D3.7 Operational rating Calculation methodology of SmartLivingEPC v3

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1.0	**Paris Fokaides**	**20.03.2015**	**V3 of D3.7 ready for submission**

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Executive Summary

This deliverable presents the third version (v3) of the operational rating calculation methodology developed under the SmartLivingEPC framework, as part of the objectives of Work Package 3. This work package aims to establish a comprehensive framework for operational energy performance assessments that align with European standards and cater to real-world building requirements. A key element of WP3 is Task 3.5, which focuses on enhancing the operational rating methodology by integrating dynamic energy performance metrics with sustainability indicators such as indoor environmental quality (IEQ), renewable energy contributions, and lifecycle cost assessments. Task 3.5 also plays a significant role in ensuring that the methodology remains adaptable to diverse building typologies and climates.

Building on the foundational methodology outlined in Deliverable 3.6, the updated framework in this deliverable incorporates refinements driven by insights from pilot studies, data from advanced monitoring tools, and feedback from stakeholders. Key improvements include the incorporation of normalization processes for climatic and occupancy variations, expansion of metrics to include carbon footprint assessments, and integration with digital logbook technologies from Task 4.4 to streamline data tracking and reporting. The refined weighting scheme introduced in this version further enhances the operational rating framework by enabling a balanced evaluation of energy, environmental, and financial indicators. This approach ensures robust compliance with EN 52000 and positions the methodology as a key tool for achieving the overarching goals of SmartLivingEPC.

The deliverable aims to provide a detailed account of the updated methodology, including its theoretical underpinnings, practical implementation, and validation results. By addressing both energy performance and broader sustainability metrics, this iteration enhances the robustness and applicability of the SmartLivingEPC framework.

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List of Acronyms and Abbreviations

Term	Description
EPC	Energy Performance Certificate
AHP	Analytic Hierarchy Process
BMS	Building Management System
CO_2	Carbon Dioxide
DHW	Domestic Hot Water
EN	European Norm (Standard)
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
kWh	Kilowatt-hour
LCC	Life Cycle Cost
MV	Mean Vote
PCA	Principal Component Analysis
ppm	Parts Per Million
R	Event Reproduction Number
TVOCs	Total Volatile Organic Compounds
WSM	Weighted Sum Model

1 Introduction

1.1 Scope and objectives of the deliverable

The SmartLivingEPC project aims to transform building energy performance certification by transitioning from static, design-based assessments to operational performance-based evaluations. This transformation is driven by the growing integration of real-time monitoring technologies, which enable continuous tracking and analysis of building performance. Incorporating metrics related to occupant behavior, energy consumption patterns, and indoor environmental quality (IEQ) allows for a more accurate and dynamic assessment of building performance. This approach also aligns with standards such as EN 52000, which emphasize the importance of operational data in defining energy efficiency and sustainability benchmarks. By addressing these aspects, the project seeks to establish a methodology that is both practical for real-world applications and adaptable to diverse building typologies. Deliverable 3.3 and 3.6 introduced a foundational methodology for operational ratings, addressing energy consumption, weather normalization, and user preferences. However, gaps remained, particularly in integrating broader sustainability metrics and refining calculation procedures.

1.2 Structure of the deliverable

Deliverable 3.7 follows a structured approach to present the updated methodology for operational rating calculations under the SmartLivingEPC framework. The document begins with an Introduction (Section 1), outlining the scope, objectives, and relation to other tasks and deliverables within the project. Section 2 introduces the key terminology relevant to building energy performance, covering energy calculation procedures, energy concepts, technical building systems, and performance metrics. The core methodology begins in Section 3, which defines the indicators used for operational rating, including energy performance, environmental quality, and Life Cycle Costing (LCC). It also discusses the rationale behind selecting these indicators and their significance in assessing building performance. Section 4 details the selection process for indicators, refining the methodology from an initial set of 71 indicators to a focused group of 15 key metrics. These indicators ensure a balance between comprehensiveness and practical application while considering data availability and regulatory compliance. Section 5 focuses on the weighting methods, with a primary emphasis on the Weighted Sum Model (WSM) used for scoring. It further explores alternative weighting techniques such as Principal Component Analysis (PCA) and Analytic Hierarchy Process (AHP). The section also addresses challenges in indicator weighting, including normalization, selection criteria, and non-linearity considerations. Section 6 outlines the thresholding methodology, explaining how performance benchmarks are established for various indicators. It describes the process of setting thresholds for energy efficiency, indoor environmental quality, and Life Cycle Costing (LCC) indicators to ensure comparability across building types and climate conditions. Section 7 provides a structured calculation framework, detailing the input data requirements, data sources, and the step-by-step methodology used to compute operational ratings. The methodology aligns with EN 52000-1 standards, ensuring consistency with European energy performance benchmarks. Section 8 presents the validation and case study results, demonstrating the practical application of the operational rating methodology. It evaluates how well the proposed system performs across different building types and climates, incorporating feedback from pilot studies and real-world implementations. The document concludes in Section 9, summarizing key findings, highlighting areas for further refinement, and outlining the next steps in improving the SmartLivingEPC operational rating methodology. Supporting materials are provided in the Annexes (A, B, C), offering additional technical details, validation datasets, and supplementary explanations.

1.3 Relation to Other Tasks and Deliverables

Deliverable 3.7 is a core part of the SmartLivingEPC framework, integrating inputs to create a detailed operational rating methodology that directly supports the platform's development. It builds on Deliverable 3.6, which established the basic framework for energy performance and operational assessments and expands it with additional contributions from various tasks. Task 3.2 provides critical real-world data from monitoring and operational evaluations, ensuring the methodology is practical and can be applied across diverse building types. Task 3.3 adds to the framework by including sustainability metrics such as indoor environmental quality (IEQ) and renewable energy contributions, broadening the scope of operational assessments. Task 4.4 supports this process by facilitating data integration and accessibility through digital logbooks, which link operational data with platform functionalities. The deliverable serves as a key input for further tasks and deliverables within the project. It informs Deliverable 4.2 by supplying data necessary for retrofitting and optimizing buildings. It supports Task 5.1 by providing the framework for refining digital tools, including APIs and interoperability measures, to enhance platform functions. Task 6.3 uses the operational rating methodology to validate its effectiveness and scalability through pilot demonstrations. The deliverable combines these contributions, ensuring an uninterrupted flow of data and ongoing refinements to the methodology, enabling the seamless integration of operational assessments into the SmartLivingEPC platform.

2 Key Terminology for Building Energy Performance

This section provides a structured overview of essential concepts relevant to assessing the energy efficiency of buildings. The definitions align with ISO 52000-1:2017, ensuring a standardized approach to evaluation.

Energy Calculation Procedures

- **Assessment Period:** Timeframe over which energy efficiency is evaluated.
- **Calculation Interval:** The periodic steps used to assess energy performance.
- **Calculation Period:** The defined span used in computational energy assessments.
- **Heating or Cooling Season:** The seasonal duration during which significant energy consumption is required for thermal regulation.

Energy Concepts

- **Air Conditioning:** A process that involves regulating temperature, ventilation, humidity, and filtration.
- **Energy Carrier:** Any medium (electricity, gas, or biomass) that enables the generation of heat, mechanical work, or chemical reactions.
- **Delivered Energy:** The energy supplied to building systems, categorized by its source.
- **Non-Renewable Energy:** Energy sourced from finite reserves such as fossil fuels.
- **Renewable Energy:** Energy derived from replenishable sources like wind, solar, and geothermal.
- **Primary Energy:** Unprocessed energy in its natural state before transformation.
- **Total Energy:** The cumulative amount of renewable and non-renewable energy consumed.

Buildings and Their Components

- **Assessed Object:** A designated structure or portion thereof undergoing energy evaluation.
- **Building:** The complete physical and technical infrastructure regulating indoor climate and services.
- **Building Fabric:** The physical elements of a building, excluding technical systems.
- **Thermal Zone:** A designated indoor space maintaining uniform temperature conditions.
- **Reference Floor Area:** A standardized metric for energy performance comparison.
- **Thermally Conditioned Space:** An area that is heated or cooled.
- **Thermally Unconditioned Space:** An enclosed space that does not receive heating or cooling.
- **Useful Floor Area:** Floor space utilized in zoning and energy assessment calculations.

Indoor and Outdoor Environmental Factors

- **Design Condition:** A set of parameters assessing air quality, lighting, temperature, and acoustics.
- **External Temperature:** The temperature of outdoor air.
- **Internal Temperature:** The calculated mean of air and radiant temperatures inside a thermal zone.

Technical Building Systems

- **Air Conditioning System:** An integrated system managing temperature, ventilation, humidity, and filtration.
- **Building Automation and Control:** Systems overseeing monitoring, optimization, and energy efficiency.
- **Technical Building System:** A collection of mechanical systems responsible for heating, cooling, lighting, and ventilation.
- **Technical Building Sub-System:** A functional component within a technical system, such as heat generation or distribution.

Energy Performance Metrics

- **Actual Measured Energy:** Energy consumption recorded without adjustments.
- **Calculated Energy Performance:** Performance computed through simulations.
- **Measured Energy Performance:** Energy use assessed via monitoring.
- **CO2 Emission Coefficient:** A factor indicating the amount of CO2 emitted per unit of energy use.
- **Primary Energy Indicator:** The ratio of primary energy demand per unit of reference area.
- **Reference Value:** A benchmark against which energy indicators are assessed.

- **Total Primary Energy Factor:** A coefficient integrating both renewable and non-renewable primary energy sources.

3 Definition of Indicators

3.1 Introduction

Indicators used to define the operational energy performance of a building are pivotal in shaping its efficiency, environmental impact, and user experience. They are essential tools for building managers and stakeholders to make informed decisions that lead to more sustainable, cost-effective, and occupant-friendly buildings. As the world moves towards more environmentally conscious building practices, the role of these indicators becomes increasingly central in the construction industries.

The operational energy performance of a building, a crucial aspect of modern architecture and sustainability, hinges significantly on the use of indicators. These indicators serve as tangible metrics that help quantify, analyze, and improve a building's energy efficiency, environmental impact, and user comfort. Understanding the importance of these indicators in defining a building's operational energy performance requires a multi-dimensional view that encompasses energy consumption, environmental impact, and occupant wellbeing.

Indicators for energy performance are vital for assessing how much energy a building consumes and the effectiveness of its energy systems. By monitoring energy use over time, these indicators can reveal patterns in energy consumption, prompting targeted strategies for energy conservation. This not only reduces operational costs but also minimizes the carbon footprint, aligning with global efforts to combat climate change. Environmental indicators, such as greenhouse gas emissions and resource utilization, are equally important. They measure the impact a building has on its surroundings. For instance, a building with high greenhouse gas emissions contributes more significantly to climate change. By tracking these indicators, building managers can implement strategies that reduce emissions, such as utilizing renewable energy sources or enhancing insulation.

Occupant wellbeing is another critical aspect that is increasingly being integrated into operational energy performance indicators. Metrics like indoor air quality, thermal comfort, and lighting quality directly impact the health and productivity of the building’s users. Poor indoor air quality, for instance, can lead to health issues, while inadequate lighting can affect mood and efficiency. Therefore, these wellbeing aspects are essential for creating spaces that are not only energy efficient but also comfortable and healthy for occupants.

Life Cycle Cost (LCC) indicators are crucial for assessing the long-term financial sustainability of a building. They encompass all costs associated with the building's lifespan, including construction, operation, maintenance, and disposal. LCC indicators help in making informed decisions about building materials, design, and operational strategies, aiming to minimize overall expenses while maintaining quality and efficiency. They are especially important in sustainable building practices, where the focus is not just on upfront costs but on reducing total expenditure and environmental impact over the building's life.

Moreover, the use of smart technology in buildings has revolutionized how these indicators are measured and analyzed. Smart meters and IoT (Internet of Things) devices can continuously monitor various aspects of a building's performance, providing real-time data. This data enables more precise adjustments to improve energy efficiency and occupant comfort. Additionally, it allows for predictive maintenance, where potential issues can be addressed before they escalate into significant problems, thus saving costs and reducing downtime.

3.2 Definition of individual indicators

In the specified section of the deliverable, a comprehensive presentation of operational energy indicators, initially identified in D3.1, is provided. These indicators are tabulated, facilitating an organized and clear understanding of each metric. The table format is intuitive and informative, listing the "Indicator Name," the "Units" in which each indicator is measured, and the "Operational Calculation Methodology" upon which each indicator is based. This structured approach not only enhances readability but also ensures that each indicator is distinctly understood in terms of its measurement and calculation basis.

These operational energy indicators are pivotal in evaluating the operational stage of a building. They encompass a broad spectrum of aspects that are crucial for assessing a building's performance during its use phase. The indicators are categorized into three primary domains: energy consumption, human well-being, and Life Cycle Cost (LCC) of the building.

Energy Consumption: This category includes indicators that directly measure the amount of energy used by the building during its operation. These metrics are essential for understanding the building's energy efficiency and are typically measured in units like kilowatt-hours (kWh). They provide insights into how effectively the building is using energy and highlight areas where energy usage can be optimized. The operational calculation methodologies for these indicators involve analyzing energy meter readings, monitoring systems, and utilizing algorithms that account for various operational parameters.

Human Well-Being: This category focuses on indicators that assess the impact of the building on its occupants' health and comfort. These include parameters like indoor air quality, virus risk, thermal comfort, lighting quality, and acoustic environment. Measured in various units such as parts per million (ppm) for air quality or decibels (dB) for sound levels, these indicators are crucial for ensuring that the building provides a conducive environment for its occupants. The calculation methodologies here might involve sensor data, occupant surveys, and environmental monitoring systems.

Life Cycle Cost (LCC): LCC indicators are integral for evaluating the overall cost-effectiveness of the building throughout its life cycle. These indicators consider not only the initial construction costs but also ongoing operational expenses, maintenance, and eventual decommissioning costs. Measured in monetary units, LCC indicators help in understanding the long-term financial implications of building design and operational choices. The methodologies for calculating LCC often involve comprehensive financial modeling and analysis of historical cost data.

The tabulation of these operational energy indicators in the deliverable is a critical step in providing a holistic view of a building's performance during its operational phase. By covering aspects of energy consumption, human well-being, and LCC, the table offers a detailed and multifaceted perspective on building performance, essential for informed decision-making and effective building management.

#	Indicator Name	Units	Operational calculation methodology based on
1	Ventilation rate (airflow)	$L/s/m^2$	EN 16798-1:2019
2	Total Volatile Organic Compounds (TVOCs)	$\mu g/m^3$	EN 16798-1:2019
3	Benzene	$\mu g/m^3$	EN 16798-1:2019
4	CO_2 indoors	ppm	EN 16798-1:2019
5	Formaldehyde	$\mu g/m^3$	EN 16798-1:2019
6	Radon	Bq/m^3	EN 16798-1:2019
7	Particulate matter <2,5 µm (PM 2.5)	$\mu g/m^3$	EN 16798-1:2019
8	Particulate matter <10 µm (PM 10)	$\mu g/m^3$	EN 16798-1:2019
9	Event reproduction number – R	-	REHVA proposal for post-COVID[1]

[1] Health-based target ventilation rates and design method for reducing exposure to airborne respiratory infectious diseases. REHVA proposal for post-COVID target ventilation rates. Rehva 2022 https://www.rehva.eu/activities/post-covid-ventilation

#	Indicator Name	Units	Operational calculation methodology based on
1	Operative Temperature	°C	EN 16798-1:2019 EN ISO 52000-1
2	Predicted Mean Vote	%	EN 16798-1:2019
3	Predicted Percentage of Dissatisfied	%	EN ISO 52000-1
4	Heating Degree Days	°C-day	EN 16798-1:2019
5	Cooling Degree Days	°C-day	EN ISO 52000-1

The energy consumption indicators are summarized in the following tables.
The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters.

#	Indicator Name	Units	Operational calculation methodology based on
1	Lighting energy consumption per total floor area	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
2	Lighting per thermally conditioned space	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
3	Lighting per thermally unconditioned space	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
4	Lighting per useful floor area	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
5	Lighting per cooled space	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
6	Lighting per elementary space	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
7	Lighting per heated space	kWh/ m^2	EN ISO 52000-1:2017, 3.4.16
8	Building's Occupancy Correction Factor - Lighting Consumption	---	EN ISO 52000-1:2017, 3.4.16

The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters. The sensor is a power meter for heating consumption.

#	Indicator Name	Units	Operational calculation methodology based on
1	Heating energy consumption per total per floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18
2	Heating per thermally conditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
3	Heating per thermally unconditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
4	Heating per useful floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18
5	Heating per elementary space	kWh/ m^2	EN 52000-1:2017, 3.4.18
6	Heating per heated space	kWh/ m^2	EN 52000-1:2017, 3.4.18
7	Climate Condition Correction Factor - Heating Energy Consumption	---	EN 52000-1:2017, 3.4.18

The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters.

#	Indicator Name	Units	Operational calculation methodology based on
1	Cooling energy consumption per total per floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18

2	Cooling per thermally conditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
3	Cooling per thermally unconditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
4	Cooling per useful floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18
5	Cooling per cooled space	kWh/ m^2	EN 52000-1:2017, 3.4.18
6	Cooling per elementary space	kWh/ m^2	EN 52000-1:2017, 3.4.18
7	Climate Condition Correction Factor - Cooling Energy Consumption	---	EN 52000-1:2017, 3.4.18

The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters. The sensor is a power meter for ventilation consumption.

Table 1: Indicators for ventilation

#	Indicator Name	Units	Operational calculation methodology based on
1	Ventilation energy consumption per total per floor area	kWh/ m^2	EN 52000-1:2017, 3.4.19
2	Ventilation per thermally conditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.19
3	Ventilation per thermally unconditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.19
4	Ventilation per useful floor area	kWh/ m^2	EN 52000-1:2017, 3.4.19
5	Ventilation per cooled space	kWh/ m^2	EN 52000-1:2017, 3.4.19
6	Ventilation per elementary space	kWh/ m^2	EN 52000-1:2017, 3.4.19
7	Ventilation per heated space	kWh/ m^2	EN 52000-1:2017, 3.4.19
8	Building's Occupancy Correction Factor - Ventilation Consumption	---	EN 52000-1:2017, 3.4.19

The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters. The sensor is a power meter for electricity consumption.

Table 2: Indicators for energy use of other services

#	Indicator Name	Units	Operational calculation methodology based on
1	Electrical appliances energy consumption per total floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
2	Electrical appliances energy use per thermally conditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
3	Electrical appliances energy use per thermally unconditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
4	Electrical appliances energy use per useful floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
5	Electrical appliances energy use per cooled space	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
6	Electrical appliances energy use per elementary space	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
7	Electrical appliances energy use per heated space	kWh/ m^2	EN 52000-1:2017, 3.4.18 & 3.4.17
8	Building's Occupancy Correction Factor – Electrical Appliances Energy Usage	---	EN 52000-1:2017, 3.4.18 & 3.4.17

The input for these indicators involves the real-time measurement obtained by building automation and control systems, as well as by smart meters. The sensor is a power meter for electricity consumption.

