Building Performance Module v2

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Executive Summary

This report covers the development of D^2EPC core Calculation Engine, which includes the Asset Rating Module, the Operational Rating module, and the Building Performance Module (BPM). The inclusion of the first two components in this deliverable was considered, as they are closely related to the BPM. A complete view of the Calculation Engine was also provided, as presented in D1.9 D^2EPC Framework Architecture and Specifications v3. The document presents a detailed description of the main activities for the implementation of the sub-modules, along with their functionalities. The deliverable also outlines the actual implementation of the components, presenting the finalised view throughout the course of the project. The document is divided into three main sections (methodologies, development, and results), as described below.

The first part aims to provide an overview of the proposed holistic energy performance certification scheme. The section provides an overview of the methodologies either applied or developed within the scope of the project. Starting with the Asset Rating methodology, the document presents the D^2EPC calculation methodology adopted based on the EN ISO 52000 series of standards. The Operational Rating module is based on a custom-made methodology within the scope of the project. As a result, the document includes the fundamental methodology concept that led to the creation of CEN TC371/WG5 for the standardisation of the methodology for operational assessment of buildings. Proceeding to the BPM, the document presents the set of indicators as derived from the four calculation submodules. The D^2EPC Information Model described at the end of Chapter 2 illustrates the mechanisms used to extract the required information for the calculations from the building's BIM file (IFC format) in order to facilitate the various calculations in a joint certification scheme.

Chapter 3 delves into the developmental aspects of each tool, offering an in-depth depiction of each tool in its finalized form. In particular, the chapter provides detailed descriptions of the developed functions and classes responsible for carrying out the calculations according to the above-described methodologies. This presentation provides the end-user with a comprehensive understanding of how information flows within the tool and the specific functionalities it encompasses. Moreover, the chapter refers to the datasets used to support the calculation procedures, along with an analysis of the procedure followed for gathering them from national-level literature. The majority of the utilised data sets are also provided in the Annex.

Chapter 4 provides a description of the interface for each tool. It outlines the step-by-step procedure required for configuring and validating the building assessment model. The detailed description of this process can be found in D5.6 for D^2EPC Manual. Additionally, the chapter elaborates on the interface for the results from each tool. The platform's capabilities to export charts from the results of each tool are described, and an explanation is given for each tool. It also provides explanations for the charts and diagrams included in the visual representation of the results. The presented results are derived from the assessment of CS1, even though the described modules have been tested at all the pilot buildings (the full description is provided in D5.8).

In conclusion, D4.5 provides an in-depth illustration of the core energy performance assessment modules in the D^2EPC platform. With this document, the end-user can have a clear view of the scope and main functionalities behind the operation of each module.

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List of Acronyms and Abbreviations

Term	Description
API	Application Programming Interface
AR	Asset Rating
ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers
BAC	Building Automation and Control
BDT	Building Digital Twin
BEM	Building Energy Modelling
BIM	Building Information Modelling
BPM	Building Performance Module
CS	Case Study
CSV	Comma-separated Values
DHW	Domestic Hot Water
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EPD	Energy Performance Declaration
EU	European Union
HC&W	Human Comfort & Wellbeing
HVAC	Heating Ventilation Air-Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Class
IML	Information Management Layer
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
JRC	Joint Research Centre
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MS	Member State
OR	Operational Rating
PM	Particulate Matter
SRI	Smart Readiness Indicator
TABS	Thermal Activated Building Systems
TVOCs	Total Volatile Organic Compounds
WBGT	Wet-bulb Globe Temperature

1 Introduction

1.1 Scope and objectives of the deliverable

This deliverable provides an in-depth analysis of the calculation components included in the building performance module as specified in WP4, their basic features and functionalities, as well as their development process. Starting from the theoretical background, the document provides a high-level description of the applied methodologies, which examine the building's energy performance in a holistic certification scheme. In addition, the document offers supplementary information detailing the calculation of each indicator from both an algorithmic and a development perspective.

The development of the three main calculation modules is aligned with the project's system architecture (as described in D1.9). Furthermore, their development took into consideration the required push and pull data interfaces (e.g. Rest API), that enable the tools to operate as a web certification service.

1.2 Structure of the deliverable

This report provides a step-by-step description of all processes followed and their results for the calculation of the D^2EPC holistic certification scheme's indicators. To cover all these facets, this report is organised as follows:

- **Chapter 2** provides a synoptic and coherent view form the adopted methodologies, as developed in WP2;
- **Chapter 3** demonstrates the basic functionalities of the included calculation modules and describes the development procedure;
- **Chapter 4** presents the results of the calculation modules from their application on the pilot buildings;
- **Chapter 5** highlights the main conclusions that derive from the above-described procedures as well as indicates actions for future enhancements.

1.3 Relation to Other Tasks and Deliverables

T4.1 is one of the core development tasks in D^2EPC, thus it is closely related both to the theoretical work implemented in the previous tasks as well as to the tasks responsible for the development of the D^2EPC platform. The modules' development is aligned with the architecture created in T1.4 and its updated version in D1.9. The development of the calculation submodules in this task is based on the work that has been done under WP2. More specifically, the SRI, Human Comfort, LCA, and LCC are based on T2.1, T2.2, T2.3, and T2.4 respectively. Additionally, the development of the Asset and Operational Energy Performance Rating calculation modules is based on the work that has been performed by the two working groups formulated during the project for this purpose as part of T5.1 (i.e. WG1 for the asset rating and WG2 for the operational rating). The retrieval of the relevant building information requires close collaboration with the work performed for the building documentation in T2.5 and T3.3. Finally, the rest of the core development tasks in WP4 (T4.2, T4.3 and T4.3) are using the work implemented in this task as a basis to create the rest of the platform's calculation functionalities.

2 Background and applied methodologies

This section provides an analytical background description of the two incorporated certification methodologies as well as the included indicators in the holistic D^2EPC certification scheme. The following sections explain the status of the present EPC market and provide an overview of the novelties introduced by D^2EPC. This chapter sets the ground for the reader to comprehend the implementation of the respective calculation modules in Chapter 3.

2.1 Asset rating

One of the fundamental calculation components for the development of the D^2EPC certification scheme is the Asset Rating module. The extensive building documentation requirements along with the complex calculation procedures urged its development from the initial stages of this project. Even though the Asset Rating methodology is a well-established concept in the domain of energy certification for buildings, as described in D1.3, its development within the scope of D^2EPC faced a series of challenges. This section gives an overview of current practices in this domain and analyzes the approach followed within the scope of this project.

The Asset Rating methodology is used to estimate the building's energy performance with the use of building energy modelling (BEM) techniques. The building's model is created by taking into account the information that defines the thermal performance of the building envelope and the energy performance of the building systems. Furthermore, pre-defined data sets are used to set the indoor and outdoor environmental conditions. It is important to highlight that the methodology does not take into consideration the building's actual operation, as the goal is to assess the energy performance of the building's structure.

Up to now, several Asset Rating schemes have been developed and implemented on a national or regional level. This strategy resulted in disparities between the various EPC schemes developed throughout the EU MSs. As an example, several countries utilise the "Reference Building" technique to classify a building's energy efficiency, whereas others rely only on values that describe the boundaries of the classes (e.g. kWh.m^2) [1]. The differences among the various methodologies result in disparities in the description of the building models. As a result, the European building stock is not described in a uniform manner, which complicates the examination of its energy behaviour. Moreover, the conventional building documentation approach with extensive building audits lengthens the issuance time, escalates the cost of Energy Performance Certificates (EPCs), and introduces the potential for human errors or biased results.

D^2EPC aims to tackle the two above-described deficiencies of the current certification schemes. Firstly, the developed approach seeks to adopt BIM literacy techniques in order to minimise the assessor's time and effort required for the construction of the building model and at the same time reduce the margin for errors in the model. Special emphasis has been given in mapping the methodology input requirements with the existing building documentation in BIM modelling. Even though a typical IFC file contains several information about the geometrical and thermal characteristics of the building envelope, it may lack several information related to the EPC certification. As a result, the assessor's role remains critical during the EPC procedure, despite the advanced automation in the proposed scheme. In *D5.6 D^2EPC Manual V2* there is a detailed list of guidelines that indicate to the assessor the required information fields for conducting an asset rating assessment with the developed module. In the introduced certification process, the assessor also is responsible for the compliance of the model with the platform's requirements and ensures the correctness of the resulted energy values.

Moreover, D^2EPC aims to tackle the misalignments created by the plethora of national EPC schemes by introducing an EU-based certification approach. The EN ISO 52000:2017 family of standards [2] was adopted for the calculation engine's implementation. This choice is based on the revised European Energy Performance of Buildings Directive (EPBD:2018 [3]), Annex I:

"Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN). This provision shall not constitute a legal codification of those standards."

Figure 1 gives an overview of the five overarching standards, which indicate the required sets of information and the flow of energy calculations. Although the standards do not provide all the required information to perform the EPC assessment. The role of national EPC approaches is also crucial in the introduced EU-based Asset rating scheme. For instance, climate (weather statistics) and energy carrier related data sets were adopted from the methodologies' implementation on a national level, along with several characteristics that may be added from the national schemes (e.g., reference building definition). In this way, the energy classification of the European building stock can be performed in a uniform manner, while each country can maintain the characteristics of their national EPC schemes. The implementation of this scheme has been investigated at the three countries with pilot buildings involved in the project: Greece; Cyprus and Germany.

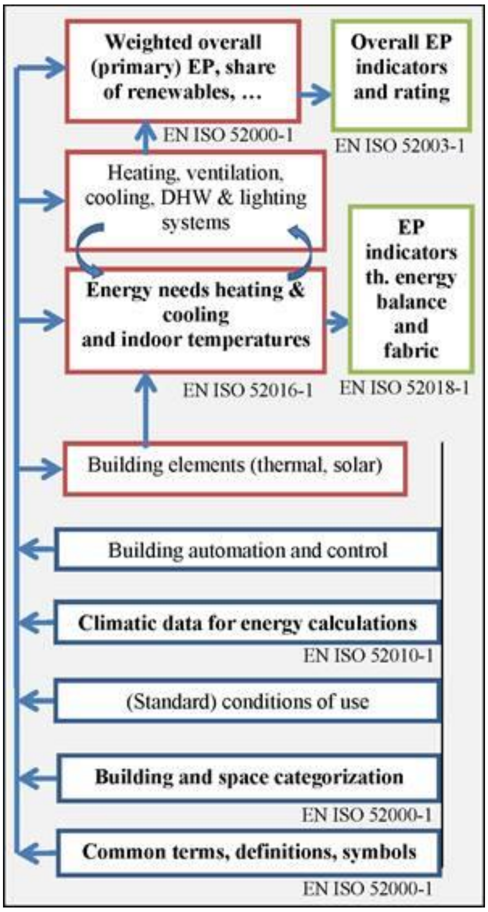


Figure 1: Flow chart of the set of EPB standards with position of the five 'overarching' EPB standards [4]

The module's development has been made as part of a holistic platform, where it is able to interact with the other modules as described in *D1.9 D^2EPC Framework Architecture and specifications v3*. Starting from the Building Digital Twin (BDT) the Asset Rating Module receives all the necessary information to conduct the calculations. Furthermore, the interactions with the Roadmapping Tool equiped with advanced retrofitting scenario evaluation capabilities, which is able to propose more accurate and efficient solutions to upgrade the energy efficiency of the examined asset.

2.1.1 Calculation Methodology

The approach followed by D^2EPC for the development of the D^2EPC Asset Rating scheme is based on a set of commonly accepted standards among the European MS. In particular, the following three main standards have been utilized for the adoption of the implemented practices:

- **ISO 52000-1:2017**, Energy performance of buildings – Overarching EPB assessment – Part 1: General framework and procedures [5].
- **ISO 52003-1:2017**, Energy performance of buildings – Indicators, requirements, ratings and certificates – Part 1: General aspects and application to the overall energy performance [6].
- **ISO 52016-1:2017,** Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedure.

Each standard provides a framework that addresses specific parts of the procedure, as stated by their titles.

The energy performance calculation is performed on a monthly step. Opting for the monthly calculation method, as opposed to an hourly approach, reduces the computational workload, simplifies building documentation demands, and subsequently minimizes the effort required from the user. This is especially important as manual inputs often introduce uncertainties and compromise overall accuracy, as elaborated earlier. Conversely, the methodology necessitates a series of correlation or adjustment factors. These factors serve to address the dynamic impact of heat transfer within a building through a statistical approach.

From a high-level point of view the whole calculation procedure has three main phases (Figure 2). Starting from the Energy Demand calculations the algorithms examine the amount of energy needed to perform the requested energy services (e.g. heating, cooling) according to a predefined set of parameters that define the indoor and outdoor operational conditions. Secondly, the methodology calculates the amount of delivered energy, the energy generated on site (in case of RES installation) or the exported energy to cover the calculated energy demand. Finally, the various energy streams from the previous phase are homogenized into primary energy to bridge the gap from the different energy sources.

Figure 2: Asset Rating calculation phases

The above-described calculation is conducted once for the examined building and in parallel for the Reference building. The latter is a theoretical building with identical geometric characteristics, but it is defined by an set of predefined values for the thermal characteristics of the building envelope and the deployed technical systems. The final EPC rating results from this comparison.

In the following paragraphs the flow of calculations from energy demand to delivered and exported energy is demonstrated, as well as the calculation of the total primary energy. It is important to highlight that the scope of this report is to give the user a high-level view of the methodology's flow of calculations and not to dive into the calculation details.

2.1.1.1 Energy Demand Calculation

The first stage of energy calculations aims to estimate the building's demand for energy according to the services included in its operation. Depending on the building type, there are different specific energy needs for each energy service. According to the building type, the set of services includes Heating, Cooling and DHW and Lighting. Figure 3 illustrates the flow of calculations.

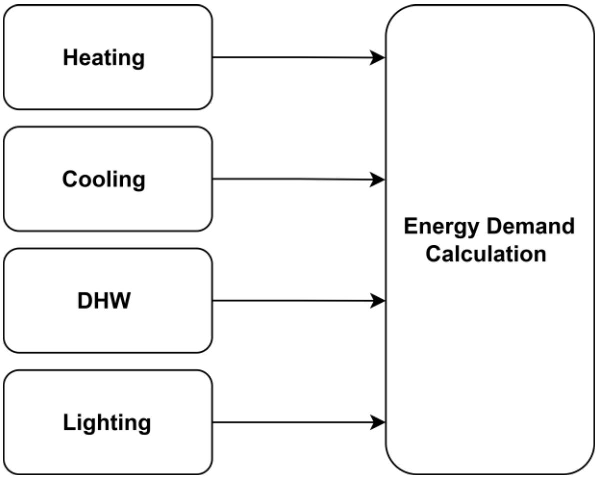


Figure 3: Energy Demand

Nevertheless, determining the monthly energy demand for heating and cooling requires an additional set of calculations that must be implemented prior to the Energy demand calculations. In this routine, the Asset Rating module takes into consideration the thermal characteristics of the building envelope as well as, the type of the examined thermal zone to estimate the heating or cooling load for each month. The heating load for each month is calculated based on the following equation:

$$\begin{aligned} Heating\ Load = \ & Transmission\ Heat\ Losses + Ventilation\ Heat\ Losses \\ & - Internal\ Heat\ Gains - Solar\ Gains \end{aligned} \tag{1}$$

2.1.1.2 Delivered Energy Calculation

The next step is to calculate the delivered energy for each distinct service. At this stage, the characteristics of the installed technical systems are taken into consideration to calculate the delivered energy demand from the value of energy demand from the previous calculation stage. The calculation is made with the use of the following formula:

$$E_{HC;del} = \frac{E_{HC;nd}}{\eta} \tag{2}$$

Where

- $E_{HC;del}$ is the delivered energy for heating / cooling, in kWh;
- $E_{HC;nd}$ is the energy need for heating / cooling, in kWh;
- η is the energy efficiency of the specific system employed to cover the required energy needs.

The algorithm also takes into consideration the energy production from the on-site renewable energy sources (RES). Therefore, for each energy service the calculation flow of the delivered energy takes the form as presented in Figure 4.

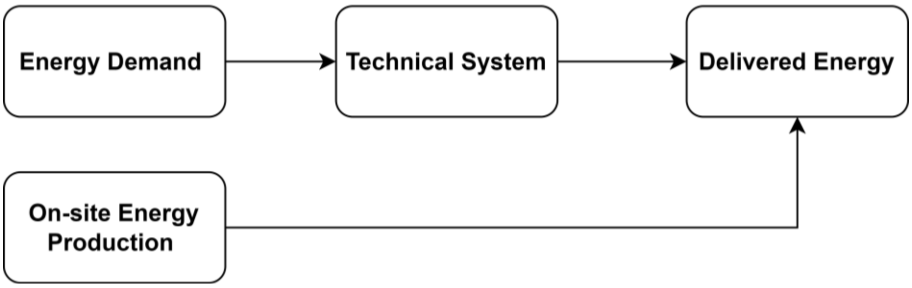


Figure 4: Delivered energy calculation flow.

Figure 5 presents an overview of the input sources of data utilized in the calculation procedure.

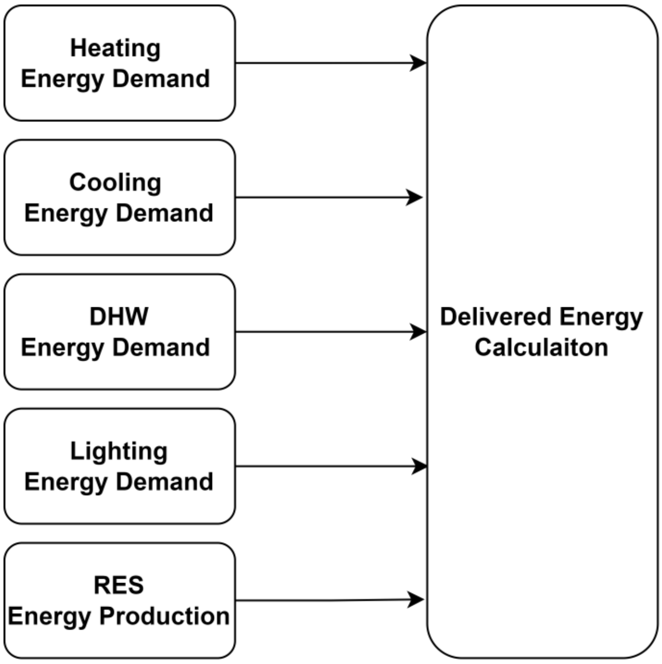


Figure 5: Delivered Energy Calculation

2.1.1.3 Primary energy calculations

Primary energy is a metric (or indicator) that is used as a common reference value to evaluate the energy delivered and the exported energy from/ by the various energy sources used in a building. As stated in standard EN ISO 52000-1:2017 [5] the primary energy is calculated with the use of primary energy factors, as shown in the following equation:

$$E_{we;del/exp;an} = f \cdot E_{del/exp;an} \tag{3}$$

Where

- $E_{we;del/exp;an}$ is the annual weighted delivered or exported energy, in kWh/m^2/yr;
- f is the primary energy factor;
- $E_{del/exp;an}$ is the final delivered or exported energy, in kWh/m^2/yr.

The primary energy factors for the conversion from final delivered to primary energy are defined at a national level, as described in Section 3.1.1.3. Figure 6 demonstrates the primary energy calculation procedure per energy carrier for all the previous stated energy services. Lastly, the weighted overall primary energy performance is given by the following equation, as stated in standard EN ISO 52000-1:2017 [5].

$$E_{we} = E_{we;del;an} - E_{we;exp;an} \tag{4}$$

Where

- $E_{we;del;an}$ is the annual weighted delivered energy, in kWh/m^2/yr
- $E_{we;exp;an}$ is the annual weighted exported energy, in kWh/m^2/yr

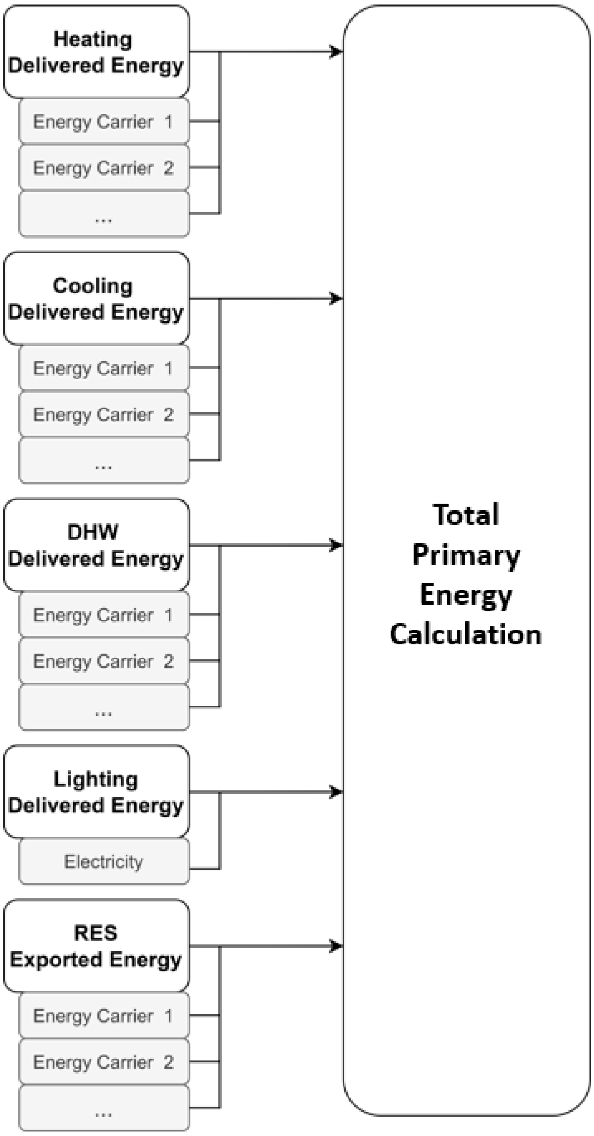


Figure 6: Primary Energy Calculation

2.1.1.4 Reference Building

The Reference Building concept is introduced to the Asset Rating methodology in order to compare the energy performance of the examined building with the correspondent value of the same building, built according to the minimum requirements of the national building codes. By definition, the reference building shares the same characteristics as the examined building, as follows:

- Geometry
- Orientation
- Use
- Standardised operation characteristics
- Climatic conditions

The differences with the actual building as examined by the thermal characteristics of the building elements (e.g. U-value), the construction's airtightness, as well as the characteristics of the technical systems (e.g. HVAC, Lighting). The weighted overall energy performance of the reference building is calculated based on predetermined reference values and is used for the energy classification procedure, as described in the following section.

2.1.1.5 Energy Class

The energy classification is based on the ratio of the examined building's primary energy consumption to the correspondent Reference Building value. This ratio is denoted as Asset Rating (AR) and it is determined with the following formula:

$$AR = f \cdot \frac{E_{we}}{E_{we;ref}} \quad (5)$$

Where

- E_{we} is the weighted overall energy performance, in kWh/m^2/yr.
- $E_{we;ref}$ is the weighted overall energy performance of a reference building, in kWh/m^2/yr.
- f is an optional dimensionless constant scale factor. In this case is considered to be equal to 1.

The final energy performance class of the examined building is determined by the presented limit values in Table 1.

Table 1: EPC ratings [6]

Class	Condition
A	0 R_r< AR≤ 0.35 R_r
B	0.35 R_r<AR≤ 0.5 R_r
C	0.5 R_r<AR≤ 0.71 R_r
D	0.71 R_r<AR≤ 1.00 R_r
E	1.00 R_r<AR≤ 1.41 R_r
F	1.41 R_r<AR≤ 2.00 R_r
G	2.00R_s ≤ AR

Where

- R_r is the energy performance regulation reference.

2.1.2 Asset Rating Indicators

The major indicator of the Asset Rating scheme is the building's energy class. The representation of the building's energy performance with a letter from A to G, simplifies the interpretation of the results by the public, who are also the main end-users. Nevertheless, the results generated from each one of the three calculation phases can be used as indicators, mainly targeted to the building engineers and EPC assessors. The calculated values per energy service can provide a clear picture about the energy consumption in a building structure and indicate the paths for future improvements. Therefore, the Asset Rating module provides the monthly results for each energy service in the three phases: Energy Demand, Final Energy and Primary Energy. In parallel, the tool calculates the as-designed values for the economic performance and the CO_2 emissions. All the results are provided as absolute energy values (kWh) or as normalized values per area (kWh/m^2).

2.2 Operational Rating

Recognizing the significant gap in European methodologies for assessing the energy performance of buildings based on their energy consumption and operational values, the D^2EPC project took the initiative to develop a common EU-based assessment scheme. Drawing insights from the findings of T1.3 regarding the current market stage and the key functionalities that need to be addressed, D^2EPC has resulted to a comprehensive methodology for evaluating the operational energy performance of buildings in the EU.

The subsequent section outlines the workflow methodology for the four main functionalities: data acquisition, validation, processing, and storage. The Operational Rating methodology generates essential Key Performance Indicators (KPIs) to describe the energy performance of a building across six main energy services (heating, cooling, DHW, lighting, electrical appliances, and total energy usage). The measured values normalized per building area, volume, occupancy, and occupancy-hours to facilitate the benchmarking and energy classification of the building. Notably, this methodology has laid the foundation for the initialization of CEN TC371/WG5, a dedicated working group on "Operational Rating of energy performance of buildings." The goal of this standardization effort is to elevate the project's findings to a standard that streamlines the operational assessment of the EU building stock in line with the objectives outlined in this project's scope.

2.2.1 Calculation Methodology

Operational rating methodology is a multistep procedure that acquires, validates, processes, and stores data, in order to produce meaningful results for the energy consumption behaviour of the building owner. Each procedure has a critical role in the tool’s smooth operation and accuracy of results.Figure 7 illustrates the calculation steps of operational rating methodology of D^2EPC:

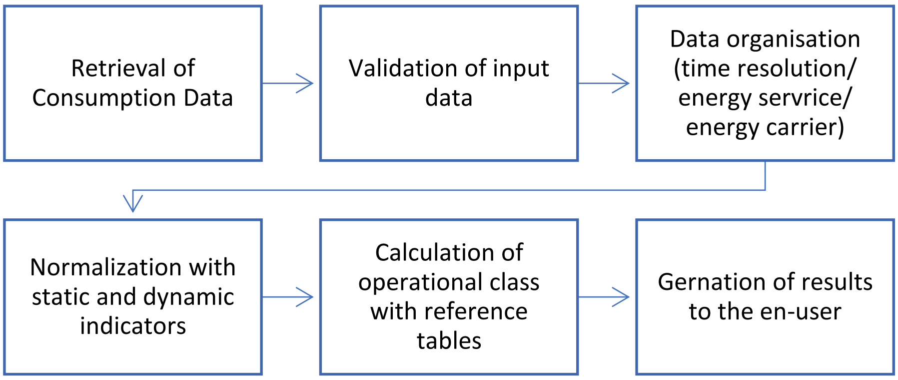


Figure 7: Operational Rating flow of calculations

2.2.1.1 Data acquisition

The first step towards the operational rating (OR) issuance is the retrieval of consumption data. OR has integrated Digital Twin functionality resulting in data retrieval from the D^2EPC repository. It is worth mentioning that the context of data must satisfy specific constraints. Towards the issuance of OR the data must refer at least to 12-month measurements, in a daily or shorter resolution. Also, it is mandatory to provide measuring data for the heating service. In case of two constraints are violated, the OR module is not able to produce results.

2.2.1.2 Validation Procedure

The accuracy of the OR module requires the implementation of validation procedures regarding BIM’s data and measurement timestamps. Validation procedures ensure that the EPC assessor has inserted the required BIM data for the meter characteristics (e.g., meter id) and general building characteristics (e.g., building usage). The timestamp validation secures that all measurements are chronically aligned. Furthermore, the Digital Twin assists the OR module by providing validation procedures for handling cumulative data and adapting the measurements accordingly.

2.2.1.3 Data Processing

Data processing consists of a structured phase where data is organized in a multi-level structure to produce the final results. The first level identifies the general building characteristics, reference classification boundaries, and organizes the measurement characteristics. Building general characteristics refer to construction year or building usage. Reference values, Measurement characteristics refer to the measurement area, the occupants of the measurement area, and the measurement time series. The second level divides data according to the time resolution into daily, monthly, and annual values. The third level of data processing converts the main measurements from final energy to primary energy and cost. Following Level 4 organizes data based on energy service and energy carrier. The overall data processing, which aims to prepare the tool's results is described in Figure 8.

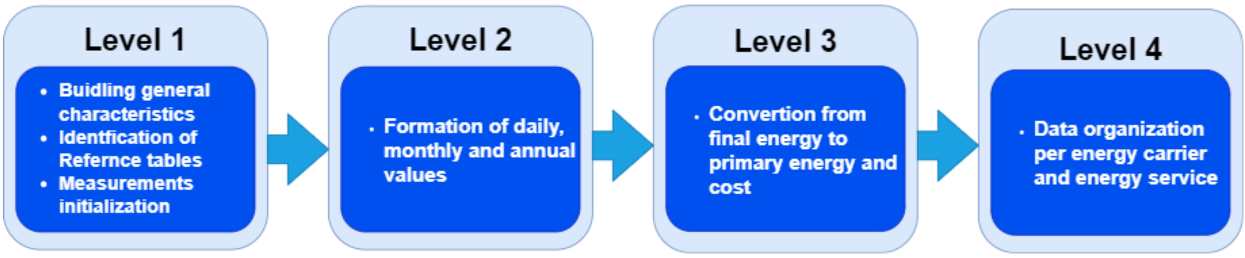


Figure 8: Overview of operational data processing

2.2.1.4 Storage practice

The generated results of the tool are stored in the repository in order to be visualized on the project's Web Platform. Moreover, the tool generates useful messages for the building owner which are integrated with Alerts and Notification Module to provide notifications for user energy behaviour.

2.2.2 Operational Rating Indicators

2.2.2.1 Power

The first energy indicators concern the total power consumption of the building.

2.2.2.1.1 Total Power/Occupancy

This indicator shows the ratio of the total power consumption of the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{total power consumption}}{\text{total number of occupants}}$$

2.2.2.1.2 Total Power/Occupancy-Hours

This indicator shows the ratio of the total power consumption of the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{total power consumption}}{\text{total number of occupants} * \text{hours of the occupants spend in the building}}$$

2.2.2.1.3 Total Power/Area

This indicator displays the ratio of the total power consumption of the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{total power consumption}}{\text{total surface area}}$$

2.2.2.1.4 Total Power/Volume

This indicator displays the ratio of the total power consumption of the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{total power consumption}}{\text{total volume of the building}}$$

2.2.2.2 Heating

It is noted that the operational assessment of heating consumption is conducted per energy carrier. In those cases that there is a sole energy carrier for heating, the indicators specified per carrier are equal to the indicators specified per total energy.

These indicators are about the power consumption needed for heating per energy carrier in a building.

2.2.2.2.1 Heating consumption/Occupancy

This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{heating power consumption per energy carrier}}{\text{total number of occupants}}$$

2.2.2.2.2 Heating consumption/Occupancy-Hours

This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{heating power consumption per energy carrier}}{\text{total number of occupants} * \text{hours of the occupants spend in the building}}$$

2.2.2.2.3 Heating consumption/Area

This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{heating power consumption per energy carrier}}{\text{total area of the building}}$$

2.2.2.2.4 Heating consumption/Volume

This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{heating power consumption per energy carrier}}{\text{total volume of the building}}$$

2.2.2.3 Cooling

It is noted that the operational assessment of heating consumption is conducted per energy carrier. In cases where there is a sole energy carrier for heating, the indicators specified per carrier are equal to those specified per total energy.

These indicators are about the power consumption needed for cooling in a building.

2.2.2.3.1 Cooling consumption/Occupancy

This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total number of occupants}}$$

2.2.2.3.2 Cooling consumption/Occupancy-Hours

This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total number of occupants} * \text{hours of the occupants spend in the building}}$$

2.2.2.3.3 Cooling consumption/Area

This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total area of the building}}$$

2.2.2.3.4 Cooling consumption/Volume

This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total volume of the building}}$$

2.2.2.4 Lighting

These indicators are concerning the power consumption used for the lighting of the building.

2.2.2.4.1 Lighting/Occupancy

This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{total lighting power consumption}}{\text{total number of occupants}}$$

2.2.2.4.2 Lighting/Occupancy-Hours

This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{total lighting power consumption}}{\text{total number of occupants} * \text{hours of the occupants spend in the building}}$$

2.2.2.4.3 Lighting/Area

This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{total lighting power consumption}}{\text{total area of the building}}$$

2.2.2.4.4 Lighting/Volume

This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{total lighting power consumption}}{\text{total volume of the building}}$$

2.2.2.5 Electrical Appliances Energy Consumption

These indicators are concerning the total energy consumption of the electric appliances of the building.

