D3.6 Operational rating calculation methodology of SmartLivingEPC

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Operational rating calculation methodology of SmartLivingEPC

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0.6	Christos Kythreotis, Paris Fokaides	03.06.2024	Final version

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List of Acronyms and Abbreviations

Term	Description
D	Deliverable
EPC	Energy Performance Certificate
EPI	Energy Performance Indicator
EU	European Union
HDD	Heating Degree-Days
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
LCC	Life Cycle Costing
MS	Member State
PE	Primary Energy
PM	Particulate Matter
PMV	Predictive Mean Vote
T	Task
TC	Thermal Comfort
VOC	Volatile Organic Compounds
WMV	Weighted Mean Vote
WP	Work Packages
PCA	Principal Component Analysis
AHP	Analytical Hierarchy Process

1 Introduction

1.1 Work package and Task description

The primary objective of Task 3.5 (T3.5) in the SmartLivingEPC project is to develop an innovative, integrated operational rating methodology for buildings, fundamentally transforming the approach to building energy performance assessment. Traditional methods primarily focus on energy meter measurements to gauge a building's efficiency. However, this new methodology extends far beyond this limited scope. It integrates additional operational measurements that encompass a broader range of aspects such as occupant well-being, indoor air quality (IEQ), and life cycle costing of various operational scenarios. This holistic approach allows for a more comprehensive understanding of a building's performance, factoring in both its environmental impact and the quality of life it offers to its occupants.

Moreover, this new rating system is designed to incorporate the operational nature of buildings, integrating enriched data regarding their life cycle and intelligence. A key component of this approach is the emphasis on the well-being of the building users, an aspect often overlooked in traditional energy performance assessments. This focus ensures that buildings are not only energy efficient but also conducive to healthy and comfortable living and working environments.

The overarching goal of T3.5, in conjunction with Work Package 3 (WP3), is to establish an integrated classification system for buildings. This system is envisaged to incorporate additional assessment schemes that provide a more nuanced understanding of a building's energy behavior. These schemes, which are discussed in various tasks of WP3, will contribute to a more nuanced and multi-dimensional building classification system.

The key deliverable of T3.5 is D3.3, the operational rating calculation methodology of the SmartLivingEPC. Scheduled for completion at Months 15, 22, and 31, this deliverable is categorized as R (Research) and PU (Public). D3.3 will encapsulate the comprehensive outcomes of T3.5, offering a structured, innovative methodology for the assessment and certification of building energy performance. This methodology is not just about assessing energy efficiency in isolation but about understanding and improving the overall performance of buildings in a way that benefits both the environment and the people who use these spaces. By doing so, D3.3 aims to set a new standard in building performance assessment, leading to more sustainable, healthy, and efficient buildings.

1.2 Background and Objectives

The background of T3.5 is rooted in the growing recognition of the need for more comprehensive and accurate methods to assess building operational performance. Traditional approaches to building energy performance have largely centered on static measurements, primarily using energy meters to monitor consumption. While these methods provide a basic understanding of energy use, they fall short in capturing the dynamic and multifaceted nature of building performance. As buildings become more complex and the emphasis on sustainability and occupant well-being grows, the limitations of traditional energy performance assessments have become increasingly apparent.
Recognizing these shortcomings, T3.5 was conceived to develop a new, integrated operational rating methodology. This methodology is designed to be more holistic, incorporating not just energy consumption data, but also other critical factors that influence a building's performance. These include aspects like indoor air quality (IEQ), which is crucial for occupant health and comfort, and life cycle costing, which considers the long-term