Table 3: Indicators for water heating

#	Indicator Name	Units	Operational calculation methodology based on
1	Domestic hot water energy consumption per total floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18
2	Water heating consumption per thermally conditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
3	Water heating consumption per thermally unconditioned space	kWh/ m^2	EN 52000-1:2017, 3.4.18
4	Water heating consumption per useful floor area	kWh/ m^2	EN 52000-1:2017, 3.4.18
5	Water heating consumption per cooled space	kWh/ m^2	EN 52000-1:2017, 3.4.18
6	Water heating consumption per elementary space	kWh/ m^2	EN 52000-1:2017, 3.4.18
7	Water heating consumption per heated space	kWh/ m^2	EN 52000-1:2017, 3.4.18
8	Building's Occupancy Correction Factor – Water Heating Consumption	---	EN 52000-1:2017, 3.4.18

The financial indicators are summarized in the following tables.
The input for these indicators involves the asset energy consumption of the building per energy price.

Table 4: Indicators as-designed

#	Indicator Name	Units	Operational calculation methodology based on
1	Total energy cost per square meter per month	€/m2/month	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1
2	Total energy cost per square meter per year	€/m2/year	

The input for these indicators involves the actual energy consumption of the building per use (heating, cooling, ventilation, lighting, appliances) or per carrier (gas and electricity), per energy price.

Table 5: Indicators as-operated

#	Indicator Name	Units	Operational calculation methodology based on
1	Cost per energy use per square meter per month	€/m^2/month	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1
2	Cost per energy use per square meter per year	€/m^2/year	
3	Cost per energy carrier per square meter per month	€/m^2/month	
4	Cost per energy carrier per square meter per year	€/m^2/year	
5	Total energy cost per square meter per month	€/m^2/month	

6	Total energy cost per square meter per year	€/m²/year	
7	Cost of Heating per Floor Area per Year	€/m²/year	
8	Cost of Cooling per Floor Area per Year	€/m²/year	
9	Cost of Lighting per Floor Area per Year	€/m²/year	
10	Cost of Domestic Hot Water per Floor Area per Year	€/m²/year	

The input for these indicators involves the actual energy consumption of the building per use (heating, cooling, ventilation, lighting, appliances) or per carrier (gas and electricity), energy price, future maintenance and operation costs, parameters (discount rate, inflation, etc.).

Table 6: Indicators predicted

#	Indicator Name	Units	Operational calculation methodology based on
1	Cost per energy use per square meter for ten (10) years	€/m²	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1
2	Cost per energy carrier per square meter for ten (10) years	€/m²	
3	Total energy cost per square meter for ten (10) years	€/m²	

4 Selection of Indicators

4.1 Introduction

In Section 2 of the deliverable, a comprehensive set of 71 indicators was meticulously presented, providing an extensive framework for assessing various aspects of building performance. However, to streamline the evaluation process and enhance practicality, the methodology has been refined to select 15 indicative indicators. These chosen indicators represent a balanced coverage of all critical aspects: energy consumption, human well-being, and Life Cycle Cost (LCC), culminating in the delivery of the SmartLivingEPC rating.

The selection process for these 15 indicators was not arbitrary; it followed a rigorous methodology to ensure that they collectively provide a comprehensive overview of a building's operational performance. This methodology involved analyzing the relevance, measurability, and impact of each of the 71 indicators, narrowing them down to a more manageable yet representative subset. The chosen indicators are not just individual metrics but are synergistic, each adding a unique dimension to the overall assessment.

For energy consumption, indicators were selected to reflect the building's efficiency in using energy resources. These include metrics like energy intensity, renewable energy usage, and peak energy demand. These indicators are crucial as they directly influence the building's environmental footprint and operational costs.

In the domain of human well-being, indicators focus on the environmental quality and comfort within the building. Metrics such as indoor air quality, thermal comfort, and virus risk were chosen. These indicators are essential as they directly affect the health, productivity, and satisfaction of the occupants, making them central to sustainable building practices.

Lastly, the LCC indicators chosen provide insights into the economic aspect of the building's operation. They encompass not just the upfront construction costs but also the ongoing maintenance, utility costs, and potential future expenses. This holistic financial view is vital for long-term sustainability and cost-effectiveness.

By consolidating these 15 indicators into the SLE rating, the methodology offers a balanced, multidimensional evaluation of a building's performance. This approach ensures that the SLE rating is not only comprehensive but also practical and applicable across a wide range of buildings, providing a valuable tool for stakeholders in making informed decisions about building design, operation, and management.

4.2 Key considerations in selecting building operational rating indicators

The selection of indicators for assessing the operational performance of buildings is a complex process guided by various criteria. These criteria ensure that the chosen indicators are not only pertinent and reliable but also practical and effective in measuring and improving building performance. In the context of the deliverable, five key criteria were employed: relevance to building performance, availability and reliability of data, methods for evaluating and selecting indicators, challenges and limitations in indicator selection, and thresholding.

Relevance to Building Performance:
The criterion of relevance to building performance is foundational in the selection of indicators for assessing a building's operational efficiency and sustainability. This relevance is not a one-size-fits-all measure; it varies significantly depending on the type and function of the building in question. The primary focus of this criterion is

to ensure that each indicator chosen is directly and meaningfully connected to key aspects of building performance, such as energy efficiency, environmental sustainability, and occupant comfort and well-being.

For a residential building, the indicators must reflect the living conditions and comfort of the occupants. In this context, thermal comfort becomes a pivotal indicator, as it directly affects the residents' quality of life. Thermal comfort indicators would measure the effectiveness of the building's heating, ventilation, and air conditioning systems in maintaining temperature and humidity levels that are conducive to the occupants' comfort. Similarly, indoor air quality is another crucial indicator for residential buildings. It involves measuring the levels of pollutants and ensuring adequate ventilation, which are essential for the health and well-being of the residents. In contrast, for commercial buildings or industrial facilities, the emphasis often shifts towards energy efficiency and operational cost-effectiveness. Here, indicators such as energy consumption per unit area, the efficiency of lighting and heating systems, and the use of renewable energy sources become more prominent. These indicators are vital for not only reducing operational costs but also for minimizing the environmental footprint of the building. For example, a commercial building might employ advanced energy metering systems to provide detailed insights into energy usage patterns, enabling targeted strategies to reduce energy consumption.
Furthermore, in educational or healthcare facilities, additional specific indicators might be relevant. For instance, in a school, lighting quality can impact the learning environment, while in a hospital, the control of infection rates and maintaining specific environmental conditions become crucial.
Additionally, the relevance of an indicator can be influenced by geographic and climatic considerations. Buildings in areas with extreme weather conditions might require indicators focused on insulation efficiency and resilience to environmental stressors. In contrast, buildings in urban settings might prioritize indicators related to noise pollution and space optimization.
The relevance of an indicator to building performance is a dynamic and context-dependent criterion. It necessitates a deep understanding of the specific needs and functions of different types of buildings. This understanding ensures that the chosen indicators provide a true and useful reflection of the building's performance, catering to the unique demands of its occupants and the environment in which it is situated.

Availability and Reliability of Data: The criteria of availability and reliability of data are vital in the selection of indicators for assessing building performance. Availability pertains to the ease with which necessary data can be gathered. Indicators that rely on readily accessible data are more feasible for consistent monitoring and analysis. For example, energy consumption data, often readily available through utility bills or energy management systems, is a commonly used indicator due to its high availability. Conversely, data that is difficult to obtain, perhaps due to technical constraints or high costs of data collection, can render an indicator impractical for regular use. This impracticality can arise from a need for specialized equipment or expertise, which may not be readily available, especially in smaller or older buildings.
Reliability, on the other hand, focuses on the accuracy and consistency of the data. It is imperative that the data used for building performance indicators is not only accurate but also consistently reliable over time and across various conditions. This reliability ensures that the indicators are truly reflective of the building's performance and not skewed by anomalies or inaccuracies in data collection. For instance, sensor data used to monitor indoor air quality must be precise and stable to be a reliable indicator of the building's environmental conditions.
Modern advancements in technology, particularly the integration of IoT (Internet of Things) devices and smart meters, have greatly enhanced the availability and reliability of data. Smart meters, for example, provide real-time energy usage data, making it easier to monitor and analyze energy consumption patterns with higher accuracy. Similarly, IoT devices can continuously monitor various aspects of a building's performance, from temperature and humidity to occupancy levels, providing a wealth of data that was previously difficult to collect. Moreover, building management systems (BMS) play a significant role in data collection. These systems centralize the control and monitoring of various building services like heating, ventilation, and air conditioning (HVAC), lighting, and security systems, thereby providing a comprehensive dataset that covers multiple aspects of building performance. Additionally, occupant feedback has emerged as a valuable source of data, particularly for indicators related to comfort and satisfaction. Surveys and feedback tools can yield insights into subjective aspects of building performance, such as thermal comfort or acoustic quality, which are not easily quantifiable through technical sensors alone.
The availability and reliability of data are essential considerations in the selection of building performance indicators. The evolution of technology in building management has significantly improved these aspects,

enabling more effective and efficient monitoring and assessment of building performance. These advancements have made it possible to gather comprehensive, accurate, and reliable data, which is crucial for informed decision-making and the continuous improvement of building operations.

Methods for Evaluating and Selecting Indicators The methodology for evaluating and selecting indicators, is a critical aspect of ensuring the effectiveness and applicability of the indicators used to measure building performance. This process incorporates both quantitative and qualitative analyses to determine how well different indicators can reflect the various aspects of a building's operation, efficiency, and impact. The selection of these indicators is not just a matter of data collection but involves a nuanced approach that ensures the indicators are meaningful and actionable.

Quantitative analysis is a key component of this methodology. It often involves statistical techniques to analyze data related to potential indicators. This could include correlation analysis to see how well an indicator correlates with desired outcomes, regression analysis to understand the predictive power of an indicator, or variance analysis to assess the consistency of an indicator across different conditions or over time. Such statistical methods provide a robust framework to objectively evaluate the effectiveness of each indicator. Qualitative analysis, on the other hand, adds depth to this evaluation by considering the contextual and subjective aspects of building performance. This might involve benchmarking potential indicators against industry standards or best practices to see how they stack up against established metrics. It could also include conducting pilot studies to test the practical application of certain indicators in real-world settings. These pilot studies are invaluable for understanding the feasibility of collecting and analyzing the data required for each indicator.

Consultation with stakeholders forms another critical part of the methodology. Engaging with building owners, operators, and occupants ensures that the selected indicators are not only theoretically sound but also practical and relevant to those who manage and use the buildings. This stakeholder input can reveal insights into the usability of the indicators, the challenges faced in data collection, and the practical implications of using these indicators for building management and improvement. The process also includes a consideration of the evolving nature of building technologies and practices. As new technologies and sustainability practices emerge, the relevance and effectiveness of indicators can change. Hence, the methodology is not static; it must be adaptable to incorporate new insights, technologies, and trends in the field.

The methodology for evaluating and selecting building performance indicators is a comprehensive process that combines quantitative analysis, qualitative assessment, pilot testing, and stakeholder consultation. This multifaceted approach ensures that the chosen indicators are not only scientifically valid and robust but also practical and relevant to the real-world operation and management of buildings. It is a dynamic process that evolves with advancements in building technologies and practices, ensuring that the indicators remain effective tools for measuring and improving building performance.

Challenges and Limitations in Indicator Selection: The process of selecting indicators for building performance assessment is fraught with various challenges and limitations that need careful navigation. One of the most significant challenges lies in striking a balance between comprehensiveness and simplicity. On the one hand, a comprehensive set of indicators can paint a detailed picture of a building's performance, accounting for various aspects like energy efficiency, environmental impact, and occupant comfort. On the other hand, an overly extensive range of indicators can lead to complexity and difficulty in management. The key is to identify indicators that provide meaningful insights without overwhelming the users or the data analysis process.

Another major limitation in the selection of indicators is the cost and effort associated with data collection and analysis. Some indicators require advanced and sometimes expensive sensors for data collection, as well as sophisticated software for data processing and analysis. This can be a significant hurdle, especially for smaller organizations or older buildings where the installation of such technology might not be feasible. The resource-intensive nature of collecting and processing data for certain indicators can limit their practicality and scalability.

Furthermore, the dynamic nature of buildings adds another layer of complexity to the selection of indicators. Buildings undergo changes in occupancy, usage, and are subject to varying environmental conditions. These changes can significantly affect building performance, and therefore, the indicators chosen must be adaptable and responsive to such fluctuations. For instance, occupancy patterns can influence energy consumption, indoor air quality, and thermal comfort. Therefore, the indicators need to be flexible enough to accurately reflect these variable conditions. Additionally, the evolving standards and regulations in building construction and performance can impact the relevance of certain indicators over time. What may be considered a critical

indicator today might become less relevant as new technologies emerge and building practices evolve. Keeping up with these changes and ensuring that the set of chosen indicators remains current and applicable is an ongoing challenge.
In essence, the selection of building performance indicators is a nuanced process that requires a careful balance of various factors. It involves weighing the depth of insight provided by the indicators against their manageability and practicality, considering the cost and technological requirements for data collection and analysis, and ensuring adaptability to the dynamic nature of building usage and conditions. This process is crucial in ensuring that the indicators selected are not only effective in theory but also viable and useful in practice.

Thresholding: Thresholding is a critical aspect of building performance assessment, refers to the establishment of minimum standards or benchmarks that indicators must meet. This process is instrumental in differentiating buildings based on their performance levels, particularly in identifying those that fall short in certain areas. Thresholds serve as a reference point against which a building's performance can be measured, enabling a clear demarcation of underperformance and setting a benchmark for improvement.
The process of setting these thresholds, however, is far from straightforward. One of the primary challenges lies in determining what constitutes an appropriate level for these standards. Ideally, thresholds should be set at a level that is ambitious enough to encourage significant improvements in building performance, yet they must remain attainable. If set too high, they might be unachievable for most buildings, discouraging efforts towards improvement. Conversely, too low a threshold may not sufficiently drive advancements in building efficiency and sustainability. To establish these benchmarks, several factors are considered. Regulatory requirements often play a key role in determining threshold levels, especially in areas where building performance is closely regulated for energy efficiency, environmental impact, or occupant health and safety. Adhering to these regulatory standards not only ensures compliance but also fosters a basic level of performance across buildings.
Industry benchmarks provide another basis for setting thresholds. These benchmarks are typically derived from the performance levels of similar buildings within a particular sector or region, offering a comparative standard that is grounded in practical, real-world performance metrics. Historical performance data of buildings can also inform threshold setting. This data offers insights into what has been historically achievable and can help in setting realistic and relevant performance goals. Furthermore, the diversity in building types and uses necessitates a tailored approach to threshold setting. For instance, the performance expectations for a residential building differ significantly from those of a commercial or industrial facility. Each building type has unique operational characteristics and requirements, which must be reflected in the thresholds set for their performance indicators.
Thresholding is a nuanced and essential process in building performance assessment. It involves setting realistic yet challenging benchmarks for performance indicators, taking into consideration regulatory standards, industry benchmarks, historical data, and the specific characteristics of different building types. Effective thresholding not only aids in identifying underperformance but also provides a clear and objective target for improvement, fostering advancements in building efficiency and sustainability.

4.3 Selected Indicators

The selection of 15 indicators for assessing the operational performance of buildings represents a balanced approach to measuring aspects related to environmental quality, energy efficiency, and financial impact. These indicators, chosen for their relevance, data availability, and practicality, offer a comprehensive view of a building's performance as illustrated in **Table 7**.

Table 7: Key Operational Rating Building Performance Assessment

Indicator Name	Indicator Description	Units
Thermal Comfort (Indoor Air Temperature)	The Indoor Air Temperature is the dry-bulb temperature measured indoors (in-room).	°C

Room CO2 Volumetric Concentration	Carbon dioxide is a widely recognized indicator of indoor air quality, primarily because it is directly related to human occupancy and ventilation.	ppm
Room Particulate Matter <2.5 µm (PM 2.5)	Fine particulate matter refers to tiny airborne particles with a diameter of 2.5 micrometers or less, generated from various sources, including combustion processes, cooking, smoking, and outdoor pollutants infiltrating indoor spaces.	$\mu g/m^3$
Event Reproduction Number (R)	The number of people who become infected per infectious occupant.	Ratio
Occupancy Feedback Indicator (MV)	The satisfaction/dissatisfaction rate of indoor air temperature and thermal comfort.	Mean Vote (scale)
Lighting Energy Consumption per Floor Area	Reflects the efficiency and design of a building's lighting system, essential for evaluating energy use and occupant comfort regarding visual tasks and overall ambiance.	kWh/m^2
Cooling Energy Consumption per Floor Area	Measures the energy efficiency of the cooling systems relative to the building size, vital for assessing energy performance and the environmental impact of air conditioning systems.	kWh/m^2
Heating Energy Consumption per Floor Area	Assesses the efficiency of heating systems, crucial in climates with significant heating demands, impacting both energy use and occupant comfort.	kWh/m^2
Appliances Energy Consumption per Floor Area	Evaluates the energy efficiency of appliances within the building, an important aspect of overall energy consumption.	kWh/m^2
DHW Energy Consumption per Floor Area	Measures the energy used for domestic hot water, a significant energy consumer, especially in residential buildings, reflecting its efficiency and sustainability.	kWh/m^2
Cost of Heating per Floor Area per Year	The total annual cost of heating a building divided by the floor area, determining the cost per square meter. Reflects actual energy consumption for heating and associated costs.	€/m^2/year
Cost of Cooling per Floor Area per Year	Calculates the total annual cost of cooling a building, spread over the floor area, providing the cost per square meter. Accounts for the actual energy used for cooling and its cost.	€/m^2/year
Cost of Lighting per Floor Area per Year	Represents the total annual cost of lighting a building divided by the floor area, yielding the cost per square meter. Includes energy consumption for lighting and related costs.	€/m^2/year
Cost of DHW per Floor Area per Year	Measures the total annual cost of domestic hot water (DHW) usage in a building, divided by the floor area, determining the cost per square meter. Reflects actual energy consumption for heating water and associated costs.	€/m^2/year

Cost of Appliances Energy per Floor Area	Measures the total annual cost of energy consumed by appliances in a building, divided by the floor area, resulting in the cost per square meter. Includes actual energy usage and associated costs based on monthly data from energy meters and submeters.	€/m²/year

These 15 indicators offer a robust framework for evaluating building performance. They cover essential aspects of air quality, energy efficiency, lighting, heating, cooling, and financial impacts. This comprehensive approach ensures that buildings are assessed not just for their operational efficiency, but also for their environmental impact and the comfort and well-being of their occupants.

4.3.1 Indoor Environment Quality Indicators

In the forthcoming five tables, a detailed description of indicators specifically related to human thermal comfort and Indoor Air Quality (IAQ) is provided. These tables comprehensively outline each indicator, delving into their relevance, measurement methods, and impact on the indoor environment. They serve as a valuable resource for understanding how these indicators contribute to assessing and enhancing the comfort and air quality within building spaces. The following tables present also the thresholds (level G) for the indicators.

