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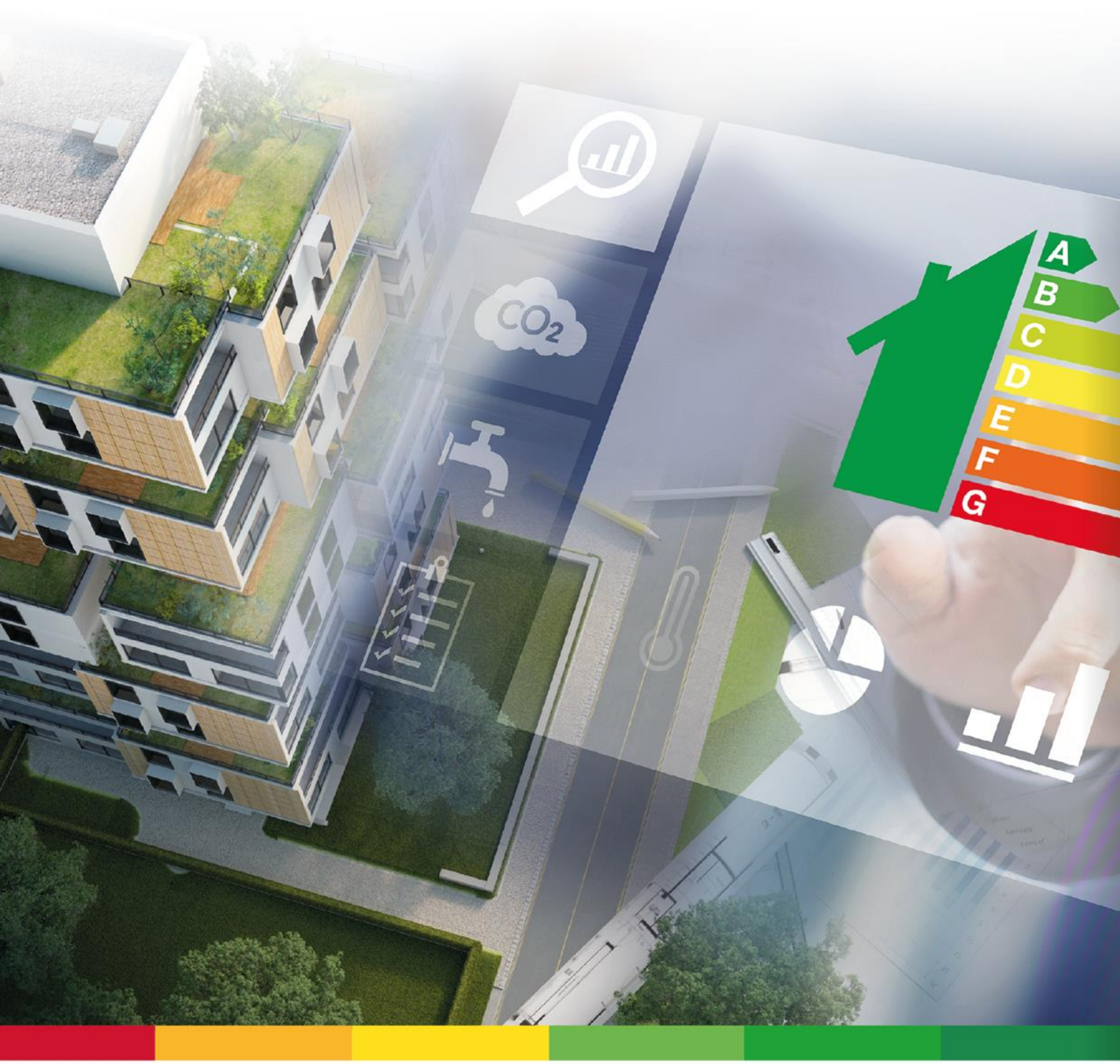
D3.1 Operational assessment methodology at building level



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Operational assessment methodology in building level

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

Term	Description
BER	Building Energy Rating
BIM	Building Information Modelling
CDD	Cooling Degree-Days
D	Deliverable
DCV	Demand Control Ventilation
DEC	Display Energy Certificate
DEC	Display Energy Certificate
EPC	Energy Performance Certificate
EPI	Energy Performance Indicator
EU	European Union
HDD	Heating Degree-Days
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
IRR	Internal Rate of Return
LCC	Life Cycle Costing
MS	Member State
NPV	Net Present Value
NS	Net Savings
PBP	Payback Period
PE	Primary Energy
PM	Particulate Matter
PMV	Predictive Mean Vote
PPD	Predicted Percentage Dissatisfied
PURES 2010	Slovenian Building Codes 2010
RH	Relative Humidity
SIR	Savings-to-Investment Ratio
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

In the ever-evolving landscape of sustainable building design and construction, the European Union (EU) remains at the forefront of pioneering initiatives to foster energy-efficient, environmentally conscious, and socially responsible structures. As the EU continues to advance its commitment to combat climate change and enhance the overall performance of buildings, the need for comprehensive methodologies to evaluate building operations becomes increasingly apparent. This deliverable D3.1, entitled *Operational Assessment Methodology in Building Level*, is an integral component of the HORIZON project *Advanced Energy Performance Assessment towards Smart Living in Building and District Level – SmartLinvingEPC*, Work Package 3 (WP3), aiming to develop an Energy Performance Certificate (EPC) framework with a holistic approach to building assessment.

WP3 centers its objective on the development of an EPC framework operational methodology, which extends beyond conventional energy performance considerations. This integrated approach embraces various aspects that significantly influence building performance and occupant satisfaction through the implementation of its tasks (T). Notably, it emphasizes the incorporation of additional critical characteristics, such as indoor environment quality (IEQ) – T3.1, assessment of operational methodologies – T3.2, and life cycle costing (LCC) of building assets – T3.3, at the complex building level.

The imperativeness of this deliverable lies in its potential to revolutionize the conventional approach to building evaluations, going beyond mere energy efficiency metrics to embrace a broader spectrum of parameters crucial for sustainable building operations. By addressing various dimensions of building performance, this methodology seeks to provide a more nuanced and comprehensive understanding of the interplay between energy efficiency, occupant well-being, environmental impact, and the overall effectiveness of operational strategies.

Throughout this deliverable, a rigorous academic exploration of existing research, industry best practices, and expert insights will form the foundation of the operational methodology. The holistic framework aims to enable stakeholders, ranging from architects and engineers to facility managers and policy-makers, to make informed decisions that promote sustainable practices, enhance the quality of indoor environments, optimize as-operated considerations, examine financial assets, and ultimately foster exemplary performance at the building complex level.

In conclusion, this deliverable represents a significant stride towards harmonizing European building standards with sustainability and resource efficiency principles. As the EU continues to embark on its mission toward a greener future, the insights derived from this Operational Assessment Methodology will undoubtedly empower stakeholders with the necessary tools to pave the way for a more sustainable, energy-conscious, and resilient built environment.

1.2 Background and Objectives

The EU has consistently championed sustainable building practices and energy efficiency measures to combat climate change and reduce environmental impact. As part of its ongoing commitment to this cause, the EU is actively engaged in this European project aimed at enhancing the operational assessment methodologies of buildings. In response to the limitations of conventional assessments primarily focused on energy performance metrics, the project identified a critical need to integrate IEQ considerations, LCC analysis, and the principles of EPCs through the operational methodology aspects. Consequently, the deliverable titled "Operational Assessment Methodology in Building Level" emerged as a pivotal component within WP3.

1.3 Scope of the deliverable

This deliverable's overarching scope is to develop a comprehensive and integrated approach toward evaluating building operations, with a focus on enhancing IEQ, incorporating LCC analysis, and aligning with the principles of EPC. The primary objective of this deliverable is to address the limitations of traditional building assessments that primarily revolve around energy performance metrics. Instead, it seeks to provide a multi-dimensional assessment framework that accounts for IEQ as a pivotal aspect in building environments. The deliverable aims to explore the various factors influencing these aspects by recognizing the profound impact of IEQ on health, well-being, lifecycle costs, and energy consumption at the operational level.

To achieve this objective, the deliverable outlines specific tasks that will be undertaken throughout its development. T3.1 - *IEQ (including virus risk mitigation) analysis and integration to SmartLivingEPC* involves a comprehensive review of all aspects pertaining to IEQ within the built environment. Through a research-driven approach, sources, tools, and measurement equipment will be identified to assess the levels of IEQ parameters. The analysis will draw from established standards, such as the Level(s) scheme and European standard EN 16798-1 (2019), laying the groundwork for an IEQ analysis procedure. The deliverable will explore methods to assess the risk of virus transmission indoors, especially relevant in the context of COVID-19. Utilizing IoT sensors and data on CO2 and occupancy, the infection risk probability will be calculated using the Wells-Riley infection risk model and event reproduction number. This innovative approach will contribute to a better understanding of indoor virus transmission risk, aiding in the formulation of robust operational methodologies. Surveys will be conducted in buildings to evaluate IEQ concerns and gauge occupants' satisfaction with their indoor environment. This valuable input will be considered in the development of the IEQ assessment methodology, ensuring that the final framework reflects the perspectives and needs of building occupants.

T3.2 - *Operational level energy analysis and integration to SmartLivingEPC* aims to establish a unified operational assessment methodology applicable to all types of buildings. By documenting current practices for operational rating across European Member States (MSs), the deliverable will incorporate inputs on the frequency of issuance, measurement weather normalization processes, measurement devices and protocols, and extracted indicators (energy and non-energy). The integration of operational data from SmartLivingEPC pilots will further demonstrate the efficacy of the assessment scheme. The deliverable will additionally explore the application of smart sensors and digital twin practices to represent the actual energy performance of buildings within a Building Information Modeling (BIM) environment. This technological integration will enhance the accuracy and efficiency of building assessments within the methodology.

T3.3 - *Financial indicators and integration to SmartLivingEPC* will delve into the methodology of LCC to ascertain the overall costs of a building asset over its anticipated life span. The analysis will encompass construction, operational, maintenance, and end-of-life costs. By evaluating pertinent data and parameters, financial indicators will be formulated and integrated into the new rating classification system of EPCs, fostering user awareness and promoting strategic planning.

The deliverable's scope encapsulates an all-encompassing methodology that transcends conventional energy performance evaluations. It strives to provide a progressive, data-driven, and inclusive framework for building assessments, aligning with the principles and objectives of the European project. Ultimately, the deliverable's findings are expected to contribute significantly to advancing sustainable building practices and achieving the EU's ambitious environmental and energy goals.

2 IEQ analysis and integration to SmartLivingEPC

2.1 Introduction

Designing buildings that are comfortable, aid productivity, and are safe for human health when both living and working is a paramount objective of European Union strategies and current research.

Buildings are very complex environments that require both theoretical and experimental understanding of the physical phenomena of heat and mass transfer through the envelope, as well as air flow effects on the thermal comfort (TC) of the occupants, which are also related to the presence of air pollutants and airborne viruses (indoor air quality, IAQ). Clearly, such a compelling task must involve structural and HVAC operation design, functional aspects of spaces in relation to occupancy schedules, all the way to including even microbiology and health studies. Since both the HVAC and thermal performance of the envelope are strongly related to energy consumption, a sizeable effect exists on the energy balance at a more complex level of building clusters and districts.

For these reasons, thermal comfort and indoor air quality are addressed together within the more comprehensive concept of indoor environmental quality (IEQ). The main point is to increase the satisfaction of building occupants in a holistic way by considering all of the IEQ aspects rather than focusing on the narrower vision of temperature profiles or air quality alone.

A major challenge thus consists of quantifying and classifying indoor environmental quality. Based on European reference standards, the European Union Level(s) framework addresses this issue by defining two IEQ indicators, 4.1 for IAQ [1] and 4.2 for thermal comfort [2]. The associated performance metrics are good quality indoor air (parameters for ventilation, CO_2, and humidity), a target list of pollutants for 4.1, and the percentage of time that is spent outside of the thermal comfort range for 4.2.

Whilst defining thermal comfort is quite straightforward, indoor air quality is subject to some complex phenomenology. Risks are always present in the indoor environment since CO_2 is directly produced by the occupants, and paints and furniture release poisonous gases such as formaldehyde. Particulate matter (PM2.5 and PM10) and CO_2 are also brought into the building via intake ventilation and air infiltration. CO_2 is particularly dangerous, as it constitutes a key factor in the proliferation of mold on surfaces and within the envelope; mold, in turn, releases several types of toxic gases in the enclosure and can damage the structures.

Ventilation is a well-tested means of protecting human health, as it minimizes the occupants' exposure to the above pollutants, including airborne viruses, by supplying healthy air and removing those dangerous agents. The 4.1 indicators of IAQ are thus focused on the design of ventilation systems and indoor conditions so that the environment is healthy for individuals. Demand control ventilation (DCV) determines the air exchange rate based on various dynamical factors like CO_2 concentration, replacing stale air with clean intake air, and controlling the build-up of the chemical and biological pollutants discussed above.

Relative humidity (RH) is strictly connected to individuals' health and comfort as well. High or low RH levels remarkably amplify thermal discomfort or induce drying out and irritation of the nose and upper respiratory tract. Mould also requires high humidity levels, additionally to carbon dioxide, to grow within the structures and on surfaces. This is a structural problem in kitchens and bathrooms, where massive moisture release occurs. Besides humidity-related problems in old buildings due to structural defects, both new and renovated properties are also prone to RH extremes due to high airtightness. Ventilation succeeds in controlling RH as well; it is, therefore, paramount to monitor and assess CO_2 and humidity levels to efficiently exploit DCV for controlling sources of moisture production.

In this section, we formulate a comprehensive assessment methodology for IEQ that is based on Level(s) and integrates within the SmartLivingEPC framework. Thermal comfort, IAQ proxies, virus risk, and occupant feedback are considered in detail, both methodologically and from the viewpoint of measurements.

2.1.1 Level(s) framework for IEQ

Operational IEQ assessment indicators are measurable indicators specified in the Level(s) framework. Level(s) is a European framework for sustainable buildings [3], providing IEQ indicators in User Manual 3, under Macro-Objective 4: Healthy and comfortable spaces, where the indicators 4.1 to 4.4 can be found for IAQ, thermal comfort, lighting, and acoustics. Regarding numeric values, Level(s) indicators 4.1 [1] and 4.2 [2] (IAQ and thermal comfort) refer to EN 16798-1:2019 standard, which uses Categories I to IV to describe IEQ level. Virus risk is currently not addressed in Level(s) and EN 16798-1:2019, but it fits into the IAQ scope specified in these documents. For daylight in buildings, Level(s) 4.3 refers to EN 17037:2018, specifying parameters that are categorized as Minimum, Medium, and High. When aiming at a healthy indoor climate, it is proposed to use the normal level of Category II specified in EN 16798-1:2019, whose values will not only ensure avoiding adverse health effects but will also improve the comfort and well-being of occupants.

Indoor air quality and thermal comfort depend on parameters that are continuously controlled with building technical HVAC systems; therefore, acceptable ranges and deviations are important to be defined to enable verification. Acoustics' parameters may be verified by discontinuous measurements typically conducted in the commissioning phase. The same applies to artificial lighting; however, in operation, energy-efficient lighting is controlled based on daylight and occupancy. Daylight requirements are mostly verified during the design phase by geometry, window types, orientation, and shading. Some of the parameters are in practice, difficult to measure as they require specific sky conditions and sun angles. This enables a set of minimum requirements for acoustics and lighting parameters, for which some guidance is provided in EN 16798-1:2019 and EN 17037:2018. For these reasons, the SLE operational IEQ assessment focuses on assessing IAQ and thermal comfort indicators.

2.2 Selection of the IEQ assessment

Measuring indoor environment quality parameters in every room of a building may seem like an ideal approach to comprehensively assessing the indoor environment. However, several practical considerations make it unfeasible to deploy sensors in every room. Factors such as the cost of sensors, time required for planning and data analysis, and logistical challenges play a significant role in limiting the widespread deployment of sensors. Therefore, a strategic approach is necessary to optimize resource allocation and prioritize room selection for IEQ measurements.

One of the primary factors that hinder the installation of sensors in every room is the cost involved. IEQ sensors can be expensive, especially when multiplied by the number of rooms in a building. Scaling up the deployment to cover every room becomes financially burdensome, particularly for large buildings with numerous spaces. Budget constraints often necessitate a more targeted approach that balances cost-effectiveness with the need for reliable IEQ data.

Another aspect to consider is the time required for planning and analyzing the collected data. Installing sensors in every room would involve extensive planning and coordination, including site visits, sensor placement, and data logging setups. The logistical complexity increases exponentially as the number of rooms increases. Additionally, the analysis of the collected data demands substantial time and computational resources, which can become overwhelming when dealing with a vast amount of sensor data. Streamlining the process by focusing on representative rooms allows for efficient data collection and analysis while still obtaining valuable insights into IEQ conditions.

Furthermore, practical considerations arise in terms of maintaining and managing a large-scale sensor network. Regular maintenance, calibration, and troubleshooting for a high number of sensors can be time-consuming and resource intensive. In cases where sensors need to be periodically replaced or serviced, the logistics become more challenging when dealing with a vast sensor array spread throughout the building. Prioritizing certain rooms for sensor deployment minimizes the complexity of maintenance, ensuring the long-term sustainability of the IEQ measurement system.

Given these challenges, it becomes evident that a more strategic and targeted approach is necessary to achieve a meaningful assessment of IEQ in buildings. By carefully selecting rooms for sensor deployment based on factors such as occupancy, room typology, and other relevant criteria, a representative sample can be obtained that captures the variability of IEQ conditions. This approach optimizes resources, both in terms of cost and time, while still providing valuable insights into the overall indoor air quality profile of the building.

When selecting a limited number of rooms for IEQ measurements in buildings where installing sensors in every room is not feasible, several criteria can be considered to ensure a representative sample, such as those described by Wargocki et al. [4]. These criteria include, but are not limited to:

- Occupied Rooms: To ensure the assessment reflects real-life IEQ conditions, prioritize selecting rooms that are actively occupied. Occupancy can affect indoor pollutant generation and ventilation rates, thus influencing IEQ parameters.
- Occupation Density: It is important to select rooms with the lowest and highest occupation density. This allows for an assessment of IEQ conditions under varying occupancy levels, which can significantly influence air quality.

- Geographic Orientations: Rooms with different geographic orientations should be chosen. This ensures that IEQ measurements capture potential variations in sunlight exposure, airflow patterns, and outdoor pollutant infiltration, which can differ depending on a room's orientation.
- Street/Road and Garden-Facing Rooms: Selecting rooms facing different environments, such as streets, roads, and gardens, helps evaluate the impact of outdoor pollution sources and vegetation on IEQ. These different settings can introduce diverse pollutant profiles and airflow characteristics.
- Typologies of Rooms: It is important to include rooms with different typologies, which may include:
  - Rooms built or retrofitted during the same time period: This accounts for potential differences in building materials, ventilation systems, and overall IEQ performance based on construction practices during specific periods.
  - Rooms sharing the same air handling unit and ventilation/air conditioning zone: This allows for assessing IEQ similarities and differences within the same controlled environment.
  - Rooms with similar building materials and furniture: Similar materials and furniture can affect IEQ through emissions of volatile organic compounds (VOCs) and other pollutants.
  - Rooms with similar types of solar shading devices: Solar shading devices can impact thermal conditions and air circulation, which can influence IEQ.
  - Specific Room Types: Buildings with office spaces, including both single and open-plan offices, allow for evaluating IEQ in different work environments. In hotels or similar establishments, selecting rooms of various sizes provides insights into IEQ variations across different guest accommodations.

By considering these room selection criteria, the IEQ measurements will provide a representative overview of the building's indoor environment, accounting for various factors that contribute to air quality variations.

2.3 IEQ assessment framework

Our previous studies have shown that raw sensor data, if not pre-treated correctly, has little value due to numerous, rather frequently occurring physical and digital disturbances. Therefore, it is critically important to:

1) Validate that the correct type of data is logged with the correct tag (e.g., CO_2).
2) Remove outliers and anomalous behavior (in practice, that can happen often) to a statistically satisfactory extent.
3) As per signal type, apply appropriate data correction algorithms for known types of disturbances (such as the CO_2 baseline shifting problem). The presence of additional data streams (outdoor CO_2 level, room temperature etc.) can be beneficial to assist the detection and correction of certain anomalies via advanced algorithms.

Since the IEQ classification is only relevant during occupied hours, it is then critically important to determine or at least estimate the occupancy times. Inadequate occupancy determination will render the IEQ classification results close to meaningless or, from an energy consumption standpoint, even counterproductive. Hence, the assessment framework should continue as follows:

4) If zone CO_2 is measured, detect occupancy from zone CO_2 measurements. If not, use electricity consumption intensity as an alternative detection method. As a last option, use standard occupancy times as defined per building/zone type.

5) Calculate and store hours spent within the respective class boundaries. For example, this calculation may be performed weekly.

As mentioned in Section 2.2.4.1 the choice of classification criteria must be critically evaluated based on occupant feedback. Furthermore, the net effect of classification criteria strictness must be assessed, finding the balance between actual occupant satisfaction, energy consumption, and health risk mitigation. A unified view of the assessed IEQ components, calculation/assessment methodologies, and data flows is portrayed in **Figure 1**.

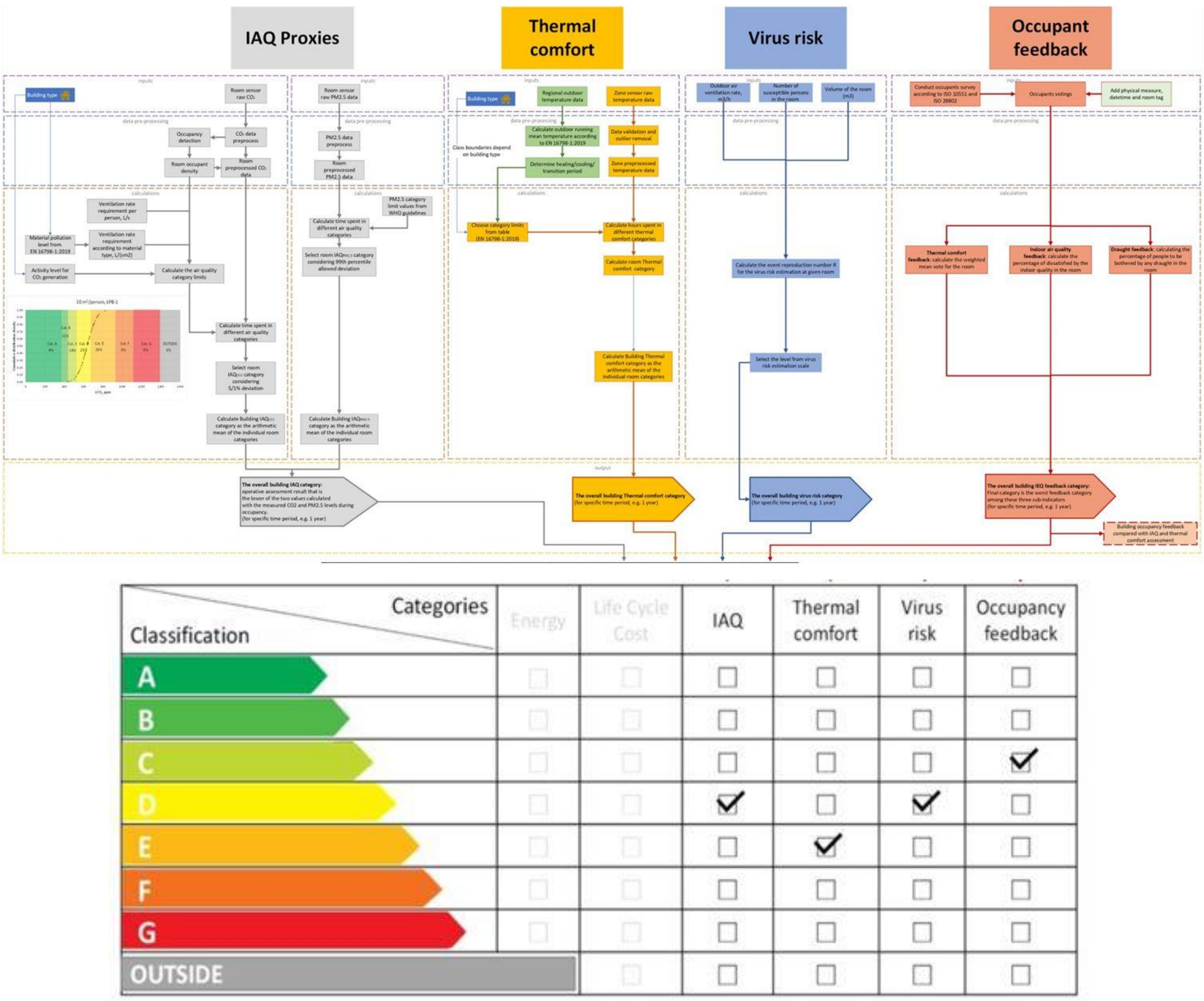


Figure 1: The framework of the IEQ assessment methodology

2.4 SmartLivingEPC Indoor Environment Quality Indicators

2.4.1 Thermal comfort

The Level(s) 4.2 indicator [2] is concerned with controlling thermal comfort. Particularly, solar gains in summer can lead to uncomfortable conditions that may require additional cooling energy. Winters are also problematic, as the European building stock as a whole cannot guarantee excellent levels of insulation, good quality windows, and the absence of cold bridges through the envelope. This can result in inadequate heating, which can increase the risk of seasonal illnesses for vulnerable residents. The EPBD 2010/31/EU, as amended by the Directive (EU) 2018/844 [5], recommends using the same indicator for cooling and heating.

