking to increase the earthquake resilience of their structures, seismic retrofitting is a feasible choice [11]. The impact of a number of retrofitting methods on lowering a building's susceptibility to earthquakes has been examined [12]. The seismic risk class, which ranges from SR1 to SR4, may therefore represent a substantial non-energy variable [13]. Better techniques for estimating seismic risk and evaluating losses in reinforced concrete structures have been developed [14].

Key factors include Indoor Environmental Quality (IEQ), which assesses air purity, thermal comfort, and acoustics, water resource efficiency, radon risk assessment, structural integrity in seismic zones, and the Accessibility Index for individuals with disabilities. By incorporating these elements, SLEPC enhances building evaluations beyond energy efficiency, promoting healthier and more sustainable spaces.

The main non-energy indicators proposed are:

- **Visual Comfort:** Ensures optimal lighting conditions through artificial illuminance levels, color rendering (CRI), and lighting temperature to enhance visual well-being.
- **Acoustic Comfort:** Evaluates sound pressure levels, frequency balance, global noise levels, and reverberation time (RT60) to maintain a comfortable and productive environment.
- **Thermal Comfort:** Assesses operative temperature, Predicted Mean Vote (PMV), and Percentage of People Dissatisfied (PPD) to ensure indoor thermal balance and occupant satisfaction.
- **Indoor Air Quality:** Monitors CO_2 levels for ventilation efficiency and radon risk rating for health safety.
- **Accessibility Index:** Measures building accessibility for individuals with disabilities, considering ramps, elevators, and signage.
- **Water Consumption Efficiency:** Evaluates water usage, fixtures, and recycling systems for sustainability.

- **Earthquake Hazard Risk:** Assesses structural resilience in seismic zones to minimize risks.

Below is the list of non-energy indicators:

Table 5: 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	°C	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)

The SmartLivingEPC (SLEPC) assessment method highlights that non-energy characteristics are equally significant as energy efficiency in building evaluations. These indicators provide a holistic view of a building's performance by emphasizing occupant well-being, health, and environmental sustainability. SLEPC ratings include non-energy attributes to provide a complete assessment that recognizes non-energy factors. The deliverable D2.4 details the asset calculation and categorization and grading methods of all non-energy indicators.

Indoor Environmental Quality (IEQ) evaluates air quality, thermal comfort, and acoustics to ensure occupant health and productivity. Water efficiency assesses appliance, fixture, and water recycling system performance. The structural integrity evaluation evaluates seismically vulnerable structures, whereas the radon risk assessment evaluates radon exposure.

Thermal comfort

Thermal comfort is an important part of SmartLivingEPC (SLEPC), which promotes Indoor Environmental Quality. Building occupant productivity, well-being, and energy efficiency benefit from ideal thermal conditions. Predicted Mean Vote (PMV) and Percentage Of Persons Dissatisfied (PPD) are critical thermal comfort indicators in SLEPC. PMV evaluation considers air temperature, mean radiant temperature, air velocity, humidity, garment insulation, and metabolic rate. PMV levels around zero indicate ideal comfort on the range from -3 to +3. Separate winter and summer estimates account for seasonal changes.

Table 6: Example of thermal comfort rating for multiple thermal zones

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

Indoor air quality

The SmartLivingEPC (SLEPC) grading system emphasizes Indoor Air Quality (IAQ) in assessing Indoor Environmental Quality (IEQ). To analyze IAQ, the system focuses on radon risk and CO2 concentrations. High CO2 levels suggest poor ventilation, which might affect occupant comfort and cognition. CO2 monitoring ensures tenant health and ventilation system efficiency. Buildings can retain naturally occurring radioactive gas radon, especially in basements, which can cause lung cancer. Radon risk assessment ensures building occupants' safety. To estimate ventilation efficiency and air quality, ppm CO2 levels may be computed in multiple building locations and compared to norms. Specialist detectors quantify radon danger as low, medium, high, and extreme. Risk is calculated using the EU Radon map and the building's GPS location. This systematic method ensures a complete and accurate IAQ evaluation in the SLEPC system by addressing ventilation and radon exposure, enabling healthier and safer indoor settings.

Table 7: Example of air quality rating for multiple thermal zones

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

Visual comfort

Luminance (lux) is measured on a surface. Proper lighting improves comfort, work performance, and eye strain. A space's Daylight Factor measures natural light as a proportion of outside lighting. Natural light increases mood and productivity, making it crucial to building performance assessment. Art studios, retail, and medical institutions require accurate color rendering from artificial light sources. The color temperature, measured in Kelvin (K), affects mood and focus and varies by building area. Visual comfort factors weighted by zone surface area provide proportionality in the final SLEPC rating.

Table 8: Example of visual comfort rating for multiple thermal zones

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

Acoustic comfort

Acoustic comfort is a key component of Indoor Environmental Quality (IEQ) according to the SmartLivingEPC (SLEPC) evaluation method, which measures global sound pressure level and reverberation duration. Environments with high decibel (dB(A)) global sound pressure levels can be unpleasant, stressful, and less productive. Reverberation duration, measured in seconds, can decrease speech comprehension and music quality. Acoustic comfort is thoroughly assessed with these metrics, boosting occupant satisfaction and well-being in living and working spaces.

Table 9: Example of noise comfort rating for multiple thermal zones

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

Accessibility

How accessible and adaptive a building is for individuals with disabilities requires the SmartLivingEPC (SLEPC) grading system accessibility evaluation. From 'Poor' to 'Excellent,' this grade considers door and corridor sizes, ramps, elevators, and signs. All inhabitants benefit from high accessibility standards, which promote diversity.

Seismic risk

Classifying buildings into four seismic risk levels (SR1 to SR4), the SLEPC methodology also assesses earthquake risk. Whereas SR2 implies a high risk of structural deterioration without stability loss, SR1 shows a considerable vulnerability to structural collapse. Buildings predicted to operate well under current regulations are indicated by SR4, whereas those vulnerable to non-structural damage are indicated by SR3. The possible hazards connected to seismic activity are identified and reduced in part by this classification.

Water consumption efficiency

Assessed by a number of criteria, including the efficiency of water fixtures (faucets, showerheads, toilets), appliances (dishwashers, washing machines), and water reuse and recycling systems (greywater recycling, rainwater harvesting), water efficiency is another essential element of the SLEPC rating. Furthermore, taken into account are the effectiveness of landscape irrigation systems and the installation of leak monitoring and repair systems.

Through the incorporation of these factors and the assignment of suitable weights, the SLEPC grading system offers a thorough and useful assessment of the accessibility, earthquake risk, and water efficiency of a building.

ACCESIBILITY	
Information	Score
Fair: The building has some accessibility features, but improvements are needed to ensure compliance with accessibility standards and regulations	65.00

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.	100.00

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

Figure 3: Example of rating for accessibility, earthquake seismic class and water efficiency

Each non-energy indication in the SLEPC rating system has an equal default weighting value. Users are free to change these weightings, though, in accordance with their requirements or priorities. Through the incorporation of these factors and the assignment of suitable weights, the SLEPC grading system offers a thorough and useful assessment of the accessibility, earthquake risk, and water efficiency of a building.

This all-inclusive method adds to the evaluation of the Indoor Environmental Quality (IEQ) overall and provides insightful information for focused enhancements to raise the standard of buildings.

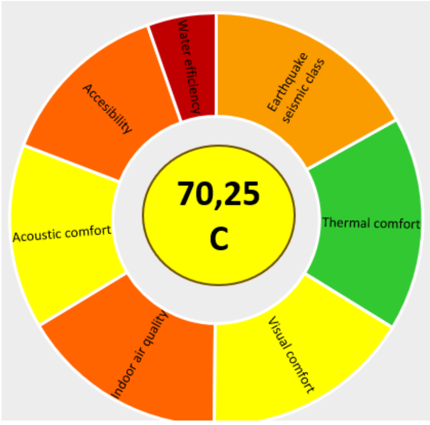


Figure 4: Example of SMARTLIVING EPC Non-energy rating

4.3 Smart readiness indicator

As indicated by the Commission Delegated Regulation 2020/2155 [54], the smart readiness of a building or building unit is determined based on the assessment of **smart-ready services** present or planned in, or relevant for, the building or building unit, and their **functionality levels**. The smart readiness of a building or building unit is expressed by a rating that derives from a total smart readiness score expressed as a percentage and that represents the ratio between the smart readiness of the building or building unit compared to the maximum smart readiness that it could reach. Therefore, it assesses the effective capabilities of the building or building unit to adapt its operation to the needs of the occupants and the grid, and to improve its energy efficiency and overall, in-use performance compared to a given potential.

The SRI methodology is structured in **three key smart readiness functionalities** (f), as highlighted in point 2 of Annex Ia, to Directive 2010/31/EU [56], within which there are certain **impact criteria** (ic).

3. Energy performance and operation.
   - Energy efficiency
   - Maintenance and fault prediction
4. Response to user needs.
   - Comfort
   - Convenience
   - Health, well-being, and accessibility
   - Information to occupants
5. Energy flexibility.
   - Energy flexibility and storage

The SRI assesses **nine technical domains** (d), also defined by [55] are listed below:

1. Heating
2. Domestic hot water
3. Cooling
4. Ventilation
5. Lighting
6. Dynamic building envelope
7. Electricity
8. Electric vehicle charging
9. Monitoring and control

For each technical domain (d), **smart-ready services** $(S_{i,d})$ shall be defined by Member States, as part of a smart-ready catalogues, including their related **functionality levels** $(FL(S_{i,d}))$, and corresponding individual scores for each impact criterion $(I_{ic}\left(FL(S_{i,d})\right))$. The smart-ready catalogues shall reflect the state of art of **smart-ready**

technologies, which may be different among building types. Hence, several smart-ready catalogues may exist. The smart-ready service catalogue shall define the maximum score of each technical domain for each impact criterion ($I_{max}(d, ic)$).

Member States shall define the respective **weighting factors** ($W_{d,ic}$) characterising the influence of each technical domain (d) on each impact criterion (ic). Such factors ought to be expressed as a percentage, the sum of which ought to be 100% for each impact criterion. Weighting factors may be different between building types. As a result, it is possible to obtain the **smart readiness score for each impact criterion** (SR_{ic}).

Member States shall define the respective **weighting factors** ($W_{f,ic}$) of relevant impact criteria (ic) within each key functionality (f), which enables to obtain **smart readiness scores** (SR_f) along the three key functionalities. Next, the **weighting factor** (W_f) indicate the influence of each key functionality (f) in the **total smart readiness score** (SR). Ultimately, the ratio between the smart readiness of the building or building unit compared to the maximum smart readiness that it could reach results in the **smart readiness rating**. The ratio yields a rating based on the **seven-class scale**: 90-100%; 80-90%; 65-80%; 50-65%; 35-50%; 20-35%; <20%, ranging from highest to lowest smart readiness.

Once the main *functionality level* has been defined to each applicable *technical domain's smart-ready service*.

Each *smart-ready service* ($S_{i,d}$) has a certain *functionality level* ($FL(S_{i,d})$), which is equivalent to a score for each *impact criterion* (ic). The scores $I_{ic}(FL(S_{i,d}))$ of each *technical domain* (d) and *impact criterion* are defined by Equation 1, as the sum of the scores of the *smart-ready services* within a given *technical domain*.

$$I(d, ic) = \sum_{i=1}^{Nd} I_{ic}\left(FL(S_{i,d})\right) \qquad \textbf{Equation 1.}$$

The calculation is reproduced considering the maximum *functionality level* per applicable *smart-ready service* contained in the *smart-ready service catalogue* ($FL_{max}(S_{i,d})$). It is indicated in Equation 2.

$$I_{max}(d, ic) = \sum_{i=1}^{Nd} I_{ic}\left(FL_{max}(S_{i,d})\right) \qquad \textbf{Equation 2.}$$

It is possible to produce the smart readiness score per *technical domain* and *impact criterion* following Equation 3.

$$SR_{d,ic} = \frac{I(d, ic)}{I_{max}(d, ic)} \cdot 100 \qquad \textbf{Equation 3.}$$

Next, the scores per *technical domain* are summed considering their respective contribution to each *impact criterion*. The result is divided by the maximum possible score, resulting in the smart readiness score per *impact criterion* (SR_{ic}) as per Equation 4.

$$SR_{ic} = \frac{\sum_{d=1}^{N} W_{d,ic} \cdot I(d, ic)}{\sum_{d=1}^{N} W_{d,ic} \cdot I_{max}(d, ic)} \cdot 100 \qquad \textbf{Equation 4.}$$

Also, the smart readiness per technical domain, following Equation 4.

$$SR_{d} = \frac{\sum_{ic=1}^{M} W_{d,ic} \cdot I(d, ic)}{\sum_{ic=1}^{M} W_{d,ic} \cdot I_{max}(d, ic)} \cdot 100 \qquad \textbf{Equation 5.}$$

The smart readiness score per *smart readiness functionality* (f) is obtained as the weighted addition of the scores per *impact criterion* as per Equation 6.

$$SR_f = \sum_{ic=1}^{M} W_f(ic) \cdot SR_{ic} \qquad \textbf{Equation 6.}$$

Finally, the total smart readiness score is obtained as the weighted addition of the scores per *smart readiness functionality* as in Equation 7.

$$SR = \sum W_f \cdot SR_f \qquad \textbf{Equation 7.}$$

For the calculation process, the contextual adaptations adopted by prerogative of EU Member States may have a significant impact.

The total smart readiness score corresponds to a smart readiness rating (SR_{class}), expressed based on seven smart readiness classes; namely, 90-100%; 80-90%; 65-80%; 50-65%; 35-50%; 20-35%; <20%, ranging from highest to lowest smart readiness.

The results of the SRI assessment are included in the SRI certificate, as indicated in Table 1 and depicted as an example in Figure 5.