economic impact of different operational scenarios. By integrating these diverse factors, the new methodology aims to provide a more complete and accurate picture of a building's performance.
Another important aspect of T3.5 is its focus on the operational nature of buildings. This involves understanding how buildings perform in real-world conditions, as opposed to theoretical or simulated environments. It also entails collecting and analyzing data on how buildings are used and how this usage impacts their energy performance. This operational focus is crucial for developing rating systems that accurately reflect the actual performance of buildings.
Deliverable D3.3, the operational rating calculation methodology, is a key output of T3.5. Scheduled for completion at various stages of the project, this deliverable is set to encapsulate the findings and methodologies developed under T3.5. As a research (R) and public (PU) deliverable, D3.3 is expected to have broad implications for the field of building energy performance. It will provide a structured, innovative methodology for assessing and certifying buildings, potentially setting new standards in the field.
The methodology developed under T3.5 and encapsulated in D3.3 is not just about improving energy efficiency; it's about redefining building performance in a more holistic manner. This includes considering the well-being of occupants, the environmental impact of buildings, and the economic implications of different operational practices. In doing so, T3.5 and D3.3 contribute to the broader goals of the SmartLivingEPC project, pushing the boundaries of how we understand and improve the buildings we live and work in.

1.3 Scope of the deliverable

The scope of this deliverable is extensive, covering the theoretical underpinnings, practical methodologies, and technological aspects of a new, integrated operational rating system for buildings. It aims to provide a more nuanced, accurate, and comprehensive assessment of building performance, considering a wide array of factors beyond just energy consumption. This deliverable begins by outlining the context, background, and objectives of the project, providing a robust framework that sets the stage for the detailed discussions in the following sections. It clearly defines the scope and lays a solid foundation for understanding the operational rating system being developed.
Definition of Indicators: This crucial section delves into the indicators used to measure the operational rating, introducing and evaluating their precision and reliability in assessing building performance. The analysis includes a review of historical data to identify trends, and considers the impact of variables such as weather conditions, occupancy patterns, and usage variability on these indicators. It also discusses the importance of certifications and standards in operational rating, highlighting the need for continuous improvement and relevance.
Selection of Indicators: This part focuses on selecting appropriate indicators for the operational rating. It discusses their relevance to building performance, data availability and reliability, and the methods used for evaluating and choosing indicators. Challenges and limitations of indicator selection are acknowledged, and the concept of thresholding is introduced. This section addresses Indoor Environment Quality Indicators, Operational Rating Indicators, and Financial Indicators, underscoring the multi-dimensional nature of building performance assessment.
Thresholding of Indicators: In this revision, there is a significant emphasis on the methodology for setting performance thresholds for the indicators. This process is crucial for ensuring that the indicators are robust and meaningful, distinguishing buildings that meet or exceed performance standards from those that do not, thereby enhancing the operational rating system's effectiveness.
Future Work: This section looks ahead to the next major milestone, scheduled for month 31, which will be the final and all-encompassing version of the SmartLivingEPC operational rating methodology. It will synthesize all prior work into a comprehensive and definitive methodology, reflecting the integration of all enhancements and feedback gathered through ongoing research and application.

Overall, this deliverable presents a detailed and progressive methodology for operational building rating, focusing on a comprehensive set of indicators beyond traditional metrics. It includes an in-depth analysis of indicator selection, with a new focus on thresholding, culminating in a synthesis of findings and implications for building performance assessment.

2 Definition of Indicators

2.1 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.

2.2 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.

Table 1: Indicators for indoor air quality

#	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

Table 2: Indicators for thermal comfort

#	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.

Table 3: Indicators for lighting

#	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.

Table 4: Indicators for heating

#	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.

Table 5: Indicators for cooling

#	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 6: 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 7: 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 8: 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 9: 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 10: 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	€/m²/year	
5	Total energy cost per square meter per month	€/m²/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 11: 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	

3 Selection of Indicators

3.1 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.

3.2 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.

3.3 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.