2.2.2.5.1 Electrical Appliances Energy Consumption /Occupancy

This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total number of occupants}}$$

2.2.2.5.2 Electrical Appliances Energy Consumption /Occupancy-Hours

This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total number of occupants} * \text{hours of the occupants spend in the building}}$$

2.2.2.5.3 Electrical Appliances Energy Consumption /Area

This indicator displays the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total area of the building}}$$

2.2.2.5.4 Electrical Appliances Energy Consumption /Volume

This indicator displays the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total volume of the building}}$$

2.2.2.6 Domestic Hot Water

It is noted that the operational assessment of domestic hot water (DHW) consumption is conducted per energy carrier. In those cases that there is a sole energy carrier for DHW, the indicators specified per carrier are equal to the indicators specified per total energy.

These indicators are about the power consumption needed for DHW per energy carrier in a building.

2.2.2.6.1 DHW consumption/Occupancy

This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of occupants (kWh/occupants)

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total number of occupants}}$$

2.2.2.6.2 DHW consumption/Occupancy-Hours

This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building (kWh/h*occupants)

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total number of occupants} * \text{hours of the occupants in the building}}$$

2.2.2.6.3 DHW consumption/Area

This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total surface area of the building (kWh/m^2)

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total area of the building}}$$

2.2.2.6.4 DHW consumption/Volume

This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total volume of the building (kWh/m^3)

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total volume of the building}}$$

2.3 Building Performance additional indicators

D^2EPC aims to increase the usability and efficiency of the next generation of EPCs by adding a wide range of indicators related to the smartness of buildings (SRI), their environmental performance and environmental efficiency, Life Cycle Assessment and financial indicators, as well as human comfort aspects. The chapters below introduce a set of indicators related to smart readiness, thermal comfort, life cycle assessment and financial indicators that are monetarily and economically optimal. Those indicators resulted from the activities of WP2 (T2.1-T2.4) and more details can be found in the respective deliverables.

2.3.1 Smart Readiness Indicators

The SRI scheme measures the "intelligence" of a building by assessing the extent to which a building can adapt its performance to the needs of its users.

The energy supply network while maintaining energy efficiency and performance. The main objectives of the SRI are to raise awareness of the benefits of smart technologies, promote the deployment of smart technologies, and increase the use of Information and Communication Technology (ICT) based products for monitoring and controlling energy use in buildings.

2.3.1.1 Calculation of Smart Readiness Indicators

In the D^2EPC project, the SRI extraction process (Figure 9) was implemented using the IFC BIM file (IFC4 schema). Based on the current capability of IFC4 to define building automation systems, the first SRI layer can, in principle, be evaluated automatically by the D^2EPC plug-in. For the first layer of the SRI to be successfully evaluated, the evaluator is asked to ensure that the "minimum modelling requirements" are met. These "minimum modelling requirements" activate the sorting process where services must be included or excluded in the counting mechanism.

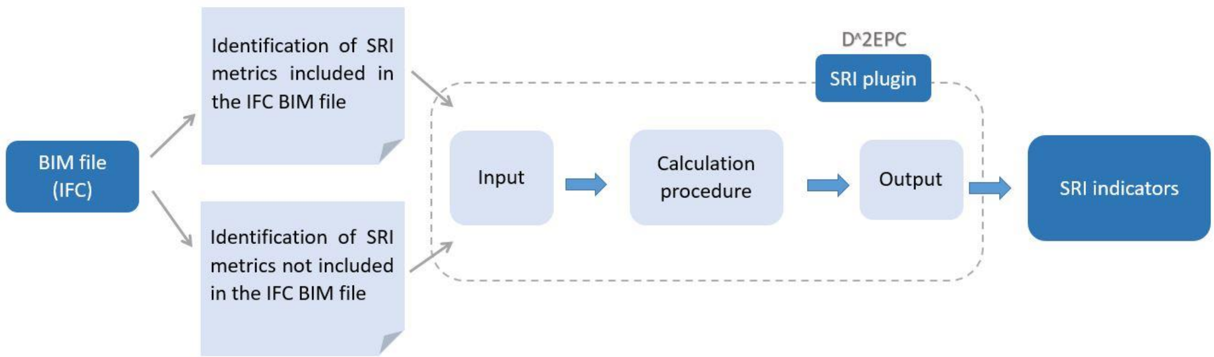


Figure 9: D^2EPC SRI Indicators Extraction

Due to the limitations of the IFC4 schema to comprehensively define the functionality levels of complex automation operations, the rating of the functionality levels is requested from the assessor within the D^2EPC SRI page in the web-platform. The features that need to be defined for the purpose of the SRI first layer are the following:

- Heating: Presence of Heating system, Emission Type, Production Type.
- Domestic Hot Water (DHW): Presence of Domestic Hot water, Production Type, Solar Collector.
- Cooling: Presence of cooling system, Emission Type.

- Controlled Ventilation: Presence of controlled ventilation system, System Type, Heat Recovery.
- Dynamic Envelope: Presence of dynamic Envelope system.
- Electricity: Renewables & Storage: Presence of Renewables, on-site renewable electricity generation, Storage of on-site generated renewable electricity, CHP (Combined Heat and Power).
- Electric Vehicle: Not supported by IFC.
-

2.3.1.2 Smart Readiness indicators

SRI indicators presented in this sub-section are a result of assessment of up to 54 functionality levels of various building systems present in the building – where these are available. These functionality levels are grouped in accordance with the assessed domain.

Table 2: SRI Indicators- Domain Scores

	Indicator Name	Description	Units
	Total SRI score	Overall SRI rank of the building considering domain scores and impact scores	%
Domain Scores	Domestic Hot Water	Domestic hot water is assessed based on 5 categories. This domain is assessed according to the energy source for heating, namely the thermal boiler, electric heating with element, heat pump and solar heating. The functionality levels of each service vary between on/off, demand and grid-oriented supply. Performance criteria also include sequencing and reporting;	%
	Ventilation	The assessment of the ventilation systems is based on 6 categories, depending on air flow, air temperature, heat recovery, free cooling, and indoor air quality (IAQ). The air flow control at the room level depends on its control functions. The air flow control varies from on/off to automatic control. Sensors in air exhaust or multiple temperature sensors contribute to overheating prevention. The air temperature control at the air handling unit level is rated based on the control of the set temperature of ventilation. Free cooling using the mechanical ventilation system is assessed based on free and night cooling and H, x-directed control. Reporting information on IAQ is considered an additional important parameter for controlled ventilation systems.	%
	Lighting	Lighting systems are rated depending on the level of control they offer (on/off, dimmable, occupancy sensors) and the interaction between natural and artificial lighting in a space.	
	Dynamic Building Envelope	The Dynamic building envelope domain scales its ratings according to the availability of manual or automatic control of window shading systems and the availability of interactive controls with HVAC and predictive blind control;	
	Electricity	Electricity is assessed based on 7 criteria, one of which is electricity storage where the type of stored technology energy is considered. Scheduled or automated management of locally generated electricity for self-consumption depending on the availability of renewable energy and predicted energy needs defines optimal levels. Similarly, the combined heat and power plant (CHP) is rated against scheduled management and RES availability, providing various levels of control. The support of grid operation modes criterion defines the variance in automated management and supply. Information such as real-time feedback, historical data, performance data and values for benchmarking are reported on local electricity generation, electricity consumption and energy storage.	

Electric Vehicle Charging	Assessing electric vehicle charging considers charging capacity allocating functionality levels according to the percentage of parking spaces fitted with charging points. Additionally, one-way controlled charging, uncontrolled charging, EV charging information and connectivity are criteria used to assess EV charging grid balancing.
Heating and Cooling	Heating and cooling systems are evaluated according to 10 individual elements. The heat emission units are evaluated based on their control mechanisms. The smartness scales consider several levels of control; for example, central, individual, or even occupancy detection control where the smartest level is indicated by the latter option. Heat generators' intelligence is evaluated based on the variance in temperature control that is dependent on the ambient temperature or on the heating load. Depending on the use of compensation and demand-based control, the fluid distribution network can be evaluated. The availability of storage vessels and the capability of heat storage control by using external signals are assessed based on the functionality levels of the heat storage. Concerning the distribution pumps, the pump speed control defines their functionality levels and the same is applied in the case of heat pump units. Other relevant to the heating system rating building services are linked with the performance of thermal activated building systems (TABS), the sequencing of the performance of different heat generators and the interaction of the heating system with the grid. Reporting the performance of heating systems is alike in several domains and takes into consideration real-time and historical data logging, including the ability of the systems for preventive maintenance. Cooling systems assessment also includes similar services. An additional element considered in cooling systems is the interlock of heating and cooling in the same thermal zone ("no interlock", "partial", "total interlock avoiding simultaneous heating and cooling").
Monitoring and Control	For monitoring and control, assessment is based on 8 categories. The ability to detect defects in building technical systems and the ability to manage HVAC systems in real time are the two main factors being examined. Smart grid integration and interoperability with DSM, central reporting and occupancy detection are also rated.

Table 3: SRI Indicators. Impact Scores.

	Indicator Name	Description	Units
Impact Scores	Energy Efficiency	’Energy efficiency’’ category includes the effects of the smart ready services on energy savings in the building. These savings do not take into consideration all sources of energy performance of the building, but contributions made by SRTs and their functionality options, e.g., energy savings as a consequence of improved control of room temperature.	%
	Energy flexibility and Storage	’’Energy Flexibility and Storage’’ category is related to the bearing of smart ready services on the flexibility potential of the building with regards to energy. Beyond electricity grids, this impact category also includes flexibility to interact with district heating and cooling grids.	%
	Comfort	’’Comfort’’ category is related to how the smart ready services influence the comfort of the occupants/building users. The category includes conscious and unconscious perception of human comfort including the aspects of indoor comfort conditions, thermal comfort, acoustic comfort and visual comfort.	%
	Convenience	The ’’Convenience’’ impact category considers the effects of the smart ready services on the convenience delivered to building users, i.e. the extent to which services “make life easier” for the user, e.g. through services that require fewer or zero manual interactions.	%
	Health, Well-being and accessibility	The ’’Health and Well-being’’ impact category relates to the effects of the smart ready services on the health and well-being of occupants/users, i.e., intelligent building control systems can improve indoor air quality compared to manual controls, hence improving occupants’ health and well-being.	%
	Maintenance and fault detection	The ’’Maintenance and Fault Prediction’’ impact category relates to the bearing of the smart ready services on the improvement of maintenance and operation of TBSs. The improvement of this category may also influence the energy efficiency of the TBSs by identifying and diagnosing inefficient operation.	%
	Information of occupants	The ’’Information to Occupants’’ impact category relates to the information delivery by the smart ready services regarding building operation and building technical systems to the occupants/users.	%

2.3.2 Human Comfort & Wellbeing Indicators

The D^2EPC Human Comfort and Wellbeing framework sets its grounds on three Indoor Environmental Quality pillars: Thermal Comfort, Visual Comfort and Indoor Air Quality It comprises of a multitude of environmental metrics and calculation methodologies in order to deliver a set of performance indicators to monitor the building’s progression with regards to the comfort and wellbeing of its occupants.

The HC&W KPIs step on preset boundaries of operation -per metric- as defined by a hybrid approach (Figure 10). On the one hand, the user previous behavior (trends and patterns) highlighted in past data is examined to infer the preferred operation for a building’s space. A specialized Comfort Profiling Engine, equipped with the appropriate data manipulation and machine-learning algorithms, undertakes this process and streams the calculated boundaries to other system components. On the other hand, in cases when the Engine is not utilized (insufficient data or Wellbeing metrics), a set of recommended boundaries as extracted from the literature (European and National standards and frameworks) is applied to act as a basis for the KPI calculations. Finally, to translate the selected environmental metrics and the corresponding recommended/preferred boundaries into performance indicators, three long-term evaluation methodologies are put into practice. The “time out of range” which calculates the percentage of hours when the ambient conditions were out of the set boundary, the “degree hours” which introduces weights (how much the conditions deviated) in the previous calculation and lastly the “footprint of the indoor environment” which is used in cases when the recommended operation is expressed in limits/categories.

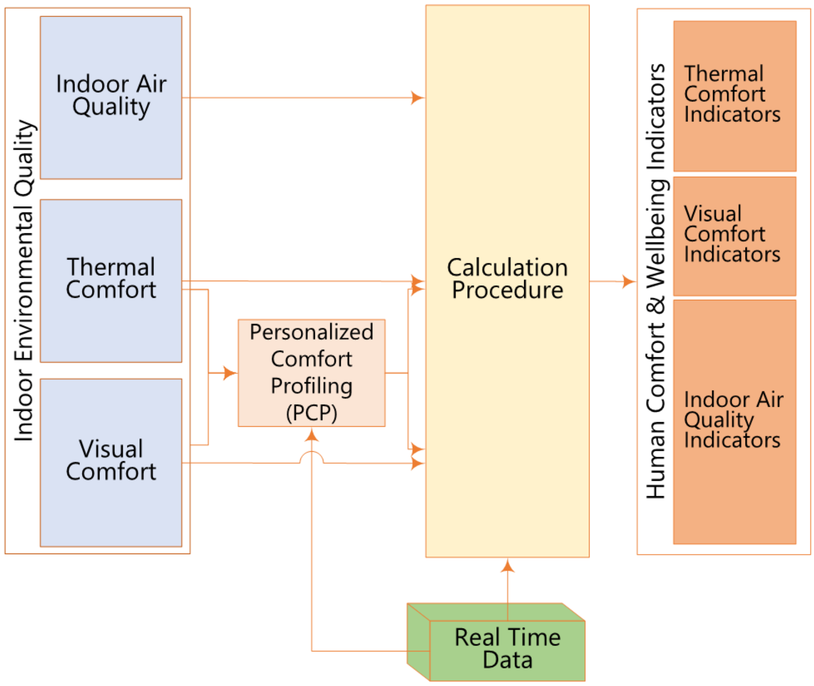


Figure 10: D^2EPC Hybrid Approach on the Human Comfort and Wellbeing framework

Figure 11 presents the human comfort and wellbeing indicators per environmental domain.

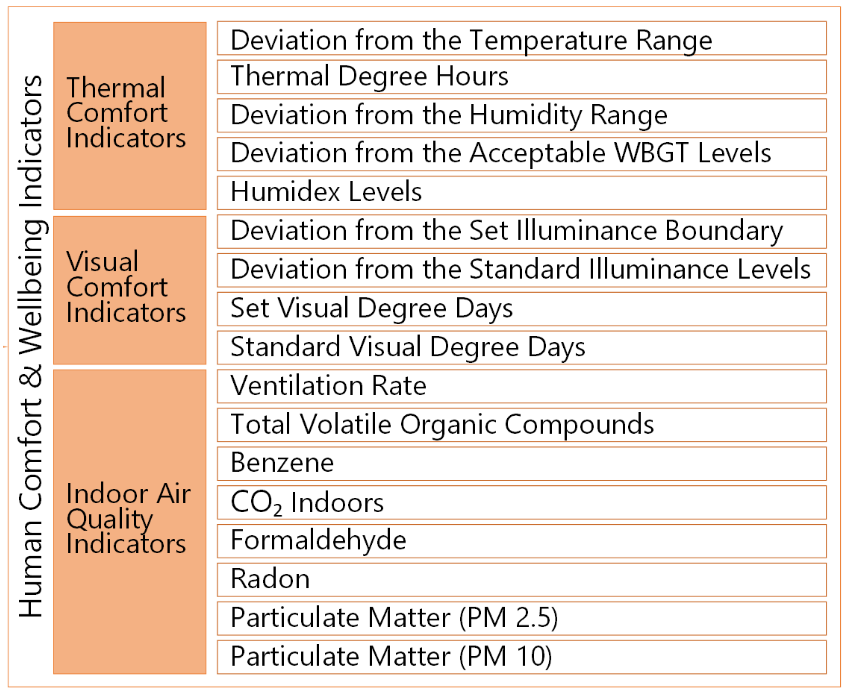


Figure 11: D^2EPC Hybrid Approach on the Human Comfort and Wellbeing framework

The new-age energy certificates are not limited to a mere energy performance assessment. In the present day, a building needs to be evaluated not only in terms of the energy consumed, but also the quality of indoor environment they provide to the occupants. As a result, the thermal and visual environment along with the quality of the indoor air are incorporated into the dynamic EPC expanding its scope. The HC&W KPIs aim to provide context to the end-user regarding the indoor ambient conditions of the spaces he/she resides in and how these improve or deteriorate with the passage of time.

The innovative Human Comfort and Wellbeing framework is solely dependent on the building data streams coming from the pilot IoT infrastructure. It is specifically designed to yield results in a purely dynamic and data-driven way without requesting extra information from the building users.

2.3.2.1 Calculation & Integration of the Human Comfort & Wellbeing KPIs

The engine that takes over the HC&W KPI calculation resides in the Building Performance Module (BPM). The latter interfaces with the appropriate data sources to acquire the (near) real-time and historical data of the pilot cases. More specifically, air temperature, relative humidity, illuminance and other gas concentrations measurements as recorded from the sensing devices deployed in the D^2EPC pilots are collected by the Information Management Layer. The personalized Comfort Profiling Engine is implemented in the IML component as well and delivers the calculated boundaries. The ambient conditions measurements and the boundaries are further streamed to the Digital Twin module and the project's repository where they can be accessed by the submodule responsible for the calculation of the comfort and wellbeing KPIs.

2.3.2.2 Thermal Comfort Indicators

In the thermal comfort case, the indicators are formed on two indoor environmental metrics, the Air Temperature and Relative Humidity, as well as their combined effect.

Table 4: Thermal Comfort Indicators

Indicator Name	I.E.Q. Domain	Environmental Parameter	Evaluation Methodology	Recommended Boundaries / Categories	Building Typologies
Deviation from the temperature range	Thermal Comfort	Indoor Dry-bulb (Air) Temperature	Time out of Range	Profiling Engine / ASHRAE 55 Indoor temperature limits	Residential/Commercial (Regularly occupied spaces by the same occupants)
Thermal Degree Hours	Thermal Comfort	Indoor Dry-bulb (Air) Temperature	Degree Hours	Profiling Engine / ASHRAE 55 Indoor temperature limits	Residential/Commercial (Regularly occupied spaces by the same occupants)
Deviation from the humidity range	Thermal Comfort / I.A.Q.	Indoor Relative Humidity	Time out of Range	Relative humidity range (Level(s) 4.3)	Residential/Commercial

Deviation from the acceptable WBGT levels	Thermal Comfort	Indoor Wet-bulb Globe Temperature (Indirectly calculated with Air Temperature and Relative Humidity)	Footprint of Indoor Environment	WBGT levels (ISO 7243:2017)	Common areas within Commercial buildings / Industrial Buildings
Humidex levels	Thermal Comfort	Indoor Humidex (Indirectly calculated with Air Temperature and Relative Humidity)	Footprint of Indoor Environment	Humidex levels	Residential/Commercial (Regularly occupied spaces)

2.3.2.3 Visual Comfort Indicators

In the visual comfort case, the measured indoor illuminance is combined with the profiling engine and some specific illuminance levels recommended by the literature to deliver the suitable indicator per typology.

Table 5: Visual Comfort Indicators

Indicator Name	I.E.Q. Domain	Environmental Parameter	Evaluation Methodology	Recommended Boundaries / Categories	Building Typology
Deviation from the set Illuminance boundary	Visual Comfort	Indoor Illuminance	Time out of Range	Profiling Engine	Residential/Commercial (Regularly occupied spaces by the same occupants)
Deviation from the standard Illuminance levels	Visual Comfort	Indoor Illuminance	Time out of Range	Illuminance Levels (EN 12464)	Residential/Commercial (based on space typology)
Set Visual Degree Hours	Visual Comfort	Indoor Illuminance	Degree Hours	Profiling Engine	Residential/Commercial (Regularly occupied spaces by the same occupants)
Standard Visual Degree Hours	Visual Comfort	Indoor Illuminance	Degree Hours	Illuminance Levels (EN 12464)	Residential/Commercial (based on space typology)

2.3.2.4 Indoor Air Quality Indicators

In the case of indoor air quality, a total of eight indicators has been incorporated in the framework. However, after a techno-economical feasibility analysis that took place, the I.A.Q. indicators have been segmented into two different categories. The “main” indicators, expected to be calculated in the D^2EPC pilots and the “complimentary” expected to be calculated in buildings that already provide the corresponding measurements.

Table 6: Indoor Air Quality Indicators

Indicator Name	I.E.Q. Domain	Environmental Parameter	Evaluation Methodology	Recommended Boundaries / Categories
CO2 Indoors	I.A.Q. (Main)	Difference between indoor and outdoor carbon dioxide concentrations	Footprint of Indoor Environment	CO2 Categories (CEN/TR 16798-1/2:2019)
TVOCs	I.A.Q. (Main)	Total Volatile Organic Compounds concentration in the indoor air	Footprint of Indoor Environment	TVOCs limits (CEN/TR 16798-1:2019)
PM2.5	I.A.Q. (Main)	Particulate Matter (2.5 µm diameter) concentration in the indoor air	Footprint of Indoor Environment	PM2.5 limits (CEN/TR 16798-1:2019)
Benzene	I.A.Q. (Complimentary)	Benzene concentration in the Indoor air	Footprint of Indoor Environment	Benzene limits (CEN/TR 16798-1:2019)
Formaldehyde	I.A.Q. (Complimentary)	Formaldehyde concentration in the Indoor air	Footprint of Indoor Environment	Formaldehyde limits (CEN/TR 16798-1:2019)
Radon	I.A.Q. (Complimentary)	Radon concentration in the Indoor air	Footprint of Indoor Environment	Radon limit (WHO Guidelines)
PM10	I.A.Q. (Complimentary)	Particulate Matter (10 µm diameter) concentration in the indoor air	Footprint of Indoor Environment	PM10 limits (CEN/TR 16798-1:2019)
Ventilation Rate	I.A.Q. (Complimentary)	Roughly estimated based on indoor hourly CO2 concentrations	Footprint of Indoor Environment	Ventilation Rate categories (CEN/TR 16798-1:2019)

2.3.3 LCA

This subsection presents the environmental sustainability indicators of the D^2EPC scheme, based on the Life Cycle Assessment approach.The Life Cycle Assessment (LCA) principles were employed for the definition of the environmental sustainability indicators. In particular, the DEPC scheme considers the provisions of the Level(s) scheme, a sustainability analysis methodology proposed by the EU. In Table 7 a comprehensive description of all 17 environmental indicators, as proposed by the Level(s) scheme and as adopted by the DEPC project, is presented. The proposed indicators are normalized per mass of materials (in kgs). To this end, the bill of quantities, extracted by a BIM parser, is also required for the whole building's sustainability assessment. The indicators are provided for the stages of:

a. Materials construction
b. transportation to the site,
c. construction/installation process, and
d. end of life.

Table 7: LCA Indicators

Indicator Name	Indicator Description	Units
Climate change (global warming potential)	Indicator of potential global warming due to emissions of greenhouse gases to the air. Climate change is defined as the impact of human emissions on the radiative forcing (i.e., heat radiation absorption) of the atmosphere. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise, i.e., the greenhouse effect. The areas of protection are human health, the natural environment, and the man-made environment.	kg CO_2 equivalents per kg [kg CO_2 eq / kg]
Ozone depletion potential	Indicator of emissions to air that causes the destruction of the stratospheric ozone layer.	kg CFC 11 equivalents [kg CFC 11 eq]
Acidification potential	Decrease in the pH-value of rainwater and fog measure, which has the effect of ecosystem damage due to, for example, nutrients being washed out of soils and increased solubility of metals into soils. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems, and materials (buildings). The major acidifying pollutants are SO2, NOx, and NHx. Areas of protection are the natural environment, the man-made environment, human health, and natural resources.	mole H+ equivalents [mol H+ eq.] kg SO_2 equivalents per kg [kg CO_2 eq / kg]
Eutrophication aquatic freshwater	Excessive growth measurement of aquatic plants or algal blooms due to high levels of nutrients in freshwater. Freshwater ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.	kg P equivalents [kg P eq.]
Eutrophication aquatic marine	Marine ecosystem reaction measurement to an excessive availability of a limiting nutrient.	kg N equivalents [kg N eq.]
Eutrophication terrestrial	Increased nutrient availability measurement in soil as a result of input of plant nutrients.	mole N equivalents [mol N eq.]
Photochemical ozone formation	Emissions of nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection. Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health, and ecosystems may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environment, and natural resources.	kg NMVOC equivalents [kg NMVOC eq.]
Depletion of abiotic resources -	Indicator of the depletion of natural non-fossil resources. "Abiotic resources" are natural sources (including energy resources) such as iron ore, crude	kg Sb equivalents [kg Sb eq.]

minerals and metals	oil, and wind energy, which are regarded as non-living. Abiotic resource depletion is one of the most frequently discussed impact categories, and there is consequently a wide variety of methods available for characterizing contributions to this category. To a large extent, these different methodologies reflect differences in problem definition. Depending on the definition, this impact category includes only natural resources, or natural resources, human health and the natural environment, among its areas of protection.	
Depletion of abiotic resources – fossil fuel	Indicator of the depletion of natural fossil fuel resources.	Mega Joules [MJ]
Water use	Indicator of the amount of water required to dilute toxic elements emitted into water or soil.	Cubic meters [m^3]
Use stage energy performance	"Operational energy consumption": primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.	kilowatt-hours per square meter per year (kWh/m^2 /yr)
Life cycle Global Warming Potential	"Carbon footprint assessment" or "whole life carbon measurement": building's contribution to greenhouse gas (GHG) emissions measurement associated with earth's global warming or climate change.	kg CO_2 equivalents per square meter per year (kg CO_2 eq./m^2/yr
Bill of quantities, materials, and lifespans	The quantities and mass of construction products and materials, as well as estimation of the lifespans measurement necessary to complete defined parts of the building.	Unit quantities, mass, and years
Construction & demolition waste and materials	The overall quantity of waste and materials generated by construction, renovation, and demolition activities; used to calculate the diversion rate to reuse and recycling, in line with the waste hierarchy.	kg of waste and materials per m^2 total useful floor area
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.	Adaptability score
Design for deconstruction, reuse, and recycling	Building design extent assessment of facilitation future recovery of materials for reuse of recycling, including assessment of the disassembly for a minimum scope of building parts ease, followed by the reuse and recycling for these parts and their associated sub-assemblies and materials ease.	Deconstruction score
Use stage water consumption	The total consumption of water measurement for an average building occupant, with the option to split this value into potable and non-potable, supplied water, as well as support measurement of the water-scarce locations identification.	m^3/yr of water per occupant

2.3.4 Financial Indicators

The financial KPIs allow the users to better understand their energy consumption, as the energy consumption is translated to monetary values. Considering that tenants operate with money on a daily basis, such an interpretation of energy use can be clearer and more understandable for them compared to other units such as kWh or m^3.

With financial KPIs, the user can compare the monetary value of actual consumption with the monetary values of the as-designed calculated consumption. Besides, the user can get an overview of predicted costs based on the inflation and discount rate. Finally, the user can get an estimation of future costs related to the building systems.

Some current EPCs already include information about the monetary value of energy consumption, which is based on the as-designed values. The estimation is typically expressed in annual values, and is based on average occupation values (number of people, operation schedule). On the other hand, the financial KPIs within the D^2EPC project represent the monetized values of energy consumption based on the monitored/operational use, meaning that the user gains insight into monthly values. The latter reflects the actual consumption, including the household appliances and with no need to estimate the number of people. Additionally, the D^2EPC version of the financial indicators provides information about predicted and estimated future values.

A set of financial Key Performance Indicators (KPIs), developed based on the literature review of well-established standards and schemes, aims to enhance the user-friendliness of the building energy performance certificate. They enable the interpretation of the individual elements of buildings' energy performance into monetary normalised values and the employment of EPCs for the financial assessment of building upgrade measures.

The purpose of the Financial KPIs is to provide users with a real-time image of the monetized performance of the building and thus increase user awareness about the energy efficiency of buildings. Even though they don't affect the energy class of the building, they are presented as additional information for the user.

The approach is to monetize the energy consumption, which means that the energy consumption is translated to EUR. Users are able to see how much money they are spending on energy and compare it with different scenarios, as explained further below.

The idea of how to define the financial indicators is based on the comparison of the current state (as-operated energy consumption) with different scenarios, for example, the as-designed energy consumption, the as-operated energy consumption at a different (past) time, the predicted energy consumption, and the building stock, as illustrated in Figure 12. The comparison between different scenarios enables users to allocate the performance of their building. The focus of the comparison is user's behaviours and his awareness of energy use rather than the improvement of the building's systems and envelope.

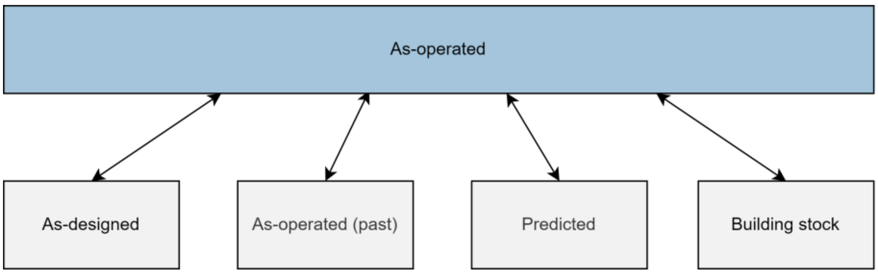


Figure 12: The comparison of scenarios

Besides the comparison between the monetized energy consumptions, the financial indicator also includes the expected cost for the replacement and maintenance of the building's systems and envelope. In this way, the user can be informed about the approximate expenses in the near future, which will allow him to better plan his expenditures.

2.3.4.1 Integration into D^2EPC

The Calculation Engine in the Service/Processing Layer is one of the fundamental components in the D^2EPC Architecture, responsible for all the calculations to assess asset and operational performance. Its sub-component Building Performance Module (BPM) calculates all the D^2EPC KPIs. The data input are based on BIM literacy, as introduced by the complete Digital Twin, utilizing the outcomes from the Asset Rating Module and the Operational Rating Module. Where applicable, inputs are also required from the user. The Building Performance Module calculate the financial KPIs, as presented in Figure 13.

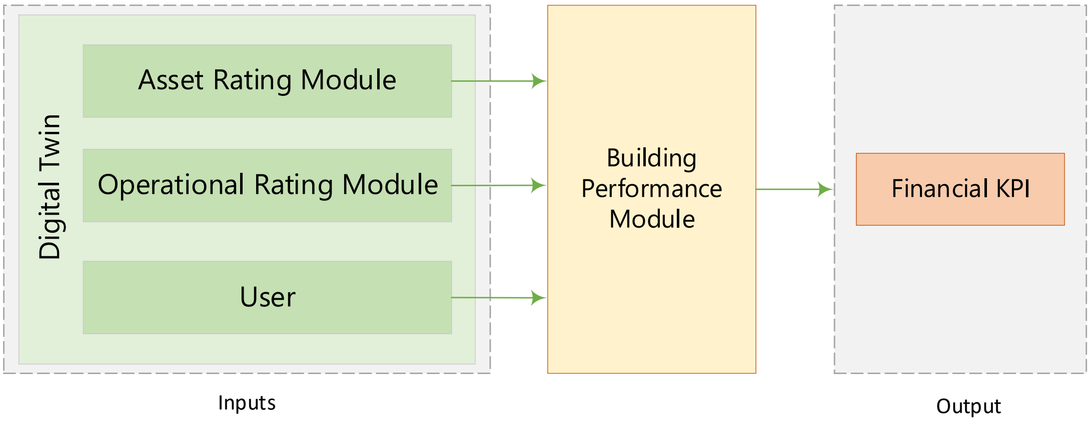


Figure 13: Process overview

2.3.4.2 The calculation of financial KPIs

Based on the acquired inputs, which consist of:

- As-designed and as-operational energy consumption;
- The price of the energy carriers, which differs in each member state, so the user provides it in each case;
- The Energy carrier per energy use, which is also provided by the user;
- The Average expected inflation and discount rate for the next 10 years;
- Building systems' information, which includes the installation date & price, life span, maintenance schedule & price;

the financial indicators can be calculated and compared between themselves. Figure 14 presents the overall outputs, which are divided into: the As-operated costs; the As-designed costs; the Total cost comparison (which compares the as-operated and as-designed costs); the Predicted costs; and the Expected costs.

