D3.3 Operational rating calculation methodology of SmartLivingEPC

Project Acronym:	SmartLivingEPC
Project Full Title:	Advanced Energy Performance Assessment towards Smart Living in Building and District Level
Grant Agreement:	101069639
Project Duration:	36 months (01/07/2022 – 30/06/2025)

Deliverable 3.3

Operational rating calculation methodology of SmartLivingEPC

Work Package:	WP3 SmartLivingEPC Framework Operational Methodology
Task:	T3.5 SmartLivingEPC operational rating calculation methodology
Document Status:	Draft v0.1
File Name:	SLE_D3.3
Due Date:	30.09.2023
Submission Date:	08.12.2023
Lead Beneficiary:	FRC

Dissemination Level	
Public	☒
Confidential, only for members of the Consortium (including the Commission Services)	☐

Authors List

Leading Author				
First Name		Last Name	Beneficiary	Contact e-mail
Nicholas		Afxentiou	FRC	res.an@frederick.ac.cy
Phoebe-Zoe		Georgali	FRC	res.gp@frederick.ac.cy
Paris		Fokaides	FRC	eng.fp@frederick.ac.cy
Co-Author(s)				
#	First Name	Last Name	Beneficiary	Contact e-mail
2	Pinelopi	Valiouli	IsZEB	p.valiouli@iszeb.gr
4	Jarek	Kurnitski	TalTech	jarek.kurnitski@taltech.ee
9	Fatemeh	Asgharzadeh	DEMO	fatemeh@demobv.nl

Reviewers List

Reviewers			
First Name	Last Name	Beneficiary	Contact e-mail
Stergios	Kokorotsikos	EUNICE	skokorotsikos@eunice-group.com
Beatriz	Fraga	IES	beatriz.fraga@iesve.com

Version History

v	Author	Date	Brief Description
1	Phoebe-Zoe Georgali Paris Fokaides	04.07.2023	First draft version of the document
2	Nicholas Afxentiou Phoebe-Zoe Georgali	20.10.2023	Additions in the document
3	Paris Fokaides	28.10.2023	Second draft version of the document
4	Phoebe-Zoe Georgali Paris Fokaides	04.12.2023	Updates based on partners' feedback, Document ready for peer review
5	Phoebe-Zoe Georgali Paris Fokaides	07.12.2023	Document updated based on peer review comment
6	Aggeliki Veliskaki	08.12.2023	Quality check and minor corrections
7	Paris Fokaides	08.12.2023	Final version ready for submission

Copyright

Table of Contents

List of Figures

List of Tables

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

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.

Introduction: Initially, the deliverable sets the stage by detailing the context, background, and objectives of the work package and task. It establishes a clear framework for the deliverable, elucidating its scope and laying the groundwork for the ensuing sections.

Definition of Indicators: A pivotal section, it explores the core of the methodology – the indicators used for measuring operational rating. This part not only introduces these indicators but also assesses their accuracy and reliability as measures of building performance. It includes an analysis of historical performance, considering past data to discern trends. Additionally, it examines the influence of weather conditions, occupancy patterns, and usage variability on building performance. The role of certifications and standards in operational rating is also discussed, emphasizing the importance of continuous improvement and the applicability of these indicators.

Selection of Indicators: This segment delves into the process of choosing appropriate indicators for the operational rating. It considers the relevance of these indicators to building performance, the availability and reliability of data, and methods for evaluating and selecting indicators. This part also acknowledges the challenges and limitations inherent in selecting indicators and introduces the concept of thresholding. Furthermore, it specifically addresses Indoor Environment Quality Indicators, Operational Rating Indicators, and Financial Indicators, underscoring the multidimensional nature of building performance assessment.

Weighting Methods: This portion discusses various methodologies for weighting different indicators within the overall operational rating. It includes a comprehensive examination of the Weighted Sum Model (WSM) and alternative weighting methods, alongside a comparative assessment of these approaches. Challenges associated with using WSM for building energy performance assessment, such as the selection of weighting criteria and normalization of diverse indicators, are also covered.

Application Programming Interface This section focuses on the Application Programming Interface, highlighting a technological aspect of the methodology. It defines the purpose of API in this context, underscores the importance of APIs for efficient and accurate indicator calculations, and provides a methodological background for API use. Additionally, it discusses user inputs for indicator scores and a user-driven approach to weight assignment in operational rating systems. Offering practical insights, this section also presents a real-world example or case study to demonstrate the application of the methodology.