- **Thermal Comfort (Indoor Air Temperature):** The Indoor Air Temperature is the dry-bulb temperature measured indoor (in room).
- **Room CO_2 volumetric concentration:** Carbon dioxide is a widely recognized indicator of indoor air quality, primarily because it is directly related to human occupancy and ventilation.
- **Room particulate matter <2,5 µm (PM 2.5) concentration:** 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.
- **Event reproduction number - R:** Number of people who become infected per infectious occupant

- **Occupancy feedback indicator (MV (mean vote)):** The satisfaction/dissatisfaction rate of indoor air temperature and thermal comfort.
- **Lighting energy consumption per Floor Area:** This indicator reflects the efficiency and design of a building's lighting system. It's essential for evaluating energy use and occupant comfort regarding visual tasks and overall ambiance.
- **Cooling energy consumption per Floor Area:** This measures the energy efficiency of the cooling systems relative to the building size. It's vital for assessing the energy performance and environmental impact of air conditioning systems.
- **Heating energy consumption per Floor Area:** Similar to cooling, this indicator assesses the efficiency of heating systems. It's crucial in climates with significant heating demands and impacts both energy use and occupant comfort.
- **Appliances energy consumption per Floor Area:** This metric evaluates the energy efficiency of appliances within the building, an important aspect of overall energy consumption.
- **Domestic Hot Water energy consumption per Floor Area**: Hot water usage can be a significant energy consumer, especially in residential buildings, making this an important efficiency and sustainability indicator.
- **Cost of Heating per Floor Area per Year:** This indicator measures the total annual cost of heating a building, divided by the total floor area, to determine the cost per square meter. It reflects the actual energy consumption for heating purposes and the associated costs. The calculation is based on monthly utility bills and energy meter readings, providing a clear picture of heating expenses on a per-square-meter basis.
- **Cost of Cooling per Floor Area per Year:** This indicator calculates the total annual cost of cooling a building, spread over the total floor area, resulting in the cost per square meter. It accounts for the actual energy used for cooling throughout the year and its cost. Utility bills and energy meter data are used to perform this calculation, offering insight into cooling expenses relative to the building's size.
- **Cost of Lighting per Floor Area per Year:** This indicator represents the total annual cost of lighting a building, divided by the total floor area, to yield the cost per square meter. It considers the actual energy consumption for lighting and the corresponding costs. Data from energy meters and submeters is used, allowing building managers to understand lighting costs in relation to the building's area.
- **Cost of Domestic Hot Water per Floor Area per Year:** This indicator measures the total annual cost of domestic hot water (DHW) usage in a building, divided by the total floor area, to determine the cost per square meter. It includes the actual energy consumption for heating water and the related costs. The calculation utilizes data from energy meters and submeters, providing a detailed view of DHW expenses in relation to the building's size
- **Cost of Appliances Energy Consumption per Floor Area per Year:** This indicator measures the total annual cost of energy consumed by appliances in a building, divided by the total floor area, resulting in the cost per square meter. It accounts for the actual energy usage by various appliances and the associated costs. The calculation is based on monthly data from energy meters and submeters for different energy carriers (electricity, gas, etc.), providing a clear understanding of the energy expenses attributed to appliances relative to the building's size.

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.

3.3.1 Indoor Environment Quality Indicators

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 12: 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 13 (from D3.4 Section 2.4.1.1)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 13: 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 14: 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 15: 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	µg/m^3
Measurement scale	Interval
Equipment	PM2.5 sensor
Thresholding	See Table 16 (from D3.1 Section 2.4.2.2)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 16: 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 17: 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 18 (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 18: 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 19: 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 20 (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 20: 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

3.3.2 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 21: 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/ m^2
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 22: 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 23: 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 24: 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 25: 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

3.3.3 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 26: 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 27: 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	€/m^2/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 28: 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	€/m^2/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 29: 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	€/m^2/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 30: 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	€/m^2/year
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{Sum\ of\ monthly\ actual\ energy\ consumption\ for\ appliances \times energy\ price\ (variable}{total\ floor\ area}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

4 Weighting methods

4.1 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.

4.2 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.

4.3 Alternative Weighting Methods

4.3.1 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.

4.3.1.1 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 amount 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.[2], [3]

- **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. [9], [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. [2]

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.