Financial Indicators	As-operated Costs	Cost per Month per Energy Use
		Cost per Month per Energy Carrier
		Total Cost per Month
		Total Cost per Year
		Total Cost per Square Meter
	As-designed Costs	Total Average Cost per Month
		Total average Cost per Year
		Total Cost per Square Meter
	Total Cost Comparison	Total Cost Comparison per Month
		Total Cost Comparison per Year
	Predicted Costs	Real Cost
		Nominal Cost
		Net Present Value
	Expected Costs	Estimation of Costs that we can Expect for the Replacement and Maintenance of Building Systems

Figure 14: Financial indicators

3Calculation Engine implementation

This calculation engine is one of the primary components of the D^2EPC architecture (Figure 15). This component is responsible for conducting all computations required for a precise evaluation of asset and operational performance. The existence of two different certification schemes triggered the development of two distinct sub-modules for each calculation. In addition, a third sub-module, the Building Performance Module, has been identified for the sole purpose of conducting the required calculations for a broad range of indicators that would enhance the EPC method (SRI, LCA, LCC, Human Comfort and Wellbeing).

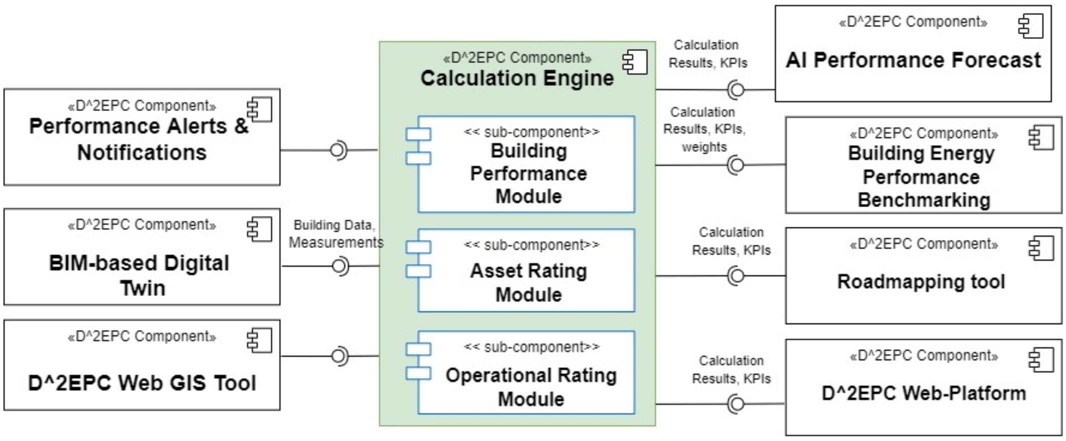


Figure 15: Calculation Engine- Architecture view

3.1 Asset Rating Module

The development of the Asset Rating calculation engine followed the methodology described in Section 2.1.1. The calculation module receives as an input the building information in a JSON file. This file is stored in the BIM-based Digital twin component and has been generated from the BIM parser sub-component. The module's operational philosophy can be described as an iteration between the listed thermal zones, technical systems, spaces and envelope elements. Each calculation phase iterates through the various entities to calculate the asset's energy performance.

Starting with the investigation of the heating and cooling demand, the module uses four functions to examine the energy exchange in each thermal zone. The *Transmission_Heat_loss* function calculates the energy loss per element from transmission, while *Ventilation_Heat_Losses* calculates the part of energy losses through air exchange in the thermal zone. Additionally, the *Internal_Heat_Gains* calculates the thermal gains from the people and equipment in the zone and the *Solar Gains function* calculates the solar energy absorbed per building element. The resulting values from each function are weighted and summed in *the Heating_Demand* and *Cooling_Demand* functions.

To complete the energy demand calculation per thermal zone two additional functions are also used. The *DHW* function calculate the DHW demand per thermal zone according to the DHW requirements from the zone's boundary conditions. In a similar manner, the *Lighting* function calculates the energy demand per thermal zone. The monthly results from all the above functions are expressed per zone, and per service. In parallel to the energy demand calculations for the examined boiling, the same functions calculate the energy demand for the Reference building, by replacing the values of the examined elements with the reference ones' while maintaining the same geometrical characteristics.

Afterwards, the final energy is calculated taking as input all the above values. The *Q_deliver* function takes as an input the generated results, as described above. For each thermal zone, the function matches the energy demand per service with the respective technical system to calculate the theoretical energy consumption. In parallel, the same calculation procedure is repeated with the respective values of the reference building's technical systems. The resulting values are expressed per thermal zone, energy service and energy carrier.

In the third calculation phase, the *Q_primary* function takes the results generated from the *Q_deliver* function. Each set of results is weighted with the appropriate primary energy factor, according to the indicated energy carrier. In the same manner, the function also calculates the cost and CO_2 emissions per service.

Finally, the *EPC_class* function benchmarks the performance of the examined building in relation to the respective reference building and results to the energy class.

It is important to mention that, the Asset Rating module has been developed with the use of the Python (3.9) programming language. Additionally, the following Python packages have been used to broaden the module's functionalities:

- Pandas 1.4.2
- Numpy 1.22.3
- XlsxWWriter 3.0.3

3.1.1 Data-sets

The calculation of the estimated energy consumption in the Asset Rating scheme is based on a set of pre-determined conditions that describe that indoor and outdoor conditions as well as further information essential for the calculation. The required information for the Asset Rating calculation can be divided into four main data sets, as presented in Figure 16. The differentiation of the four data sets per country created a plethora of information and led to the creation of four dedicated datasets for a systematic development approach.

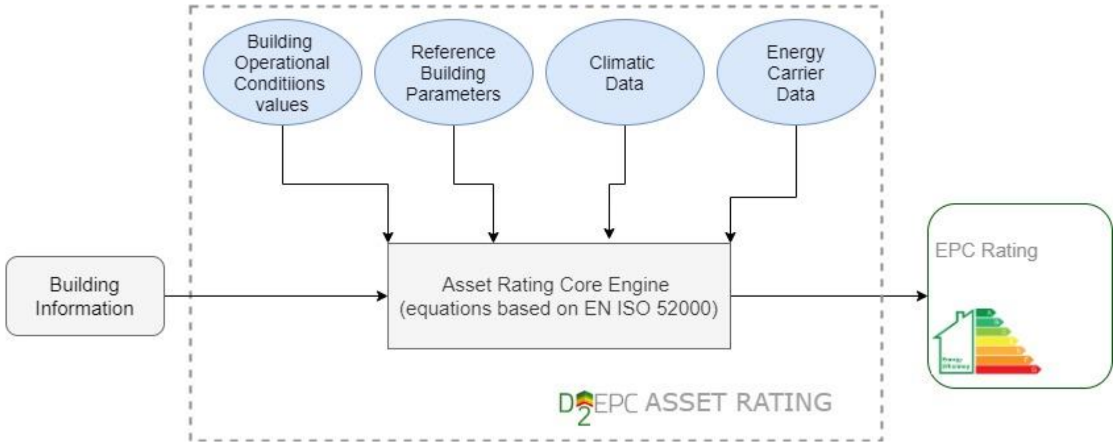


Figure 16: Asset Rating data sets requirements

3.1.1.1 Climatic Zones

Asset rating module demands solar irradiation and average temperature data to proceed with the energy calculations for EPC issuance. The first investigated dataset is related to the climatic conditions of each geographic region. To form a climatic data set that complies with national technical directives, a classification of each country's climatic zone is mandatory. As stated above the included pilot countries are Greece, Cyprus and Germany. Greece and Cyprus are divided into four climatic zones, while Germany has 15 climatic regions.

The extraction of the values for each climatic zone has been based on a variety of climatic data sources, like PVGIS, NASA climatic data sets, and commercialized data sets. To extract the most accurate measurement data, deviation comparisons have been made between the national technical directives of Greece, Germany, Lithuania, and the Netherlands and each data source's results. The commercialized data sets provided accurate results but there was a limitation to seamless data exchange. The data source with the most accurate results was collected through the PVGIS website which provides a free and open-source data set, named PVGIS-SARAH 2. PVGIS – SARAH 2 is the most updated data set, which covers all Europe countries and provides data for solar irradiation and temperature from a time horizon from 2005 to 2020. PVGIS-SARAH 2 uses data from geostationary meteorological satellites and mathematical algorithms to estimate solar irradiation at ground level [7].

Data extraction from PVGIS – SARAH 2 has been made using Python programming and the requests module. In the first stage, using the Geopy library it is feasible to extract the latitude and longitude of a specific town in a specific climatic zone for each country. The latitude, longitude, start year, end year, and desired format of the output result are used as input for the temperature request from the data set. The result is the average temperature per month in Celsius degrees per year in a JavaScript Notation Object (JSON) format. For example, requests return the average temperature of January 2005, and January 2006 until January 2020. Then, a calculation of the mean value of the average temperature of each month is conducted.

Likewise, a separate set of requests has being made for extraction the monthly solar irradiation, which requires input latitude, longitude, the format of the output result, start year, end year, for a specific orientation and specific surface slope. The surface slope that is used for request input is 0, 90 and 45 degrees. The resulted orientations are presented in Table 8. In total, seventeen requests have been made to acquire a complete climatic dataset. The request returns the hourly value of solar irradiation for a specific daily hour for each day, month and year day for the requested time horizon. Data is gathered and organized into a mean value for all years per month. The returned result is measured in $W/m^2/hour$, so it is converted to kWh/m^2.

Table 8: Orientation to degrees

ORIENTATION	DEGREES
NORTH-WEST	135
WEST	90
SOUTH-WEST	45
SOUTH	0
SOUTH-EAST	-45
EAST	-90
NORTH-EAST	-135

The final results of the requests are stored in an excel file and fed into the Asset rating module to perform the required calculations. With this approach, D^2EPC managed to develop a complete and uniform climatic data set with the monthly average climatic values of each zone.

Annex A includes the tables of the climatic zone descriptions for the six pilot buildings. The three zones refer to Thessaloniki, Greece for CS1, Nicosia, Cyprus for CS4 and Berlin, Germany for CS2, CS3, CS5 and CS6.

3.1.1.2 Reference Building

The reference building includes both the parameters that describe the building envelope and the respective technical systems. The included values at the building envelope level define the elements'

U-value, as well as additional characteristics for the opaque and transparent elements, respectively. Regarding the technical systems, the reference-building data set includes information that describes the system's efficiency. The selection of the reference building values depends mostly on the type of the examined building, either Residential or Tertiary.

The incorporated values derive from national EPC methodologies and have been collected through the "D^2EPC Questionnaire: Input Parameters for Asset Rating". The values used for the description of the Reference Building in Greece, Cyprus and Germany are listed in Annex A.

3.1.1.3 Energy Carriers

The data that describe an energy carrier are differ per country, as they are affected from the national energy mix. The data set includes the following field values for each energy carrier:

- The primary energy factor is the value that describes the conversion from delivered to primary energy. A further distinction is made for each energy carrier between the renewable and non-renewable part. In total, three main values describe the conversion from final to primary energy:
    - Total primary energy factor (f_p_tot)
    - renewable primary energy factor (f_p_ren)
    - non-renewable primary energy factor (f_p_nren)
- The CO_2 emissions factor, the conversion factor from final energy to CO_2 emissions [kg CO2/unit of fuel]
- Cost, the update values of cost per energy carrier [€/kWh].

The incorporated values derive from national EPC methodologies and have been collected through the "D^2EPC Questionnaire: Input Parameters for Asset Rating". The energy carrier values of Greece, Cyprus and Germany are listed in Annex A.

3.1.1.4 Thermal Zones' Boundary Conditions

The description of the indoor environment conditions in a thermal zone is conducted with the following list of parameters. More specifically, the provided values describe the operating schedules, the heating and cooling demands, ventilation requirements and lighting related information. As these values can differ per country ,(even for the same type of thermal zones) a dedicated data set has been also developed for this purpose.

The following fields are described in each case:

- Heating Set point
- Cooling Set point
- Fresh air requirement
- Internal heat gains from people
- Internal heat gains from lighting
- Internal heat gains from equipment
- Lighting Power Density
- Operational Days per week
- Operational Hours per Day
- Annual Operational hours at day
- Annual Operational hours at night
- Occupancy Dependency factor
- Daylight dependency factor
- Constant Illuminance factor
- DHW requirement
- Luminance

The incorporated values derived from national EPC methodologies and have been collected through the "D^2EPC Questionnaire: Input Parameters for Asset Rating". The values that describe the boundary conditions at in set of thermal zones applied to Greece, Cyprus and Germany are listed in Annex A.

3.2 Operational Rating Module

3.2.1 Development

The scope of this section is to provide more technical details to the user regarding the calculation rationale of the tool through a brief analysis of the various functionalities. The tool's main functionalities consist of data pre-processing from digital twin, conversion to daily values, timestamp homogenization, organization on different time steps (daily, monthly, annual), and energy classification. It is worth mentioning that every tool's functionality differs significantly in order to produce specific results, which are described in Section 4.2.2.

The Operational Rating Module follows the rationale of the project architecture. Operational Rating is based on structured programming and the flow is divided into multiple sub functions. The module can operate as a stand-alone tool, and it is designed as a package in order to extend the applicability of the module to third-party members. The current version of the Operational Rating module has been implemented in Python programming language, version 3.9. Towards the development of the module, the following packages were used:

- Pandas
- Collections
- Datetime
- NumPy

Operational Rating can produce results both from historical data in a CSV format or real-time data in a JavaScript Object Notation format (JSON) format. Finally, the produced results are saved in the D^2EPC repository in JSON format to be used as input to the D^2EPC Web Platform for visualization purposes. Visualization of OR results are presented in Section 4.2.

3.2.1.1 Data retrieval and preprocessing

From the start of the operation, the Operational Rating (OR) module utilizes Digital Twin functionality in order to retrieve energy measurements from the D^2EPC repository. Digital Twin extracts the last 365 days' data from the repository and matches the measurements with the corresponding meter characteristics through the *add_measurements* method. Meter characteristics refer to the measurement's area, volume, occupants, and occupancy hours. Furthermore, meter characteristics refer to the energy service of the measurement (heating, on-site RES, electrical appliances, etc.) and the energy carrier of the measurement (Oil, Natural Gas, etc.). Moreover, Digital Twin handles cumulative energy measurements in order to provide an appropriate format for Operational Rating Module execution.

3.2.1.2 Time resolution and timestamp homogenization

After the data retrieval, the OR module seeks to homogenize the resolution of every dataset by calling the *convert_every_timeseries_to_daily_values function*. The main purpose of this function is to convert data with different time resolutions (per min, per hour, etc.) to daily resolution data. The next step is to validate if every retrieved dataset contains 365 values by utilizing the *homogenizing_input_timestamps* function. Apart from length validation, the function checks if every dataset has measurements with missing dates or nan values and fills the measurement's time series accordingly.

3.2.1.3 Daily data

In the organization of daily data two main functions were developed. The first function (*create_indicator_for_daily_values*) takes as inputs the retrieved measurements time-series and converts them into primary energy values. The second function (*format_Daily_visualization*) schematizes the final output by providing the total primary energy consumption for all energy services in daily resolution.

3.2.1.4 Monthly data

In contrast to the daily analysis, monthly data proceed to more calculations. During the monthly analysis, daily data are organized in monthly values and in the categories of final energy, primary energy, and cost with the *create_monthly_prim_and_cost* procedure. Every main category of monthly values is normalized based on the selected parameters for all energy services by implementing *monthly_indicators_per_measurement* function. After the values are normalized, the function *organize_service_for_monthly_values* assist in the data categorization based on the energy service. The monthly data processing ends with a procedure that organizes and stores the data based on the final output structure. The structure of the monthly data output is shown in Figure 17.

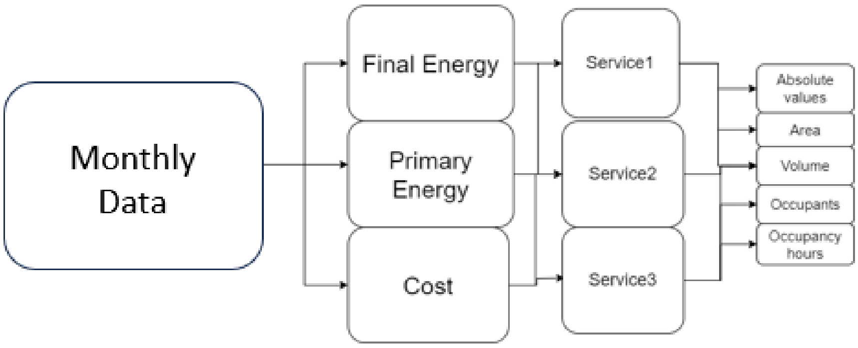


Figure 17: Structure of monthly data output

3.2.1.5 Annual data

The developed annual data functions take as input the monthly values. Apart from energy service, the annual time step data are organized per energy carrier (Electricity from Grid, Onsite RES) for all energy services by utilizing the *organise_the_annual_values_per_energy_carrier_and_service* function. The structure of the annual data is depicted in Figure 18.

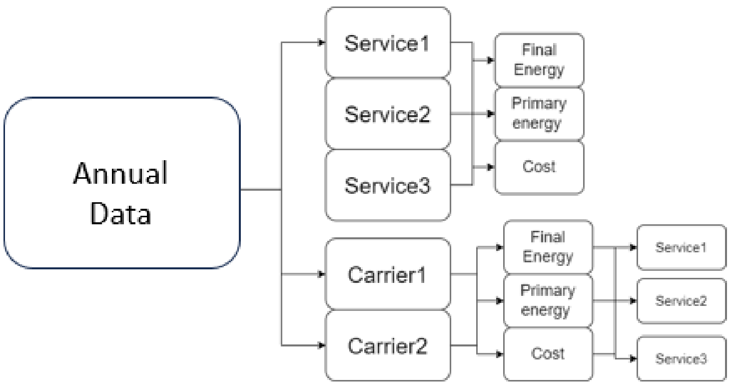


Figure 18: Structure of annual data output

3.2.1.6 Energy classification

After the calculation of the results for different time steps, Operational Rating Module calculates energy classification values. The required inputs for energy classification include the total annual primary energy consumption value normalized per area and general building info. General building info (construction year, building type, country, etc.) identifies the boundaries of the appropriate reference table, which are presented in section 3.2.2.1. Inputs are given to the *operational_classification* functions. Figure 19) depicts the input and the generated output of *operational_classification* functions.

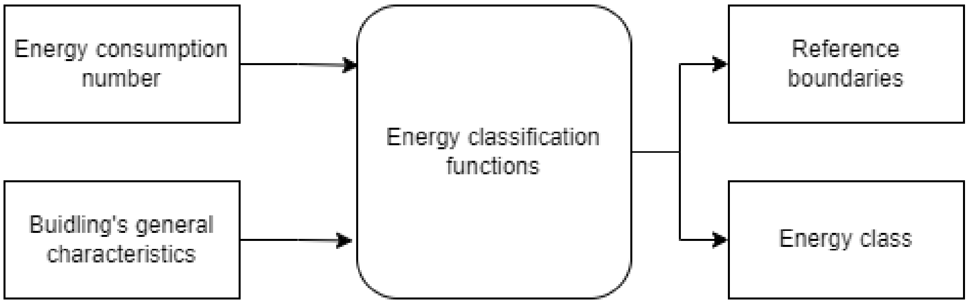


Figure 19: Energy classification functionality

3.2.2 Features

3.2.2.1 Reference tables

The D^2EPC operational rating is conducted in accordance to the building stock as the reference method, described in the European standard 52003:2017 Energy performance of buildings — Indicators, requirements, ratings and certificates [11] and more specifically, in accordance with Article 10 – EPB rating. The formatted Reference tables express the building's total primary energy, normalized for area indicator [kWh/m2]. An example of the Cypriot building stock is provided. The assessment of the Cypriot building stock was conducted, in accordance with the minimum requirements for class A buildings set by the competent authority in Cyprus, as well as on a Joint Research Center (JRC) Technical Report concerning the energy consumption of the building stock in Cyprus [8], [9], [10]. The energy classification of the Cypriot building stock is presented in Table 9.
The energy performance of the building stock, may differ with regards to the following non-exhaustive list of parameters:

- the age of the building
- the type of the building(residential, non-residential, office building etc.)
- the climatic zone

Table 9: Reference table for Cypriot residential buildings

Building type	Age	A	B	C	D	E	F	G
Single house	<1981	100	200	302	402	502	605	705
	1981-2006	100	167	235	302	370	437	505
	>2006	100	157	216	273	329	389	446
Semi-detached + Rowhouses	<1981	100	192	286	378	470	564	656
	1981-2006	100	162	221	284	346	405	467
	>2006	100	151	203	254	305	356	408
Apartment blocks	<1981	100	221	346	467	589	713	834
	1981-2006	100	189	275	365	454	540	629
	>2006	100	176	251	327	402	478	554
Other types of building	<1981	100	186	270	356	443	527	613
	1981-2006	100	157	213	270	327	383	440
	>2006	100	149	194	243	292	338	386

Following Cyprus, reference tables have been formed for Greece and Germany with the aim of a holistic approach for every pilot case. For the county of Germany, class A was formed by German Building Energy AcT [11] and an EU commission study [12]. The consumption of current building stock is retrieved from research reports [13].

For the Greece reference table, class A is formed by an EU commission study [12], and consumption of current building stock was retrieved from tables of national authorities [14].

The reference tables for Greece and Germany are presented in Annex A.

3.2.3 Data- sets

The operational energy classification, conducted in accordance with the building stock as the reference method, is described in the European standard 52003:2017 “Energy performance of buildings — Indicators, requirements, ratings, and certificates”. More specifically, in Article 10 – EPB rating, the assessment of the building stock, of the individual EU MS, requires the extraction of datasets, concerning typical values for its energy performance. In the Operational Rating module, a number of data sets have been developed for the tool’s successful operation. Every data set is stored in the D^2EPC repository and can be accessed from the Digital Twin when the tool is operational. Data sets refer to the Measurements values, Reference tables, primary energy and cost factors, and climatic zone data set. The measurement data set contains the consumption data provided by the various pilot sites, with daily resolution. A reference table data set is mandatory for building classification in an energy class, which contains all the classification boundaries for pilot countries. Primary energy and cost factor data set are required for conversions for a variety of energy carriers. The Primary energy factor and cost data set were retrieved from the Asset Rating Module data sets. Also, the climatic zone data set is useful to identify the corresponding climatic zone of the Reference table in combination with the building’s usage and construction year. Climatic data were collected from Asset’s Rating climatic data set.

3.3 Building Performance Module

The Building Performance Module (BPM) is responsible for calculating the set of the project's indicators, as described in Section 2.3. To this end, it consists of four distinct submodules for each indicator category. Both static and dynamic information from the D^2EPC Repository are fed as input, as well as additional information from the user through the Web Platform.

The BPM tool was developed using the Python programming language and is based on a fully object-oriented approach. Additionally, it is designed as a Python package, which entails easy deployment and possible exploitation by other, third-party services.

The following sections describe the aforementioned submodules in more detail.

3.3.1 SRI calculation submodule

This submodule's internal calculations follow the guidelines of the *SRI assessment package* [15]. The main classes are depicted in Figure 20 and Figure 21 below.

The lowest-level class is the *SRIService*. It includes all the information relevant to a smart service i.e. its functional level(s), the specific level(s) share and if it is applicable or not. This class is inherited by all the classes representing the domain-specific services. Each of the latter includes attributes for the corresponding domain, the service unique code, a variable stating if the service affects the maximum score irrespectively of its applicability and a mapper between the function levels to their description.

Moving to the upper level, the *SRIDomain* class contains all information regarding a domain. This includes the domain's services, a variable indicating if the domain is present (and if it is mandatory) and the domain impact scores, which are calculated internally. The class is inherited by all the nine classes representing the different domains. Each of the latter contains a variable with all the included services, which essentially are objects generated from the services' classes that were previously described.

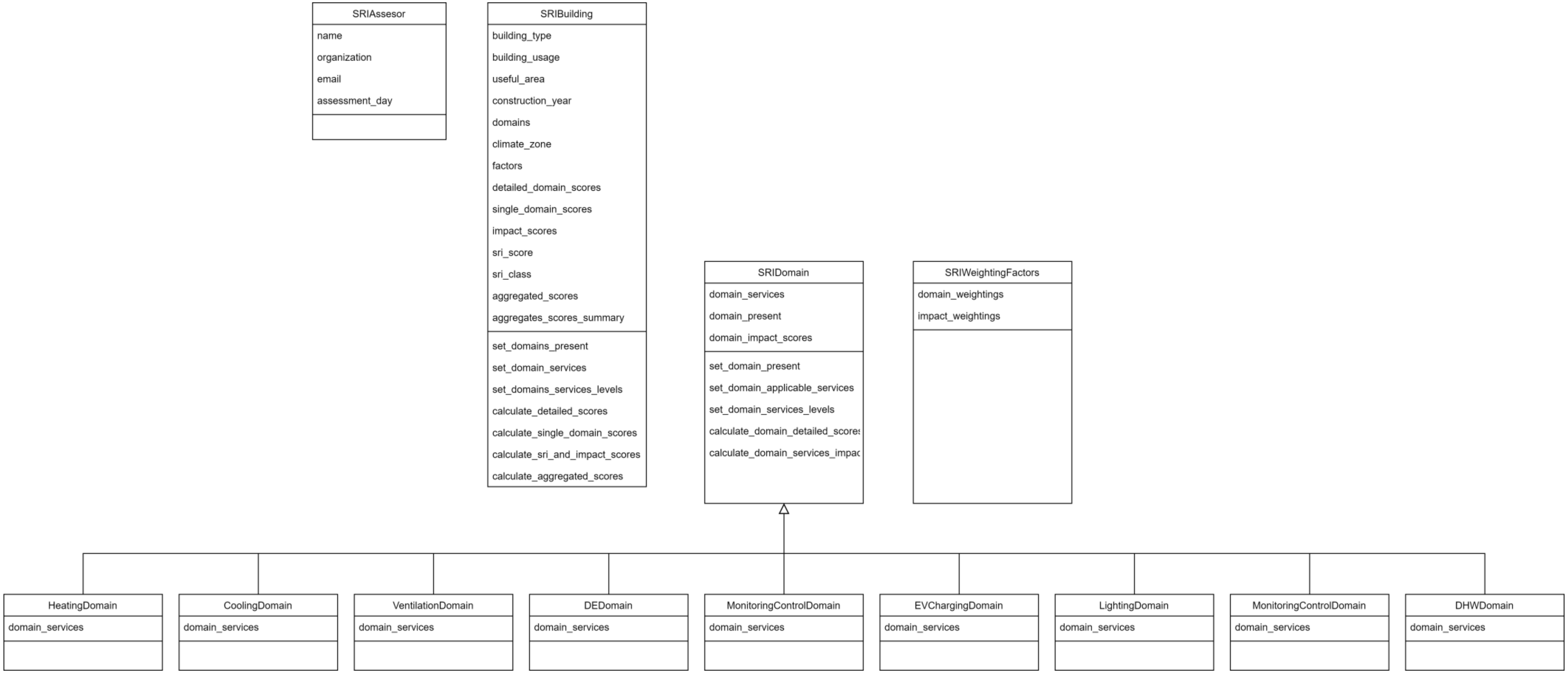


Figure 20: SRI calculation submodule main object classes

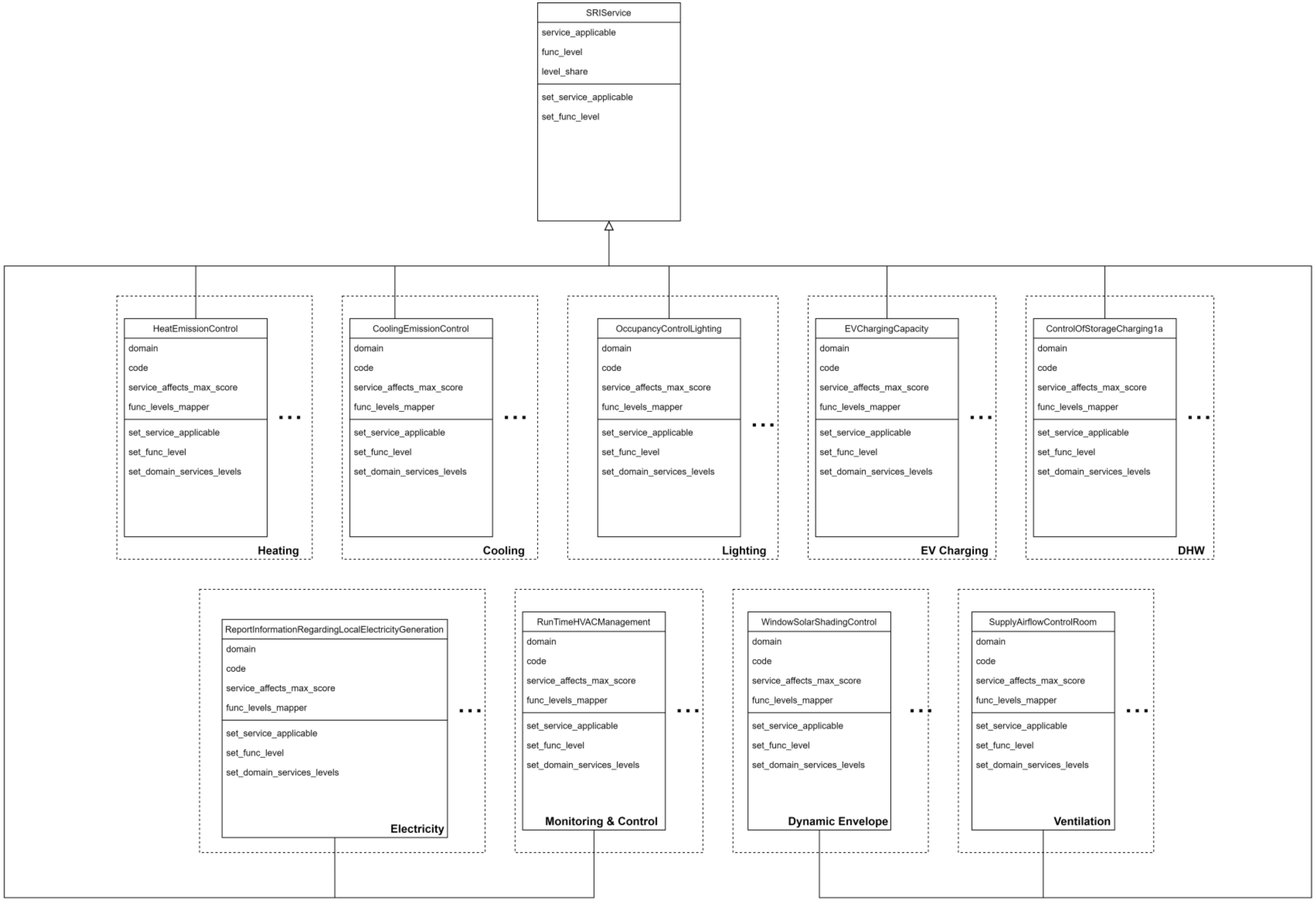


Figure 21: SRI calculation submodule services object classes

The *SRIAssessor* and *SRIBuilding* classes enclose information regarding the assessor and the building under study, respectively. The latter includes variables that store data useful for the calculations, such as the building type and usage, its useful area, its construction year and current state etc. Additionally, several class methods are implemented to set the present domain services and their respective services, along with their functional level, while the rest of them perform the necessary calculations at each step of the process.

The procedure followed to extract the SRI overall and specific scores is depicted in Figure 22 below. The first step towards the SRI calculation is providing the assessor's and the studied building's parameters, as displayed earlier. Following, the building's present domains must be specified, along with their presence status (present, not present but mandatory, not present but not mandatory) and the services that they include. Finally, the input services' levels must be provided. The module is then able to calculate the SRI detailed scores as well as the aggregated ones, which yield the SRI overall score and class, the impact scores and the domain scores.

The required information should be provided using the JSON format.

