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# Building Performance Module v1

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# DELIVERABLE D4.1
# Building Performance Module v1

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## Version History

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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 and in order to provide a complete view of the Calculation Engine, which was introduced in D1.4 D^2EPC Framework Architecture and specifications v1. In the document, there is a detailed description of the main actives that took place for the implementation of the sub-modules along with their functionalities. The deliverable also outlines the actual implementation of the components up to M24 of the project, considering the current development status under a public dissemination level.

Firstly, the document aims to provide the user with an overview of the proposed holistic energy performance certification scheme. To this end, the theoretical foundations of the applied methodologies are provided to describe the included functionalities. The Asset and Operational Rating schemes for the building's energy performance provide a clear distinction in examining an asset with the use of static and dynamic data. Moreover, the provided set of indicators, developed in WP2, expands the provided functionalities and the end-user's awareness about the performance in the domains of automation/control (SRI), sustainability (LCA, LCC) and human comfort and wellbeing.

In the second section of this report, the development of the aforementioned components is detailed. The applied algorithms are provided in each case in the form of charts and diagrams. Additionally, there is a description of the required data sources for each calculation. The integration of the developed component into the D^2EPC platform, and especially with the Building Digital Twin module, will enable the automation of certain calculation procedures. Finally, each component is tested based on data from one pilot building. The resultant indicators from each calculation are provided in the last part of this deliverable.

The complete design and implementation of the D^2EPC core Calculation Engine, in coordination with the completed development of other interacting D^22EPC solution components, is anticipated to be presented in the second and final edition of this deliverable, which is due in M36 of the project.

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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 |
| 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 |
| 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 aims to provide 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 the reader a high-level description of the applied methodologies, which examine the building's energy performance in a holistic certification scheme. There is additional information about how to calculate each indicator from both an algorithmic and a development standpoint.

The development of the three main calculation modules is aligned with the project's system architecture (as described in D1.7). Furthermore, their development took into consideration the required push and pull data interfaces (e.g. Rest API), that will be developed in the following steps, and will enable it to operate as a web certification service. Implementation of components from T4.2 and T4.3 will be amended in the second version of the deliverable.

## 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 to the reader in 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 forwards tasks 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 D1.7. 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 done at WG1 and WG2, under T5.1. 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 going to use 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 intense 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 indicate the energy performance of the building's structure.

Up to now, the Asset Rating scheme has been developed and implemented on a national or regional level. This strategy resulted in inescapable disparities between the various EPC schemes developed throughout Europe. As an example, several countries utilise the "Reference Building" technique to classify a building's energy efficiency, whereas others rely only on reference figures [3]. The differences among the various methodologies result in disparities in the description of the building models. In addition, the conventional building documentation procedure lengthens the issuance time, raises the EPC cost, and is susceptible to human mistake or lack of impartiality. As a result, the European building stock is not described in a uniform manner, which complicates the examination of its energy behaviour.

D^2EPC aims to tackle the two above-described deficiencies of present 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. A typical IFC file contains several information about the geometrical and thermal characteristics of the building envelope, although it may lack several information related to the EPC certification, mostly in the description of the technical systems. As a result, the assessor's role remains critical during the EPC procedure, despite the advanced automation in the proposed scheme. D5.1 "D^2EPC Manual V1" *guidelines* describe in detail all the expected parameters from an IFC file that should be included in order to create the building's energy model. In the introduced certification process, the assessor 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 [4] 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 in 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 peculiarities of their national EPC schemes. The implementation of this scheme is currently being investigated in the six countries involved in the project: Greece; Cyprus; Germany; Lithuania; Spain; and the Netherlands.