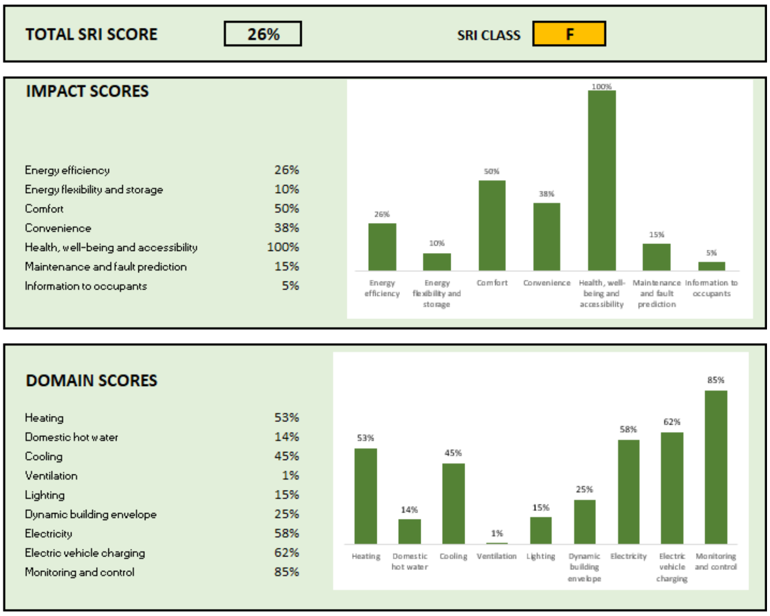


Figure 5: Example of rating of SRI

4.4 Environmental Indicators

Directive (EU) 2024/1275, adopted in April 2024, constitutes the recast of the EU's Energy Performance of Buildings Directive (EPBD). This legal framework provides essential regulatory context for LCA-focused initiatives, as it broadens and updates building performance requirements across Europe—specifically incorporating whole-life carbon emissions considerations. Notably, the recast EPBD mandates the calculation and disclosure of a building's life-cycle Global Warming Potential (GWP). Under Article 7, Member States are required to ensure that the life cycle GWP of all new buildings is assessed according to a common European framework and reported within the building's Energy Performance Certificate (EPC) [1]. To facilitate a phased implementation, Directive 2024/1275 stipulates that, from 1 January 2028, all new buildings exceeding 1000 m² must calculate and disclose their life cycle GWP. By 1 January 2030, this requirement extends to all new buildings, irrespective of size 111. Through this explicit inclusion of GWP, the Directive underscores the critical importance of Life Cycle Assessment (LCA) in the building sector. Further, Directive 2024/1275 harmonizes the approach to calculating life cycle GWP. Annex III specifies that total GWP values shall be expressed in $kgCO_2$-equivalent per square meter (over a 50-year reference study period) for each life-cycle stage, adhering to the EN 15978 standard and aligning with the scope defined by the EU's Level(s) framework (indicator 1.2) 222. This ensures that all Member States employ recognized European standards and incorporate consistent data sources (e.g., environmental product declarations). Moreover, the Directive empowers the European Commission to adopt a Delegated Act by the end of 2025 to refine the common calculation framework across the EU [1]. In summary, Directive 2024/1275 effectively integrates GWP and LCA into building performance regulations. Its requirements are relevant to advancing life-cycle-based EPC systems.

The SmartLivingEPC project evaluates building performance and environmental impact using many variables. These indicators extend climate change, ozone depletion, acidification, eutrophication (freshwater and marine), photochemical ozone generation, and more. The study also considers global warming, water use, operational energy performance, and abiotic resource depletion. Additional criteria include building material amount, waste generation and transportation during construction and destruction, and flexibility, refurbishment, removal, recycling, and reuse design principles. By measuring water use throughout building use, the project ensures sustainability and performance.

In Table 10: Environmental assessment output data are summarized the environmental indicators and their corresponding units:

Table 10: Environmental assessment output data

Indicator Name	Indicator Description	Units
Climate 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. 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.	kg P equivalents [kg P eq.]
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
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	Adaptability score

	function and for the possibility to extend its useful service life into the future.	
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

The SmartLivingEPC (SLE) environmental assessment system was developed based on the Level(s) framework to ensure alignment with EU-wide sustainability principles and standardized LCA methodologies. Level(s) was chosen for its holistic life cycle approach, comprehensive set of indicators, and adaptability to different building types and contexts. By leveraging Level(s), the SLE system ensures consistency with European policy objectives while addressing key challenges such as data comparability, regional variations, and the integration of smart readiness aspects into environmental performance assessments. Level(s), the European Commission's sustainability assessment framework for buildings, does not prescribe specific benchmark values for Life Cycle Assessment (LCA) indicators. Instead, it provides a standardized methodology for assessing environmental performance, recognizing the complexity and variability inherent in building projects. The absence of fixed benchmarks stems from several challenges, including regional differences in energy grids, climate conditions, and material supply chains, which significantly affect LCA results. Additionally, variations in building functions, design choices, and operational lifespans make a one-size-fits-all benchmarking approach impractical. Establishing benchmarks also requires extensive datasets to ensure representativeness, which remains a challenge due to limited LCA data availability across EU member states. Furthermore, evolving construction technologies and policy developments necessitate adaptable, context-specific assessments rather than static benchmarks.

Despite the improved regulatory focus on LCA and GWP, a major challenge remains, the absence of established benchmarks or reference values for interpreting these results in the building sector. Although practitioners now possess tools to calculate a building's life cycle GWP, there is often no uniform baseline against which to compare these calculations. This shortfall complicates the process of determining whether a given GWP value indicates strong or weak environmental performance and makes it more difficult to formulate clear reduction targets. Evidence from the EU's Level(s) pilot program reveals that "there is a lack of benchmarks in order to optimise a building," noting the absence of a reference building or baseline for LCA comparisons [53]. Consequently, merely disclosing a GWP figure may not drive substantial improvement if developers and owners cannot contextualize that figure. In addition, design teams may be uncertain about expected or achievable reductions in embodied carbon, given no explicit performance limits.

Directive 2024/1275 seeks to address this shortfall by charting a path toward the eventual creation of benchmarks, though it does not immediately set EU-wide limit values for GWP. It obliges Member States to develop national roadmaps by 1 January 2027, outlining how they plan to introduce limit values for buildings' life cycle GWP [51]. These roadmaps will likely propose indicative targets starting in 2030 and aim for progressively stricter limits aligned with Europe's climate neutrality objectives [51]. The European Commission is expected to support these efforts by sharing guidelines and best practices from Member States that already have embodied carbon regulations (e.g., France, the Netherlands, and several Nordic countries) [51]. Until such benchmarks are formalized, anticipated closer to 2030, the focus remains on data transparency: mandating GWP reporting on EPCs to build a robust dataset on building LCA performance. Voluntary reference scales and rating bands for GWP (e.g., low/medium/high categories) have emerged as one interim measure to guide decision-making. EU-level initiatives such as Level(s) and European Commission sponsored research are working to establish baseline values and more granular indicators [52]. For instance, the recast EPBD highlights the need for "maximum limit values…detailed for different climatic zones and building typologies," reflecting the importance of context-specific LCA benchmarks [51].

In conclusion, the lack of codified LCA benchmarks represents a challenge as Europe gradually integrates whole life carbon into standard practice. Directive 2024/1275 solidifies the principle that measuring and disclosing GWP is mandatory now, with a clear intent to follow through with performance thresholds.

Conclusion – the rating of environmental indicators will be considered **class A (score 100)**

4.5 Final rating methodology

The SmartLivingEPC (SLEPC) rating system uses a thorough process to assess a building's performance in terms of both energy and non-energy aspects across a number of metrics. Finding and rating each indicator - Smart Readiness Indicators (SRI) for smart capabilities, energy efficiency metrics for heating, cooling, DHW, ventilation and lighting systems, and non-energy indicators like Indoor Air Quality (IAQ), i.e. thermal comfort, visual comfort, acoustic comfort, plus the accessibility level, the seismic risk, and water efficiency - is the first step. Using LEVEL(S) methods, which consider life cycle analysis, water usage, and the possibility of global warming, environmental effects are evaluated. **Every part receives a score according to the particular requirements.**

The second stage is putting a weighting strategy into place to equalize the significance of different metrics. Although all non-energy indicators have identical default weighting values, users can change these weights according to their needs or preferences, guaranteeing a flexible and contextually appropriate evaluation framework.

Ultimately, the SLEPC grading system adds together the weighted scores to determine the building's total performance score. A final class rating ranging from A to G is then calculated from this score; a higher score denotes greater performance. With its thorough and useful assessment of a building's performance, this methodology eventually promotes sustainability and occupant wellbeing while addressing smart readiness, energy efficiency, and other non-energy aspects.

	Class (-)	Score (-)	Weighting *default*	Weighting *user*	Class (-)	Score (-)
ENERGY	C	87,55	40		C	67,50
LCA	A	100,00	5			
NON-ENERGY	C	70,25	30			
SRI	F	25,64	25			
				0	67,5 C	

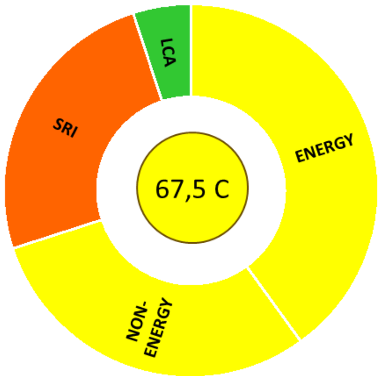


Figure 6: Example of SMARTLIVING EPC rating

4.5.1 Study case – pilot building Frederick University

For the **SmartLiving EPC** project, the energy performance, consumption, and CO_2 emissions of the Frederick University Building were carefully analysed, taking into account the overall approach and the specific conditions of each building as part of the project framework.

The energy analysis of the building involved assessing its **current energy performance**, including factors such as insulation, heating and cooling systems, and lighting efficiency. The **primary energy consumption** for the building was calculated based on their energy needs for heating, cooling, ventilation, lighting, and hot water supply. These values were derived from the existing building infrastructure and the specific systems in place.

The Frederick University building was analysed in terms of individual **energy consumption** patterns, considering:

- **Building Insulation** – The thermal performance of each building's walls, roof, and windows.
- **HVAC Systems** – The heating, ventilation, and air conditioning systems in place, including energy efficiency and the potential for renewable energy integration (e.g., solar panels, geothermal systems).
- **Lighting and Appliances** – The energy use of lighting systems and other electrical appliances installed in each building.

The building's energy consumption was then compared to the national standards and regional norms for energy efficiency in residential buildings, with a focus on identifying opportunities for improvement through smart technologies, building retrofits, and optimized energy management.

The **CO_2 emissions** for the building were calculated based on the amount of **primary energy consumption** and the associated **carbon intensity** of the energy sources used (i.e., fossil fuels, renewable sources, etc.). A key factor in the emission calculation was the extent of renewable energy sources integrated into the building, particularly any efforts to reduce emissions via energy-saving systems, green building technologies, or smart grid integration.

CO_2 emissions were estimated using the following factors:

- **Fuel Type** – The energy sources powering the building (natural gas, electricity, renewable energy, etc.).
- **Energy Efficiency** – The overall efficiency of the building's energy systems.
- **Operational Emissions** – Emissions generated during the normal operation of the buildings, accounting for energy needs for heating and cooling.

The **smart grid** infrastructure and **energy communities** in the neighbourhood, particularly for pilot sites 4-9, were also factored into these calculations, as the integration of such systems could significantly reduce emissions through energy-sharing and optimization across multiple buildings.

The detailed analysis was crucial for developing the business scenarios and use cases for the SmartLiving EPC project. The technical systems recorded during the survey provided the foundational data for:

- **Energy Performance Optimization**: Identifying areas where energy efficiency improvements could be made, such as better insulation, updated HVAC systems, or the installation of smart meters.
- **Reduction of CO_2 Emissions**: Pinpointing the most effective strategies for reducing emissions, including the integration of renewable energy sources, smart grid solutions, and energy management systems.
- **Neighbourhood and Community Energy Solutions**: Understanding the role of smart grids and energy communities in reducing overall energy consumption and emissions for multiple buildings at once.

By using these findings, the project will be able to offer insights into how building's energy performance can be optimized and how smart technologies can reduce consumption and emissions in a residential setting.

In the **SmartLiving EPC** project for analysing the energy performance of buildings, the **Sarah3 database** was used to access precise meteorological data. **Sarah3** is a high-quality database that provides detailed climate and weather information, essential for accurately assessing energy consumption and CO_2 emissions of buildings. The use of this database was critical for ensuring the reliability of the energy analysis.

The database includes key parameters such as:

- **Temperature**: Essential for evaluating heating and cooling needs.
- **Solar Radiation**: Important for assessing the potential for renewable energy integration, such as solar panels.
- **Wind Speed and Precipitation**: These factors influence the building's thermal performance and energy efficiency.

For the **SmartLiving EPC** project, **Sarah3** was used to gather accurate data related to **climatic conditions** in **Limassol**, including average temperatures, solar radiation, and other environmental factors that directly impact energy performance.

The data provided by **Sarah3** allowed the project to:

- **Accurately assess energy consumption**: The temperature data from Sarah3 helped determine the heating and cooling requirements for each building, leading to more precise calculations of energy needs.
- **Enhance CO_2 emissions calculations**: The climatic data enabled a more accurate estimation of the energy used for heating, cooling, and lighting, contributing to a more reliable assessment of emissions.