4.3.1.2 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). [11], [12]

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

4.3.1.3 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:

$$Z = \frac{X - \mu}{\sigma} \qquad \text{(Eq. 1)}$$

Where ***X*** is the original value, ***μ*** is the mean, and ***σ*** 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:

$$\Sigma = \frac{1}{n-1} \cdot (Z^T \cdot Z) \quad \text{(Eq. 2)}$$

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

Equation for calculating eigenvectors and eigenvalues:

$$\Sigma \cdot v = \lambda \cdot v \quad \text{(Eq. 3)}$$

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 31: 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

4.3.1.4 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:

$$\text{Matrix } A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ \frac{1}{a_{12}} & 1 & a_{23} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 \end{bmatrix} \qquad \text{(Eq. 4)}$$

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:

$$w_i = \frac{\text{average of row } i}{\text{sum of all row averages}} \qquad \text{(Eq. 5)}$$

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 32: AHP Pairwise Comparison Matrix

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

Table 33: Sum of each column

	IAQ	Energy Rating	LCC
Sum	1.7	3.5	8.0

Table 34: Normalized relative weights

	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 35: Row average weights

	Weights
IAQ	0.595
Energy Rating	0.277
LCC	0.128

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

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

4.3.2 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 36: WSM applicability for Buildings Energy Performance Assessment

Advantage	Description in Building Energy performance Assesment
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.

4.4 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 37: 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.

4.4.1 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 of 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.

4.4.2 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.

4.4.3 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.

5 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.

5.1 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.

5.2 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.

5.2.1 Thresholding of Indoor Environment Quality Indicators

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 38: 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 13 (from D3.4 Section 2.4.1.1)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 39: 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 40: 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 41: 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 16 (from D3.1 Section 2.4.2.2)
Sampling Frequency	15 min (max hourly)
Calculation Methodology	-
Regulatory Compliance	EN 16798-1:2019

Table 42: 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 43: 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 18 (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 44: 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 45: 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 20 (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 46: 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 (Table 42)
The PM2.5 concentration limits show a gradation from Category A (5 µg/m3) to Category G (25 µg/m3), which indicates increasing levels of particulate matter that are permissible in indoor air.

Virus Risk Estimation (Table 44)
The virus risk estimation scale is particularly topical, 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 (Table 45)
The mean vote (MV) scale ranges from -1.0 to +1.0, 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.[14], [15]

5.2.2 Thresholding of Operational rating energy indicators

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 47** by applying an adjustment factor as shown in **Table 48**, 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 47 and Table 48, 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 47: 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)* [1]

Table 48: 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.

[1] https://www.cystat.gov.cy/en/default

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**:

$$L = A \times 0.80 \quad \text{(Eq. 6)}$$

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**:

$$U = A \times 1.10 \quad \text{(Eq. 7)}$$

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*)**:

$$ESP = E - L \quad \text{(Eq. 8)}$$

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 3 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 49: 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

5.2.3 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 50**.

Table 50: 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.

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

6 Technical Framework and Methodology for API-Based Indicator Calculation and Rating System Design

6.1 Definition and purpose of API in the context of calculating indicators building

In the context of computing building performance indicators, an Application Programming Interface (API) was developed. The fundamental design of this API is structured to adeptly handle two critical components of the building performance assessment process. First, it accommodates the individual ratings, which are assigned by assessors. Secondly, the API embraces the weighting factors associated with these individual ratings, a pivotal element of the assessment process. These weighting factors are also provided manually by domain experts, further enhancing the depth and accuracy of the evaluation.

By considering both the individual ratings and their associated weighting factors, the API facilitates a holistic and refined approach to building performance assessment.