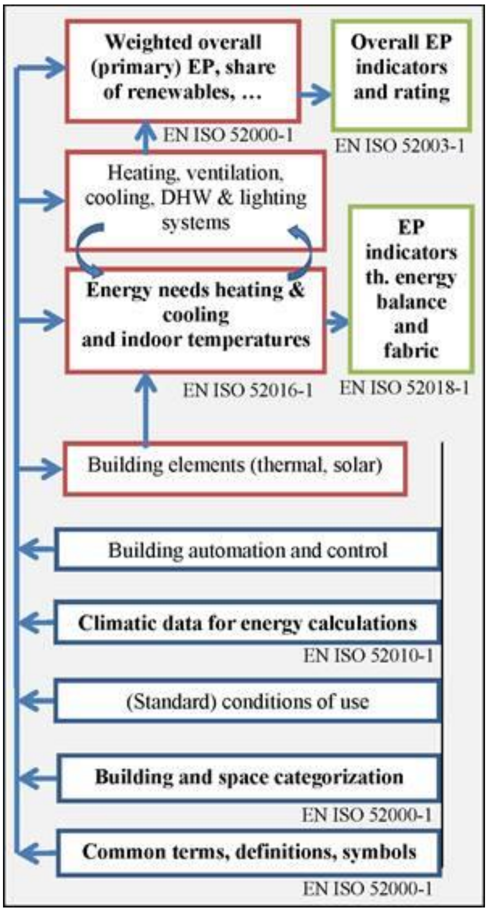


**Figure 1: Flow chart of the set of EPB standards with position of the five ‘overarching’ EPB standards [6]**

In general, the Asset Rating module is the backbone of the introduced certification scheme. The development of the calculation component should be made as part of a holistic platform, where it will be able to interact with the other modules as described in D1.7 D^2EPC Framework Architecture and specifications v2. 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 rest of the calculation modules can examine the building’s operation under various operational conditions or renovation scenarios. As a result, the platform demonstrates advanced benchmarking capabilities and is able to indicate more accurate and efficient solutions to upgrade the energy efficiency of the examined asset.

## 2.2 Operational EPC

### 2.2.1 Introduction

Because of significant differences in current European EPC processes sometimes leading to suboptimal results, D^2EPC intends to provide the groundwork for a next generation of dynamic Energy Performance Certificates (EPCs) for buildings. It remains a fact, that as of today, there is still no standardized procedure for the definition of the operational rating of buildings. As a result, the suggested scheme will contribute to the reinterpretation of EPC-related policies and the updating of current standards, as well as implementation advice, and will incorporate incentivization and restriction practices into the EPC reasoning. The collective analysis of data for the specific features of operational EPCs, revealed that 11 EU MSs have adopted the methodology based on operational rating methodology and implementation among the 27. In some EU MSs, both the actual and calculated energy consumptions are foreseen.

In order to provide responses to the existing gaps and discrepancies in the extraction of the operational rating of buildings, D^2EPC developed a working group, with terms of reference to develop and deliver a methodology for the operational energy performance ratings of buildings, which will be used in the framework of the D^2EPC project. Specifically, Working Group 2 has dealt with the following subjects:

1. The definition of the parameters that should be considered for the development of the operational rating methodology
2. The documentation of existing practices in EU Member States, in relation to operational rating of the energy performance of buildings
3. The development of the D^2EPC operational energy rating parameters.

In terms of the D^2EPC Working Group 02, the following **methodology** was utilized:

1. Field research, through the analysis of existing reports related to the operational energy performance rating of buildings in Europe
2. Targeted questionnaires to stakeholders in the 14 Member States, in which the operational rating is adopted and implemented.

The **output** of Working Group was the following:

1. A reference report describing the current situation with the operational energy performance rating of buildings in Europe
2. Agreement on the main parameters to be considered in the building's operational performance rating scheme of the D^2EPC tool.

Specifically, decisions will be made on the following issues:

1. Types of buildings and conditions where the D^2EPC operational rating can be applied
2. Indicators of D^2EPC operational scheme (e.g., heating, cooling, lighting, domestic hot water) focus on private appliances and total energy demand in residential buildings are not supported by all partners.
3. The method for obtaining refence values, based on which the rating will be calculated
4. Normalization practices for operational values
5. Frequency of issuance
6. Methods of measurement of actual consumption and details (e.g. metering instruments, responsibilities, etc.)