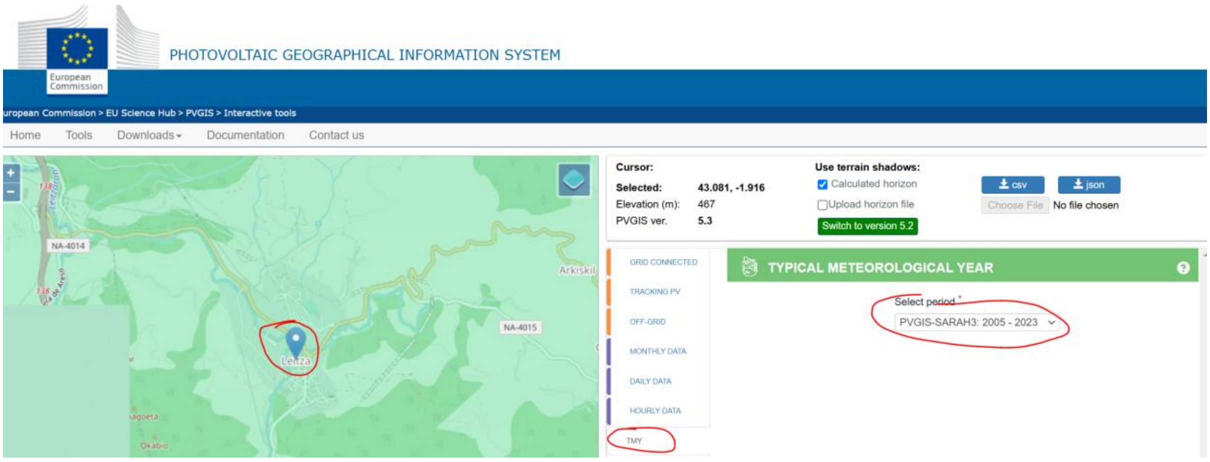
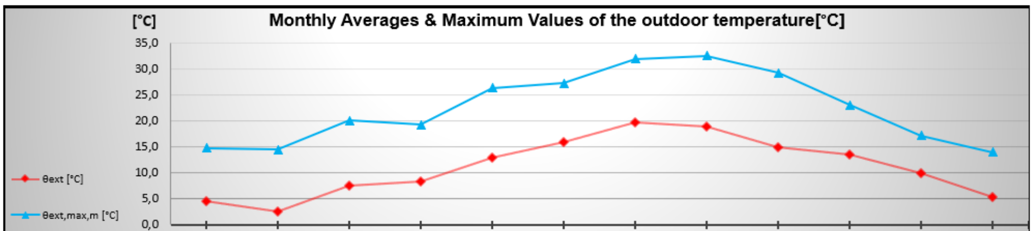


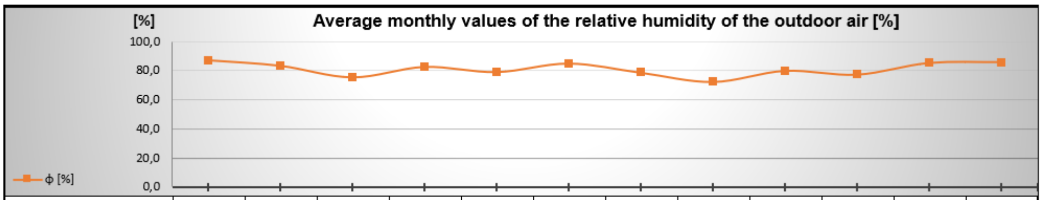
Figure 7: Example of weather data extraction from PVGIS

TYPICAL METEOROLOGICAL YEAR (TMY)

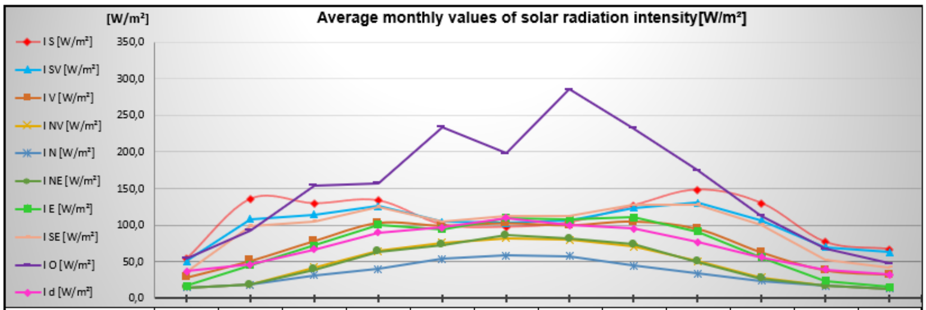
EPB Center has created a tool to convert such a JRC-TMY data set into the format that is needed as input for the demo XLS on (EN) **ISO 52010-1**. For the studied buildings, there is climatic data used to calculate the energy requirements for heating and cooling:



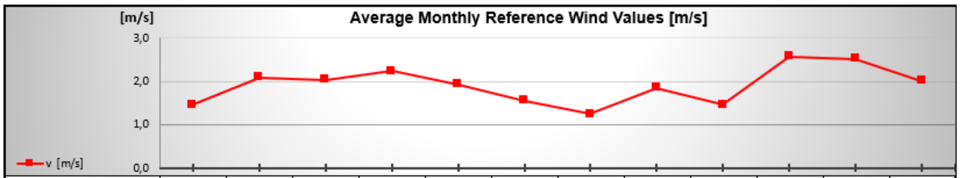
	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
θ_{ext} [°C]	4,5	2,5	7,5	8,3	13,0	15,9	19,8	19,0	14,9	13,5	9,9	5,3
$\theta_{ext,max,m}$ [°C]	14,7	14,4	20,1	19,3	26,4	27,2	32,0	32,6	29,3	23,1	17,1	13,9



	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
φ [%]	86,9	83,2	75,5	82,5	79,0	84,7	78,6	72,4	79,8	77,3	85,1	85,7



	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
I S [W/m²]	53,6	135,6	129,6	133,6	100,7	97,3	103,6	126,8	148,4	130,1	76,7	67,0
I SV [W/m²]	50,7	108,2	114,4	126,0	104,1	102,9	106,5	123,7	130,4	106,8	69,5	62,7
I V [W/m²]	28,5	51,1	78,2	102,8	99,2	102,5	99,7	104,8	94,8	62,9	38,4	32,5
I NV [W/m²]	14,5	18,8	42,1	64,5	75,9	81,8	79,8	70,8	50,3	28,6	17,8	13,3
I N [W/m²]	14,5	18,1	31,6	39,6	53,4	58,0	57,4	44,5	33,6	24,0	16,7	13,3
I NE [W/m²]	14,5	18,4	39,4	63,7	73,2	86,1	81,0	73,9	49,6	27,1	16,7	13,3
I E [W/m²]	17,3	45,0	71,9	100,4	94,7	109,8	107,1	110,5	91,0	56,4	24,0	15,4
I SE [W/m²]	35,9	98,7	104,8	125,1	104,1	112,4	112,2	127,1	127,9	100,9	51,8	42,1
I O [W/m²]	54,5	93,2	154,3	157,6	234,0	197,7	285,9	232,7	175,4	112,6	67,3	47,4
I d [W/m²]	37,0	46,3	66,5	89,7	96,4	109,7	99,8	94,9	76,8	56,3	39,4	32,4



	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
v [m/s]	1,5	2,1	2,0	2,2	1,9	1,6	1,2	1,9	1,5	2,6	2,5	2,0

Figure 8: Weather data for Frederick University – pilot building #2

Frederick University's building comprises classrooms, computer and engineering laboratories, art and craft studios, workshops, a library, seminar rooms, administration and faculty offices, and a large cafeteria. The building was constructed in 1996, and an additional floor was constructed in 2021. New classrooms, a library, study areas, and a seminar room have been added to the newly renovated building's floor.

Figure 9: Principal facade of the Frederick University, Limassol

The useful floor area, usable height, and usable volume of the pilot building in the Smart Living EPC project were considered as follows:

Number of floors (including Ground floor)	4
Volume	m^3
Total building volume (m3)	16084
Heating volume (m3)	13711
Cooling volume (m3)	13711
Specific volume (corridors) (m3)	2431
Area	m^2
Total surface area (m2)	5361
Heating area (m2)	4570
Cooling area (m2)	4570

Operating scenario of the building is taken from the deliverable D1.3 and from the energy audit of the building:

Month	Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	No.days	Week	Month
		Number of hours of use per day [h]								Total hours [h]	
January	Week 1	12	12	12	12	12			15	60	180
	Week 2	12	12	12	12	12				60	
	Week 3	12	12	12	12	12				60	
February	Week 4	12	12	12	12	12			15	60	180
	Week 5	12	12	12	12	12				60	
	Week 6	12	12	12	12	12				60	
March	Week 7	12	12	12	12	12			20	60	240
	Week 8	12	12	12	12	12				60	
	Week 9	12	12	12	12	12				60	
	Week 10	12	12	12	12	12				60	
April	Week 11	12	12	12	12	12			15	60	180
	Week 12	12	12	12	12	12				60	
	Week 13	12	12	12	12	12				60	
May	Week 14	12	12	12	12	12			15	60	180
	Week 15	12	12	12	12	12				60	
	Week 16	12	12	12	12	12				60	
June	Week 17	12	12	12	12	12			15	60	180
	Week 18	12	12	12	12	12				60	
	Week 19	12	12	12	12	12				60	
July									0		0
August									0		0
September	Week 20	12	12	12	12	12			10	60	120
	Week 21	12	12	12	12	12				60	
October	Week 22	12	12	12	12	12			15	60	180
	Week 23	12	12	12	12	12				60	
	Week 24	12	12	12	12	12				60	
November	Week 25	12	12	12	12	12			15	60	180
	Week 26	12	12	12	12	12				60	
	Week 27	12	12	12	12	12				60	
December	Week 28	12	12	12	12	12			15	60	180
	Week 29	12	12	12	12	12				60	
	Week 30	12	12	12	12	12				60	

ZONING OF THE BUILDING INTO SUBZONES WITH THE SAME MAIN DESTINATION - THERMAL ZONES

ZT1	**Subzone category**		
	Heating/ Cooling/ Ventilation	Domestic hot water	Artificial lighting
	02 - Education building	**13 - Schools without showers or bathrooms**	**04 - Educational buildings**
	Type of technical systems of installations related to the subzone		
	Heating/ Cooling/ Ventilation	Domestic hot water	Artificial lighting
	Higher Education	**a - Schools without showers or bathrooms (for one student per program)**	**a - Classroom**
	The type of fuel used as the main source of energy		
	Heating	Domestic hot water	
	Environmental energy (aerothermal, geothermal, hydrothermal)	**Electricity consumed from the grid**	

The building has recently gone through a renovation on the second floor. The Roof is constructed with the following materials (from the inside out): interior plaster, reinforced concrete, coating, exterior plaster, and waterproofing. The Floors are constructed with the following materials (from the inside out): concrete reinforced with 1% steel and lightweight concrete. The non-bearing walls are constructed with perforated brick masonry, coated inside and outside with plaster, with the additional decorative bricks as a final layer on the outside.

Figure 10: East perspective of the building

The envelope elements and surfaces were taken and measured from the architectural plans and 3D model of the building. The envelope elements were realized as follows:

Opaque building element 1 — Element code: Exterior Wall

No.	Type	Layer	δ [m]	ρ [kg/m³]	λ [W/mK]	c [J/kg/K]	a	λ' [W/mK]	R [m²K/W]
1	Superficial resistance	To the outside							0,042
2	OTHER	Exterior plaster	0,02	0	1,000	0	1,00	1,000	0,020
3	OTHER	Perforated brick	0,2	0	0,400	0	1,00	0,400	0,500
4	OTHER	Exterior plaster	0,02	0	1,000	0	1,00	1,000	0,020
5	OTHER	Decorative brick	0,03	0	0,600	0	1,00	0,600	0,050
6				0	0,000	0			
7				0	0,000	0			
8				0	0,000	0			
9				0	0,000	0			
10	Superficial resistance	Horizontal / vertical upward flow							0,125

Specific mass [kg/m²]: 0

Thermal resistance R = 0,757 [m²K/W] — TYPE: OPAQUE

Opaque building element 2 — Element code: Gr_floor

No.	Type	Layer	δ [m]	ρ [kg/m³]	λ [W/mK]	c [J/kg/K]	a	λ' [W/mK]	R [m²K/W]
1	Superficial resistance	Horizontal / vertical upward flow							0,125
2	OTHER	Flooring	0,01	0	0,100	0	1,00	0,100	0,100
3	OTHER	Concrete reinforced with 1% steel	0,05	0	2,300	0	1,00	2,300	0,022
4	OTHER	Lightweight concrete	0,15	0	0,180	0	1,00	0,180	0,833
5				0	0,000	0			
6				0	0,000	0			
7				0	0,000	0			
8				0	0,000	0			
9				0	0,000	0			
10	Superficial resistance								0

Specific mass [kg/m²]: 0

Thermal resistance R = 1,080 [m²K/W] — TYPE: GROUND

Opaque building element 3 — Element code: Roof

No.	Type	Layer	δ [m]	ρ [kg/m³]	λ [W/mK]	c [J/kg/K]	a	λ' [W/mK]	R [m²K/W]
1	Superficial resistance	To the outside							0,042
2	OTHER	Waterproofing	0,01	0	0,230	0	1,00	0,230	0,043
3	OTHER	Exterior plaster	0,02	2000	1,000	900	1,00	1,000	0,020
4	OTHER	Coating	0,01	1200	0,350	1500	1,00	0,350	0,029
5	Concretes	Reinforced concrete (2600 kg/m3)	0,15	2600	2,030	840	1,00	2,030	0,074
6	OTHER	Interior plaster	0,02	2000	1,000	900	1,00	1,000	0,020
7				0	0,000	0			
8				0	0,000	0			
9				0	0,000	0			
10	Superficial resistance	Horizontal / vertical upward flow							0,125

Specific mass [kg/m²]: 482

Thermal resistance R = 0,353 [m²K/W] — TYPE: ROOF

1 - W_1

Code	Envelope type	Type of layer structure
W_1	Window	Double Glazing

b_w [m]	h_w [m]	b_f [m]	A_p From total area	A_p [m²]	A_g [m²]	A_f [m²]	A_w [m²]	l_g [m]	l_{gb} [m]	l_p [m]
					0,00	0,00	0,00		0,00	

Thermal properties of components

Glazing type: Double Glazing				-		Glazing type: -						-										
Glass type	Internal Gas type	U_{g1} From product sheet	U_{g1} W/m²K	d mm	R_s m²K/W	Glass type	Internal Gas type	U_{g2} From product sheet	U_{g2} W/m²K	U_g From product sheet	U_g W/m²K	External layer Tip	d mm	Internal layer Tip	d mm	Protective layer Tip	d mm	U_p From product sheet	U_p W/m²K	Frame type	U_f From product sheet	U_f W/m²K
Float	Air		2,80								2,80									AL		3,11

Type of sun protection device	Position	Transparency
-	Exterior	Opaque
Air Permeability Class	**Device color**	
2 - Large	Dark	