2.4.1.1 Assessment methodology

The Level(s) framework approaches the thermal comfort issue at the stages of building design (level 1, ignored here) and in-use performance, levels 2 and 3, which constitutes the core of our operational performance testing methodology. The in-use performance is based on climate and use corrections, metering, and comparison of estimated satisfaction levels with those obtained from occupier surveys.

In order to comply with level 3 of Level(s), the monitoring and metering strategy is realized in the present approach with the pilot buildings that are described in D1.2, and more specifically T1.3. The data collection and reporting are articulated as follows:

1. Data is collected after a minimum occupancy time and continues to be recorded for an agreed period.
2. In the case of comparison with other buildings, corrections of the performance will be made according to use and climate (test reference year - TRY) following the national method or EN ISO 52000-1.
3. Analysis of the data will evaluate the percentages of time spent within the upper and lower T bounds.

Level 2 provides prescriptions for calculating with computer simulations the Predicted Percentage Dissatisfied (PPD) design stage estimate, which requires input data for clothing, activity, air, and mean radiant temperature, draught, and humidity. In our operational assessment, local thermal discomfort parameters such as radiant asymmetry and draught are not assessed, as there is no viable method to carry out continuous monitoring of such parameters. Indoor thermal comfort is accordingly assessed with measured room air temperatures in selected rooms.

In other words, we shall use as input for the calculations only room air temperature, outdoor4 temperature, and building type to define the category limits according to the default parameters (e.g., typical activity and clothing levels). The method is to calculate the percentage (%) of time that is spent within each thermal comfort category according to the limits in **Table 1**. The TAIL methodology [4] considers that “the temperatures can exceed the indicated range by 1 °C for no more than 5%, and by 2 °C for no more than 1% of the occupancy time during which the measurements were performed (during the working hours in offices and night-time sleeping hours in hotels).” The output is the room thermal comfort category. The Predicted Mean Vote (PMV) and the appropriate PPD value will be calculated as well, to be compared with the occupants’ feedback that is described in Section 2.2.4. The procedure is illustrated in **Figure 2**.

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

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

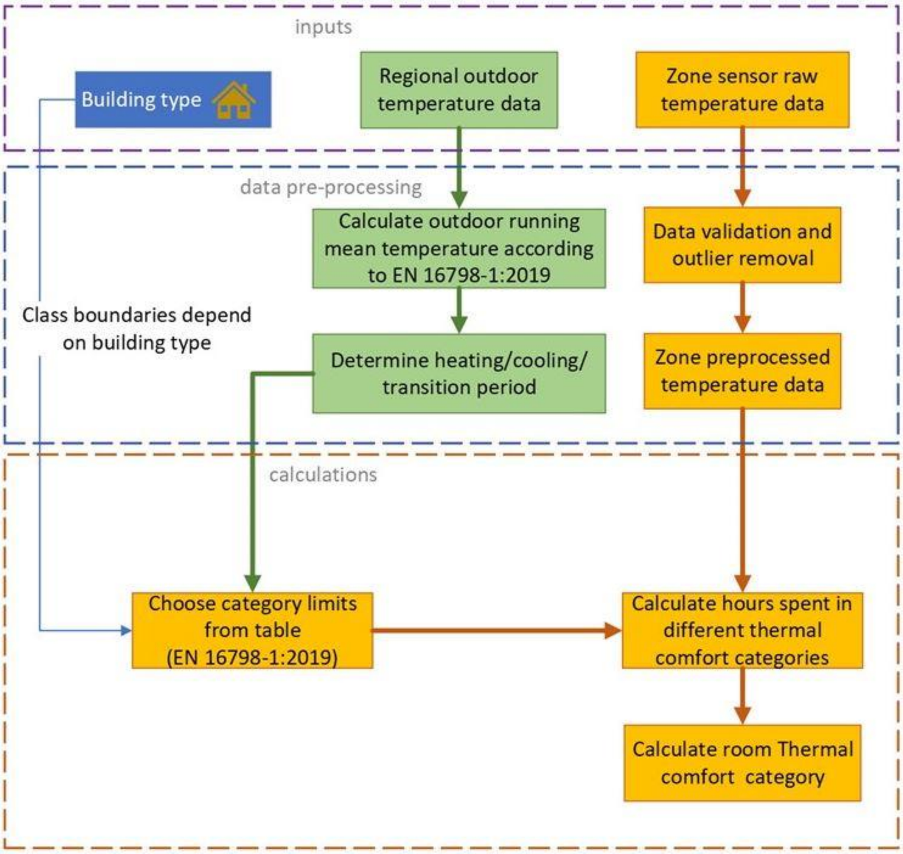


Figure 2: Procedure for computing the Thermal Comfort category according to EN 16798-1:2019

2.4.2 Indoor air quality proxies

When measuring indoor air quality (IAQ), selecting the most appropriate variables to monitor is essential for obtaining a comprehensive understanding of the indoor environment. While there are numerous pollutants and variables present in indoor air, such as radon, volatile organic compounds (VOCs), and formaldehyde, specific choices must be made regarding which parameters to include in the measurement protocol. In this context, carbon dioxide (CO_2) and fine particulate matter (PM2.5) have been chosen as indicative variables due to their significance in assessing IAQ and their practical considerations, while other variables were omitted.

Carbon dioxide is a widely recognized indicator of indoor air quality, primarily because it is directly related to human occupancy and ventilation. As humans exhale CO_2, its concentration increases in poorly ventilated spaces, potentially leading to discomfort, drowsiness, and decreased cognitive function. Monitoring CO_2 levels provides insights into the effectiveness of ventilation systems and the adequacy of fresh air supply. Furthermore, high CO_2 concentrations can indicate the presence of other indoor pollutants, as insufficient ventilation can result in the accumulation of various contaminants. CO_2 is also a relatively easy parameter to measure, with cost-effective sensors readily available in the market.

Fine particulate matter refers to tiny airborne particles with a diameter of 2.5 micrometers or less. These particles can be generated from various sources, including combustion processes, cooking, smoking, and outdoor pollutants that infiltrate indoor spaces. PM2.5 is of particular concern due to its ability to penetrate deep into the respiratory system, potentially causing adverse health effects. Monitoring PM2.5 levels allows for an assessment of the level of particulate pollution and can help identify sources of indoor particle emissions. Like CO_2, PM2.5 measurements are relatively accessible through commercially available sensors, making them a practical choice for IAQ assessment.

While variables such as radon, VOCs, and formaldehyde are also important contributors to IAQ, their inclusion in the measurement protocol depends on several factors. Radon, for instance, is a radioactive gas that can seep into buildings from the ground and is associated with an increased risk of lung cancer. However, radon levels can vary significantly depending on geographical location and building characteristics, making it a more site-specific concern that may require separate testing. VOCs and formaldehyde, on the other hand, encompass a wide range of indoor pollutants originating from building materials, furnishings, cleaning products, and human activities. Monitoring these variables often requires more complex and specialized instrumentation, which may not be suitable for widespread deployment due to cost and operational considerations.

2.4.2.1 CO2-based assessment procedure

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

To calculate the design ventilation rate, the standard takes into account both the occupant density and the specific CO_2 emissions associated with occupant activity levels. Category boundary values for the equivalent increase in CO_2 levels are derived from this design ventilation rate. The assessment process utilizes the existing room use plan and measurements of CO_2 levels or air flow rates, depending on the available data. Depending on the measured parameter, the result is either expressed as a building IAQ category or a building IAQ score.

In the case of constant air volume (CAV) systems, a validated air flow rate measurement protocol may be employed as an alternative to direct air flow measurements. However, to accurately conduct the calculation procedure, certain additional information is required. Firstly, an external signal, obtained through direct measurement or indirect assessment of occupancy (as described in T4.2), is necessary to determine whether the rooms are occupied or unoccupied. Furthermore, as the assessment is based on the CO_2 balance of the room, the number of occupants present and/or the ventilation air flow rate in the room must also be known.

The calculation procedure for a single room is described in **Figure 3**, with the required inputs and calculations. Category limit values of room CO_2 concentration are calculated based on the number of people present in the room (occupant density), the level of their activity (CO_2 generation) as well as the building materials emission, according to the ventilation rates provided in **Table 2** and **Table 3**. This is done by solving the room CO_2 mass balance according to ambient CO_2 concentration, CO_2 generation in the room, and fresh air exchange rate.

Table 2: Ventilation rate requirements, occupant component [modified from EN 16798-1:2019]

Category	**Ventilation rate requirement per person, L/s**	
	Non-adapted	**Adapted**
Category A	10.00	3.50
Category B	8.50	3.00
Category C	7.00	2.50
Category D	5.50	2.00
Category E	4.00	1.50
Category F	3.25	1.25
Category G	2.50	1.00

Table 3: Ventilation rate requirements, materials component [modified from EN 16798-1:2019]

Category	**Ventilation rate requirement according to material type, L/(sm²)**		
	Very low polluting	**Low polluting**	**Non low polluting**
Category A	0.50	1.00	2.00
Category B	0.43	0.85	1.70
Category C	0.35	0.70	1.40
Category D	0.28	0.55	1.10
Category E	0.20	0.40	0.80
Category F	0.18	0.35	0.70
Category G	0.15	0.30	0.60

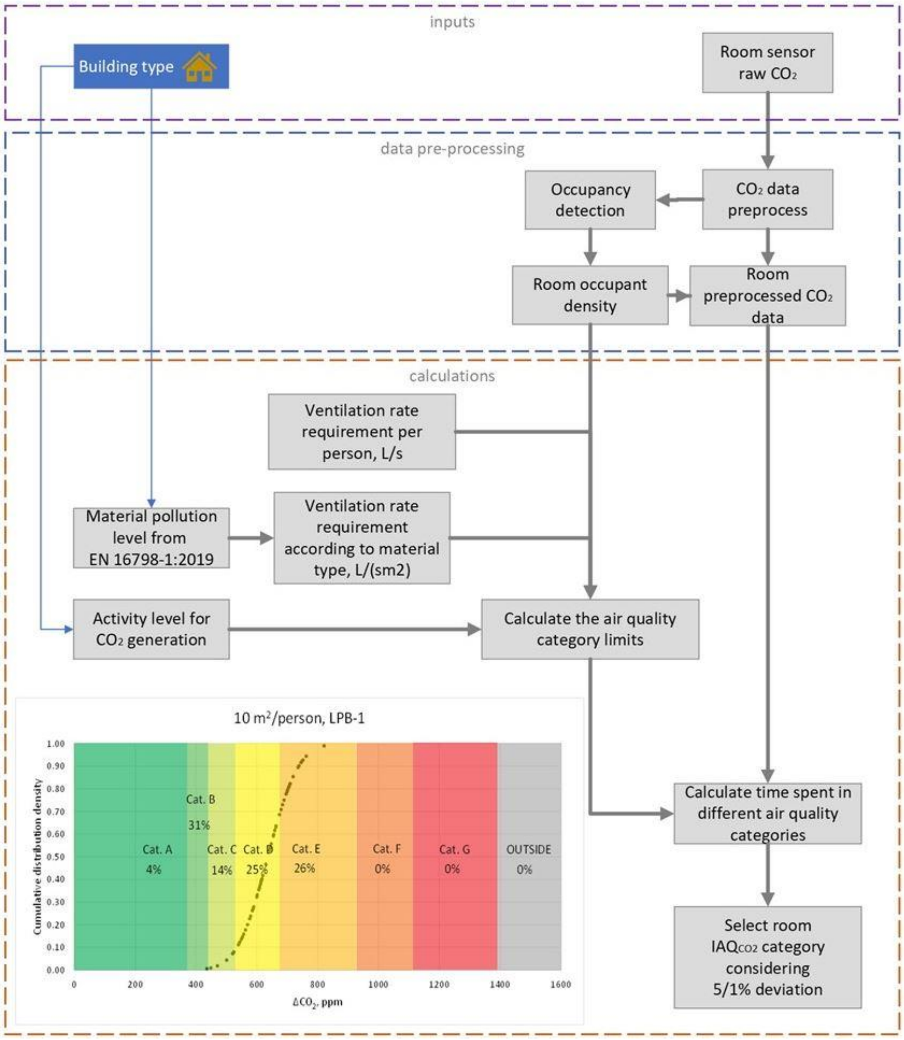


Figure 3: CO_2 level-based IAQ assessment procedure for a single room

The resulting room IAQ category is calculated according to the time spent in each of the categories, following a 5/1% allowed deviation like in the TAIL calculation methodology [4]. Specifically, the CO_2 levels cannot exceed the boundary values in one category lower for 5% of the occupied time and 1% of the time for the limit two (2) categories lower. Building IAQ category is calculated as the arithmetic mean of the individual room categories. Figure 4 - Figure 6 provide an example dataset of measured CO_2 values during occupied periods, room and building IAQ category calculation procedure based on this dataset as well as a possible visualization of the temporal distribution of the IAQ categories in the rooms during occupancy.

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6
625	774	996	682	978	1219
634	837	898	705	905	1367
401	647	729	1046	1044	1448
534	724	807	939	859	1182
596	602	810	828	994	1368
514	816	714	1171	621	1157
657	800	735	1097	1145	783
943	677	808	803	796	1326
638	910	922	1083	826	1160
592	607	864	943	953	1311
557	543	691	873	938	1254
845	571	799	891	720	1317
617	862	773	1058	900	1207
643	787	872	1007	779	1014
400	755	905	905	1106	1375
827	574	901	1032	1058	1541
400	617	898	827	800	1116
793	730	983	1118	952	1404
651	584	900	1073	1087	1336
529	730	723	738	993	1045
735	825	779	887	1293	1282
618	494	712	1047	1077	1316
623	888	892	1049	813	1284
630	642	945	1013	673	1380
690	649	884	875	832	1354
570	521	676	765	1037	1372

Figure 4: User input of measured CO_2 values during occupancy

	User input										
Non low polluting	Materials emission	Select building material emission class (Default: Low polluting)									
420	Outdoor CO_2	Input outdoor air CO_2 concentration (420 ppm current value, many standards operate with 400 ppm)									
		Input occupant density and CO_2 generation (see values on EN 16798-1 data sheet)									
		Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
Occupant density	m^2/person	7.5	8.2	6	9.3	7	5.5	8	8	8	8
CO_2 emission	q_{CO2}, L/h	20	20	20	20	20	20	20	20	20	20
Cat. A CO_2	C, ppm	642	630	673	614	651	685	-	-	-	-
Cat. B CO_2	C, ppm	681	668	717	649	692	731	-	-	-	-
Cat. C CO_2	C, ppm	737	721	781	698	751	798	-	-	-	-
Cat. D CO_2	C, ppm	824	803	879	773	841	901	-	-	-	-
Cat. E CO_2	C, ppm	976	946	1051	906	999	1081	-	-	-	-
Cat. F CO_2	C, ppm	1074	1038	1166	989	1102	1202	-	-	-	-
Cat. G CO_2	C, ppm	1214	1169	1331	1108	1249	1378	-	-	-	-
Cat. A share	-	68%	23%	9%	3%	1%	0%	-	-	-	-
Cat. B share	-	13%	13%	11%	2%	1%	0%	-	-	-	-
Cat. C share	-	11%	21%	24%	4%	3%	0%	-	-	-	-
Cat. D share	-	7%	26%	34%	11%	12%	0%	-	-	-	-
Cat. E share	-	2%	16%	21%	31%	33%	9%	-	-	-	-
Cat. F share	-	0%	1%	1%	22%	29%	17%	-	-	-	-
Cat. G share	-	0%	0%	0%	20%	18%	43%	-	-	-	-
Not acceptable share	-	0%	0%	0%	7%	4%	31%	-	-	-	-
Room IAQ score	-	1.62	3.00	3.50	5.48	5.54	6.96	-	-	-	-
Room IAQ category (5/1%)		D	E	E	OUTSIDE	G	OUTSIDE	-	-	-	-
Building IAQ score	-	**4.35**									
Building IAQ category	-	**F**									

Figure 5: Calculation table of IAQ score and category

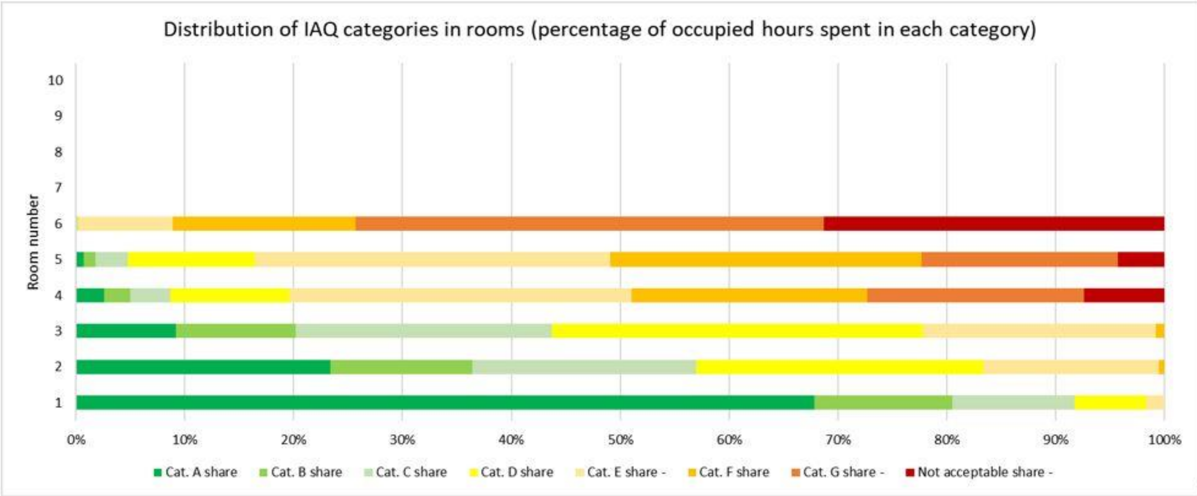


Figure 6: Visual representation of the distribution of IAQ categories

2.4.2.2 PM2.5-based assessment procedure

This assessment is based on the adapted limit values of PM2.5 from the WHO guidelines. A comparison of different air pollutant limit levels between the EU Air quality Directives and WHO Air Quality Guidelines published by the European Environment Agency is shown in **Figure 8** [6].

The Assessment is based on both 24-hour mean values, with a 99th percentile allowed deviation over these limits annually. Category limit concentrations are shown in **Table 4**. The overall calculation principle is similar to the CO_2 assessment. The calculation procedure for a single room is described in **Figure 7**, with the required inputs and calculations. The example is shown in **Figure 9** - **Figure 11**.

Table 4: PM2.5 annual mean category limit values

Category	**Limit concentration (µg/m^3)**
Category A	5
Category B	7.5
Category C	10
Category D	12.5
Category E	15
Category F	20
Category G	25
Outside allowed limit	≥25.0

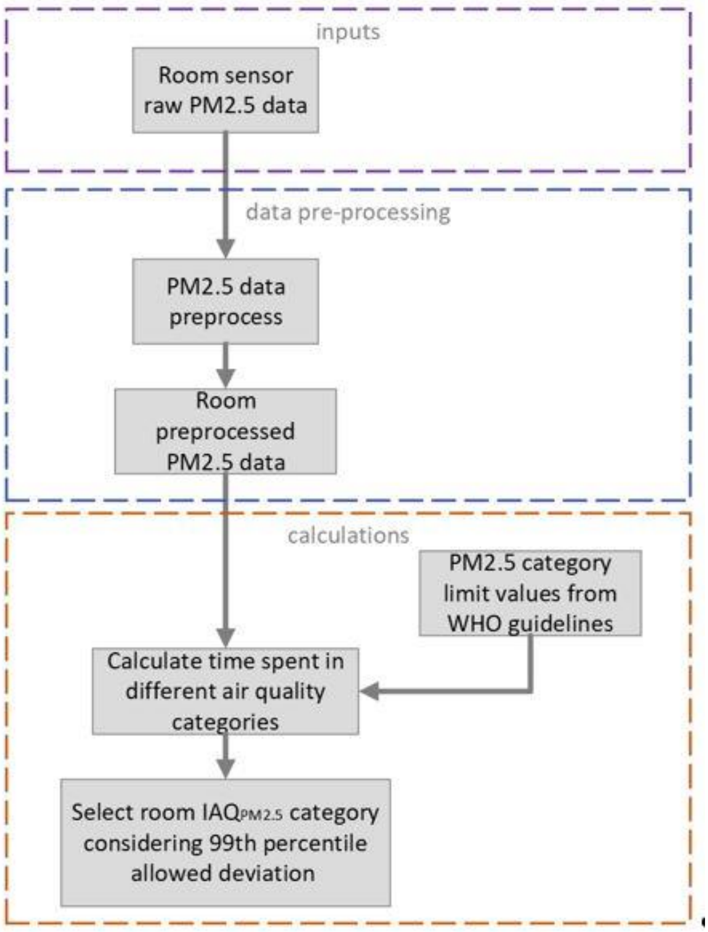


Figure 7: PM2.5 level-based IAQ assessment procedure for a single room

		EU Air Quality Directives			WHO Air Quality Guidelines					
Pollutant	Averaging period	Objective	Concentration	Comments	Concentration					Comments
					Interim targets				AQG level	
					1.	2.	3.	4.		
$PM_{2.5}$	24-hour	Target value			75	50	37,5	25	15 µg/m³	99th percentile (i.e. 3–4 exc. Days/year)
$PM_{2.5}$	Annual	Limit value	25 µg/m³		35	25	15	10	5 µg/m³	
$PM_{2.5}$	Annual	Indicative limit value	20 µg/m³							
PM_{10}	24-hour	Limit value	50 µg/m³	Not to be exceeded on more than 35 days/year	150	100	75	50	45 µg/m³	99th percentile (i.e. 3–4 exc. Days/year)
PM_{10}	Annual	Limit value	40 µg/m³		70	50	30	20	15 µg/m³	
O_3	Max. daily 8-hour mean	Target value	120 µg/m³	Not to be exceeded on more than 25 days/year (averaged over 3 years)						
O_3	Max. daily 8-hour mean	Long-term objective	120 µg/m3							
O_3	8-hour	Target value			160	120	–	–	100 µg/m³	99th percentile (i.e. 3–4 exc. Days/year)
O_3	Peak season *	Target value			100	70	–	–	60 µg/m³	
NO_2	Hourly	Limit value	200 µg/m³	Not to be exceeded on more than 18 hours/year					200 µg/m³	
NO_2	Annual	Limit value	40 µg/m³		40	30	20	–	10 µg/m³	
NO_2	24-hour	Target value			120	50	–	–	25 µg/m³	99th percentile (i.e. 3–4 exc. Days/year)
SO_2	Hourly	Limit value	350 µg/m³	Not to be exceeded on more than 24 hours/year						
SO_2	24-hour	Limit value	125 µg/m³	Not to be exceeded on more than 3 days/year	125	50	–	–	40 µg/m³	99th percentile (i.e. 3–4 exc. Days/year)
CO	Max. daily 8-hour mean	Limit value	10 mg/m³						10 mg/m³	
CO	24-hour	Target value			7	–	–	–	4 mg/m³	99th percentile (i.e. 3–4 exc. Days/year)
C_6H_6	Annual	Limit value	5 µg/m³						1,7 µg/m³	Reference level
BaP	Annual	Target value	1 ng/m³	Measured as content in PM_{10}						
Pb	Annual	Limit value	0,5 µg/m³	Measured as content in PM_{10}					0,5 µg/m³	
As	Annual	Target value	6 ng/m³	Measured as content in PM_{10}					6,6 ng/m³	Reference level
Cd	Annual	Target value	5 ng/m³	Measured as content in PM_{10}					5 ng/m³	
Ni	Annual	Target value	20 ng/m³	Measured as content in PM_{10}					25 ng/m³	Reference level