## 2.2.2 Main findings of WG2

Based on the research conducted, it was observed that the operational rating applies in existing buildings, either residential, non-residential, or in parts of buildings with a non-residential use. When constructing a new building, the energy usage measurement for heating, comfort cooling, domestic hot water, and the building energy separately should be possible. For building extensions, measurements can be made through the existing building's measurement system. A key value for the EPCs' classification and issuance is the thermal energy per unit of conditioned building area (kWh/($m^2$a)). Apart from this value, the following values could also be used: (a) annual energy per unit of conditioned building area (kWh/($m^2$a)), (b) annual electricity supply per unit of conditioned building area (kWh/($m^2$a)), (c) annual primary energy for the operation of the building per unit of conditioned building area (kWh/($m^2$a)), and (d) annual $CO_2$ emissions due to the operation of the building per unit of conditioned area of the building (kg /($m^2$a)).

As a common ground in most EU MSs, the issuance frequency of an operational EPC currently issued to receive a building permit for existing buildings is up to ten years. It would be recommended that the consumption, production, and occupancy data are updated and displayed annually or even biannually. The energy usage indicators may be revised and subsequently documented in the database each year. Descriptions of inhabitants, illumination profiles, small power equipment, operating times, and indoor climatic conditions are information that should be included in the standardized data. It was observed that the responsibility for getting the necessary measuring equipment lies with the owner/investor of the building or with the authorized person (usually the manager of the building). However, the distribution network operator (for gas and electricity) is responsible for meters installation on top of that.

In the following table, the main features of the investigated aspects are provided in a tabulated form.

| **Research Points** | **Brief Findings** |
|---|---|
| Operational rating EPCs application | ▪ 11 EU MSs employ measured energy rating to assess the energy performance of buildings<br>▪ operational rating applies in existing buildings, either residential, non-residential, or in parts of buildings with a non-residential use<br>▪ when the data on the measured energy use is not available or reliable, then an energy certificate based on calculation is issued instead of the certificate based on measured energy<br>▪ a display energy certificate (DEC) focused on the current energy use of the building as a key tool to indicate actual energy performance based on a benchmark is applied<br>▪ limitations of employing operational rating methodology are lack of metering infrastructure for heat supply from the district heating network or gas network, decentral technical systems in the building, or renovation/construction works that may affect the energy performance in the last 3 years preceding the preparation of the EPC |
| Issuance of EPCs considering total energy consumption or individual energy consumption streams | ▪ the total energy consumption is considered for buildings' operational rating<br>▪ the energy usage measurement for heating, comfort cooling, domestic hot water, and the building energy separately should be possible, when constructing a new building<br>▪ few countries distinguish between renewable and non-renewable energy calculation data |