Window/door transmittance - U'W ; U'D [W/m2K]: 3,70

Ψ_{fg} Entered	Ψ_{fg} W/mK	Ψ_{gb} Entered	Ψ_{gb} W/mK	Ψ_{fp} Entered	Ψ_{fp} W/mK	U'_w W/m²K	ΔR Entered	ΔR m²K/W	U_{WS} W/m²K	$U_{W;m}$ W/m²K	U'_w W/m²K
	0,08		0,03								3,70

$\tau_{e,B}$ Entered	$\tau_{e,B}$ [-]	$\rho_{e,B}$ Entered	$\rho_{e,B}$ [-]	$\rho_{v,B}$ Entered	$\rho_{v,B}$ [-]	$\alpha_{e,B}$ [W/m²K]

τ_e Entered	τ_e [-]	ρ_e Entered	ρ_e [-]	ρ'_e Entered	ρ'_e [-]	τ_v Entered	τ_v [-]	ρ_v Entered	ρ_v [-]	ρ'_v Entered	ρ'_v [-]
	0,74		0,14		0,14		0,82		0,15		0,15

$\tau_{v,B}$ Entered	$\tau_{v,B}$ [-]	$\rho'_{e,B}$ Entered	$\rho'_{e,B}$ [-]	$\rho'_{v,B}$ Entered	$\rho'_{v,B}$ [-]	G [W/m²K]

g Entered	g [-]	α_e [W/m²K]	α_v [W/m²K]	$\tau_{e,tot}$ [-]	$\tau_{v,tot}$ [-]	g_{tot} [-]
	0,76	0,13	0,03	0,74	0,82	0,76

Ffr,wi - the surface fraction of the window frame	0,00

Figure 11: Data about thermal resistances of envelope elements

Here is the translation of the explanation regarding the envelope elements of the building, which have been centralized in the energy calculation table:

1	ZTC1.1	$\theta_{int;H}$ [°C]	$\theta_{int;C}$ [°C]	$A_{use;zi}$ [m²]	q [m³/h]		Internal heat capacity	Heavy
		22,0	25,0	4570,0	6855,0		Cm;zi/Ause;zi[J/m²K]:	260000

	Code	$A_{e;i}$ W/D No.	$A_{e;i}$ W/D [m²]	$A_{e;i}$ W/D [m²]	$A_{e;i}$ [m²]	Orientation	r [-]	R' [m²K/W]	U'i [W/m²K]	Adjacent space type	Adjacent zone code	H_g [W/K]	H_d [W/K]	H_{iu} [W/K]	H_{ve} [W/K]
1	Exterior Wall				291,3	E	0,85	0,64	1,55	Ext.			452,67		
2	Exterior Wall				518,0	S	0,85	0,64	1,55	Ext.			804,96		
3	Exterior Wall				269,0	V	0,85	0,64	1,55	Ext.			418,11		
4	Exterior Wall				510,7	N	0,85	0,64	1,55	Ext.			793,72		
5	Gr_floor				1387,4	-	1,5	1,62	0,62	Ground		406,46			
6	Roof				1387,4	ORIZ	0,88	0,31	3,22	Ext.			4466,20		
7	W_1		77,7	77,7		E		0,27	3,70	Ext.			287,49		
8	W_1		225,0	225,0		S		0,27	3,70	Ext.			832,65		
9	W_1		129,7	129,7		V		0,27	3,70	Ext.			479,93		
10	W_1		279,1	279,1		N		0,27	3,70	Ext.			1032,74		
11															
12															
13															
14															
15															2262,15
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															
26															
27															
28															
29															
30															
												406,46	9568,46	0,00	2262,15

Figure 12: Thermal losses calculation

GROUND LOSSES:

Exposed perimeter: [m]	Wall thickness: [m]	Ψ_{wf} [W/mK]	λ_g [W/mK]	ρc [J/m³K]	δ [m]	α [months]	β [months]	τ [months]	$\bar{\theta}_{int}$ [°C]	$\hat{\theta}_{int}$ [K]	$\bar{\theta}_e$ [°C]	$\hat{\theta}_e$ [K]
		• Thermal characteristics:				• Thermal flow characteristics:						
155,30	0,30	1,00	2,0	2,00E+06	3,20	0	1	2	23,5	1,5	19,5	8,6

	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec	
$\theta_{int;H}$ [°C]	22,0	22,0	22,0	22,0	22,0	22,0	22,0	22,0	22,0	22,0	22,0	22,0	HEATING
$\theta_{int;C}$ [°C]	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	COOLING
$\theta_{int;adj}$ [°C]	15,0	15,0	15,0	15,0	20,0	20,0	20,0	20,0	20,0	15,0	15,0	15,0	
θ_{ext} [°C]	11,2	10,8	13,8	17,0	20,2	25,5	28,9	27,8	24,9	22,6	18,0	12,9	
b [-]	0,65	0,63	0,85	1,39	1,12	-0,57	-0,29	-0,34	-0,70	-12,65	1,75	0,77	
H_{ia} [W/K]	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	Max
H_a [W/K]	3,26	3,14	4,26	6,94	5,61	-2,83	-1,44	-1,72	-3,51	-63,25	8,74	3,83	8,7
H_g [W/K]	324,70	354,06	397,47	443,29	479,23	495,68	488,23	458,86	415,45	369,64	333,69	317,24	
H_u [W/K]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,0
H_{tr} [W/K]	9896,41	9925,66	9970,19	10018,68	10053,30	10061,31	10055,25	10025,60	9980,41	9874,85	9910,89	9889,53	10061,3

HEATING	Night set back		HEATING	Daytime set back		HEATING	Weekend set back	
	$\Delta t_{H;red;y}$	12		$\Delta t_{H;red;y}$			$\Delta t_{H;red;y}$	48
	$n_{rep;red;y}$	5		$n_{rep;red;y}$			$n_{rep;red;y}$	1
	$f_{H;red;y}$	0,36		$f_{H;red;y}$	0,00		$f_{H;red;y}$	0,29

COOLING		
	$\Delta t_{C;red;w\,knd}$	48
	$n_{rep;red;y}$	1
	$f_{C;red;w\,knd}$	0,29
	$b_{C;red;w\,knd}$	0,6
	$a_{C;red;w\,knd}$	0,89

$\eta_{HU;rvd}$	
$(\Delta x \cdot t)_{a;sup}$	
$\varphi_{V;comf2}$	
$f_{DHU;C;ss}$	

Low	15
$a_{H;0}$	0,8
$\tau_{H;0}$	70
H_{final} [W/K]	12323,46

Figure 13: Ground heat losses calculation

The internal heat gains consider the heat emissions from people, lighting, and equipment:

1	ZTC1.1

	Type	Thermal power Default N	Default [W]	User [W]	Jan [zile]	Feb [zile]	Mar [zile]	Apr [zile]	May [zile]	Iun [zile]	Iul [zile]	Aug [zile]	Sep [zile]	Oct [zile]	Nov [zile]	Dec [zile]	Number Hours / [h]
					Operating period												
1	Lighting - Compact fluorescent		0	46128	22	20	22	21	22	21	0	0	21	22	22	21	10
2	Occupants light activity	715	78650		22	20	22	21	22	21	0	0	21	22	22	21	10
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
	Total power and operating hours		78650	46128	220,0	200,0	220,0	210,0	220,0	210,0	0,0	0,0	210,0	220,0	220,0	210,0	2140,0

Figure 14: Internal heat gains – lighting and occupants

The solar heat gains take into account each envelope element considered in the heat loss section that is exposed to solar radiation:

1	ZTC1.1

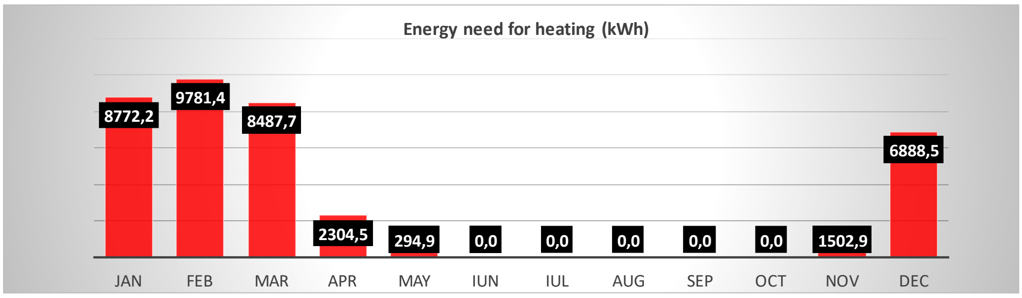
	Code	Type	A_{eli} [m²]	U_{eli} [W/m²K]	Orientation	Tilt Angle Entered	Tilt Angle [°]	$\alpha_{sol;k}$ [-]	$g_{gl;n;wi}$ [-]	$g_{gl;wi}$ [-]	$F_{fr;wi}$ [-]	$F_{sky;k}$ [-]	$F_{sh;dir}$ [-]
1	Exterior Wall	OPAQUE	291,27	1,55	E		90	0,30				0,50	0,70
2	Exterior Wall	OPAQUE	517,95	1,55	S		90	0,30				0,50	0,70
3	Exterior Wall	OPAQUE	269,03	1,55	V		90	0,30				0,50	0,70
4	Exterior Wall	OPAQUE	510,72	1,55	N		90	0,30				0,50	0,70
5	Gr_floor	GROUND	1387,38	0,62				0,30					0,00
6	Roof	ROOF	1387,38	3,22	ORIZ		0	0,30				1,00	0,90
7	W_1	TRANSPARENT	77,70	3,70	E		90		0,76	0,68	0,25	0,50	0,70
8	W_1	TRANSPARENT	225,04	3,70	S		90		0,76	0,68	0,25	0,50	0,70
9	W_1	TRANSPARENT	129,71	3,70	V		90		0,76	0,68	0,25	0,50	0,70
10	W_1	TRANSPARENT	279,12	3,70	N		90		0,76	0,68	0,25	0,50	0,70

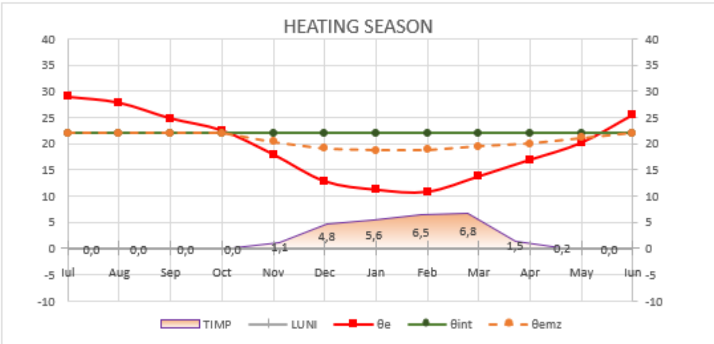
Figure 15: Solar heat gains calculation

Furthermore, the energy calculations were performed, and the heating load of the building and the duration of the heating season were determined, accounting for the building's particular architecture and exposure to solar radiation.

	Energy need for heating [kWh]													
	ZTC code	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec	Total
1	ZTC1.1	8772,2	9781,4	8487,7	2304,5	294,9	0,0	0,0	0,0	0,0	0,0	1502,9	6888,5	38032,1

	ZONE	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec	Total
1	ZT1	8772,2	9781,4	8487,7	2304,5	294,9	0,0	0,0	0,0	0,0	0,0	1502,9	6888,5	38032,1
	Total ZT	8772,2	9781,4	8487,7	2304,5	294,9	0,0	0,0	0,0	0,0	0,0	1502,9	6888,5	38032,1





	θ_e	θ_{int}	θ_{emz}	TIME [DAYS]
Iul	28,95	22,00	22,00	0,00
Aug	27,82	22,00	22,00	0,00
Sep	24,85	22,00	22,00	0,00
Oct	22,55	22,00	22,00	0,00
Nov	18,00	22,00	20,38	1,05
Dec	12,87	22,00	19,14	4,80
Jan	11,25	22,00	18,78	5,55
Feb	10,85	22,00	18,81	6,45
Mar	13,79	22,00	19,45	6,80
Apr	16,95	22,00	20,05	1,50
May	20,22	22,00	21,16	0,15
Iun	25,53	22,00	22,00	0,00

Figure 16: Heating demand calculation pilot building #2

The building's heating and cooling needs are covered by the Central system VRF. Air conditioning units operate daily, Monday to Friday, depending on the teaching hours. The units can be seen in Figure 49, and the following tables introduce some basic characteristics. The operating temperature is adjusted according to the demand from the staff of the university. Total thermal/cooling power [kW]:

- Total thermal power [kW] - T: 366
- Total cooling power [kW] - C: 336

Figure 17: Central system VRF pilot building #2

The energy calculation for heating has been carried out based on the thermal characteristics of the building envelope, internal heat gains, and the efficiency of the heating system. The analysis includes heat losses at the terminal units (fan coils), distribution losses, circulation pump energy consumption, and generation losses associated with the centralized VRF system.