Future work: In the last section an overview of the content of the deliverable is presented. Discussion concerning the content of the upcoming enhancements, scheduled for month 22, is also discussed, which will include adopting additional weighting techniques, setting performance thresholds for these indicators, introducing a rating scale for the operational rating and adapting the API to reflect these methodological updates.

Overall, the deliverable presents a comprehensive methodology for operational building rating, encompassing a range of indicators beyond traditional energy metrics, focusing on accuracy, reliability, and the impact of various factors like weather and occupancy. It includes a detailed analysis of indicator selection and weighting methods, with an emphasis on the application of API technology and practical examples, culminating in a synthesis of findings and implications for building energy 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 indicators 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, 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)	µg/m^3	EN 16798-1:2019
3	Benzene	µg/m^3	EN 16798-1:2019
4	CO_2 indoors	ppm	EN 16798-1:2019
5	Formaldehyde	µg/m^3	EN 16798-1:2019
6	Radon	Bq/m^3	EN 16798-1:2019
7	Particulate matter <2,5 µm (PM 2.5)	µg/m^3	EN 16798-1:2019
8	Particulate matter <10 µm (PM 10)	µg/m^3	EN 16798-1:2019

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 per 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 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 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 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 use per 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	Water heating consumption per 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	€/m^2/year	
5	Total energy cost per square meter per month	€/m^2/month	
6	Total energy cost per square meter per year	€/m^2/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	€/m^2	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	€/m^2	
3	Total energy cost per square meter for ten (10) years	€/m^2	

3.Selection of Indicators

3.1 Introduction

In Section 2 of the deliverable, a comprehensive set of 70 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 (SLE) 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 70 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 acoustic performance 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.

- **Ventilation Rate (Airflow):** This indicator measures the rate at which outdoor air replaces indoor air. It's crucial for maintaining indoor air quality and ensuring adequate air circulation, directly impacting occupant health and comfort.
- **Total Volatile Organic Compounds (TVOCs):** TVOCs are a key measure of air quality, indicating the presence of various organic chemicals in the air. High levels of TVOCs can be detrimental to health, making this an important indicator for occupant well-being.
- **Benzene:** Benzene is a specific VOC known for its harmful health effects. Monitoring benzene levels is vital in environments where its presence is a concern, such as in industrial buildings or areas with high traffic pollution.

- **CO2 indoors:** Indoor CO2 levels are an indicator of air quality and ventilation effectiveness. Elevated levels can indicate poor air circulation and can impact cognitive function and comfort.
- **Formaldehyde:** As a common indoor air pollutant, formaldehyde levels are a significant indicator of air quality, particularly in new buildings where off-gassing from new materials can be a concern.
- **Lighting 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 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 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.
- **Energy Use for Appliances per Floor Area:** This metric evaluates the energy efficiency of appliances within the building, an important aspect of overall energy consumption.
- **Energy Use for Domestic Hot Water 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 per Energy Use per Square Meter per Month/Year:** These indicators provide a financial perspective on energy efficiency, translating energy consumption into monetary terms on a monthly and yearly basis.
- **Cost per Energy Carrier per Square Meter per Month/Year:** By breaking down costs by energy carrier (like electricity, gas, etc.), these indicators offer insights into the economic impact of different energy sources and their efficiency.
- **Total Energy Cost per Square Meter per Month:** This comprehensive financial indicator encapsulates the overall cost burden of energy use, essential for economic assessments and long-term planning.

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.

Table 12: Ventilation Rate (Airflow) indicator

Indicator Name	**Ventilation Rate (Airflow)**
Indicator Description	The ventilation rate is the magnitude of outdoor airflow to a room or building through the ventilation system or device.
Units	m^3/h
Measurement scale	Interval
Equipment	Airflow meters, and pressure gauges
Thresholding	To be described
Sampling Frequency	Hourly, Daily
Calculation Methodology	-
Regulatory Compliance	ISO 7730:2005 EN 16798-1:2019

Table 13: Total Volatile Organic Compounds (TVOCs) indicator

Indicator Name	**Total Volatile Organic Compounds (TVOCs)**
Indicator Description	TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air.
Units	ppm
Measurement scale	Interval
Equipment	TVOC meters, monitors equipped with sensors capable of detecting a broad range of volatile organic compounds
Thresholding	To be described
Sampling Frequency	Hourly, Daily
Calculation Methodology	-
Regulatory Compliance	ISO 16000-6:2021 EN 16798-1:2019