Table 8: Thermal comfort indicator (indoor air temperature)

Indicator Name	**Indoor Air Temperature**
Indicator Description	The Indoor Air Temperature is the dry-bulb temperature measured indoor (in room).
Units	°C
Measurement scale	Interval
Equipment	Temperature sensor
Thresholding	See Table 9 (from D3.4 Section 2.4.1.1)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 9: Indoor air temperature ranges for thermal comfort categories from EN 16798-1

Category	Residential buildings (1.2 met)		Residential buildings (1.5 met)		Offices, classrooms etc. (1.2 met)	
	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo
A	21.0-25.0	23.5-25.5	18.0-25.0	-	21.0-23.0	23.5-25.5
B	20.5-25.0	23.3-25.75	17.0-25.0	-	20.5-23.5	23.3-25.75
C	20.0-25.0	23.0-26.0	16.0-25.0	-	20.0-24.0	23.0-26.0
D	19.0-25.0	22.5-26.5	15.0-25.0	-	19.5-24.5	22.5-26.5
E	18.0-25.0	22.0-27.0	14.0-25.0	-	19.0-25.0	22.0-27.0
F	17.5-25.0	21.5-27.5	-	-	18.0-25.0	21.5-27.5
G	17.0-25.0	21.0-28.0	-	-	17.0-25.0	21.0-28.0
OUTSIDE	not in 17.0-25.0	not in 21.0-28.0	not in 14.0-25.0	-	not in 17.0-25.0	not in 21.0-28.0

Table 10: IAQ indicator (room CO_2 volumetric concentration)

Indicator Name	**Room CO_2 volumetric concentration**
Indicator Description	Carbon dioxide is a widely recognized indicator of indoor air quality, primarily because it is directly related to human occupancy and ventilation.
Units	ppm
Measurement scale	Interval
Equipment	CO_2 sensor
Thresholding	Calculated according to D3.4 Section 2.4.2.1
Sampling Frequency	15 min (max hourly)
Calculation Methodology	Calculated according to D3.4 Section 2.4.2.1
Regulatory Compliance	EN 16798-1:2019

Table 11: IAQ indicator (Room particulate matter <2,5 µm (PM 2.5) concentration)

Indicator Name	**Room particulate matter <2,5 µm (PM 2.5) concentration**
Indicator Description	Fine particulate matter refers to tiny airborne particles with a diameter of 2.5 micrometers or less. These particles can be generated from various sources, including combustion processes, cooking, smoking, and outdoor pollutants that infiltrate indoor spaces
Units	$\mu g/m^3$
Measurement scale	Interval
Equipment	PM2.5 sensor
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 12: PM2.5 annual mean category limit values

Category	Limit concentration (μg/m³)
Category A	5
Category B	7.5
Category C	10
Category D	12.5
Category E	15
Category F	20
Category G	25
Outside allowed limit	≥25.0

Table 13: Virus risk indicator

Indicator Name	Event reproduction number - R
Indicator Description	Number of people who become infected per infectious occupant
Units	-
Measurement scale	Interval
Equipment	-
Thresholding	See Table 14 (from D3.4 Section 2.4.2.3)
Sampling Frequency	-
Calculation Methodology	Calculated according to D3.4 Section 2.4.2.3
Regulatory Compliance	REHVA proposal for post-COVID[1]

[1] Health-based target ventilation rates and design method for reducing exposure to airborne respiratory infectious diseases. REHVA proposal for post-COVID target ventilation rates. Rehva 2022 https://www.rehva.eu/activities/post-covid-ventilation

Table 14: Proposed virus risk estimation scale based on R values at specified risk levels

Risk level	R_0, N° of new disease cases by one infector	*R* in offices	*R* in meeting rooms	*R* in classrooms
A	0.8	0.32	0.071	0.300
B	0.85	0.34	0.076	0.319
C	0.9	0.36	0.080	0.338
D	0.925	0.37	0.082	0.347
E	0.95	0.38	0.084	0.356
F	0.975	0.39	0.087	0.366
G	1.0	0.40	0.089	0.375
Outside	>1.0	>0.40	>0.089	>0.375

Table 15: Occupancy feedback indicator (MV (mean vote))

Indicator Name	MV (mean vote)

Indicator Description	The satisfaction/dissatisfaction rate of indoor air temperature and thermal comfort.
Units	-
Measurement scale	Interval
Equipment	-
Thresholding	See Table 16 (from D3.4 Section 2.4.3.5)
Sampling Frequency	Usually year (or if needed)
Calculation Methodology	Calculated according to D3.4 Section 2.4.3.5
Regulatory Compliance	EN 16798-1:2019, ISO 10551, ISO 28802 and EN ISO 7730

Table 16: The feedback indicator threshold

Feedback category	Thermal comfort (mean vote in 5-point scale)
A	-0.2 ≤ (P)MV ≤+0.2
B	-0.35 ≤ (P)MV ≤ +0.35
C	-0.5 ≤ (P)MV ≤ +0.5
D	-0.6 ≤ (P)MV ≤ +0.6
E	-0.7 ≤ (P)MV ≤ +0.7
F	-0.85 ≤ (P)MV ≤ +0.85
G	-1.0 ≤ (P)MV ≤ +1.0
OUTSIDE	(P)MV > 1.0

4.3.2 Operational Rating Indicators

The subsequent five tables offer a thorough presentation of indicators pertinent to the operational rating of buildings. These tables detail the indicators, emphasizing their role in evaluating the building's operational efficiency and performance. This information is crucial for stakeholders seeking to understand and improve the overall operational effectiveness of their buildings.

Table 17: Lighting energy consumption per total floor area

Indicator Name	Lighting energy consumption per total floor area
Indicator Description	This indicator displays the total lighting power consumption of the building in kWh per the total area of the building.
Units	kWh/ m²
Measurement scale	Ratio
Equipment	Power meters used to measure the electrical consumption of lighting systems.
Thresholding	To be described
Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total lighting power consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.16

Table 18: Cooling energy consumption per total floor area

Indicator Name	Cooling energy consumption per total floor area
Indicator Description	This indicator displays the total cooling power consumption of the building in kWh per the total area of the building.
Units	kWh/ m^2
Measurement scale	Ratio
Equipment	Power meters used to measure the electrical consumption of cooling systems.
Thresholding	To be described
Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total cooling energy consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18

Table 19: Heating energy consumption per total floor area

Indicator Name	Heating energy consumption per total floor area
Indicator Description	This indicator displays the total heating power consumption of the building in kWh per the total area of the building.
Units	kWh/ m^2
Measurement scale	Ratio
Equipment	Power meters used to measure the electrical consumption of heating systems.
Thresholding	To be described
Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total heating energy consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18

Table 20: Appliances energy consumption per total floor area

Indicator Name	Appliances energy consumption per total floor area
Indicator Description	This indicator displays the total heating power consumption of the building in kWh per the total area of the building.
Units	kWh/ m^2
Measurement scale	Ratio
Equipment	Power meters used to measure the electrical consumption of appliances.
Thresholding	To be described

Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total energy consumption for appliances}}{\text{total floor area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18 3.4.17

Table 21: Domestic hot water energy consumption per total floor area

Indicator Name	**Domestic hot water energy consumption per total floor area**
Indicator Description	These indicator presents the energy costs based on the actual energy use.
Units	kWh/ m^2
Measurement scale	Ratio
Equipment	Power meters used to measure the energy use for domestic hot water
Thresholding	To be described
Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total energy consumption for DHW power}}{\text{total floor area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18

4.3.3 LCC Indicators

In the following five tables, a comprehensive description of indicators related to Life Cycle Costing (LCC) is provided. These tables systematically break down each LCC indicator, highlighting their significance in evaluating the long-term economic aspects of building operations. This detailed presentation is essential for understanding the financial implications throughout the lifespan of a building, from initial construction to eventual decommissioning or renovation.

Table 22: Cost of heating per floor area per year

Indicator Name	**Cost of heating per floor area per year**
Indicator Description	These indicator presents the energy costs based on the actual energy use
Units	€/m^2/year
Measurement scale	Ratio
Equipment	Utility bills, energy meters.
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ heating \times energy\ price\ (variable)}{total\ floor\ area}$

Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 23: Cost of cooling per floor area per year

Indicator Name	**Cost of cooling per floor area per year**
Indicator Description	These indicator presents the energy costs based on the actual energy use
Units	€/m²/year
Measurement scale	Ratio
Equipment	Utility bills, energy meters.
Thresholding	To be described
Sampling Frequency	Yearly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ cooling \times energy\ price\ (variable)}{total\ floor\ area}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 24: Cost of lighting per floor area per year

Indicator Name	**Cost of lighting per floor area per year**
Indicator Description	These indicator presents the energy costs based on the actual energy use
Units	€/m²/year
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ lighting \times energy\ price\ (variable)}{total\ floor\ area}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 25: Cost of domestic hot water per floor area per year

Indicator Name	**Cost of domestic hot water per floor area per year**
Indicator Description	These indicator presents the energy costs based on the actual energy use
Units	€/m²/year
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Yearly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ DHW \times energy\ price\ (variable)}{total\ floor\ area}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 26: Cost of appliances per floor area per year

Indicator Name	**Cost of appliances per floor area per year**
Indicator Description	These indicator presents the energy costs based on the actual energy use
Units	€/m²/year
Measuremen t scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ appliances \times energy\ price\ (variable}{total\ floor\ area}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

5 Weighting methods

5.1 Introduction

In this comprehensive report, we delve into the nuances of assessing building energy performance through various weighting methods, with a particular focus on the Weighted Sum Model (WSM). The report is structured to provide a thorough understanding of these methods, their applications, and the inherent challenges they present in the context of building energy efficiency. Section 3 offers a detailed exploration of the Weighted Sum Model (WSM), a widely used method in the assessment of building energy performance. This section outlines the fundamental principles of WSM, highlighting its relevance and utility in evaluating various energy-related indicators within buildings. Moving forward, Section 3.2 introduces alternative weighting methods. This part of the report broadens the perspective by contrasting WSM with other prevalent methods, offering insights into their unique approaches and the contexts in which they are most effective. In Section 3.3, a comparative assessment between the Weighted Sum Model and these alternative methods is presented. This comparative analysis aims to shed light on the strengths and limitations of each method, providing a balanced view of their applicability in building energy performance assessment. The report then delves deeper into the challenges specific to WSM in Section 3.4, addressing crucial aspects such as the selection of weighting criteria, normalization of diverse indicators, and the critical assumption of linearity in WSM's application. Each of these challenges – detailed in Sections 3.4.1, 3.4.2, and 3.4.3, respectively – is analysed to understand how they impact the accuracy and reliability of the WSM in assessing building energy performance. Overall, this report aims to offer a comprehensive understanding of the Weighted Sum Model and its alternatives, providing valuable insights for professionals and stakeholders in the field of building energy efficiency.

5.2 The Weighted Sum Model (WSM)

The Weighted Sum Model is a mathematical technique used in decision making, especially in contexts where multiple criteria need to be considered. It is a simple yet powerful method to evaluate and compare a set of alternatives based on a weighted sum of their attributes. WSM is provided as follows:

Basic Concept: In the WSM, each option or alternative is evaluated based on several criteria. Each criterion is assigned a weight that reflects its relative importance. The performance of each alternative is then assessed against these criteria.

Assignment of Weights: The first step in the WSM is to determine the weights for each criterion. These weights are typically based on expert opinion, stakeholder input, or other relevant sources. The weights are normalized so that their sum equals one (or 100%), ensuring that the relative importance of each criterion is accurately represented.

Evaluation of Alternatives: Each alternative is evaluated on each criterion. This evaluation can be based on quantitative data, qualitative assessments, or a combination of both, depending on the nature of the criteria.

Multiplication of Scores by Weights: For each alternative, the score on each criterion is multiplied by the weight of that criterion. This step creates a set of weighted scores for each alternative, reflecting both the performance on each criterion and the importance of that criterion.

Summation: The weighted scores for each alternative are summed up to yield a total score. This total score represents the overall performance of the alternative, taking into account all the criteria and their respective weights.

Comparative assessment: The total scores of all alternatives are compared. The alternative with the highest total score is typically considered the best choice, assuming a higher score is better. This makes the WSM a straightforward method for ranking and selecting among different options.

Flexibility and Applications: The WSM is flexible and can be adapted to a wide range of decision-making situations, such as project selection, resource allocation, and policy evaluation. It is particularly useful in scenarios where decision criteria are diverse and need to be quantitatively aggregated.

Limitations: One limitation of the WSM is that it assumes independence among criteria and a linear relationship between criteria weights and the overall score. It may not be suitable for complex scenarios where these assumptions do not hold.

The Weighted Sum Model (WSM) can be effectively used in assessing the energy performance of buildings by evaluating various energy-related indicators. This process involves assigning weights to different indicators based on their importance and impact on the building's overall energy efficiency. Here's how the WSM can be applied in this context:

Selection of Energy-Related Indicators: The first step is to identify key indicators that influence the energy performance of buildings. These might include factors like insulation quality, energy consumption, types of energy sources used, HVAC efficiency, window efficiency, lighting efficiency, renewable energy utilization, and more.

Normalization of Indicators: Since these indicators may be measured in different units (like kWh for energy consumption, R-value for insulation, etc.), they need to be normalized to a common scale. This could be done by converting them into dimensionless scores or percentages.

Calculation of Weighted Scores: For each building being assessed, calculate the weighted score for each indicator by multiplying the normalized value of the indicator by its assigned weight.

Summation to Obtain Total Energy Performance Score: Sum the weighted scores of all indicators for each building. This gives a total energy performance score that reflects the combined effect of all considered energy-related aspects.

Ranking and Comparison: Buildings can then be ranked or compared based on their total energy performance scores. Buildings with higher scores are considered more energy efficient.

Incorporation into Decision-Making: These scores can be used to make decisions about energy improvements, certifications, or in comparing the energy efficiency of buildings in real estate markets.

Sensitivity Analysis: It’s often beneficial to conduct sensitivity analysis by varying the weights of the indicators to see how it affects the overall energy performance scores. This helps in understanding the robustness of the assessment and in identifying the most influential factors.

By using the WSM in this way, it's possible to get a comprehensive, quantifiable assessment of a building's energy performance. This model allows for a systematic evaluation that can guide energy efficiency improvements and investments in the building sector.

5.3 Alternative Weighting Methods

5.3.1 Weighting in Composite Indicators

In the context of developing a composite indicator for the SmartLivingEPC project, weighting is a critical component that determines the relative importance of different indicators within the index. These indicators—Indoor Air Quality (IAQ), energy rating, and Life Cycle Costing (LCC)—are fundamental in assessing the performance and sustainability of smart living environments. Weighting in composite indicators serves two primary purposes:

1. **Explicit Importance:** This represents the deliberate assignment of importance to different indicators, pillars, or sub-pillars based on their perceived relevance to the overall objective of the composite indicator.

2. **Implicit Importance:** This involves understanding the trade-offs between different indicators. Changing the weight of one indicator affects the balance and interaction among all indicators, which can significantly impact the final outcome of the composite index.

The choice of weights can significantly influence the final scores and rankings of the entities being evaluated, often referred to as the "index problem." Furthermore, stakeholders may have varying opinions on the most suitable weighting scheme, reflecting differing priorities and perspectives. Ultimately, a composite indicator is a product of both its theoretical framework and the transparency of its methodology.

5.3.1.1 Approaches to Setting Weights

Weighting is a central aspect of constructing composite indicators, and there are several approaches to setting weights, each with its own methodology and implications. Here, we explore some of these approaches in greater detail.

1. Equal Weights

This approach is one of the simplest and most transparent methods of weighting. Each indicator, pillar, or sub-pillar is given the same weight, suggesting that all components are of equal importance. This method is often used when there is no clear rationale for prioritizing one element over another or to avoid bias when subjective judgments are at risk of being contentious. However, the simplicity of equal weighting can also be a limitation, as it may not accurately reflect the relative importance of different factors in some contexts.

2. Weighting Based on Statistical Methods

These methods rely on statistical techniques to derive weights objectively from the data itself, often attempting to maximize the explanatory power of the composite index.

- **Principal Component Analysis (PCA)/Factor Analysis**: These methods reduce the dimensionality of data by identifying a few unobservable variables (factors or components) that capture the most variance in the data set. Weights are assigned based on the contribution of each indicator to these principal components or factors, thus reflecting the underlying data structure. [6] , [7] ,
- **Data Envelopment Analysis (DEA)**: DEA is used to evaluate the efficiency of different decision-making units (e.g., companies, countries). In the context of weighting, it can be used to derive weights that maximize an entity's relative efficiency based on the inputs and outputs defined in the index. [8]
- **Regression Approach**: This involves using regression models to determine how well each indicator predicts some outcome of interest. The weights are based on the statistical significance and coefficients of the indicators in the regression model, assigning higher weights to indicators that are better predictors.

3. Weights Based on Public/Expert Opinion

These methods incorporate judgments from the public or experts, providing a way to reflect societal or expert views on the importance of different indicators.

- **Budget Allocation and Analytic Hierarchy Process (AHP)**: In the budget allocation method, participants distribute a fixed number of resources (e.g., points or money) among various indicators, reflecting their perceived importance. AHP involves structuring multiple criteria into a hierarchy, comparing them pairwise, and calculating weights based on the relative priorities assigned through these comparisons. Both methods directly involve stakeholders in the weighting process, which can enhance the legitimacy and acceptability of the index.[10] , [9]

- **Conjoint Analysis**: This statistical technique is used primarily in market research to determine how people value different features of a product or service. Applied to index weighting, conjoint analysis can reveal how different indicators are valued relative to each other by asking stakeholders to rank or choose between different sets of indicators with varying levels.

Each of these approaches has its strengths and limitations. The choice of method depends on the specific objectives of the index, the nature of the data, the availability of expert or public input, and the desired balance between objectivity and subjectivity in reflecting importance. Deciding on the most appropriate weighting method requires careful consideration of these factors to ensure the composite index is robust, credible, and useful for its intended purpose. [10]

Examples of Weighting Schemes in Other Indices:

- **Human Development Index:** Uses equal weights.
- **Social Progress Index:** Employs PCA for deriving weights.
- **Gender Equality Index:** Based on expert opinion. [16]

Choosing and Applying Weighting Schemes

The selection and application of a weighting scheme must be aligned with the project's goals, the nature of the data, and the interests of stakeholders. It requires a balance between statistical rigor and practical relevance, ensuring that the composite index accurately reflects the dimensions it intends to measure while being understandable and acceptable to its users.

For example, applying PCA might reveal that IAQ has the most significant variance across buildings, suggesting a higher weight. Conversely, using AHP might result in higher weights for energy efficiency based on expert assessments of its long-term impact on sustainability and cost.

The methodology for developing composite indicators in the SmartLivingEPC project thus emphasizes the importance of a transparent, theoretically sound approach that accommodates the diverse perspectives of stakeholders. This ensures that the final indicator is not only robust and meaningful but also broadly supported and effectively utilized.

Detailed Explanation of PCA and AHP Methods

Principal Component Analysis (PCA):

PCA is a statistical technique used to emphasize variation and bring out strong patterns in a dataset. It's particularly useful when the dimensions of the data are high as it simplifies the complexity without losing critical information. The process starts by standardizing the scale of the variables, which is crucial when the variables operate on different scales.