#	ZT	ZONE	Emission device type	Nr.	Ctrl.	Ctrl.	Stra.	Stra.	Stra.	Rad.	Ingl.	Ingl.	Ingl.	Int.	Hid.	Aut.
um	[-]	[-]			$\Delta\theta_{ctr,1}$	$\Delta\theta_{ctr,2}$	$\Delta\theta_{str;1}$	$\Delta\theta_{str;2}$	θ'_{str}	$\Delta\theta_{rad}$	$\Delta\theta_{emb1}$	$\Delta\theta_{emb2}$	$\Delta\theta$	$\Delta\theta_{im}$	$\Delta\theta_{hydr}$	$\Delta\theta_{room}$
1	ZT1	ZTC1.1	Radiators/convectors	73	[1]	Yes	[6]	[3]						[1]		
2																
3																
4																
5																

#	ZONE	H	θ_{int}	$Q_{em,out}$	$\theta_{int;inc}$	$Q_{em,ls}$	$\varepsilon_{em;ls;a}$	P_{ctr}	$P_{H,aux}$	P_{fan}	W_{ctr}	W_{fan}	$W_{em,ls,aux}$	$W_{em,ls,aux}$	$\Phi_{H;n}$
um	[-]	[m]	[C]	[kWh]	[ºC]	[kWh]	[-]	[W]	[W]	[W]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
1	ZTC1.1	3	22	38032,100	25,1	5359,069	1,14	5	0	50	1,578	1151,940	1153,518	0,000	366
2				0,000											
3				0,000											
4				0,000											
5				0,000											
				$Q_{em,out}$		$Q_{em,ls}$					W_{ctr}	W_{fan}	$W_{em,ls,aux}$	$W_{em,ls,aux}$	
			TOTAL	38032,100	TOTAL	5359,069				TOTAL	1,578	1151,940	1153,518	0,000	

Figure 18: Heat emitters – calculation

Calculation of energy consumption through distribution - Simplified calculation

Building length (A)	49	[m]	$\theta_{ah,H,(V)}$	20	[ºC]
Building width (B)	28	[m]	$\theta_{ah,H,(S)}$	20	[ºC]
Floor height (C)	3	[m]	$\theta_{ah,H,(A)}$	20	[ºC]
Number of floors	4	[-]	$\theta_{H,em,in}$	80	[ºC]
Outside shafts	Nu	[-]	$\theta_{H,em,out}$	60	[ºC]
			$f_{H,dis,rbl}$	0,5	

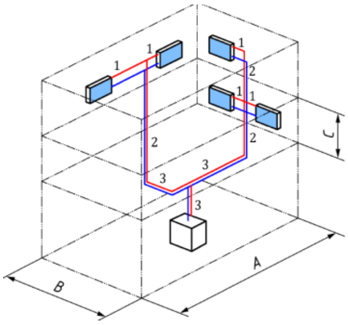
Select linear thermal transmittance of pipes

Age/class of building

x From 1995 – assumed that insulation thickness is approximately equal to the pipe external diameter

Non - insulated pipes exposed

Non - insulated pipes installed in external walls



Pipe lengths

Li,V	150	[m]
Li,S	418	[m]
Li,A	171	[m]
L_{max}	171	[m]

Distribution energy losses $\theta_{H,em,mean}$ 70,0 [ºC]

TOTAL ENERGY LOSS THROUGH DISTRIBUTION

$Q_{H,dis,ls,total}$	3263,261	[kWh/an]
$q_{H,dis,ls,total}$	0,71	[kWh/m^2,an]
$Q_{H,dis,rbl}$	1631,631	[kWh/an]

	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec	Total
ZT1	688,6	800,3	843,7	186,1	18,6	0,0	0,0	0,0	0,0	0,0	130,3	595,6	3263,261
ZT2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
ZT3	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	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	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
TOTAL	688,6	800,3	843,7	186,1	18,6	0,0	0,0	0,0	0,0	0,0	130,3	595,6	3263,261

Figure 19: Heating distribution heat losses

Calculation of auxiliary energy consumption - if circulation pump details are known

#	ZONE	Lmax	t_{H,op_P1}	t_{H,op_P}	$P_{el\text{-}H,op\_P}$	$W_{H,dis,an}$	Insulated	$f_{aux,rbl}$	$Q_{H,dis,aux,rbl}$	$Q_{H,dis,aux,rvd}$	ZONE
um	[-]	[m]	[h]	[h]	[W]	[kWh]	[-]	[-]	[kWh]	[kWh]	[-]
1	ZT1	0,0	315,6		9000	2840,400	No	0,25	710,100	2130,300	ZTC1.1
2									0,000		
3									0,000		

Electric consumption of pumps 2840,400 [kWh/an]   Specific electric consumption of pumps 0,62 [kWh/m^2,an]

Figure 20: Auxiliary electric consumption for heating - pumps

HEATING SYSTEM 2 - AIR HEATING AND OVERHEAD RADIANT HEATING SYSTEMS

Heating (H)

Serviced zone: x ZT1

Percentage of zone demand: 100

Reference area: ZTC1.1

- Type of heating generator: Electric heating devices (radiator, convector)
- Heating generator fuel / energy source: Electricity consumed from the grid
- Heating generator control: Modulating control
- Condensation heating: Condensing heater
- Pilot flame ignition: Heater with pilot flame
- Ventilation requirement: Not a type A heater, no heated room ventilation
- Thermal power at maximum load: 366 [kW]
- Thermal power at minimum load: 91,5 [kW]
- Year of installation: after 2005
- Auxiliary energy data: Air heater (axial blowing) — Default value
- Generator jacket losses: Well insulated and maintained — αlrh,plt 1,19 [%]

$\alpha_{lrh;ch;ON}$	0,00	[%]	$\Phi_{lrh;aux;br;known}$		[W]	nlrh;ch;ON	0,10	[-]
$f_{lrh;corr;ch;ON}$	0,00	[%]	$\Phi_{lrh;aux;blw;known}$		[W]	Φlrh;aux;br	0,00	[W]
$\vartheta_{lrh;air;test;ON}$	0,00	[°C]	$\Phi_{lrh;aux;br;def}$	0,00	[W]	$\Phi_{lrh;aux;blw}$	3294,00	[W]
$\alpha_{lrh;ch;ON;min}$	0,00	[%]	$\Phi_{lrh;aux;blw;def}$	3294,00	[W]			

- Device type (with or without pilot flame): Heater without permanent pilot flame — αlrh,plt 0,00 [%]
- Values for combustion efficiency: Multi-stage or modulating appliances with modulated combustion air flow — ηlrh,comb 94,00 [%]; ηlrh,comb,Pmin 104,00 [%]
- Location of the generator: Heater located outside the heated space — klrh,aux,rh 0,80 [-]
- Correction of thermal losses through the casing: Heater installed outdoors — klrh,env 1,00 [-]
- Building height: 3,00 | 3,00 [m]
- The difference between temp. radiant and temp. air: 2,50 [°C]
- Vertical temperature gradient: 0,10 [°C/m]

	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
Egen,in [kWh]	8031,993	8937,056	7667,711	2106,997	272,671	0,000	0,000	0,000	0,000	0,000	1368,888	6275,177
Wgnr;aux [kWh]	219,380	254,956	268,790	59,292	5,929	0,000	0,000	0,000	0,000	0,000	41,504	189,734

Egen,in, tot 34660,5 [kWh]   Wgen 1039,6 [kWh]

Figure 21: Air heating system calculation

The results of the energy calculation for heating are explained in the following tables. The conversion factors from final energy to primary energy and from primary energy to equivalent CO2 emissions are taken from national standards.

Country : Cyprus

Fuel/Energy Source - Electric vector: Electricity consumed from the grid

fPnren	fPren	fPtot
2,4	0,5	2,9

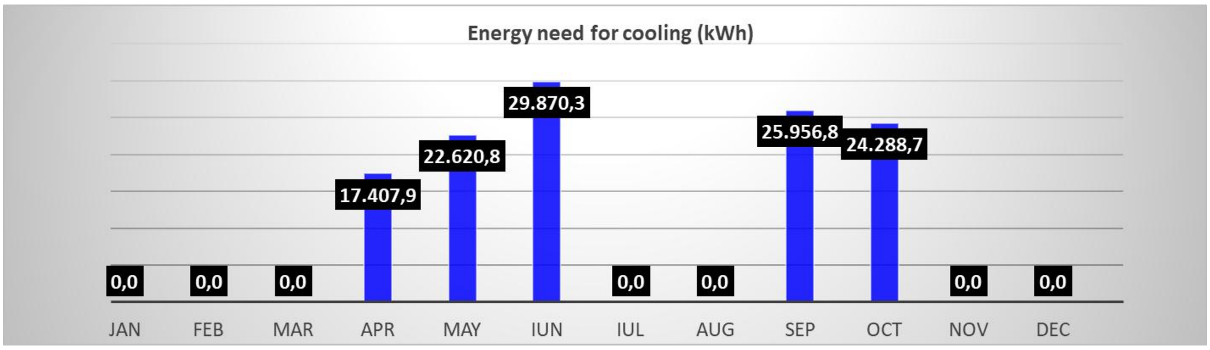
Utilities	Values dependent only on the EPB standard [kWh/m2,y]	
Heating system	Electric final energy consumption	12096,10

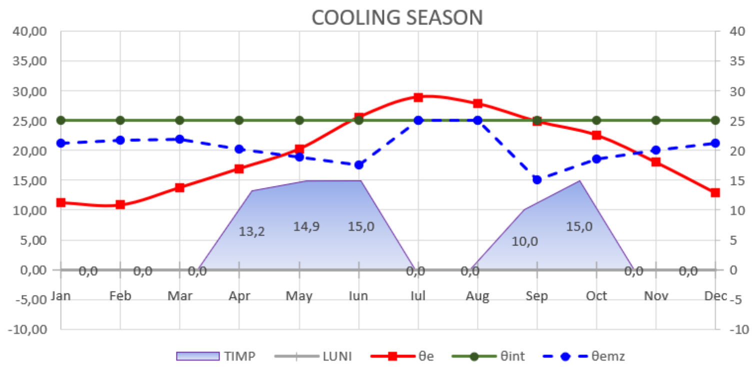
Values dependent on the national annex A (normative) [kWh/m2,y]		
Heating system	Non-renewable primary energy consumption, Electric vector	29030,65
	Renewable primary energy consumption, Electric vector	6048,05

Total Primary Energy Consumption for the Cooling system , Electric vector	35078,70	kWh/m2,y

Figure 22: Primary energy calculation - heating

For the calculation of the cooling energy vector, the procedure is similar to heating as it follows:





	θ_e	θ_{int}	θ_{emz}	TIME [DAYS
Jan	11,25	25,00	21,22	0,00
Feb	10,85	25,00	21,65	0,00
Mar	13,79	25,00	21,82	0,00
Apr	16,95	25,00	20,19	13,20
May	20,22	25,00	18,90	14,85
Iun	25,53	25,00	17,63	15,00
Iul	28,95	25,00	25,00	0,00
Aug	27,82	25,00	25,00	0,00
Sep	24,85	25,00	15,03	10,00
Oct	22,55	25,00	18,57	15,00
Nov	18,00	25,00	20,12	0,00
Dec	12,87	25,00	21,27	0,00

#	ZT	ZONE	Emission device type	Nr.	Ctrl.	Ctrl.	Stra.	Ingl.	Aut.	Ratio for solar / internal heat gains
um	[-]	[-]			$\Delta\theta ctr,1$	$\Delta\theta ctr,2$	$\Delta\theta str$	$\Delta\theta_{emb}$	$\Delta\theta_{room}$	
1	**ZT1**	**ZTC1.1**	**Systems for blowing cold air (fans...)**	**73**	**[3]**	**Yes**	**[4a]**	**[4a]**		**Medium**
2										
3										
4										
5										

#	ZONE	H	θ_{int}	$Q_{em,out}$	$\theta_{int;rac}$	$Q_{em,ls}$	$\varepsilon_{em;ls;a}$	P_{ctr}	PC,aux	P_{fan}	W_{ctr}	W_{fan}	$W_{em,ls,aux}$	$W_{em,ls,aux}$	$\Phi_{C;n}$
um	[-]	[m]	[C]	[kWh]	[ºC]	[kWh]	[-]	[W]	[W]	[W]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
1	ZTC1.1	3	25	120144,566	26,6	5825,191	1,05	**5**	**0**	**50**	4,083	2980,590	2984,673	0,000	**336**
2															
3															
4															
5															
			TOTAL	**120144,566**	TOTAL	**5825,191**				TOTAL	**4,083**	**2980,590**	**2984,673**	**0,000**	

Calculation of energy consumption through distribution - Simplified calculation

Building length (A)	49,45	[m]	$\theta_{aC,(V)}$	24	[ºC]
Building width (B)	28,2	[m]	$\theta_{aC,(S)}$	24	[ºC]
Floor height (C)	3	[m]	$\theta_{aC,(A)}$	24	[ºC]
Number of floors	4	[-]	$\theta_{C,em,in}$	12	[ºC]
Outside shafts	Nu	[-]	$\theta_{C,em,out}$	7	[ºC]
			$f_{C,dis,rbl}$	0,65	

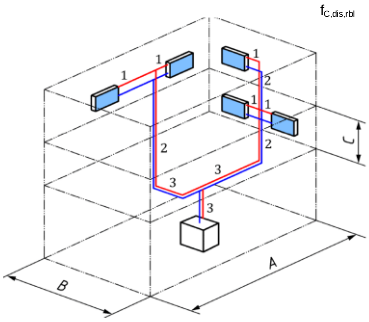
Select linear thermal transmittance of pipes

Age/class of building

x	**From 1995 – assumed that insulation thickness is approximately equal to the pipe external diameter**

Non - insulated pipes exposed

Non - insulated pipes installed in external walls



Pipe lengths

Li,V	150		[m]
Li,S	418		[m]
Li,A	171		[m]
L_{max}	171		[m]

Distribution energy losses $\theta_{C,em,mean}$ 9,5 [ºC]

TOTAL ENERGY LOSS THROUGH DISTRIBUTION

$Q_{C,dis,ls,total}$	2448,625	[kWh/an]
$q_{C,dis,ls,total}$	0,54	[kWh/m^2,an]
$Q_{C,dis,rbl}$	1591,606	[kWh/an]

	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec	Total
ZT1	0,0	0,0	0,0	475,0	534,3	539,7	0,0	0,0	359,8	539,7	0,0	0,0	2448,625
ZT2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
ZT3	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	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	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
TOTAL	**0,0**	**0,0**	**0,0**	**475,0**	**534,3**	**539,7**	**0,0**	**0,0**	**359,8**	**539,7**	**0,0**	**0,0**	**2448,625**

Figure 23: Cooling distribution calculation for pilot #2

Calculation of auxiliary energy consumption - if circulation pump details are known

#	ZONE	Lmax	t_{C,op_P1}	t_{C,op_P}	P_{el,C,op_P}	$W_{C,dis,an}$	Insulated	$f_{aux,rbl}$	$Q_{C,dis,aux,rbl}$	$Q_{C,dis,aux,rvd}$	ZONE
um	[-]	[m]	[h]	[h]	[W]	[kWh]	[-]	[-]	[kWh]	[kWh]	[-]
1	ZT1	0,0	816,6		9000	7349	No	0,3	1837,350	5512,050	ZTC1.1
2									0,000		
3									0,000		