Table 14: Benzene indicator

Indicator Name	**Benzene**
Indicator Description	Benzene concentration in the indoor air
Units	ppm
Measurement scale	Interval
Equipment	Gas chromatography equipment, benzene detectors
Thresholding	To be described
Sampling Frequency	Hourly, Daily
Calculation Methodology	-
Regulatory Compliance	ISO 16000-6:2021 EN 16798-1:2019

Table 15: CO2 indoors indicator

Indicator Name	**CO2 indoors**
Indicator Description	The CO_2 concentration of an indoor space
Units	ppm
Measurement scale	Interval
Equipment	CO2 sensors, monitors that measure carbon dioxide levels in indoor spaces
Thresholding	To be described
Sampling Frequency	Hourly, Daily

Calculation Methodology	-
Regulatory Compliance	ISO 16000-8:2007 EN 16798-1:2019

Table 16: Formaldehyde indicator

Indicator Name	**Formaldehyde**
Indicator Description	Formaldehyde concentration in the indoor air
Units	ppm
Measurement scale	Interval
Equipment	Formaldehyde meters, monitors equipped with specific sensors for formaldehyde detection
Thresholding	To be described
Sampling Frequency	Hourly, Daily
Calculation Methodology	-
Regulatory Compliance	ISO 16000-3:2022 EN 16798-1:2019

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 17: Lighting per floor area indicator

Indicator Name	**Lighting per 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 18: Cooling per floor area indicator

Indicator Name	Cooling per 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	$\frac{\text{total cooling power consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18

Table 19: Heating per floor area indicator

Indicator Name	Heating per 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	$\frac{\text{total heating power consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18

Table 20: Energy use for Appliances per floor area indicator

Indicator Name	Energy use for Appliances per 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	$\frac{\text{total energy use for appliances power consumption}}{\text{total area of the building}}$
Regulatory Compliance	EN 52000-1:2017, 3.4.18 3.4.17

Table 21: Energy use for Domestic hot water per floor area indicator

Indicator Name	**Energy use for Domestic hot water per floor area**
Indicator Description	This indicator displays the total domestic hot water 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 energy use for domestic hot water
Thresholding	To be described
Sampling Frequency	Daily, Monthly, Yearly
Calculation Methodology	$\frac{\text{total energy use for DHW power consumption}}{\text{total area of the building}}$
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 22: Cost per energy use per square meter per month

Indicator Name	**Cost per energy use per square meter per month**
Indicator Description	This indicator presents the energy costs based on the actual energy use per use, per square meter, per time unit of month
Units	€/m^2/month
Measurement scale	Ratio
Equipment	Utility bills, energy meters.
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{\text{monthly actual energy consumption per use} \times \text{energy price}}{\text{total floor area}}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021

	Level(s), 6.1

Table 23: Cost per energy use per square meter per year indicator

Indicator Name	Cost per energy use per square meter per year
Indicator Description	This indicator presents the energy costs based on the actual energy use, per use, per square meter, per time unit of year
Units	€/m^2/month
Measurement scale	Ratio
Equipment	Utility bills, energy meters.
Thresholding	To be described
Sampling Frequency	Yearly
Calculation Methodology	$\frac{\text{annual actual energy consumption per use} \times \text{energy price}}{\text{total floor area}}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 24: Cost per energy carrier per square meter per month indicator

Indicator Name	Cost per energy carrier per square meter per month
Indicator Description	This indicator presents the energy costs based on the actual energy use, per carrier, per square meter, per time unit of month
Units	€/m^2/month
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{\text{monthly actual energy consumption per carrier} \times \text{energy price}}{\text{total floor area}}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 25: Cost per energy carrier per square meter per year indicator

Indicator Name	**Cost per energy carrier per square meter per year**
Indicator Description	This indicator presents the energy costs based on the actual energy use, per carrier, per square meter, per time unit of year
Units	€/m^2/month
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Yearly
Calculation Methodology	$\frac{\text{annual actual energy consumption per carrier} \times \text{energy price}}{\text{total floor area}}$
Regulatory Compliance	ISO 15686-5 EN 15459:2007 EN 16627:2015 EN 15643:2021 Level(s), 6.1

Table 26: Total energy cost per square meter per month indicator

Indicator Name	**Total energy cost per square meter per month**
Indicator Description	This indicator presents the energy costs based on the actual energy use, per use, per square meter, per time unit of month
Units	€/m^2/month
Measurement scale	Ratio
Equipment	Energy meters, submeters for different energy carriers (electricity, gas, etc.)
Thresholding	To be described
Sampling Frequency	Monthly
Calculation Methodology	$\frac{\text{total monthly actual energy consumption} \times \text{energy price}}{\text{total floor area}}$
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, we present a comparative assessment between the Weighted Sum Model and these alternative methods. 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 (WSM) 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. Here's a detailed description of the Weighted Sum Model:

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.