Figure 8: EU and WHO air quality directives and guidelines for harmful pollutants

		Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7
Cat. A PM2.5	(µg/m^3)	15	15	15	15	15	15	15
Cat. B PM2.5	(µg/m^3)	20	20	20	20	20	20	20
Cat. C PM2.5	(µg/m^3)	25	25	25	25	25	25	25
Cat. D PM2.5	(µg/m^3)	38	38	38	38	38	38	38
Cat. E PM2.5	(µg/m^3)	50	50	50	50	50	50	50
Cat. F PM2.5	(µg/m^3)	63	63	63	63	63	63	63
Cat. G PM2.5	(µg/m^3)	75	75	75	75	75	75	75
Cat. A share	-	72%	30%	5%	0%	0%	0%	0%
Cat. B share	-	22%	35%	24%	0%	0%	0%	0%
Cat. C share	-	6%	28%	39%	4%	0%	0%	0%
Cat. D share	-	1%	7%	32%	76%	8%	0%	0%
Cat. E share	-	0%	0%	0%	20%	74%	1%	0%
Cat. F share	-	0%	0%	0%	0%	18%	53%	1%
Cat. G share	-	0%	0%	0%	0%	0%	45%	52%
Not acceptable share	-	0%	0%	0%	0%	0%	1%	48%
Room PM2.5 score	-	1.35	2.12	2.98	4.16	5.10	6.45	7.47
Room PM2.5 category (99th percentile)	-	3	4	4	5	6	7	8
Room PM2.5 category (99th percentile)		C	D	D	E	F	G	OUTSIDE
Building IAQ score	-	**4.23**						
Building IAQ category	-	**E**						

Figure 9: Calculation table of PM2.5 score and category

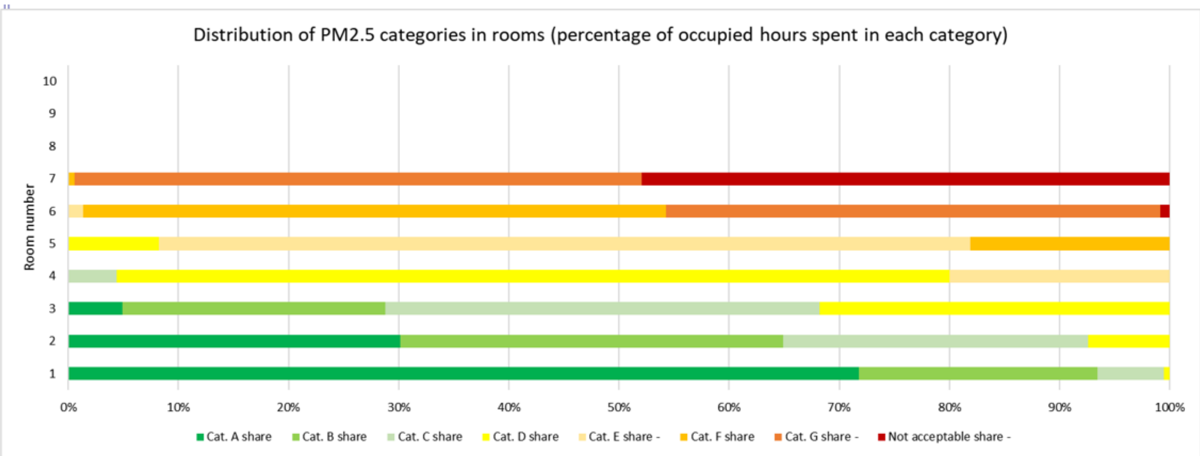


Figure 10: Visual representation of the distribution of PM2.5 categories

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7
15	3	31	34	50	55	77
17	20	24	31	42	63	76
19	12	30	33	36	59	76
17	18	19	45	49	62	72
2	8	25	31	48	65	82
19	23	32	35	34	52	75
12	15	19	29	48	68	79
18	17	22	31	45	65	77
17	11	25	37	43	64	70
13	5	20	30	41	60	69
10	14	23	34	47	48	81
19	20	16	30	51	67	73
9	14	26	25	44	62	67
16	17	28	33	37	61	70
15	21	28	34	36	69	75
14	20	21	41	38	53	79
8	17	30	33	45	60	73
1	20	31	30	52	63	74
1	15	15	44	43	60	72
8	15	21	33	37	63	83
14	9	16	33	44	64	74
8	22	19	31	43	61	70
11	14	28	33	49	58	71

Figure 11: User input of measured daily mean PM2.5 values

The overall building IAQ category to be displayed as an operative assessment result is the lower of the two values calculated with the measured CO_2 and PM2.5 levels during occupancy.

2.4.2.3 Infection-risk-based ventilation rates and risk assessment methodology

The main engineering measures to control the virus risk are ventilation, air filtration, and disinfection, as shown in **Figure 12**. In virus risk control, the virus concentration in the air is a central issue because the exposure (=dose) is a product of the breathing rate, concentration, and time.

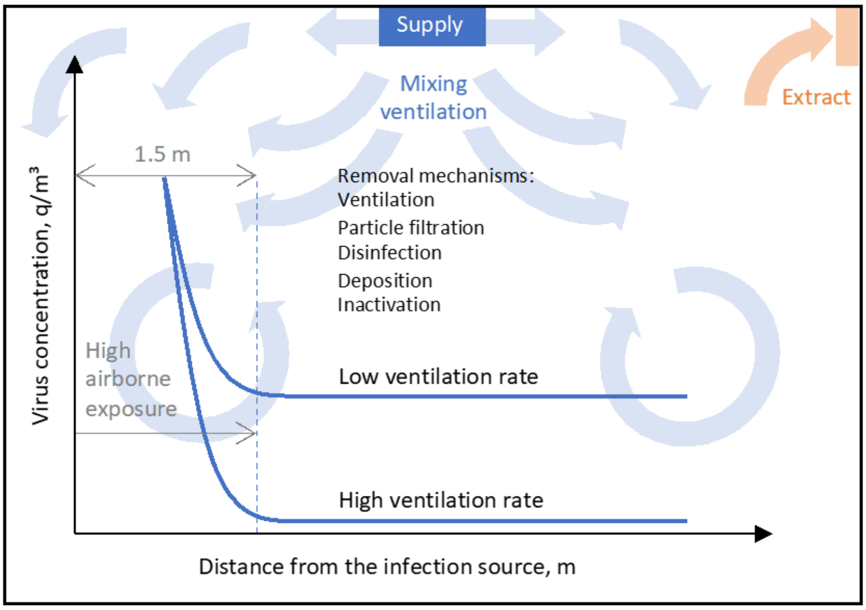


Figure 12: Main removal mechanisms of virus-containing particles

For the concentration control of virus-containing particles, these removal mechanisms can be applied, i.e. viruses can be removed with outdoor air ventilation and filtration or deactivated with UVG. It should be noted that ventilation applies for long-range transmission; therefore, in the case of general ventilation solutions, a physical distance >1.5 m should be applied, meaning that, for instance, in meeting rooms, every second seat needs to be empty.

Virus risk can be calculated from the probability of infection for a susceptible person, for which the infection risk-based ventilation calculation method developed by REHVA [7] can be applied. The required outdoor air ventilation rate in the steady state at a given infection risk probability and fully mixing air distribution can be calculated as follows [8]:

$$Q = \frac{(1-\eta_i) I q Q_b (1-\eta_s) D}{\ln\left(\frac{1}{1-p}\right)} - \left(\lambda_{dep} + k + k_f + k_{UV}\right) V \qquad (1)$$

where:

Q outdoor air ventilation rate (m^3/h)

p probability of infection for a susceptible person (-)

q quanta emission rate per infectious person (quanta/(h pers))

Q_b volumetric breathing rate of an occupant (m^3/h), see **Table 5**

I number of infectious persons (-), default value $I = 1$

η_s facial mask efficiency for a susceptible person (-)

η_i facial mask efficiency for an infected person (-)

D duration of the occupancy (h)

λ_{dep} deposition onto surfaces (1/h)

k virus decay (1/h)

k_f filtration by a portable air cleaner (1/h)

k_{UV} disinfection by upper room ultraviolet germicidal irradiation UVGI (1/h)

V volume of the room (m^3)

This general equation includes other potential virus removal mechanisms in addition to outdoor air ventilation, such as air cleaners, UVGI, and facial masks, which may not be present in many situations. In the case of one infectious person, no facial masks, and no air cleaners and UVGI, Equation (1) simplifies this to the following:

$$Q = \frac{q Q_b D}{\ln\left(\frac{1}{1-p}\right)} - \left(\lambda_{dep} + k\right) V \qquad (2)$$

If a portable air cleaner is used, the filtration removal rate (k_f) is calculated based on the airflow rate through the filter (Q_f), the removal efficiency of the filter (η_f), and room volume V:

$$k_f = \frac{Q_f \eta_f}{V} \qquad (3)$$

For portable cleaners with a high-efficiency particle air (HEPA) filter, the clean air delivery rate (CADR, m^3/h) can be used to calculate the filtration removal rate as $k_f = CADR/V$. The removal efficiency of filters and the CADR are particle-size dependent. These parameters will be estimated based on the size range of 0.3–0.5 µm [9].

An acceptable individual probability *p* for a specific room can be calculated based on the event reproduction number *R,* defined as the number of new disease cases divided by the number of infectors $R = N_c/I$. Considering that the number of new cases $N_c = p\,N_s$ an acceptable individual probability for a specific room can be calculated as follows:

$$p = \frac{RI}{N_s} = \frac{RI}{(N - I)(1 - f_v \eta_v)} \tag{4}$$

where:

R event reproduction number (-)

N_s the number of susceptible persons in the room, $N_s = N - I$ if no vaccinated/immune persons

f_v fraction of the local population who are vaccinated, $f_v = 0$ for no vaccination (-)

η_v the efficacy of the vaccine against becoming infectious, $\eta_v = 1$ for ideal protection (-)

Acceptable *R* during one room-occupancy event can be based on the assumption that the likelihood of infecting others (i.e. the number of infections per unit time) is approximately constant over the infectious period. In such cases, an infectious person will not infect more than one person during the infectious period:

$$\frac{R}{R_0} \cong \frac{D}{D_{inf}} \quad \Rightarrow \quad R \leq \frac{D}{D_{inf}} \quad \text{when} \quad R_0 \leq 1 \tag{5}$$

where:

R event reproduction number, i.e. number of people who become infected per infectious occupant

D room occupancy period, i.e. length of time when both infectious and susceptible persons are present in the room at the same time (h)

D_{inf} the total interaction time when an infectious individual is in the vicinity of any susceptible persons during the whole pre-symptomatic infectious period (h)

R_0 basic reproduction number that describes the spread of an epidemic in the population (-)

The pre-symptomatic infectious period typically ends at the onset of symptoms when the infectious person self-isolates at home or is otherwise 'removed' from contact with susceptible individuals. This period may last some days, on average approximately two (2) days for influenza and 2½ days for SARS-CoV-2. For example, if an infectious person is in the vicinity of susceptible persons (e.g. on public transport, at work/school) for 20 hours altogether during the infectious period, then he or she must not infect more than $R = 1/20 = 0.05$ persons per hour, on average, in order to remain within the limit of $R_0 \leq 1$.

It should be noted that when there are a very low number of susceptible persons in the room (such as in an office with only a few individuals working there), Equation (7) produces high values for the individual probability, which may be additionally limited to some value, for instance, $p \leq 0.1$. This is currently not done in **Table 5** and **Table 6**; hence, in offices where R = 9/22.5 = 0.4, the individual probability will be higher than 0.1 if the number of occupants is four (4) or fewer.

It is possible to simplify Equations (1) and (2) by using the Taylor approximation of an exponential $e^n \cong 1 + n$ at low doses that allow for the rewriting of the Wells-Riley equation $p = 1 - e^{-n}$ as follows:

$$\mathrm{n} \cong \frac{1}{1-\mathrm{p}} - 1 \tag{6}$$

where:

n quanta inhaled by the occupant (quanta)

Taylor approximation provides reasonable accuracy at low *p* values, for instance, 2.4% at *p* = 0.05 and 4.7% at *p* = 0.1. By using another approximation $1/(1-p) \cong 1 + p$ that applies if $|p| \ll 1$, Equation (1) can be rearranged as follows:

$$\mathrm{Q} = \frac{(1-\eta_i)\mathrm{q}\mathrm{Q_b}(1-\eta_s)\mathrm{D}\mathrm{N_s}}{\mathrm{R}} - \left(\lambda_{dep} + \mathrm{k} + \mathrm{k_f} + \mathrm{k_{UV}}\right)\mathrm{V} \tag{7}$$

This equation enables us to calculate infection-risk-based ventilation rates in a simple fashion when substituting the default values of quanta emission rate, breathing rate, and occupancy duration.

Ventilation rate *Q* in Equation (7) applies at fully mixing air distribution. For an actual air distribution solution deviating from fully mixing, the ventilation rate needs to be adjusted with ventilation effectiveness (REHVA 2022). The ventilation rate Q_s to be supplied by the ventilation system can be calculated as follows:

$$\mathrm{Q_s} = \frac{\mathrm{Q}}{\varepsilon_b} \tag{8}$$

where:

Q target ventilation airflow rate for the breathing zone from equation 2.2.3.7 (L/s)

Q_s design ventilation airflow rate at actual air distribution solution (L/s)

ε_b point source ventilation effectiveness for the breathing zone (-)

For the virus risk estimation in a given room, the event reproduction number from Equations (7) and (8) can be calculated:

$$\mathrm{R} = \frac{(1-\eta_i)\mathrm{q}\mathrm{Q_b}(1-\eta_s)\mathrm{D}\mathrm{N_s}}{\mathrm{Q_s}\varepsilon_b + \left(\lambda_{dep} + \mathrm{k} + \mathrm{k_f} + \mathrm{k_{UV}}\right)\mathrm{V}} \tag{9}$$

Here it is important to note that *R* depends on the occupancy time in the room that is treated as a room category-specific parameter. With previous assumptions for occupancy times *R* values for R_0 = 1 and other risk levels are provided in **Table 5**.

Table 5: Proposed virus risk estimation scale based on R values at specified risk levels

Risk level	**R_0, No of new disease cases by one infector**	***R* in offices**	***R* in classrooms**	***R* in meeting rooms**
A	0.8	0.32	0.071	0.300
B	0.85	0.34	0.076	0.319
C	0.9	0.36	0.080	0.338
D	0.925	0.37	0.082	0.347
E	0.95	0.38	0.084	0.356
F	0.975	0.39	0.087	0.366
G	1.0	0.40	0.089	0.375
Outside	>1.0	>0.40	>0.089	>0.375

For the virus risk evaluation in the actual room, ventilation rate and number of susceptible persons (*N*-1) are to be used to calculate *R* with Equation (9) and then be compared with risk level values in **Table 5**. Therefore, the following **measured/monitored data** is needed from each room for the virus risk estimation:

Q outdoor air ventilation rate (m^3/h)

N_s number of susceptible persons in the room

V volume of the room (m^3)

For the rest of the parameters in Equation (9), **room category-specific default values can be used**. The following default values can be used for mask efficiency, other removal mechanisms, quanta emission rates, and breathing rates:

- facial cloth mask efficiency [10] for a susceptible person η_s= 0.3, if there is no mask (default assumption) η_s= 0
- facial cloth mask efficiency for an infected person η_i = 0.5, if there is no mask (default assumption) η_i = 0
- fraction of the local population who are vaccinated f_v = 0
- surface deposition loss rate [11] λ_{dep} = 0.24 1/h
- virus decay [12] *k* = 0.63 1/h
- quanta emission rate time average values calculated based on median viral loads [13] of SARS-CoV-2, i.e. *q* = 4 quanta/(h pers) in classrooms, 6 quanta/(h pers) in offices and gyms, and 10 quanta/(h pers) in meeting rooms and restaurants
- number of infectious persons in the room *I* = 1 pers
- breathing rate time-averaged values Q_b = 0.60 m^3/h in offices, Q_b = 0.57 m^3/h in classrooms, Q_b = 0.65 m^3/h in meeting rooms and restaurants and Q_b = 1.9 m^3/h in gyms
- occupancy duration *D* = 2, 6, and 9 hours in meeting rooms, classrooms, and offices, respectively

- interaction time of an infectious individual is in the vicinity of susceptible persons, including traveling, lunches, and other out-of-home activities, 22.5 h in offices and 16 h in schools over 2.5 days of the pre-symptomatic infectious period
- some values for the point source ventilation effectiveness are available in (REHVA 2022)

2.4.3 Occupant feedback

The methods described in the previous sections rely on fixed classification criteria for the assessment of IEQ. It is also important to get feedback directly from the room users to cross-check if the calculated IEQ classifications correspond to the actual satisfaction level of the users.

2.4.3.1 Assessment methodology

Occupancy feedback will focus on the occupant's subjective assessment of general thermal comfort (also including draught components as a separated sub-indicator) and indoor air quality. This assessment does not include local thermal comfort, such as vertical air temperature difference, range of floor temperature, or radiant temperature asymmetry. The assessment is based on **ISO 10551** [14] and **ISO 28802** [15]**,** which provide a reference evaluation method and post-occupancy surveys of indoor environments and user perceptions of comfort and well-being.

A comparison of the estimated and actual post-occupancy evaluation of satisfaction/dissatisfaction with the thermal environment is performed using the Predicted Percentage Dissatisfied (PPD), which shall be estimated based on **EN ISO 7730** [16] (for mechanically cooled buildings) or the acceptable summer indoor temperature range (for buildings without mechanical cooling).

The output of occupancy feedback is the worst category out of the three components' average category over the total building. Furthermore, the statistical distribution of categories, including all rooms in a building, should be presented. The category limits used for the IAQ, thermal comfort, and draught assessment scale originate from **EN 16798-1:2019** [17].

2.4.3.2 The structure of the feedback

The feedback survey has to follow the instructions in standards **ISO 10551 and ISO 28802.**

The occupancy feedback has to be a whole package that should include components in **Table 6** together with **physical measures, datetime, and room tag.** The air temperature is assumed to be close to the operative temperature. **Figure 13** is one possible example of the voting part of the feedback survey.

Table 6: The components of occupancy feedback about the indoor environment

Feedback component	Scale/answer	Physical measure
Questions about indoor environmental quality		
General thermal comfort occupants will experience now or during the past hour	+3 (Hot) ... -3 (Cold)	air temperature, humidity
The air quality occupant experiences now or during the past hour	1 Not smelly ... 4 very smelly	CO_2 level in ppm and PM2.5
The draught occupant experiences now or during the past hour	1 No draught ... 4 Strong draught	air temperature, humidity
An open question about specific sources of pollution or discomfort that negatively affect the perception of air quality or thermal comfort "now".	Open answer	---
A closed question about their general satisfaction with air quality and thermal environment, when only two answers are possible, one positive and one negative.	Satisfied Not satisfied	---
General questions		
Occupants have to mark the exact location that is under assessment during the feedback.	Mark the exact location on the room map	Three dimensions for measurement points of physical measures
Clothing	Select the clothing level you wear now (pictures)	x
Core activity	Select the activity level you have now (pictures)	x
Demographic information about the respondent	Age group Gender	x

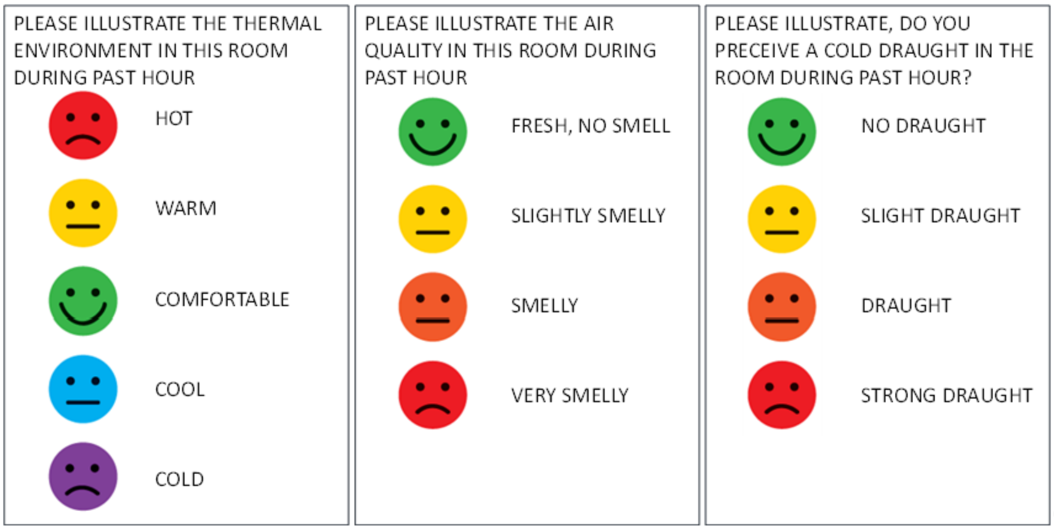


Figure 13: Example of the feedback questions for continuous survey

2.4.3.3 Data and Parameters for IEQ Analysis Survey

The survey has to be conducted by specialists in the field of human psychology and indoor comfort factors, who will decide upon the questions to ask about and which aspects to focus on.

The survey has to be sent out to all building or room occupants, and there should be a system established to obtain as high a response rate as possible – according to Level(s), at least 30% of the results to be considered representative.

The frequency of the survey should be:

- at least once in 5-year intervals, or
- after the renovation, or
- after the change in HVAC system control, or
- after the change of occupiers or the purpose of the use in a specific building part

According to ISO 10551, "the persons submitted to repeated application of the same judgement scales should be informed beforehand, in order to avoid undesired reactions and to present arguments justifying the application of the procedure."

The report about the results of the survey has to be delivered to the building manager, the building owner, and (preferably) the building occupants [2]. All feedback data should be stored so that each room and complaint can be analyzed separately.

The representative groups should be selected by specialists in indoor comfort factors considering the aspects that will influence IAQ. The feedback of each representative group needs to be analyzed separately. Possible representative groups are:

- The representative groups of people in the building (tenants, students, teachers, preschool children etc.)
- Occupants in the area with the same HVAC systems (with or without mechanical cooling and ventilation; with or without heating or cooling systems)
- Occupants in rooms with the same building façade (south and north façade feedback should be separated)

2.4.3.4 Physical measurements during the feedback

During the feedback, the physical measures mentioned in **Table 6** have to be measured and feasible to link with the feedback. For environments where people move around or for large groups of people, ISO 28802:2012 directs that a representative sample of spaces will be required to be measured (for example, in the school gym, there should be multiple measurement points).