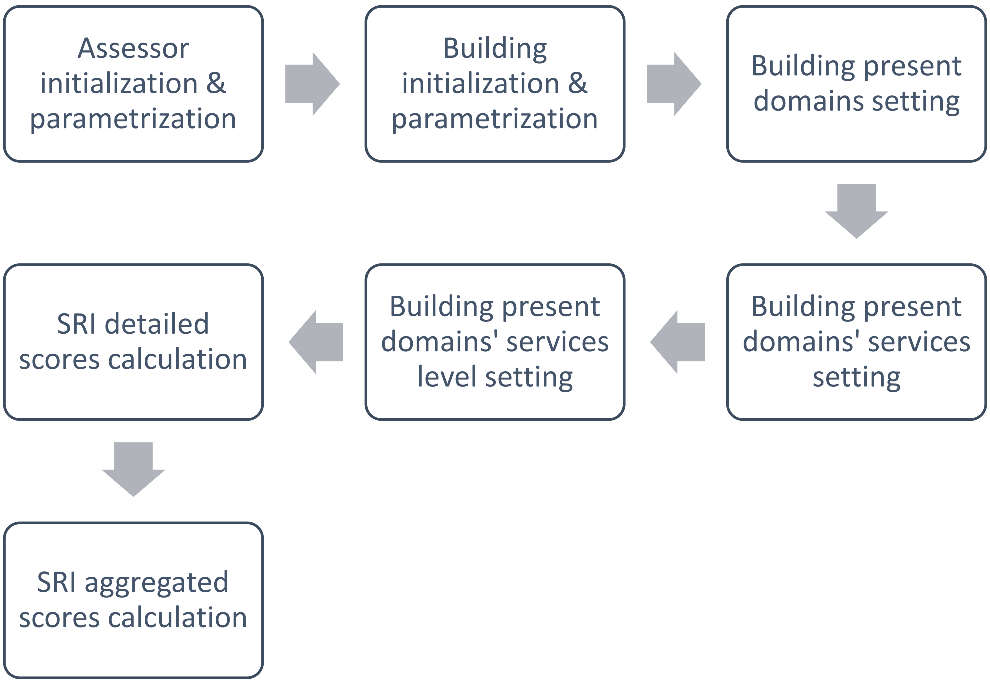


Figure 22: SRI calculation procedure

3.3.2 Human Comfort & Wellbeing Indicators calculation submodule

This subcomponent's internal calculations follow the guidelines and relevant standards that were elaborated in the deliverable 2.2 "Human-Centric Indicators and User Profiles for next-generation EPCs v1" and finalized in its updated second version. The main object classes are outlined in Figure 23 below.

The main class is the *HCWIndicators*, which contains all the relevant variables that are commonly utilized by the different sets of studied indicators. These include the *start* and *end* timestamps as well as the *room_id,* which are used to identify the required amount of data (in terms of time period and building space of interest) and collect them from the D^2EPC Repository. Additionally, the *occupancy_status* is a commonly shared series of presence events that is used by all calculations. It corresponds to the hourly occupancy profile of the building under study. In case of insufficient data, the building is considered to always be occupied.

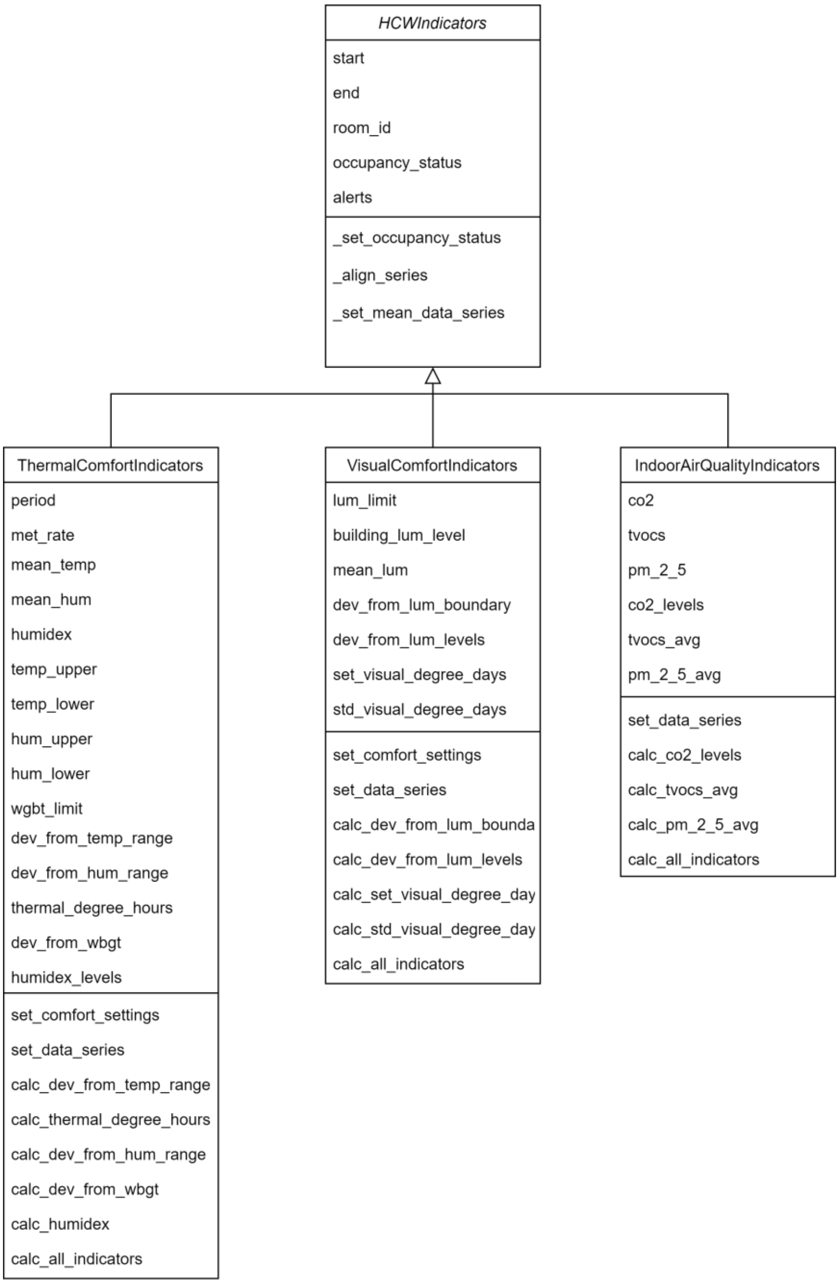


Figure 23: HC&W Indicators calculation submodule main object classes

The *ThermalComfortIndicators* class includes all the necessary parameters and methods to calculate the five thermal comfort indicators (deviation from the temperature range, thermal degree hours, deviation from the humidity range, deviation from the acceptable WBGT levels and Humidex levels). The comfort boundaries (minimum/maximum temperature/humidity, WGBT level limits) as well as the necessary data series (mean temperature/humidity) are set by dedicated functions.

The *VisualComfortIndicators* class includes all the necessary parameters and methods to calculate the four visual comfort indicators (deviation from the set luminance boundary, deviation from the standard luminance levels, set visual degree-days, standard visual degree-days). The comfort boundaries (bottom set luminance boundary) as well as the necessary data series (mean luminance) are set by dedicated functions.

Finally, the *IndoorAirQualityIndicators* class includes all the necessary parameters and methods to calculate the three indoor air quality indicators (CO_2 indoors, average TVOCs, and average PM 2.5). The level limits are set by relevant standards and the necessary data series (CO_2/TVOCs/PM2.5 concentrations) are set by dedicated functions.

The D^2EPC BIM-based Digital Twin has been fully integrated into the subcomponent, towards simplifying the required data collection and post-processing. A digital instance of the building is built within the component upon provision of the necessary data models for the building parameters and actual measurements. It provides the ability to easily parse the building spaces and their corresponding sensors, identifying the measurements of interest (temperature, humidity, luminance, CO_2, TVOCs, and PM2.5). Subsequently, the measurements that are available for each space are provided to the aforementioned class functions (along with other necessary parameters, e.g., comfort settings) in order to calculate the corresponding set of indicators.

3.3.3 LCA Indicators calculation submodule

This subcomponent's internal calculations follow the guidelines and relevant standards that were elaborated within the activities of T2.3 "Energy performance & LCA Indicators Analysis for EPCs". The main object classes are outlined in Figure 24. Each building material is represented by a *Material* class object, which encloses the material properties as well as the corresponding methods that allow the easy setup of input information related to the material's Energy Performance Declaration (EPD). Additionally, each LCA indicator corresponds to an *Indicator* class object, which includes all the methods necessary for calculating the environmental impact per life-cycle stage, per material and per material group.

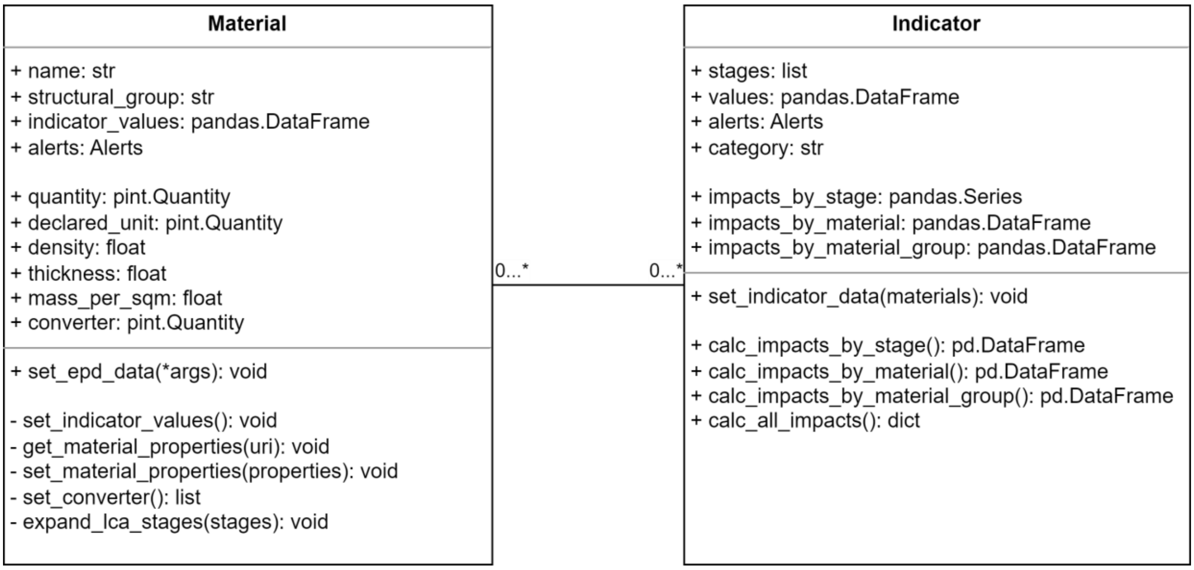


Figure 24: LCA submodule main object classes

The calculation process is depicted in Figure 25. The first step regards the formulation of the bill of materials of the building under study. Each material entry in the aforementioned list should include the name, the structural group under which it is categorized (External walls, internal walls, slabs, roofs, doors, windows) and the quantity of the material and its corresponding unit. Following next, the source of the EPD-related data for each material has to be defined by selecting at least one of the options:

- Auto-searching the required information within the component. A dataset has been included within the tool, which contains EPD data for common materials and allows their quick parametrization;

- Providing the URI of a material EPD, which belongs to the open data set network that is supported by the ECO PORTAL[1]. The latter serves as a central access point for retrieving EPD data from many providers in a common digital format, namely the ILCD+EPD. Within the LCA subcomponent, dedicated methods were developed for properly accessing the platform's corresponding API and post-processing of the fetched data, which established easy access to more than 6000 EPDs.
- Providing the required EPD indicator data explicitly, in a specific input format.

The last requirement concerns the provision of additional material properties, mainly in the case that the EPD indicator data are provided directly. Herein, at least the defined declared unit must be present, which enables the calculation of each indicator based on the material's quantity. Additional material properties may need to be provided, i.e. its density, default thickness or mass per unit of area, which are utilized for converting the quantity's unit to the declared one.

Upon completion of the aforementioned setup process, the calculation of the LCA indicators can be performed.

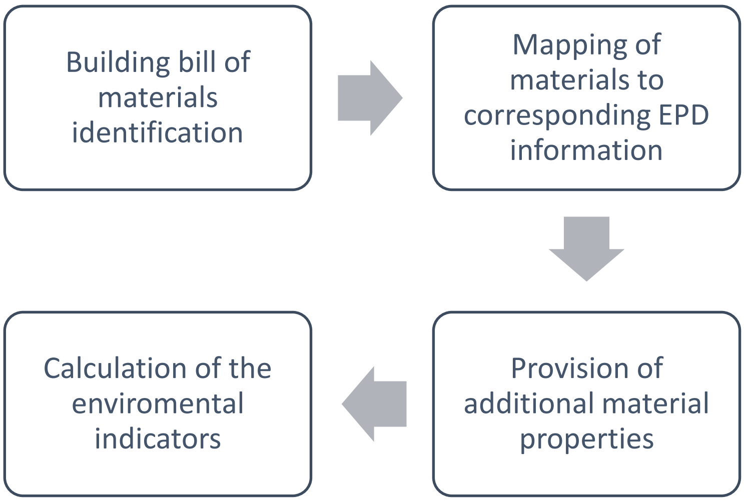


Figure 25: LCA submodule calculation procedure

[1] https://www.eco-platform.org/eco-portal-access-point-to-digital-product-data

3.3.4 Financial Indicators calculation submodule

This subcomponent's internal calculations follow the guidelines and relevant standards that were elaborated within the activities of Task 2.4 "Analysis of cost and economic indicators for EPCs". The main object classes are outlined in Figure 26 below. The main class is the *GenericCosts,* which contains all the relevant parameters for the calculation of energy costs based on provided data. These include the building ID and area, monthly energy data that are organized by energy carrier and energy use as well as energy carrier pricing data. Several class methods are implemented to calculate the monthly cost per energy use, the monthly cost per energy carrier, the total monthly cost (absolute and per square meter) and the total annual cost. The class is inherited by the two child classes (*AsOperatedCosts* and *AsDesignedCosts*) that calculate the as-operated and as-designed costs, respectively.

Finally, the *AsPredictedCosts* class calculates the nominal cost and the net present value for the next 10 years.

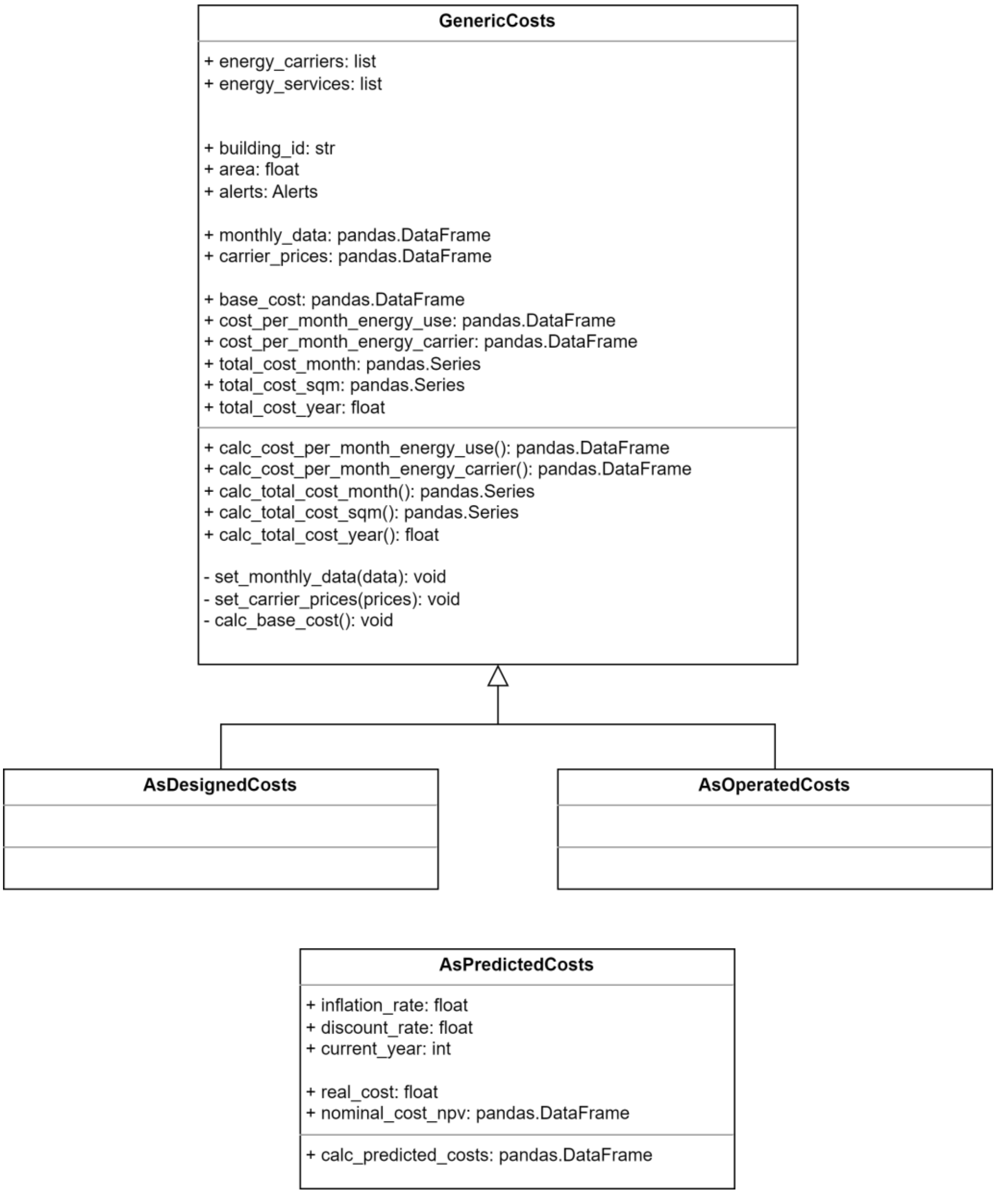


Figure 26: Financial Indicators submodule main object classes

Similarly to the HC&W indicators calculation subcomponent, the D^2EPC BIM-based Digital Twin has been integrated in order to ease the actual data collection and post-processing, regarding the as-operated costs calculation. The asset rating calculation engine is also incorporated in order to retrieve the as-designed energy values. Instantiation

The procedure followed to extract the financial indicators is depicted in Figure 27.

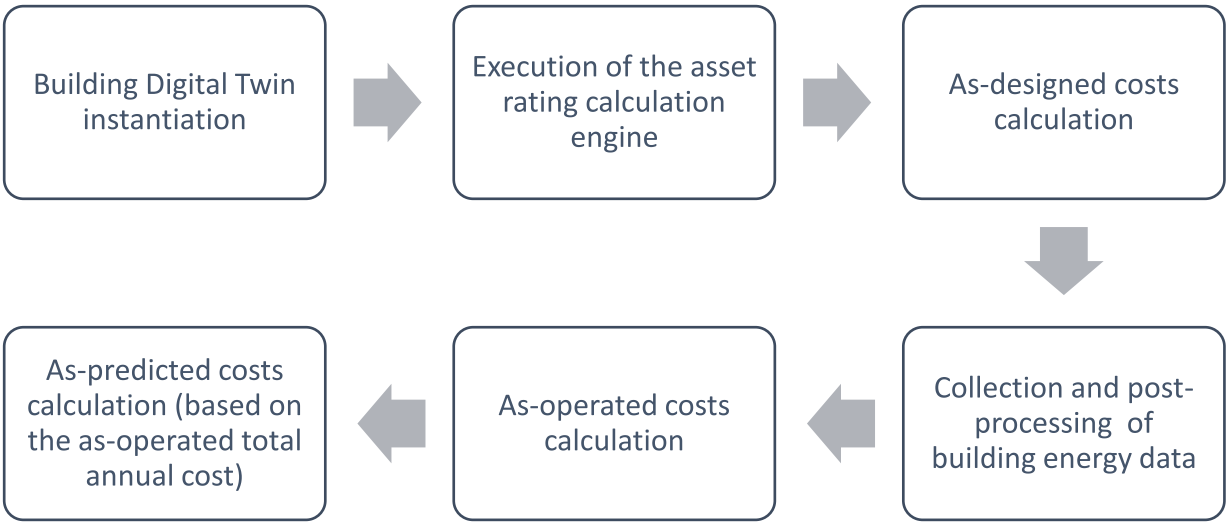


Figure 27: Financial Indicators calculation procedure

4 Assessment Validation and Results Visualization

Each assessment tool described in Section 3 is equipped with a dedicated user interface within the D^2EPC Web-platform. The page for each tool allows users to input the necessary information for the assessment or retrieve them from the BIM-based Digital Twin. After validation, users can request the assessment. This chapter outlines the process required for each module and illustrates the results generated by each tool, respectively.

The demonstrated content derives from the application of the modules on the nZEB Smart Home pilot building (CS1). The entire procedure was thoroughly tested and successfully implemented in all six distinct pilot buildings as part of the project. The comprehensive analysis of the results for all the pilot buildings can be found in D5.8.

4.1 Asset Rating Module

Having available the BIM file of an asset, the EPC Assessor is able to upload it on the D^2EPC Web Platform and request the Asset Rating calculation. Prior to the final calculation, a validation procedure takes place to ensure the correctness of the building's model. In the case of missing data or fields with values out of boundaries, the assessor must fill or correct the requested fields in order to proceed to the calculation (Figure 28). In this way, the module's internal validation mechanism ensures the validity of the generated results.

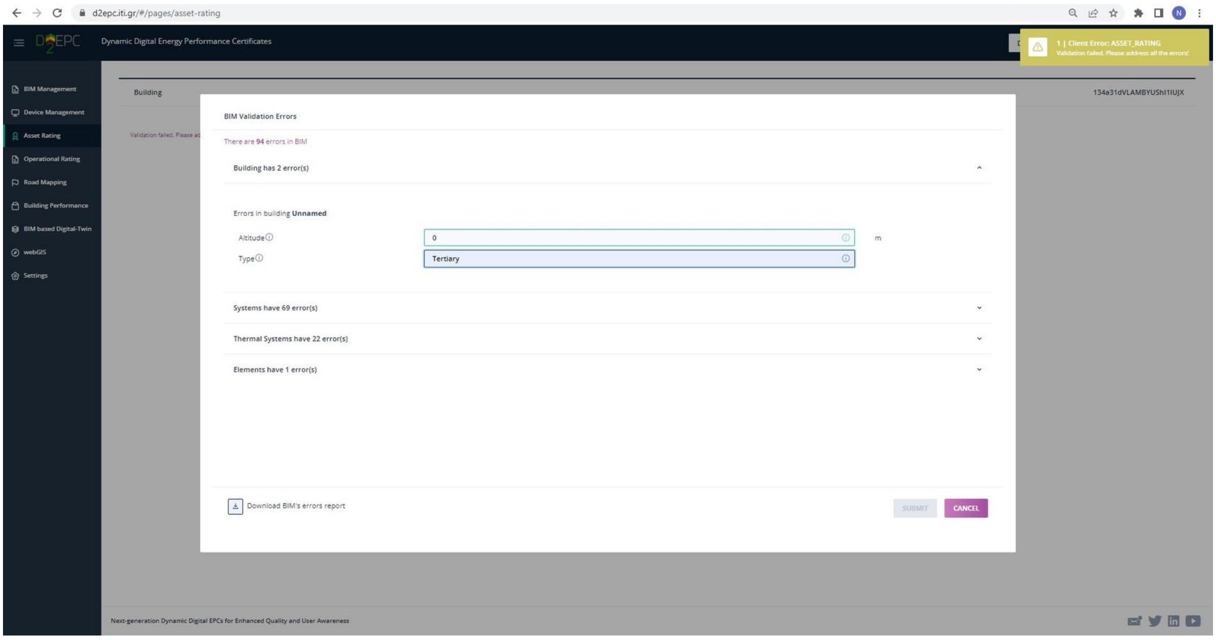


Figure 28: Asset Rating validation

The results derived from the Asset Rating Module are presented through the D^2EPC Web Platform.The platform was designed to convey a comprehensive array of information to the EPC assessor in an efficient manner.The platform demonstrates the monthly results from all the calculation stages in an effective and comprehensive way. The provision of these results is critical for the assessor to comprehend and identify any misalignments or possible errors that may occur during the EPC certification procedure. Moreover, the Asset Rating page presents the resulted KPIs and the building's energy class.

Firstly, the platform presents a diagram with the building's energy demand (Figure 29). In the bar chart the monthly energy demand values can be presented as a total or distinguished per energy service (heating, cooling, DHW, Lighting). The end-user has the ability to isolate a desired time-period (Figure

30), download it as an image, or view the numeric values in a tabulated form (Figure 33). Lastly, the provision of the calculation can be presented either as normalised values [kWh/m^2] or as absolute values (Figure 34), to enhance even more the end-user experience and the conceptualization of the building's energy performance.

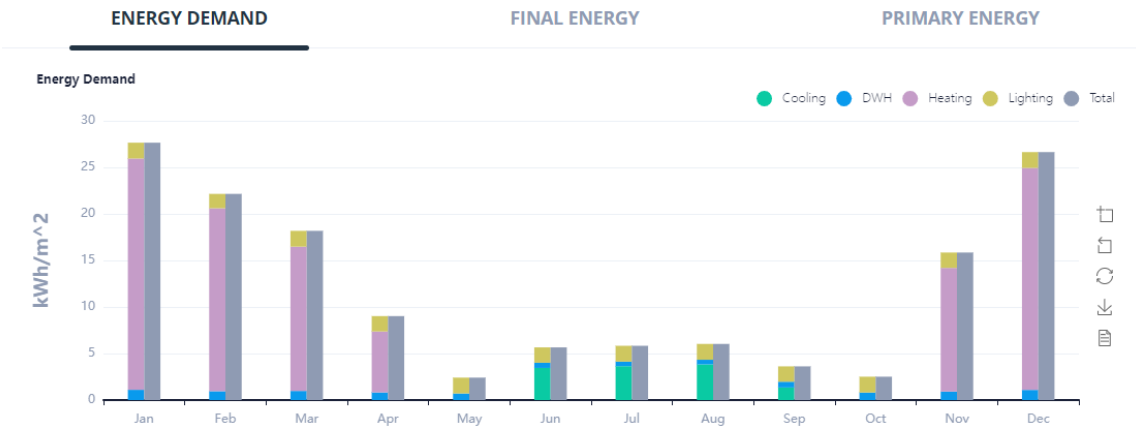


Figure 29: Energy Demand diagram [kWh/m^2]

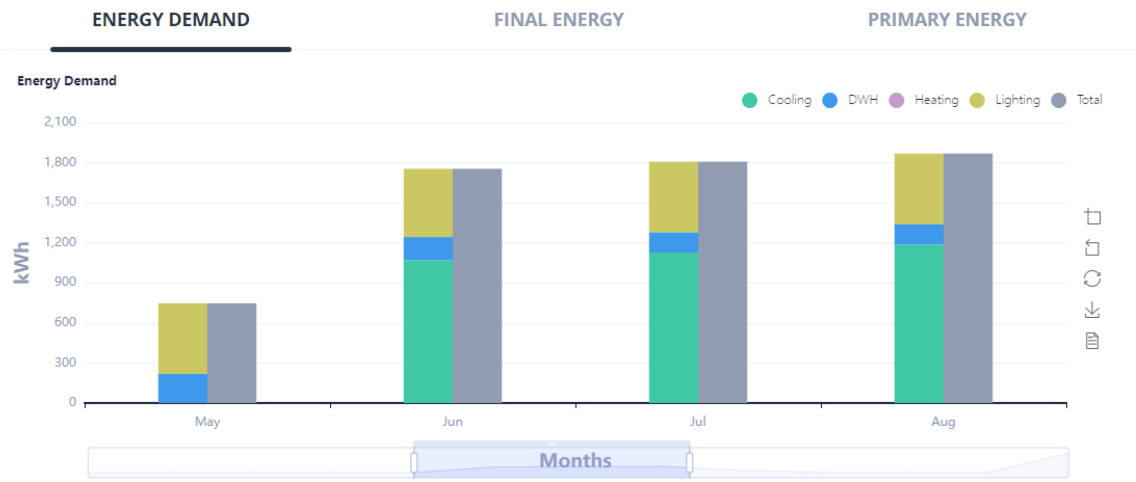
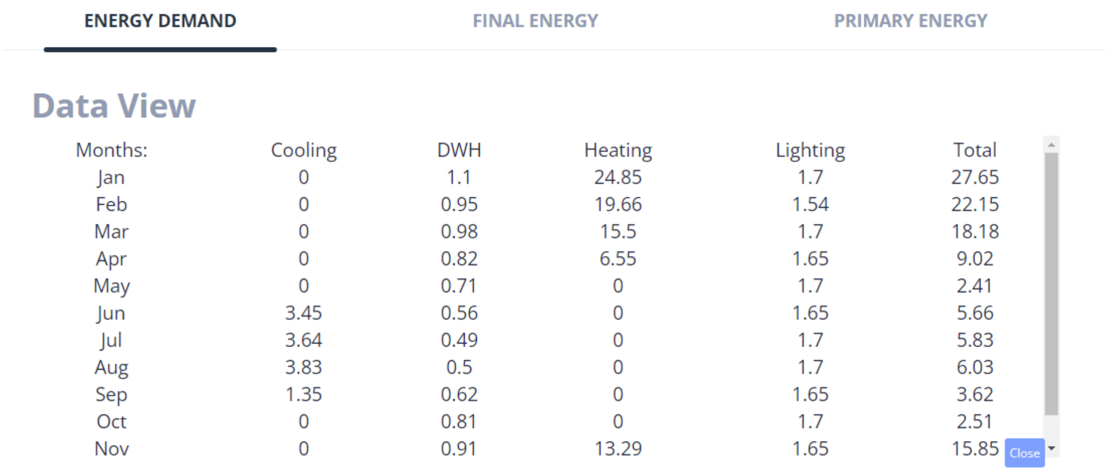


Figure 30: Energy Demand diagram - summer months' isolation



ENERGY DEMAND FINAL ENERGY PRIMARY ENERGY

Data View

Months:	Cooling	DWH	Heating	Lighting	Total
Jan	0	1.1	24.85	1.7	27.65
Feb	0	0.95	19.66	1.54	22.15
Mar	0	0.98	15.5	1.7	18.18
Apr	0	0.82	6.55	1.65	9.02
May	0	0.71	0	1.7	2.41
Jun	3.45	0.56	0	1.65	5.66
Jul	3.64	0.49	0	1.7	5.83
Aug	3.83	0.5	0	1.7	6.03
Sep	1.35	0.62	0	1.65	3.62
Oct	0	0.81	0	1.7	2.51
Nov	0	0.91	13.29	1.65	15.85

Close

Figure 31: Energy demand - data view

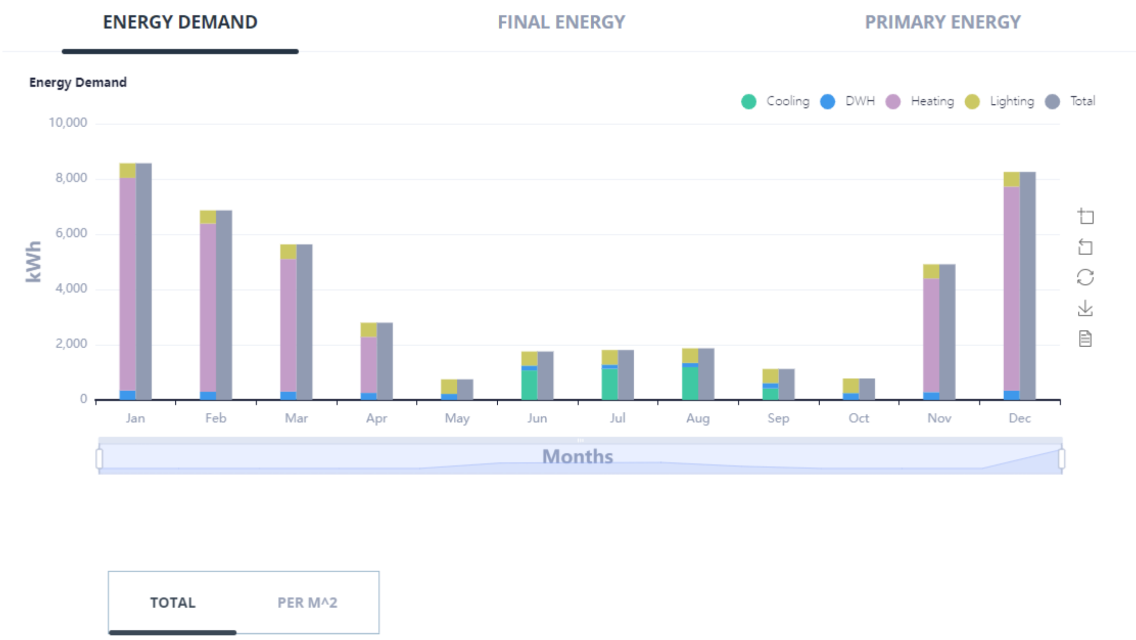


Figure 32: Energy Demand Diagram – absolute energy values

All the above-described functionalities are also available for the calculation steps of final energy (Figure 33) and primary energy (Figure 34). In these cases, the annual energy profile of the building also shows how much energy is produced on-site by installed renewable energy sources (e.g., PV and solar thermal collectors).