1. **Standardization**: Each variable (IAQ, energy rating, LCC) is standardized to have zero mean and unit variance.
2. **Covariance Matrix**: Compute the covariance matrix to understand how the variables vary from the mean with respect to each other.
3. **Eigenvalues and Eigenvectors**: Calculate eigenvalues and eigenvectors of the covariance matrix. The eigenvectors determine the directions of the new feature space, and the eigenvalues determine their magnitude. In other words, the eigenvectors represent the principal components, and the eigenvalues define their importance. [6]

4. **Component Selection**: Typically, the principal components that account for the most variance are selected. The first principal component has the highest eigenvalue and is thus considered the most significant feature.

Example of PCA Weight Derivation:

- Suppose the first principal component for an energy assessment project loads significantly on IAQ (0.70) compared to energy rating (0.20) and LCC (0.10). These loading factors effectively become the weights, indicating that IAQ is the most influential factor in this model.

5.3.1.2 Analytic Hierarchy Process (AHP):

AHP helps decision-makers face a complex problem by breaking it down into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The steps involve:

1. **Hierarchy Construction**: Decompose the decision problem into a hierarchy of more straightforward problems.

2. **Pairwise Comparisons**: Perform pairwise comparisons of the elements at each level of the hierarchy. For this, use a scale of absolute judgments that represents how much more one element is important than another with respect to the criterion of the parent element.

3. **Priority Calculation**: Use the eigenvector method to derive priority scales from these comparisons, which involves calculating the principal eigenvector of the pairwise comparison matrix.

4. **Consistency Check**: Evaluate the consistency of the judgments, ensuring they are not random and adhere to logical reasoning. This is done using a consistency ratio (CR), and judgments are reconsidered if the CR is unacceptable (usually above 0.1). [9] [8]

Example of AHP Application:

- An expert panel assesses the relative importance of IAQ, energy rating, and LCC regarding sustainable living. If IAQ is twice as important as energy rating and five times as important as LCC, these judgments are used to construct a pairwise comparison matrix and subsequently compute the weights.8

5.3.1.3 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a statistical method utilized to reduce the dimensionality of a dataset while retaining those variables that contribute most to its variance. Here's a detailed breakdown using a method derived from the presentation material:

Steps for PCA:

1. **Standardization of the Dataset:** Normalize each indicator to have a mean of zero and a standard deviation of one. This step ensures comparability among variables that may operate on different scales.

Equation:

$$Z = \frac{X - \mu}{\sigma}$$

Where $\boldsymbol{X}$ is the original value, $\boldsymbol{\mu}$ is the mean, and $\boldsymbol{\sigma}$ is the standard deviation of each variable and **Z** The standardized value (also known as the z-score).

2. **Construction of the Covariance Matrix:** The covariance matrix helps in understanding how variables change together.

Equation:

$$\Sigma = \frac{1}{n-1} \cdot (Z^T \cdot Z)$$

3. **Eigen decomposition:** Calculate eigenvalues and eigenvectors of the covariance matrix to identify the principal components.

Equation for calculating eigenvectors and eigenvalues:

$$\Sigma \cdot v = \lambda \cdot v$$

Selection of Principal Components: Select the principal components based on the size of their eigenvalues. Larger eigenvalues capture more variance.

Example using PCA:

Assume the following eigenvalues and corresponding eigenvectors have been calculated from the covariance matrix:

Table 27: PCA Eigenvalues and Eigenvectors

Component	Eigenvalue	Eigenvector (IAQ, Energy Rating, LCC)
PC1	2.5	(0.7, 0.2, 0.1)
PC2	1.2	(0.4, 0.5, 0.1)
PC3	0.3	(0.1, 0.3, 0.6)

From this, we would primarily focus on PC1 as it captures the largest variance. The weights derived from the first principal component are:

- **IAQ:** 0.7
- **Energy Rating:** 0.2
- **LCC:** 0.1

5.3.1.4 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It uses a pairwise comparison approach to set priorities and make the best decision.

Steps for AHP:

1. **Establishing Criteria and Alternatives:** Define and list all criteria and alternatives that will be considered in the decision-making process.

2. **Pairwise Comparison Matrix:** Compare each element against every other element in a pairwise fashion to assign relative importance values.

Matrix Formation:

$$\text{Matrix } A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ \frac{1}{a_{12}} & 1 & a_{23} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 \end{bmatrix}$$

Where $\boldsymbol{a_{12}}$, $\boldsymbol{a_{13}}$, and $\boldsymbol{a_{23}}$ are the importance values.

3. **Deriving Weights:** Normalize the pairwise comparison matrix and calculate the priority vector (weights) by averaging across rows.

Normalization and Weight Calculation:

$$w_i = \frac{\text{average of row } i}{\text{sum of all row averages}}$$

4. **Consistency Check:** Validate the consistency of the comparisons using the Consistency Ratio (**CR**) to ensure the judgments are reliable.

AHP Example:

Consider a pairwise comparison matrix filled out by experts evaluating the importance of IAQ, energy rating, and LCC.

Table 28: AHP Pairwise Comparison Matrix

Pilot	IAQ	Energy Rating	LCC
Pilot #1	1	2	5
Pilot #2	0.5	1	2
Pilot #3	0.2	0.5	1

Table 29: Sum of each column

Sum	IAQ	Energy Rating	LCC
Sum	**1.7**	**3.5**	**8.0**

Table 30: Normalized relative weights

Pilot	IAQ	Energy Rating	LCC

Pilot #1	0.588	0.571	0.625
Pilot #2	0.294	0.286	0.25
Pilot #3	0.118	0.143	0.125

Table 31: Row average weights

Domain	Weights
Indoor Air Quality	0.595
Energy Rating	0.277
Life cycle costing	0.128

After normalization and averaging of the weights, might be calculated as follows:

- **IAQ:** 0.595
- **Energy Rating:** 0.277
- **LCC:** 0.128

5.3.2 Comparative Assessment between Weighting Sum Model and other Weighting Methods

The superiority of WSM in building energy performance assessments largely depends on the specific requirements of the assessment, the nature of the data available, and the level of complexity the decision-makers are prepared to handle. The WSM has several advantages, particularly in the context of assessing the energy performance of buildings, which can make it superior to other multi-criteria decision-making methods in certain scenarios:

Simplicity and Transparency: WSM is straightforward and easy to understand. This simplicity is beneficial when communicating the methodology and results to stakeholders who may not have a technical background, such as building owners, real estate developers, or policy makers.

Ease of Implementation: It requires relatively less computational effort compared to methods like AHP, TOPSIS, or ELECTRE. This makes WSM more accessible and practical for practitioners who may not have specialized software or extensive expertise in complex decision-making methodologies.

Flexibility in Indicator Selection: WSM allows for a wide range of indicators to be included in the analysis. This is particularly useful in building assessments where diverse factors (such as energy consumption, insulation effectiveness, use of renewable energy sources) need to be considered.

Direct Interpretation of Weights: The weights in WSM directly reflect the importance of each criterion. This is particularly useful when there are clear priorities or regulatory guidelines regarding what aspects of a building's energy performance are most critical.

Adaptability to Different Standards and Regulations: WSM can easily be adapted to align with various energy performance standards and regulations. The weights can be adjusted to reflect changes in policy or technological advancements.

Useful for Comparative Analysis: WSM is well-suited for comparing multiple buildings or design alternatives in a straightforward manner, as it aggregates performance across various criteria into a single score.

Compatibility with Linear Criteria: If the criteria involved in assessing building energy performance are linear and additive, WSM is an appropriate choice, as it inherently assumes linearity in the aggregation of criteria.

However, it's important to note that while WSM has these advantages, it may not always be the best choice. The method assumes that criteria are independent and additive, which might not always be the case in real-world scenarios. Complex interactions between different aspects of a building's energy performance may require more sophisticated methods like AHP or TOPSIS, which can handle interdependencies and non-linear relationships better. The following table highlights the aspects that make WSM a favourable method in certain scenarios related to building energy performance assessment.

Table 32: WSM applicability for Buildings Energy Performance Assessment

Advantage	Description in Building Energy performance Assessment
Simplicity and Transparency	WSM's straightforward approach is easy to understand and communicate to stakeholders, making it ideal for diverse audiences including building owners, developers, and policymakers.
Ease of Implementation	The model requires less computational effort and specialized knowledge compared to more complex methods, facilitating quicker and more accessible analysis.
Flexibility in Indicator Selection	WSM allows for a wide range of energy-related indicators to be included, accommodating diverse factors like energy consumption, insulation, and renewable energy sources.
Direct Interpretation of Weights	The weighting in WSM directly reflects the importance of each criterion, making it easy to align with clear priorities, regulations, or policy guidelines regarding energy performance.
Adaptability to Standards and Regulations	The model can be easily adjusted to reflect different energy performance standards and evolving regulations, making it relevant and adaptable to various policy contexts.
Suitability for Comparative Analysis	WSM is effective for comparing multiple buildings or alternatives, as it consolidates various criteria into a single, comprehensive score, facilitating straightforward comparisons.
Compatibility with Linear Criteria	WSM is appropriate for scenarios where the assessment criteria are linear and additive, a common situation in building energy performance evaluations.

5.4 Challenges in using WSM for building energy performance assessment

While the Weighted Sum Model (WSM) offers a straightforward and effective approach for assessing the energy performance of buildings, it also presents several challenges that need to be carefully considered:

Selection and Weighting of Criteria: One of the main challenges is the subjective nature of selecting and weighting the different energy performance indicators. Determining the appropriate weights requires expert knowledge and can be influenced by subjective biases or varying priorities among stakeholders.

Assumption of Linearity and Independence: WSM assumes that the criteria are independent and additive. Energy performance factors in buildings can be interdependent (e.g., the interaction between insulation and heating efficiency). This interdependence can lead to oversimplifications in the assessment.

Normalization of Diverse Indicators: Energy performance indicators may vary widely in nature and unit of measurement (e.g., kWh for energy consumption, R-values for insulation). Normalizing these diverse indicators to a common scale can be challenging and may introduce inaccuracies.

Handling of Qualitative Data: If some of the indicators are qualitative (e.g., architectural aesthetics, occupant comfort), quantifying them for inclusion in a WSM analysis can be difficult and may require subjective judgment calls.

Scalability and Complexity of Buildings: The scalability of WSM can be a challenge for large or complex buildings where energy performance assessment requires a more nuanced understanding of various interacting systems.

Dynamic Nature of Building Performance: Buildings' energy performance can change over time due to factors like aging infrastructure, changes in occupancy, or climatic conditions. The static nature of WSM does not account for these temporal variations.

Oversimplification of Complex Issues: WSM might oversimplify complex issues related to sustainability and energy efficiency, potentially leading to decisions that do not fully capture the multi-faceted nature of building energy performance.

Sensitivity to Weight Changes: The final assessment is highly sensitive to the assigned weights. Small changes in weights can significantly alter the outcome, making the decision process potentially volatile if the weights are not set accurately.

Despite these challenges, WSM remains a useful tool in certain contexts for building energy performance assessment. However, it's important to acknowledge these limitations and, where necessary, consider more sophisticated models or a combination of methods to obtain a comprehensive understanding of a building's energy performance.

The following table highlights the key considerations and potential limitations when employing WSM for building energy performance assessments, underlining the importance of a cautious and well-informed application of the method.

Table 33: Challenges when using WSM for buildings energy assessment

Challenge	Description
Selection and Weighting of Criteria	Determining appropriate weights for various energy performance indicators can be subjective and influenced by biases or differing stakeholder priorities.
Assumption of Linearity and Independence	WSM assumes criteria are independent and additive, which may not hold true due to interdependencies among various building energy performance factors.
Normalization of Diverse Indicators	Normalizing indicators with different units and natures (e.g., kWh, R-values) to a common scale can be challenging and might introduce inaccuracies.
Handling of Qualitative Data	Quantifying qualitative aspects like aesthetic value or occupant comfort for inclusion in WSM can be difficult, often requiring subjective judgments.
Scalability and Complexity of Buildings	Applying WSM to large or complex buildings can be challenging due to the need for a more nuanced understanding of interacting energy systems.
Dynamic Nature of Building Performance	The static nature of WSM doesn't account for changes in building energy performance over time due to factors like aging, occupancy changes, or varying climatic conditions.
Oversimplification of Complex Issues	WSM might oversimplify complex sustainability and energy efficiency issues, potentially leading to incomplete decision-making.

Sensitivity to Weight Changes	The outcomes of WSM are highly sensitive to changes in the weights of the criteria, which can make the decision process volatile.

5.4.1 Selection of weighting criteria

The challenge of selecting and weighting criteria in the Weighted Sum Model (WSM) for building energy performance assessment is a critical issue that warrants a detailed analysis. This process is inherently subjective, as it involves deciding which factors are most crucial in determining a building's energy efficiency and how much importance should be assigned to each.

Subjectivity in Criteria Selection: The first step, selecting the right criteria, is pivotal. Energy performance in buildings encompasses a wide array of factors – from thermal insulation and HVAC efficiency to renewable energy usage and window glazing. However, not all these factors may be relevant or equally important in every assessment. The selection largely depends on the specific goals of the assessment (e.g., reducing carbon footprint, minimizing energy costs, etc.) and the type of building being assessed (residential, commercial, historical significance, etc.). This choice can significantly influence the assessment's outcome, as it determines what aspects of energy performance are considered.

Expert Knowledge and Diverse Opinions: Determining the weights for each selected criterion typically requires expert knowledge. Experts in building energy efficiency might have differing opinions based on their experiences, research focus, or industry trends. For instance, one expert might prioritize insulation in colder climates, while another might focus on solar energy utilization in sunnier regions. This diversity of opinions reflects the complexity and variability of building energy performance but also introduces a degree of subjectivity into the weighting process.

Stakeholder Biases and Priorities: The weighting process can also be influenced by the biases or priorities of different stakeholders. A building developer might prioritize cost-effective measures, while a government entity might emphasize regulatory compliance or environmental impact. These differing priorities can lead to weights that reflect the interests of more influential stakeholders, rather than an objective assessment of each criterion's importance to building energy performance.

Balancing Quantitative and Qualitative Criteria: Some energy performance indicators are quantitative (like energy consumption in kWh), while others might be more qualitative (like architectural aesthetics or occupant comfort). Balancing these different types of criteria and assigning appropriate weights to qualitative factors can be challenging. Quantitative factors are easier to measure and compare, but qualitative aspects are also crucial for a holistic assessment of energy performance.

Implications for Decision-Making: The subjective nature of selecting and weighting criteria has significant implications for decision-making. The final assessment can vary greatly depending on the chosen criteria and their weights, potentially leading to different conclusions about a building's energy performance. This variability can affect decisions about energy improvements, policy-making, and even financial investments in the building sector.

While the selection and weighting of criteria in the WSM are indispensable for assessing building energy performance, they bring considerable subjectivity into the process. This subjectivity necessitates a careful, transparent, and inclusive approach, ideally involving a diverse group of experts and stakeholders to capture a broad range of perspectives and priorities.

5.4.2 Normalization of diverse indicators

The normalization of diverse indicators in the context of assessing the energy performance of buildings using the Weighted Sum Model (WSM) is a complex and critical task. This process involves converting different energy performance indicators, which may vary widely in nature and units of measurement, into a common scale. This challenge has several layers, each contributing to the overall complexity of achieving an accurate and fair assessment.

Variability in Indicators: Energy performance in buildings is evaluated using a variety of indicators, such as kilowatt-hours (kWh) for measuring energy consumption, R-values for insulation efficiency, and percentages for renewable energy utilization. These indicators not only differ in their units of measurement but also in what they fundamentally represent - some are direct measures of energy use, while others are indicative of energy conservation or efficiency.

The Challenge of Normalization: Converting these diverse indicators into a common scale (e.g., a scale from 0 to 1 or 0 to 100) is essential for the WSM to work effectively. However, this process is not straightforward. It involves determining a baseline or reference point for each indicator and then scaling or transforming the values in relation to this baseline. The difficulty lies in ensuring that this normalization process maintains the integrity and relative significance of each indicator. For example, a small improvement in insulation (R-value) might have a more significant impact on energy efficiency than a similar percentage improvement in renewable energy usage.

Risk of Inaccuracies: Inaccuracies can easily creep in during normalization. This could be due to oversimplification in the conversion process, misunderstanding the nature of the indicators, or underestimating the complexity of their interactions. For instance, reducing energy consumption in kWh might not always correlate linearly with improvements in energy efficiency, especially if different energy sources (with varying environmental impacts) are involved.

Comparability Issues: Another challenge is ensuring that the normalized indicators are comparable across different buildings or scenarios. Factors such as building size, location, usage, and local climate conditions can significantly impact energy performance indicators. Normalization needs to account for these variations to enable fair comparisons.

Subjectivity and Methodological Choices: The choice of normalization method itself can introduce subjectivity. Different methods (e.g., min-max normalization, z-score standardization) can yield different results, influencing the final assessment. The decision on which normalization technique to use often depends on the specific context of the assessment and the nature of the data available.

Impact on Decision-Making: The way indicators are normalized can significantly influence the outcomes of the energy performance assessment. Decisions regarding building improvements, policy implementations, and investments can be swayed based on how the normalization is handled, emphasizing the need for a meticulous and transparent approach.

Normalizing diverse indicators in building energy performance assessment is a crucial yet challenging step. It requires careful consideration of the nature of each indicator, a judicious choice of normalization techniques, and an awareness of the potential impact of methodological decisions on the assessment's outcomes.

5.4.3 Assumption of linearity

The assumption of linearity and independence in the Weighted Sum Model (WSM) poses significant challenges when applied to the assessment of building energy performance. This model presumes that each criterion contributes independently and linearly to the overall assessment, an assumption that may not always hold true in the complex context of building energy dynamics. Analysing this assumption reveals several critical implications:

Oversimplification of Interactions: Buildings are systems where various components and factors interact in complex ways. For instance, the efficiency of heating, ventilation, and air conditioning (HVAC) systems is not just a standalone factor but is influenced by the building's insulation, air tightness, and even occupancy patterns. WSM’s linear and independent approach might fail to capture these intricate interactions, leading to oversimplified evaluations.

The Challenge of Interdependence: In reality, energy performance factors in buildings are often interdependent. For example, the impact of window glazing on energy efficiency is contingent on other factors like the building's orientation, shading, and insulation. Such interdependencies mean that the effect of improving one aspect cannot be fully understood without considering its relationship with others.

Risk of Inaccurate Prioritization: Due to its linear approach, WSM could inaccurately prioritize certain measures over others. In a scenario where interdependent factors are treated as independent, an enhancement in one area (like installing energy-efficient lighting) might appear more beneficial than it actually is when not considering its interplay with other factors (like natural light availability).

Non-Linear Relationships: Many energy performance factors have non-linear impacts. For instance, the energy savings from additional insulation may diminish after a certain point, a concept known as the law of diminishing returns. WSM's linear approach cannot adequately capture such non-linearities, potentially leading to misguided recommendations or investments.

Inadequate Representation of Comprehensive Performance: A building's overall energy performance is a cumulative effect of various elements working together. WSM, by treating each criterion independently, might not accurately represent the holistic performance of the building, especially where synergies between different energy-saving measures play a critical role.