2.4.3.5 Analysis of the survey results and final output

Thermal comfort feedback assessment should be done by calculating the weighted mean vote (WMV) with equation (10) for each representative group in the building. The example in **Table 7** shows that 4 people feel warm and 14 feel comfortable. Therefore, the MV = +0.43, and the thermal comfort feedback category is C. The mean vote should be calculated for each room and for each group mentioned in Section 2.2.4.3. The mean votes of the groups will be averaged over the building. The mean vote of each room will be later used for the statistical distribution.

$$MV = \frac{0\cdot \text{Ncomfortable} + 1.5\cdot(\text{Nwarm}+\text{Ncool}) + 3\cdot(\text{Nhot}+\ \text{Ncold})}{N_{total}} \quad (10)$$

where:

$N_{comfortable}$, N_{warm}, N_{cool}, N_{hot}, N_{cold} – number of people experienced specific thermal comfort sensations.

Table 7: Thermal comfort feedback assessment scale and answers for one representative group

Sensation	COLD	COOL	COMFORTABLE	WARM	HOT
Scale	-3	-1.5	0	+1.5	+3
No. of answers	0	0	10	4	0

Indoor air quality feedback assessment should be done by calculating the percentage of dissatisfied (PD_{IAQ}) with indoor air quality. The example in Table 8 shows that 2 out of 14 are dissatisfied with IAQ. Therefore, 14% are dissatisfied, and the IAQ feedback category is A. The PD_{IAQ} should be calculated for each room and for each group mentioned in sub-section 2.4.3.3. The PD_{IAQ} of the groups will be averaged over the building. The PD_{IAQ} of each room will be later used for the statistical distribution.

Table 8: Indoor air quality feedback assessment scale and answers for one representative group

Indoor air quality assessment	FRESH, NO SMELL	SLIGHTLY SMELLY	SMELLY	VERY SMELLY
Scale	0	1	2	3
No. of answers	12	2	0	0

Draught feedback assessment should be done by calculating the percentage of people to be bothered by any draught (PD_{DR}). The example in Table 9 shows that 4 out of 14 are bothered by draught. Therefore, 29% of people are dissatisfied, and the draught feedback category is G. The PD_{DR} should be calculated for each room and for each group mentioned in Table 9. The PD_{DR} of the groups will be averaged over the building. The PD_{DR} of each room will be later used for the statistical distribution.

Table 9: Draught feedback assessment scale and answers for one representative group

Draught level	NO DRAUGHT	SLIGHT DRAUGHT	DRAUGHT	STRONG DRAUGHT
Scale	0	1	2	3
No. of answers	10	4	0	0

The final category has to be the worst feedback category among these three sub-indicators presented in Table 10.

Table 10: The feedback categories are limited to three sub-indicators

Feedback category	Thermal comfort (mean vote in 5-point scale)	IAQ (percentage dissatisfied by indoor air quality)	Draught (percentage of people bothered by draught)
A	-0.2 ≤ (P)MV ≤+0.2	PD < 15%	PD < 10%
B	-0.35 ≤ (P)MV ≤ +0.35	PD < 17.5%	PD < 13.3%
C	-0.5 ≤ (P)MV ≤ +0.5	PD < 20%	PD < 16.7%
D	-0.6 ≤ (P)MV ≤ +0.6	PD < 25%	PD < 20%
E	-0.7 ≤ (P)MV ≤ +0.7	PD < 30%	PD < 23.3%
F	-0.85 ≤ (P)MV ≤ +0.85	PD < 35%	PD < 26.7%
G	-1.0 ≤ (P)MV ≤ +1.0	PD < 40%	PD < 30%
OUTSIDE	(P)MV > 1.0	PD > 40%	PD > 30%

2.4.3.6 Additional analysis and measurements

If the feedback category is outside the limits, then the feedback should be analyzed group or room based. Additional measurement and survey should be conducted by indoor environment specialists. This should be based on standards **ISO 10551 and ISO 28802.**

2.5 Measurement equipment specifications

Operational indoor air quality (IEQ) measurements involve the assessment of various physical quantities to ensure a satisfactory indoor environment. **Table 11** provides a list of the required physical quantities for conducting the assessment. The data measurement and logging interval is set at 15 minutes, which is considered optimal for balancing data density, analysis, and post-processing, while still providing valuable information compared to shorter logging intervals.

To streamline the measurement process, it is recommended to use a single Internet of Things (IoT) device that can measure multiple parameters simultaneously. This approach simplifies data collection and reduces the number of devices required. For example, an IoT device with capabilities to measure air temperature, relative humidity, CO_2 concentration, and fine particulate matter (PM2.5) would be ideal for capturing key indicators of indoor air quality.

One critical aspect in assessing IEQ is occupancy detection, as it significantly influences the overall evaluation. While standardized building use and occupancy profiles are commonly used for energy efficiency assessments, they may not accurately reflect the actual room utilization and occupancy patterns. Therefore, relying solely on such profiles can lead to misleading results in IEQ assessments. It is important to account for variations in room utilization during different times of the day or week.

To address this issue, there are two possible approaches. First, occupancy and occupancy levels can be inferred using methods developed in T4.2, which focuses on monitoring the dynamic behaviour of buildings in terms of both energy and non-energy aspects. By analysing energy consumption patterns, lighting usage, or other relevant factors, it may be possible to estimate the presence and level of occupancy indirectly.

Alternatively, occupancy sensors can be installed in the rooms being assessed. This ensures a more accurate and direct measurement of occupancy, as well as the associated IEQ conditions. However, it is important to consider privacy and data protection laws when implementing occupancy sensors to avoid infringing on individuals' rights.

The specific devices to be used for IEQ measurements will be determined during the pilot planning, preparation, and methodology demonstration in WP6. At that stage, the overall data structure, formats, and exchange procedures will have been specified, enabling the selection of appropriate devices and ensuring compatibility with the data management system being employed.

Table 11: Measured equipment details.

Measured quantity	Unit	Logging interval	Network protocol
Room air temperature	°C	15 minutes	tbd
Room air relative humidity	%	15 minutes	tbd
Room air CO_2 volumetric concentration	ppm	15 minutes	tbd
Room air PM2.5	µg/m3	15 minutes	tbd
Outdoor air temperature	°C	15 minutes	tbd
Outdoor air relative humidity	%	15 minutes	tbd
Outdoor air CO_2 volumetric concentration	ppm	15 minutes	tbd
Outdoor air PM2.5	µg/m3	15 minutes	tbd
Ventilation volumetric air flow rate (if measured, no need to measure the number of occupants) *In CAV system, design air flow rate may be used instead. System status to be monitored or inferred from CO_2 level readings.	L/s	15 minutes	tbd
Room occupancy (presence sensor)	Binary	15 minutes	tbd
Number of occupants (only in the case if no ventilation rate measurement)	person	15 minutes	tbd
Occupant feedback questionnaire	Categoric scale	When prompted/on user demand	tbd

2.6 Classification scale and categories

The output of all indicators'' assessment has to be classified on the same scale. One possible example is described in **Figure 14** – the example with IEQ categories. Standards four categories will change to seven (like in the EPC assessment) to unify the SmartLivingEPC operational rating.

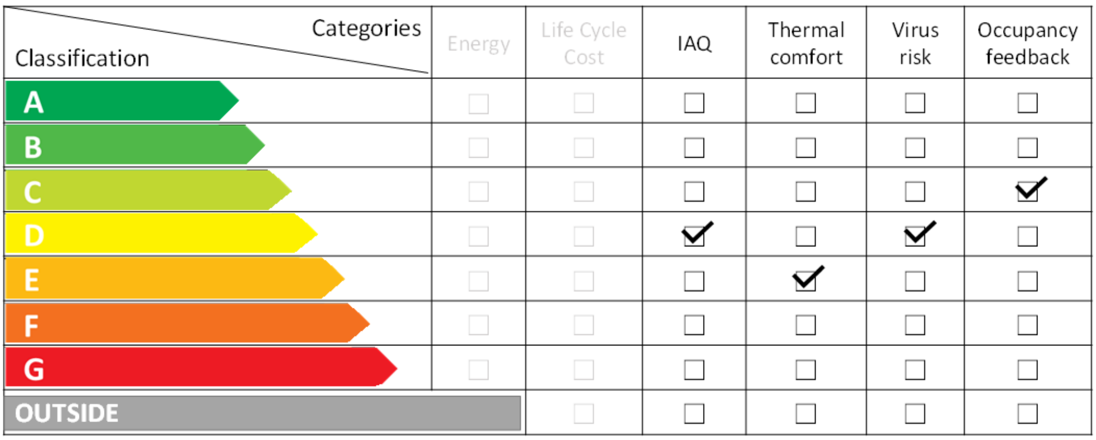


Figure 14: Proposed combined label for SmartLivingEPC operational rating indicators

3 Operational Level Energy Analysis and Integration to SmartLivingEPC

3.1 Documentation of Current Practices for Operational Rating across Europe

3.1.1 Introduction

This section comprises the required information for an operational rating in thirteen EU countries' energy performance certificates to enable the documentation of the status of the operational rating procedures in European member states, which will be done under T3.2. The purpose of this section is to offer input on the following aspects of the operational rating:

1. How is the delivered energy measured
2. How is the rating performed (reference building or average building stock performance)
3. What indicators are delivered (building or building use)
4. What utility types are measured (H, C, DHW, V, L)
5. Normalization practices (weather, occupancy, level of services)
6. Time span of measurements and duration of the certificate
7. Measurement practices – equipment, minimum requirements
8. Relation of operational with asset rating (if any)
9. For what building categories is this operational assessment utilized

3.1.2 Slovenia

The content and the methodology for commissioning the energy performance certificates in Slovenia are described in the Official Gazette of the Republic of Slovenia, No. 92/14, 47/19 and 158/20 – ZURE: "Rules on the methodology for the construction and issue of energy performance certificates of buildings" [18].

In the Slovenian regulation, there are two types of energy performance certificates.

- The calculated energy performance certificate is issued for newly built buildings and newly built parts of buildings, existing residential buildings, and dwellings.
- The measured energy performance certificate is issued for existing non-residential buildings or non-residential parts of buildings. A metered EPC rating is the first choice and is also simpler and at a lower cost [19]. However, if the independent expert estimates that the data on actual energy use is not reliable, a calculated instead of the measured energy performance certificate is issued.

3.1.2.1 How is the delivered energy measured?

The measured energy performance certificate should be based on energy use measurements. Energy consumption values should be available or measured for the last three completed calendar years before the year of commissioning of the energy performance certificate in accordance with the SIST EN 15603. If data on energy consumed for the last three years is not available, the data should be at least for the last two or the last completed calendar year preceding the year of delivering the certificate. Energy consumption data shall be determined through energy bills or other records issued from individual energy products.

3.1.2.2 How is the rating performed?

The minimum requirement of a near-zero-energy building is the reference value of annual primary energy for the operation of building Qp (kWh/a), which is set out in the action plan for almost zero-energy buildings for each year. The average energy use of a reference building is the benchmark calculated based on the average energy use values derived from data from the Register of EPCs for buildings built in the last ten years.

3.1.2.3 What indicators are delivered?

The energy indicators used for the measured energy performance certificate are described in Article 5 of the Slovenian Regulation as follows:

- annual final energy for heating per unit of conditioned area (kWh/(m^2a)),
- annual electricity consumption per unit of conditioned area (kWh/(m^2a)),
- annual primary energy for the operation of a building per unit of conditioned building area (kWh/(m^2a)),
- annual CO_2 emissions from the operation of the building per unit of conditioned area of the building Ak (kg/(m^2a)).

3.1.2.4 What utility types are measured?

According to PURES 2010, system energy efficiency is achieved by selecting products that fulfill the energy efficiency requirements, with corresponding design and construction rules for sub-systems. The regulation has imposed system performance requirements via many rules on product and sub-system energy efficiency. The rules address the heating, ventilation, cooling, AC, and lighting sub-systems and the energy efficiency of products [20].

3.1.2.5 Normalization practices

The energy performance certificate is introduced in the form of a continuous scale. All indicators are presented as specific values, commonly per square meter of useful area and year. Energy efficiency indicators are based on physical quantities, such as specific energy needs for heating, specific final energy for the operation of the buildings, specific primary energy needed for the operation of the buildings, or expressed as ratings (0–100). In this case, the rating of a reference building or potential rating after implementing proposed energy efficiency measures is presented [21].

3.1.2.6 Time span of measurements and duration of the certificate?

The energy performance certificate is valid for ten years.

3.1.2.7 Measurement practices – equipment, minimum requirements?

An independent expert responsible for the commission of the energy performance certificate should consider the information on the construction of the building, photo-documentation, the building log, and measurement of the energy performance of the building and systems (e.g., thermo-surface inspection of the building, measurements of the air tightness, measurement of the characteristics of energy installations and systems in the building). The minimum requirement is the annual heat required benchmark for heating QNH (kWh/a) and is laid down in the Regulation governing energy efficiency in buildings for each year.

3.1.2.8 Relation of operational with asset rating?

Not any relation.

Figure 15: Slovenia Operational EPC first and second page [1]

3.1.2.9 For what building categories this operational assessment is utilized?

The two types of energy performance certificates assess different building categories. The calculated energy performance certificate is issued for newly built buildings and newly built parts of buildings, existing residential buildings, and dwellings. The measured energy performance certificate is issued for existing non-residential buildings or non-residential parts of buildings.

3.1.3 Ireland

The Display Energy Certificate (DEC) system is used in Ireland to calculate a building's energy rating. The DEC is a building operational performance indicator that measures the yearly primary energy consumption associated with building operation as a percentage of a value considered typical for the particular kind of building. The DEC certificate also includes a performance indicator for carbon dioxide emissions. This is calculated by comparing the yearly carbon dioxide emissions per unit of building area caused by energy use to a number considered average for the type of building.

3.1.3.1 How is the delivered energy measured?

The user guide covers the technique for calculating a display energy certificate (DEC). This is the official Irish method for determining and evaluating the energy performance of public buildings [22].
The methodology necessitates determining:

- Building Category
- Location of Building (Building Name, Address)
- Basic Technical Characteristics of the building
- Separable Energy uses if any.
- Total Useful Floor Area of the building (and how it has been obtained) or other allowed area metric, including Total Useful Floor Area attributable to each benchmark category and to separable energy use (where exists)
- Recorded hours of occupancy
- Energy consumption (meter readings or suppliers estimates) and measurement period.
- Results of previous DEC assessments, where they exist.

3.1.3.2 How is the rating performed?

The operating energy consumption is compared to Benchmarks for similar Building Categories/Types. There are 29 different categories of reference buildings specified. The number of distinct building types is entered when a building has a mix of applications that would place sections of the building in different benchmark categories. A maximum of five construction types are permitted (results are normalized by useful floor area).

3.1.3.3 What indicators are delivered?

An operational BER for the building, given as a grade on a subdivided A-G scale, represents the equivalent primary energy consumption per unit floor space as a percentage of a value considered normal for the particular kind of structure.

- A primary energy indicator expressed in terms of primary energy use per unit floor area.
- A subsidiary CO2 performance indicator shown as a position on a linear scale representing the annual CO2 emission per unit of area of the building caused by its consumption of energy as a percentage of a value that would be considered typical for the building) together with a numerical indicator of the CO2 emissions of the building.
- Histograms of trends in energy and CO2 performance in up to three most recent years.
- A Building identifier, e.g., name, address. This should be sufficient to uniquely identify the building.
- Basic building technical information, e.g., building type, floor area, main heating fuel, main heating/cooling type, sufficient to assist in understanding of the more detailed information contained on the certificate;
- A unique DEC number is provided by SEAI.
- Period of validity of the certificate. This commences on a Nominated date chosen by SEAI. The period is 365 days. For other than the first DEC for a building, there should be no gap from the period covered by the previous DEC, but there may be an overlap of up to 90 days where this facilitates the preparation of the DEC taking account of the fuel measurement system and consumption data available.
- Unique assessor number. Each assessor is assigned a unique assessor number.
- Primary electrical and heating energy per unit floor area for the building being assessed and for the relevant benchmark building type. For the building, this is the net primary energy figure, excluding separable energy and any renewable energy generated on-site, derived for the assessment period of 365 days.

3.1.3.4 What utility types are measured?

The calculation needs the user to specify whether the primary heating fuel is metered or estimated by the utility (Mains Gas, LPG, Heating oil Coal Anthracite, Smokeless fuel (inc. Coke), Biomass, Dual fuel appliances (mineral + wood), Electricity District Cooling District Heating).

3.1.3.5 Normalization practices

The calculation [23] relies on operational energy consumption within the building, taking into consideration a variety of criteria that are used to normalize energy use. The operating energy consumption is compared to Benchmarks for comparable Building Categories/Types. The energy assessor picks the suitable benchmark category related to the building usage from a list of 29 Building Categories. If a building has numerous uses, up to five building types can be assigned to it. These are weighted according to useable floor space. Furthermore, the usable floor area may be weighted based on the area needed for various functions: General office, General retail, large non-food store, small food store, and large food store.

The effect of weather volatility is mitigated by normalizing heating energy demand versus heating degree days. The heating-degree days recorded during the measurement period are compared to those recorded by the nearest meteorological station during the same time period. Ireland is served by eight weather stations. The number of hours of occupancy is also used to normalize. The standard occupancy is determined by the building category. Alternatively, "Extended Hours" may be chosen if the energy assessor can demonstrate that the building is inhabited for considerably longer times than the typical hours specified for the benchmark category, and the benchmark information allows for adjustment for extended hours of usage.

3.1.3.6 Time span of measurements and duration of the certificate?

The primary measurement limitation is a yearly measurement of heating energy. The Main Heating Fuel Measurement Period must be 365 days +/- 31 days to be considered in the computation. All additional energy measurement periods (i.e., for other energy types/end uses) must have start and end dates that are within +/- 31 days of the assessment period. The certificate duration is 365 days from the Nominated Issue Date of the DEC. The Nominated Issue Date of the DEC must be within 180 days of the end of the assessment period.

3.1.3.7 Measurement practices – equipment, minimum requirements?

In general, an accurate reading of fuel and electricity use should be obtained once a year. The date of meter reading or other methods of measurement should be documented if it differs from the proper yearly date. The energy assessor will choose measurements with as close start and finish dates as feasible throughout 365 days and compute consumption based on the difference between readings. The consumption and dates are entered into the program, and the usage is adjusted to 365 days. If the measurement time falls beyond the limitations specified in Section 3.3 and Appendix 1 [5], the program will default to the lowest operational rating grade, G.

Utility bills are another valid source of energy use data. These may include approximations, which may be utilized if no other source of exact readings is available. When using estimates, energy assessors must state that the data entered into the program is an estimate. After the first year, there should be no necessity to employ approximated readings because the demand for readings will be completely understood. Only estimates from utility providers are permitted.

3.1.3.8 Relation of operational with asset rating?

Not any relation.

3.1.3.9 For what building categories this operational assessment is utilized?

Operational ratings are only applied to large public buildings and large private sector buildings, which are frequently visited by the public. Such buildings are required to publicly display their energy performance via a DEC. A large building is defined as one having a useful floor area of more than 500m^2. Note that display energy certificates do not apply to dwellings subject to an asset rating EPC, called a building energy rating (BER).

The 29 building categories addressed are:

1. General office
2. High street agency
3. General retail
4. Large non-food shop
5. Small food shop
6. Large food shop
7. Restaurant
8. Bar, pub, or licensed club
9. Hotel
10. Cultural activities Museum, art gallery, or other public building
11. Entertainment halls
12. Swimming pool center
13. Fitness and health center
14. Dry sports and leisure facility
15. Covered car park.
16. Public buildings with light usage
17. Schools and seasonal public buildings
18. University campus
19. Clinic Health centers
20. Hospital — clinical and research
21. Long term residential
22. General accommodation
23. Emergency services
24. Laboratory or operating theatre
25. Public waiting or circulation
26. Terminal Regional transport terminal with concourse
27. Workshop
28. Storage facility
29. Cold storage

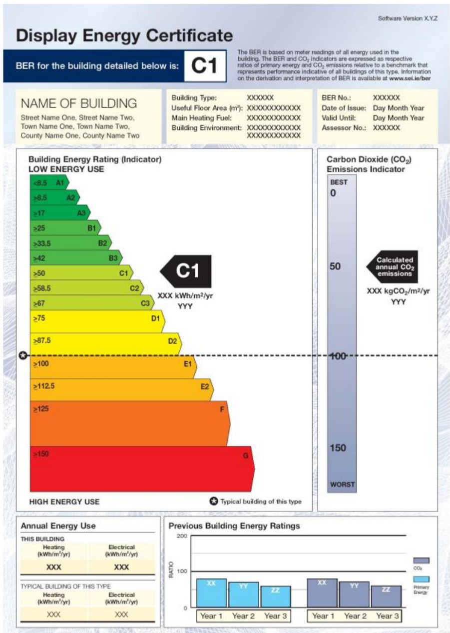


Figure 16: Draft Irish DEC

3.1.4 Denmark

The initial Danish energy certification scheme was established in 1997 and consisted of two parts resulting in three different databases. Part I: Small buildings and owner-occupied flats that should have been approved before being sold. Part 2: Large buildings (> 1.500 square meters (m2)). As a result of the EPBD, the Danish certification method was revised in 2006. Denmark's EPC laws were revised in 2011 to allow measured performance to inform the EPC for most large building types. According to reports, compliance is high for big commercial structures.

3.1.4.1 How is the delivered energy measured?

Figure 17 shows the approaches that have been used in Denmark for energy certification. The asset rating and the operational rating.

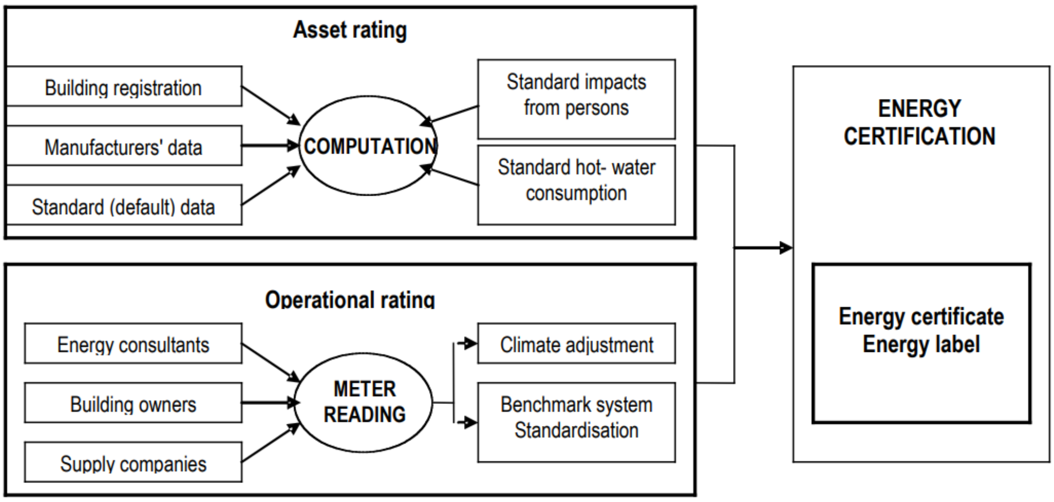


Figure 17: Approaches for energy certification

3.1.4.2 How is the rating performed?

Meter readings for the operational rating, as shown in **Figure 17**, are based on information from energy consultants, building owners, and supply companies. To qualify for certification based on real consumption, the operational record must include monthly readings of energy usage for at least a year.

3.1.4.3 What indicators are delivered?

The procedure's end results are the Energy Certificate and label.

3.1.4.4 What utility types are measured?

The energy label determines the energy consumption for heat, domestic hot water, cooling, ventilation, and lighting, as well as the energy consumption of other technical installations, apparatus, etc.

3.1.4.5 Normalization practices

Following the collection of data, a procedure of normalizing in terms of climate adjustment and benchmark system standardization occurs.

3.1.4.6 Time span of measurements and duration of the certificate?

Not specified.