Assignment of Weights: Assign weights to each indicator based on its relative importance in assessing energy performance. Factors that have a greater impact on energy efficiency should be given higher weights. The determination of weights can be based on expert opinions, industry standards, or specific goals of the energy performance assessment (like prioritizing renewable energy use or reducing carbon footprint).

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

When considering alternatives to the Weighted Sum Model (WSM), there are several methods that offer different approaches and complexities to address the limitations of WSM or to suit specific decision contexts better. Here are some notable alternatives:

Analytic Hierarchy Process (AHP): AHP is a popular method that uses pairwise comparisons and a hierarchical structure to determine the weights of criteria. It's particularly useful when decision criteria are qualitative and subjective. AHP helps in dealing with complex decisions by breaking them down into a hierarchy of more easily comprehended sub-problems.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the ideal solution and the farthest from the worst. This method considers both the best and worst possible solutions in the decision-making process, providing a more comprehensive evaluation.

ELECTRE (Elimination and Choice Expressing Reality): ELECTRE methods use pairwise comparisons and are particularly suited for situations where there is no single best option but rather a set of acceptable alternatives. It's useful for dealing with complex scenarios with conflicting and non-commensurable criteria.

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations): This method is good for handling both qualitative and quantitative criteria. PROMETHEE uses preference functions to rank alternatives and is known for its ability to handle complex scenarios with conflicting criteria.

Data Envelopment Analysis (DEA): DEA is used primarily for efficiency analysis, particularly in the assessment of performance of organizational units (like departments, branches). It evaluates the relative efficiency of decision-making units based on their inputs and outputs.

Goal Programming: This method extends linear programming to handle multiple, often competing objectives. It's used when decision-makers have specific goals or targets for each criterion and want to minimize the deviations from these targets.

Multi-Attribute Utility Theory (MAUT): MAUT is useful when dealing with decisions under uncertainty. It extends traditional utility theory to multiple attributes by constructing a utility function for each criterion and combining them into an overall utility function.

Fuzzy Set Theory: For situations where criteria and evaluations are not precisely defined, fuzzy set theory offers a way to handle imprecision and vagueness. It's particularly useful in situations where human judgment and subjectivity are involved.

Simple Multi-Attribute Rating Technique (SMART): SMART simplifies the weighting and scoring process. It's a more straightforward alternative to AHP, useful for less complex decision-making scenarios.

Each of these methods has its unique strengths and applications, and the choice among them depends on the specific nature of the decision problem, the type of data available, and the decision-maker's preference for handling complexity and uncertainty.

4.4 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 27: WSM applicability for Buildings Energy Performance Assessment

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

4.5 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 28: 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.

4.5.1 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.

4.5.2 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.

4.5.2 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. Analyzing 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. Technical Framework and Methodology for API-Based Indicator Calculation and Rating System Design

5.1 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.