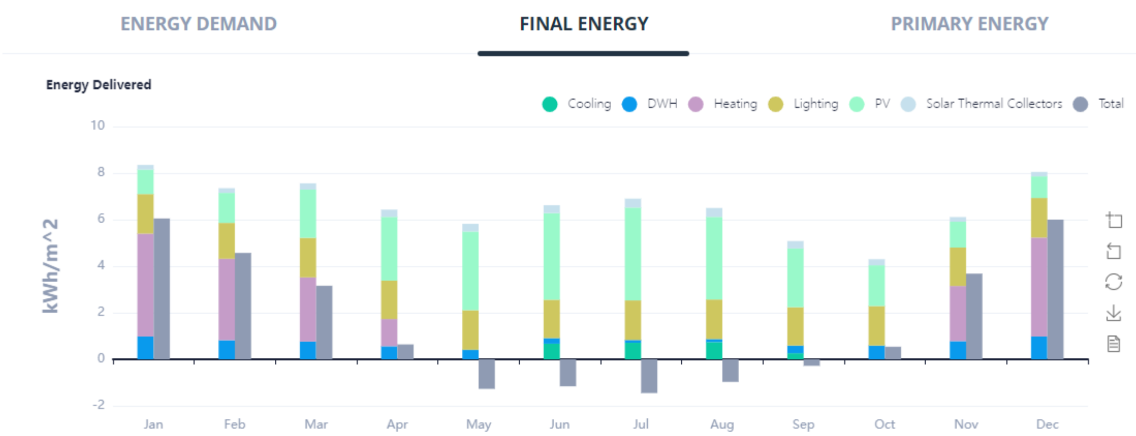


Figure 33: Final Energy Diagram

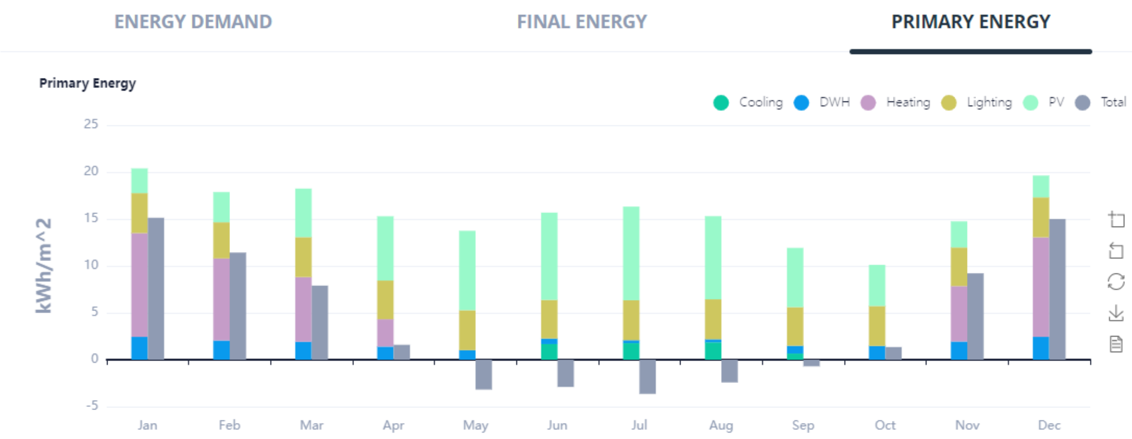


Figure 34: Primary Energy Diagram

Proceeding to the section with the KPIs, the end-user can find the total annual values of energy consumption. Figure 35 presents the annual energy consumption per energy service, while Figure 36 presents it per energy carrier. A small set of financial and environmental indicators is also included in the Asset Rating demonstration. Figure 37 presents the total cost of the building's annual energy consumption per energy carrier, and Figure 38 demonstrates the annual CO_2 emissions per energy carrier. All the KPIs can be presented as absolute or normalised values.

Figure 35: Annual energy consumption per energy service

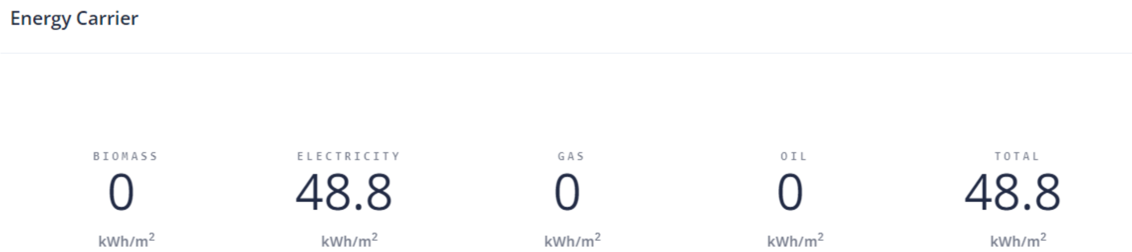
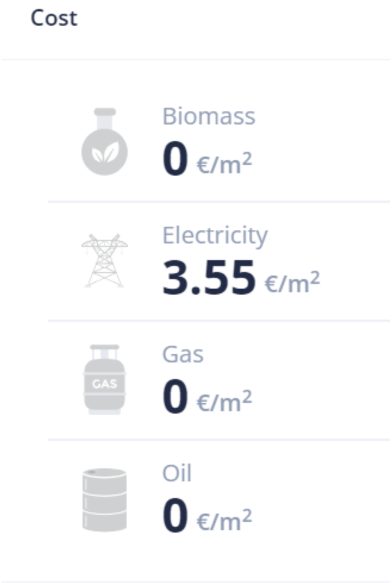


Figure 36: Annual energy consumption per energy carrier



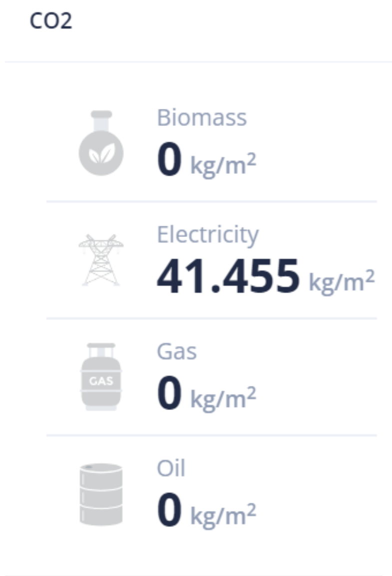


Figure 37: Financial Indicators **Figure 38: Environmental Indicators**

The final and most important indicator is the building's energy class. The representation of the energy class is made according to the format presented in Figure 39. At the bottom of the scheme, the "Energy Efficiency Rating" value indicates the ratio between the examined and the reference building's energy performance. This value is used to classify the building into one of the seven energy classes according to the limit values presented within each class.

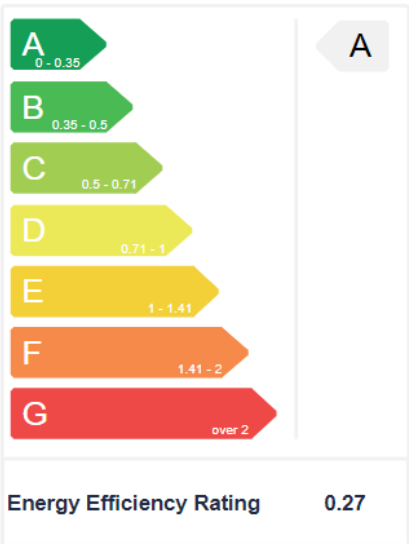


Figure 39: Energy Class

4.2 Operational Rating Module

The validation of the Operational Rating Module concentrates on two basic fields. The first field of validation refers to general building characteristics (building's usage, construction year), and the second field to meter characteristics (meter_id, energy service, energy carrier). If the required fields are empty, then the validator demands the end-user to fill corresponding fields with appropriate values.

The output of the Operational Rating seeks to provide a holistic view regarding the impact of the energy consumption behavior of the building owner. The JSON format output contains meaningful results for the WebPlatform and Alerts and Notifications Module. The overall overview of the Operational Results are presented as follows:

```
{
    "type": "object",
    "properties": {
        "connected_with": {
            "type": "array"
        },
        "device_id": {
            "type": "string"
        },
        "energy_carrier": {
            "type": "string"
        },
        "energy_service": {
            "type": "array"
        },
        "measurement_types": {
            "type": "array"
        },
        "meter_id": {
            "type": "string"
        },
        "name": {
            "type": "string"
        },
        "refers_to": {
            "type": "array"
        },
        "space_id": {
            "type": "string"
        }
    },
    "required": [
        "energy_carrier",
        "energy_service",
         "meter_id",
        "device_id"
    ]
}
```

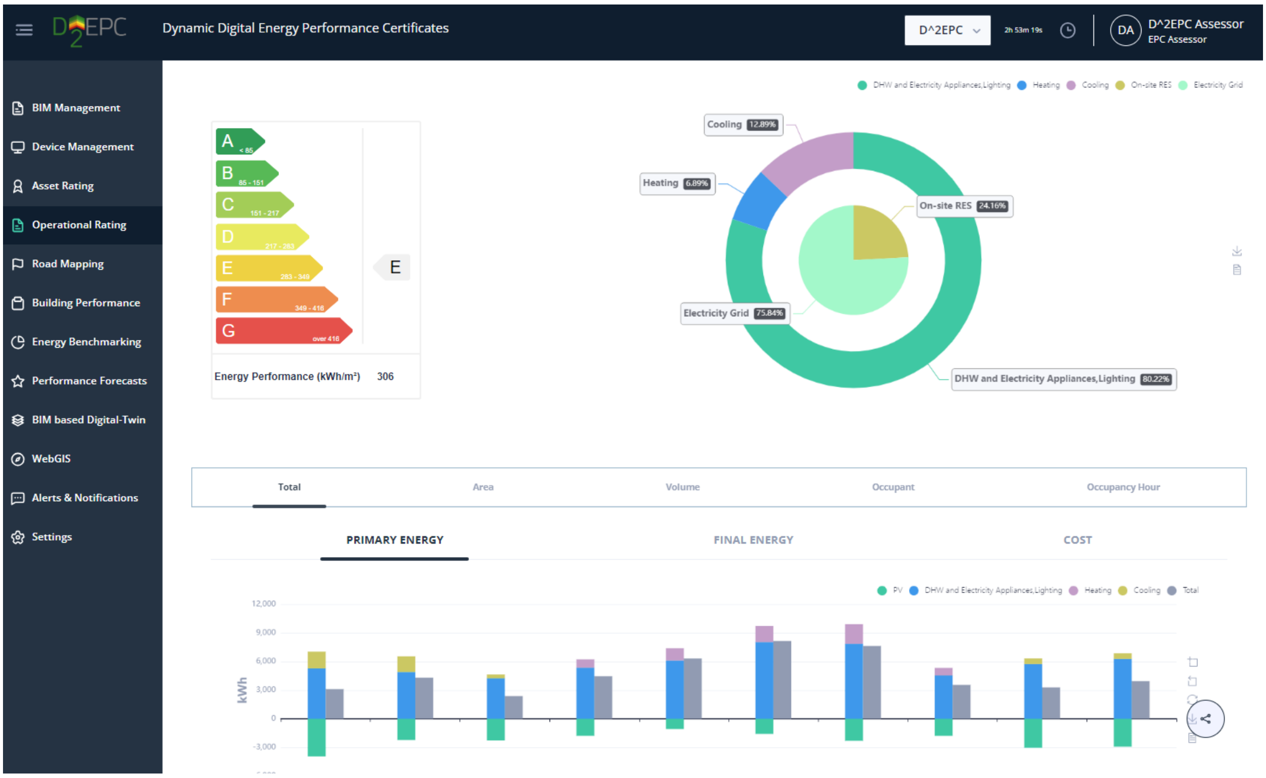


Figure 40: Overview of Operational Rating interface

The results are categorized into different time steps with different calculated indicators. The daily data concerns the daily total primary energy of the building for all services expressed in kWh. The daily values are depicted with a heat map. Heat maps declare the high values of consumption with intense colour. Heat map is shown in Figure 41.

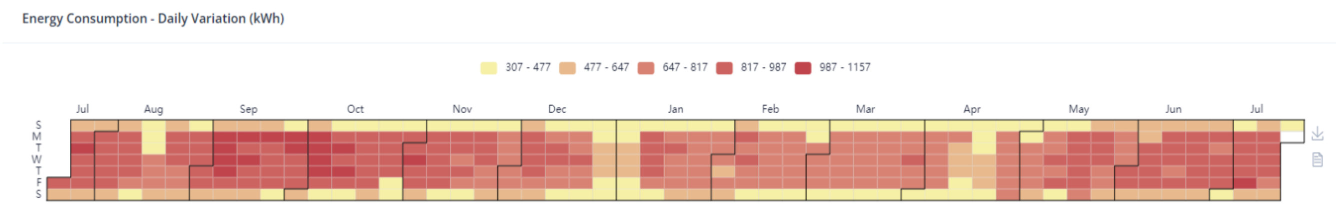


Figure 41: Heat maps of daily energy consumption

The monthly values are presented in three main categories 1) Final energy [kWh], 2) Primary energy [kWh], and 3) Operational Cost [Euros]. Each category is normalized based on static (area, volume) or dynamic (occupants) indicators for every energy service (Heating, DHW, Electrical Appliances, etc.). Monthly data are depicted through bar charts where main categories and indicators can be selected from the corresponding field in the interface. The bar charts are shown in Figure 42.

Figure 42: Bar chart of monthly energy consumption values

The annual values are depicted through 2 pie charts, which data are expressed in terms of primary energy. The outer pie chart expresses the calculated values per energy service and the inner circle depicts the calculated values per energy carrier. The depiction of annual values is shown in Figure 43.

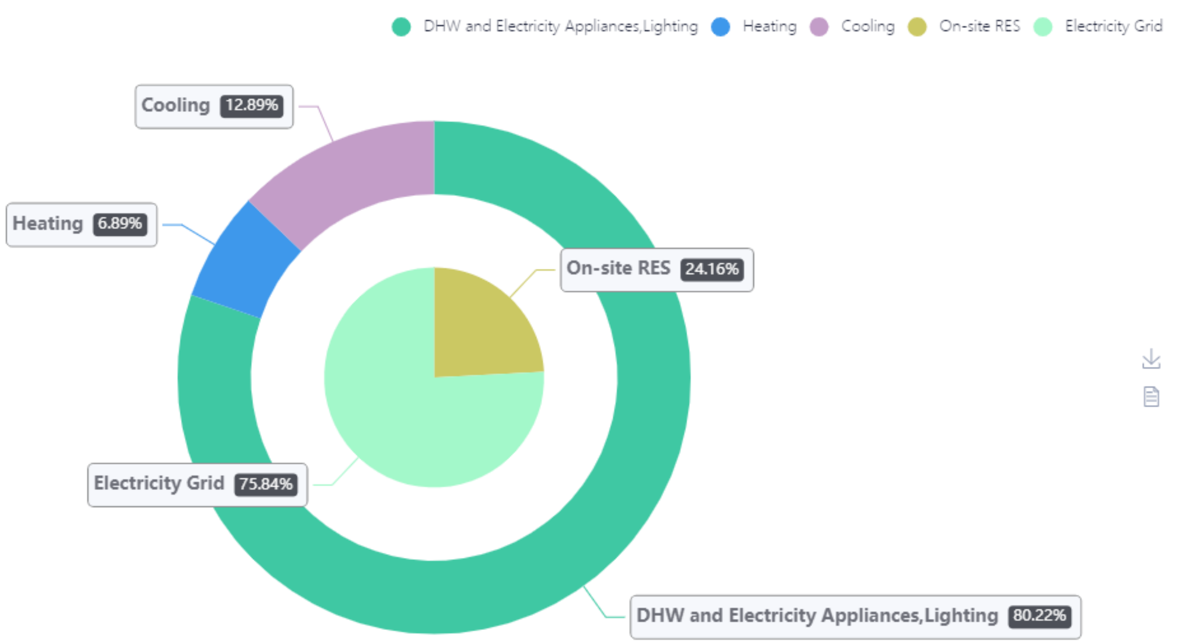


Figure 43: Annual energy consumption values

Finally, the dates section, indicates the starting and ending timestamp of the collected data for Operational rating issuance. Energy class is the building's operational energy class, which was calculated from the classification of the energy consumption number to the energy classification boundaries. The energy consumption number is expressed in terms of primary energy per area [kWh/m2] and the classification boundaries are defined by the tool based on the building's usage (Hotels, single houses, private offices, etc.). The energy class, the classification boundaries and the energy consumption are shown in Figure 44.

Figure 44: Operational Energy Class

The presented results refer to Case Study 1, CERTH's nZEB Smarthome, for the time period of July 2022 to June 2023. It is worth mentioning that CERTH's Smarthome achieves E energy class despite the electrical production of PV. The main reason is that CERTH's Smarthome contains a highly energy-consuming data centre and private offices which justifies that the majority of consumption derives from electrical appliances from Figure 43 (annual pie charts).

Apart from the Web Platform output, Operational Rating Module forms a suggestion regarding the user's operational behaviour. The suggestion is given as input to the Alerts and Notifications Module.

4.3 Building Performance Module

4.3.1 SRI calculation submodule

A detailed setup process for the SRI calculation has been designed in the D^2EPC Web Platform. The first step regards the insertion of all information necessary regarding the assessor (Figure 45) and the building characteristics (Figure 46), respectively. Following next, the user is able set the presence of each one of the smart domains and of the corresponding smart services (Figure 47). Additionally, the functionality level for each service as well its coverage (entire building or part of it) can be defined. It is important to highlight that BIM data extraction takes place prior to providing the SRI input form to the user. Required building parameters as well as the presence of domain and services, along with the determined functionality levels, are automatically filled-in where possible.

However, due to the limited SRI-related information found in any BIM file, the BIM Parser subcomponent of the Building Digital Twin can contribute mainly to the high-level triage process, identifying some active domains and services and up to the third functionality level. The extensive investigation within Task 2.1 revealed that revisions or/and additions might be required by the assessor, in order to compensate for input information that is missing or cannot be included in BIM files. As an example, information regarding the installed EV charging station in Case Study 1 is not included in the studied BIM file, though the respective domain and its corresponding services need to be examined under the SRI assessment. To this end, the input form in Figure 47 are fully customizable, allowing the user to edit the corresponding fields, providing additional information or overwriting the already inserted one.

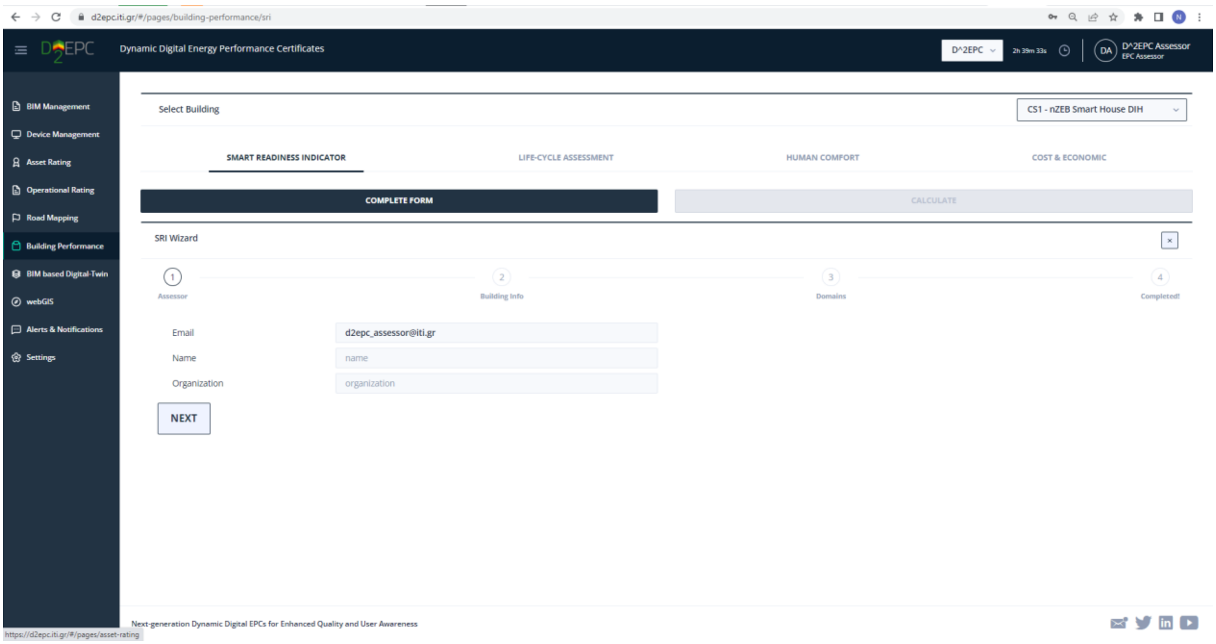


Figure 45 Provision of the SRI assessor information

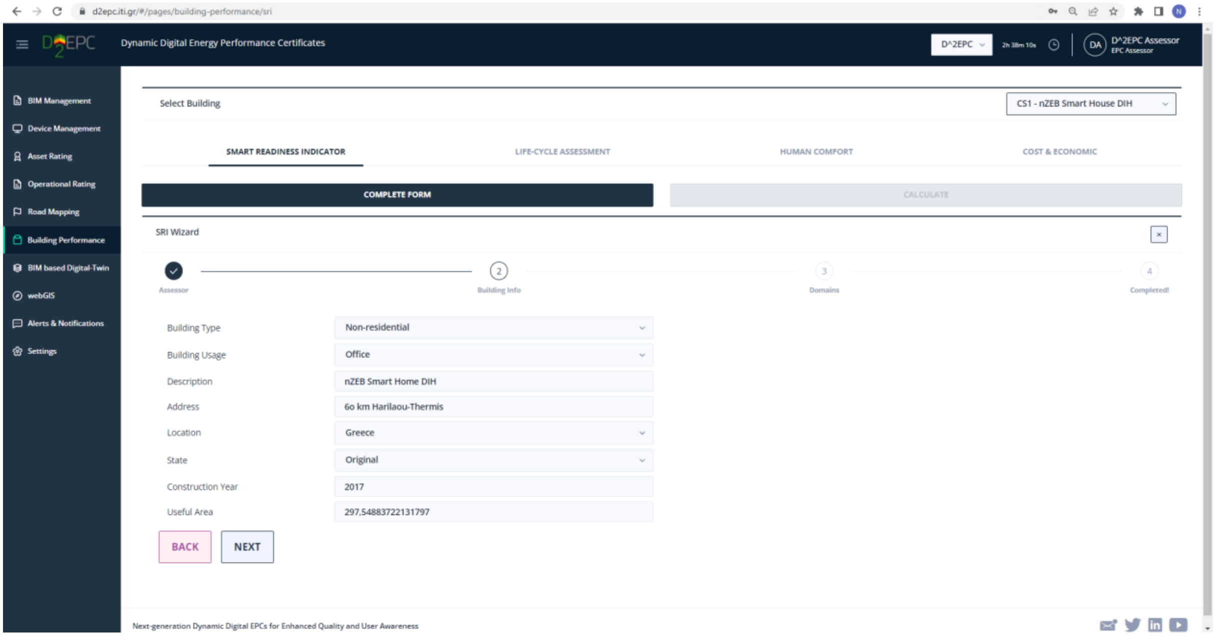


Figure 46 Provision of SRI-related building information

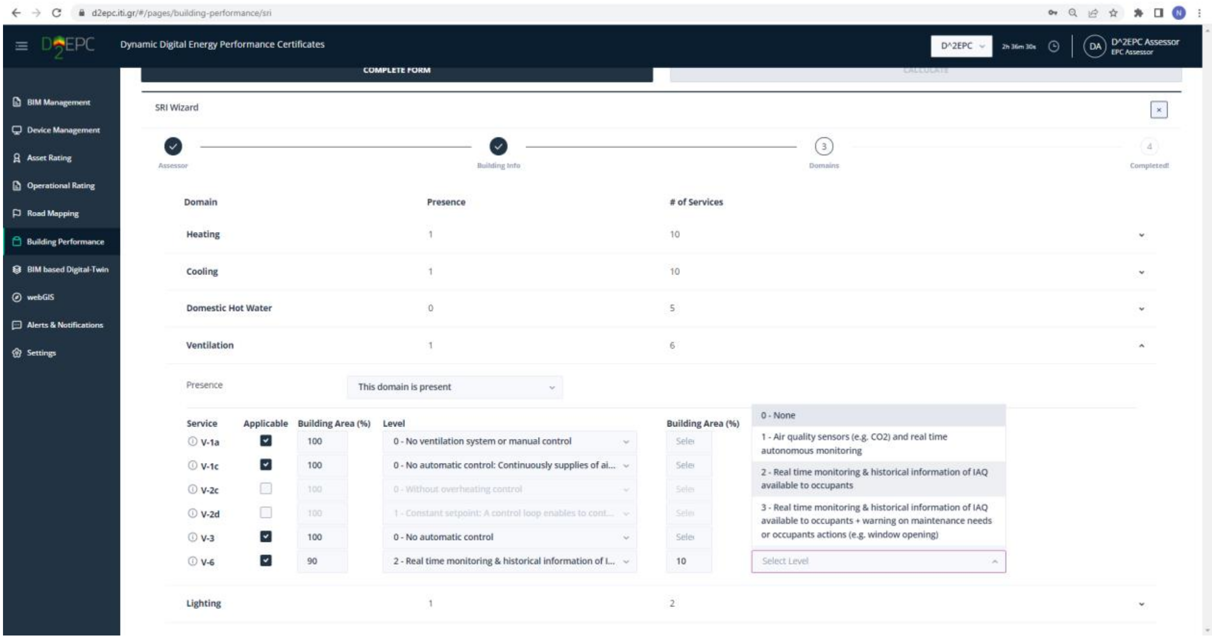


Figure 47 Parametrization of SRI domains and services

An example of the input information provided to the SRI-calculation submodule, upon completion of the setup process, is shown below.

```
{
    "assessor": {
        "email": "d2epc_assessor@iti.gr",
        "name": null,
        "organization": null
    },
    "building_info": {
        "address": "6o km Harilaou-Thermis",
        "building_id": "134a31dVLAMBYUShIBlUJY",
        "building_type": "Non-residential",
        "building_usage": "Office",
        "construction_year": 2017.0,
        "description": "nZEB Smart Home DIH",
        "location": "Greece",
        "state": "Original",
        "useful_area": 297.54883722131797
    },
    "smart_services": [
        {
            "domain": "Heating",
            "presence": 1,
            "services": [
                {
                    "applicable": true,
                    "levels": [
                        3
                    ],
                    "service": "H-1a"
                },
                {
                    "applicable": false,
                    "levels": [
                        1
                    ],
                    "service": "H-1b"
                },…
            ]
        },
        {
            "domain": "Cooling",
            "presence": 1,
            "services": […]
        }, …
    ]
}
```


Upon executing the calculation, the SRI calculation results are provided to the user, as presented in Figure 48 and Figure 49. They include overall SRI achieved score and the corresponding SRI class, followed by the impact and domain scores, as well as the detailed and aggregated scores. It is worth mentioning that cross-validation of the results against the output of the SRI calculation package has been successfully carried out for all case studies.

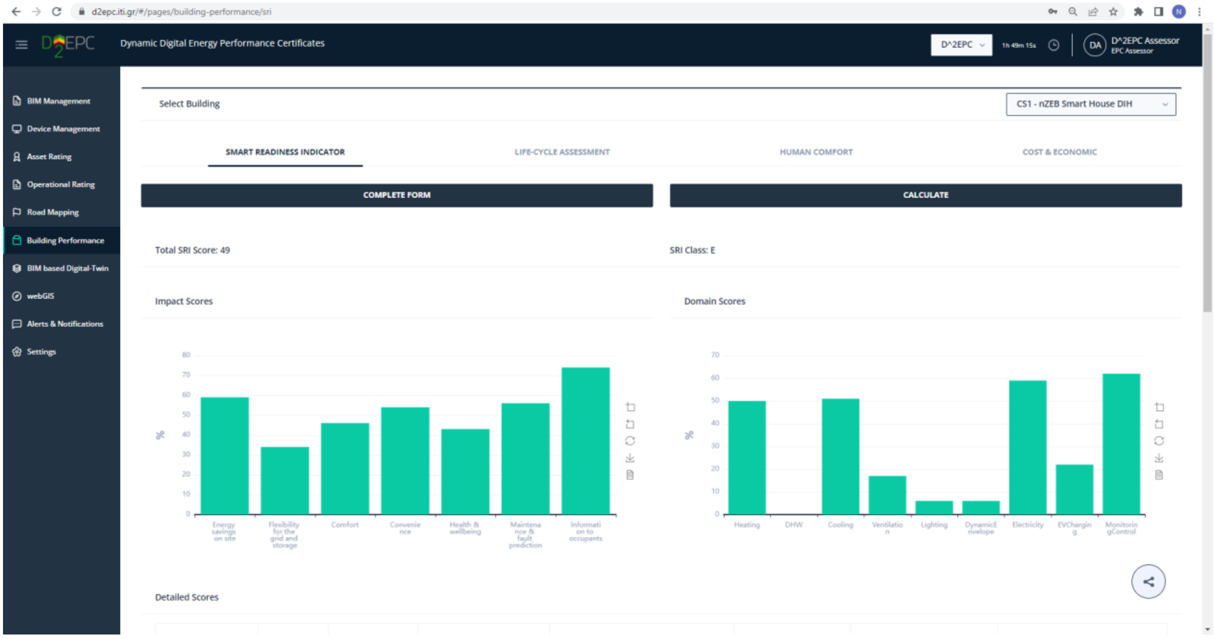


Figure 48 SRI calculation results; total score, class, impact and domain scores

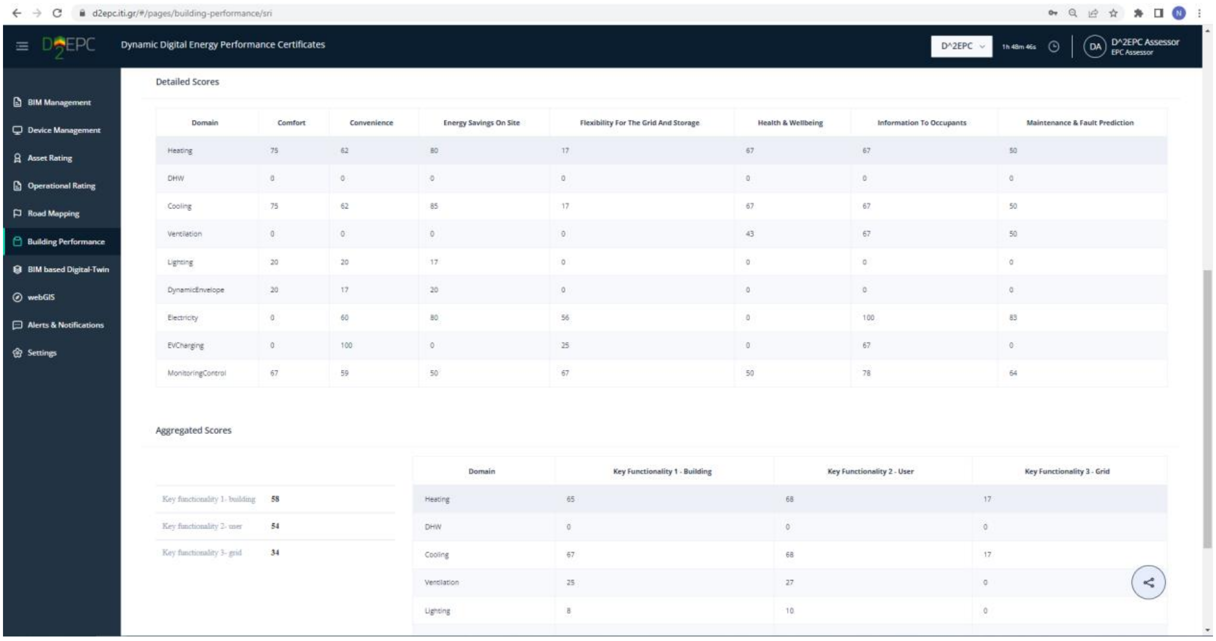


Figure 49 SRI calculation results; detailed and aggregated scores

4.3.2 Human Comfort & Wellbeing Indicators calculation submodule

Figure 50 shows the initial parametrization of the HC&W calculation. The user is able to select among the different building spaces where at least one group of indicators has been calculated. By default, all the indicators are calculated over a six-month time scale, though the option for selecting another timeframe (e.g., one year) is also available.