3.1.4.7 Measurement practices – equipment, minimum requirements?

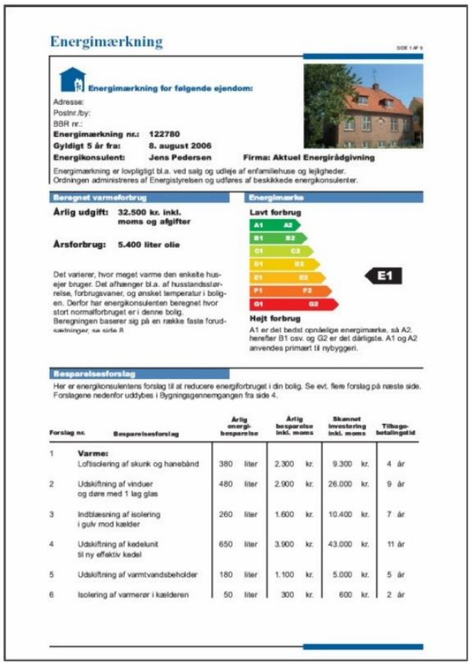
Unknown.

3.1.4.8 Relation of operational with asset rating?

Not any relation.

3.1.4.9 For what building categories this operational assessment is utilized?

While implementing the European EPBD, Denmark chose to apply asset rating (or computed data) to all building types, new and old. The current Danish energy certification process, which has been in existence since 2006, is divided into two parts (small buildings < 1.000 m2 and big buildings > 1.000 m2), but both are certified using estimated energy performance rather than a measured net energy rating.



Energimærkning

Energimærkning for følgende ejendom:

Adresse:
Postnr./by:
BBR nr.:
Energimærkning nr.: 122780
Gyldigt 5 år fra: 8. august 2006
Energikonsulent: Jens Pedersen **Firma:** Aktuel Energirådgivning

Energimærkning er lovpligtigt bl.a. ved salg og udleje af enfamiliehuse og lejligheder.
Ordningen administreres af Energistyrelsen og udføres af beskikkede energikonsulenter.

Beregnet varmeforbrug

Årlig udgift: 32.500 kr. inkl. moms og afgifter

Årsforbrug: 5.400 liter olie

Det varierer, hvor meget varme den enkelte husejer bruger. Det afhænger bl.a. af husstandsstørrelse, forbrugsvaner, og ønsket temperatur i boligen. Derfor har energikonsulenten beregnet hvor stort normalforbruget er i denne bolig. Beregningen baserer sig på en række faste forudsætninger, se side 8.

Energimærke

Lavt forbrug

A1 A2
B1 B2
C1 C2
D1 D2
E1 E2
F1 F2
G1 G2

E1

Højt forbrug

A1 er det bedst opnåelige energimærke, så A2, herefter B1 osv. og G2 er det dårligste. A1 og A2 anvendes primært til nybyggeri.

Besparelsesforslag

Her er energikonsulentens forslag til at reducere energiforbruget i din bolig. Se evt. flere forslag på næste side. Forslagene nedenfor uddybes i Bygningsgennemgangen fra side 4.

Forslag nr.	Besparelsesforslag	Årlig energibesparelse	Årlig besparelse inkl. moms	Skønnet investering inkl. moms	Tilbagebetalingstid
1	**Varme:** Loftisolering af skunk og hanebånd	380 liter	2.300 kr.	9.300 kr.	4 år
2	Udskiftning af vinduer og døre med 1 lag glas	480 liter	2.900 kr.	26.000 kr.	9 år
3	Indblæsning af isolering i gulv mod kælder	260 liter	1.600 kr.	10.400 kr.	7 år
4	Udskiftning af kedelunit til ny effektiv kedel	650 liter	3.900 kr.	43.000 kr.	11 år
5	Udskiftning af varmtvandsbeholder	180 liter	1.100 kr.	5.000 kr.	5 år
6	Isolering af varmerør i kælderen	50 liter	300 kr.	600 kr.	2 år

Figure 18: Example of Danish EPC [BuildingRating.org]

3.1.5 Poland

The EPB standards from CEN are not officially utilized in this country.

3.1.5.1 How is the delivered energy measured?

The energy measured is delivered through the heat meters (District heating), gas meters (gas boiler/boilers), central heat meters or HCA in locals/flats and water meters.

3.1.5.2 How is the rating performed?

Calculations are performed for each building, and then the maximum level for each building type is determined example. EP maximum for a single family is 70 kWh/m2/year; multifamily is 65; the public building is 45; hospital or medical center is 190.

3.1.5.3 What indicators are delivered?

The focus is on asset EP, but there is also an option for existing buildings to generate EPCs based on real measurements, so operational assessments are also available, provided we have at least three years of energy consumption data.

3.1.5.4 What utility types are measured?

All should be measured; lighting and cooling (mostly powered by electricity) are sometimes not separated; H and DHW are occasionally not separated as well.

3.1.5.5 Normalization practices

In EPC calculations, the standard weather conditions in the building's specific location are considered, as well as the interior heat gain depending on occupancy and the efficiency of individual H, DHW, and C systems.

3.1.5.6 Time span of measurements and duration of the certificate?

EPCs are valid for ten years; real methods need archival (minimum three-year) energy consumption values for specific buildings.

3.1.5.7 Measurement practices – equipment, minimum requirements?

Heat meters are used to measure the temperature. Heat meters (preferred), but also HCA, are used in flats, while water meters are used for DHW.

3.1.5.8 Relation of operational with asset rating?

No, according to EPC no. The procedure is chosen by the auditor (asset or operational).

3.1.5.9 For what building categories this operational assessment is utilized?

It is achievable for all categories if the auditor has access to the necessary data.

3.1.6 Czech Republic

The EPB standards from CEN are officially utilized in this country, having been incorporated indirectly to national rules and standards.

3.1.6.1 How is the delivered energy measured?

The energy measured is delivered through the Gas meter, electric meter, and heat (calorimetric).

3.1.6.2 How is the rating performed?

A reference building is used to set up reference values; it has the same shape and function as a normal building but contains reference values for building structures and building technical systems. As a result, all construction categories are covered.

3.1.6.3 What indicators are delivered?

The procedure's end results are the Energy Certificate and label.

3.1.6.4 What utility types are measured?

Depending on the building, it is usually merely heat/electricity production/use in the event of various owners submetering, but not utilities.

3.1.6.5 Normalization practices

A standard normalization of weather and operation.

3.1.6.6 Time span of measurements and duration of the certificate?

EPB certificates do not need measurements. The EPB accreditation is valid for ten years or until the building is renovated.

3.1.6.7 Measurement practices – equipment, minimum requirements?

A broad response is not available, so the answer is unknown.

3.1.6.8 Relation of operational with asset rating?

Not any relation.

3.1.6.9 For what building categories this operational assessment is utilized?

For new buildings, deliver energy, primary energy from non-renewable sources, and average U value. For renovations, a collection of indications is based on the scope of the work.

3.1.7 Sweden

The EPB standards from CEN are partially officially utilized in this country.

3.1.7.1 How is the delivered energy measured?

The measured energy consumption is processed and distributed into energy for heating, domestic hot water, property energy, and any comfort cooling, which is further subdivided into electrical energy, district heating, district cooling, biofuel, fossil oil, and fossil gas.

3.1.7.2 How is the rating performed?

Building by building in comparison to the current Swedish National Board of Housing, Building, and Planning standards on maximum energy usage in various types of buildings, which are continuously revised. The energy consumption requirement that would apply when constructing a new building of the same kind is given as the primary energy number of the building.

3.1.7.3 What indicators are delivered?

Energy performance is now given in primary energy numbers rather than specific energy use as of January 1, 2019. The primary energy number is used to assess the energy performance of a structure. On July 1, 2017, it was incorporated into the Housing Authority's building rules.

3.1.7.4 What utility types are measured?

Energy use for heating, comfort cooling, domestic hot water, and the building's property electricity.

3.1.7.5 Normalization practices

The energy usage for domestic hot water, actual historical indoor temperatures, and internal loads must all be considered when adjusting the energy use to what it would be under normal use. After that, a typical year adjustment of climate-dependent energy usage is performed. These two steps, taken together, comprise the genuine normalization of energy usage.

3.1.7.6 Time span of measurements and duration of the certificate?

A 10-year energy declaration is valid. Private homeowners (villas and townhouses not owned by a condominium association) are exempt from subsequent EP certification until the building is sold.

3.1.7.7 Measurement practices – equipment, minimum requirements?

Specific measurement protocols are prescribed for different types of measurements.

3.1.7.8 Relation of operational with asset rating?

The energy consumption of a building is often assessed via measurement (but verification by calculation is possible in specific cases).

3.1.7.9 For what building categories this operational assessment is utilized?

EP certification of buildings is required in four main situations:

1. Newly constructed buildings.
2. When the floor area of the building is greater than 250 square meters and is frequently visited by the public.
3. When buildings are pleased with the right of use.
4. When buildings are sold.

Some buildings are not covered by the requirement for an energy declaration. Buildings that are not heated to more than ten degrees, for example, do not need an energy declaration. There are also general exceptions to the requirement to declare energy for certain buildings.

3.1.8 Latvia

In Latvia, metered energy data may be used to generate EPCs. The legislation allows for it to be based on calculated or measured data; thus, it is up to the building owner to choose which approach to utilize. However, the procedure is not completely documented, and there is no clear direction on employed data quality, weather normalization, and so on. Energy usage for heating and non-renewable primary energy consumption are both reported in measured energy data-based EPCs.

3.1.8.1 How is the delivered energy measured?

Metered energy data may be used for the generation of EPCs.

3.1.8.2 How is the rating performed?

There are two types of energy efficiency: energy required for heating and total primary energy for all building systems. The NZEB building should be A-class in terms of both heating energy and total primary energy.

The monthly energy calculation approach for residential (single and multi-family) buildings and the employed dynamic method for office buildings is proposed by general guidance. Overheating should be calculated on an hourly basis. If the energy consumption for cooling (calculated of "assumed values") is applied, no overheating calculation is required.

3.1.8.3 What indicators are delivered?

Heating and total primary energy.

3.1.8.4 What utility types are measured?

Unknown.

3.1.8.5 Normalization practices

The technique is not fully described, and there is no clear direction on data quality, weather normalization, and other issues.

3.1.8.6 Time span of measurements and duration of the certificate?

Unknown.

3.1.8.7 Measurement practices – equipment, minimum requirements?

The minimum allowed reference levels of heating consumption (kWh / m2) for newly designed and existing buildings are shown in **Table 12**.

Currently, NZEB buildings' definition also considers primary energy. The latest revision of Latvian legislation has replaced the total primary energy factor with the non-renewable energy factor. The minimum allowed level of non-renewable primary energy consumption is shown in **Table 13**. Non-renewable primary energy covers the EPBD scope, including lighting in residential buildings.

Table 12: Minimum reference level of energy consumption for heating

Energy performance class of buildings	Residential buildings and non-residential buildings		Residential buildings	Non-residential buildings	
	heated area, m²				
	from 50 to 120	from 120 to 250	> 250		
			Single-family houses, apartment buildings, cohabitation houses of different social groups, residential buildings for public use	Office buildings, educational buildings, hotels, restaurants, sports facilities, wholesale, and retail buildings	Hospitals
A+ NZEB	≤ 35	≤ 35	≤ 30	≤ 35	≤ 40
A NZEB	≤ 60	≤ 50	≤ 40	≤ 45	≤ 50
B	≤ 75	≤ 65	≤ 60	≤ 65	≤ 70
C	≤ 95	≤ 90	≤ 80	≤ 90	≤ 100
D	≤ 150	≤ 130	≤ 100	≤ 110	≤ 120
E	≤ 180	≤ 150	≤ 125	≤ 150	≤ 160
F	> 180	> 150	> 125	> 150	> 160

Table 13: Minimum level of non-renewable primary energy consumption for residential buildings

Energy performance class of buildings	Residential buildings		Single-family houses, apartment buildings, cohabitation houses of different social groups, collaborative housing
	heated area, m²		
	from 50 to 120	from 120 to 250	> 250
A+ NZEB	≤ 65	≤ 65	≤ 65
A NZEB	≤ 110	≤ 100	≤ 95
B	≤ 140	≤ 130	≤ 125
C	≤ 160	≤ 155	≤ 145
D	≤ 200	≤ 190	≤ 165
E	≤ 230	≤ 210	≤ 180
F	≤ 260	≤ 260	≤ 220
G	> 260	> 260	> 220

Table 14: Minimum level of non-renewable primary energy consumption for non-residential buildings

Energy performance class of buildings	Offices, educational institutions, sports facilities	Hospitals, hotels, restaurants	Wholesale and retail buildings
A+ NZEB	≤ 90	≤ 130	≤ 120
A NZEB	≤ 110	≤ 170	≤ 150
B	≤ 160	≤ 240	≤ 190
C	≤ 210	≤ 280	≤ 215
D	≤ 250	≤ 320	≤ 230
E	≤ 300	≤ 380	≤ 300

F	≤ 400	≤ 450	≤ 400
G	virs 400	virs 450	virs 400

3.1.8.8 Relation of operational with asset rating?

The legislation allows for it to be based on calculated or measured data; thus, it is up to the building owner to choose which approach to utilize.

3.1.8.9 For what building categories this operational assessment is utilized?

For all building categories.

3.1.9 Estonia

In Estonia, the energy efficiency requirements for buildings are established by the maximum allowed primary energy (PE) usage, such that the minimum requirements and energy performance certificate utilize the same approach specified in the national legislation [24]. The energy performance of a building is reported as an Energy Performance Indicator (EPI) value in kWh/ (m^2 a), and the permissible EPI value limit varies depending on the building type. The EPI number includes the energy used for space heating, cooling, DHW generation, lighting, appliances, and auxiliary equipment such as fans and pumps. Because all usual energy needs are included in these energy uses, estimated and measured energy usage are similar. When determining the EPI value, exported energy is not included.

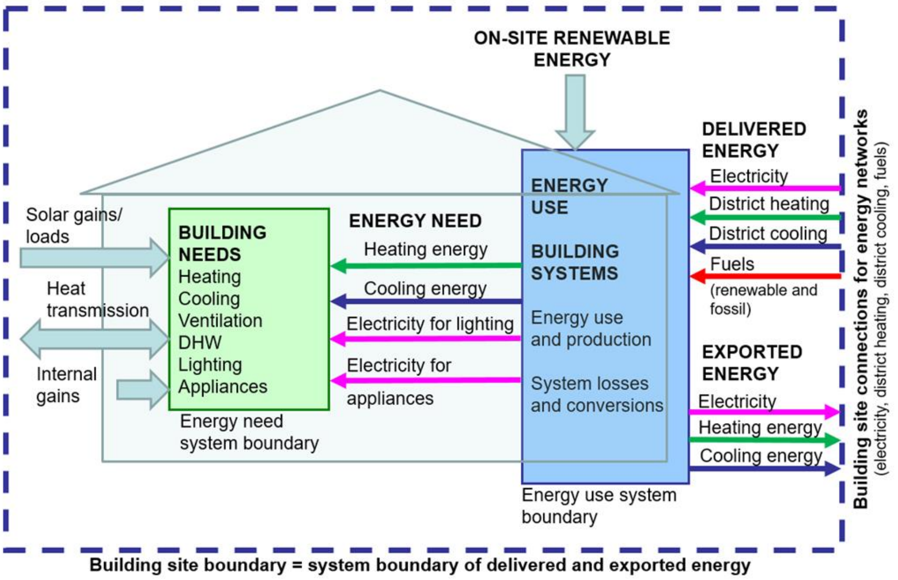


Figure 19: System boundaries for energy need, energy use, delivered energy, exported energy, and on-site generated renewable energy [26]

3.1.9.1 How is the delivered energy measured?

The EPC of an existing building may be calculated using data from the main energy meters (grid electricity, district heating and cooling, gas, etc.) and solid fuels. If such energy meters are not installed, the EPC will be computed using the values from the main energy meters. There are regulations for new buildings that require distinct energy uses to be monitored. However, in existing structures, just the primary meters are frequently present.

3.1.9.2 How is the rating performed?

The EPI value calculation adheres to the system boundaries defined by REHVA's definition [25], wherein solely the on-site generated renewable energy utilized for self-consumption and other on-site purposes is taken into account while being subtracted from the overall energy consumption [26]. When determining the EPI value, exported energy is not included. **Figure 19** depicts the system boundaries.

3.1.9.3 What indicators are delivered?

The energy performance of a building is expressed as an Energy Performance Indicator (EPI) value in kWh/ (m^2 a), and the allowed EPI value limit varies depending on the building type.

3.1.9.4 What utility types are measured?

The energy needed for space heating, cooling, DHW generation, lighting, appliances, and auxiliary equipment such as fans and pumps is included.

3.1.9.5 Normalization practices

Weather-dependent heating energy must be normalized with the degree day method in the EPC calculation based on metered energy data. The energy performance certificate regulation [27] offers some guidelines on how to estimate weather-dependent heating if separate energy meters are not available. No normalization for operation hours or occupancy does not follow the standard use of the building. Energy data used in the EPC calculation must be at least one full year, but using the data from the last three years is recommended if available. EPC calculation is on annual bases, including weather normalization with annual (not monthly) degree days.

3.1.9.6 Time span of measurements and duration of the certificate?

The calculated EPC for a new building/major renovation is valid for two years after construction, after which it must be updated to the metered energy consumption-based EPC of an existing building, which is necessary when buildings are sold or rented. The existing building EPC is valid for ten (10) years.

3.1.9.7 Measurement practices – equipment, minimum requirements?

The EPI value is resulted from delivered energy (= the net purchased energy) multiplied by the relevant primary energy factors (f). The calculation for delivered energy is based on hourly time step data (except for simplified calculations available for detached houses). The national requirements for nZEB building and primary energy factors are shown in **Table 15** and **Table 16**.

Table 15: Maximal primary energy requirements for different building types, according to national regulations [24]

Building type	EPI value requirement, kWh/(m² a)			
	NZEB (EPC class A)	**NZEB (EPBD scope)**	**Low energy building (EPC class B)**	**Renovation of existing building (EPC class C)**
Small residential buildings (detached house, row house): a) net heated area <120 m² b) net heated area 120-220 m² and row house c) net heated area >220 m²	 145 120 100	 89.4 73.4 59.5	 165 140 120	 185 160 140
Multi-apartment buildings	105	45.9	125	150
Military barracks	170	85.9	200	250
Office buildings, libraries, and research buildings	100	62.1	130	160
Accommodation building, hotel	145	138	170	220
Commercial buildings	130	118	150	210
Public buildings	135	135	160	220
Commerce buildings and terminals	160	154	190	230
Educational buildings	100	82.6	120	160
Pre-school institutions for children	100	90	120	165
Healthcare buildings	100	83.7	130	170
Warehouse	65	65	80	100
Industrial building	110	68.7	140	170
Buildings with high energy use (process energy)	820	-	850	950

Table 16: Primary energy factors (f) according to Estonian regulation [24]

Energy carrier	f
Electricity	2.0
District heating*	0.9
Efficient district heating	0.65
District cooling**	0.4
Efficient district cooling	0.2
Natural gas, oil, coal, peat, solid fossil fuel	1.0
Wood, biofuel	0.65

3.1.9.8 Relation of operational with asset rating?

The calculation methodology includes the following factors that are used both for minimum requirements and EPCs [18]:

- Thermal transmittance of building envelopes, linear and point thermal transmittance of thermal bridges, and air leakage.
- Indoor air temperature
- DHW demand
- Ventilation
- Thermal loads from occupants, lights, appliances, hot water, and solar heat
- Thermal and electrical energy used for spaces heating, ventilation heating, DHW system
- Electricity use for ventilation system (fan and pump), lighting, equipment
- On-site energy generation: with photovoltaic (PV) panels, solar thermal collectors, wind
- Heat recovery from wastewater and/or ventilation.

The EPI value is calculated according to the following equation [7]:

$$\mathrm{EPI} = \frac{f_{DH.PF}\, Q_{DH} + \sum_i f_{F.PF}\, Q_F + f_{E.PF}\, Q_E}{A_{net}} \qquad (21)$$

where:

f_(DH.PF) is the primary energy factor for district heating, dimensionless

Q_DH is the annual delivered district heating energy, kWh/a

f_(F.PF) is the primary energy factor for fuel, dimensionless

Q_F is the annual delivered fuel (all fuels are treated as delivered energy), kWh/a

f_(E.PF) is the primary energy factor for electricity, dimensionless

Q_E is the annual delivered electricity, kWh/a

A_net is the net heated building area, m2. The calculation method is provided in the regulation [26].

3.1.9.9 For what building categories this operational assessment is utilized?

Standard use definition for building categories:

- Small residential buildings (detached house) net heated area <120 m2
- Small residential buildings (detached house, row house) net heated area 120-220 m2
- Small residential buildings (detached house) net heated area >220 m2
- Apartment building
- Military barracks
- Office building, library, and science building
- Accommodation building, hotel
- Commercial building
- Public building

- Commerce building and terminal
- Educational buildings
- Day-care center, pre-school institution for children
- Health care facility
- Industrial building
- Warehouse

3.1.10 Italy

An energy audit is a method that may be conducted on any type of building to find improvement measures that can be utilized to reduce the building's consumption. The goal of a diagnostic is to prioritize the simulated interventions, optimize the cost-benefit ratio, and select the most cost-effective interventions.

Building energy audit is a need in many circumstances, in addition to being one of the most common simulations in the energy analysis landscape.

If the EPC in Italy offers a snapshot and describes the energy efficiency of one building in comparison to another, the diagnostic allows us to know how much fuel is used as a function of the real climate, occupancy, and usage of the building's rooms.

3.1.10.1 How is the delivered energy measured?

The energy measured delivered through the:

- Energy bills.
- Meter readings.
- Statistical market data.
- Semi-empirical estimates.

3.1.10.2 How is the rating performed?

A licensed professional can prepare this type of energy diagnosis, thus simply registering in a professional register.

3.1.10.3 What indicators are delivered?

The goal of this diagnostic is to prioritize the simulated interventions, maximize the cost-benefit ratio, and select the most cost-effective interventions.

3.1.10.4 What utility types are measured?

The energy balance must be performed for the reasons listed:

Energy carriers:

- Electricity, gasoline, diesel, gas, steam, etc.

Energy uses:

- Winter and summer air conditioning.
- DHW production and utilization.
- Room lighting.
- Process machines.
- Air compressors.

It may be described graphically, very simply, using a Sankey diagram, one example of which is shown in **Figure 20**.

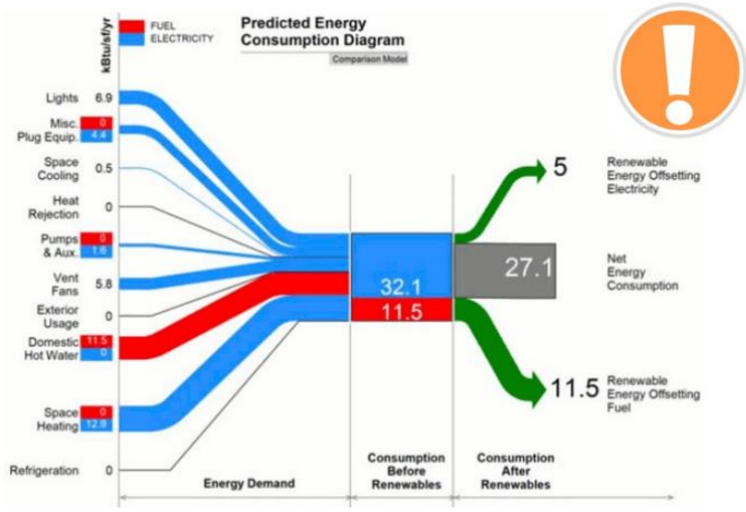


Figure 20: Sankey diagram

The collection frequency should be as high as possible:

- Real-time.
- At least weekly.
- If difficult: monthly.
- No less than annually.

3.1.10.5 Normalization practices

Unknown.

3.1.10.6 Time span of measurements and duration of the certificate?

Unknown.

3.1.10.7 Measurement practices – equipment, minimum requirements?

The Energy Audit Calculation Methodology is shown in **Figure 21**.