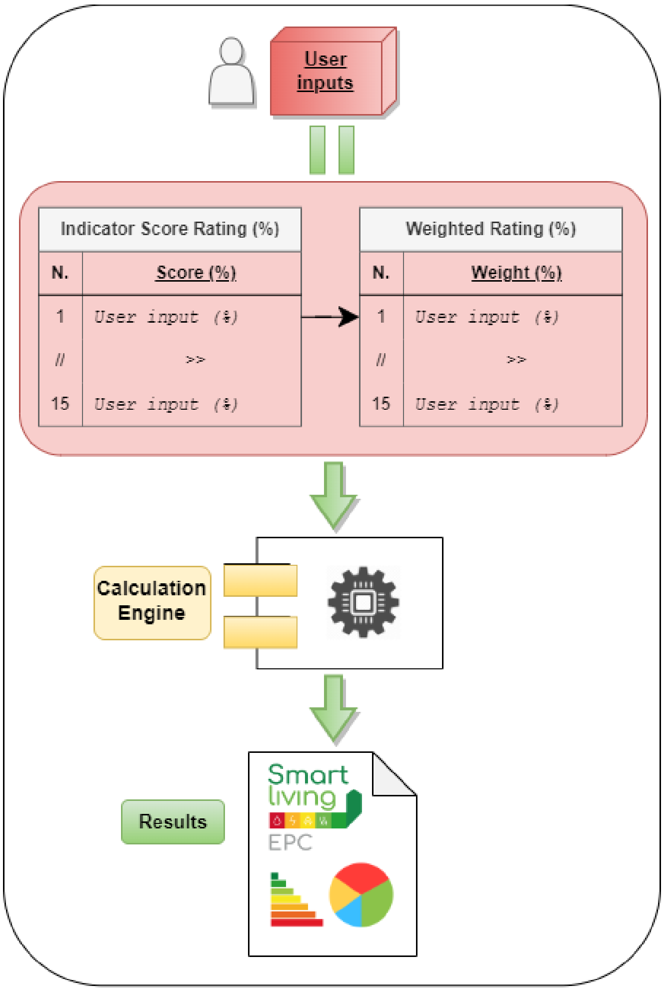


Figure 1: Theoretical background of indicator calculation

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 endeavor. To