Electric consumption of pumps **7349,40** [kWh/an] Specific electric consumption of pumps **1,61** [kWh/m^2,an]

Country : Cyprus

Fuel/Energy Source - Electric vector

Electricity consumed from the grid

fPnren	fPren	fPtot
2,4	0,5	2,9

Utilities	Values dependent only on the EPB standard [kWh/m2,y]	
Heating system	Electric final energy consumption	16057,30

Values dependent on the national annex A (normative) [kWh/m2,y]		
Heating system	Non-renewable primary energy consumplion, Electric vector	38537,52
	Renewable primary energy consumption, Electric vector	8028,65

Total Primary Energy Consumption for the Cooling system , Electric vector	46566,17	kWh/m2,y

Figure 24: Primary energy calculation - cooling

For the calculation of the energy consumption for DHW, we consider the equivalent number of occupants inside the building based on the surface area of the building:

Energy consumption for DHW need

	ZT code	Subzone category ZT / Building Type	Destination of the zone ZT / Room Type
1	ZT1	13 - Schools without showers or bathrooms	a - Schools without showers or bathrooms (for one student per program)

Recirculation pump	NO
DHW 24h/24h	NO
Pump control	NO
Isolated pump	NO

Daily DHW operation schedule	12	[h/day]
Number of tapings per time step	1	[1/zi]

	Days											
	Jan	Feb	Mar	Apr	May	Iun	Iul	Aug	Sep	Oct	Nov	Dec
Number of operating days	15	15	20	15	15	15	0	0	10	15	15	15

• f - Number of units:	715,00	[–]
• V w,f,day - daily specific need for a consumer:	5,00	[l/unit,day]
• V w,day - daily DHW volume need:	3575,00	[l/day]

Number of students: 715 [persons]

Figure 25: Domestic hot water calculation for pilot #2

Country : Cyprus

Fuel/Energy Source for DHW (need, distribution, storage and generation)	fPnren	fPren	fPtot
Electricity consumed from the grid	2,9	0	2,9

Fuel/Energy Source for Auxiliary systems (circulation pumps)	fPnren	fPren	fPtot
Electricity consumed from the grid	2,9	0	2,9

Utilities	Values dependent only on the EPB standard [kWh/m2,y]	
DHW system	Thermal final energy consumption	19470,50
	Electric final energy consumption	0,00

Values dependent on the national annex A (normative) [kWh/m2,y]		
DHW system	Non-renewable primary energy consumption, Thermal vector	0,00
	Renewable primary energy consumption, Thermal vector	0,00
	Non-renewable primary energy consumption, Electric vector	56464,44
	Renewable primary energy consumption, Electric vector	0,00

Total Primary Energy Consumption for the DHW system , Thermal vector	0,00	kWh/m2,y
Total Primary Energy Consumption for the DHW system , Electric vector	12,36	kWh/m2,y

Figure 26: Primary energy calculation – Domestic hot water

Energy consumption for the lighting system was considered based on the lighting power, illuminance, lamp type and automatic control of the lighting system as it follows:

Estimated lighting power:		[W]	**Known lighting power :**	57660,0	[W]
- Type of Control:	Manual				
- Battery charging of emergency luminaires :	No		- Emergency lighting battery consumption :	0	[kWh/m²y]
- Standby energy for automatic lighting controls:	No		- Standby power consumption :	0	[kWh/m²y]
- Constant Illuminance System?	No		- Constant Illuminance Factor, Fc:	1	[-]
			- Absence factor, Fa :	0,25	[-]
			- Occupancy dependent lighting control system factor, Foc:	1	[-]
			-occupancy dependency factor, Fo:	0,95	[-]
			- Daylight Dependency Factor, Fd:	0,635	[-]
- Day Time Use [h] :	1800		- Emergency charging power - Pem :	0,0	[W]
- Night Time Use [h] :	200				
- Total hours use :	2000		- Lighting controls power - Ppc :	0,0	[W]
Total annual consumption of electricity for the lighting system :	73565,510	[kWh/y]			
LENI (Preliminary)	16,10	[kWh/m^2,y]			

Figure 27: Lighting calculation for pilot #2

Country : Cyprus

Fuel/Energy Source - Primary energy conversion factors	fPnren	fPren	fPtot
Electricity consumed from the grid	2,9	0	2,9

Utilities	Values dependent only on the EPB standard [kWh/m2,y]	
Lighting system	Electric final energy consumption	16,10

Values dependent on the national annex A (normative) [kWh/m2,y]		
Lighting system	Non-renewable primary energy consumption	46,68
	Renewable primary energy consumption	0,00

Total Primary Energy Consumption for the Lighting system , Electric vector	46,68	kWh/m2,y

Figure 28: Primary energy calculation – Lighting

Energy indicators

Energy class for the building and CO2 emissions are detailed in the following table:

Frederick University pilot #2		
	Primary energy (kWh/m2,y)	CO2 emissions (kgCO2/m2,y)
Heating	7,68	7,59
DHW	12,36	12,22
Lighting	46,68	46,17
Cooling	10,19	10,08
Ventilation	0	0
Total	**76,90**	**76,05**

Non-Energy indicators

As concerns, the non-energy we have:

Calculated parameters		
Volume	105	300
CO2 exhalation (m3/h/pers)	0.02	0.013
CO2 exhalation (m3/h)	0.06	0.026
Infiltrations (vol/h)	0.5	1
Infiltrations (m3/h)	52.5	300
Total flow (m3/h)	202.5	300
Air changes inside (vol/h)	1.93	1
OUTPUT PARAMETERS		
AVERAGE CO2 (ppm)	1500	486
ZONE COMPLIANCE	66.67%	100.00%
	E	A
ALL ZONES COMPLIANCE	83.3%	
	B	

Figure 29: Indoor Air Quality score and class for the building two zones

INPUT DATA	Analyzed zones	
	1	2
Length (m)	10	10
Width (m)	2	5
Height (m)	2.5	2.5
Destination	Classrooms	Classrooms
Type window	Double glazing - PVC/Ai - low e	Single
Windows area (m2)	2	8
α (degree) - vertical	90	90
Maintenance factor	0.6	0.6
t coefficient	0.7	0.97
Luminaire temperature (K)	4000	4000
Luminaire color rendering	90	40
Type luminaire	LED lamp	LED lamp
Electric power (W)	40	200
Luminous flux (lm)	3600	18000
Illuminance (lx)	180	360
Zone surface (m2)	20	50
Percentage (%)	29%	71%
Target illuminance (lx)	300	300
Target color rendering	90	90
Target color temperature (K)	4000	4000
Target daylight	6%	6%
Daylight factor	2.0%	6.2%
Score	73.1	86.1
Rating	C	B
Overall score	82.4	
Overall rating	B	

Frequency (Hz)	Rating sound pressure level & global sound pressure level	
125 Hz	A	B
250 Hz	A	B
500 Hz	A	A
1000 Hz	A	A
2000 Hz	A	C
4000 Hz	A	A
Lp (dB)	A	B
Global dB(A)	B	D
	Rating reverberation time	
Target reverberation (sec)	0.64	0.64
RT60(sec)	0.60	0.47
Rating	B	D
	Final rating	
Zone rating	B	C
Building rating	C	

Figure 30: Visual and acoustic comfort non-energy indicators for two zones

Mean radiant temperature (oC)		
MRT	18.7	19.1
Calculation of indoor relative humidity (%)		
saturation vapor pressure	8.717	4.222
actual vapor pressure	566.63	274.42
absolute humidity (g/m3)	4.41	2.22
Moisture from occupants (g)	2400	800
Air change rate (vol/h)	0.1	0.6
Ventilation moisture (g/h)	27.811	399.181
absolute humidity (g/m3)	1.606	0.500
saturation vapor pressure	23.32596022	23.32596022
relative humidity	9.31%	2.90%
PMV_winter	-0.85	-0.82
PPD_winter	20.33%	19.13%
Score	80.8	82.0
Rating	B	B
Overall score	81.8	
Overall rating	B	

Figure 31: Thermal comfort non-energy indicator for two zones

For the accessibility the score is 85 , for earthquake seismic risk is 100 and water efficiency 75. The final rating for non-energy parameters is 85.56 and the class B.

<u>Smart readiness indicator</u>

The building scores a 28% overall SRI. Energy flexibility 9,6%, response to user needs 36,5%, and energy performance and operation 36,7% are the scores per main functionality. The Figure that follows displays the impact and domain scores.

IMPACT SCORES	
Energy efficiency	49%
Energy flexibility and storage	10%
Comfort	47%
Convenience	21%
Health, well-being and accessibility	38%
Maintenance and fault prediction	25%
Information to occupants	40%
	33%

DOMAIN SCORE	
Heating	37%
Domestic hot water	0%
Cooling	37%
Ventilation	0%
Lighting	51%
Dynamic building envelope	0%
Electricity	42%
Electric vehicle charging	0%
Monitoring and control	17%

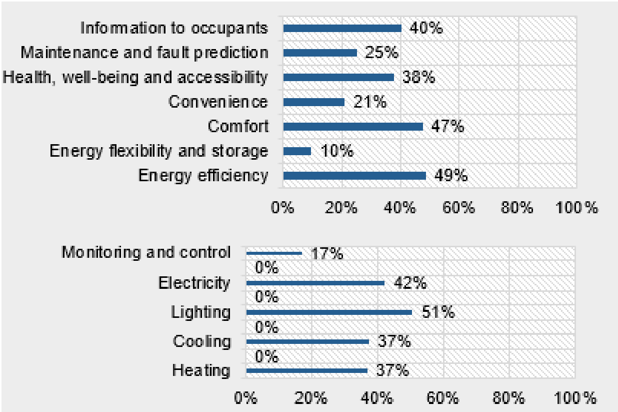


Figure 32: SRI index for Frederick's University

Environmental indicators

Life Cycle Stage A1-A3:

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	5.86E+06	5.05E-01	2.73E+04	4.34E+03	2.42E+03	2.12E+02	1.21E+08
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	9.21E+08	1.05E+01	1.61E+06	4.59E+05	6.96E+04	1.23E+02	4.99E+09
Concrete, Cast In Situ	3.22E+09	3.68E+01	5.62E+06	1.60E+06	2.44E+05	4.31E+02	1.75E+10

Life Cycle Stage A4(Transport from the gate to the site):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	1.41E+05	2.42E-02	5.35E+02	1.31E+02	2.63E+01	7.07E-01	2.12E+06
Vapour Retarder	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	4.53E+07	7.07E-09	1.05E+05	2.55E+04	-3.52E+04	3.22E+00	6.14E+08
Concrete, Cast In Situ	1.59E+08	2.47E-08	3.68E+05	8.91E+04	-1.23E+05	1.13E+01	2.15E+09

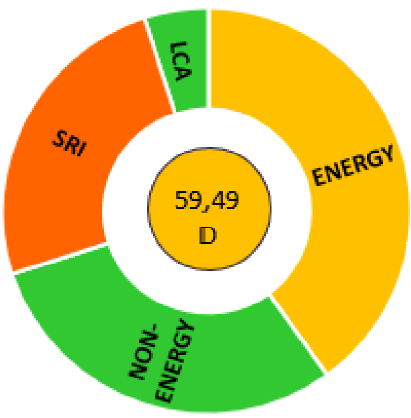
Life Cycle Stage A5(Assembly):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	1.21E+07	8.08E-01	6.16E+04	3.74E+04	6.56E+03	2.12E+02	1.41E+08
Vapour Retarder	-	-	-	-	-	-	-

Figure 33: Calculation of environmental indicators

Final rating for Pilot #2

	Class (-)	Score (-)	Weighting *default*	Weighting *user*	Class (-)	Score (-)
ENERGY	D	54,55	40		D	59,49
LCA	A	100,00	5			
NON-ENERGY	B	85,57	30			
SRI	F	28,00	25			
				0	59,49 D	



5 Asset rating calculation methodology for building complexes

5.1 Expansion of the methodology to neighborhood level

Traditional **Energy Performance Certificates (EPCs)** focus on **individual buildings**, evaluating their energy consumption, efficiency, and sustainability. However, as urban energy systems evolve, buildings are no longer isolated entities; they interact with their surroundings through shared energy infrastructure, district heating and cooling systems, smart grids, and **energy communities**.

To address these complexities, SmartLivingEPC extends its methodology to the **neighbourhood level**, introducing a new certification framework that evaluates the performance of building clusters, urban blocks, and districts. This approach reflects the increasing role of collective energy management and ensures better integration of renewable energy sources, load balancing, and urban-scale energy optimization.

Expanding **SmartLivingEPC** to the neighborhood scale is essential due to:

- The rise of energy communities: Neighborhoods are increasingly adopting shared renewable energy generation, such as photovoltaic (PV) parks, wind turbines, and energy storage systems.
- Smart grid integration: Buildings are becoming active participants in demand response programs, peer-to-peer energy trading, and load flexibility management.
- Shared infrastructure: District-level systems, such as district heating/cooling and community-level battery storage, require assessment beyond individual building EPCs.
- Urban planning considerations: Microclimate effects, urban heat islands, and mobility-related energy consumption impact overall energy efficiency and sustainability.

SmartLivingEPC integrates **new performance indicators** at the neighbourhood scale, covering **energy, environmental, and smart infrastructure factors**.

These are summarized in the table below:

Table 11: Building neighbourhood level KPI's

Indicator	Description
Street Lighting	Measures the availability of artificial lighting in public areas, impacting energy use, security, and accessibility.
Waste Generation	Assesses waste generated per person compared to the national average.
Waste Recycling Rate	Measures the percentage of waste recycled within the neighborhood.
Wastewater Processing Rate	Denotes the availability of wastewater treatment services.
District Heating System	Evaluates the energy used by centralized heating systems.
District Cooling System	Measures the energy used by centralized cooling systems.
District Heating Potential	Assesses the potential for using industrial waste heat for district heating.
RES Ratio	Measures the presence of renewable energy systems in the neighborhood.
PV Ratio	Evaluates the presence of photovoltaic systems.
STC Ratio	Measures the presence of solar thermal collectors.
GEO Ratio	Evaluates the presence of geothermal systems.
Potential RES Ratio	Assesses potential for buildings to connect to district-level RES.
PPA and VPPA Contracts	Shows the percentage of buildings with Power Purchase Agreements (PPA) and Virtual PPAs.
SMI Ratio	Measures installation of smart metering systems.