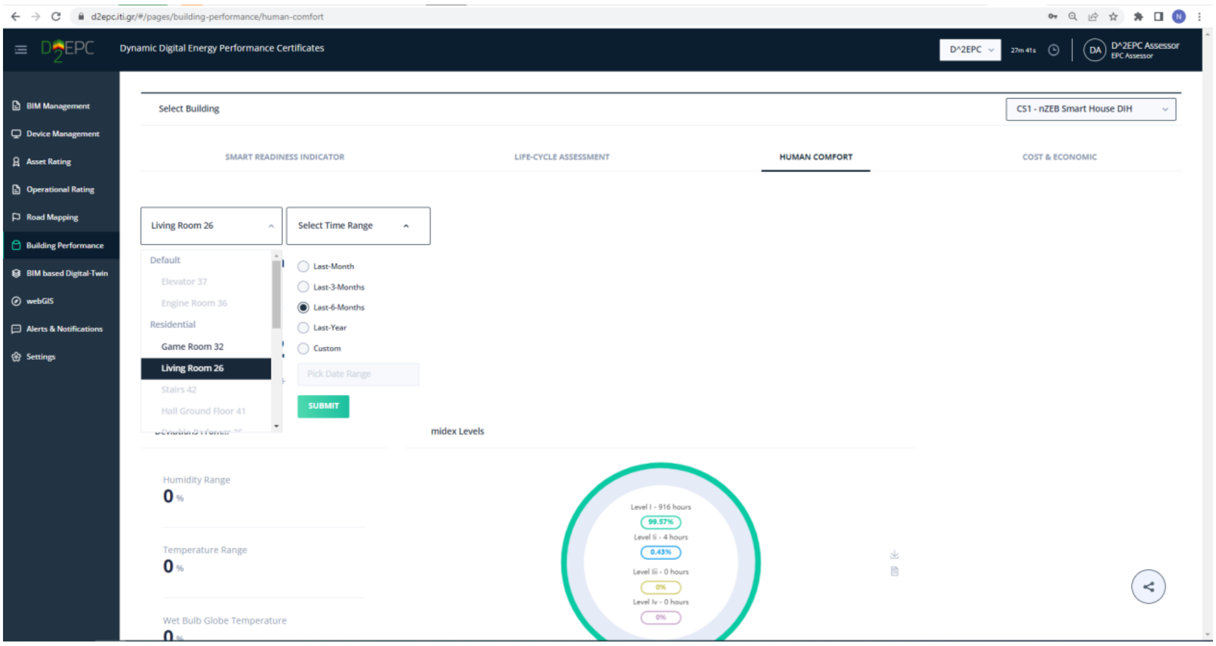


Figure 50 Provision of HC&W indicators-related information

The tool utilizes actual building measurements for each space, which are retrieved from the D^2EPC Repository through the Building Digital Twin. Figure 51 - Figure 57 present such data that are collected for a space in CS1.

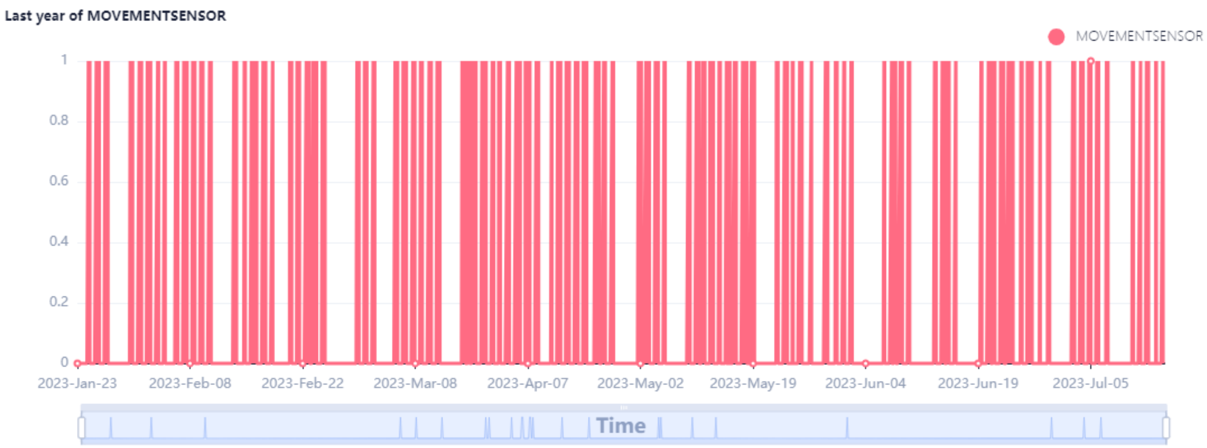


Figure 51 CS1 presence measurements

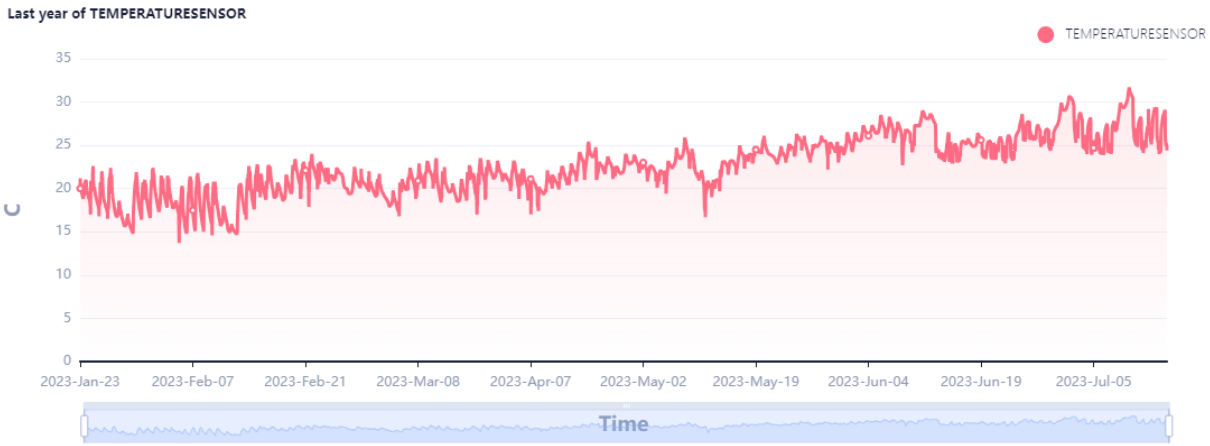


Figure 52 CS1 temperature measurements

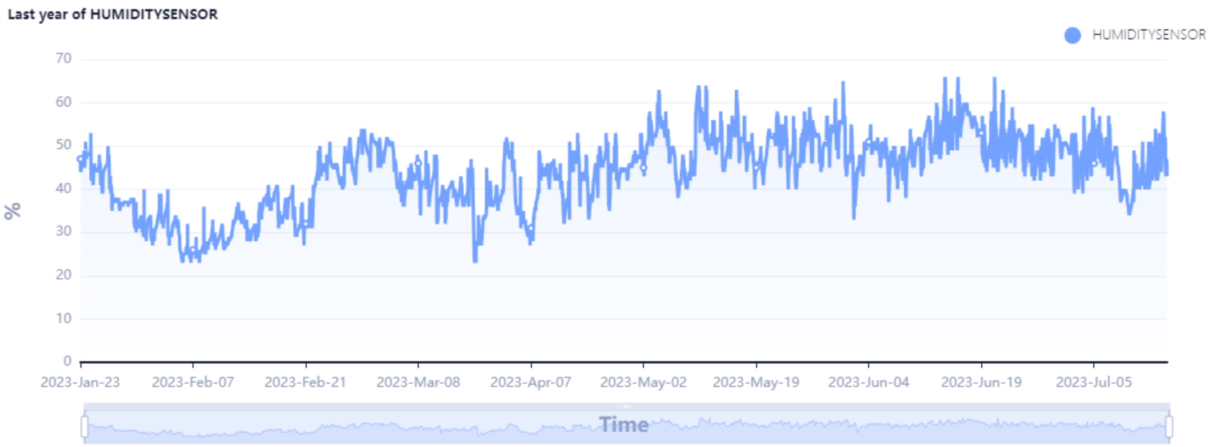


Figure 53 CS1 humidity measurements

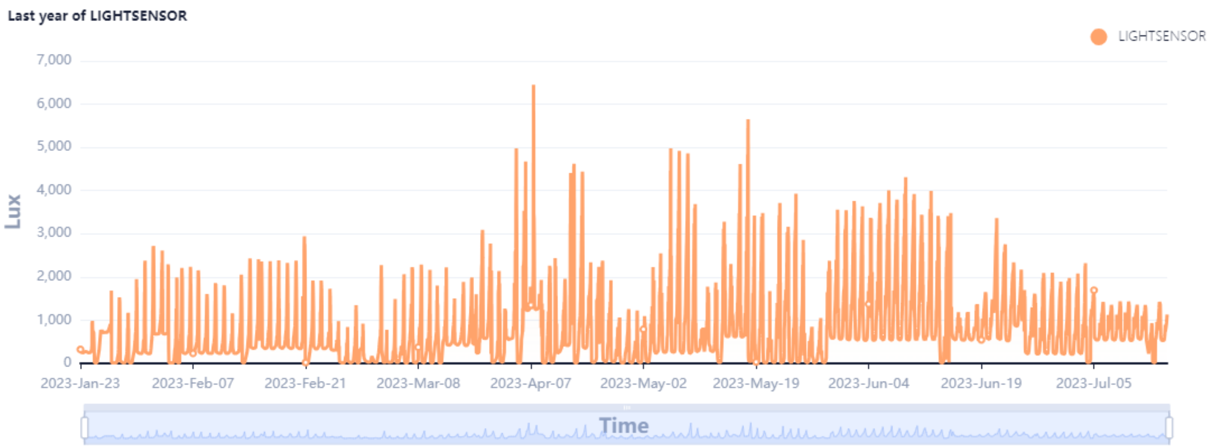


Figure 54 CS1 luminance measurements

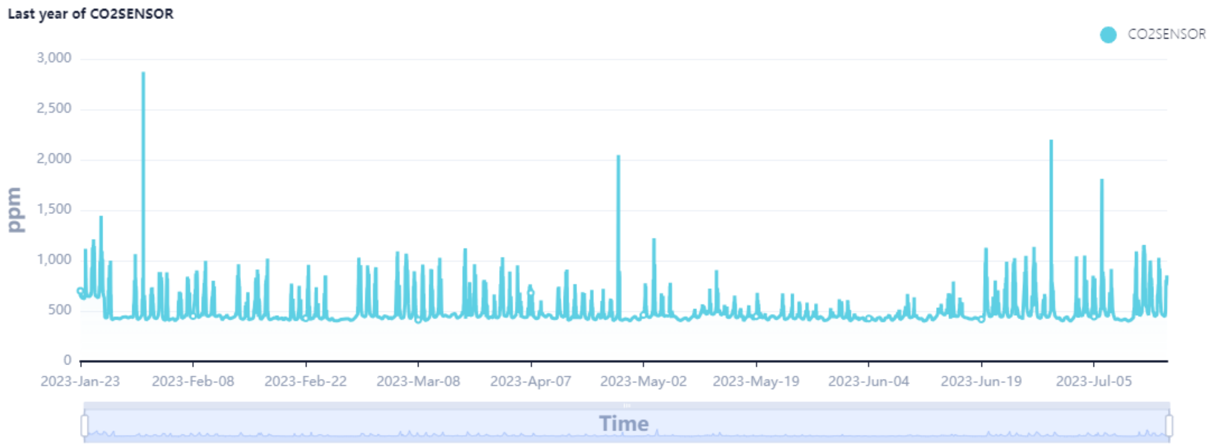


Figure 55 CS1 CO2 measurements

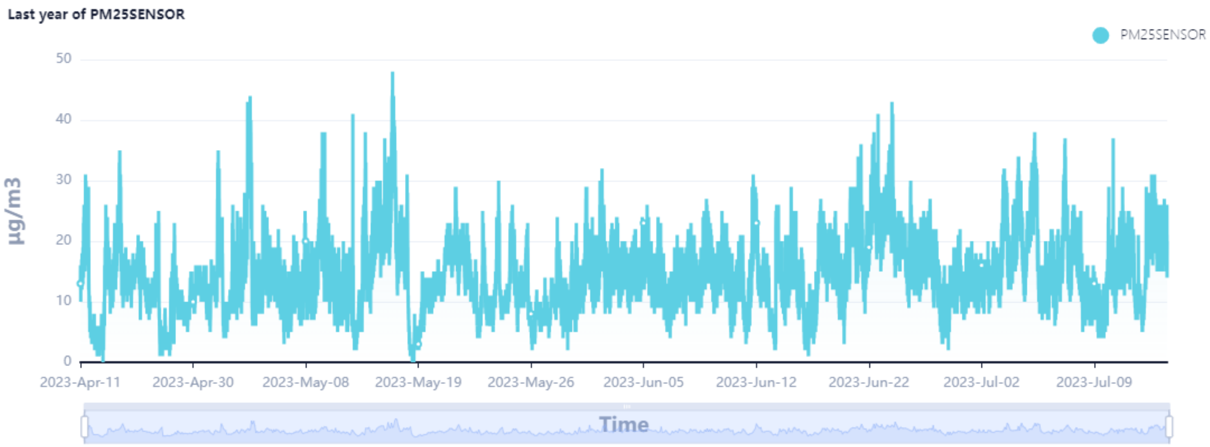


Figure 56 CS1 PM2.5 measurements

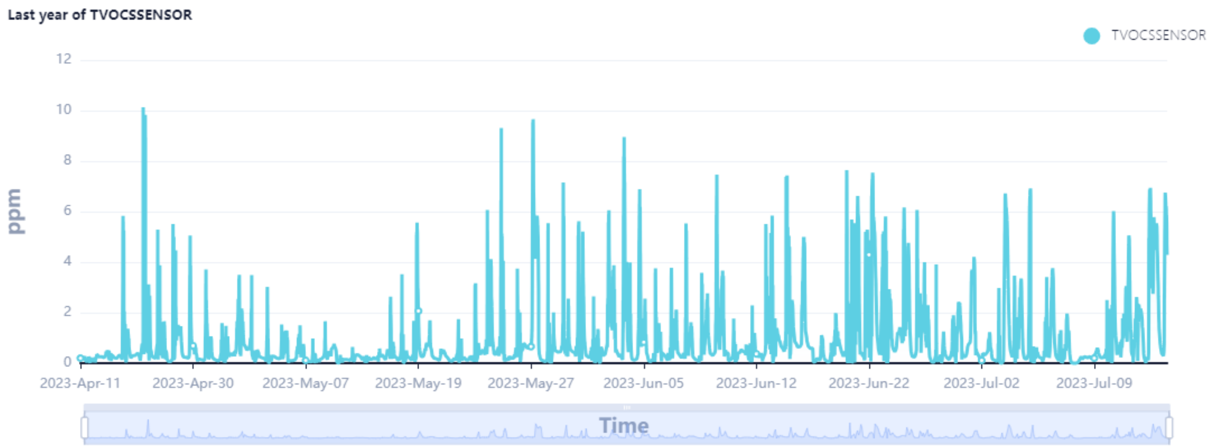


Figure 57 CS1 TVOCs measurements

Figure 58 - Figure 60 present the HC&W indicators results for a space of CS1. It is important to mention that unit tests have been performed for each calculation method and, in case of more complex calculations (e.g. humidex levels), the results have been validated against the output of corresponding online tools.

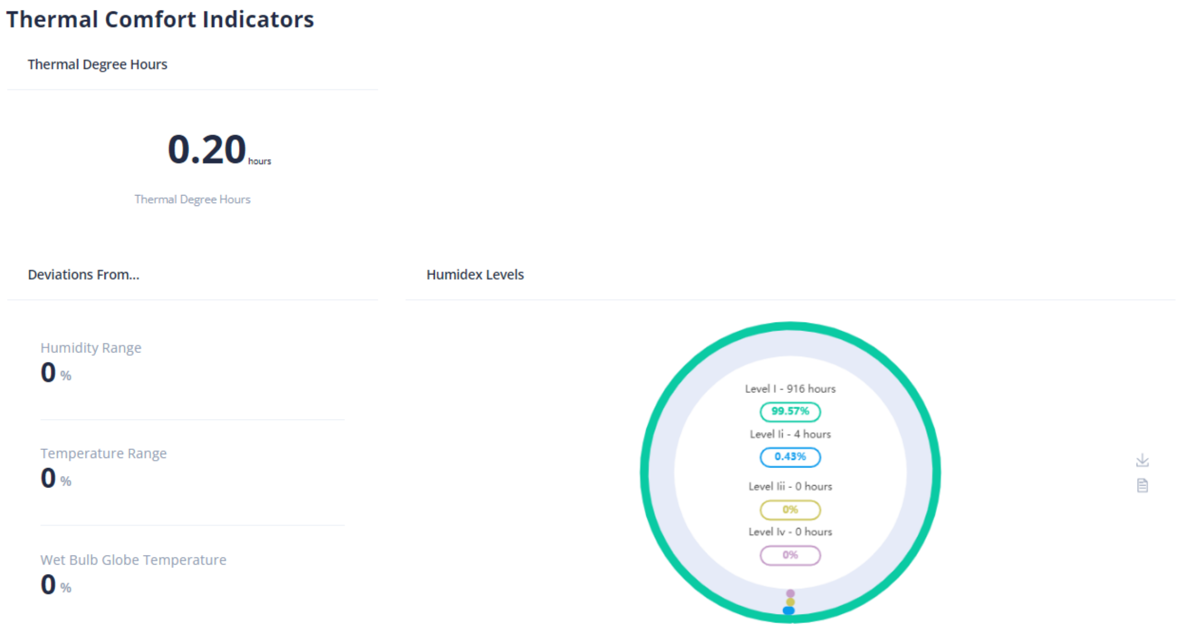


Figure 58 CS1 thermal comfort indicator results

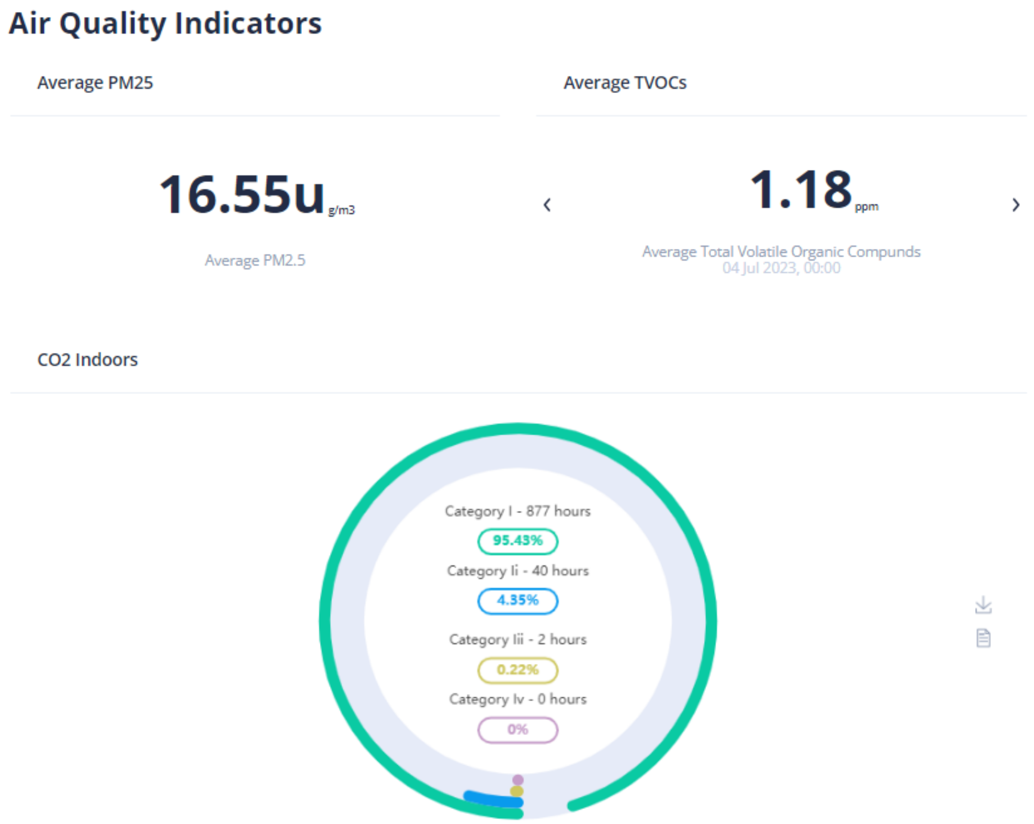


Figure 59 CS1 air quality indicators results

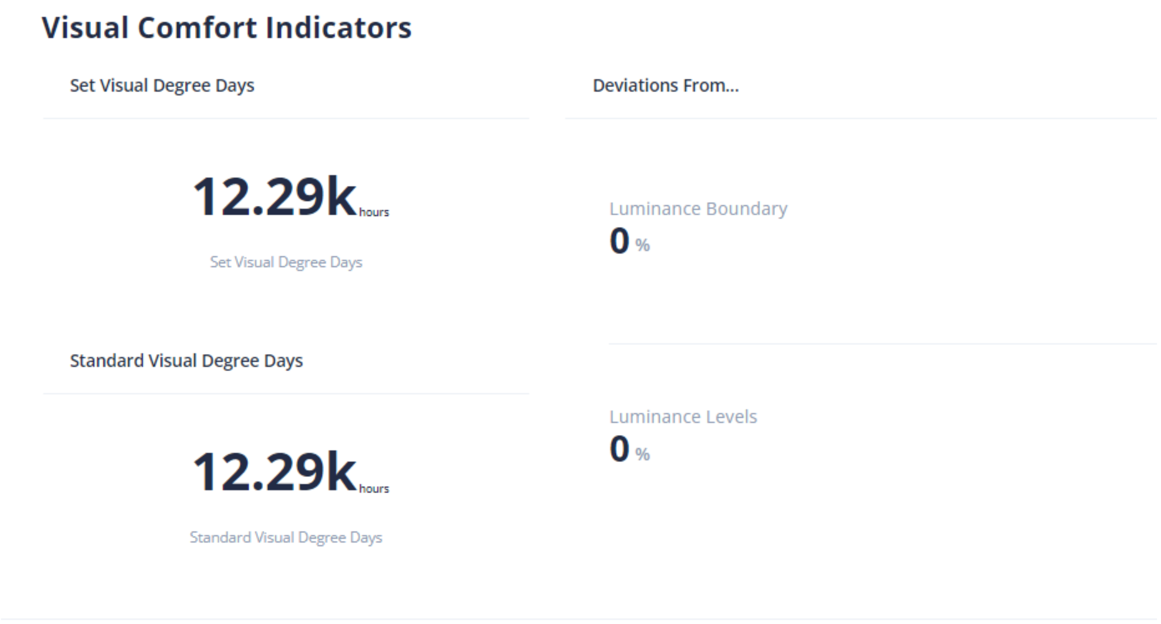


Figure 60 CS1 visual comfort indicators results

4.3.3 LCA Indicators calculation submodule

A dedicated interface for the setup process of the LCA calculation has been integrated into the D^2EPC Web Platform. The first execution of the tool triggers the BIM Parser subcomponent of the Digital Twin, which extracts the bill of materials available in the building's BIM file. The latter includes the name of the material, its structural group and its calculated quantity (based on dimensions) along with the corresponding unit. A sample output including building materials of Case Study 1 is shown below.


```
{
    "lca_data": [
        {
            "structural_group": "External_walls",
            "material": "Finishing Coating",
            "quantity": 2.2594099136842,
            "unit": "m^3"
        },
        {
            "structural_group": "Internal_walls",
            "material": "FIBRAN gyps SUPER",
            "quantity": 2.7408564855808732,
            "unit": "m^3"
        },
        {
            "structural_group": "Doors",
            "material": "Doors_Alumil_Supreme_S77_PHOS_Single:My Glass Door Alumil",
            "quantity": 4.840000000000001,
            "unit": "m^2"
        },
        {
            "structural_group": "Windows",
            "material": "Windows_Alumil_Supreme_S77_PHOS_Fixed:Windows_Alumil_S77_Fixed_9_triple_glazing",
            "quantity": 3.465,
            "unit": "m^2"
        },
        {
            "structural_group": "Slabs",
            "material": "FIBRAN xps seismic 400 (2)",
            "quantity": 20.392207633580433,
            "unit": "m^3"
        },
        {
            "structural_group": "Roofs",
            "material": "Ceiling Tile 600 x 600 Insulation",
            "quantity": 16.400609794075574,
            "unit": "m^3"
        },
        ...
    ]
}
```


The extracted materials are stored in the D^2EPC Repository and displayed to the user, as shown in Figure 61 below, where they can also be filtered based on their structural group.

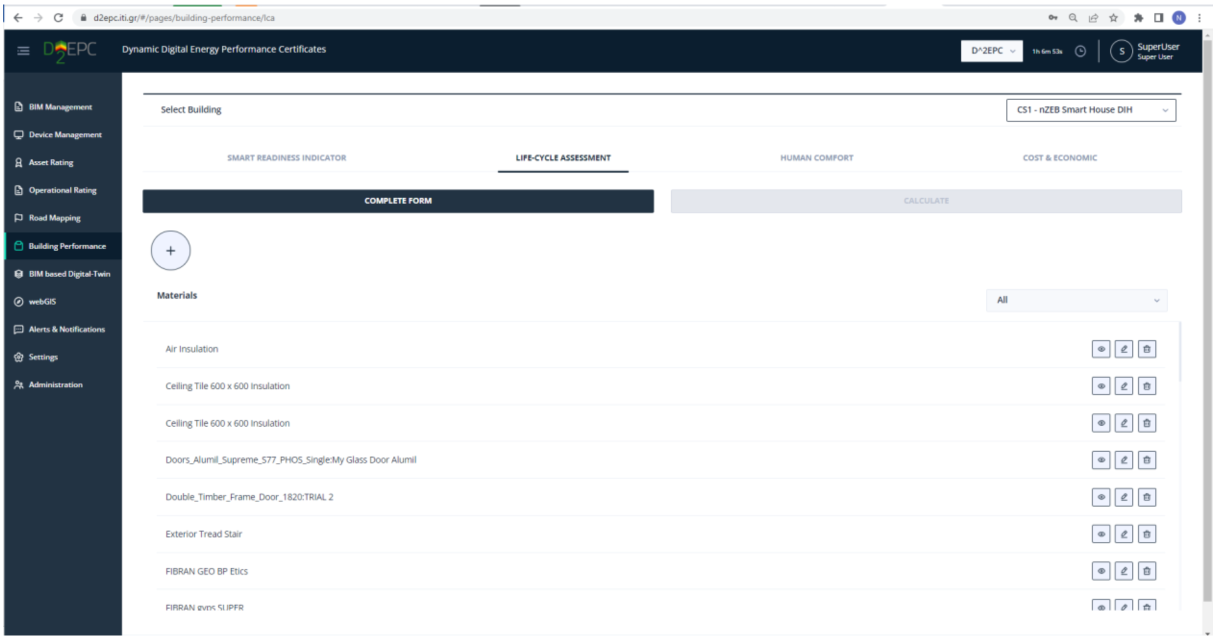


Figure 61 Case Study 1 extracted materials

Subsequently, the information of each material can be corrected, if needed, and the relevant EPD indicators data can be provided. As already mentioned, three options are available for realizing the latter. The EPD auto-search within the tool's dataset can be selected via a simple radio button. Alternatively, a URI linked to data in the ECO PORTAL can be retrieved by the integrated search process, as presented in Figure 62. Based on the material name, a dropdown list of the found EPD entries is returned to the user along with some basic data, including the link to actual EPD in the corresponding external data set (Figure 63), which can be visited in order to gain access to more details. The JSON file below shows an example of the received data payload.

```
{
    "processInformation": {
        "dataSetInformation": {
            "UUID": "edab317d-6e11-44ad-a679-7af509d3f565",
            "name": {
                "baseName": [{
                        "value": "Metal Ceiling Tiles & Panels (0.6 mm, with acoustic fleece)",
                        "lang": "en"
                    }
                ],
                "functionalUnitFlowProperties": [...]
            },
            "classificationInformation": {...},
            "generalComment": [...]
        },
        "quantitativeReference": {
            "referenceToReferenceFlow": [0]
        },
        "time": {...},
        "geography": {...},
        "technology": {...}
    },
    "modellingAndValidation": {...},
    "administrativeInformation": {...},
    "exchanges": {...},
    "LCIAResults": {
        "LCIAResult": [{
                "referenceToLCIAMethodDataSet": {
                    "shortDescription": [{
                            "value": "Global Warming Potential total (GWP-total)",
                            "lang": "en"
                        }
                    ],
                    "type": "LCIA method data set",
                    "refObjectId": "6a37f984-a4b3-458a-a20a-64418c145fa2",
                    "uri": "../lciamethods/6a37f984-a4b3-458a-a20a-64418c145fa2.xml"
                },
                "other": {
                    "anies": [{
                            "name": "referenceToUnitGroupDataSet",
                            "value": {
                                "shortDescription": [...],
                                "type": "unit group data set",
                                "refObjectId": "1ebf3012-d0db-4de2-aefd-ef30cedb0be1",
                                "uri": "../unitgroups/1ebf3012-d0db-4de2-aefd-ef30cedb0be1.xml"
                            }
                        }, {
                            "value": "19.2978638061653",
                            "module": "A1-A3"
                        }, {
                            "value": "0",
                            "module": "C1"
                        }, {
                            "value": "0.0143038503602263",
                            "module": "C2"
                        }, {
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                            "module": "C3"
                        }, {
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                            "module": "C4"
                        }, {
                            "value": "-9.127060549094",
                            "module": "D"
                        }
                    ]
                }
            },
            {...},
            ...
        ]
    },
    "otherAttributes": {
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    },
    "version": "1.1",
    "locations": "../ILCDLocations.xml"
}
```

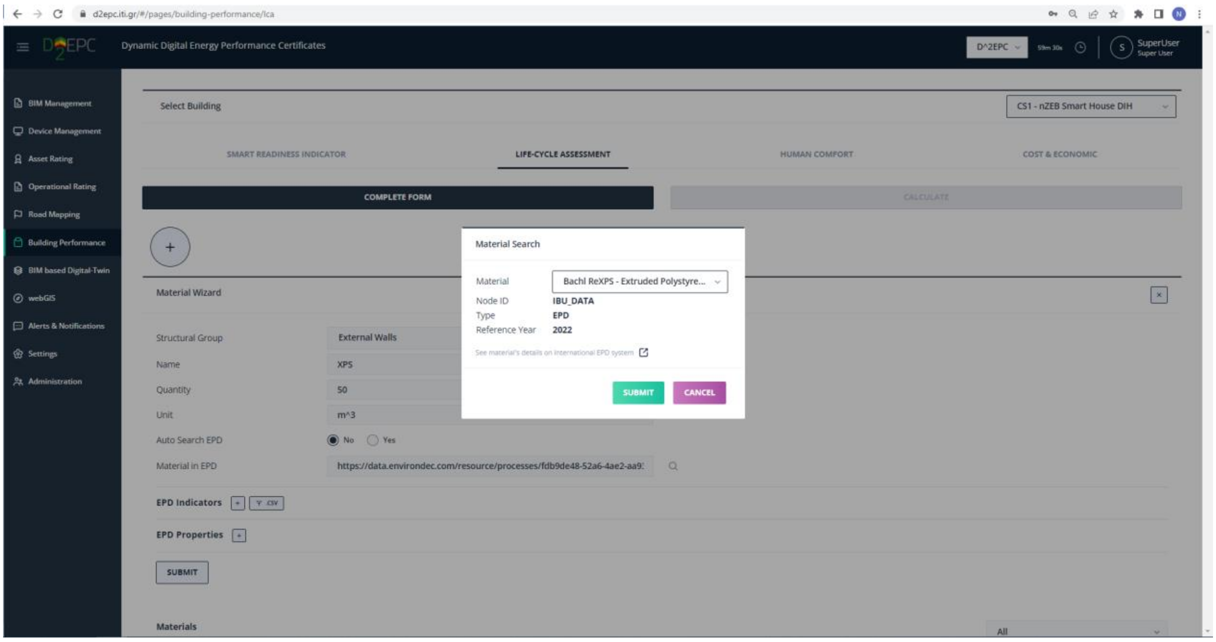

Figure 62 ECO PORTAL interfacing for retrieving material EPDs

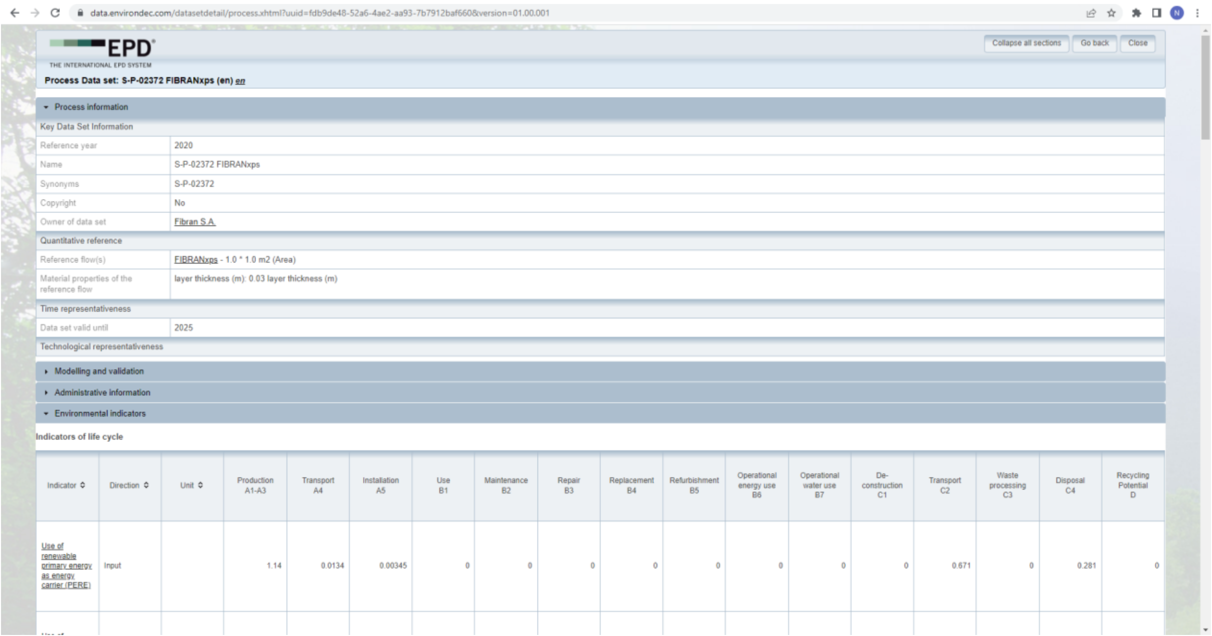

Figure 63 EPD entry in external data set

The third option concerns the manual input of EPD data through the provided user forms or through the uploading of a CSV file in a predefined format, an example of which is shown below.

```
Indicator,A1-A3,A4,A5,C1-C4,D
GWP,4.28E+00,2.58E-01,1.66E-02,2.83E-01,0.00E+00
ODP,4.16E-07,5.90E-08,2.16E-09,6.47E-08,0.00E+00
AP,2.13E-02,1.29E-03,6.07E-05,1.41E-03,0.00E+00
EP,1.59E-02,5.35E-05,5.66E-06,5.86E-05,0.00E+00
POCP,9.46E-03,1.40E-03,6.39E-05,1.53E-03,0.00E+00
ADPE,7.34E-05,7.18E-06,3.18E-07,7.87E-06,0.00E+00
ADPF,7.98E+01,3.94E+00,2.08E-01,4.32E+00,0.00E+00
PERM,0.00E+00,0.00E+00,0.00E+00,0.00E+00,0.00E+00
PENRT,7.62E+01,4.17E+00,2.15E-01,4.57E+00,0.00E+00
PERT,5.99E+00,5.30E-02,6.30E-03,5.81E-02,0.00E+00
FW,4.71E-01,5.82E-03,9.29E-04,6.38E-03,0.00E+00
```

The aforementioned input forms can also be used to provide relevant material properties. Figure 64 displays an example of such a manual information insertion.