complement the API's functionality, a Python Streamlit frontend was concurrently developed.

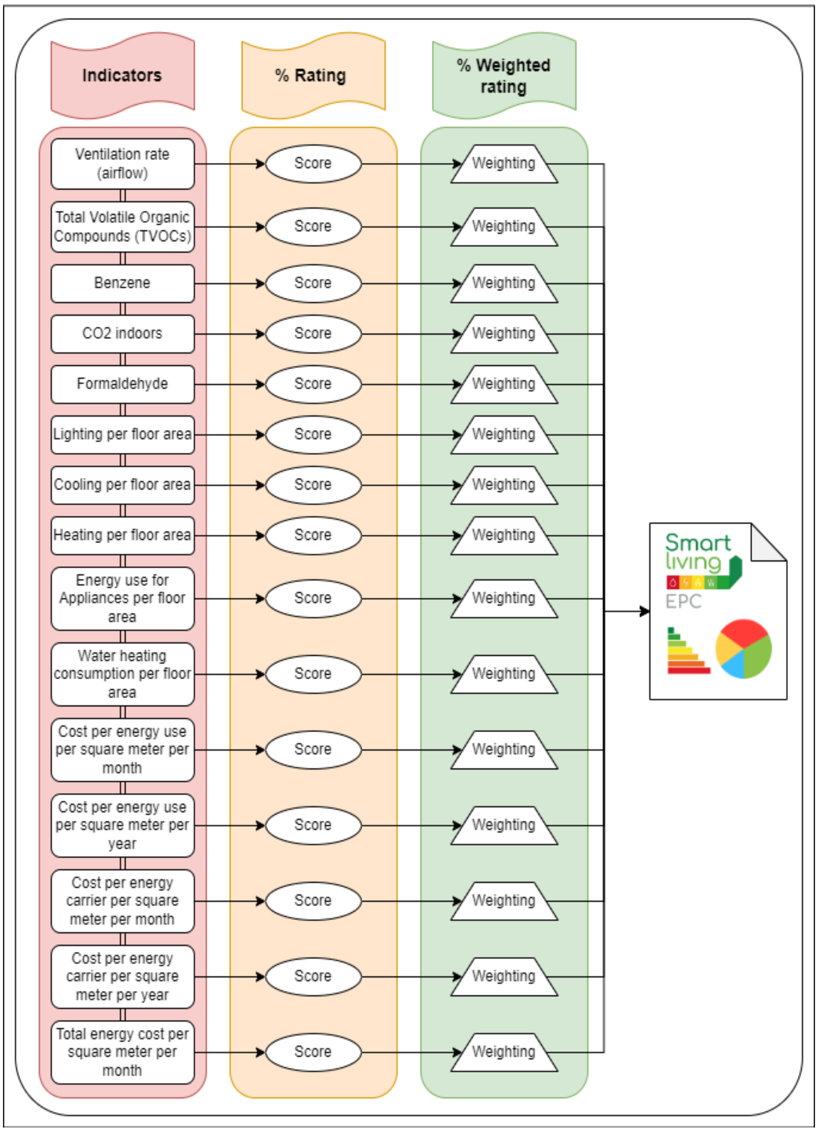
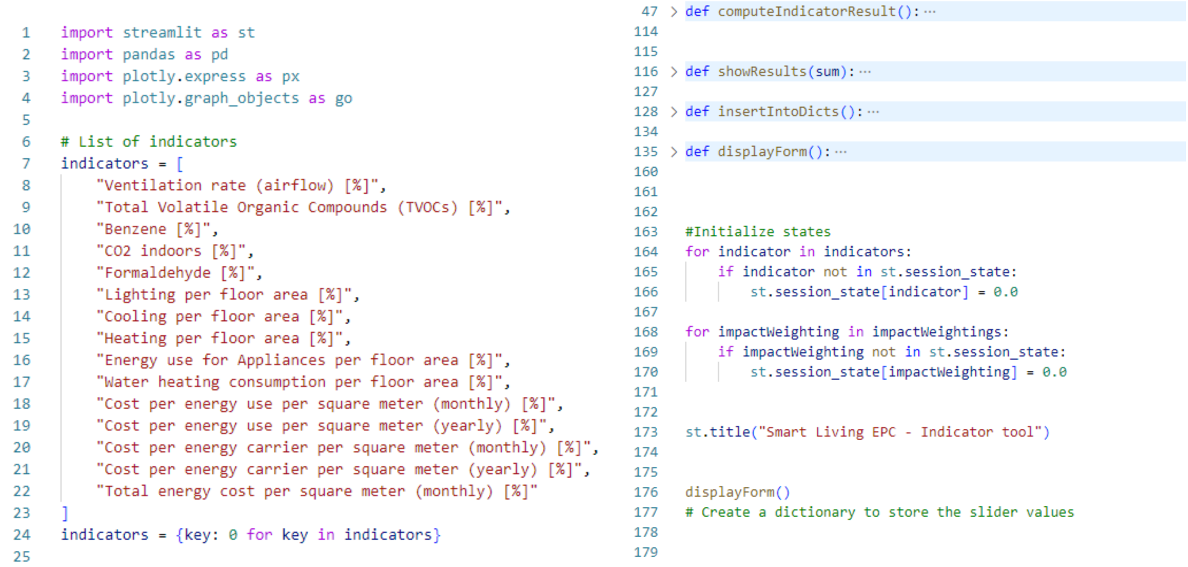