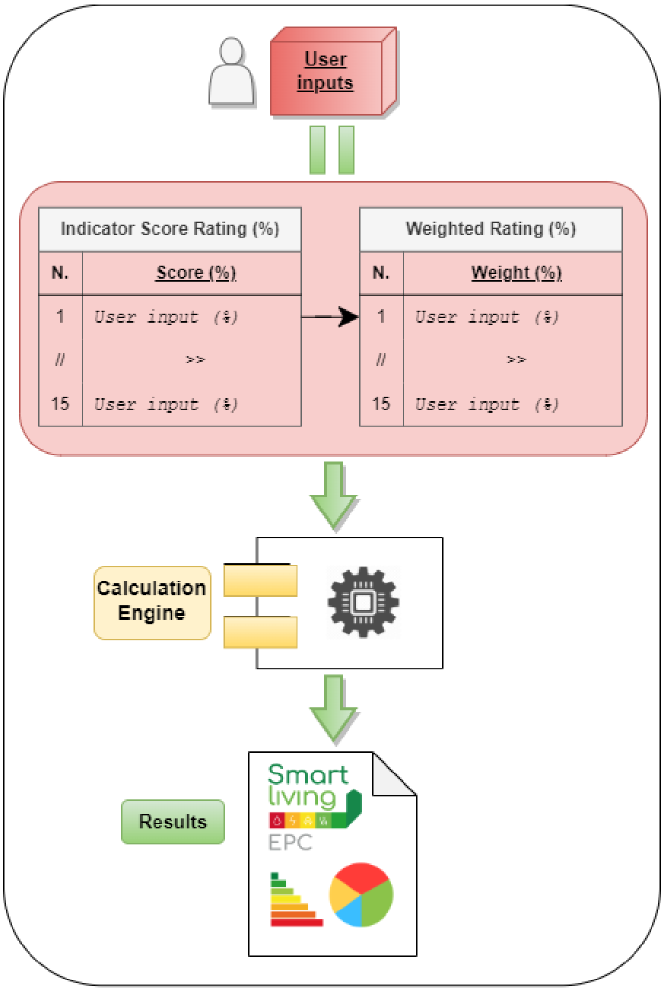

Figure 3: Theoretical background of indicator calculation

At the heart of this API lies the Weighted Sum Method, employed to calculate the operational rating of buildings. This method represents a pivotal step in the process, where the API melds individually assigned ratings with their corresponding weighting factors. The ultimate outcome of this calculation is the operational rating, a key indicator of a building's performance under assessment.

The selection of the Python programming language for the development of the API was underpinned by a confluence of compelling factors. Python's inherent versatility, combined with its expansive library support, rendered it an eminently suitable choice for this endeavour.