Limitations in Decision-Making: Decision-making based on WSM’s linear and independent assessment may result in sub-optimal choices for energy efficiency improvements. It could lead to investing in measures that appear effective in isolation but are less so in the building’s overall energy ecosystem.

While WSM offers a structured and straightforward method for evaluating building energy performance, its assumption of linearity and independence can be a significant limitation. It risks oversimplifying the complex interdependencies of building energy factors, potentially leading to inaccurate assessments and decisions. Recognizing these limitations is crucial for professionals and decision-makers in the field of building energy efficiency, urging them to complement WSM with other methods or approaches that account for the complex interactions inherent in building systems.

6 Thresholding

In this chapter, the role of thresholding within the SmartLivingEPC project will be explored, a methodology that establishes benchmarks for building level performance assessments. At the heart of SmartLivingEPC's approach, thresholding emerges as a strategic tool, aimed at enhancing energy performance and sustainability across various indicators such as Indoor Environment Quality (IEQ), Life Cycle Costing (LCC), and operational efficiency. This methodology not only adheres to strict energy consumption metrics but also encapsulates broader sustainability goals, setting the stage for a comprehensive analysis of building operations.

Thresholding's significance extends beyond mere compliance; it acts as a catalyst for operational improvements, promoting a standardized assessment process adaptable to technological progress and regulatory evolution. This chapter delves into the nuanced processes of setting and applying thresholds—balancing ambition with practicality and ensuring relevance across diverse building types and uses. Through a detailed examination, this chapter aims to underscore the transformative potential of thresholding in driving the SmartLivingEPC project towards its goals of smarter, more sustainable living environments.

Thresholding introduces standardization into the evaluation of building operations, making sustainability goals concrete and actionable. It ensures that performance assessments are consistent and objective, allowing for adaptations based on technological advancements and regulatory changes. The role of thresholding in SmartLivingEPC is significant. It allows for the benchmarking of building performance against standards, highlighting areas for improvement. This process is crucial for meeting regulatory requirements and obtaining sustainability certifications, which can enhance property values and demonstrate environmental responsibility.

Implementing thresholds involves selecting relevant indicators that reflect energy use, environmental impact, and occupant comfort. These thresholds are set based on industry standards and regulations, balancing ambition with realism. Through data collection and analysis, building performance is evaluated against these thresholds, resulting in an operational rating that reflects energy efficiency and sustainability.

However, thresholding faces challenges in ensuring fairness across various building types and operational contexts. Regularly updating thresholds to reflect new research, stakeholder engagement, and allowing for customization are essential for maintaining relevance.

In summary, thresholding is central to SmartLivingEPC's methodology, offering a systematic approach to improve building performance. By applying thresholding principles, SmartLivingEPC aims to advance energy efficiency, sustainability, and enhance the living environment.

6.1 Methodology for Setting Thresholds

The methodology for setting thresholds within the SmartLivingEPC project is a nuanced process that aims to create a balance between ambition and practicality, ensuring that the established benchmarks effectively guide buildings towards improved energy performance and sustainability. This methodological approach is rooted in a comprehensive understanding of the regulatory landscape, industry standards, historical building performance, and the inherent variability in building types and uses.

Benchmarking

Benchmarking involves comparing current building performance standards against industry best practices and established benchmarks to set realistic yet challenging performance goals. This process is instrumental in ensuring that the thresholds are not only ambitious but also achievable, encouraging stakeholders to strive for excellence in building performance. Benchmarking takes into account the performance of similar building types, both regionally and globally, allowing for a comparative analysis that highlights areas for improvement and innovation. It involves gathering data from a wide range of sources, including sustainability certifications, energy performance databases, and case studies of high-performing buildings.

Historical Data Analysis

Utilizing historical performance data is key to understanding how buildings have performed over time, which in turn informs the setting of attainable and ambitious thresholds. This analysis considers trends in energy efficiency, technological advancements, and changes in occupancy patterns, providing a data-driven foundation for threshold setting. Historical data analysis helps to identify achievable performance levels based on past successes and challenges, ensuring that the thresholds reflect realistic expectations for improvement while still pushing the envelope in terms of building performance. It involves reviewing energy consumption records, maintenance logs, and renovation histories to assess the potential for energy savings and sustainability improvements.

Adaptability

The diversity of buildings in terms of function, usage, design, and geographic location necessitates a flexible approach to threshold setting. Recognizing that a one-size-fits-all strategy is ineffective, the SmartLivingEPC methodology emphasizes the need for adaptable thresholds that can be customized to fit the specific needs and circumstances of each building. This adaptability ensures that the thresholds are relevant and applicable across a broad spectrum of building types, from residential homes to commercial offices and industrial facilities. It requires a deep understanding of the unique characteristics and operational requirements of different building categories, as well as the environmental conditions of various geographic regions.

In summary, the methodology for setting thresholds in the SmartLivingEPC project is a comprehensive and iterative process that balances regulatory compliance, industry standards, historical performance insights, and the need for adaptability. By meticulously applying this methodology, the project aims to establish benchmarks that drive the building sector towards greater energy efficiency, environmental sustainability, and improved occupant comfort, contributing to the broader EU goals of achieving a carbon-neutral built environment.

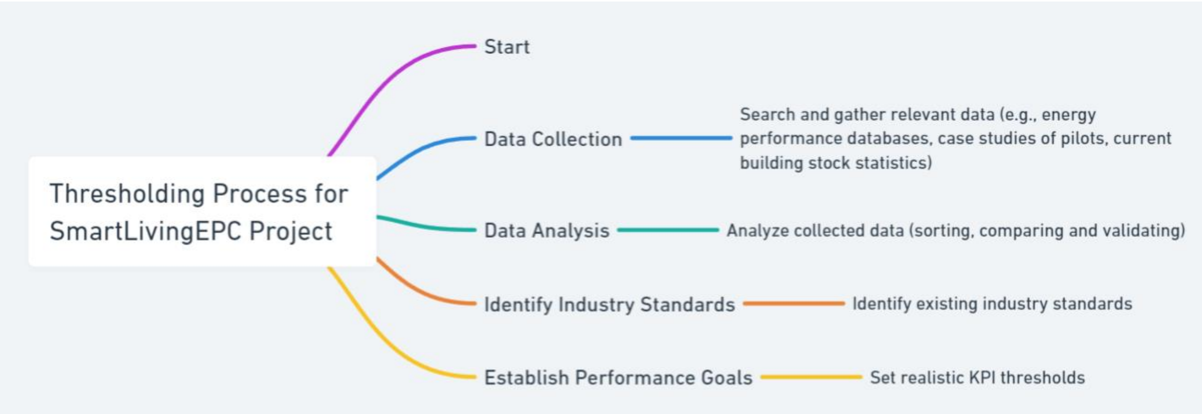

Figure 1: Thresholding process mind map.

6.2 Application of Thresholds in Operational Rating methodology

The application of thresholds in the operational rating process is a nuanced approach within the SmartLivingEPC framework, meticulously designed to enhance building performance assessment and improvement strategies. This structured application serves not only as a benchmark for compliance but also as a roadmap for targeted enhancements in energy efficiency and sustainability. As buildings are evaluated, integrated into the rating system, and subjected to continuous improvement efforts, the role of thresholds becomes increasingly central. However, this approach does entail specific challenges and considerations that need meticulous attention to ensure the effectiveness and adaptability of thresholding in operational rating.

Detailed Application of Thresholds in Operational Rating

Indicator Assessment: The first step involves a thorough evaluation of each building against selected performance indicators. This evaluation is grounded in comparing actual performance data with predefined thresholds, determining compliance levels, and identifying performance gaps. For instance, if a building's energy consumption per square meter exceeds the threshold set for energy efficiency, this indicates a need for improvement. Such assessments are not only quantitative but also qualitative, considering factors like occupant comfort and indoor air quality, thus ensuring a holistic view of building performance.

Rating System Integration: Incorporating thresholds into the SmartLivingEPC rating system is pivotal. This integration ensures that operational ratings reflect a comprehensive assessment of building performance across various dimensions. The operational rating, derived from how well a building meets or exceeds these thresholds, offers a clear, quantifiable metric for comparing buildings. This comparative metric is invaluable for stakeholders, including building owners, tenants, and regulatory bodies, providing a transparent view of building performance relative to established benchmarks.

Improvement Prioritization: Identifying indicators that fall below set thresholds is crucial for prioritizing improvement initiatives. This process enables stakeholders to allocate resources effectively, focusing on areas with the most significant potential for enhancing overall building performance. Prioritization based on thresholding ensures that investments in energy efficiency and sustainability yield the highest impact, fostering a strategic approach to building upgrades and retrofitting.

Challenges and Considerations in Threshold Application

Dynamic Nature of Standards: The evolving landscape of environmental goals and technological advancements necessitates regular updates to thresholds. This dynamic nature ensures that thresholds remain aligned with current best practices and innovation in building technology, maintaining their relevance and effectiveness. Periodic reviews and updates to thresholds accommodate new insights, regulatory changes, and advancements in sustainable building practices, ensuring the operational rating system evolves in tandem with the industry.

Diversity and Complexity: The broad spectrum of building types, uses, and geographic contexts introduces significant complexity into the thresholding process. A flexible approach to thresholding acknowledges this diversity, avoiding oversimplification and ensuring that thresholds are applicable and relevant across various scenarios. Customizing thresholds to account for specific characteristics of building types, operational contexts, and regional environmental conditions is essential for maintaining the integrity and applicability of the operational rating system.

In conclusion, the application of thresholds within the SmartLivingEPC operational rating process is a critical yet complex endeavor, requiring ongoing refinement and adjustment. By navigating these challenges with a strategic and informed approach, the SmartLivingEPC project can ensure that thresholding remains a powerful tool for driving advancements in building energy efficiency and sustainability, ultimately contributing to broader environmental and social goals.

6.2.1 Thresholding of Indoor Environment Quality Indicators

The Indoor Environmental Quality assessment is based on EN 16798-1:2019 and the thresholding is focused on the level of expectations the occupancy has. The EN 16798-1:2019[1] have four categories for the indoor environmental quality as level of expectations of occupants: high, medium, moderate and low. The SmartLivingEPC approach divided them to eight categories. The medium category (Category B-C) is preferred and usually the goal for most room types. High environmental quality is preferred to rooms with more sensitive persons (e.g. childrens, elder people, etc.). However, the final threshold is Category G, as the poorest environmental quality. If the indicator is not within the eight categories, the IEQ will be outside of threshold limits. The description category limits are presented in the forthcoming five subsections for various indoor environment quality (IEQ) indicators. The thresholds are strategically set to safeguard occupant health and enhance comfort in indoor settings. The indicator score will be calculated for thermal comfort, IAQ and virus risk indicators for Overall Operational Rating calculation.In the forthcoming five tables, a detailed description of indicators specifically related to human comfort and Indoor Air Quality (IAQ) is provided. These tables comprehensively outline each indicator, delving into their relevance, measurement methods, and impact on the indoor environment. They serve as a valuable resource for understanding how these indicators contribute to assessing and enhancing the comfort and air quality within building spaces. The following tables present also the thresholds (level G) for the indicators.

Table 34: Thermal comfort indicator

Indicator Name	Indoor Air Temperature
Indicator Description	The Indoor Air Temperature is the dry-bulb temperature measured indoor (in room).
Units	°C
Measurement scale	Interval
Equipment	Temperature sensor
Thresholding	See Table 9 (from D3.4 Section 2.4.1.1)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

The thermal comfort indicator includes indoor dry-bulb temperature measurement and will be calculated by the methodology oulined in D3.4 section 2.4.1.1. The category is calculated using the TAIL methodology that defines that “the temperatures can exceed the indicated range by 1 °C for no more than 5%, and by 2 °C for no more than 1% of the occupancy time during which the measurements were performed (during the working hours in offices and night-time sleeping hours in hotels).” The temperature ranges as for the categories are presented in **Table 35**. In general, The SmartLivingEPC thermal comfort assessment follows next steps:

1) Calculate first the hours that the indoor temperatures are 1°C and 2°C over each category limits
2) Calculate the percentages over total hours.

Finally, using the 5/1% rule (respectively for 1°C and 2°C), choose the category of room thermal comfort

Table 35: Indoor air temperature ranges for thermal comfort categories from EN 16798-1

Category	Residential buildings (1.2 met)		Residential buildings (1.5 met)		Offices, classrooms etc. (1.2 met)	
	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo	Temperature range for heating seasons, °C Clothing approx. 1,0 clo	Temperature range for cooling seasons, °C Clothing approx. 0,5 clo
A	21.0-25.0	23.5-25.5	18.0-25.0	-	21.0-23.0	23.5-25.5
B	20.5-25.0	23.3-25.75	17.0-25.0	-	20.5-23.5	23.3-25.75
C	20.0-25.0	23.0-26.0	16.0-25.0	-	20.0-24.0	23.0-26.0
D	19.0-25.0	22.5-26.5	15.0-25.0	-	19.5-24.5	22.5-26.5
E	18.0-25.0	22.0-27.0	14.0-25.0	-	19.0-25.0	22.0-27.0
F	17.5-25.0	21.5-27.5	-	-	18.0-25.0	21.5-27.5
G	17.0-25.0	21.0-28.0	-	-	17.0-25.0	21.0-28.0
OUTSIDE	not in 17.0-25.0	not in 21.0-28.0	not in 14.0-25.0	-	not in 17.0-25.0	not in 21.0-28.0

6.2.1.1 IAQ CO_2 indicator assessment

The operational rating assessment for indoor air quality within the SmartLivingEPC framework follows the guidelines outlined in EN 16798-1:2019, which provides criteria for assessing indoor air quality and ventilation rates. Specifically, Method 1 of the standard is employed, which determines design ventilation rates based on perceived air quality, considering both the occupant density, and building materials used.

Category limit values of room CO_2 concentration are calculated based on the number of people present in the room (occupant density), the level of their activity (CO_2 generation) as well as the building materials emission, according to the ventilation rates provided in tables in D3.4. This is done by solving the room CO_2 mass balance according to ambient CO_2 concentration, CO_2 generation in the room, and fresh air exchange rate. The room IAQ Category will be calculated using TAIL calculation methodology [1] . Specifically, the CO2 measurements cannot exceed the range defined by the indicated category boundaries and the lower category boundaries for more than 5% of the occupied time and the range defined by the next lowest category boundaries 1% of the time. The examples of the category selection are outlined in Table 36 **and Table 37**. Building IAQ category is calculated as the arithmetic mean of the individual room categories.

Table 36: Example 1 for IAQ CO2 assessment

Category	A	B	C	D	E	F	G	OUTSIDE
Percentage in category	5%	90%	1%	2%	1%	1%	0%	0%
Percentage of measurements exceeding the category limits	95%	5%	4%	2%	1%	0%	0%	0%
Selected category			C					

Table 37: Example 2 for IAQ CO2 assessment

Category	A	B	C	D	E	F	G	OUTSIDE
Percentage in category	0%	80%	12%	5%	2%	1%	0%	0%
Percentage of measurements	100%	29%	8%	3%	1%	0%	0%	0%

exceeding the category limits								
Selected category				D				

Table 38: IAQ indicator (room CO_2 volumetric concentration)

Indicator Name	Room CO_2 volumetric concentration
Indicator Description	Carbon dioxide is a widely recognized indicator of indoor air quality, primarily because it is directly related to human occupancy and ventilation.
Units	ppm
Measurement scale	Interval
Equipment	CO_2 sensor
Thresholding	Calculated according to D3.4 Section 2.4.2.1
Sampling Frequency	15 min (max hourly)
Calculation Methodology	Calculated according to D3.4 Section 2.4.2.1
Regulatory Compliance	EN 16798-1:2019

Table 39: IAQ indicator (Room particulate matter <2,5 μm (PM 2.5) concentration)

Indicator Name	Room particulate matter <2,5 μm (PM 2.5) concentration
Indicator Description	Fine particulate matter refers to tiny airborne particles with a diameter of 2.5 micrometers or less. These particles can be generated from various sources, including combustion processes, cooking, smoking, and outdoor pollutants that infiltrate indoor spaces
Units	$\mu g/m^3$
Measurement scale	Interval
Equipment	PM2.5 sensor
Thresholding	See Table 12 (from D3.1 Section 2.4.2.2)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 40: PM2.5 annual mean category limit values

Category	Limit concentration ($\mu g/m^3$)
Category A	5
Category B	7.5
Category C	10

Category D	12.5
Category E	15
Category F	20
Category G	25
Outside allowed limit	≥25.0

Table 41: Virus risk indicator

Indicator Name	**Event reproduction number - R**
Indicator Description	Number of people who become infected per infectious occupant
Units	-
Measurement scale	Interval
Equipment	-
Thresholding	See Table 14 (from D3.4 Section 2.4.2.3)
Sampling Frequency	-
Calculation Methodology	Calculated according to D3.4 Section 2.4.2.3
Regulatory Compliance	REHVA proposal for post-COVID[1]

[1] Health-based target ventilation rates and design method for reducing exposure to airborne respiratory infectious diseases. REHVA proposal for post-COVID target ventilation rates. Rehva 2022 https://www.rehva.eu/activities/post-covid-ventilation

Table 42: Proposed virus risk estimation scale based on R values at specified risk levels

Risk level	***R_0*, N° of new disease cases by one infector**	***R* in offices**	***R* in classrooms**	***R* in meeting rooms**
A	0.8	0.32	0.071	0.300
B	0.85	0.34	0.076	0.319
C	0.9	0.36	0.080	0.338
D	0.925	0.37	0.082	0.347
E	0.95	0.38	0.084	0.356
F	0.975	0.39	0.087	0.366
G	1.0	0.40	0.089	0.375
Outside	>1.0	>0.40	>0.089	>0.375

Table 43: Occupancy feedback indicator (MV (mean vote))

Indicator Name	**MV (mean vote)**
Indicator Description	The satisfaction/dissatisfaction rate of indoor air temperature and thermal comfort.
Units	-
Measurement scale	Interval

Equipment	-
Thresholding	See Table 16 (from D3.4 Section 2.4.3.5)
Sampling Frequency	Usually year (or if needed)
Calculation Methodology	Calculated according to D3.4 Section 2.4.3.5
Regulatory Compliance	EN 16798-1:2019, ISO 10551, ISO 28802 and EN ISO 7730

Table 44: The feedback indicator threshold

Feedback category	Thermal comfort (mean vote in 5-point scale)
A	-0.2 ≤ (P)MV ≤+0.2
B	-0.35 ≤ (P)MV ≤ +0.35
C	-0.5 ≤ (P)MV ≤ +0.5
D	-0.6 ≤ (P)MV ≤ +0.6
E	-0.7 ≤ (P)MV ≤ +0.7
F	-0.85 ≤ (P)MV ≤ +0.85
G	-1.0 ≤ (P)MV ≤ +1.0
OUTSIDE	(P)MV > 1.0

Analysing the category limits presented in the tables for various indoor environment quality (IEQ) indicators, it becomes clear that these thresholds are strategically set to safeguard occupant health and enhance comfort in indoor settings. Each category limit, particularly the most stringent ones, plays a critical role in guiding building operations and maintenance. Let's discuss some key points for a few selected indicators:

PM2.5 Concentration Limits

The PM2.5 concentration limits show a graduation from Category A (5 µg/m3) to Category G (25 µg/m3) as shown in **Table 40**, which indicates increasing levels of particulate matter that are permissible in indoor air. The room IAQ category has been selected similarly as for IAQ CO_2 indicator assessment.