| | |
|---|---|
| | ▪ measurements can be made through the existing building's measurement system for building extensions<br>▪ key values for the EPCs' classification and issuance:<br>1. thermal energy per unit of conditioned building area (kWh/($m^2$a))<br>2. annual energy per unit of conditioned building area (kWh/($m^2$a))<br>3. annual electricity supply per unit of conditioned building area (kWh/($m^2$a))<br>4. annual primary energy for the operation of the building per unit of conditioned building area (kWh/($m^2$a))<br>5. Annual $CO_2$ emissions due to the operation of the building per unit of conditioned area of the building (kg /($m^2$a)). |
| Operational rating delivered reference value | ▪ few EU MSs have an energy performance scale for each building type related to either the average consumption of the building or the primary energy indicator<br>▪ the classification system for the energy performance of buildings is determined by thermal energy for heating the building per unit of conditioned building area (kWh/($m^2$a)) |
| Operational rating EPCs issuance frequency | ▪ the issuance frequency of an operational EPC currently issued to receive a building permit for existing buildings is up to 10 years<br>▪ an EPC needs to be revised in case of altering the energy performance of the building (renovation)<br>▪ the EPC of new buildings is valid for up to 2 - 4 years<br>▪ an energy labeling has as a prerequisite the existence of energy consumption monthly readings over at least 1 year or an issuance frequency of 5 years<br>▪ the consumption, production, and occupancy data are recommended to be updated and displayed annually as a continuous process<br>▪ the energy usage indicators may be revised and subsequently documented in the database each year |
| Energy consumption measurement and installing equipment responsibility | ▪ the energy consumption corresponds to the provided quantity of the respective energy carrier so that the indicated quantity on the monthly energy bill can be used<br>▪ descriptions of inhabitants, illumination profiles, small power equipment (appliance for heating/cooling/DHW etc.), operating times, and indoor climatic conditions are information that should be included in the standardized data<br>▪ the responsibility for getting the necessary measuring equipment lies with the owner/investor of the building or with the authorized person (usually the manager of the building)<br>▪ the distribution network operator (for gas and electricity) is responsible for meters installation |
| Weather normalization procedures | ▪ weather normalization is used among the EU MSs<br>▪ it is recommended as an adjustment procedure of the energy usage for year-to-year comparisons<br>▪ the average monthly values of the outside temperature for at least 1 year in the examined area are needed<br>▪ the energy measurement based on a reference year condition and the recalculation to this respect could be a way in achieving an improved energy performance in buildings |

### 2.2.3 CEN Working Group on the development of operational energy performance certification of buildings

Recognizing the major gap in the European standardisation literacy concerning buildings operational rating, D^2EPC initiated a new CEN Working Group, entitled Operational assessment of buildings energy performance for energy classification purposes. The purpose of this standardization activity in the field of the energy assessment of buildings during the use stage (operation) is focused on systems' standards, limited to buildings and the direct environment of the building. This WG will create the platform to develop these "operational EPCs", based on the assessment of the energy performance of buildings during the "use stage". A presentation was made in last CEN/TC 371 meeting is available in CEN Documents as N756. The TC agreed to create a task group to deal with the proposal and to assess the "way forward". Based on the assessment made, this proposal for a new working group is presented in CEN/TC 371.

The first meeting, planned for the 21st of October 2022, is intended to define the first WI (or Wis) to be developed, based on the feedback from experts and delegates.

## 2.3 Set of D^2EPC 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.

### 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 2**)** 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.

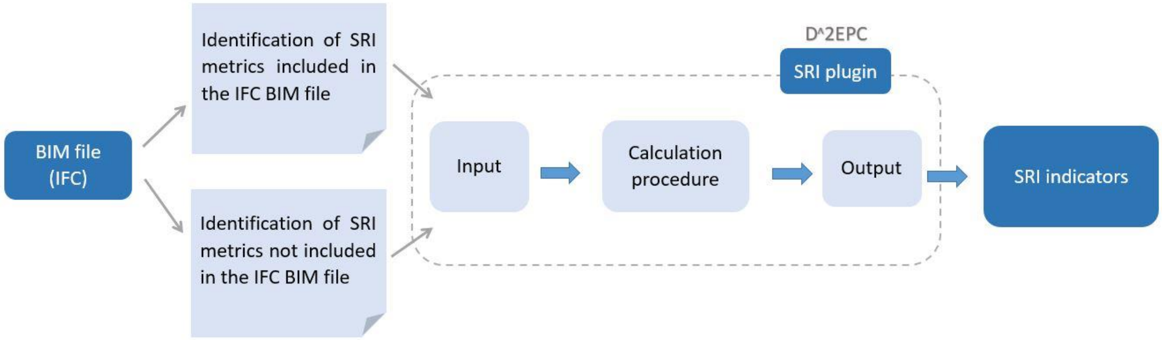


**Figure 2: D^2EPC SRI Indicators Extraction**

Due to the limitations of the IFC4 schema to comprehensively define the functionality levels of complex automation operations, the rating of the functionality levels will be requested by the assessor within the D^2EPC SRI Plugin. 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 1: 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 2: 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 3). 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.