Figure 2: API calculation rational

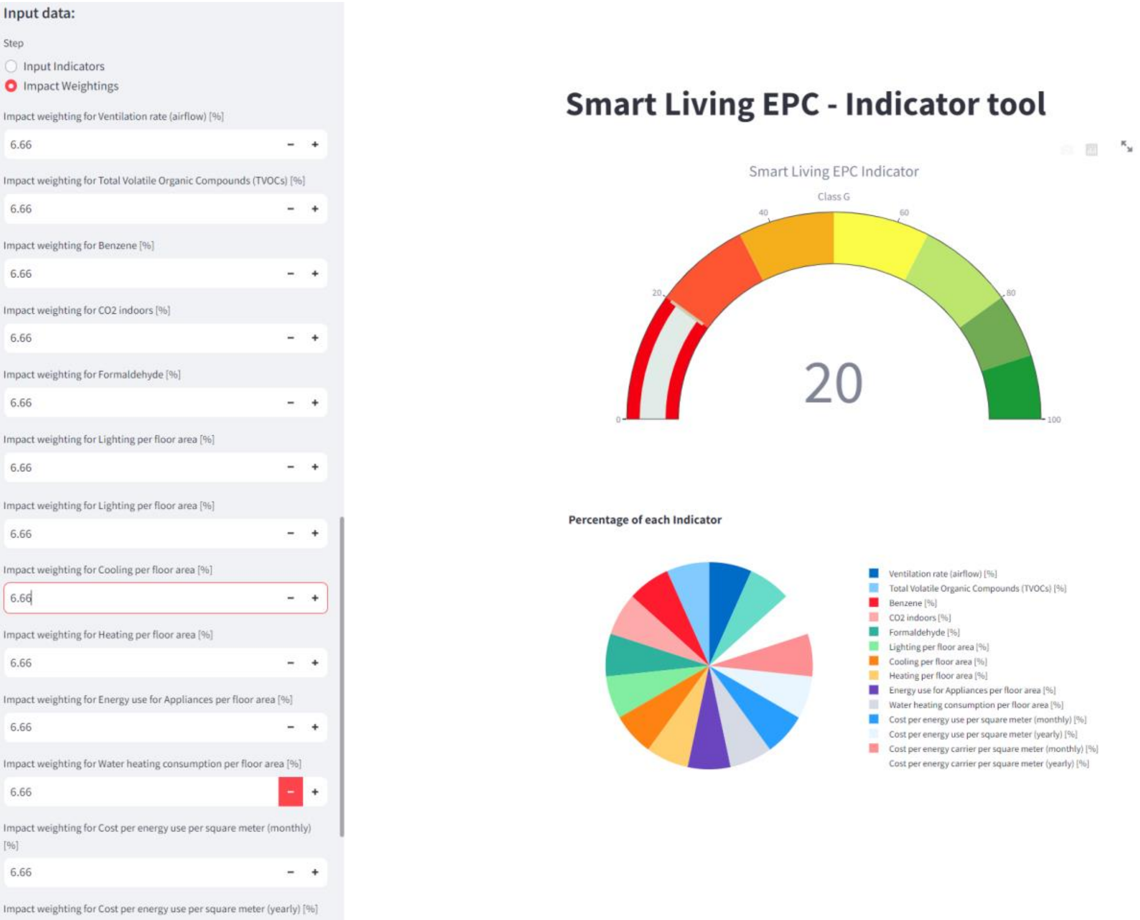


```
import streamlit as st
import pandas as pd
import plotly.express as px
import plotly.graph_objects as go

# List of indicators
indicators = [
    "Ventilation rate (airflow) [%]",
    "Total Volatile Organic Compounds (TVOCs) [%]",
    "Benzene [%]",
    "CO2 indoors [%]",
    "Formaldehyde [%]",
    "Lighting per floor area [%]",
    "Cooling per floor area [%]",
    "Heating per floor area [%]",
    "Energy use for Appliances per floor area [%]",
    "Water heating consumption per floor area [%]",
    "Cost per energy use per square meter (monthly) [%]",
    "Cost per energy use per square meter (yearly) [%]",
    "Cost per energy carrier per square meter (monthly) [%]",
    "Cost per energy carrier per square meter (yearly) [%]",
    "Total energy cost per square meter (monthly) [%]"
]
indicators = {key: 0 for key in indicators}