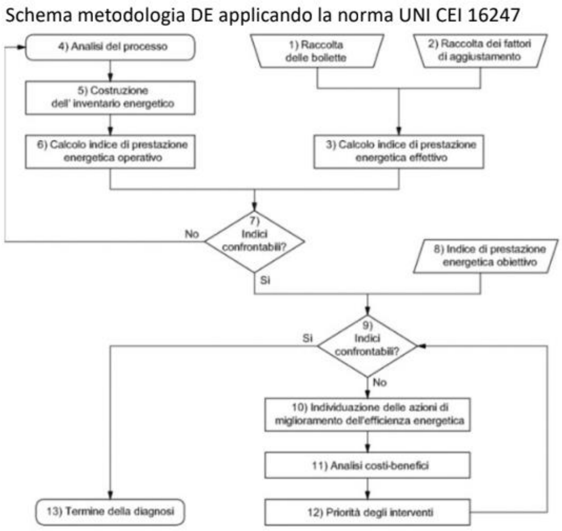


Figure 21: DE Methodology

DE instrumentation for this methodology:

- Laser distance meter for measuring the geometric dimensions.
- Digital camera for surveying energy-intensive elements of the envelope and systems
- Luxmeter for measuring light intensity.
- Psychrometer, for measuring the psychrometric parameters of the air (temperature and relative humidity)
- Thermoflow meter, for measuring the coefficient of transmission heat emission of a dispersing element
- Power grid analyzer.
- IR thermocamera, to detect anomalies in the emission of energy, thus thermal discontinuities, presence of moisture, electrical and water faults, etc.

For residential buildings, the Minimum Requirements Decree (DM 26/06/2015), which implements Law 90/2013, requires energy diagnostics in buildings and specifies the alternative design scenarios to be compared. The decree's recommended list is non-exhaustive and highlights the need for an in-depth understanding of the building upstream of any actions affecting the building-plant system.

3.1.10.8 Relation of operational with asset rating?

Unknown.

3.1.10.9 For what building categories this operational assessment is utilized?

The different "objects" of the diagnosis:

1. Business [28]
    - Large enterprises or, as specified by Mise, those enterprises employing more than 250 people, whose annual turnover exceeds €50 million or whose annual balance sheet total exceeds €43 million.
    - Energy-intensive enterprises that, according to Art. 2 of M.D. 5/4/2013, consume at least 2.4 GWh of energy (electric or other sources) and whose ratio of the actual cost of energy used to the value of turnover is not less than 3 percent.
2. Public buildings and public administrations
3. Residential building

3.2 Data and Parameters for Operational Rating Analysis

According to EN ISO 52000-1:2017, the measured energy indicator and the measured energy performance are the energy performance indicator based on measured energy performance and the energy performance based on weighted, measured amounts of delivered and exported energy, respectively. The measured energy performance, also known as operational energy performance, is the weighted sum of all energy carriers used by the building, as measured by meters or derived from measured energy by other means. It is a measure of the in-use performance of the building after correction or extrapolation. This is particularly relevant to the certification of actual energy performance. Operational performance is only applicable to existing buildings in the use phase. Buildings' energy operational indicators are essential for measuring and evaluating the energy performance of buildings, which is critical for achieving energy efficiency and sustainability goals. By tracking these indicators, building owners and managers can identify areas where energy efficiency improvements can be made, which can reduce energy consumption, lower operating costs, and mitigate the environmental impact of building operations.

Energy consumption indicators are one of the most common and straightforward indicators used to measure building energy performance. They can measure the total energy used by a building, a specific system, or individual equipment. Energy consumption indicators can provide valuable insights into overall energy usage trends, which can help building owners and managers identify opportunities for reducing energy consumption and optimizing energy use. Energy consumption indicators can also deliver information related to the efficiency of building components, such as heating and cooling systems, lighting, and insulation, among others. By measuring the energy efficiency of these components, building owners and managers can identify areas where upgrades or replacements may be necessary to improve overall energy efficiency and reduce energy consumption.

Greenhouse gas emissions indicators are also critical for measuring the environmental impact of building operations. These indicators can track emissions from building operations, including energy consumption, transportation, and waste management. By measuring greenhouse gas emissions, building owners and managers can identify opportunities for reducing emissions and mitigating the environmental impact of building operations.

Finally, renewable energy production indicators can assess the contribution of renewable energy sources to a building's energy mix. These indicators can help building owners and managers determine the feasibility of implementing renewable energy technologies, such as solar or wind power, to meet their energy needs.

In conclusion, buildings' energy operational indicators play a crucial role in evaluating building energy performance, identifying opportunities for energy efficiency improvements, and reducing the environmental impact of building operations. By tracking these indicators, building owners and managers can optimize energy use, reduce operating costs, and achieve their sustainability goals.

Table 17: Energy performance of buildings assessment types [ISO 52000-1:2017]

Type	Sub-type	Input data			Type of application
		Use	Climate	Building	
Calculated (asset)	Design	Standard	Standard	Design	Building permit, certificate under conditions
	As built	Standard	Standard	Actual	Energy performance certificate, regulation
	Actual	Actual	Actual	Actual	Validation
	Tailored	Depending on purpose			Optimization, validation, retrofit planning, energy audit
Measured (operational)	Actual	Actual	Actual	Actual	Monitoring
	Climate corrected	Actual	Corrected to standard	Actual	Monitoring or energy audit
	Use corrected	Corrected to standard	Actual	Actual	Monitoring
	Standard	Corrected to standard	Corrected to standard	Actual	Energy performance certificate, regulation

3.3 Smart Living EPC Operational Rating Indicators

The operational or measured energy indicator is a performance indicator that assesses the energy performance of a building based on actual energy consumption or usage data. It is a ratio that compares the amount of energy used or consumed by a building to its size, occupancy, or other relevant factors. This indicator is commonly used to evaluate the energy efficiency of buildings, identify areas of improvement, and measure the effectiveness of energy management strategies.

- The numerator of the indicator can be either an **energy use or an energy carrier**. Energy use refers to the amount of energy consumed by a building, while energy carrier refers to the type of energy used, such as electricity, natural gas, or fuel oil. The choice of the numerator depends on the purpose of the evaluation and the availability of data. Energy use is often used for benchmarking and comparison purposes, while energy carrier is used to identify specific areas of improvement. The availability of measured energy data for specific services and building zones depends on the number and quality of installed metering devices.

- The denominator of the indicator can be **space in terms of area or volume, the occupancy, and the time bin**. The space can be the total floor area, the heated area, or the conditioned area, depending on the level of detail required. The occupancy can be the number of occupants or the occupancy hours. The choice of the denominator depends on the type of building and the purpose of the evaluation. For example, a retail store may use the total floor area as the denominator, while a hospital may use the occupancy hours. The indicator can also be defined for different time bins, such as monthly, quarterly, or annually. This allows for a more detailed analysis of energy consumption patterns and trends. For example, a monthly indicator can identify seasonal variations in energy consumption, while an annual indicator can identify long-term trends and the effectiveness of energy management strategies. The measurement interval is the time span between readings of meters or use of known amounts of energy. If there are several energy carriers and/or energy uses, measurement intervals can be asynchronous.
- The measured energy indicator can be **corrected for weather conditions and level of service**. Weather correction involves adjusting the energy consumption data for variations in weather conditions, such as temperature and humidity. Level of service correction involves adjusting the energy consumption data for changes in building operation and usage, such as changes in occupancy or equipment usage, as well as the quality of comfort.

The measured energy indicator is a useful tool for evaluating the energy performance of buildings based on actual energy consumption or usage data. It can be used to benchmark energy performance, identify areas of improvement, and measure the effectiveness of energy management strategies. The choice of numerator and denominator depends on the purpose of the evaluation and the availability of data. Weather and level of service corrections can be applied to improve the accuracy of the indicator, and different time bins can be used for a more detailed analysis of energy consumption patterns and trends.

3.3.1 Energy Use and Energy Carrier

Energy Uses

1. **Lighting** (EN 52000-1:2017, 3.4.16 energy use for lighting electrical energy input to a lighting system)
2. **Heating** (EN 52000-1:2017, 3.4.18 energy use for space heating or cooling or domestic hot water energy input to the heating, cooling or domestic hot water system to satisfy the energy need for heating, cooling (including dehumidification) or domestic hot water respectively)
3. **Cooling** (EN 52000-1:2017, 3.4.18 energy use for space heating or cooling or domestic hot water energy input to the heating, cooling or domestic hot water system to satisfy the energy need for heating, cooling (including dehumidification) or domestic hot water respectively)
4. **Ventilation**: (EN 52000-1:2017, 3.4.19 energy use for ventilation electric energy input to a ventilation system for air transport and heat recovery)
5. **Energy use for other services** (EN 52000-1:2017, 3.4.18 3.4.17 energy use for other services energy input to appliances providing services not included in the EPB services

6. **Water heating** (EN 52000-1:2017, 3.4.18 energy use for space heating or cooling or domestic hot water energy input to the heating, cooling or domestic hot water system to satisfy the energy need for heating, cooling (including dehumidification) or domestic hot water respectively)

Energy Carriers

According to EN ISO 52000-1:2017, the delivered energy (3.4.6) is the energy, expressed per energy carrier, supplied to the technical building systems through the assessment boundary to satisfy the uses taken into account or to produce the exported energy. The energy carrier (3.4.9) is a substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes. It may be energy from non-renewable sources (3.4.10) that is energy from a source that is depleted by extraction, or energy from renewable sources (3.4.11), that is energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogases.

There are several energy carriers that can be used for buildings, both renewable and non-renewable. The most common ones for non-renewable energy carriers include:

1. **Electricity:** This is the most widely used energy carrier for buildings. It can be generated from a variety of sources, including coal, natural gas, nuclear power, and renewable sources like solar and wind.
2. **Natural gas:** It is commonly used for space and water heating in buildings. It is a fossil fuel that is cleaner than coal and oil but still emits greenhouse gases when burned.
3. **Heating oil:** This is another fossil fuel that is commonly used for space and water heating in buildings. It is less commonly used today than in the past but is still used in some regions.
4. **Propane:** This is a type of liquefied petroleum gas (LPG) that can be used for space and water heating as well as cooking in buildings. It is often used in rural areas where natural gas is not available.

The most common ones for renewable energy carriers include:

1. **Solar energy:** This includes both passive and active solar technologies that can be used for space and water heating as well as electricity generation.
2. **Biomass:** This includes organic materials such as wood, agricultural waste, and other plant matter. It can be burned to generate heat or electricity.
3. **Geothermal energy:** This is heat that is generated from the earth's core and can be used for space and water heating in buildings.
4. **Wind energy:** This can be used to generate electricity that can be used in buildings. It requires wind turbines to convert the kinetic energy of the wind into electrical energy.

Finally, district heating may include both renewable and non-renewable energy carriers. District heating involves the centralized generation of heat or cooling that is distributed through a network of pipes to multiple buildings. It can use a variety of energy sources, including biomass, geothermal energy, and waste heat from industrial processes.

3.3.2 Building Spaces

▪ Building spaces

According to EN ISO 52000-1:2017, building spaces may include:

1. **reference floor area** (3.1.12): floor area used as a reference size
2. **thermally conditioned space** (3.1.16): heated and/or cooled space
3. **thermally unconditioned space** (3.1.17): room or enclosure that is not part of a thermally conditioned space
4. **useful floor area** (3.1.18): area of the floor of a building needed as a parameter to quantify specific conditions of use that are expressed per unit of floor area and for the application of the simplifications and the zoning and (re-)allocation rules
5. **cooled space** (3.1.9): room or enclosure, which for the purposes of a calculation, is assumed to be cooled to a given temperature set-point or set-points
6. **elementary space** (3.1.10): space room, part of a room or group of adjacent rooms that belong to one thermal zone and one service area of each service, used to administer the boundaries of the thermal zones and service areas and to administer the exchange of data between the service areas and thermal zones
7. **heated space** (3.1.11): room or enclosure which, for the purposes of a calculation, is assumed to be heated to a given temperature set-point or set-points

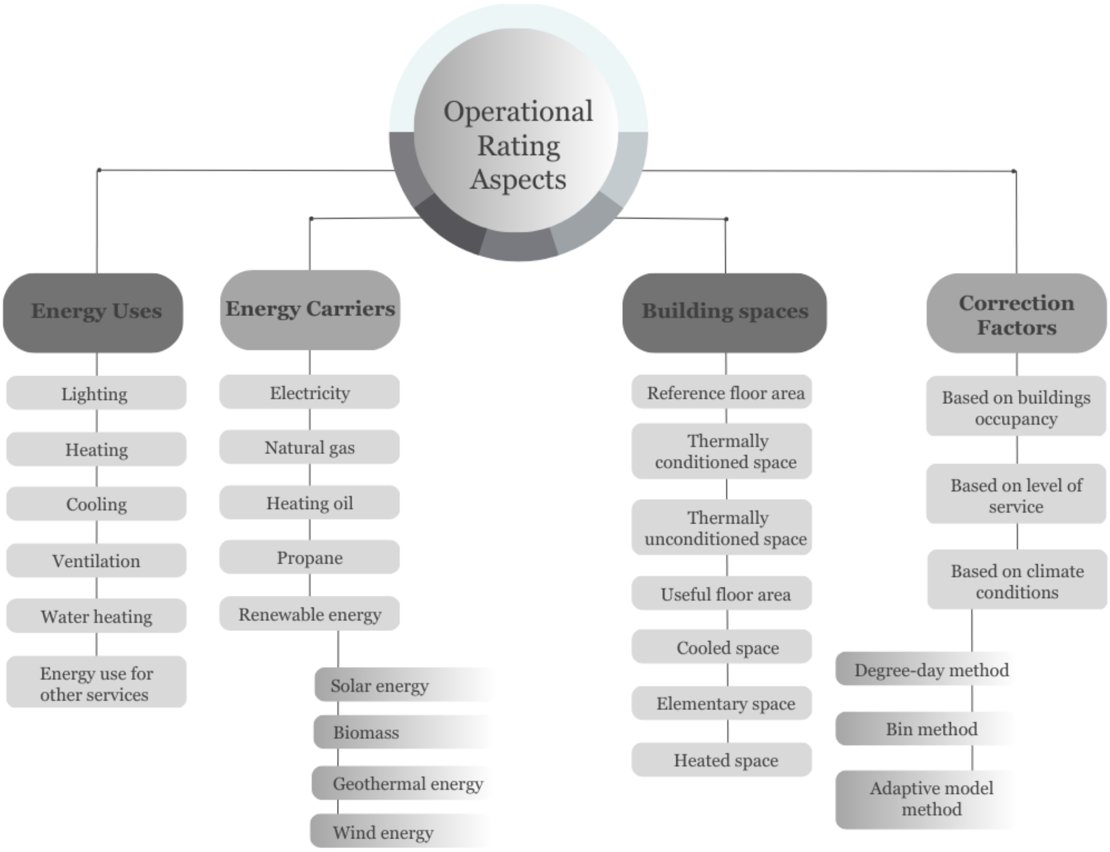


Figure 22: Operational rating aspects

3.3.3 Correction Factors

▪ Correction of operational performance based on buildings occupancy

The occupancy of a building refers to the number of people or activities that occur within it regularly. This includes both permanent occupants, such as employees or residents, as well as temporary occupants, such as visitors or event attendees. The occupancy of a building is a key factor in determining its energy operational rating, as the energy consumption of a building is heavily influenced by the activities and behaviors of its occupants. To extract the energy operational rating of a building, it is important to understand the patterns of occupancy within the building, including the number of occupants, the hours of occupancy, and the types of activities that take place. This information can be used to determine the energy needs of the building, including heating, cooling, lighting, and other energy-consuming systems. In addition to the physical occupancy of the building, it is also important to consider the behavioral factors that influence energy consumption, such as occupant comfort preferences, equipment usage patterns, and energy-saving behaviors. By understanding the occupancy patterns and behaviors within a building, it is possible to develop strategies for optimizing energy use and improving the energy operational rating of the building.

▪ Correction of operational performance based on climate conditions

Correction of operational performance based on climate conditions refers to the process of adjusting the energy consumption data of a building to account for variations in outdoor temperature and other climate factors. This correction is necessary because the energy consumption of a building is heavily influenced by outdoor conditions, such as temperature, humidity, and wind speed.

The correction of operational performance based on climate conditions typically involves comparing the actual energy consumption of a building to a baseline model that considers the outdoor temperature and other climate factors. The baseline model is typically developed using historical weather data and other building performance data, such as the building envelope, HVAC system efficiency, and occupancy patterns. By comparing the actual energy consumption of the building to the baseline model, it is possible to identify areas where the building is underperforming or overperforming relative to its expected energy use. This information can be used to develop strategies for optimizing energy use and improving the operational performance of the building. The correction of operational performance based on climate conditions is an important tool for assessing the operational energy class of buildings, particularly in regions with variable climates or extreme weather conditions. By accounting for climate factors in the evaluation of building performance, it is possible to develop more accurate benchmarks for energy use.

Commonly used methodologies that can be used for the correction of operational performance based on climate conditions are the following:

1. **Degree-day method:** This method is based on the concept of heating degree-days (HDD) and cooling degree-days (CDD). HDD and CDD are measures of the deviation of outdoor temperature from a base

temperature, typically 65°F (18°C). The degree-day method involves comparing the actual energy consumption of a building to a baseline model that takes into account the HDD and CDD for the time period being evaluated. The difference between the actual and baseline energy consumption is then adjusted based on the degree-day values.

2. **Bin method:** The bin method is based on the use of weather bins, which are ranges of outdoor temperature and humidity conditions. The bin method involves comparing the actual energy consumption of a building to a baseline model that takes into account the weather bin data for the time period being evaluated. The difference between the actual and baseline energy consumption is then adjusted based on the bin data.
3. **Adaptive model method:** This method involves the use of machine learning algorithms to develop an adaptive model of building performance. The adaptive model is trained on historical weather and energy consumption data and is designed to automatically adjust to changes in building occupancy, equipment, and other factors. The adaptive model can be used to correct the operational performance of a building based on real-time weather data and can provide insights into energy-saving opportunities and maintenance needs.

▪ Correction of operational performance based on level of service

Correction of buildings' energy operational performance based on the level of service refers to the process of adjusting the energy consumption data of a building to account for variations in the level of service provided to the building's occupants. The level of service refers to the degree of comfort, safety, and other factors that are provided to building occupants, such as temperature, air quality, lighting, and security. The correction of operational performance based on the level of service typically involves comparing the actual energy consumption of the building to a baseline model that takes into account the level of service provided to the occupants. By comparing the actual energy consumption of the building to the baseline model, it is possible to identify areas where the building is underperforming or overperforming relative to its expected energy use based on the level of service provided to the occupants. This information can be used to develop strategies for optimizing energy use and improving the operational performance of the building. The correction of operational performance based on the level of service is an important tool for evaluating the energy efficiency of buildings, particularly in buildings where the level of service varies based on occupancy or use. By accounting for the level of service in the evaluation of building performance, it is possible to develop more accurate benchmarks for energy use and identify opportunities for energy savings that might otherwise be overlooked.

3.3.4 Other aspects

The indicators should be expressed in primary energy. Different values for the primary energy factors are possible for energy exported, re-delivered or exported to functions at the building site that are not included in the energy performance. When expressing a primary energy use, it shall be specified if it is total primary energy, non-renewable primary energy or renewable primary energy.

Greenhouse gas emission factors could also be expressed in kg of CO_2 equivalent per kWh and may also include the equivalent emissions of other greenhouse gas emissions like methane, water vapor etc.

The cost weighting factors could be expressed in currency units per kWh.

4 Financial Indicators and Integration to SmartLivingEPC

In this section, the financial indicators, as a part of the operational rating methodology, will be discussed. This chapter presents the progress of the works done in T3.3, financial indicators, and integration to SmartLivingEPC. Therefore, further progress and complete results of the task will be presented in D3.4 and D3.7 of the project.

The approach has been to connect to other EU initiations, frameworks, and previous projects for the Next Generation EPC cluster, bring financial indicators as additional informative indicators for the operational rating methodology, and integrate them into the operational classification system.

An introduction to the Life Cycle Costing methodology is introduced in Section 4.1, in addition to a review of the related standards and Level(s) framework. Section 4.2 presents an introduction to user awareness and smart planning in regard to financial indicators. Section 4.3 introduces the data and parameters related to the calculation of financial indicators. Section 4.4 presents the financial indicators and their calculation.

The methodology will be examined and validated by implementing it to the use cases from the demonstration cases. The results can cause revisions in the methodology, which will be updated in the second version of the deliverable, D3.4.

For the integration of financial indicators to SmartLivingEPC, a classification methodology will be established, which will be presented in the second version of this deliverable, D3.4.

4.1 Life Cycle Costing (LCC) Methodology

Life Cycle Costing (LCC) methodology is a comprehensive approach used to assess the total cost of owning and operating an asset or a project throughout its entire life cycle. It considers all relevant costs and benefits associated with the asset from its initial conception through construction or acquisition, operation, maintenance, and finally, its disposal or end-of-life.

The main objective of LCC is to aid decision-makers in making informed choices by considering the long-term financial implications of various alternatives. This methodology is commonly applied in different fields, including construction, engineering, and facility management, to compare options, evaluate cost-effectiveness, and identify the most economically viable solution.

4.1.1 Standards and Framework

As a part of the literature review, the standards related to LCC methodology were reviewed, a summary of which is presented below. In addition, the framework of Level(s), and its LCC indicator have been studied to align the methodology as much as possible.

4.1.1.1 ISO 15686-5

Buildings and construction assets – Service life planning – Part 5 _ Life Cycle Costing [29]

ISO 15686-5 focuses on providing the principles and procedures for conducting LCC assessments to support decision-making throughout the life cycle of buildings and constructed assets, as shown in **Figure 23**. It provides guidance on the economic aspects of service life planning, including cost estimation, evaluation, and comparison.

ISO 15686-5 defines various cost categories to be considered in LCC assessments, including capital costs, operating costs, maintenance costs, and disposal costs, as shown in **Figure 24**. It provides guidance on identifying and categorizing costs to ensure a comprehensive analysis.

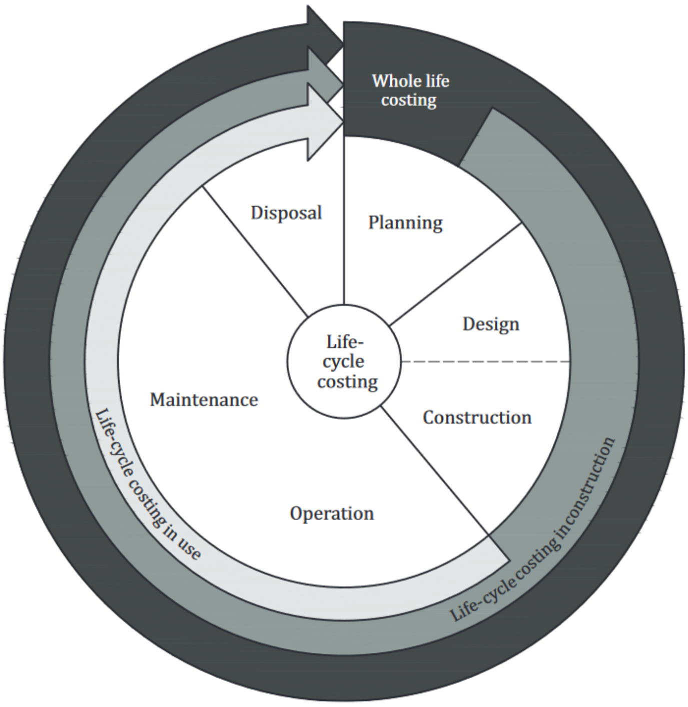


Figure 23: ISO 15686-5 Different Stages

The standard highlights the significance of accounting for the time value of money in LCC assessments. It explains the concept of discounting and recommends appropriate discount rates to bring future costs and benefits to their present values. It outlines the data requirements for LCC assessments, including accurate cost data, projected service life, inflation rates, and discount rates. It emphasizes the importance of using reliable data sources and considering uncertainties in cost estimation. It suggests presenting costs and benefits in a clear and transparent manner, including sensitivity analyses and assumptions made during the assessment process.