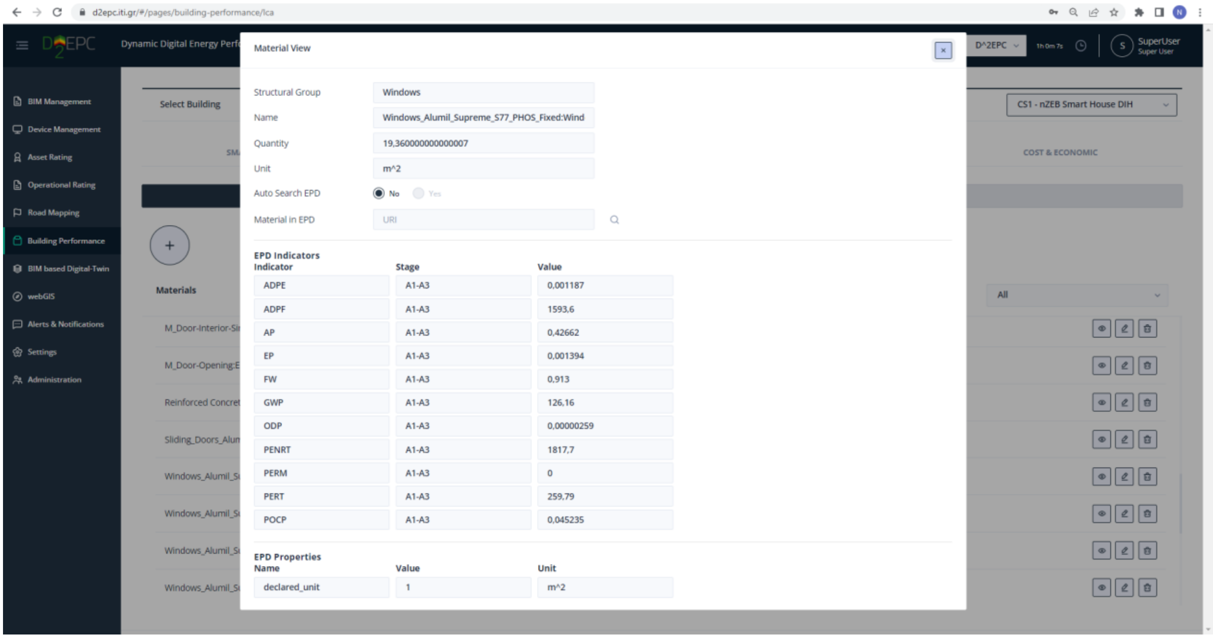

Figure 64 Manually inserted EPD data

Upon completing the previously described setup process, the LCA results for the indicators available can be calculated. Figure 65 and Figure 66 present the environmental impacts for Case Study 1, per material/ life-cycle stage and per material structural group, respectively.

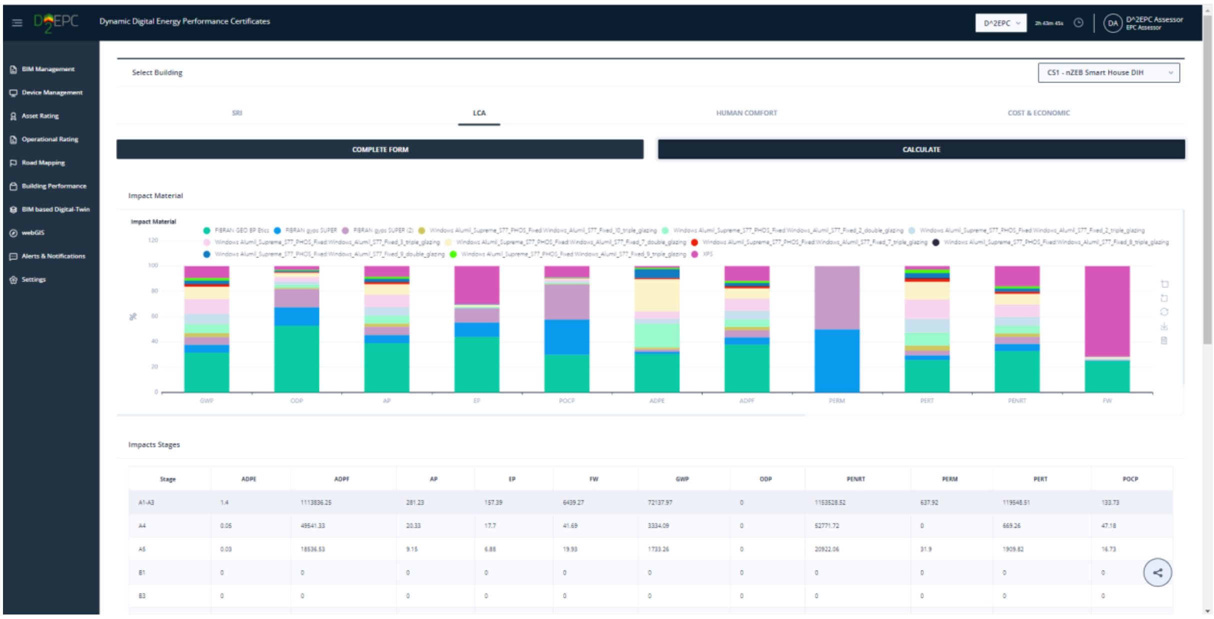

Figure 65 LCA indicator impacts per material/life-cycle stage

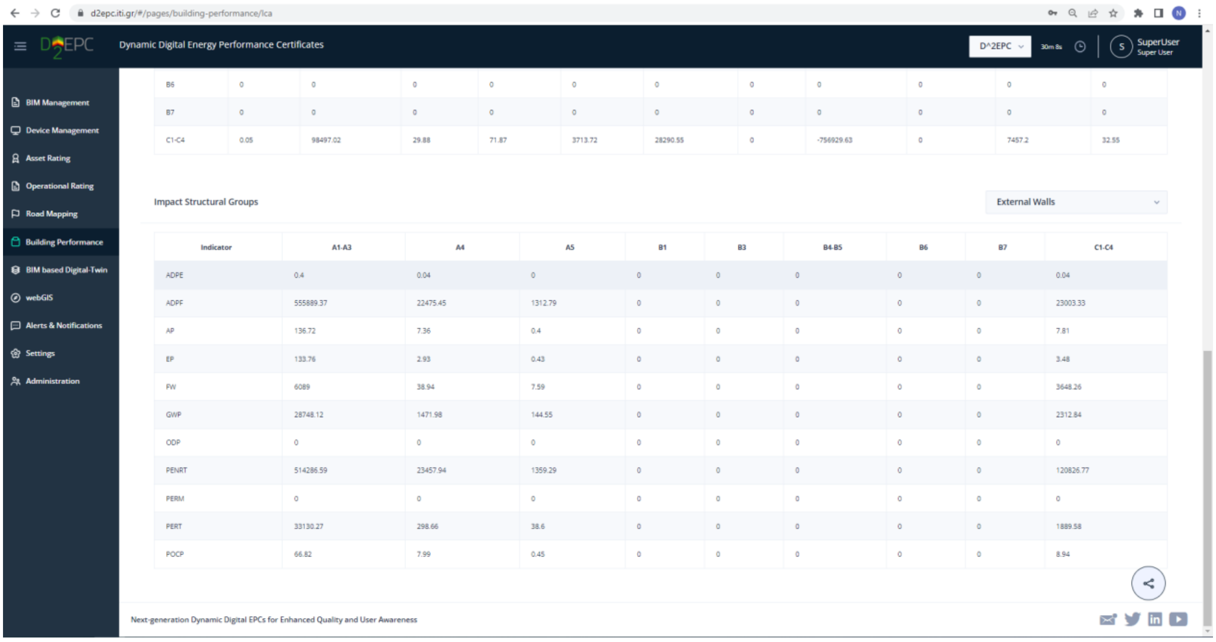

Figure 66 LCA indicator impacts per material group

4.3.4 Financial Indicators calculation submodule

Figure 67 shows the initial parametrization of the Financial indicators in the D^2EPC Web Platform. The user is able to set the monthly pricing for each one of the supported energy carriers, which is used for the calculation of the as-designed and the as-operated costs, as well as to provide the inflation and the discount rates, required to calculate the as-predicted costs.

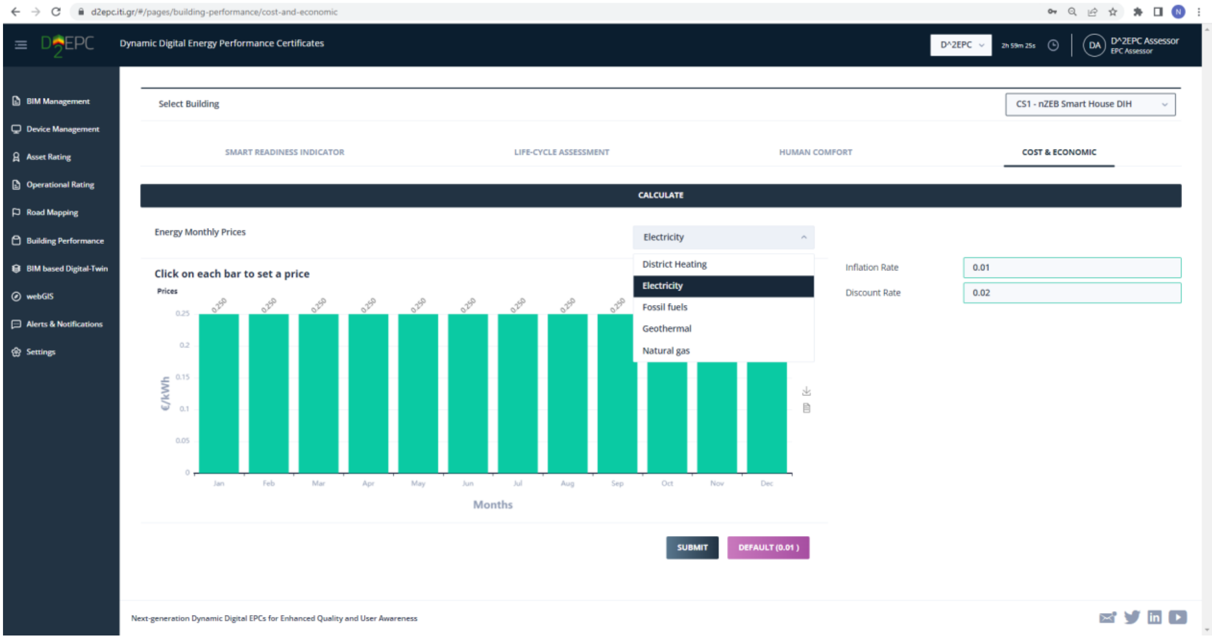

Figure 67 Parametrization of the financial indicators for Case Study 1

The tool utilizes the asset-based EPC results as well as actual building measurements, which are retrieved from the asset rating calculation engine and from D^2EPC Repository through the Building Digital Twin, correspondingly. Figure 68-Figure 71 present such data that are collected from electrical energy meters of Case Study 1.

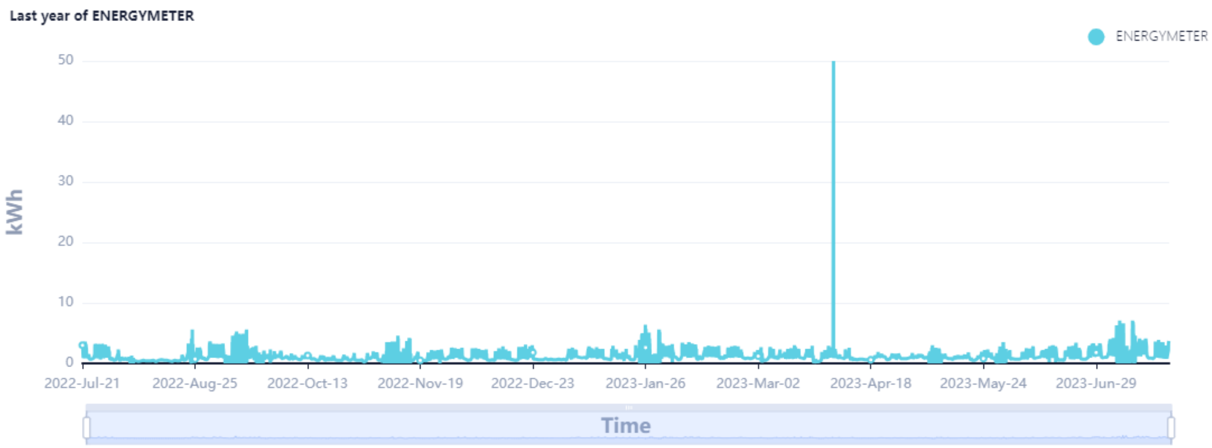

Figure 68 CS1 energy consumption measurements

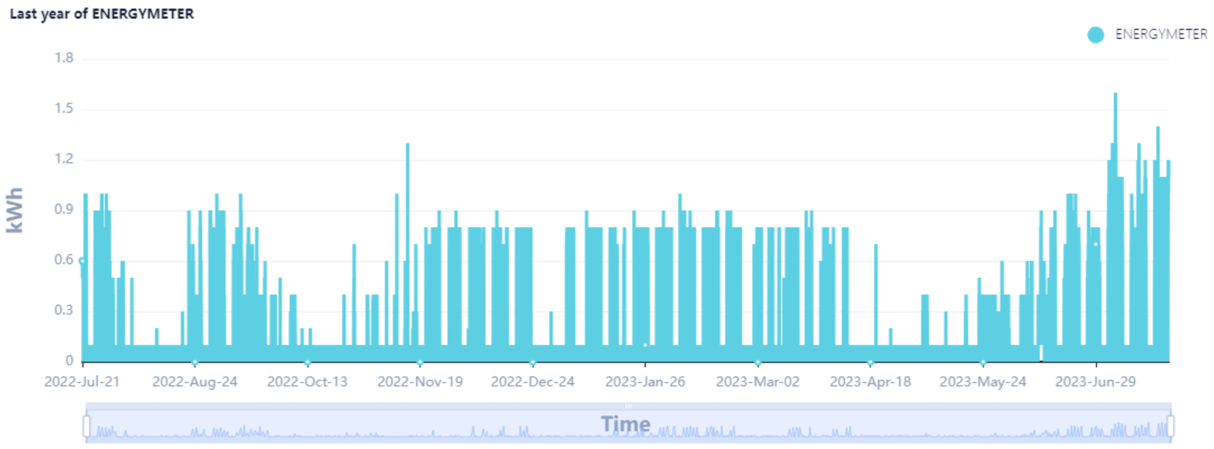

Figure 69 CS1 heating/cooling energy consumption measurements (ground floor)

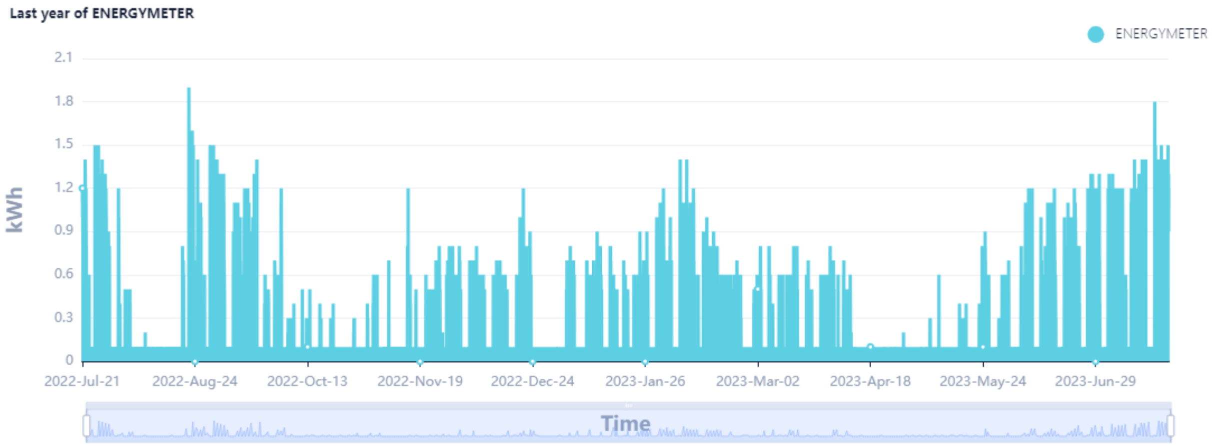

Figure 70 CS1 heating/cooling energy consumption measurements (1st floor)

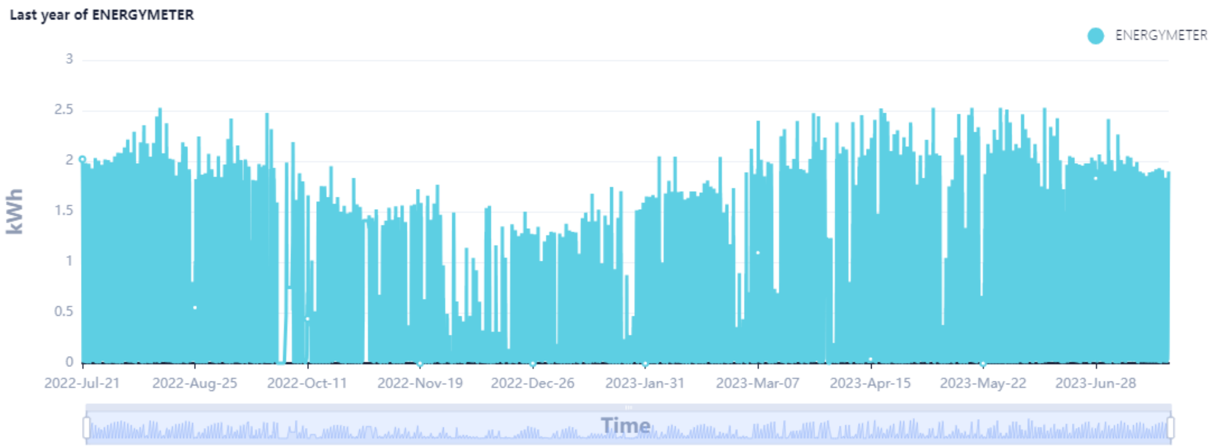

Figure 71 CS1 PV energy production

The Financial indicators results for Case Study 1 are presented in Figure 72-Figure 75. The user is able to toggle between different results (per carrier/use, monthly/per area and per year) and compare the as-designed with the as-operated building energy performance. Additionally, a graph with the NPV and the nominal costs (as-predicted costs) is placed below the aforementioned.

Particularly for the actual results of Case Study 1, it is important to highlight that as-designed costs are calculating as negative due to the expected large on-site photovoltaic energy production, which significantly exceed the expected energy demand. On the other side, the as-operated costs present the costs based on actual energy measurements and are significantly higher, which stems from the significant contribution of building appliances (mainly workstations and servers), as well as the increased cooling load during the summer months, which is not covered by the on-site energy production.

Finally, towards validating the calculations' accuracy, a comparison has been performed against corresponding results from data spreadsheets that implement the same computational process.

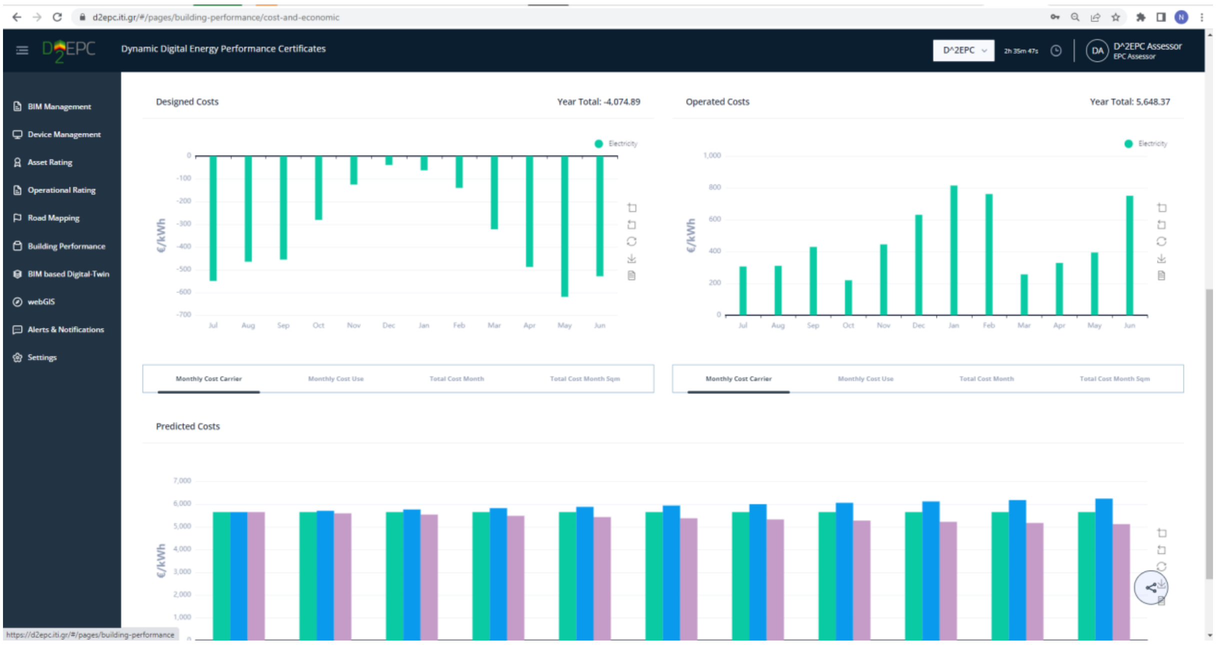

Figure 72 Comparison of as-designed/as-operated costs per energy carrier

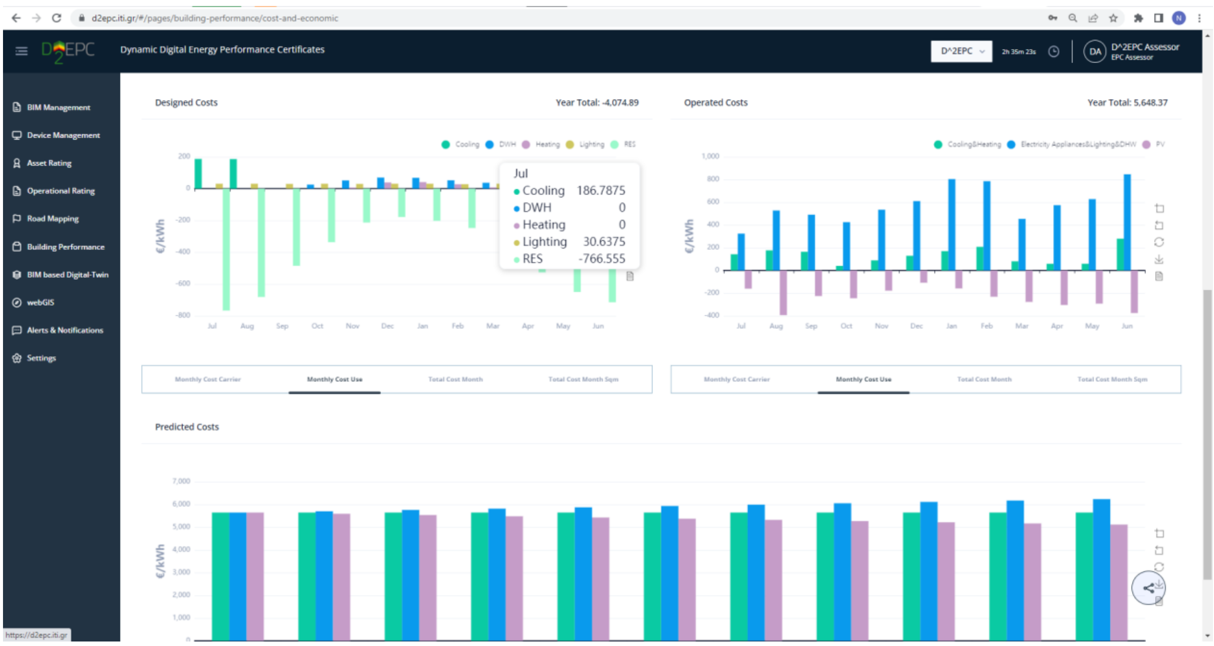

Figure 73 Comparison of as- designed/as-operated costs per energy use

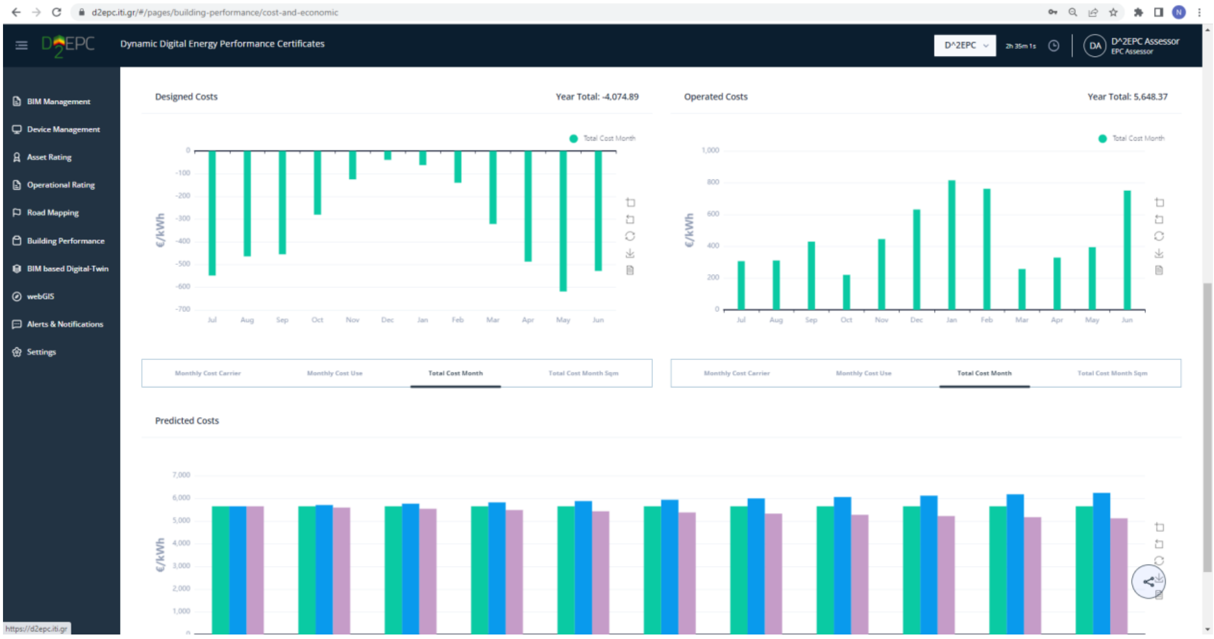

Figure 74 Comparison of monthly as- designed/as-operated costs

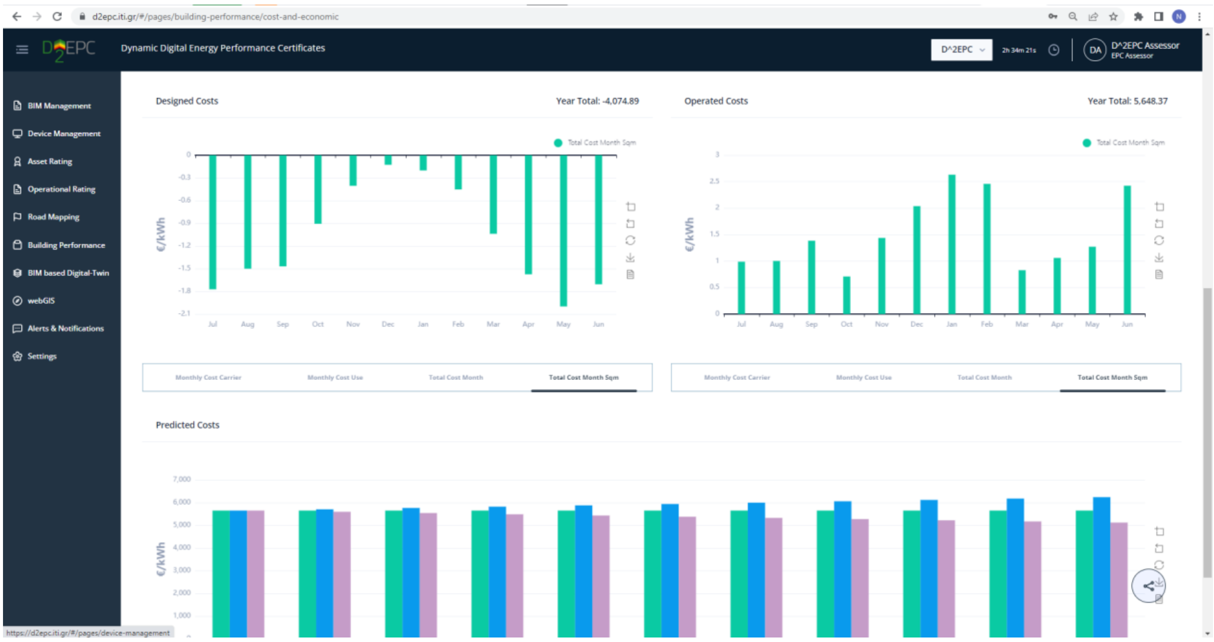

Figure 75 Comparison of as- designed/as-operated costs per building area

5 Conclusions

This report outlines the procedure followed thought the course of the project for the development of D^2EPC's core engine and the application of its three main submodules to the pilot buildings. The successful completion of this task enabled the D^2EPC platform to deliver the core calculation functionalities required for a holistic building certification, in accordance with the introduced holistic scheme. The deployment of the developed tools on the pilot buildings tested both the applications and the methodologies across a wide range of scenarios. Moreover, the insights gained from the application of these tools to the pilot buildings offered valuable information on the D^2EPC platform's effectiveness and reliability.