```

```
> 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 4: Back-end programming illustration of the calculation

5.2 Worked Example



Input data:

Step

○ Input Indicators
● Impact Weightings

Impact weighting for Ventilation rate (airflow) [%]
6.66

Impact weighting for Total Volatile Organic Compounds (TVOCs) [%]
6.66

Impact weighting for Benzene [%]
6.66

Impact weighting for CO2 indoors [%]
6.66

Impact weighting for Formaldehyde [%]
6.66

Impact weighting for Lighting per floor area [%]
6.66

Impact weighting for Lighting per floor area [%]
6.66

Impact weighting for Cooling per floor area [%]
6.66

Impact weighting for Heating per floor area [%]
6.66

Impact weighting for Energy use for Appliances per floor area [%]
6.66

Impact weighting for Water heating consumption per floor area [%]
6.66

Impact weighting for Cost per energy use per square meter (monthly) [%]
6.66

Impact weighting for Cost per energy use per square meter (yearly) [%]

Smart Living EPC - Indicator tool

Figure 5: Worked Example – API Front-End

With user-inputted normalized scores and weights, the algorithm proceeds to compute the composite indicator, merging quantitative data and user-defined priorities. Utilizing a weighted sum approach, each normalized indicator score is multiplied by its corresponding weight, and the results are summed. This calculation reflects the varying importance attributed to indicators by stakeholders, yielding a nuanced representation of performance. The algorithm's flexibility accommodates diverse perspectives through user-assigned weights.

The 15 indicator scores and weights conform to a standardized scale of 0 to 100, ensuring uniformity and a well-defined metric system. The resulting composite indicator, expressed as a percentage, quantitatively represents system performance.

Following this, the algorithm translates the composite indicator into score classes (A to G), simplifying interpretation and facilitating communication of overall performance. Each score class corresponds to specific percentage ranges, aiding user comprehension and standardizing performance discussions across different contexts. This translation simplifies complex data and fosters effective communication among stakeholders.

6. Further Work

This deliverable outlines the methodology used for extracting the operational rating of a building by integrating multiple indicators. The operational rating, a crucial aspect of building assessment, reflects the actual energy and resource efficiency of a building during its use. To determine this rating, various indicators are utilized, each representing a specific aspect of building performance, such as energy consumption, water usage, and indoor environmental quality.

The methodology employed in this deliverable hinges on the combination of these indicators to provide a comprehensive operational rating. This process involves the careful selection and analysis of each indicator, ensuring that they collectively offer a holistic view of the building's performance. To achieve this, we applied the Weighted Sum Method (WSM), a widely recognized technique in multi-criteria decision-making processes. WSM allows for the aggregation of different indicators by assigning a specific weight to each, reflecting its relative importance. This approach ensures that more critical aspects of building performance have a proportionately greater impact on the final operational rating.

Looking forward to the next development steps, which are scheduled for delivery in month 22, we plan to enhance our methodology by **incorporating additional weighting techniques beyond WSM**. This expansion aims to provide a more nuanced and flexible approach to indicator weighting, accommodating a broader range of building types and use cases. By exploring alternative weighting methods, we can tailor the assessment process more closely to the unique characteristics and priorities of each building, thereby increasing the accuracy and relevance of the operational rating.

An additional aspect for further inclusion in the succeeding deliverables pertains to **extending the operational assessment methodology to the neighborhood scale**. This expansion aims to provide a holistic evaluation of entire neighborhoods or communities, considering not only individual building performance but also their collective impact on resource consumption and environmental sustainability. At the neighborhood scale, the assessment would incorporate indicators related to community-wide energy usage, transportation infrastructure, waste management, and green spaces. The methodology for neighborhood-scale assessment could involve the development of composite indicators that reflect the collective performance of buildings, infrastructure, and public spaces within a specific geographical area. The neighborhood scale methodology will be delivered by Task 3.4 and deliverable 3.2.

Another significant advancement in the upcoming development phase will be **the thresholding of the 15 selected indicators**. Thresholding involves setting reference values or benchmarks for each indicator, against which the building's performance can be measured. These reference values will be derived from industry standards, best practices, and historical data, providing a robust basis for comparison. By implementing thresholds, we can more effectively gauge the performance of a building in relation to established norms and identify areas where improvements are needed.

In future work, a significant focus will be placed on **developing an association between the operational score derived from the methodology and a corresponding class rating system**. This system will categorize buildings into different classes based on their operational performance scores, providing a straightforward and intuitive way to understand and compare building efficiencies. The classification will be designed to align with recognized standards and will likely range from high-performing, energy-efficient buildings at one end of the spectrum to those with room for significant improvement at the other. This score-class association will not only simplify the interpretation of a building's operational rating for stakeholders but also promote a competitive drive towards higher efficiency and sustainability standards in the building industry. By doing so, it will facilitate clearer communication with building owners, managers, and regulatory bodies, and serve as a vital tool for driving improvements in the sector.

Furthermore, the next edition of the deliverable will see the **adaptation of the Application Programming Interface (API) to align with the revised content of the methodology**. The API plays a pivotal role in facilitating

the operational rating process, as it allows for the efficient collection, processing, and analysis of data from various building management systems and sensors. The updates to the API will ensure that it supports the new weighting techniques and thresholding processes, enabling a seamless and automated assessment workflow.
In brief, the upcoming deliverable will include

- Incorporation of diverse weighting methods beyond WSM for tailored building assessments.
- Inclusion of neighborhood scale assessment
- Introduction of thresholding for 15 indicators, based on industry standards and data.
- Development of a score-class rating system for easy comparison of building efficiencies.
- Adaptation of the API to support new methods and enhance assessment automation.

In summary, this deliverable has laid the groundwork for a comprehensive and adaptable methodology for extracting the operational rating of buildings. The upcoming developments, including the introduction of additional weighting techniques, the implementation of thresholds, and the corresponding adaptation of the API, represent significant steps forward in enhancing the precision and applicability of the operational rating. These enhancements will not only improve the accuracy of the rating but also provide valuable insights for building owners and managers to optimize the performance and sustainability of their properties.

HE Grant Agreement Number: 101069639
Document ID:
WP3/D3.3

Advanced Energy Performance Assessment towards Smart Living in Building and District Level

https://www.smartlivingepc.eu/en/

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

https://twitter.com/SmartLivingEPC

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

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement number 101069639. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' view.