Virus Risk Estimation

The virus risk estimation scale is particularly topical as shown in **Table 42**, considering the global focus on airborne transmission of diseases post-COVID. The table details R values from a low-risk scenario (R = 0.32 in offices for Category A) to a threshold limit (R = 0.40 in offices for Category G), which is set at the point of maintaining an R value at or below 1.0 to prevent exponential spread.

- **Practical Application**: This scale assists in implementing targeted ventilation and occupancy strategies to keep the R value under control, especially in high-density settings like offices and classrooms.
- **Customized Responses**: Different settings (offices, classrooms, meeting rooms) have tailored R values reflecting the typical occupancy and room usage, allowing for more specific risk management.

Occupancy Feedback Indicator - MV

The mean vote (MV) scale ranges from -1.0 to +1.0 as shown in **Table 44**, where Category G allows the widest range of thermal discomfort before considered outside acceptable limits. This scale is crucial for:

- **Feedback Loop**: It directly involves occupant feedback to gauge the effectiveness of the indoor climate control strategies.

- **Adaptive Comfort Models**: This range reflects an adaptive comfort model where the perception of comfort can vary widely among individuals, allowing building systems to adjust based on a broader range of feedback.

These category limits are not just arbitrary figures but are based on research and consensus among experts to balance comfort, health, and practicality. The challenge lies in maintaining environments within these limits, which requires sophisticated monitoring and control systems. Furthermore, each category boundary serves as a trigger point for action, ensuring that deviations are addressed promptly to mitigate any adverse effects on occupants' comfort and health.
The detailed categorization and associated limits underline the need for a nuanced approach to managing indoor environments, emphasizing the importance of continuous monitoring and agile management practices to stay within these prescribed thresholds.

6.2.1.2 Calculating the indicator score

The category for each room will be determined according to the SmartLivingEPC methodology. The score for each room and component will be selected from the Category-Score table (**Table 45**), based on the calculated category. The total score for each component will be calculated as the arithmetic mean of the rooms' IEQ scores for that specific component, only including rooms where the indicator was measured, and a score was assigned. For visualization, the Total Category for each component will be determined based on the Category-Score table. The Score for each indicator will be weighted according to the SmartLivingEPC methodology.

The total IEQ score for the building will be the lowest (i.e., worst) score among the four components: IAQ-CO_2, IAQ-$PM_{2.5}$, thermal comfort, and virus risk. For example, if the Virus risk has the lowest score, this will be selected as the final IEQ score. If a component score is missing (e.g. the indicator was not measured), it will be excluded from the assessment, with a note indicating which component is missing.

The Occupancy Feedback is not included in the building IEQ score. However, if occupancy feedback is collected, it should be presented alongside the Building IEQ score/class.

Note: The Building IEQ score will be calculated using only the components measured in the building. For example, if PM2.5 measurements are not available in any building rooms, it will be excluded from the assessment, but it should be noted which component(s) are missing from the assessment.

Table 45 : The Category-Score table for the IEQ assessment method

Category	Score
A	100
B	87.5
C	75
D	62.5
E	50
F	37.5
G	25
OUTSIDE	0

6.2.2 Thresholding of Operational rating energy indicators

6.2.2.1 Cyprus Case study

After delving into the methodology and importance of thresholding in SmartLivingEPC's operational rating system, it becomes pivotal to apply these principles to specific energy indicators. This section transitions from theoretical groundwork to practical application, illustrating how thresholds are meticulously established and utilized to foster energy efficiency and sustainability.

The process of establishing thresholds for the operational rating energy indicators involves setting both upper and lower limits for each operational rating energy indicator. This dual-threshold approach is designed to cater to the diversity of the building stock and account for varying levels of energy consumption performance. The upper threshold sets a maximum acceptable limit to encourage energy reduction, while the lower threshold establishes a performance baseline that buildings should strive to surpass for enhanced sustainability.

The thresholds are derived from the Cyprus building stock data as shown in **Table 46** by applying an adjustment factor as shown in **Table 46**, which reflects the ambition of the SmartLivingEPC project to achieve energy efficiency improvements while considering the practicality of such improvements in terms of technology and cost.

Establishing Upper and Lower Thresholds:

The establishment of upper and lower thresholds for operational rating energy indicators is a nuanced process that reflects the SmartLivingEPC project's commitment to promoting energy efficiency and sustainability. This dual-threshold approach caters to the diversity within the building stock, encouraging reductions in energy consumption while setting performance baselines that aspire for sustainability enhancements. The process, detailed through Table 46 and **Table 47**, relies on comprehensive data analysis from the Cyprus building stock, incorporating an adjustment factor to reflect both ambition and practicality.

For instance, lighting energy consumption per total floor area is calibrated with upper and lower thresholds derived from the Cyprus stock average, adjusted by 10% on either side. This strategic adjustment aims to encourage the adoption of energy-efficient lighting solutions while recognizing the variability in existing buildings' energy usage patterns. Similarly, thresholds for cooling, heating, appliances, and domestic hot water energy consumption are set with the objective of stimulating the adoption of advanced technologies and efficient practices.

Table 46: Typical Energy Demand per Type of Residence in Cyprus

Building Type	Construction Year	Space Heating (kWh/m²/year)	Space Cooling (kWh/m²/year)	DHW (kWh/m²/year)
Single-family Houses	Before 1981	54	72	23
Single-family Houses	1981-2006	40	54	18
Single-family Houses	After 2006	36	50	18
Two-family Houses and Terraced Houses	Before 1981	43	58	15
Two-family Houses and Terraced Houses	1981-2006	39	44	23
Two-family Houses and Terraced Houses	After 2006	45	84	18

Apartments	Before 1981	33	76	15
Apartments	1981-2006	56	53	23
Apartments	After 2006	41	41	28
Other Types of Houses	Before 1981	37	53	15

* *Author elaborated, utilizing data sourced from the Cyprus Statistical Service (CYSTAT)*

Table 47: Proposed Upper and Lower Threshold Values for Operational rating energy Indicators

Indicator	Lower Threshold (kWh/m²/year)	Upper Threshold (kWh/m²/year)	Basis for Threshold Setting
Lighting Energy Consumption per total floor area	Average - 10%	Average + 10%	Statistics from the building stock in Cyprus
Cooling Energy Consumption per total floor area	Average - 20%	Average + 20%	Statistics from the building stock in Cyprus
Heating Energy Consumption per total floor area	Average - 15%	Average + 15%	Statistics from the building stock in Cyprus
Appliances Energy Consumption per total floor area	Average - 20%	Average + 10%	Statistics from the building stock in Cyprus
Domestic Hot Water Energy Consumption per total floor area	Average - 25%	Average + 15%	Statistics from the building stock in Cyprus

**Average refers to the average energy consumption per building type and period from the Cyprus building stock data.*

Analytical Justification for the Determination of Threshold Settings

The decision to calculate the lower threshold as 80% of the average consumption and the upper threshold at 110% is rooted in a balanced consideration of ambition and feasibility. This strategic choice aims to set a realistic yet challenging framework for energy performance across different building types.

- **Lower Thresholds**: The establishment of lower thresholds at 80% of the average consumption is designed to push for advancements in energy efficiency by identifying and promoting the adoption of best practices. This threshold acts as a motivator for stakeholders to implement cost-effective energy-saving measures, such as upgrading to LED lighting, enhancing insulation, or installing more efficient HVAC systems, which can significantly reduce a building's energy footprint.

- **Upper Thresholds**: Conversely, setting upper thresholds at 110% of the average aims to highlight buildings that, while not excessively inefficient, have clear room for improvement. This consideration helps in targeting interventions for buildings that might otherwise be overlooked, ensuring that efforts to enhance energy efficiency are inclusive and comprehensive.

The lower and upper thresholds for each energy indicator are derived from the average energy consumption (***A***) of the building stock. Mathematically, these thresholds are calculated as follows:

- **Lower Threshold (*L*) Calculation**:

$$L = A \times 0.80$$

This equation represents the target for energy efficiency improvements, set at 80% of the average consumption, aiming to reduce energy usage.

- **Upper Threshold (*U*) Calculation**:

$$U = A \times 1.10$$

This equation sets the maximum acceptable limit for energy consumption at 110% of the average, identifying buildings that, while not excessively inefficient, require improvements.

Application in Performance Classification

The operational rating of a building in terms of a specific energy indicator (***E***) can be classified based on its comparison with the thresholds:

- If $E \leq L$, the building is classified as a high performer in energy efficiency for that indicator.
- If $L < E < U$, the building falls within the acceptable range but has room for improvement.
- If $E \geq U$, the building is identified as needing targeted interventions to reduce energy consumption.

Identification of Improvement Opportunities

The difference between the actual energy consumption and the thresholds can guide the prioritization of improvements:

- **Energy Savings Potential (*ESP*)**:

$$ESP = E - L$$

This equation calculates the potential energy savings if measures are implemented to bring the building's performance from its current state to the lower threshold level.

Table 48 further exemplifies the application of these thresholds, presenting specific average, lower, and upper threshold values for each energy indicator. These figures are not arbitrary but are calculated based on rigorous analysis and the ambition to align with the SmartLivingEPC project's sustainability goals. The average values for lighting and appliances, for example, are estimated from space heating consumption, adjusted to reflect specific energy-saving targets.

This careful calibration of thresholds illustrates the SmartLivingEPC project's strategic approach to classify buildings according to their energy performance. It highlights opportunities for improvement by setting benchmarks that encourage best practices in energy efficiency while ensuring buildings with higher consumption remain within a reasonable range for potential enhancements.

Table 48: Proposed Threshold Values operational rating energy Indicators.

Indicator	Average (kWh/m²/year)	Lower Threshold (kWh/m²/year)	Upper Threshold (kWh/m²/year)
Lighting Energy Consumption per total floor area	33.92	27.14	37.31
Cooling Energy Consumption per total floor area	58.5	46.80	64.35
Heating Energy Consumption per total floor area	42.4	33.92	46.64
Appliances Energy Consumption per total floor area	38.16	30.53	41.98
Domestic Hot Water Energy Consumption per total floor area	19.6	15.68	21.56

6.2.2.2 Spain Case study

The primary energy consumption thresholds and nearly zero-energy building (NZEB) benchmarks for Spain were extracted from official sources, ensuring alignment with regulatory frameworks and best practices. These sources include the Technical Building Code (CTE), which establishes energy performance regulations in Spain (Ministerio de Transportes, Movilidad y Agenda Urbana, 2020), the BPIE (2021) energy performance study, which provides NZEB benchmarks and policy recommendations for energy-efficient buildings (Buildings Performance Institute Europe [BPIE], 2021), and Spanish government energy performance reports, which outline national building stock classification and energy consumption thresholds (Spanish Government Energy Performance Reports, 2021). These sources provide primary energy limits and classifications that align with established energy efficiency methodologies.[21]

Spain's primary energy classification follows a structured model, where the energy performance classes (A-G) are defined. Class A represents the NZEB benchmark, set at 50-65 kWh/m² for residential buildings and 80-90 kWh/m² for tertiary buildings (BPIE, 2021)[19] . Class D corresponds to the average primary energy consumption of buildings before NZEB implementation (Spanish Government Energy Performance Reports, 2021). Class G represents the highest energy-consuming buildings, based on published thresholds in national reports. For the remaining energy classes (B, C, E, and F), values were interpolated in a linear progression, ensuring consistency with national benchmarks.

Buildings were classified into two age groups. New buildings constructed after 2020 must comply with Spain's latest NZEB regulations, which were introduced in 2019 and **became mandatory in 2020** (Ministerio de Transportes, Movilidad y Agenda Urbana, 2020)[19] . Existing buildings constructed before 2020 operate under older efficiency regulations, resulting in a higher energy demand threshold.

The classification follows Spain's building stock categorization, derived from government energy performance reports (Spanish Government Energy Performance Reports, 2021)[20] . Residential buildings include single-family and multi-family buildings, while tertiary buildings include hotels, hospitals, schools, public buildings, retail spaces, and offices.

The data was structured such that each building type and age group is listed only once, with energy performance classes (A-G) displayed as separate columns. This prevents redundant information and facilitates comparisons across building categories.

Table 49: Building Type Classification and Energy Performance Thresholds

Building Type	Age Category	Class A	Class B	Class C	Class D	Class E	Class F	Class G
Single-family house	<2020	50	65	80	100	120	140	160
Single-family house	>2020	50	65	80	100	120	140	160
Multi-family building	<2020	50	65	80	100	120	140	160
Multi-family building	>2020	50	65	80	100	120	140	160
Hotels	<2020	80	100	120	140	160	180	200
Hotels	>2020	80	100	120	140	160	180	200
Schools	<2020	80	100	120	140	160	180	200
Schools	>2020	80	100	120	140	160	180	200
Public buildings	<2020	50	65	80	100	120	140	160
Public buildings	>2020	50	65	80	100	120	140	160
Supermarkets	<2020	80	100	120	140	160	180	200
Supermarkets	>2020	80	100	120	140	160	180	200
Hospitals	<2020	80	100	120	140	160	180	200
Hospitals	>2020	80	100	120	140	160	180	200
Restaurants	<2020	80	100	120	140	160	180	200
Restaurants	>2020	80	100	120	140	160	180	200
Offices	<2020	80	100	120	140	160	180	200
Offices	>2020	80	100	120	140	160	180	200
Retail shops	<2020	80	100	120	140	160	180	200
Retail shops	>2020	80	100	120	140	160	180	200

Theshold setting: For Spain, the operational rating thresholds are derived from the Class D primary energy consumption values, representing the average performance of the building stock before the implementation of nearly zero-energy building (NZEB) regulations. An adjustment factor of ±15% is introduced, setting the lower threshold at 85% of Class D and the upper threshold at 115% of Class D. For example, in the case of single-family houses, where Class D is 100 kWh/m²/year, the thresholds are defined as 85 kWh/m²/year for the lower limit and 115 kWh/m²/year for the upper limit. This approach ensures that buildings classified within these thresholds reflect typical energy consumption patterns while encouraging energy efficiency improvements in line with national benchmarks.

6.2.2.3 Estonia Case study

Estonian Building Stock Overview

Estonia's building stock reflects the country's harsh winter climate, where low temperatures and extended heating seasons drive high energy demand for space heating. Unlike Mediterranean nations, where cooling is a primary concern, Estonian energy policy focuses on optimizing heating efficiency, improving insulation, and reducing primary energy reliance on fossil fuels.

Estonia has an advanced regulatory framework for building energy performance, with strict thermal transmittance (U-value) requirements for new and renovated buildings. The Nearly Zero Energy Building (NZEB) directive has been fully integrated into Estonia's national energy policy, requiring new buildings to have an annual primary energy consumption of no more than 160 kWh/m² for small residential buildings and 150 kWh/m² for multi-apartment buildings.

The Estonian building repository, managed by the Consumer Protection and Technical Regulatory Authority, collects and analyzes:

- Insulation and thermal envelope performance, tracking improvements in building shell efficiency.
- Primary energy conversion factors, mapping district heating vs. individual heat pump adoption trends.
- Building energy consumption data, categorized by building type, construction period, and renovation status.

These data sources help policymakers evaluate energy efficiency trends and guide decisions on heating sector decarbonization.

Energy Performance and Consumption Trends

Energy performance studies in Estonia highlight a 24% decrease in unit heat consumption per square meter since 2000, largely due to:

- Heat Pump Adoption: Estonia has seen a rapid transition from direct electric heating to air-source and ground-source heat pumps. Modern heat pumps have achieved efficiency gains of up to 300%, reducing heating energy demand per unit by 40% compared to conventional systems.
- District Heating Expansion: Estonia has one of the most efficient district heating networks in the EU, covering over 60% of residential and commercial buildings. Recent upgrades have reduced heat losses by 15-20% in urban heating networks.
- Insulation and Airtightness Improvements: Estonia's Passive House standard mandates triple-glazed windows, super-insulated facades, and mechanical ventilation with heat recovery, leading to heating energy savings of up to 50% in newly constructed buildings.

Estonia's energy certification system has evolved towards real performance-based assessment rather than theoretical calculations. Key initiatives include:

- Smart Energy Monitoring: The government has rolled out advanced digital energy tracking systems, allowing real-time benchmarking of building energy use.
- Strict Retrofit Regulations: Estonia enforces mandatory energy efficiency audits every 5 years for buildings over 500m². This has accelerated retrofitting in the commercial and public building sectors.
- Carbon Reduction Goals: By 2035, Estonia plans to fully phase out fossil fuel heating systems, replacing them with biomass, geothermal, and solar-assisted heating solutions.

The integration of district heating optimization, high-efficiency insulation, and renewable heating sources has positioned Estonia as a leader in cold-climate energy-efficient building policies. By 2030, Estonia aims to reduce heating-related emissions by 50%, contributing to the EU's climate neutrality targets. An overview of this is shown in **Table 50**. [22]

Table 50: EPI Value Requirements for Estonia (kWh/m² per year)

Building Type	NZEB (Class A) EPBD Scope	NZEB (Class A)	Low Energy Building (Class B)	Renovation of Existing Building (Class C)
Small Residential Buildings				
a) Net heated area <120 m²	89.4	145	165	185
b) Net heated area 120-220 m² and row house	73.4	120	140	160
c) Net heated area >220 m²	59.5	100	120	140
Multi-apartment buildings	45.9	105	125	150
Military barracks	85.9	170	200	250
Office buildings, libraries, and research buildings	62.11	100	130	160
Accommodation buildings, hotels	138	145	170	220
Commercial buildings	118	130	150	210
Public buildings	135	135	160	220
Commerce buildings and terminals	154	160	190	230
Educational buildings	82.6	100	125	160
Pre-school institutions for children	90.0	120	140	165
Healthcare buildings	83.7	100	130	170
Warehouse	54.0	65	80	100
Industrial building	68.7	110	140	170
Buildings with high energy consumption	Na	820	850	950

Considerations for thresholding for a Cold Climate and Heating-Dominated Load
Estonia's operational energy rating system must account for:

- Dominance of heating in energy consumption: Heating accounts for up to 80% of total building energy use in Estonia. Unlike in Spain, where thresholds need to consider cooling variations, Estonia's rating system must integrate climate-adjusted performance metrics to reflect actual heating efficiency rather than raw consumption figures.
- Impact of district heating and electrification: The widespread use of district heating networks in Estonia leads to lower-than-expected primary energy consumption per square meter compared to individual heating systems. Operational thresholds must incorporate seasonal efficiency adjustments to fairly classify buildings using district heating versus electric or biomass-based systems.
- Stricter insulation standards driving lower energy thresholds: Estonia has mandated high efficiency building envelopes in new and renovated structures. Buildings constructed after 2005 consume up to 50% less heating energy than pre-1980 buildings. As a result, separate operational thresholds must be established for modern vs. older building stock to ensure fair classification.
- **Threshold Setting:** For Estonia, where heating dominates total energy consumption, the threshold values are based on NZEB and Class B limits, which represent the high-performance segment of the building stock.