BEMS Ratio	Evaluates the implementation of Building Energy Management Systems (BEMS).
EV Charger Service Ratio	Measures the capacity of EV chargers to meet local fleet needs.
V2G EV Chargers Ratio	Shows the percentage of EV chargers with Vehicle-to-Grid (V2G) capability.
EV Chargers by Building	Measures the number of EV chargers per building.
Transport Mode	Reflects residents' transportation choices using the 'modal split' metric.
Fuel Cars Ratio	Evaluates the presence of fossil fuel-powered vehicles per inhabitant.
EV Cars Ratio	Measures the presence of electric vehicles per inhabitant.
Bike Lanes Ratio	Measures the percentage of road length designated for bike lanes.
Proximity	Assesses accessibility of essential services within walking distance.
Sharing Mobility	Measures adoption of car-sharing services.
Age of the Building Stock	Shows the percentage of buildings over 30 years old in the neighborhood.
Renovated 30-Year-Old Buildings	Measures the percentage of 30+ year-old buildings that have been renovated.
SmartLiving EPC Asset Rating	Shows the efficiency in energy consumption of buildings from SmartLiving EPC.
SmartLiving EPC SRI	Measures a building's ability to host smart-ready services.
SmartLiving EPC LCA	Evaluates the environmental impact of buildings based on their life cycle.
SmartLiving EPC Non-Energy	Measures the impact of non-energy aspects on buildings.
Debt Ratio	Shows the percentage of households late in paying utility bills.
Low Absolute Energy Expenditure	Measures percentage of households with energy expenditures below half the national median.
High Share of Energy Expenditure in Income	Measures percentage of households with energy expenditures above double the national median.
Thermal Comfort Threshold	Measures the percentage of homes not meeting thermal comfort needs.
Heat Island	Measures local temperature increase in urban areas vs peripheral ones.
Air Quality	Measures urban air quality, showing the percentage of the affected population.
Noise	Measures the percentage of the population affected by high noise levels.

The **calculation method** for the neighborhood-level indicators in **SmartLivingEPC** is designed to ensure **accurate, standardized, and scalable assessments**. Each indicator is computed based on **quantifiable metrics**, using **data from municipal records, GIS mapping, surveys, and real-time monitoring systems**.

The **methodology follows three key principles**:

- **Standardization** – Ensuring all calculations align with **European standards (ISO, EPBD, Level(s))**, allowing for cross-city comparisons.
- **Integration with Smart Data** – Leveraging **IoT sensors, smart meters, and GIS mapping** for real-time accuracy.
- **Multi-Source Validation** – Cross-checking values using **municipal databases, national energy reports, and private sector datasets**.

Table 12: Building neighbourhood level KPI’s calculation method

Indicator	**Calculation Method**
Street Lighting	Percentage of neighborhood surface illuminated over total pedestrian areas.
Waste Generation	Total waste generated divided by inhabitants, normalized by national average.
Waste Recycling Rate	Total recycled waste divided by total waste, multiplied by 100.

Wastewater Processing Rate	Percentage of neighborhood covered by wastewater system.
District Heating System	Percentage of building area heated by district systems.
District Cooling System	Percentage of building area cooled by district systems.
District Heating Potential	Percentage of thermal energy consumption covered by residual heat.
RES Ratio	Percentage of buildings with renewable energy installations.
PV Ratio	Percentage of buildings with photovoltaic installations.
STC Ratio	Percentage of buildings with solar thermal collectors.
GEO Ratio	Percentage of buildings with geothermal systems.
Potential RES Ratio	Percentage of buildings that could connect to renewable energy at district level.
PPA and VPPA Contracts	Percentage of buildings with active PPA or VPPA contracts.
SMI Ratio	Percentage of buildings with smart metering systems.
BEMS Ratio	Percentage of buildings with BEMS.
EV Charger Service Ratio	Percentage of cars that can be fully charged daily by installed EV chargers.
V2G EV Chargers Ratio	Percentage of EV chargers with V2G capability.
EV Chargers by Building	Percentage of buildings with EV chargers.
Transport Mode	Modal split metric for transport choices.
Fuel Cars Ratio	Percentage of fossil fuel-powered vehicles per inhabitant.
EV Cars Ratio	Percentage of electric vehicles per inhabitant.
Bike Lanes Ratio	Percentage of road length designated for bike lanes.
Proximity	Percentage of population within 500m of key services.
Sharing Mobility	Percentage of inhabitants using car-sharing services.
Age of the Building Stock	Percentage of buildings over 30 years old.
Renovated 30-Year-Old Buildings	Percentage of renovated buildings over 30 years old.
SmartLiving EPC Asset Rating	SmartLiving EPC efficiency rating.
SmartLiving EPC SRI	SmartLiving EPC Smart Readiness Indicator rating.
SmartLiving EPC LCA	SmartLiving EPC Life Cycle Assessment rating.
SmartLiving EPC Non-Energy	SmartLiving EPC Non-Energy rating.
Debt Ratio	Percentage of households late in paying utility bills.
Low Absolute Energy Expenditure	Percentage of households spending less than half the national median on energy.
High Share of Energy Expenditure in Income	Percentage of households spending more than double the national median on energy.
Thermal Comfort Threshold	Percentage of homes not meeting thermal comfort needs.
Heat Island	Temperature difference between urban and peripheral areas.
Air Quality	Percentage of the population affected by low air quality.
Noise	Percentage of the population affected by high noise levels.

The **SmartLivingEPC neighbourhood-level rating system** relies on **multiple data sources** to ensure accuracy, reliability, and scalability across different urban contexts. The integration of **municipal records, smart sensors, GIS mapping, and survey-based assessments** allows for a **comprehensive evaluation of urban energy performance**.

<u>**Geographic Information Systems (GIS) & Municipal Databases**</u>

Used for: Mapping urban infrastructure, transportation networks, renewable energy installations, and land use.
Examples of Indicators Using GIS Data:

- **Street lighting coverage** (identifying illuminated pedestrian areas).
- **Bike lane ratio** (percentage of roads dedicated to cycling).
- **Proximity to services** (access to essential urban functions like public transport, schools, and healthcare).

Energy Supplier & Utility Company Records

Used for: Analysing energy consumption, renewable energy integration, and smart metering implementation. **Examples of Indicators Using Utility Data**:

- **RES Ratio (Renewable Energy Share)** – Measures the proportion of energy supplied by renewables.
- **Smart Metering Implementation (SMI Ratio)** – Percentage of buildings equipped with smart energy meters.
- **District heating/cooling system efficiency** – Energy used by shared heating/cooling networks.

House-to-House Surveys & Public Administration Reports

Used for: Assessing indoor comfort, energy poverty, and user satisfaction with energy services. **Examples of Indicators Using Surveys**:

- **Thermal Comfort Deficiency** – Percentage of households reporting heating/cooling inadequacy.
- **Low/High Share of Energy Expenditure in Income** – Identifying energy poverty risks.
- **Debt Ratio** – Households facing difficulty in paying energy bills.
- Open Data & National Environmental Agencies

Examples of Indicators Using Open Data:

- **Air Quality Levels** – Percentage of the population exposed to pollution above recommended limits.
- **Heat Island Effect** – Temperature difference between urban cores and suburban areas.
- **Noise Pollution** – Percentage of residents affected by high noise levels.

Private Sector & Mobility Service Providers

Used for: Assessing **electric vehicle (EV) adoption, car-sharing trends, and smart mobility integration**.

Examples of Indicators Using Mobility Data:

- **EV Chargers per Building** – Number of EV chargers installed in the neighborhood.
- **Transport Mode Split** – Percentage of trips made using public transport, bicycles, or electric vehicles.
- **Car-Sharing Adoption** – Percentage of residents using shared mobility solutions.

Table 13: Building neighbourhood level KPI's data source

Indicator	Data Source
Street Lighting	Municipal GIS maps
Waste Generation	Municipal/national observatories
Waste Recycling Rate	Municipal reports
Wastewater Processing Rate	Municipal GIS maps
District Heating System	Municipal GIS/EPC
District Cooling System	Municipal GIS/EPC
District Heating Potential	Municipal GIS/EPC
RES Ratio	House-to-house surveys
PV Ratio	House-to-house surveys
STC Ratio	House-to-house surveys
GEO Ratio	House-to-house surveys
Potential RES Ratio	Municipal GIS/EPC

PPA and VPPA Contracts	Energy company records
SMI Ratio	Energy company records
BEMS Ratio	Energy company records
EV Charger Service Ratio	Municipal GIS/EPC
V2G EV Chargers Ratio	Municipal GIS/EPC
EV Chargers by Building	Municipal GIS/EPC
Transport Mode	Public administration/surveys
Fuel Cars Ratio	House-to-house surveys
EV Cars Ratio	House-to-house surveys
Bike Lanes Ratio	Municipal GIS
Proximity	OpenStreetMap/municipal GIS
Sharing Mobility	Car-sharing companies
Age of the Building Stock	Municipal GIS
Renovated 30-Year-Old Buildings	Municipal GIS
SmartLiving EPC Asset Rating	SmartLiving EPC assessments
SmartLiving EPC SRI	SmartLiving EPC assessments
SmartLiving EPC LCA	SmartLiving EPC assessments
SmartLiving EPC Non-Energy	SmartLiving EPC assessments
Debt Ratio	House-to-house surveys/energy company records
Low Absolute Energy Expenditure	House-to-house surveys/energy company records
High Share of Energy Expenditure in Income	House-to-house surveys/energy company records
Thermal Comfort Threshold	House-to-house surveys
Heat Island	EU Copernicus program
Air Quality	National/local air quality reports
Noise	National/local noise reports

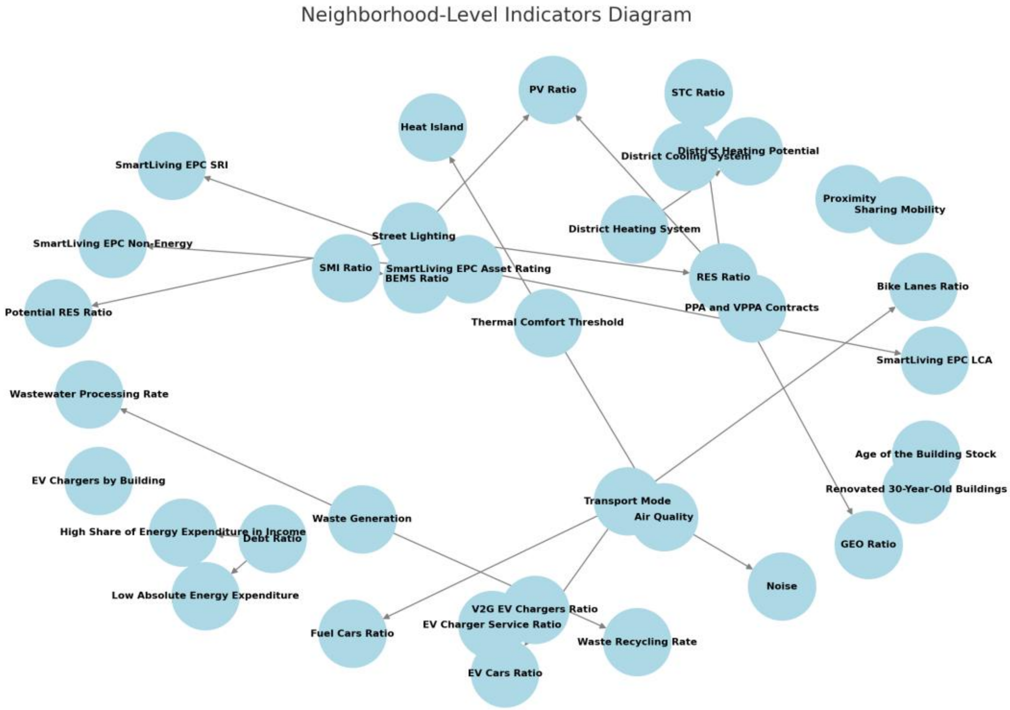


Figure 34: Example of Building Neighbourhood KPI's interactions

5.2 Rating assessment and benchmarking procedures of the SLEPC building complex

The SmartLivingEPC (SLEPC) grading system's weighting method allows each Key Performance Indicator (KPI) to be assigned a **constant weight of 2.70, signifying equal significance**. This approach disregards specific community demands even if it simplifies the process. As an alternative, the weighting might be altered to accommodate local officials' or inhabitants' unique needs and cultural norms. By include stakeholders in the weighing process, this participatory action technique makes sure the weights align with the goals and interests of the community. Local stakeholders find the certification more acceptable and significant since this method allows neighborhoods to include their own identity and criteria into the final rankings. There are several advantages of using participatory weighing. It enables various communities to place differing values on various subjects, guaranteeing that the finished certificate honors local requirements and character. It also allows residents to customize neighborhood weights based on their preferences. Additionally, by avoiding direct neighborhood comparisons, this method helps to prevent conflicts and makes it easier to apply the SLEPC tool politically and administratively. **Three weighting options are provided by the method: a Generic Rating with equal weights, a Neighborhood Rating that uses participatory techniques, and a European Rating that reflects more general preferences gleaned from surveys.** This adaptability ensures that the method works for a variety of needs and circumstances, ranging from local community evaluations to more broad municipal or individual assessments.