Ultimately, this successful development and implementation of D^2EPC's core engine and submodules represent a significant advancement towards achieving a more comprehensive and efficient approach to building certification and energy performance evaluation.

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Annex A: Data-sets for Asset Rating

Climatic Zones

Table 10: Climatic Zone- Berlin, Germany

Month	Heating period	Cooling period	Avg. Temperature	Solar Irradiation																
				SR_H	SR_90_N	SR_90_NE	SR_90_NW	SR_90_E	SR_90_W	SR_90_SW	SR_90_SE	SR_90_S	SR_45_N	SR_45_NE	SR_45_NW	SR_45_E	SR_45_W	SR_45_SW	SR_45_SE	SR_45_S
1	1	0	0,9	21,4	6,5	6,5	6,5	16,0	14,0	31,8	34,0	42,8	11,4	11,7	11,6	21,4	19,8	34,0	35,6	41,8
2	1	0	1,8	39,6	10,1	12,2	11,6	29,2	26,5	49,0	51,8	63,8	17,8	21,6	21,1	39,1	36,9	56,5	58,3	67,2
3	1	0	4,9	78,2	19,4	26,9	28,2	50,5	51,1	75,1	73,6	86,6	34,4	47,8	48,7	72,3	73,4	95,8	94,5	105,6
4	1	0	10,3	131,8	29,4	47,7	50,0	80,4	81,8	101,4	103,1	106,9	60,9	86,4	86,3	120,6	119,3	143,2	144,3	152,4
5	0	0	14,5	158,1	43,6	66,3	66,8	94,8	92,1	98,7	103,7	95,8	99,6	116,4	112,7	144,6	138,4	153,3	158,2	157,9
6	0	0	18,2	170,4	50,7	72,8	74,6	97,6	97,9	98,1	101,9	90,9	117,0	127,9	126,3	152,2	148,9	159,2	162,4	160,8
7	0	0	20,1	167,3	47,7	69,8	73,2	97,0	97,7	102,2	102,1	94,7	110,3	122,2	123,8	148,1	148,9	161,1	161,1	162,5
8	0	0	19,4	143,1	35,6	55,8	57,4	87,5	86,3	100,8	104,1	102,8	77,8	99,5	98,7	130,8	128,3	147,6	150,2	154,9
9	1		15,5	100,8	23,0	35,5	35,9	65,6	64,7	89,2	92,6	102,3	41,3	63,1	62,0	95,0	92,1	118,2	120,8	130,8
10	1	0	10,6	57,0	14,3	18,0	18,3	39,3	38,5	64,8	66,7	81,2	25,3	32,2	32,0	55,0	53,3	77,3	78,7	89,7
11	1	0	5,9	26,8	7,6	8,1	8,0	18,7	18,9	39,3	39,1	50,8	13,5	14,4	14,3	25,7	25,9	42,3	42,4	50,6
12	1	0	2,9	17,3	5,4	5,4	5,4	12,6	13,0	29,9	29,7	39,1	9,5	9,5	9,6	17,0	17,1	30,4	30,3	36,9

Table 11: Climatic Zone - Nicossia, Cyprus

Month	Heating period	Cooling period	Avg. Temperature	Solar Irradiation																
				SR_H	**SR_90_N**	**SR_90_NE**	**SR_90_NW**	**SR_90_E**	**SR_90_W**	**SR_90_SW**	**SR_90_SE**	**SR_90_S**	**SR_45_N**	**SR_45_NE**	**SR_45_NW**	**SR_45_E**	**SR_45_W**	**SR_45_SW**	**SR_45_SE**	**SR_45_S**
1	1	0	9,2	81,6	15,6	18,4	18,9	49,7	49,8	93,9	94,2	120,9	27,5	37,4	37,1	74,7	73,7	114,3	114,8	134,2
2	1	0	10,2	101,0	18,3	25,6	25,5	58,5	58,2	93,4	95,5	115,9	32,0	52,4	51,8	90,1	88,9	124,5	125,7	142,1
3	1	0	13,0	153,5	25,0	43,1	45,1	83,9	85,9	114,4	113,9	127,2	59,6	91,3	91,4	134,6	134,5	168,7	168,8	183,6
4	0,5	0	17,0	184,6	30,5	58,0	62,2	92,3	97,7	107,2	104,6	101,8	105,5	123,2	126,4	156,2	159,9	180,2	177,2	185,2
5	0	0,5	21,6	222,8	42,2	75,5	85,8	104,9	116,4	107,3	101,2	81,6	154,7	160,5	169,3	184,0	193,7	199,3	193,3	194,0
6	0	1	26,3	240,3	49,2	82,4	97,0	109,1	124,9	104,4	96,3	66,8	179,4	177,8	191,3	194,9	209,3	205,8	197,2	193,8
7	0	1	29,5	244,6	45,5	79,6	98,3	109,5	130,8	113,0	101,1	75,5	175,2	175,0	192,2	196,5	215,8	215,6	203,6	203,9
8	0	1	29,3	221,2	31,0	66,4	77,9	104,1	120,5	121,6	111,2	101,1	132,1	145,8	157,8	181,2	195,6	212,1	201,9	210,6
9	0	0,5	25,7	182,1	21,3	48,4	52,1	95,8	100,9	126,5	122,9	130,6	74,4	107,0	110,3	155,7	160,0	195,3	191,9	207,5
10	0	0	20,6	138,3	19,8	32,5	33,8	78,9	78,8	122,1	122,0	147,1	36,7	71,0	71,0	122,7	121,8	168,3	168,1	189,8
11	1	0	15,1	97,1	15,6	20,4	20,6	58,9	59,1	109,8	109,6	140,6	27,6	42,6	42,7	88,2	88,2	135,9	135,6	158,8
12	1	0	11,0	77,3	14,3	16,5	17,0	48,4	49,3	98,0	97,1	127,2	25,2	32,5	32,8	71,1	71,4	115,4	114,7	136,3

Table 12: Climatic Zone - Thessaloniki, Greece

Month	Heating period	Cooling period	Avg. Temperature	Solar Irradiation																
				SR_H	SR_90_N	SR_90_NE	SR_90_NW	SR_90_E	SR_90_W	SR_90_SW	SR_90_SE	SR_90_S	SR_45_N	SR_45_NE	SR_45_NW	SR_45_E	SR_45_W	SR_45_SW	SR_45_SE	SR_45_S
1	1,0	0,0	6,3	61,7	12,1	13,6	14,0	38,2	41,4	83,7	79,4	106,6	21,4	26,2	26,8	55,3	58,6	95,5	92,2	111,9
2	1,0	0,0	7,9	75,5	15,4	19,7	20,4	45,3	47,4	79,1	76,7	96,3	27,2	38,5	39,3	67,5	69,4	98,8	97,0	112,1
3	1,0	0,0	10,7	121,1	22,3	35,4	37,7	67,9	72,1	99,7	96,3	112,1	44,0	69,9	72,2	106,0	109,6	140,1	136,9	151,9
4	1,0	0,0	15,2	160,5	30,3	52,4	55,7	84,5	88,8	103,9	99,9	102,4	86,2	105,0	108,2	137,0	141,7	163,3	159,9	169,1
5	0,0	0,0	20,2	198,2	42,3	71,5	74,1	102,5	102,4	104,3	104,3	91,3	131,2	143,2	143,6	170,0	169,8	182,2	182,6	183,4
6	0,0	1,0	24,5	217,9	48,3	81,0	83,3	109,3	110,1	102,3	103,8	82,5	154,4	162,0	162,8	185,1	184,5	191,7	192,3	189,2
7	0,0	1,0	26,8	233,8	45,8	82,1	88,6	116,4	122,8	116,0	113,7	92,9	156,8	166,4	171,9	196,7	202,1	212,1	208,9	208,9
8	0,0	1,0	26,2	207,8	31,8	64,5	71,6	106,6	115,0	126,6	119,6	114,9	113,9	134,5	140,9	175,1	183,6	206,8	200,8	210,3
9	0,0	0,0	22,3	147,9	24,1	43,4	46,0	81,8	85,4	112,1	109,0	120,4	58,2	87,7	90,3	128,7	132,6	164,0	160,7	175,6
10	0,5	0,0	16,7	102,7	19,1	27,0	29,1	59,6	64,3	102,2	95,6	119,8	33,4	53,3	55,7	90,2	95,5	131,7	126,4	146,3
11	1,0	0,0	11,9	65,1	13,6	15,7	16,0	38,9	43,0	81,3	74,8	100,5	24,0	30,1	31,3	57,3	62,5	95,4	90,3	109,3
12	1,0	0,0	6,9	54,4	11,5	12,0	12,7	33,9	37,9	79,8	74,0	101,1	20,3	22,8	23,8	48,9	53,1	88,4	83,7	103,4

Reference Building

Table 13: Reference Building - Cyprus

Reference Building Fields	Building Type	
	Residential	Non Residential
Technical Systems		
Heating		
Type	Heat pump	Heat pump
Energy Source	Electricity	Electricity
Efficiency	0.9	0.9
Cooling		
Type	Heat pump	Heat pump
Energy Source	Electricity	Electricity
Efficiency	3.2	3.2
Domestic Hot Water (DHW)		
Type	Electric boiler	Electric boiler
Energy Source	Electricity	Electricity
Efficiency	0.85	0.85
DHW percentage covered from RES	0.15	0.15
Lighting		
Type	LED	LED
Energy Source	Electricity	Electricity
Envelope		
Opaque Elements		
External Wall		
U-Value	0.7225	0.7225
a	0.3	0.3
Door		
U-Value	3.23	3.23
a	0.2	0.2
Roof		
U-Value	0.6375	0.6375
a	0.3	0.3
Floor		
U-Value	0.6375	0.6375
Transparent Elements		
Window		
U-Value	3.23	3.23
gw	0.85	0.85
French Door		
U-Value	3.23	3.23
gw	0.85	0.85
Thermal bridge		
Linear Thermal Transmittance	0.55	0.55

Table 14: Reference Building - Germany

Reference Building Fields	Building Type	
	Residential	Non Residential
Technical Systems		
Heating		
Type	Boiler	Boiler
Energy Source	Natural Gas	Natural Gas
Efficiency	0.92	0.92
Cooling		
Type	No cooling	Heat pump
Energy Source		Electricity
Efficiency		3.2
Domestic Hot Water (DHW)		
Type	Boiler	Boiler
Energy Source	Natural Gas	Natural Gas
Efficiency	0.92	0.92
DHW percentage covered from RES	0.15	0.15
Lighting		
Type	Not specified	Fluorescent lamp
Energy Source	Electricity	Electricity
Ventilation		
Type	No Ventilation	N/A
Energy Source		N/A
Envelope		
Opaque Elements		
External Wall		
U-Value	0.28	0.28
A	0.3	0.3
Door		
U-Value	1.8	1.8
A	0.2	0.2
Roof		
U-Value	0.2	0.2
A	0.3	0.3
Floor		
U-Value	0.4	0.4
Transparent Elements		
Window		
U-Value	1.3	1.3
Gw	0.6	0.6
French Door		
U-Value	1.3	1.3
Gw	0.6	0.6
Thermal bridge		
Linear Thermal Transmittance	0.55	0.55

Table 15: Reference Building - Greece

Reference Building Fields	Building Type	
	Residential	Non Residential
Technical Systems		
Heating		
Type	Heat pump	Heat pump
Energy Source	Electricity	Electricity
Efficiency	3.2	3.2
Cooling		
Type	Heat pump	Heat pump
Energy Source	Electricity	Electricity
Efficiency	3.2	3.2
Domestic Hot Water (DHW)		
Type	Electric boiler	Electric boiler
Energy Source	Electricity	Electricity
Efficiency	0.85	0.85
DHW percentage covered from RES	0.15	0.15
Lighting		
Type	LED	LED
Energy Source	Electricity	Electricity
Envelope		
Opaque Elements		
External Wall		
U-Value	0.4	0.4
a	0.3	0.3
Door		
U-Value	2.25	2.25
a	0.2	0.2
Roof		
U-Value	0.4	0.4
a	0.3	0.3
Floor		
U-Value	0.4	0.4
Transparent Elements		
Window		
U-Value	2.25	2.25
gw	0.85	0.85
French Door		
U-Value	2.25	2.25
gw	0.85	0.85
Thermal bridge		
Linear Thermal Transmittance	0.55	0.55

Thermal Zones' Boundary Conditions

Table 16: Thermal Zones' Boundary Conditions - Cyprus

Boundary conditions field	Units	Zone Type							
		Residence	Hotel	Offices	Conference space	Pastry shop	Library	Restaurant	Non-conditioned
Heating Set point	˚C	22	22	22	22	22	22	22	0
Cooling Set point	˚C	25	25	25	25	25	25	25	0
Fresh air requirement	$m^3/h/m^2$	0.75	3	3	27.5	20	6.6	17.5	0
Internal heat gains from people	W/m^2	3.75	11	3.08	6.16	4.5	10	4.5	0
Internal heat gains from lighting	$W/\ m^2$	0	16	16	16	16	16	16	0
Internal heat gains from equipment	$W/\ m^2$	1.875	1.5	2.4	0.1	6.2	3	5	0
Lighting Power Density	$W/\ m^2$	6.4	16	24.14	4.4	16	16	16	0
Operational Days per week	days	7	5	5	5	5	5	5	0
Operational Hours per Day	hours	18	9	9	9	9	9	9	0
Annual Operational hours at day	hours	1820	3276	2600	2600	2600	1040	2600	0
Annual Operational hours at night	hours	1680	3713	0	0	0	520	0	0
Occupancy Dependency factor		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0
Daylight dependency factor		0.646	0.646	0.646	0.646	0.646	0.646	0.646	0
Constant Illuminance factor		1	1	1	1	1	1	1	0
DHW requirement	$m^3/\ (m^2*yr.)$	2	0	0	0	0.58	0	2.04	0
Luminance	lx	200	200	500	200	300	300	300	0

Table 17: Thermal Zones' Boundary Conditions - Germany

Boundary conditions field	Units	Zone Type							
		Residence	Hotel	Offices	Conference space	Pastry shop	Library	Restaurant	Non-conditioned
Heating Set point	˚C	20	20	20	20	20	20	20	0
Cooling Set point	˚C	25	26	26	26	26	26	26	0
Fresh air requirement	$m^3/h/m^2$	0.5	3	4	2	7	8	1	0
Internal heat gains from people	W/m^2	3.75	2.9	1.25	1.5	3.8	7	9.8	0
Internal heat gains from lighting	W/ m^2	0	16	16	16	16	16	16	0
Internal heat gains from equipment	W/ m^2	1.875	1.8	1.75	1	0.3	0	0.6	0
Lighting Power Density	W/ m^2	6.4	16	16	16	16	16	16	0
Operational Days per week	days	7	5	5	5	5	5	5	0
Operational Hours per Day	hours	18	10	10	10	10	10	10	0
Annual Operational hours at day	hours	1820	755	2543	1300	2543	2999	2404	0
Annual Operational hours at night	hours	1680	3260	207	260	207	601	1796	0
Occupancy Dependency factor		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0
Daylight dependency factor		0.646	0.646	0.646	0.646	0.646	0.646	0.646	0
Constant Illuminance factor		1	1	1	1	1	1	1	0
DHW requirement	$m^3/ (m^2*yr.)$	2	0	0	0	0.58	0	2.04	0
Luminance	lx	200	200	500	200	300	300	300	0

Table 18: Thermal Zones' Boundary Conditions - Greece

Boundary conditions field	Units	Zone Type							
		Residence	Hotel	Offices	Conference space	Pastry shop	Library	Restaurant	Non-conditioned
Heating Set point	˚C	20	20	20	20	20	20	20	0
Cooling Set point	˚C	26	26	26	26	26	26	26	0
Fresh air requirement	$m^3/h/m^2$	0.75	3	3	27.5	20	6.6	17.5	0
Internal heat gains from people	W/m^2	3	11	10	16	36	10	26	0
Internal heat gains from lighting	$W/\ m^2$	0	16	16	16	16	16	16	0
Internal heat gains from equipment	$W/\ m^2$	1.5	1.5	2.4	0.1	6.2	3	5	0
Lighting Power Density	$W/\ m^2$	6.4	16	16	16	16	16	16	0
Operational Days per week	days	7	5	5	5	5	5	5	0
Operational Hours per Day	hours	18	10	10	10	10	10	10	0
Annual Operational hours at day	hours	1820	3276	2250	1300	2912	1040	1250	0
Annual Operational hours at night	hours	1860	3713	500	260	2548	520	1250	0
Occupancy Dependency factor		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0
Daylight dependency factor		0.646	0.646	0.646	0.646	0.646	0.646	0.646	0
Constant Illuminance factor		1	1	1	1	1	1	1	0
DHW requirement	$m^3/\ (m^2*yr.)$	2	0	0	0	0.58	0	2.04	0
Luminance	lx	200	300	500	500	250	500	200	0

Energy Carriers

Table 19: Energy Carriers' Data Set - Cyprus

Energy Carrier		f_p_nren [kWh/KWh]	f_p_ren [kWh/KWh]	f_p_tot [kWh/KWh]	K_CO2 [kg/kWh]	Fuel cost [€/kWh]
Delivered from Distant						
Fossil Fuels	Solid					
	Coal	1.1	0	1.1	0.291	0.0208
	Carbon					
	Liquid					
	Heating Oil					
	LPG	1.1	0	1.1	0.249	0.033
	Gaseous					
	Natural Gas	1.1	0	1.1	0.194	0.1
Bio Fuels	Solid					
	Biomass	0.2	1	1.2	0.025	0.9
	Wood					
	Pellet					
	Liquid					
	Bio Oil					
	Gaseous					
	Bio Gas	0.5	1	1.5	0.025	0.133
Electricity		2.3	0.2	2.5	0.42	0.295
Thermal Energy						
Delivered from nearby						
District Heating		1.3	0	1.3	0.26	0.069
District Cooling						
Electricity from nearby						
Delivered from on-site						
Solar	PV	0	1	1	0	
	Thermal Solar	0	1	1	0	
Wind		0	1	1	0	
Enviroment	Geo-, aero-, hydro	0	1	1	0	
Exported						
Electricity	To the grid	2.3	0.2	2.5	0.42	
	to non EPB uses	2.3	0.2	2.5	0.42	
	Temp. exported electricity					

Table 20: Energy Carriers' Data Set - Greece

Energy Carrier		f_p_nren [kWh/KWh]	f_p_ren [kWh/KWh]	f_p_tot [kWh/KWh]	K_CO2 [kg/kWh]	Fuel cost [€/kWh]
Delivered from Distant						
Fossil Fuels	Solid					
	Coal	1.1	0	1.1	1.32	0.0208
	Carbon					
	Liquid					
	Heating Oil	1.1	0	1.1	0.264	0.09
	LPG					
	Gaseous					
	Natural Gas	1.05	0	1.05	0.169	0.075
Bio Fuels	Solid					
	Biomass	0.2	1	1.2		0.064
	Wood					
	Pellet					
	Liquid					
	Bio Oil					
	Gaseous					
	Bio Gas					
Electricity				2.9	0.989	0.17
Thermal Energy						
Delivered from nearby						
District Heating				0.7	0.347	0.069
District Cooling						
Electricity from nearby						
Delivered from on-site						
Solar	PV	0	1	1	0	
	Thermal Solar	0	1	1	0	
Wind		0	1	1	0	
Environment	Geo-, aero-, hydrothermal	0	1	1	0	
Exported						
Electricity	To the grid					
	to non EPB uses					
	Temp. exported electricity					

Table 21: Energy Carriers' Data Set - Germany

Energy Carrier		f_p_nren [kWh/KWh]	f_p_ren [kWh/KWh]	f_p_tot [kWh/KWh]	K_CO2 [kg/kWh]	Fuel cost [€/kWh]
Delivered from Distant						
Fossil Fuels	Solid					
	Coal	1.1	0	1.1	0.4	0.0208
	Carbon					
	Liquid					
	Heating Oil	1.1	0	1.1	0.31	0.1
	LPG	1.1	0	1.1	0.27	0.08
	Gaseous					
	Natural Gas	1.1	0	1.1	0.412	0,0806
Bio Fuels	Solid					
	Biomass					
	Wood	0.2	1	1.2		0.055
	Pellet					0.08
	Liquid					
	Bio Oil	0.5	1	1.5	0.21	0,13
	Gaseous					
	Bio Gas	0.5	1	1.5	0.14	0.133
Electricity		1.8	1	2.8	0.56	0,189
Thermal Energy				2.8	0.86	
Delivered from nearby						
District Heating		1.3	0	1.3	0.0925	0.154
District Cooling						
Electricity from nearby				1.8	0.56	0.43
Delivered from on-site						
Solar	PV	0	1	1	0	
	Thermal Solar	0	1	1	0	
Wind		0	1	1	0	
Environment	Geo-, aero-, hydrothermal	0	1	1	0	
Exported						
Electricity	To the grid					
	to non EPB uses					
	Temp. exported electricity					

Annex B: Energy Class boundaries for Operational Rating

Greece

Table 22: Reference Values for Greek residential buildings

Building type	Climatic zone	Age	A	B	C	D	E	F	G
Single house	A	>2017	80,0	95,3	110,7	126,0	141,3	156,7	172,0
		<2017	95,0	148,0	201,0	254,1	307,1	360,1	413,1
	B	>2017	80,0	113,1	146,2	179,4	212,5	245,6	278,7
		<2017	95,0	174,3	253,6	332,9	412,2	491,5	570,8
	C	>2017	80,0	146,4	212,8	279,2	345,6	412,0	478,4
		<2017	95,0	211,6	328,2	444,8	561,4	678,0	794,6
	D	>2017	80,0	156,5	233,0	309,6	386,1	462,6	539,1
		<2017	95,0	228,9	362,8	496,8	630,7	764,6	898,5
Multi family building	A	>2017	80,0	88,0	95,9	103,9	111,9	119,9	127,8
		<2017	95,0	127,2	159,4	191,6	223,8	256,1	288,3
	B	>2017	80,0	95,5	111,0	126,5	142,0	157,5	173,0
		<2017	95,0	137,4	179,8	222,2	264,5	306,9	349,3
	C	>2017	80,0	129,2	178,5	227,7	277,0	326,2	375,4
		<2017	95,0	158,6	222,2	285,8	349,3	412,9	476,5
	D	>2017	80,0	133,4	186,9	240,3	293,7	347,2	400,6
		<2017	95,0	168,0	241,1	314,1	387,1	460,2	533,2

Table 23: Reference Values for Greek tertiary buildings

Building type	Climatic zone	Age	A	B	C	D	E	F	G
Hotels and other accommodation	A	>2016	85,0	170,6	256,2	341,8	427,5	513,1	598,7
		<2016	90,0	206,7	323,4	440,1	556,8	673,6	790,3
	B	>2016	85,0	186,5	288,0	389,5	491,0	592,5	694,0
		<2016	90,0	230,0	370,1	510,1	650,2	790,2	930,3
	C	>2016	85,0	176,7	268,4	360,1	451,7	543,4	635,1
		<2016	90,0	207,5	325,0	442,6	560,1	677,6	795,1
	D	>2016	85,0	225,8	366,6	507,4	648,3	789,1	929,9
		<2016	90,0	310,8	531,6	752,4	973,2	1194,0	1414,7
Schools	A	>2016	85,0	97,1	109,2	121,3	133,5	145,6	157,7
		<2016	90,0	115,8	141,6	167,4	193,2	219,0	244,8
	B	>2016	85,0	103,1	121,2	139,3	157,4	175,5	193,5
		<2016	90,0	123,5	157,0	190,5	223,9	257,4	290,9
	C	>2016	85,0	105,2	125,3	145,5	165,7	185,9	206,0
		<2016	90,0	134,5	179,1	223,6	268,2	312,7	357,3
	D	>2016	85,0	142,5	199,9	257,4	314,8	372,3	429,7
		<2016	90,0	141,2	192,4	243,7	294,9	346,1	397,3
Public buildings	A	>2016	85,0	269,6	454,2	638,7	823,3	1007,9	1192,5
		<2016	90,0	303,1	516,2	729,4	942,5	1155,6	1368,7
	B	>2016	85,0	277,4	469,7	662,1	854,4	1046,8	1239,2
		<2016	90,0	313,6	537,3	760,9	984,6	1208,2	1431,8

Building type	Climatic zone	Age	A	B	C	D	E	F	G
	C	**>2016**	85,0	270,4	455,9	641,3	826,8	1012,2	1197,6
		<2016	90,0	320,2	550,5	780,7	1010,9	1241,2	1471,4
	D	>2016	85,0	279,8	474,5	669,3	864,0	1058,8	1253,5
		<2016	90,0	334,3	578,6	822,8	1067,1	1311,4	1555,7
Supermarkets and malls	A	>2016	85,0	164,1	243,2	322,3	401,4	480,5	559,6
		<2016	90,0	204,4	318,7	433,1	547,4	661,8	776,2
	B	>2016	85,0	170,7	256,4	342,1	427,8	513,5	599,2
		<2016	90,0	210,6	331,2	451,9	572,5	693,1	813,7
	C	>2016	85,0	167,8	250,6	333,4	416,2	499,1	581,9
		<2016	90,0	213,0	336,1	459,1	582,1	705,2	828,2
	D	>2016	85,0	167,4	249,8	332,2	414,5	496,9	579,3
		<2016	90,0	224,4	358,8	493,2	627,5	761,9	896,3
Hospitals and clinics	A	>2016	85,0	179,9	274,7	369,6	464,4	559,3	654,1
		<2016	90,0	196,9	303,8	410,8	517,7	624,6	731,5
	B	>2016	85,0	186,5	288,0	389,5	491,0	592,5	694,0
		<2016	90,0	207,1	324,2	441,3	558,4	675,5	792,6
	C	>2016	85,0	185,0	285,1	385,1	485,2	585,2	685,2
		<2016	90,0	207,2	324,3	441,5	558,6	675,8	792,9
	D	>2016	85,0	185,5	286,1	386,6	487,1	587,6	688,2
		<2016	90,0	200,3	310,6	420,9	531,2	641,5	751,8
Restaurants and taverns	A	>2016	85,0	269,6	454,2	638,7	823,3	1007,9	1192,5
		<2016	90,0	303,1	516,2	729,4	942,5	1155,6	1368,7
	B	>2016	85,0	277,4	469,7	662,1	854,4	1046,8	1239,2
		<2016	90,0	313,6	537,3	760,9	984,6	1208,2	1431,8
	C	>2016	85,0	270,4	455,9	641,3	826,8	1012,2	1197,6
		<2016	90,0	320,2	550,5	780,7	1010,9	1241,2	1471,4
	D	>2016	85,0	279,8	474,5	669,3	864,0	1058,8	1253,5
		<2016	90,0	334,3	578,6	822,8	1067,1	1311,4	1555,7
Private offices	A	>2016	85,0	146,2	207,3	268,5	329,7	390,8	452,0
		<2016	90,0	177,8	265,7	353,5	441,3	529,2	617,0
	B	>2016	85,0	152,0	218,9	285,9	352,8	419,8	486,8
		<2016	90,0	177,8	265,6	353,5	441,3	529,1	616,9
	C	>2016	85,0	151,1	217,2	283,3	349,4	415,5	481,6
		<2016	90,0	179,4	268,7	358,1	447,4	536,8	626,2
	D	>2016	85,0	147,0	208,9	270,9	332,9	394,9	456,8
		<2016	90,0	185,1	280,2	375,3	470,4	565,6	660,7
Retail shops	A	>2016	85,0	164,1	243,2	322,3	401,4	480,5	559,6
		<2016	90,0	204,4	318,7	433,1	547,4	661,8	776,2
	B	>2016	85,0	170,7	256,4	342,1	427,8	513,5	599,2
		<2016	90,0	210,6	331,2	451,9	572,5	693,1	813,7
	C	>2016	85,0	167,8	250,6	333,4	416,2	499,1	581,9
		<2016	90,0	213,0	336,1	459,1	582,1	705,2	828,2
	D	>2016	85,0	167,4	249,8	332,2	414,5	496,9	579,3
		<2016	90,0	224,4	358,8	493,2	627,5	761,9	896,3

Cyprus

Table 24: Reference Values for Cypriot residential buildings

Building type	Age	A	B	C	D	E	F	G
Single house	<1981	100	200	302	402	502	605	705
	1981-2006	100	167	235	302	370	437	505
	>2006	100	157	216	273	329	389	446
Semi-detached + Rowhouses	<1981	100	192	286	378	470	564	656
	1981-2006	100	162	221	284	346	405	467
	>2006	100	151	203	254	305	356	408
Apartment blocks	<1981	100	221	346	467	589	713	834
	1981-2006	100	189	275	365	454	540	629
	>2006	100	176	251	327	402	478	554
Other types of building	<1981	100	186	270	356	443	527	613
	1981-2006	100	157	213	270	327	383	440
	>2006	100	149	194	243	292	338	386

Table 25: Reference table for Cypriot tertiary buildings

Building type	Age	A	B	C	D	E	F	G
Hotels and other accommodation	<2006	125	419	713	1007	1301	1596	1890
	>2006	125	313	502	691	880	1069	1258
Schools	<2006	125	170	216	262	308	354	400
	>2006	125	143	159	178	197	213	232
Public buildings	<2006	125	170	219	265	311	359	405
	>2006	125	143	165	184	203	224	243
Supermarkets and malls	<2006	125	537	948	1361	1774	2184	2597
	>2006	125	394	662	932	1202	1469	1739
Hospitals and clinics	<2006	125	440	759	1075	1391	1709	2025
	>2006	125	327	532	734	937	1142	1345
Restaurants and taverns	<2006	125	659	1196	1731	2265	2803	3337
	>2006	125	475	829	1180	1531	1885	2236
Private offices	<2006	125	348	572	797	1021	1245	1469
	>2006	125	265	402	543	683	821	961
Retail shops	<2006	125	300	473	648	824	996	1172
	>2006	125	230	338	443	548	656	761
Other	<2006	125	705	1288	1868	2449	3032	3613
	>2006	125	508	888	1272	1655	2036	2419

Germany

Table 26: Reference Values for German residential buildings

Building type	Age	A	B	C	D	E	F	G
Single house	<1978	25	179,6	334,2	488,87	643,5	798,1	952,7
	1979-2001	25	112,6	200,1	287,67	375,2	462,8	550,3
	2002	25	71,5	118,1	164,6	211,1	257,7	304,2
Semi-detached + Rowhouses	<1978	25	130,9	236,8	342,68	448,6	554,5	660,4
	1979-2001	25	92,6	160,2	227,73	295,3	362,9	430,5
	2002	25	67,1	109,2	151,3	193,4	235,5	277,6
Apartment blocks	<1978	25	132,7	240,4	348,12	455,8	563,5	671,2
	1979-2001	25	96,6	168,2	239,87	311,5	383,1	454,7
	2002	25	56,7	88,3	119,99	151,7	183,3	215,0
Other types of building	<1978	25	113,4	201,8	290,27	378,7	467,1	555,5
	1979-2001	25	-	-	-	-	-	-
	2002	25	-	-	-	-	-	-

Table 27: Reference Values for German tertiary buildings

Building type	Age	A	B	C	D	E	F	G
Hotels and other accommodation	<2006	50	85,1	120,2	155,3	190,4	225,5	260,6
Schools	<2006	50	59,2	68,5	77,7	86,9	96,2	105,4
Public buildings	<2006	50	56,7	63,4	70,1	76,8	83,5	90,2
Supermarkets and malls	<2006	50	61,1	72,1	83,2	94,3	105,3	116,4
Hospitals and clinics	<2006	50	73,9	97,7	121,6	145,5	169,3	193,2
Restaurants and taverns	<2006	50	94,5	139,1	183,6	228,1	272,7	317,2
Private offices	<2006	50	58,4	66,7	75,1	83,5	91,8	100,2
Retail shops	<2006	50	56,9	63,7	70,6	77,5	84,3	91,2
Other	<2006	50	705,0	1288,0	1868	2449,0	3032,0	3613,0