An adjustment factor of ±20% is applied to account for variations in building performance and heating demands. For example, in multi-apartment buildings, where the Class B threshold is 125 kWh/m²/year, the lower threshold is set at 100 kWh/m²/year and the upper threshold at 150 kWh/m²/year. Similarly, for small residential buildings (120-220 m²), where the Class B threshold is 120 kWh/m²/year, the lower threshold is 96 kWh/m²/year, and the upper threshold is 144 kWh/m²/year. This ensures a balanced classification system that reflects Estonia's strict energy efficiency policies while maintaining adaptability across different building types.

6.2.3 Thresholding of Life Cycle Costing Indicators

In assessing the financial indicators, it's crucial to recognize their twofold nature. On one hand, operational rating indicators offer insights into the efficiency and effectiveness of energy usage within a system or process. These indicators provide a tangible measure of how effectively energy is being utilized, highlighting areas for optimization and improvement. On the other hand, benchmarks for the costs of consumed energy offer a comparative framework for understanding the financial implications of energy usage. By considering the average energy prices alongside consumption rates, a more nuanced understanding of the financial indicators is possible.

The thresholding of the financial indicators, therefore, is derived from the multiplication of energy consumption and average energy prices. This calculation considers the predominant energy carriers within specific countries, recognizing the varying cost structures and consumption patterns across regions.

Operational Energy Indicators

The first aspect of the financial indicators' thresholding is aligned with the operational rating indicators thresholding. Which is based on the average energy need per use, per floor area, per year of buildings. As in the case of Cyprus, the thresholds are presented in **Table 48**.

Table 51: Thresholding of operational rating indicators

Indicator	Average (kWh/m²/year)	Lower Threshold (kWh/m²/year)	Upper Threshold (kWh/m²/year)
Lighting Energy Consumption per total floor area	33.92	27.14	37.31
Cooling Energy Consumption per total floor area	58.5	46.80	64.35
Heating Energy Consumption per total floor area	42.4	33.92	46.64
Appliances Energy Consumption per total floor area	38.16	30.53	41.98
Domestic Hot Water Energy Consumption per total floor area	19.6	15.68	21.56

Energy Prices

In terms of energy prices, it is important to consider the following points:

Energy prices differ by country:

- Energy prices vary significantly from one country to another due to factors such as government policies, energy source availability, infrastructure development, and market dynamics.
- It is important to consider regional or national energy price variations when setting thresholds for financial indicators. For example, buildings located in countries with higher energy prices may have different threshold levels compared to those in countries with lower energy prices.
- It is important to customize the thresholds based on the specific context of each building's geographical location, which is reflected in the operational energy indicators already.

Energy prices change over time:

- Energy prices are volatile, and they can fluctuate due to factors such as geopolitical events, supply and demand dynamics, technological advancements, and regulatory changes.
- It is important that the threshold levels be regularly reviewed and updated according to the changes in energy prices. This could involve setting dynamic thresholds that adjust periodically based on the latest energy price data or establishing thresholds with built-in mechanisms for adjustment in response to significant price fluctuations.

Main energy carriers per use differ by country:

- The energy carriers may vary per use in countries or regions. This may include electricity, natural gas, district heating, oil, coal, biomass, or renewable sources such as solar or wind energy.
- The choice of energy carriers can affect the cost structure and efficiency of building operations. For example, buildings relying on electricity for heating may have different cost profiles compared to those using natural gas or district heating systems.
- The variations in energy carriers impact the calculation and interpretation of financial indicators, and this should be considered when setting thresholds. For instance, buildings in regions with higher reliance on renewable energy may have lower thresholds for carbon emissions but higher thresholds for electricity costs.

By considering the abovementioned points, the energy prices (natural gas, electricity, district heating prices) are sourced from the average prices of electricity of the first semester of 2023 for residential and non-residential buildings per country as presented in Annex A. In this division, the household buildings' annual consumption is between 2500 kWh and 5000 kWh, and the non-household buildings annual consumption is between 500 MWh and 2000 MWh. The average energy prices of natural gas and district heating are presented in Annex B and C.

Therefore, the thresholds from the side of energy consumption are determined per country, as well as the thresholds from the side of energy costs. The suggested upper and lower thresholds of the energy costs are established as 120% and 80% as calculated below. These thresholds are established based on the range of energy rates from different countries, and with the objective to encourage lowering the costs of the energy per household. Besides the energy saving measures, that can improve the energy efficiency of the building, this indicator motivates the users to consider measures such as improving user behaviour to avoid higher rates (for example difference between daytime and nighttime rates for some energy suppliers) or considering upgrading energy carriers.

$$U_{financial\ indicator} = U_{operational\ energy\ indicator} \times A_{energy\ price} \times 1.20$$
$$L_{financial\ indicator} = L_{operational\ energy\ indicator} \times A_{energy\ price} \times 0.80$$

Interpreting Financial Indicators Rating

Since the thresholding of financial indicators are based on two different aspects, the following points should be considered to interpret them correctly, and to use the financial insight to improve the performance of the building:

Operational energy use component in financial indicators:

- Impact on total cost: The energy use component directly influences the energy cost. A higher energy use, regardless of energy price, leads to a higher total cost. This could indicate inefficiencies in energy management or operational practices.

- Benchmarking and comparison: When comparing financial indicators across buildings or industry standards, the energy use component is vital. Buildings with above-average energy use will have higher total cost indicators, highlighting potential areas for improvement in energy efficiency.
- Normalization for fair comparison: Normalizing energy use enables fair comparisons between buildings of different sizes or usage patterns. It ensures that variations in energy use are accurately reflected in the financial indicators and are not solely attributed to differences in building characteristics.
- Efficiency opportunities: Buildings with higher-than-average energy use represent opportunities for energy efficiency improvements. Analyzing energy use patterns can identify areas of excessive consumption, guiding the implementation of targeted energy conservation measures to reduce costs.

Energy price component in financial indicators:

- Impact of price fluctuations: Changes in energy prices directly affect the energy cost indicator. If energy prices increase due to factors like high consumption or expensive contracts, the total cost indicator will rise, even if energy use remains constant.
- Contractual considerations: Expensive energy provider contracts or unfavorable pricing structures can significantly impact the energy price component of the financial indicators. Reviewing and renegotiating contracts may be necessary to mitigate cost increases.
- Long-Term planning: Monitoring energy price trends and understanding contractual obligations are crucial for long-term financial planning. Anticipating and managing potential price increases can help minimize the impact on total energy costs.

Choice of energy carrier in financial indicators:

- Comparison of energy carriers: If there are cheaper energy carriers available, but a more expensive one is being used, it can inflate the financial indicators. Assessing the cost-effectiveness of different energy carriers is essential for optimizing energy expenditure.
- Consideration of alternatives: Evaluating alternative energy sources or technologies can help identify opportunities for cost savings. Transitioning to cheaper or more efficient energy carriers, such as renewables or district heating, may reduce overall energy costs.
- Lifecycle Cost Analysis (LCC): Consideration of the lifecycle cost, including acquisition, operation, and maintenance expenses, is essential when evaluating different energy carriers. Cheaper upfront costs may not necessarily translate to lower total costs over the asset's lifespan. The user can utilize the LCC comparison component of the financial indicators (will be available in the web platform) to make informed decisions in this regard.

Example of Cyprus

In the case of Cyprus, electricity is the main energy carrier for the five energy uses, therefore, the average energy price of electricity is integrated in the thresholding of the operational energy indicators. The result is presented in Figure 2.

Residential										
	Heating		Cooling		DHW		Lighting		Appliance	
	Energy Consumption (kWh/m²/year)	Energy cost (€/m²/year)	Energy Consumption (kWh/m²/year)	Energy cost (€/m²/year)	Energy Consumption (kWh/m²/year)	Energy cost (€/m²/year)	Energy Consumption (kWh/m²/year)	Energy cost (€/m²/year)	Energy Consumption (kWh/m²/year)	Energy cost (€/m²/year)
A	33,92	€ 12,68	46,80	€ 17,50	15,68	€ 5,86	17,14	€ 6,41	30,53	€ 11,42
B	35,04	€ 13,10	49,73	€ 18,59	16,66	€ 6,23	18,84	€ 7,04	32,44	€ 12,13
C	36,16	€ 13,52	52,65	€ 19,69	17,64	€ 6,60	20,53	€ 7,68	34,35	€ 12,84
D	37,28	€ 13,94	55,58	€ 20,78	18,62	€ 6,96	22,23	€ 8,31	36,25	€ 13,56
E	38,40	€ 14,36	58,50	€ 21,87	19,60	€ 7,33	23,92	€ 8,94	38,16	€ 14,27
F	39,52	€ 14,78	61,43	€ 22,97	20,58	€ 7,69	25,62	€ 9,58	40,07	€ 14,98
G	40,64	€ 15,20	64,35	€ 24,06	21,56	€ 8,06	27,31	€ 10,21	41,98	€ 15,70

Figure 2: Threshold setting for LCC indicators, Cyprus

7 From Data to Results: A Structured Calculation Framework

7.1 Energy Performance Metrics in SmartLivingEPC

Energy performance metrics provide a structured and standardized approach within the SmartLivingEPC framework, ensuring compliance with European regulations and enabling accurate benchmarking of buildings. These metrics form the foundation for energy performance evaluations, allowing for objective comparisons and informed decision-making.

The methodology aligns with EN 52000-1, which defines energy performance calculation frameworks based on primary energy use, renewable energy contributions, and indoor environmental quality. The key performance indicators (KPIs) used for assessment are detailed below.

Primary Energy Use

Definition and Importance

Primary energy use quantifies the total energy demand of a building, including:

- Delivered energy from external sources.
- Exported energy generated on-site and supplied to the grid.
- Conversion losses within energy systems.

This metric ensures that energy assessments align with European performance standards, allowing comparisons across building types, climates, and energy sources.

EN 52000-1 Framework Compliance

- Defines primary energy factors (PEFs) to account for source-to-use efficiency losses.
- Considers non-renewable and renewable primary energy contributions separately.
- Supports energy performance certification and compliance with nearly Zero Energy Building (nZEB) standards.

Calculation Methodology

Primary energy use follows the EN 52000-1 balance equation:

$$PE_{\text{net}} = (PE_{\text{delivered}} \times f_{\text{del}}) - (PE_{\text{exported}} \times f_{\text{exp}})$$

Where:

$PE_{\text{delivered}}$ = *Delivered energy, weighted by its primary energy factor*

PE_{exported} = *Exported energy, weighted by its primary energy factor*

PE_{net} = *Net primary energy demand after adjustments for on-site generation.*

This ensures that renewable energy contributions and grid interactions are accounted for when assessing overall building efficiency.

Unit of Measurement:

- Expressed in kilowatt-hours per square meter per year (kWh/m²·year).

Indoor Environmental Quality (IEQ)

Definition and Importance

Indoor Environmental Quality (IEQ) measures factors that impact occupant health and comfort, including:

- Thermal comfort – maintaining stable indoor temperatures and humidity levels.
- Air quality – ensuring adequate ventilation and pollutant control.
- Lighting and visual comfort – providing sufficient daylight and glare reduction.
- Acoustics – maintaining acceptable noise levels in indoor spaces.

EN 16798-1 Framework Compliance

- Defines acceptable IEQ thresholds based on occupant well-being and energy use considerations.
- Includes ventilation rate calculations to ensure adequate air exchange.
- Links thermal comfort and HVAC efficiency to minimize excessive energy consumption.

Measured Parameters

IEQ is assessed based on four key categories:

A. Air Quality

- CO_2 Concentrations (ppm) – High levels indicate inadequate ventilation.
- Particulate Matter (PM2.5 & PM10, µg/m³) – Measures airborne pollutants affecting respiratory health.
- Ventilation Rate (l/s per person) – Ensures fresh air supply meets regulatory standards.

B. Thermal Comfort

- Operative Temperature (°C) – Measured in occupied zones based on seasonal targets.
- Relative Humidity (%) – Maintained within 40-60% for optimal comfort and efficiency.

C. Lighting Conditions

- Daylight Factor (%) – Evaluates natural lighting availability.
- Glare Index – Ensures visual comfort in workspace environments.

D. Acoustics and Noise Control

- Background Noise Levels (dB) – Regulates external and internal noise disturbances.
- Reverberation Time (s) – Affects speech intelligibility in enclosed spaces.

Unit of Measurement:

- Expressed in varied units (ppm, μg/m³, °C, %, dB) depending on the specific IEQ component being evaluated.

Renewable Energy Contribution (REC)

Definition and Importance

Renewable Energy Contribution (REC) quantifies the share of total energy demand met through renewable sources, such as:

- Photovoltaic (PV) solar energy.
- Wind power generation.
- Biomass heating systems.
- Geothermal and solar thermal technologies.

EN 52000-1 Compliance and Considerations

- Distinguishes between on-site, nearby, and external renewable energy sources.
- Assesses renewable energy efficiency factors based on conversion losses and system performance.
- Encourages on-site renewable energy generation to minimize grid dependency.

The renewable energy ratio is computed as:

$$REC = \left(\frac{E_{\text{renewable}}}{E_{\text{total}}}\right) \times 100$$

where:

- $E_{\text{renewable}}$ = Renewable energy produced on-site and used directly within the building.
- E_{total} = Total energy demand, including delivered and on-site generated energy.

A higher REC value indicates greater sustainability, while low REC values highlight opportunities for further renewable energy integration.

Unit of Measurement:

- Expressed as a percentage (%) of total energy demand.

Climate-Corrected Delivered Energy

Definition: Delivered energy is adjusted for climatic conditions to enable fair comparisons between buildings located in different regions or subject to varying weather conditions. By applying degree-day corrections, the output represents the building's energy performance under standardized climate conditions. Degree-day normalization corrects energy use based on climatic conditions using Heating Degree Days (HDD) and Cooling Degree Days (CDD) indices.

- HDD represents the severity of cold weather and is calculated when outdoor temperatures fall below 15°C, with a base temperature of 18°C. The formula used is:
  - If Tm ≤ 15°C, then HDD = Σ(18°C - Tm)
  - Otherwise, HDD = 0

- CDD represents the severity of hot weather and is calculated when outdoor temperatures exceed 24°C, with a base temperature of 21°C. The formula used is:
    - If Tm ≥ 24°C, then CDD = Σ(Tm - 21°C)
    - Otherwise, CDD = 0

Purpose: This output ensures that variations due to weather do not obscure a building's true energy performance, enabling meaningful cross-regional benchmarking and policy compliance.

7.2 Overview of Required Inputs

The operational rating process requires several key inputs to ensure a comprehensive, accurate, and reliable assessment of a building's energy performance. These inputs span multiple categories, including energy data, building-specific characteristics, climatic conditions, operational details, and system properties. A robust dataset ensures that the calculated operational rating reflects real-world building performance and facilitates meaningful comparisons across diverse scenarios. Below is a detailed breakdown of the required inputs:

- **Energy Carrier Data**:
    - **Meter Readings**: Precise and periodic readings of delivered and exported energy from meters are essential. This includes energy carriers such as electricity, gas, and district heating. Sub-metering for specific zones or systems provides additional granularity.
    - **Invoices and Bills**: Utility invoices and fuel purchase records serve as supplementary data sources. These documents validate the meter readings and provide insights into billing cycles and patterns.
    - **Operational Data from Building Automation and Control Systems (BACS)**: Modern buildings often employ BACS to monitor and control energy usage in real time. These systems generate detailed logs of energy flows, equipment performance, and anomalies, contributing to operational data.
- **Building Characteristics**:
    - **Floor Area and Zoning**: Accurate measurements of the total building area, along with information on zoning and space usage, are critical. For instance, areas designated for residential, office, or mixed-use purposes have distinct energy consumption patterns.
    - **Usage Type**: Building usage type, such as residential, office, commercial, or industrial, determines baseline energy needs and operational expectations.
    - **Insulation Levels**: Thermal insulation properties, including wall, roof, and floor insulation levels, impact the building's thermal performance and heating/cooling requirements.
    - **HVAC System Specifications**: Heating, ventilation, and air conditioning (HVAC) systems are major energy consumers. Understanding system design, capacity, and efficiency ratings is crucial for modeling energy performance.
    - **Other Building Services**: Additional systems, such as domestic hot water (DHW), lighting, and renewable energy installations (e.g., solar panels), must be documented for a complete performance picture.
- **Climatic Data**:
    - **External Air Temperatures**: Hourly, daily, or seasonal temperature data directly influence heating and cooling loads. Data can be obtained from nearby meteorological stations or on-site weather monitoring.
    - **Degree Days**: Heating and cooling degree days (HDD/CDD) quantify climatic demands for space heating or cooling. They are calculated based on external temperatures relative to a standard base temperature.
    - **Humidity Levels**: Relative humidity data complements temperature data in evaluating indoor air quality and the efficiency of HVAC systems.
    - **Weather Station Data**: Regional or site-specific meteorological data provides context for energy performance under varying climate conditions.

- **Operational Data**:
    - **Occupancy Schedules**: Detailed occupancy profiles define when and how spaces are used. For instance, offices have peak usage during work hours, while residential buildings see energy peaks in the morning and evening.
    - **Setpoint Temperatures**: The temperature settings for heating and cooling systems during occupied and unoccupied periods significantly impact energy use.
    - **Indoor Air Quality (IAQ) Levels**: Parameters such as CO2 levels, particulate matter (PM2.5, PM10), and ventilation rates are crucial for indoor environment quality (IEQ) assessments.
    - **Usage Patterns**: Detailed data on how systems like heating, cooling, lighting, and domestic hot water are utilized ensures that energy consumption is modeled accurately.
- **Constants and Physical Properties**:
    - **System Efficiency Ratings**: Information on the efficiency of boilers, chillers, heat pumps, and other equipment enables precise energy use calculations.
    - **Primary Energy Factors (PEFs)**: PEFs account for the upstream energy inputs required to deliver usable energy to the building. These factors differ by energy carrier (e.g., electricity, gas) and reflect energy generation and transmission losses.
    - **Emission Factors**: Emission factors quantify the greenhouse gas emissions associated with energy use. They enable life cycle and carbon footprint assessments of building energy performance.

By gathering and integrating these inputs, the operational rating process ensures an accurate representation of building energy performance under real-world conditions, supporting informed decision-making and optimization strategies.

Table 52: Inputs specific to the SmartLivingEPC Operational Rating Framework

Category	Input	Description
Energy Carrier Data	Meter Readings	Periodic readings of delivered and exported energy, including electricity, gas, and district heating.
	Sub-Metering Data	Granular data from sub-meters for specific building zones or systems.
	Utility Invoices and Bills	Records validating energy use and providing billing cycle insights.
Building Characteristics	Floor Area and Zoning	Accurate measurements of total building area and usage types (residential, office, or mixed-use).
	Usage Type	Classification of building type (e.g., residential, commercial, industrial).
	Insulation Levels	Thermal insulation properties of walls, roofs, and floors.
	HVAC System Specifications	Design, capacity, and efficiency ratings of HVAC systems.
	Renewable Energy Installations	Details of solar panels, wind turbines, or other renewable systems.
Climatic Data	Degree Days	Heating and cooling degree days (HDD/CDD) for climate demand quantification.
	Weather Station Data	External temperature and humidity data from meteorological stations.
	Humidity Levels	Data for evaluating indoor air quality and HVAC efficiency.
Operational Data	Occupancy Schedules	Profiles defining usage times for spaces (e.g., office hours, residential peaks).
	Setpoint Temperatures	Target heating/cooling temperatures during occupied/unoccupied periods.