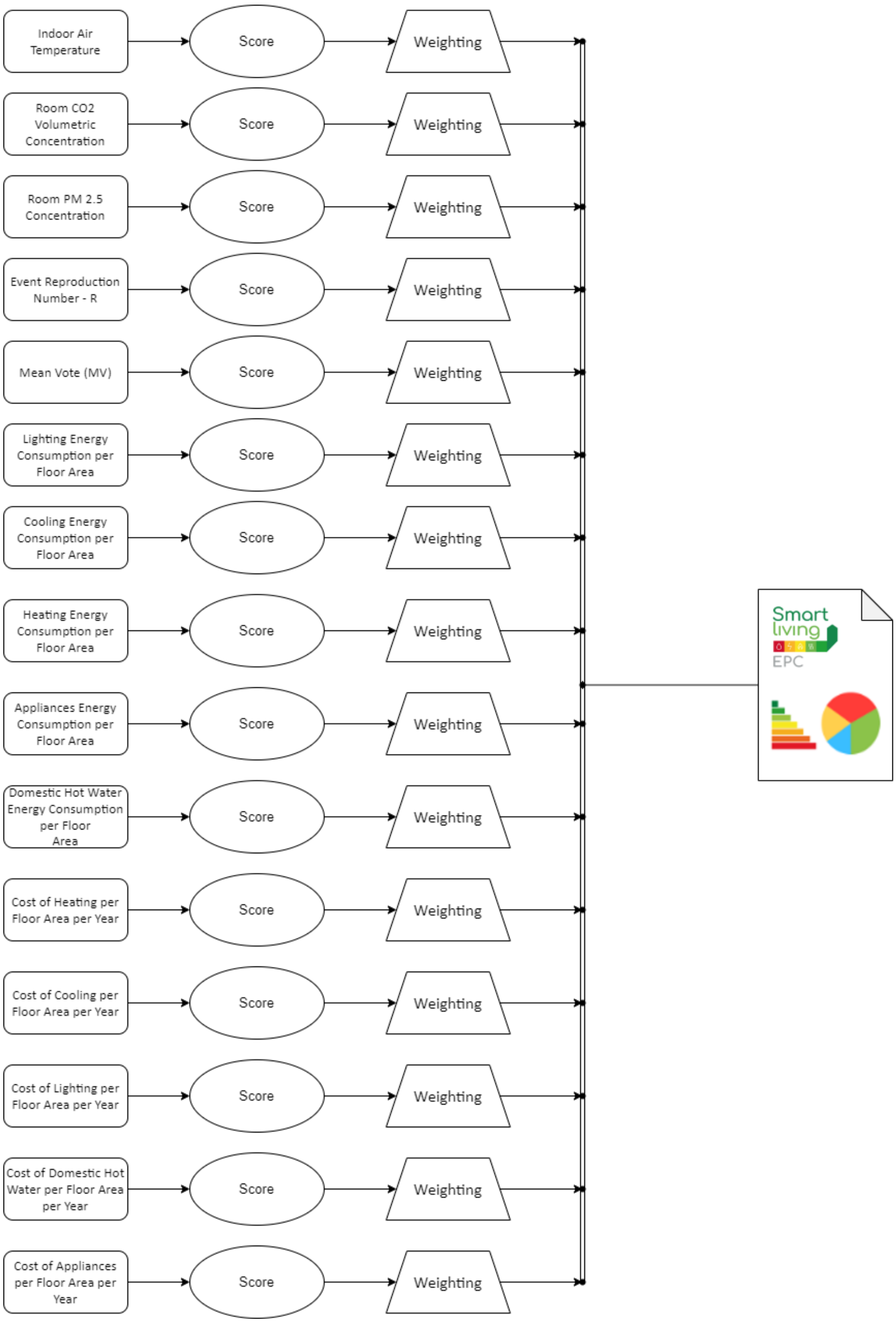

Figure 4: API calculation rationale.

```python
import streamlit as st
import pandas as pd
import plotly.express as px
import plotly.graph_objects as go

# List of indicators
indicators = [
    "Indoor Air Temperature [°C]",
    "Room CO2 Volumetric Concentration [ppm]",
    "Room PM 2.5 Concentration [µg/m3]",
    "Event Reproduction Number - R [-]",
    "Mean Vote (MV) [-]",
    "Lighting Energy Consumption per Floor Area [kWh/m2]",
    "Cooling Energy Consumption per Floor Area [kWh/m2]",
    "Heating Energy Consumption per Floor Area [kWh/m2]",
    "Appliances Energy Consumption per Floor Area [kWh/m2]",
    "Domestic Hot Water Energy Consumption per Floor Area [kWh/m2]",
    "Cost of Heating per Floor Area per Year [€/m2/year]",
    "Cost of Cooling per Floor Area per Year [€/m2/year]",
    "Cost of Lighting per Floor Area per Year [€/m2/year]",
    "Cost of Domestic Hot Water per Floor Area per Year [€/m2/year]",
    "Cost of Appliances per Floor Area per Year [€/m2/year]"
]

indicators = {key: 0 for key in indicators}
```

```python
> def computeIndicatorResult(): ···

> def showResults(sum): ···

> def insertIntoDicts(): ···

> def displayForm(): ···


#Initialize states
for indicator in indicators:
    if indicator not in st.session_state:
        st.session_state[indicator] = 0.0

for impactWeighting in impactWeightings:
    if impactWeighting not in st.session_state:
        st.session_state[impactWeighting] = 0.0


st.title("Smart Living EPC - Indicator tool")


displayForm()
# Create a dictionary to store the slider values
```