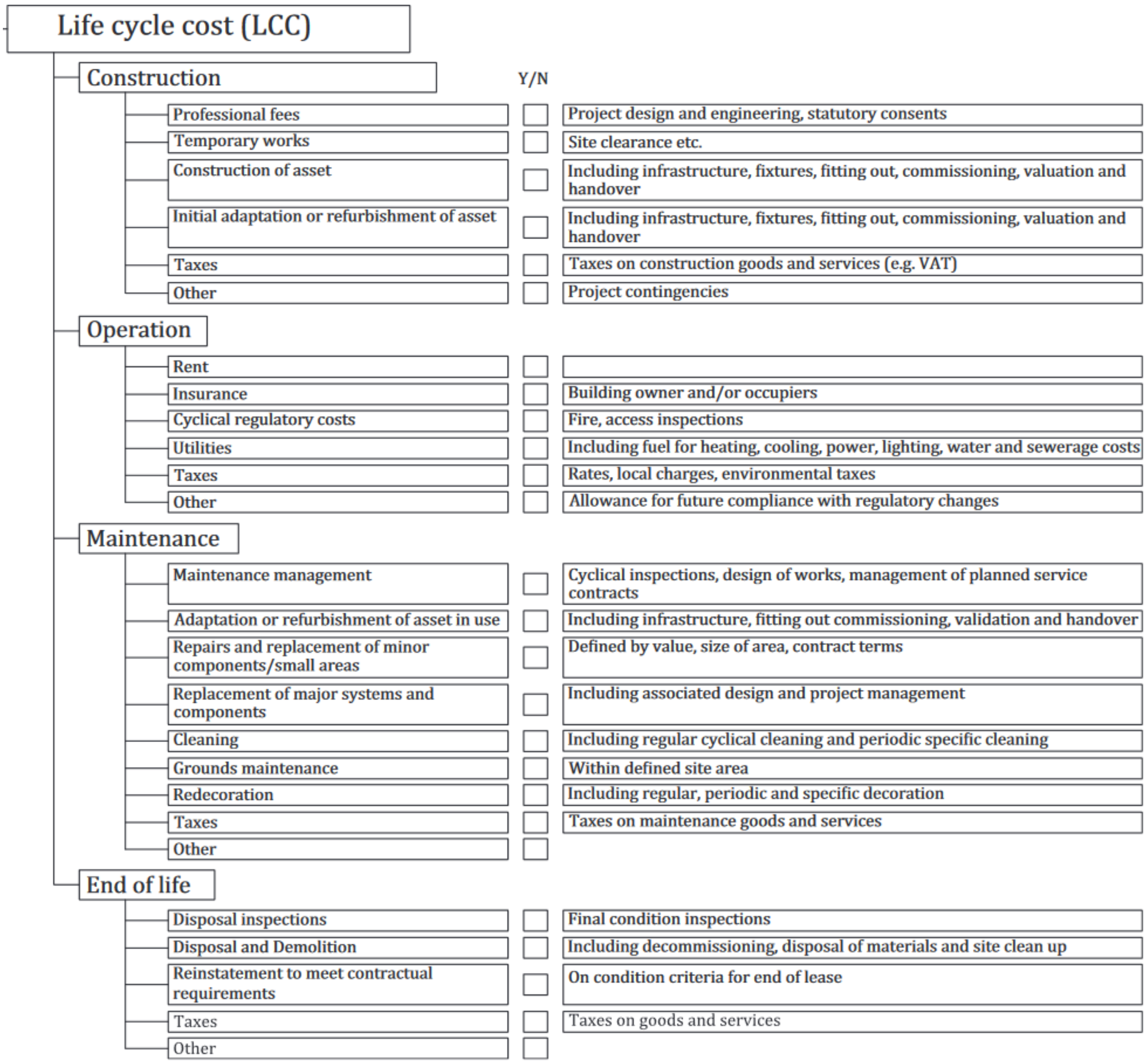


Figure 24: ISO 15686-5 Classification of Costs

To consider the abovementioned costs in the different stages that they occur, the Net Present Value is used to calculate the sum of the present value of the stream of the future costs and benefits, using the following formula:

$$\mathrm{NPV} = \sum(\mathrm{Cn} \times \mathrm{q}) = \sum_{\mathrm{n}=1}^{\mathrm{p}} \frac{\mathrm{Cn}}{(1+\mathrm{d})^{\mathrm{n}}} \quad (12)$$

where:

NPV = Net Present Value

C = Cost in year n

q = Discount factor

d = Expected real discount rate per annum

n = Number of years between the base date and the occurrence of the cost

p = The period of analysis

According to ISO 15686-5, issues that should be included as an integral part of LCC analysis regarding operation and maintenance are as follows:

- performance over time of each element in the anticipated building location
- identification of probable dates of failure and whether they conform to the client brief or regulations
- work required and associated costs to retain and/or restore the element to acceptable performance at various stages through its life (by maintenance or replacement)
- costs associated with loss of the amenity due to unavailability or failure
- costs associated with degraded performance
- reduced service life (of the building or element as appropriate) resulting from any maintenance regime
- costs that a particular operation and maintenance plan incur at the design stage (e.g., the costs of building in access for cleaning or replacement regimes)
- maintenance and associated management costs that tend to occur/recur on regular, short-term cycles.
- replacement costs that can occur on (a) relatively longer cycle(s) and can be analyzed separately or as part of the capital costs
- energy and other consumable/utilities costs associated with mechanical and electrical plant and machinery

4.1.1.2 EN 15459:2007

Energy performance of buildings - Economic evaluation procedure for energy systems in buildings [30]

EN 15459 provides guidance on the economic evaluation of energy systems within the context of building energy performance. It aims to provide a standardized procedure for assessing the life cycle costs and energy savings associated with different energy systems, such as heating, cooling, ventilation, and lighting. The standard outlines a systematic approach for conducting LCC assessments, considering factors such as investment costs, operational costs, maintenance costs, energy savings, and other economic indicators. It promotes a consistent framework to evaluate the financial viability of energy system options.

It introduces energy performance indicators (EPIs) as a means of quantifying and comparing the energy performance of different systems. These indicators help to assess the potential energy savings and corresponding cost implications associated with alternative energy system options. It specifies the data needed for input, such as energy consumption profiles, energy prices, investment costs, maintenance costs, and expected service life. It also addresses uncertainties and sensitivity analysis in data inputs. It provides guidance on calculating various financial indicators to facilitate decision-making, such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Life Cycle Cost (LCC).

4.1.1.3 EN 16627:2015

Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [31]

EN 16627:2015 provides guidance for assessing the economic performance of buildings as a part of the sustainability evaluation of the building. One of the introduced approaches of this standard is LCC. This is done by considering costs over the life cycle of the building.

4.1.1.4 EN 15643:2021

Sustainability of construction works – Assessment of buildings [32]

EN 15643:2021 promotes more sustainable construction techniques. This standard is part of a set of documents developed under the Mandate M/350, issued by the European Commission, to assess the sustainability of buildings based on three pillars: environmental, social, and economic.

4.1.1.5 Level(s) Framework

In the context of the global 2030 sustainable development agenda, Level(s) is an assessment and reporting tool for the sustainability performance of buildings firmly based on circularity [33]. It provides a common language for the building transformation process in line with the European Union's sustainable initiatives. According to the recast of the directive 2019/790 of the Energy Performance of Buildings Directive, "*The Level(s) framework for sustainability performance assessments has inspired and supported the proposal for the revision of this Directive to include the assessment of Whole Life Carbon for new buildings*" [34].

Level(s) introduces Life cycle costs as indicator 6.1 under the macro-objective "optimized life cycle cost and value". Indicator 6.1 is described in three levels, as shown in **Table 18**. The reference standard for calculating the life cycle costs of each life cycle stage shall be EN 15459, ISO 156865, and EN 16627. The reference standards for calculating the lifetime of each life cycle stage shall be EN 15459, ISO 15686-5, and EN 16627. The format for reporting the results of an assessment for this indicator is shown in **Table 19** and **Table 20** [35].

Table 18: Level(s) indicator 6.1 LCC levels

Level	**Activities related to the use of indicator 6.1**
1. Conceptual design	▪ Life cycle thinking
2. Detailed design and construction (based on calculations, simulations, drawings, and quotations)	▪ Cost estimation and modelling
3. In-use performance (invoices, meter readings, and contractual agreements)	▪ Verification of as-built costs: based on the final cost and the as-built specifications ▪ Metered utility costs: **real energy and water cost performance data** ▪ Monitoring of maintenance and replacement costs: refinement of projections over time as real performance data comes it

The LCC unit of measurement is Euros per square meter of useable floor area per year (€/m2/yr), which is calculated based on NPV, with a reference period of 50 years. The NPV is based on real costs and excludes inflation. Inflation may be included in the discount rate.

For the calculation of the LCC, the costs shall include and be classified as follows:

- Initial capital costs: those related to the construction of the building (initial costs)
- Annual running costs: projected annual costs associated with the future operation of the building (e.g., utility costs)
- Annual and periodic capital costs: the projected costs associated with the maintenance, repair and/or replacement of building elements and components.

The future projections provided by the European Commission in the guidance to the Delegated Regulation (EU) No 244/2012 may be used as reference values for this indicator [35].

Table 19: Level(s): Format for reporting the results of an LCC assessment – performance assessment results

Type of cost	Normalised cost by life cycle stage (€/m^2/yr)			
	A **Product and construction stages**	**B** **Use stage**		**C** **End of life stage**
Initial costs	*Construction*	*Refurbishment and adaption*		*Deconstruction and demolition*
Annual costs	-	*Energy*	*Water*	-
	-	*Maintenance, repair and replacement*		-
Periodic costs	-	*Maintenance, repair and replacement*		-
Global costs by life cycle stage	*Sum of stage A costs*	*Sum of stage B costs*		*Sum of stage C costs*

Level(s) LCC system boundary should be aligned with EN 15978, Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. The minimum required scope for this indicator is as follows:

- Use stage energy and water costs (life cycle stages B6 & B7)
- Construction (life cycle stages A1-3) and long-term maintenance, repair, and replacement costs (life cycle stages B2-4)

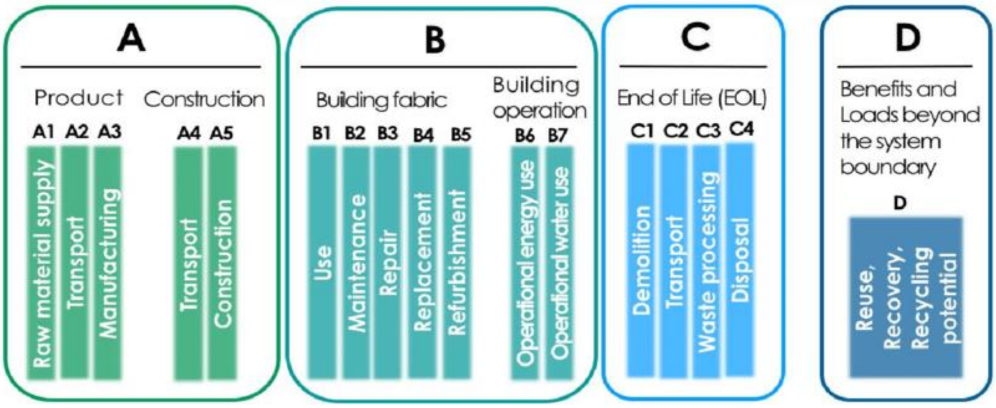


Figure 25: EN 15978 LCC System Boundary

Table 20: Level(s): Format for reporting the results of an LCC assessment – data transparency report

Building elements	Types of data source used for the identified life cycle stages *			
	A Product and construction stages	Basis for future assumptions		
		B2 Maintenance	B3 Repair	B4 Replacement
Foundations				
Load bearing structural frame				
Non-load bearing elements				
Facades				
Roof				
Parking facilities				
Fixed lighting system				
Energy system				
Ventilation system				
Sanitary systems				
Miscellaneous systems				

** Data sources classification to be used:*

1. Generic or default national or EU data
   1a. Default data provided at EU or national level
   1b. Default data provided by an existing assessment or reporting scheme
2. Older or less geographically specific benchmarked and averaged data
   2a. Published benchmark data, aggregated and averaged from similar projects
   2b. Estimates from published, average cost data obtained from contractors and suppliers
3. Recent tender and market estimates
   3a. Analysis of the bills of quantities and schedules from other similar projects
4. Current tender and market estimates
   4a. Direct estimates based on offers from contractors and suppliers

4.1.2 Methodology

The operational methodology aims to integrate other aspects rather than energy performance into EPCs. Financial indicators are purposed to add more information for the users regarding the costs associated with the energy performance of their buildings, and for this purpose, the LCC methodology is considered as a proper direction. LCC can be calculated at various stages of the life cycle of a building, considering all costs of construction, operation, maintenance, and end-of-life. The financial indicators provide monetized values of the aspects of the energy performance of a building. Therefore, in the context of the operational methodology, the indicators reflect the economic aspect of the actual performance of their buildings.

According to the recast of the Directive 2019/790 of the Energy Performance of Buildings Directive, Article 16: EPCs:

> "*The energy performance certificate shall include recommendations for the cost-effective improvement of the energy performance and the reduction of operational greenhouse gases emissions of a building or building unit, unless the building or building unit already complies with the relevant zero-emission building standard*" [34].

Therefore, besides monetizing the energy use and performance of a building, financial indicators can also play a role when these recommendations are provided. For this purpose, besides the main financial indicators, a complimentary group of financial indicators is defined to enable the users to compare the different alternatives when making decisions for the improvement of the energy performance of their buildings.

4.1.2.1 Defining the financial indicators

The main financial indicators are defined in three categories:

- As-designed:

  This category indicates the asset values of the building's energy consumption and, therefore, provides the monetized value of the energy performance of the building as designed. The importance of this category is that it enables the users to compare the energy performance of their buildings as it was designed to as it is operational.
- As-operated:

  This category indicates the operational value of the building's energy consumption and, therefore, provides the monetized value of the energy performance of the building as operated. The importance of this category is that it enables the users to understand the energy consumption of their building, evaluate their behavior, and use this information to make decisions for improving the energy use of their building and increasing their energy savings.
- Predicted:

  This category indicates the predicted values of the building's energy consumption and, therefore, provides the monetized value of the predicted energy performance of the building. The importance of this category is that it enables the users to understand the monetized value of their building's energy consumption with an LCC approach by considering the future maintenance and replacement costs for a specific period of time.

The input for the *as-designed* indicators is provided by the asset data, which is the designed energy consumption in kWh per square meter per month. The input for the *as-operated* indicators is provided by the operational outputs of the EPC, which are the actual measured energy consumption values of the building. In addition, the operational performance of the building provides the input for the *predicted* indicators.

The other data and parameters considered in the calculation of the financial indicators are elaborated in Section *Data and Parameters for Financial Analysis*. The calculation of financial indicators is elaborated on in Section 4.3.

To be able to classify these indicators, it is important to make them comparable. Therefore, the indicators are defined per square meter of floor area. This makes it possible to classify the outcome of these indicators for buildings. The classification system for the financial indicators will be established and presented in the next version of the deliverable, D3.4.

As mentioned above, in addition to the main categories of financial indicators, a group of complementary financial indicators is defined to help the users in decision-making processes regarding the improvement of the energy performance of their buildings by providing financial insight. These are relevant when the LCC approach is used for the comparison of multiple alternatives. These indicators are elaborated on in Section 4.4.

- Payback Period (PBP)
- Net Savings (NS)
- Savings-to-Investment Ratio (SIR)

4.2 User Awareness and Smart Planning

The operational rating is helpful to the users to monitor their energy use, assess their behavior, and make decisions for strategies to increase energy savings [36]. In the same way, the purpose of the financial indicators in the operational rating is to increase user awareness and encourage smart planning. However, providing additional information to EPC does not necessarily increase user awareness for a non-expert user. It is important to provide informative indicators which are easy to understand. Different financial indicators can be chosen; however, it is important to understand the use of these indicators in the context of this project and operational rating methodology. The financial indicators here are defined to provide information for users regarding the energy performance of their buildings.

One of the aspects of LCC is the calculation of the costs in different stages and proving the present value of these costs. Therefore, at its core, it provides a comprehensive understanding of the value of operating an asset or the different costs related to it. Understanding the LCC of a building helps users recognize that the initial investment is just one part of the equation. By considering long-term operating costs and potential savings, users can make strategic decisions to invest in energy-efficient technologies and materials during the planning phase.

In general, according to ISO 15686-5, the typical decisions informed by LCC are as follows [29]:

- evaluation of different investment scenarios (e.g., to adapt and redevelop an existing facility or to provide a totally new facility) at the investment planning stage.
- choices between alternative designs for the whole or part of a constructed asset (asset, system, or detailed element level LCC analysis) during the design and construction stage.
- choices among alternative components, all of which have acceptable performance (component-level LCC analysis) during the construction or in-use stages.

- comparison and/or benchmarking analysis of previous decisions, which may be at the level of individual cost headings (e.g., energy costs, cleaning costs) or at a strategic level (e.g., open plan versus cellular office accommodation).
- estimation of future costs for budgetary purposes or for the evaluation of the acceptability of an investment based on the cost of ownership.

Financial indicators play a crucial role in increasing user awareness of their buildings' energy performance and promoting smart planning. These financial indicators are important for evaluating the economic viability of energy efficiency measures and sustainable building practices. They enable decision-makers to prioritize investments that yield the most significant energy savings and financial benefits over the building's lifetime. The complementary financial indicators can increase awareness as follows:

- The Net Savings indicator demonstrates the potential cost savings from energy performance improvements, which can attract the attention of building owners and occupants. When users realize the potential for reduced utility bills and operating expenses, they are more likely to adopt energy-saving behaviors and invest in energy performance improvement measures.
- By the Payback Period indicator, users can understand the time it takes to recover their initial costs. Shorter payback periods encourage users to make smarter, more immediate decisions regarding energy-efficient retrofits and upgrades.
- The Savings-to-Investment Ratio indicator can help the user to evaluate the retrofit projects for their building with other investments they consider and to prioritize and plan smartly.

Another aspect is user awareness about the impacts of their behavior on the energy consumption of the building. For commercial building owners, financial indicators can be used to inform and engage tenants about the benefits of energy efficiency. Transparent reporting on energy consumption and potential cost savings can encourage tenants to participate actively in energy-saving efforts.

By combining financial indicators with data-driven insights and user engagement strategies, smart planning can be achieved. This includes incorporating energy-efficient technologies, establishing energy reduction targets, optimizing building layouts, and adopting flexible approaches to adapt to changing energy needs. Overall, financial indicators enable users to make informed decisions that promote energy efficiency, reduce operating costs, and contribute to sustainable and smart planning for the future. As a result, by combining user awareness and smart planning strategies, significant energy performance improvements can be achieved.

4.3 Data and Parameters for Financial Analysis

As mentioned in sub-section 4.1.2, the input for the energy use of a building is provided by the asset model and the operational data of the building. The asset model of the building also provides the useable floor area of the building.

Besides the energy consumption of the building, the following parameters should be considered:

- Discount rate: According to ISO 15686-5, the type of discount rate, either real or nominal, should be clearly distinguished.

- Inflation: According to ISO 15686-5, if real costs are used in the LCC analysis, assumptions about the general rate of inflation should not be required. However, if nominal costs are used in the LCC analysis, assumptions can be made about discount rates (and underlying inflation rates), but they should be explicit, and the sensitivity should be checked.
  - The nominal cost is the current value without taking inflation into account.
  - The real cost is the nominal value after it has been adjusted for inflation.
- Energy and utility costs: According to ISO 15686-5, Where analysis is made of energy costs, present-day supply costs should be used unless it is foreseeable that the relative costs can change between alternative energy sources. Where an investment appraisal assesses energy-efficient technology, energy savings should be treated as a future income stream (or negative cost) for comparison purposes.

According to Regulation 244/2012, Article 3, Comparative methodology framework:

"Member States shall complement the comparative methodology framework by determining for the purpose of the calculations:

(a) the estimated economic lifecycle of a building and/or building element.

(b) the discount rates.

(c) the costs for energy carriers, products, systems, maintenance costs, operational costs, and labor costs.

(d) the primary energy factors.

(e) the energy price developments to be assumed for all energy carriers considering the information in Annex II to this Regulation" [37].

Therefore, the parameters regarding the energy prices, maintenance costs, and discount rate will be provided from the national reports on the Comparative methodology framework. The collected information for the pilot countries from these national reports will be provided in the next version of the deliverable, D3.4.

In addition, regarding the recommendations for the improvement of energy performance, a set of possible measures will be inventoried to be used as an input module for planning and decision-making. This input can be used to define multiple alternatives with different LCC values, which finally helps the users to choose the best option for energy performance improvement of their buildings by, for example, changing a technical system. This module will be provided in the next version of the deliverable, D3.4.

4.4 SmartLivingEPC Financial Indicators

The financial indicators will be integrated into the EPC as a part of the operational rating. Therefore, a classification system will be developed for this purpose. The defined indicators are divided into three categories as follows:

1. As-designed:
   - Total energy cost per square meter (per month and per year)

2. As-operated:
   - Cost per energy use per square meter (per month and per year)
   - Cost per energy carrier per square meter (per month and per year)
   - Total energy cost per square meter (per month and per year)

3. Predicted:
   - Total cost per energy use for N years
   - Total cost per energy carrier for N years
   - Total cost for N years

The *as-designed* indicators refer to the asset data of the building, indicating the costs as calculated. The *as-operated* indicators refer to the actual energy consumption of the building. The *predicted* indicators indicate the total costs of energy, in addition to the future costs of maintenance and replacement, for the period of 10 years.

All these indicators are presented per square meter, enabling a better comparison between the categories and the sub-indicators themselves. The *as-designed* indicators, in comparison to *as-operated*, can also be useful for the classification system.

The LCC approach is used mostly for the *predicted* group of indicators, considering the costs in the lifetime of the component or building and taking different yet related types of costs into account. This approach is also aligned with Level(s) indicator 6.1 LCC.

The abovementioned indicators can be informative for the user; however, they are not the best indicators for making decisions between different alternatives when for example, different measures are possible to be taken to improve the energy performance of the building. LCC can indeed be a helpful methodology for such decisions. Therefore, a complementary group of financial indicators is defined to be used for the comparison of different alternatives. The purpose of these indicators is to give the user a set of monetized values, easy to understand and helpful in terms of comparison of different alternatives.

Payback Period (PBP):

- The payback period indicates the time required to recover the initial investment cost. It is calculated by dividing the initial cost by the annual cash inflows generated by the investment.
- The payback period is the minimum number of years, y, for which:

$$\sum_{t=1}^{y} \frac{S_t - \Delta I_t}{(1+d)^t} \geq \Delta I_0 \tag{13}$$

where:

y = Minimum length of time over which future net cash flows have to be accumulated in order to offset initial investment costs

S_t = Savings in year t in operational costs associated with the alternative

ΔI_0 = Initial investment costs associated with a given alternative

ΔI_t = Additional investment-related costs in year t, other than initial investment costs

d = Discount rate

Net Savings (NS):

- The indicator quantifies the financial savings achieved through energy-efficient measures. It compares the energy cost of an energy-efficient building with a reference building, considering factors such as energy consumption, utility rates, and operational periods.
- Net Savings can be calculated by the following formula:

$$NS_{A:BC} = \sum_{t=0}^{N} \frac{S_t}{(1+d)^t} - \sum_{t=0}^{N} \frac{\Delta I_t}{(1+d)^t} \quad (14)$$

where:

$NS_{A:BC}$ = NS, in PV Euros, of alternative (A), relative to the base case (BC)

S_t = Savings in year t in operational costs associated with the alternative

ΔI_t = Additional investment-related costs in year t associated with the alternative

t = Year of occurrence (where 0 is the base date)

d = Discount rate

N = Number of years in the study period

Savings-to-Investment Ratio (SIR):

- The indicator measures the energy and operational savings ratio to additional investment costs, calculated for the energy-saving alternative relative to a base case. This indicator is used to rank alternatives.
- The SIR is calculated by the following formula:

$$SIR_{A:BC} = \sum_{t=0}^{N} \frac{S_t}{(1+d)^t} \Bigg/ \sum_{t=0}^{N} \frac{\Delta I_t}{(1+d)^t} \quad (15)$$

where:

$SIR_{A:BC}$ = SIR of alternative (A), relative to the base case (BC)

S_t = Savings in year t in operational costs associated with the alternative

ΔI_t = Additional investment-related costs in year t associated with the alternative

t = Year of occurrence (where 0 is the base date)

d = Discount rate

N = Number of years in the study period

5 Conclusions

The deliverable *Operational Assessment Methodology in Building Level* has successfully addressed the need for a comprehensive and integrated approach to building evaluations, encompassing various indoor environment quality indicators, operational rating Indicators, and financial indicators.