DIMENSION	CATEGORY	INDICATOR	PROJECT VALUE	DEFAULT WEIGHTING	Class	RATING				
Environmental	Neighborhood services	Street Lighting and public area lighting	55	2.7	D	65	53	C	D	D
		Waste Generation	60	2.7	D					
		Waste Recycling rate	95	2.7	A					
		Wastewater Processing rate	85	2.7	B					
		District Heating System	18	2.7	G					
		District Cooling System	90	2.7	A					
		District Heating Potential	54	2.7	D					
	Renewable Energies	RES ratio	45	2.7	E	48		E		
		PV ratio	25	2.7	F					
		STC ratio	24	2.7	F					
		GEO ratio	85	2.7	B					
		Potential RES ratio	60	2.7	D					
	Demand Side Management	PPA and VPPA contracts	85	2.7	B	46		E		
		SMI ratio	48	2.7	E					
		BEMS ratio	5	2.7	G					
Infrastructure	EV chargers	EV charger service ratio	45	2.7	E	39	44	E	E	
		V2G EV chargers ratio	25	2.7	F					
		EV chargers by building	48	2.7	E					
	Mobility and transport	Modal Split	35	2.7	E	48		E		
		Fuel Cars ratio	18	2.7	G					
		EV Cars ratio	45	2.7	E					
		Bike lanes ratio	85	2.7	B					
		Proximity	85	2.7	B					
		Shared Mobility	18	2.7	G					
	Neighborhood Building Inventory	Age of the building stock	5	2.7	G	44		E		
		Renovated 30-year-old buildings	85	2.7	B					
		SmartLivingEPC Asset Rating	65	2.7	C					
		SmartLivingEPC SRI	49	2.7	E					
		SmartLivingEPC LCA	32	2.7	F					
		SmartLivingEPC Non Energy	28	2.7	F					
Social	Energy poverty	Debt ratio	18	2.7	G	71	69	C	C	
		Low absolute energy expenditure	85	2.7	B					
		High share of energy expenditure in income	85	2.7	B					
		Thermal comfort threshold	95	2.7	A					
	Quality of Life	Heat Island	100	2.7	A	68		C		
		Air Quality	80	2.7	B					
		Noise	24	2.7	F					
			53.8	100						

Figure 35: Example of complex asset rating

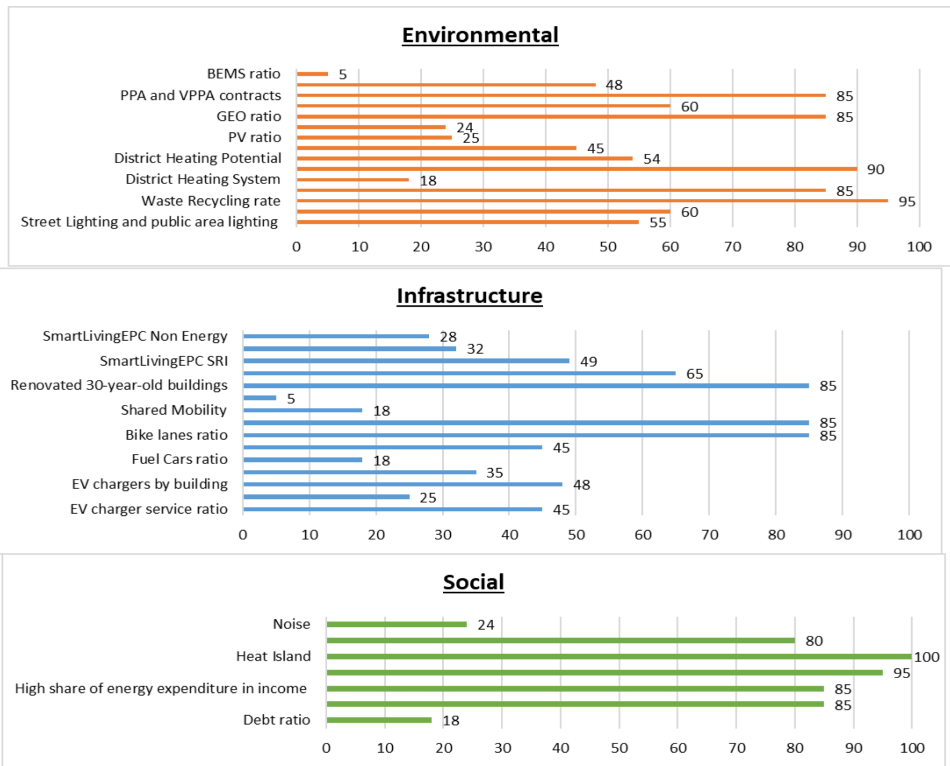


Figure 36: Example of data presentation

5.3 Interactions between buildings and shared energy resources

Buildings are now linked parts of urban energy networks as energy systems develop rather than independent entities. Beyond single building evaluations, the SmartLivingEPC framework guarantees a systematic approach to energy efficiency, decarbonization, and resilience by including interconnections between buildings and shared energy resources.

This section investigates how shared resources such district heating, renewable energy installations, and storage systems affect energy performance at a communal level as well as how buildings interact with one another and how energy flows within a community.

5.4 Smart grids and local energy communities

Supporting local energy communities—where many buildings coordinate energy generation, consumption, and storage for best efficiency—smart grids have become vital. Smart grids and local energy communities have emerged from the shift toward distributed rather than centralized energy systems, therefore changing the way energy is generated, transported, and used. These ideas are included into the SmartLivingEPC framework's building and neighborhood rating system to guarantee fit with future energy trends.

The function of smart grids, the rise of local energy communities, and how these changes improve energy efficiency, flexibility, and resilience at the neighborhood level are examined in this part.

An advanced electrical network integrating digital connectivity, automation, and real-time data analytics to maximize energy output, delivery, and consumption is a smart grid. Unlike conventional networks, which run on a one-way energy flow model, smart grids let buildings participate as both consumers and producers ("prosumers"), therefore enabling two-way energy exchange.

6 SmartLivingEPC outcomes

6.1 Certification and labelling framework

The SmartLivingEPC (SLEPC) Certificate is designed to give a comprehensive overview of a building's performance, including its energy efficiency, environmental impact, and smart preparedness. Offering a thorough rundown of the building's attributes and performance metrics, the certificate's UI is designed to be both user-friendly and instructive. The certificate begins by listing the building's address, geolocation (latitude and longitude), type (residential or commercial), physical data (total floor area, volume, and year of construction), and local climate.
By providing an overall grade that is broken down into categories like energy consumption, renewable ratio, interior comfort, LCA indications, and smart readiness, the performance summary provides a concise overview of the building's benefits and drawbacks. Additionally, it outlines the building's future potential and provides recommendations for improving its performance class. The detailed metrics include energy indicators (delivered energy, primary non-renewable and renewable energy, exported energy, all in kWh/m2), environmental indicators (Life Cycle Global Warming Potential), and non-energy performance metrics (indoor air quality, thermal comfort, and water efficiency) in addition to smart readiness. Every subcategory has a score and a classification.
The certificate number, issuing date, validity period, and signature of the energy assessor are among the administrative details provided for authentication. The certificate also includes graphical representations of these metrics. The SLEPC Certificate is intended to be a thorough evaluation tool for assessing a building's performance. It offers a comprehensive assessment that goes beyond what traditional energy certifications can offer. By combining a wide range of indicators and useful insights, the initiative's main goal is to improve building performance and support more general sustainability goals.

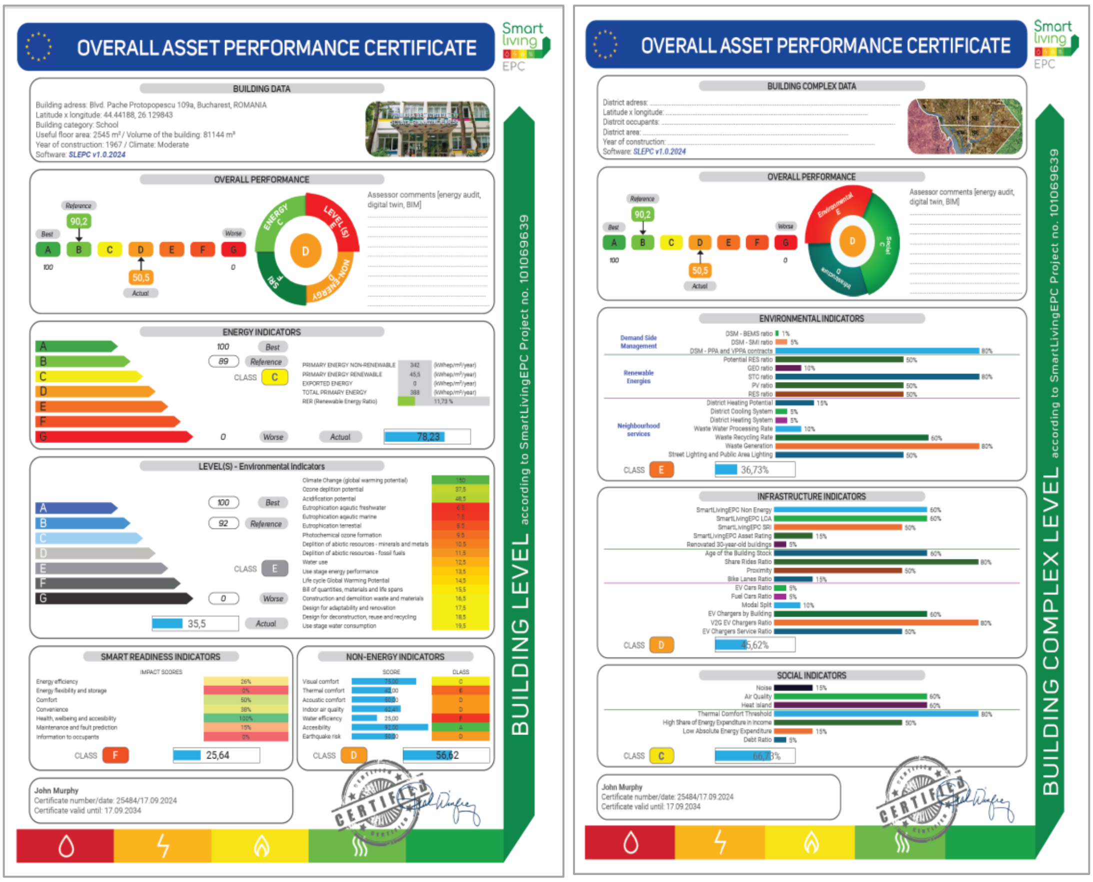


Figure 37: Proposed model for SLEPC certificate – building level and building complex (district) level

The SmartLivingEPC (SLEPC) certificate evaluates energy efficiency, non-energy indicators, Life Cycle Assessment (LCA), and smart readiness indicators to classify buildings in performance classes A through G. The SmartLivingEPC has a 0–100 score and an A–G labeling and performance classification system.

Regarding energy indicators: Low primary energy use and lots of renewable energy make Class A buildings the most energy-efficient. As grades drop to G, energy efficiency drops significantly. Due to their high energy use, non-renewable energy use, and absence of renewable energy, Class G buildings have inefficient heating systems. **Non-Energy Indicators:** Class A buildings perform best in indoor air quality, thermal comfort, noise protection, visual comfort, accessibility, seismic risk, and water efficiency due to advanced supplies and technology. These traits worsen with lower performance classes. Class G buildings need repairs due to poor indoor air quality, inefficient heating and cooling, and excessive water use from outdated plumbing.

Life-cycle assessment indicators: A buildings have a low carbon footprint, resource efficiency, and environmental impact due to their sustainable materials and methods.

Indicates Smart Readiness: Class A buildings use cutting-edge smart technologies and building management systems for complete control and monitoring. Classes below G reduce management system efficiency and smart technology adoption. Due to outdated management systems and no smart technology integration, Class G buildings need major upgrades.

The numerical rating within each class provides a more specific insight of the building's performance and guides owners to opportunities for improvement.

7 Conclusions

The **SmartLivingEPC methodology** represents a **significant advancement** in the field of **building energy performance assessment**, incorporating **energy, non-energy, environmental, and smart readiness indicators** into a comprehensive rating framework. The third version of the **SmartLivingEPC Asset Rating Calculation Methodology (D2.7)** refines previous versions by enhancing **methodological clarity and expanding assessment metrics**.

Key Takeaways from SmartLivingEPC D2.7:

1. **Enhanced Energy Performance Metrics**
    - The methodology provides **detailed calculations** for primary and final energy consumption, renewable energy integration, and grid interaction.
    - It ensures compliance with **ISO 52000-1** and the **Energy Performance of Buildings Directive (EPBD)**.
    - A refined **energy classification system (A-G)** simplifies the interpretation of a building's performance.
2. **Integration of Non-Energy Indicators**
    - Beyond energy consumption, the framework evaluates **Indoor Environmental Quality (IEQ)**, including **thermal comfort, visual comfort, acoustic comfort, and indoor air quality**.
    - Structural resilience, **earthquake risk**, and **building accessibility** are integrated into the assessment.
    - The methodology incorporates **radon risk analysis**, a critical health factor often overlooked in traditional EPCs.
3. **Life-Cycle Environmental Impact Assessment**
    - The methodology integrates **Life Cycle Assessment (LCA)**, in line with the **EU Level(s) framework**, ensuring a **whole-building sustainability perspective**.
    - It accounts for **carbon emissions (Global Warming Potential - GWP), water usage, material recyclability, and pollution impact**.
    - SmartLivingEPC aligns with **Directive (EU) 2024/1275**, ensuring **mandatory GWP reporting** and contributing to future **benchmarking of environmental performance**.
4. **Smart Readiness and Digitalization**
    - The methodology integrates the **Smart Readiness Indicator (SRI)**, evaluating a building's adaptability to **smart technologies, automation, and energy flexibility**.
    - It ensures compatibility with **Building Information Modeling (BIM) and Digital Building Logbooks (DBLs)**, enhancing the **accuracy and transparency of EPCs**.
    - Real-time monitoring and **IoT-enabled performance tracking** bridge the gap between theoretical energy assessments and actual building operations.
5. **Expansion to Neighborhood-Level Assessments**
    - The framework extends **beyond individual buildings**, incorporating **neighborhood-level energy and environmental KPIs**.
    - It evaluates **shared energy infrastructure**, including **district heating/cooling systems, microgrids, and peer-to-peer energy trading**.
    - SmartLivingEPC supports the **development of Local Energy Communities (LECs)**, aligning with the **EU's smart city and energy transition goals**.
6. **Pilot Validation and Practical Implementation**

- The methodology was tested on the **Frederick University pilot building**, validating the **reliability and scalability** of the SmartLivingEPC rating system.
- Results demonstrate the **practical application of smart energy monitoring, EPC automation, and advanced rating methodologies**.
- The study highlights **opportunities for improving energy efficiency, reducing carbon emissions, and enhancing building sustainability**.

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