Figure 5: Back-end programming illustration of the calculation

6.2 Worked Example

For this version of the deliverable, the algorithm has been adapted to employ user-inputted normalized scores and weights to compute a composite indicator, integrating quantitative data with user-defined priorities. Utilizing the Weighted Sum method, each normalized indicator score is multiplied by its respective weight, and the resultant values are aggregated. This method reflects the varying importance assigned to different indicators by stakeholders, providing a nuanced representation of performance. The algorithm's flexibility enables it to accommodate diverse perspectives through user-assigned weights. The 15 adapted indicator scores and weights adhere to a standardized scale ranging from 0 to 100, ensuring uniformity and precision in the metric system. The resulting composite indicator, expressed as a percentage, quantitatively represents system performance. Subsequently, the algorithm converts the composite indicator into score classes (A to G), streamlining interpretation and enhancing communication of overall performance. Each score class corresponds to specific percentage ranges, facilitating user comprehension and standardizing performance discussions across various contexts.

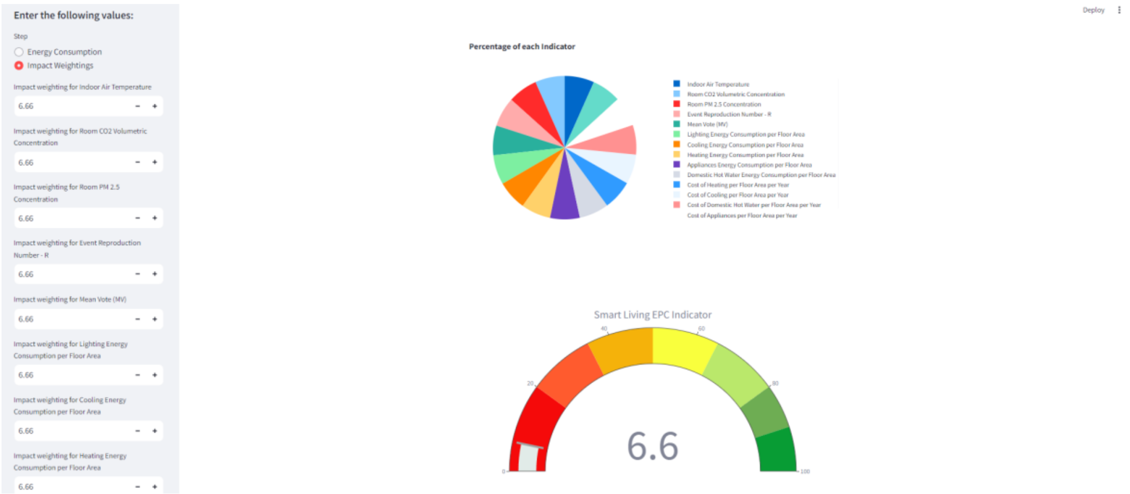

Figure 6: Worked example of the composite indicator calculation

7 Conclusion

Deliverable 3.6 refines the operational rating calculation methodology as part of the SmartLivingEPC project, aimed at refining the assessment of building energy performance. This methodology broadens the conventional scope by integrating traditional energy consumption metrics with innovative indicators for indoor air quality, occupant comfort, and life cycle costing. It also introduces thresholding for these indicators, which establishes performance benchmarks essential for consistent and meaningful evaluation.

The choice of the Weighted Sum Model (WSM) over other weighting methods is highlighted, providing a balanced approach to evaluating multiple aspects of building performance. The WSM was selected for its straightforward application and ability to aggregate diverse indicators into a single operational score, making it particularly suitable for this multidimensional assessment framework.

Collaboration with stakeholders and experts has been pivotal in adapting and refining the methodology to ensure its relevance. With the final version due for completion in Month 31, further enhancements will be based on comprehensive feedback and the latest findings from this iterative development process.

This deliverable significantly contributes to the SmartLivingEPC project's objectives of enhancing energy efficiency and promoting sustainability within the European Union. By offering a nuanced tool for building assessment that incorporates thresholding and an effective weighting model, this methodology supports the project's broader goals.

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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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