By incorporating IEQ indicators, such as indoor air quality and thermal comfort, the assessment methodology recognizes the paramount importance of occupant health, well-being, and productivity. The consideration of these indicators allows for a holistic evaluation of building environments, resulting in enhanced building performance and occupant satisfaction. The inclusion of a comprehensive set of operational rating indicators enables a detailed assessment of energy consumption and operational efficiency within buildings. Lighting, heating, cooling, ventilation, electrical appliances, and water heating are integral components that significantly influence overall energy consumption and building performance. The utilization of these indicators ensures a nuanced evaluation of energy usage patterns, enabling stakeholders to identify potential areas for improvement and resource optimization. The incorporation of financial indicators, such as total energy cost per square meter per month, cost per energy use per square meter per year, and cost per energy carrier per square meter for ten (10) years, facilitates a comprehensive financial analysis of building operations. These indicators allow stakeholders to assess the economic viability of different energy carriers, identify cost-saving opportunities, and make informed decisions that align with sustainable and cost-effective building practices.

The development of an integrated operational assessment methodology, incorporating IEQ, operational rating, and LCC indicators, represents a significant advancement in building evaluation practices. By standardizing the assessment process across building types and European MSs, this deliverable fosters a unified approach to building assessments. This standardization promotes transparency, comparability, and exchange of best practices among stakeholders, further supporting the EU's overarching sustainability goals.

The deliverable's outcomes significantly advance sustainable building practices and optimize energy efficiency. The incorporation of IEQ parameters ensures that occupant health and well-being remain at the forefront of building operations, while Operational Rating and financial indicators drive energy-conscious decision-making and cost-effective resource allocation. The operational assessment methodology proposed in this deliverable has the potential to yield substantial socio-economic benefits. By optimizing energy consumption and reducing operational costs, buildings can mitigate environmental impact and foster economic resilience. Moreover, the focus on occupant well-being and productivity can create healthier and more comfortable indoor environments, positively impacting the quality of life for building occupants.

In conclusion, the deliverable *Operational Assessment Methodology in Building Level* represents a significant step forward in the evaluation of building operations, going beyond conventional energy performance metrics. As this deliverable continues to evolve and refine, it holds the promise of shaping the future of European building practices, fostering greener, healthier, and more economically viable built environments.

6 References

[1]. Dodd N., Donatello S. & Cordella M. 2021. Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, User Manual 1: Introduction to the Level(s) common framework (Publication version 1.1).

[2]. Dodd N., Donatello S. & Cordella.M., 2021. Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[3]. Level(s) - European framework for sustainable buildings, URL: https://environment.ec.europa.eu/topics/circular-economy/levels_en

[4]. Pawel Wargocki, Wenjuan Wei, Jana Bendžalová, Carlos Espigares-Correa, Christophe Gerard, Olivier Greslou, Mathieu Rivallain, Marta Maria Sesana, Bjarne W. Olesen, Johann Zirngibl, Corinne Mandin. TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project), Energy and Buildings, Volume 244, 2021

[5]. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

[6]. European Environmental Agency - https://www.eea.europa.eu/themes/air/air-quality-concentrations/air-quality-standards

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

[8]. Kurnitski, J, Kiil, M, Wargocki, P, Boerstra, A, Seppänen, O, Olesen, B, and Morawska, L. Respiratory infection risk-based ventilation design method. Building and Environment, 206, 2021 https://doi.org/10.1016/j.buildenv.2021.108387

[9]. Criteria for room air cleaners for particulate matter https://www.rehva.eu/fileadmin/content/documents/Downloadable_documents/REHVA_COVID-19_Recommendation_Criteria_for_room_air_cleaners_for_particulate_matter.pdf

[10]. Ueki, H et al., 'Effectiveness of face masks in preventing airborne transmission of SARS-CoV-2', MSphere, vol. 5, no. 5, 2020.

[11]. Buonanno, G, Morawska, L, and Stabile, L, 'Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: prospective and retrospective applications', Environ. Int., vol. 145, p. 106112, 2020. https://doi.org/10.1016/j.envint.2020.106112

[12]. Van Doremalen, N et al., 'Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1', N. Engl. J. Med., vol. 382, no. 16, pp. 1564–1567, 2020.

[13]. Aganovic, A, Cao, G, Kurnitski, J, and Wargocki, P, 'New dose-response model and SARS-CoV-2 quanta emission rates for calculating the long-range airborne infection risk', Building and Environment (2023), doi: https://doi.org/10.1016/j.buildenv.2022.109924

[14]. Ergonomics of the physical environment – Subjective judgement scales for assessing physical environments, ISO 10551:2019, 2019

[15]. Ergonomics of the physical environment - Assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people, ISO 28802:2012, 2012

[16]. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, ISO 7730:2005

[17]. Energy performance of buildings – Ventilation for buildings, Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics' can be ordered via your National Standardization Body, EN 16798-1:2019

[18]. Rules on the methodology for the construction and issue of energy performance certificates of buildings (pisrs.si), (accessed on Dec 2022)

[19]. Implementation of the EPBD in Slovenia (epbd-ca.eu), (accessed on Dec 2022)

[20]. Energy-Performance-Certificates-EPC-across-the-EU.-A-mapping-of-national-approaches-2014.pdf (bpie.eu), (accessed on Dec 2022)

[21]. Medved S., Domjan S., Arkar C., 2019, Sustainable Technologies for Nearly Zero Energy Buildings: Design and Evaluation Methods, Springer Tracts in Civil Engineering, https://doi.org/10.1007/978-3-030-02822-0

[22]. https://www.seai.ie/publications/Public-Buildings-Technical-Manual.pdf

[23]. https://www.seai.ie/publications/Public-Buildings-User-Guide.pdf

[24]. "REHVA nZEB Task Force and CEN EPBD. Technical definition for nearly zero energy buildings. REHVA Journal, (03)," 2013.

[25]. Estonian Government Ordinance No. 63: "Hoone energiatõhususe miinimumnõuded" [Minimum requirements for buildings energy performance] (in Estonain), RT I, 2018, redacted 25.08.2019.

[26]. Estonian Government Ordinance No. 58: "Hoone energiatõhususe arvutamise metoodika" [Calculation methodology for building energy efficiency] (in Estonian), RT I, 2015, redacted 25.08.2019.

[27]. Estonian Government Ordinance No. 36: "Nõuded energiamärgise andmisele ja energiamärgisele" [Requirements and procedure for the energy performance certificate] (in Estonian), RT I, 2015, redacted 10.07.2020.

[28]. Legislative Decree No. 102/2014 implementing Directive 2012/27/EU "Measures for the promotion and improvement of energy efficiency that contribute to the achievement of the national energy savings target"

[29]. ISO 15686-5:2017. Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing.

[30]. EN 15459:2007. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings

[31]. CEN EN 16627:2015, Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods

[32]. CEN EN 15643:2021, Sustainability of construction works - Framework for assessment of buildings and civil engineering works

[33]. https://environment.ec.europa.eu/topics/circular-economy/levels_en

[34]. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast), European Commission, 2021, retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021PC0802

[35]. Level(s) indicator 6.1: Life cycle costs user manual: introductory briefing, instructions and guidance (Publication version 1.1), European Commission, 2021, retrieved from: https://academy.europa.eu/mod/scorm/player.php

[36]. Koltsios, S, Fokaides, P, Georgali, P-Z, et al. An enhanced framework for next-generation operational buildings energy performance certificates. Int J Energy Res. 2022; 46(14): 20079- 20095. doi:10.1002/er.8517

[37]. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (OJ C, C/115, 19.04.2012, p. 1, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012XC0419(02))

Annex

A.1 Indoor Environment Quality Indicators

A.1.1 Indoor air quality

Usage	Indicator Name	Indicator Description	Units
Indoor air quality	Ventilation rate (airflow)	The ventilation rate is the magnitude of outdoor airflow to a room or building through the ventilation system or device. The indicator is reported based on the % of hours of each category compared to the total hours of the period of interest.	L/s/m²
	Total Volatile Organic Compounds (TVOCs)	TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air.	µg/m³
	Benzene	Benzene concentration in the indoor air	µg/m³
	CO_2 indoors	The CO_2 concentration of a space along with the respective outdoor concentration are measured for a period of interest (occupied hours).	ppm
	Formaldehyde	Formaldehyde concentration in the indoor air	µg/m³
	Radon	Radon concentration in the indoor air	Bq/m³
	Particulate matter <2,5 µm (PM 2.5)	Particles' that are 2,5 µm in diameter or smaller concentration in the indoor air.	µg/m³
	Particulate matter <10 µm (PM 10)	Particles' that are 10 µm in diameter or smaller concentration in the indoor air.	µg/m³

A.1.2 Thermal comfort

Usage	Indicator Name	Indicator Description	Units
Thermal comfort	Operative Temperature	It assesses the actual operative temperature within the building, which is the average of the air temperature and the mean radiant temperature, which accounts for the effects of both air temperature and radiant heat exchange.	°C
	Predicted Mean Vote	PMV is a numerical indicator used to predict the mean thermal sensation of a group of occupants. It takes into account various environmental factors, such as air temperature, humidity, air speed, and clothing insulation.	%
	Predicted Percentage of Dissatisfied	PPD is a percentage that estimates the thermal dissatisfaction of occupants based on predicted conditions. It complements the PMV by providing an estimate of the percentage of people likely to be dissatisfied with the thermal environment.	%
	Heating Degree Days	HDD represents the sum of the degree differences between the outdoor temperature and the base temperature (usually 18°C or 20°C) over a specified period. It is used to estimate the heating energy demand of a building.	°C-day
	Cooling Degree Days	CDD represents the sum of the degree differences between the outdoor temperature and the base temperature over a specified period. It is used to estimate the cooling energy demand of a building.	°C-day

A.2 Operational Rating Indicators

A.2.1 Lighting

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 lighting consumption. Follows a worked example:

$$\frac{\text{total lighting power consumption}}{\text{total floor area of the building}} = \frac{10227.6\ kWh}{487\ m^2} = 21.0\ \text{kWh}/\ m^2$$

Usage	Indicator Name	Indicator Description	Algorithm	Units
Lighting	Lighting per floor area	This indicator displays the total lighting power consumption of the building in kWh per the total area of the building.	$\frac{\text{total lighting power consumption}}{\text{total area of the building}}$	kWh/ m^2
	Lighting per thermally conditioned space	This indicator displays the total lighting power consumption of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total lighting power consumption}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Lighting per thermally unconditioned space	This indicator displays the total lighting power consumption of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total lighting power consumption}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Lighting per useful floor area	This indicator displays the total lighting power consumption of the building in kWh per the total useful floor area of the building.	$\frac{\text{total lighting power consumption}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Lighting per cooled space	This indicator displays the total lighting power consumption of the building in kWh per the total cooled space of the building.	$\frac{\text{total lighting power consumption}}{\text{total cooled space of the building}}$	kWh/ m^2

	Lighting per elementary space	This indicator displays the total lighting power consumption of the building in kWh per the total elementary space of the building.	$\frac{\text{total lighting power consumption}}{\text{total elementary space of the building}}$	kWh/ m^2
	Lighting per heated space	This indicator displays the total lighting power consumption of the building in kWh per the total heated space of the building.	$\frac{\text{total lighting power consumption}}{\text{total heated space of the building}}$	kWh/ m^2
	Building's Occupancy Correction Factor - Lighting Consumption	The energy consumption of a building is heavily influenced by the activities and behaviors of its occupants. A negative number is good; it represents energy savings in lighting due to efficient practices or technologies. A positive number is bad, since it indicates room for improvement in lighting energy consumption. A zero value indicates satisfactory performance.	---	---

A.2.2 Heating

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.

Usage	Indicator Name	Indicator Description	Algorithm	Units
Heating	Heating per floor area	This indicator displays the total heating power consumption of the building in kWh per the total area of the building.	$\frac{\text{total heating power consumption}}{\text{total area of the building}}$	kWh/ m^2
	Heating per thermally conditioned space	This indicator displays the total heating power consumption of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total heating power consumption}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Heating per thermally unconditioned space	This indicator displays the total heating power consumption of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total heating power consumption}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Heating per useful floor area	This indicator displays the total heating power consumption of the building in kWh per the total useful floor area of the building.	$\frac{\text{total heating power consumption}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Heating per elementary space	This indicator displays the total heating power consumption of the building in kWh per the total elementary space of the building.	$\frac{\text{total heating power consumption}}{\text{total elementary space of the building}}$	kWh/ m^2
	Heating per heated space	This indicator displays the total heating power consumption of the building in kWh per the total heated space of the building.	$\frac{\text{total heating power consumption}}{\text{total heated space of the building}}$	kWh/ m^2
	Climate Condition Correction Factor - Heating Energy	A negative number is good. It means the actual energy consumption of a building was avoided compared to the outdoor temperature and other climate factors usage from the baseline	---	---

	Consumption	model. A positive number is bad, since it means usage actually went up compared to the outdoor temperature and other climate factors from the baseline model.		

A.2.3 Cooling

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 cooling consumption. Follows a worked example:

$$\frac{\text{total cooling power consumption}}{\text{total cooled space of the building}} = \frac{12059.4\ kWh}{465\ m^2} = 24.8\ \text{kWh}/\ m^2$$

Usage	Indicator Name	Indicator Description	Algorithm	Units
Cooling	Cooling per floor area	This indicator displays the total cooling power consumption of the building in kWh per the total area of the building.	$\frac{\text{total cooling power consumption}}{\text{total area of the building}}$	kWh/ m^2
	Cooling per thermally conditioned space	This indicator displays the total cooling power consumption of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total cooling power consumption}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Cooling per thermally unconditioned space	This indicator displays the total cooling power consumption of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total cooling power consumption}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Cooling per useful floor area	This indicator displays the total cooling power consumption of the building in kWh per the total useful floor area of the building.	$\frac{\text{total cooling power consumption}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Cooling per cooled space	This indicator displays the total cooling power consumption of the building in kWh per the total cooled space of the building.	$\frac{\text{total cooling power consumption}}{\text{total cooled space of the building}}$	kWh/ m^2

	Cooling per elementary space	This indicator displays the total cooling power consumption of the building in kWh per the total elementary space of the building.	$\frac{\text{total cooling power consumption}}{\text{total elementary space of the building}}$	kWh/ m^2
	Climate Condition Correction Factor - Cooling Energy Consumption	A negative number is good. It means the actual energy consumption of a building was avoided compared to the outdoor temperature and other climate factors usage from the baseline model. A positive number is bad, since it means usage actually went up compared to the outdoor temperature and other climate factors from the baseline model.	---	---

A.2.3 Ventilation

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.

Usage	Indicator Name	Indicator Description	Algorithm	Units
Ventilation	Ventilation per floor area	This indicator displays the total ventilation power consumption of the building in kWh per the total area of the building.	$\frac{\text{total ventilation power consumption}}{\text{total area of the building}}$	kWh/ m^2
	Ventilation per thermally conditioned space	This indicator displays the total ventilation power consumption of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total ventilation power consumption}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Ventilation per thermally unconditioned space	This indicator displays the total ventilation power consumption of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total ventilation power consumption}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Ventilation per useful floor area	This indicator displays the total ventilation power consumption of the building in kWh per the total useful floor area of the building.	$\frac{\text{total ventilation power consumption}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Ventilation per cooled space	This indicator displays the total ventilation power consumption of the building in kWh per the total cooled space of the building.	$\frac{\text{total ventilation power consumption}}{\text{total cooled space of the building}}$	kWh/ m^2
	Ventilation per elementary space	This indicator displays the total ventilation power consumption of the building in kWh per the total elementary space of the building.	$\frac{\text{total ventilation power consumption}}{\text{total elementary space of the building}}$	kWh/ m^2
	Ventilation per heated space	This indicator displays the total ventilation power consumption of the building in kWh per the total heated space of the building.	$\frac{\text{total ventilation power consumption}}{\text{total heated space of the building}}$	kWh/ m^2
	Building's	The energy consumption of a building is heavily influenced by the	---	---

	Occupancy Correction Factor - Ventilation Consumption	activities and behaviors of its occupants. A negative number is good; it represents energy savings in lighting due to efficient practices or technologies. A positive number is bad, since it indicates room for improvement in lighting energy consumption. A zero value indicates satisfactory performance.		

A.2.4 Energy use for other services

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.

Usage	Indicator Name	Indicator Description	Algorithm	Units
Energy use for other services	Electrical appliances energy use per floor area	This indicator displays the total electrical appliances energy use of the building in kWh per the total area of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total area of the building}}$	kWh/ m^2
	Electrical appliances energy use per thermally conditioned space	This indicator displays the total electrical appliances energy use of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Electrical appliances energy use per thermally unconditioned space	This indicator displays the total electrical appliances energy use of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Electrical appliances energy use per useful floor area	This indicator displays the total electrical appliances energy use of the building in kWh per the total useful floor area of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Electrical appliances energy use per cooled space	This indicator displays the total electrical appliances energy use of the building in kWh per the total cooled space of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total cooled space of the building}}$	kWh/ m^2
	Electrical appliances energy use per elementary space	This indicator displays the total electrical appliances energy use of the building in kWh per the total elementary space of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total elementary space of the building}}$	kWh/ m^2

	Electrical appliances energy use per heated space	This indicator displays the total electrical appliances energy use of the building in kWh per the total heated space of the building.	$\frac{\text{total electrical appliances energy use}}{\text{total heated space of the building}}$	kWh/ m^2
	Building’s Occupancy Correction Factor – Electrical Appliances Energy Usage	The energy consumption of a building is heavily influenced by the activities and behaviors of its occupants. A negative number is good as it suggests energy savings due to lower occupancy. A positive number is bad, as it indicates higher energy consumption associated with higher occupancy levels compared to the baseline model's assumptions	---	---

A.2.5 Water heating

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.

Usage	Indicator Name	Indicator Description	Algorithm	Units
Water heating	Water heating consumption per floor area	This indicator displays the total water heating consumption of the building in kWh per the total area of the building.	$\frac{\text{total water heating consumption}}{\text{total area of the building}}$	kWh/ m^2
	Water heating consumption per thermally conditioned space	This indicator displays the total water heating consumption of the building in kWh per the total thermally conditioned space of the building.	$\frac{\text{total water heating consumption}}{\text{total thermally conditioned space of the building}}$	kWh/ m^2
	Water heating consumption per thermally unconditioned space	This indicator displays the total water heating consumption of the building in kWh per the total thermally unconditioned space of the building.	$\frac{\text{total water heating consumption}}{\text{total thermally unconditioned space of the building}}$	kWh/ m^2
	Water heating consumption per useful floor area	This indicator displays the total water heating consumption of the building in kWh per the total useful floor area of the building.	$\frac{\text{total water heating consumption}}{\text{total useful floor area of the building}}$	kWh/ m^2
	Water heating consumption per cooled space	This indicator displays the total water heating consumption of the building in kWh per the total cooled space of the building.	$\frac{\text{total water heating consumption}}{\text{total cooled space of the building}}$	kWh/ m^2
	Water heating	This indicator displays the total water heating consumption of the	$\frac{\text{total water heating consumption}}{\text{total elementary space of the building}}$	kWh/ m^2

	consumption per elementary space	building in kWh per the total elementary space of the building.		
	Water heating consumption per heated space	This indicator displays the total water heating consumption of the building in kWh per the total heated space of the building.	$\frac{\text{total water heating consumption}}{\text{total heated space of the building}}$	kWh/ m^2
	Building's Occupancy Correction Factor – Water Heating Consumption	The energy consumption of a building is heavily influenced by the activities and behaviors of its occupants. A negative number is good as it implies that the actual water heating energy consumption is lower than what was expected based on baseline assumptions. A positive number is bad, as it indicates higher water heating energy consumption than anticipated based on the baseline model, which might suggest potential inefficiencies or wasteful behavior.	---	---

A.3 Financial Indicators

A.3.1 As-designed

The input for these indicators involves the asset energy consumption of the building per energy price.

Usage	Indicator Name	Indicator Description	Algorithm	Units
As-designed	Total energy cost per square meter per month	This indicator presents the total energy costs based on the design information, per square meter, per time unit of month	$\frac{\text{monthly average designed energy consumption} \times \text{energy price}}{\text{total floor area}}$	€/m2/month
	Total energy cost per square meter per year	This indicator presents the total energy costs based on the design information, per square meter, per time unit of year	$\frac{annual\ designed\ energy\ consumption \times energy\ price}{total\ floor\ area}$	€/m2/year

A.3.2 As-operated

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.

Usage	Indicator Name	Indicator Description	Algorithm	Units
As-operated	Cost per energy use per square meter per month	This indicator presents the energy costs based on the actual energy use per use, per square meter, per time unit of month	$\frac{\text{monthly actual energy consumption per use} \times \text{energy price}}{\text{total floor area}}$	€/m²/month
	Cost per energy use per square meter per year	This indicator presents the energy costs based on the actual energy use, per use, per square meter, per time unit of year	$\frac{\text{annual actual energy consumption per use} \times \text{energy price}}{\text{total floor area}}$	€/m²/year
	Cost per energy carrier per square meter per month	This indicator presents the energy costs based on the actual energy use, per carrier, per square meter, per time unit of month	$\frac{\text{monthly actual energy consumption per carrier} \times \text{energy price}}{\text{total floor area}}$	€/m²/month
	Cost per energy carrier per square meter per year	This indicator presents the energy costs based on the actual energy use, per carrier, per square meter, per time unit of year	$\frac{\text{annual actual energy consumption per carrier} \times \text{energy price}}{\text{total floor area}}$	€/m²/year
	Total energy cost per square meter per month	This indicator presents the energy costs based on the actual energy use, per use, per square meter, per time unit of month	$\frac{\text{total monthly actual energy consumption} \times \text{energy price}}{\text{total floor area}}$	€/m²/month
	Total energy cost per square meter per year	This indicator presents the energy costs based on the actual energy use, per use, per square meter, per time unit of year	$\frac{\text{total annual actual energy consumption} \times \text{energy price}}{\text{total floor area}}$	€/m²/year

A.3.3 Predicted

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.).

Usage	Indicator Name	Indicator Description	Algorithm	Units
Predicted	Cost per energy use per square meter for ten (10) years	This indicator presents the predicted energy costs, including the future costs of maintenance and operation, based on the actual energy use, per use, per square meter, for the period of ten (10) years	$\frac{\text{NPV of energy cost per use in 10 years}}{\text{total floor area}}$	€/m²
	Cost per energy carrier per square meter for ten (10) years	This indicator presents the predicted energy costs, including the future costs of maintenance and operation, based on the actual energy use, per carrier, per square meter, for the period of ten (10) years	$\frac{\text{NPV of energy cost per carrier in 10 years}}{\text{total floor area}}$	€/m²
	Total energy cost per square meter for ten (10) years	This indicator presents the predicted energy costs, including the future costs of maintenance and operation, based on the actual energy use, per use, per square meter, for the period of ten (10) years	$\frac{\text{NPV of total energy and maintenance and operation costs in 10 years}}{\text{total floor area}}$	€/m²

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

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

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