	Indoor Air Quality (IAQ) Parameters	CO2 levels, particulate matter (PM2.5, PM10), and ventilation rates for IEQ assessments.
	Equipment Usage Patterns	Data on heating, cooling, lighting, and domestic hot water consumption patterns.
Constants and Physical Properties	Calorific Values and Energy Densities	Fuel energy content (e.g., natural gas, oil, biomass) and their energy densities.
	System Efficiency Ratings	Efficiency ratings for boilers, chillers, heat pumps, and other systems.
	Primary Energy Factors (PEFs)	Conversion factors for delivered energy to primary energy, varying by energy carrier.

This **Table 52** outlines the essential inputs, specifically tailored to the SmartLivingEPC framework, ensuring comprehensive energy performance assessments under real-world conditions. Let me know if you'd like further customization.

7.3 Data Sources for Measured Energy Performance

Accurate and comprehensive data sources are critical for operational rating calculations, as they ensure the validity, consistency, and precision of the assessment. A combination of direct measurements, utility records, building documentation, and external references provides the foundation for a robust operational energy assessment. Below is a detailed description of the key data sources:

- **Direct Measurements**:
  - **Smart Meters**: Smart meters provide precise, real-time readings of delivered energy. They are critical for monitoring energy consumption for electricity, gas, and district heating. Sub-metering data enhances granularity by offering insights into energy use in specific building zones or systems (e.g., lighting, HVAC, or specific floors).
  - **Indoor Environment Sensors**: Sensors measure key indoor environmental parameters such as temperature, humidity, and air quality (e.g., CO2 levels). These data points are essential for assessing Indoor Environmental Quality (IEQ) and understanding its impact on energy performance.
- **Utility Invoices and Contracts**:
  - **Energy Consumption Records**: Utility invoices provide a detailed breakdown of energy consumption across billing periods, helping validate meter readings and identify trends in energy use.
  - **Cost Data**: Energy bills also contain cost information that can be useful for life cycle costing (LCC) analysis. This data helps calculate the financial implications of operational energy performance.
  - **Renewable Energy Documentation**: Invoices or contracts related to renewable energy systems (e.g., solar power purchase agreements) and records of exported energy (e.g., electricity fed back into the grid) are vital for understanding renewable energy contributions.
- **Building Documentation**:
  - **Floor Plans**: Accurate floor plans are essential for calculating the total area of the building and its zoning, which influence energy performance metrics such as energy use per square meter.
  - **HVAC System Specifications**: Documentation of heating, ventilation, and air conditioning (HVAC) systems, including design parameters, capacities, and efficiency ratings, ensures accurate modeling of energy use.
  - **Occupancy Schedules**: Records of how building spaces are utilized, including peak and off-peak hours, enable detailed modeling of operational patterns and their impact on energy consumption.
- **External Sources**:

- **Meteorological Data**: Regional or site-specific meteorological data, such as temperature, degree days (heating and cooling), and humidity levels, are necessary for climate normalization of energy performance data. These data points can be sourced from national weather services or local monitoring stations.
- **Primary Energy and Emissions Factors**: National or regional databases provide standardized factors for converting delivered energy into primary energy and estimating associated emissions. These factors account for the upstream energy requirements and carbon footprint of various energy carriers, such as electricity, gas, and biomass.

By leveraging these diverse and complementary data sources, the operational rating process ensures that the measured energy performance accurately reflects real-world conditions. This comprehensive approach supports benchmarking, optimization, and informed decision-making for building energy efficiency improvements.

7.4 Calculation Methodology

The operational rating methodology involves several detailed calculation steps to process input data into meaningful outputs, ensuring an accurate assessment of energy performance under real-world conditions. Each step accounts for critical factors like delivered energy, exported energy, renewable energy contributions, and climate normalization. Below is a comprehensive breakdown of the methods:

SmartLivingEPC Operational Rating Methodology

The operational rating methodology involves a series of structured and detailed calculation steps to process input data into meaningful outputs. These steps ensure an accurate assessment of a building's energy performance under real-world conditions, incorporating key factors such as delivered energy, exported energy, renewable energy contributions, and climate normalization. The methodology follows a systematic approach to ensure transparency, consistency, and compliance with European performance standards. Below is a comprehensive breakdown of the calculation steps:

Step 1: Measured Energy Data Collection

To establish an accurate energy performance baseline, data is collected through:

- **Smart Meters and Sub-Metering Devices**: Real-time monitoring of electricity, heating, and cooling energy use.
- **Utility Records and Bills**: Cross-verification of consumption data.
- **Delivered Energy Data**: Measurement of energy sourced externally (e.g., grid electricity, district heating, natural gas, etc.).
- **Exported Energy Data**: Quantification of on-site renewable energy generation supplied to the grid.

Step 2: Climate Adjustment & Standardization

Buildings in different climatic zones experience varying heating and cooling demands. To enable fair comparisons, energy consumption is adjusted using **degree-day normalization**:

- **Heating Degree Days (HDD)**: Quantifies the demand for heating based on outdoor temperature deviations below 15°C.
- **Cooling Degree Days (CDD)**: Measures cooling demand when temperatures exceed 24°C.
- **Standardized Energy Values**: Adjustment of measured energy data to account for deviations from standardized operating conditions.

This process ensures that **climate variations do not skew performance assessments** and facilitates meaningful benchmarking.

Step 3: Performance Indicator Scoring

Once the climate-adjusted energy data is obtained, key **performance indicators (KPIs)** are computed, including:

- **Energy Efficiency Metrics**:
  - Heating and cooling energy per square meter (kWh/m² per year).
  - Total operational energy demand.
- **Renewable Energy Contributions**:
  - Percentage of total energy demand met through renewable sources.
  - Net-zero energy balance assessments.
- **Indoor Environmental Quality (IEQ) Scores**:
  - CO2 levels (ppm) as an indicator of air quality.
  - Thermal comfort parameters (operative temperature and humidity levels).
  - Daylight factor and glare index for lighting conditions.

Each performance metric is then **normalized** against benchmark reference values to ensure comparability across different building types, locations, and operational contexts.

Step 4: Life Cycle Costing (LCC) Analysis

To provide a comprehensive evaluation of building energy performance, **Life Cycle Costing (LCC)** is integrated into the operational rating methodology. LCC ensures that long-term cost-effectiveness is assessed alongside energy efficiency and sustainability by:

- **Calculating Initial Investment Costs**:
  - Acquisition and installation expenses of energy-efficient systems and renewable energy technologies.
- **Operational & Maintenance Costs**:
  - Evaluating recurring expenses for HVAC systems, lighting, insulation, and other building components.
- **Energy Costs Over Time**:
  - Estimating total energy expenses based on projected consumption trends and market rates.
- **End-of-Life & Replacement Costs**:
  - Factoring in decommissioning, recycling, and replacement of outdated building systems.

Step 5: Weighted Score Aggregation

A **Weighted Sum Model (WSM)** is applied to combine individual performance indicators into a final operational rating. This process involves:

- **Assigning Weights to Indicators**: Reflecting the relative importance of:
  - **Energy consumption efficiency** (e.g., delivered vs. exported energy).
  - **Indoor environmental quality** (e.g., air quality, thermal comfort, acoustic conditions).
  - **Sustainability contributions** (e.g., renewable energy share, emissions reduction).
- **Computing the Aggregated Score**: A weighted sum of all normalized indicator values, ensuring a balanced assessment that aligns with European regulatory frameworks.

The inclusion of LCC in SmartLivingEPC supports **financial decision-making**, helping stakeholders balance **economic feasibility with energy performance goals**.

Step 6: Output Metrics & Final Rating

Upon completing the calculations, the methodology generates several **key output metrics**, including:

- **Climate-Adjusted Delivered Energy**: Standardized energy consumption accounting for climatic conditions.
- **Renewable Energy Utilization Percentage**: Share of total energy demand covered by renewable sources.
- **Operational Energy Consumption per m²**: A fundamental metric for benchmarking building energy efficiency.
- **Indoor Air Quality and Thermal Comfort Metrics**: Ensuring compliance with health and well-being standards.
- **Life Cycle Cost Metrics**: Comprehensive cost assessments over the building's lifetime.

8 Conclusion

Deliverable 3.7 presents the latest advancements in the SmartLivingEPC operational rating methodology, integrating refinements from previous deliverables, pilot studies, and expert feedback. This updated framework enhances the accuracy, applicability, and adaptability of building energy performance assessments, aligning with European standards such as EN 52000-1.

A key outcome of this deliverable is the selection of 15 critical indicators, carefully chosen from an initial set of 71, covering energy consumption, indoor environmental quality (IEQ), and Life Cycle Costing (LCC). These indicators provide a comprehensive yet manageable approach to evaluating operational performance across diverse building typologies and climatic conditions.

The weighting methodology, with a primary focus on the Weighted Sum Model (WSM), ensures a balanced evaluation of multiple performance criteria. Alternative weighting approaches such as Principal Component Analysis (PCA) and Analytic Hierarchy Process (AHP) were also explored to validate the robustness of the assessment. Additionally, the normalization and thresholding processes introduced in this version enhance comparability across different buildings and operational conditions.

A significant enhancement in this iteration is the integration of digital logbook technologies (Task 4.4) to streamline data collection, management, and reporting. The methodology now supports automated tracking of operational performance, ensuring real-time monitoring and continuous improvements.

By bridging the gap between design-based energy assessments and real-world operational data, this deliverable strengthens the SmartLivingEPC framework, paving the way for more data-driven, transparent, and standardized energy performance evaluations. Future work will focus on the validation and further refinement of the methodology through pilot demonstrations and stakeholder engagement, ensuring its alignment with evolving regulatory and market needs.

This deliverable serves as a milestone in the transition toward a more dynamic and holistic approach to building energy performance assessment, ultimately contributing to the broader goals of energy efficiency, sustainability, and smart living in the built environment.

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Annex A

Table 1: Natural gas prices, first semester of 2021-2023
(€ per kWh)

	Households (¹)			Non-households (²)		
	2021S1	2022S1	2023S1	2021S1	2022S1	2023S1
EU	0,0638	0,0861	0,1187	0,0302	0,0652	0,0826
Euro area	0,0684	0,0908	0,1253	0,0308	0,0636	0,0808
Belgium	0,0468	0,0943	0,1146	0,0221	0,0488	0,0624
Bulgaria	0,0368	0,0764	0,0897	0,0248	0,0600	0,0653
Czechia	0,0562	0,0696	0,1138	0,0251	0,0680	0,0769
Denmark	0,0895	0,1509	0,1655	0,0339	0,1062	0,0671
Germany	0,0647	0,0806	0,1230	0,0319	0,0533	0,0808
Estonia	0,0435	0,1106	0,1099	0,0317	0,1014	0,0834
Ireland	0,0620	0,0847	0,1465	0,0331	0,0671	0,0765
Greece	0,0449	0,0821	0,1171	0,0252	0,0751	0,0757
Spain	0,0691	0,0897	0,1077	0,0237	0,0729	0,0670
France	0,0691	0,0859	0,1043	0,0343	0,0614	0,0812
Croatia	0,0374	0,0412	0,0410	0,0294	0,0561	0,0651
Italy	0,0703	0,0986	0,0981	0,0272	0,0734	0,0913
Latvia	0,0297	0,0462	0,1105	0,0232	0,0711	0,1038
Lithuania	0,0279	0,0587	0,0587	0,0285	0,1057	0,0768
Luxembourg	0,0438	0,0856	0,0875	0,0322	0,0781	0,1185
Hungary	0,0307	0,0291	0,0337	0,0224	0,0577	0,1077
Netherlands	0,0961	0,1244	0,2481	0,0422	0,0765	0,0865
Austria	0,0636	0,0767	0,1560	0,0312	0,0642	0,0768
Poland	0,0376	0,0549	0,0683	0,0281	0,0752	0,1036
Portugal	0,0762	0,0837	0,1406	0,0245	0,0692	0,0530
Romania	0.0317e	0.0611e	0,1431	0.0242e	0.0836e	0,1074
Slovenia	0,0547	0,0691	0,0971	0,0310	0,0680	0,0814
Slovakia	0,0411	0,0488	0,0571	0,0275	0,0594	0,0980
Finland	:	:	:	0,0600	0,1370	0,1159
Sweden	0,1438	0.2216e	0,2189	0,0680	0.1429e	0,1197
Liechtenstein	0,0713	0,1128	0,2000	0,0509	0,0993	0,1098
United Kingdom	:	:	:	:	:	:
Bosnia and Herzegovina	0,0321	0,0438	0,0588	0,0354	0,0456	0,0579
Moldova	0,0243	0,0842	0,1082	0,0186	0,0758	0,1390
North Macedonia	0,0488	0,1210	0,1036	0,0236	0,0906	0,0657
Albania	0.0000e	0.0000e	:	:	0.0000e	:
Serbia	0,0337	0,0336	0,0408	0,0286	0,0370	0,0466
Türkiye	0,0189	0,0170	0,0246	0,0156	0,0526	0,0519
Ukraine	0,0273	:	:	0,0217	:	:
Georgia	0,0117	0,0151	0,0182	0,0172	0,0239	0,0321

(:) not available
(e) Estimate
(c) Confidential
(¹) Annual consumption: 5 555 kWh < consumption < 55 555 kWh (20 - 200 GJ).
(²) Annual consumption: 2 778 MWh < consumption < 27 778 MWh (10 000 - 100 000 GJ).
Source: Eurostat (online data codes: nrg_pc_202 and nrg_pc_203)

Annex B

Table 2: Eletricity prices, first semester of 2021-2023
(€ per kWh)

	Households (¹)			Non-households (²)		
	2021S1	2022S1	2023S1	2021S1	2022S1	2023S1
EU	0,2203	0,2525	0,2890	0,1285	0,1833	0,2095
Euro area	0,2322	0,2609	0,3009	0,1381	0,1912	0,2140
Belgium	0,2702	0,3437	0,4350	0,1218	0,1943	0,2269
Bulgaria	0,1024	0,1093	0,1137	0,0962	0,1736	0,1470
Czechia	0,1802	0,2445	0,3212	0,0883	0,1573	0,1974
Denmark	0,2900	0,4559	0,3811	0,0797	0,1609	0,1339
Germany	0,3193	0,3279	0,4125	0,1813	0,2132	0,2192
Estonia	0,1324	0,2056	0,2160	0,0957	0,1625	0,1567
Ireland	0,2555	0,2324	0,2477	0,1512	0,2176	0,2829
Greece	0,1680	0,2101	0,2325	0,1174	0,2310	0,2133
Spain	0,2323	0,3071	0,1823	0,1074	0,1879	0,1160
France	0,1946	0,2092	0,2317	0,1057	0,1273	0,2548
Croatia	0,1291	0,1354	0,1310	0,1025	0,1554	0,2925
Italy	0,2259	0,3115	0,3782	0,1584	0,2525	0,2443
Cyprus	0,1976	0,2607	0,3739	0,1515	0,2471	0,2762
Latvia	0,1403	0,1759	0,3054	0,1012	0,1250	0,1465
Lithuania	0,1348	0,1497	0,2812	0,1046	0,1803	0,1664
Luxembourg	0,1988	0,2017	0,2008	0,0954	0,1294	0,2485
Hungary	0,1003	0,0948	0,1161	0,0920	0,1494	0,3030
Malta	0,1285	0,1298	0,1256	0,1345	0,1347	0,1345
Netherlands	0,1281	0,0451	0,4750	0,1128	0,1722	0,2370
Austria	0,2216	0,2249	0.2653e	0,1228	0,1617	0,2597
Poland	0,1548	0,1464	0,1769	0,1092	0,1555	0,2135
Portugal	0,2089	0,2199	0,2071	0,1066	0,1202	0,0954
Romania	0,1536	0,2362	0,4199	0,0992	0,2347	0,3289
Slovenia	0,1662	0,1390	0,1917	0,0920	0,1585	0,2213
Slovakia	0,1668	0,1796	0,1892	0,1275	0,2160	0,2687
Finland	0,1767	0,1934	0.2383e	0,0676	0,0808	0,0950
Sweden	0,2114	0,2278	0,2668	0,0711	0,1121	0,1067
Iceland	0,1355	0,1530	0,1531	0.0532e	0.0756e	0.0783e
Liechtenstein	0,2071	0,2201	0,4351	0,1000	0,1405	0,3255
Norway	0,1826	0,1994	0,1919	0,0811	0,1467	0,1140
Bosnia and Herzegovina	0,0875	0,0887	0,0874	0,0747	0,0741	0,0910
Montenegro	0,0980	0,0961	0,0968	0,0867	0,0850	0,0861
Moldova	0,0851	0,1172	0,1989	0,0633	0,0761	0,1465
North Macedonia	0,0841	0,0940	0,1053	0,0752	0,1685	0,1690
Albania	0.0925e	0,0941	0,1010	0.1039e	0,1057	0.1135e
Serbia	0,0791	0,0808	0,0964	0,0795	0,0964	0,1384
Türkiye	0,0834	0,0866	0,0842	0,0661	0,1181	0,1276
Ukraine	0,0485	:	:	0,0595	:	:
Kosovo (³)	0,0605	0.0611e	0,0671	0,0673	0,0670	0,0730
Georgia	0,0631	:	0,0847	0,0713	:	0,0928

(:) not available
(e) Definition defersEstimated values
(¹) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(²) Annual consumption: 500 MWh < consumption < 2 000 MWh.
(³) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.
Source: Eurostat (online data codes: nrg_pc_204 and nrg_pc_205)

Annex C

Table3: Annual average district heating prices
(€ per kWh)

	2013*	2017**	2021***	2022****
Austira	0,0680			
Bulgaria	0,0335			
Croatia	0,0457			
Czech Republic	0,0673			
Denmark	0,1040		0,0952	
Estonia	0,0608	0,0600		0,1160
Finland	0,0587			
France	0,0673			
Germany	0,0763		0,0912	
Hungary	0,0432			
Iceland	0,0158			
Italy				
Latvia	0,0540			
Lithuania	0,0702			
Netherlands	0,0698		0,0977	
Norway	0,0734			
Poland	0,0436			
Romania	0,0623			
Slovakia	0,0828			
Slovenia	0,0594			
Sweden	0,0731		0,0855	
Switzerland	0,0410			
UK	0,0457			
All countries, average	0,0652			

* *Source* : EUROPEAN DISTRICT HEATING PRICE SERIES - Report 2016:316, Energiforsk AB
** *Source* : Analysis of cost-optimal minimum energy efficiency requirements for buildings, Estonia, 2017
*** *Source* : DISTRICT HEATING TARIFFS IN EUROPE - Comparison of tariffs and regulation in Europe, Government of Denmark, 2021
**** *Source* : Analysis of cost-optimal minimum energy performance levels of buildings, Estonia, 2022

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