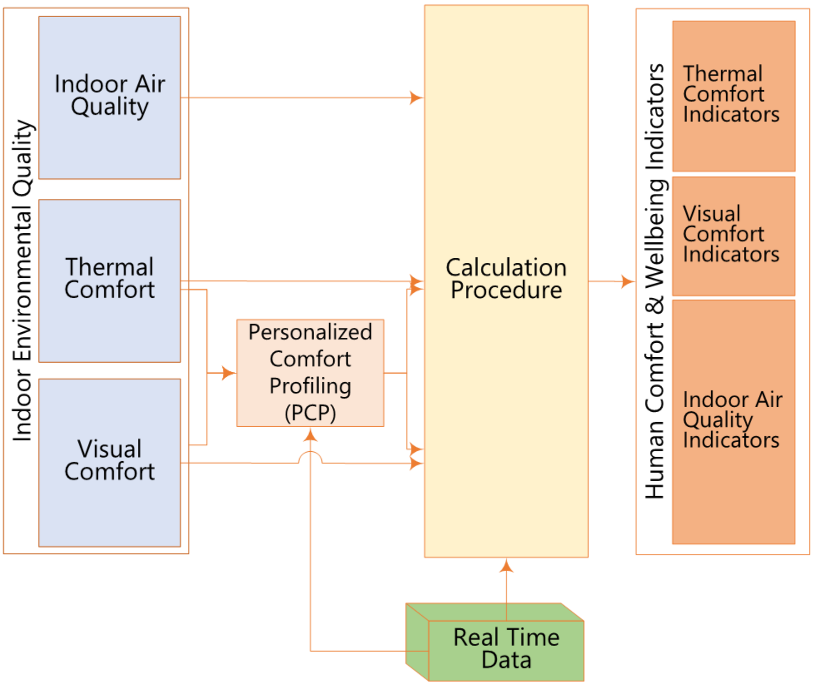


**Figure 3: D^2EPC Hybrid Approach on the Human Comfort and Wellbeing framework**

Figure 4 presents the human comfort and wellbeing indicators per environmental domain.

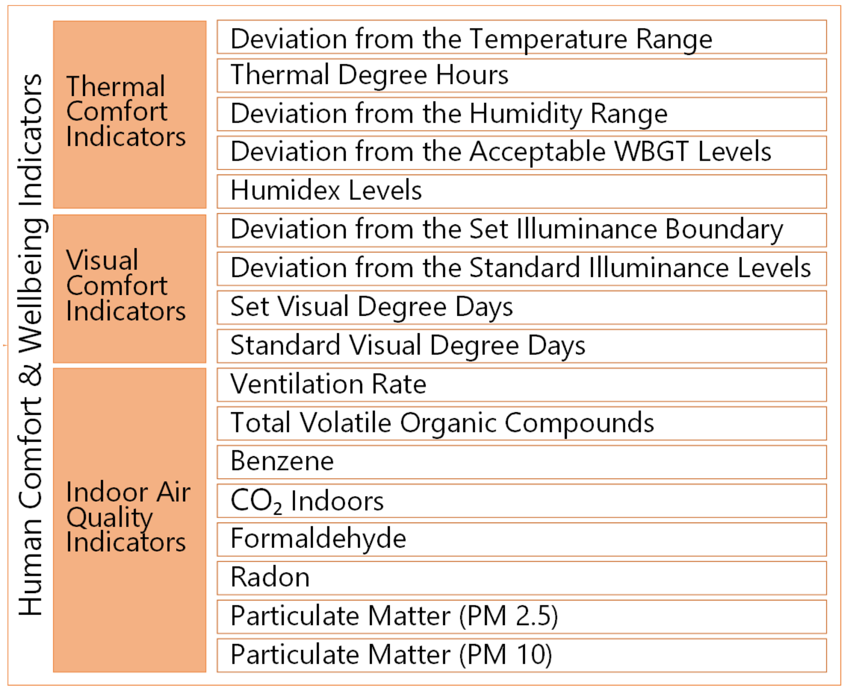


**Figure 4: D^2EPC Hybrid Approach on the Human Comfort and Wellbeing framework**

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 will take 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 3: 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 4: 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 5: 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 6 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 6: 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.]<br><br>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 will allow the user to better understand their energy consumption, as it will be translated into 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 will be able to show the monetized values of energy consumption based on the monitored/operational use, meaning that the user will have an insight into monthly values. This will reflect 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. They will not affect the energy class of the building, but they will be 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 will be 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 5. The comparison between different scenarios will allow 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.

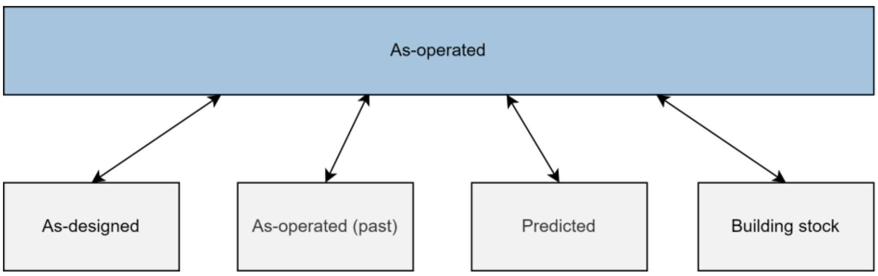


**Figure 5: The comparison of scenarios**

Besides the comparison between the monetized energy consumptions, the financial indicator will also include the expected cost for the replacement and maintenance of the building's systems and envelope. In this way, the user will 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. Besides, the sub-component Building Performance Module (BPM) will calculate all the D^2EPC KPIs. The data input will be 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 will be also required from the user. The Building Performance Module will then calculate the financial KPIs, as presented in Figure 6.

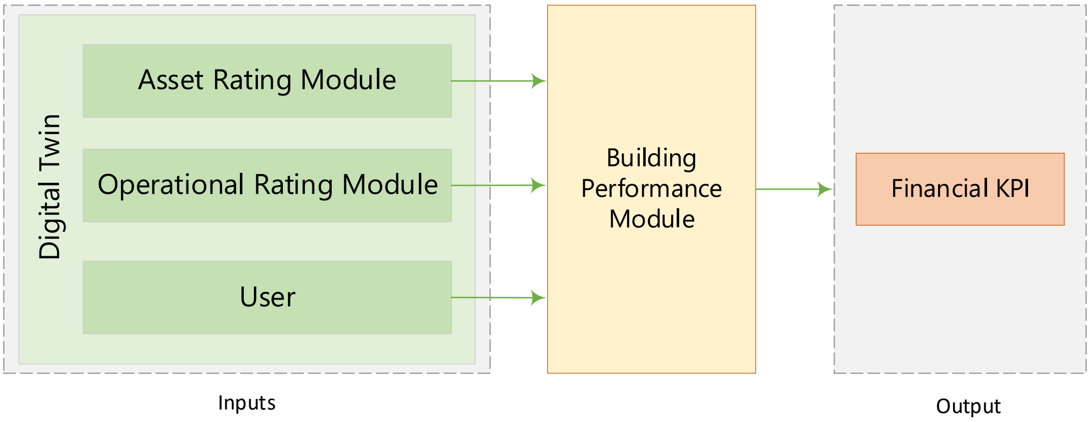


**Figure 6: Process overview**

#### 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 7 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.

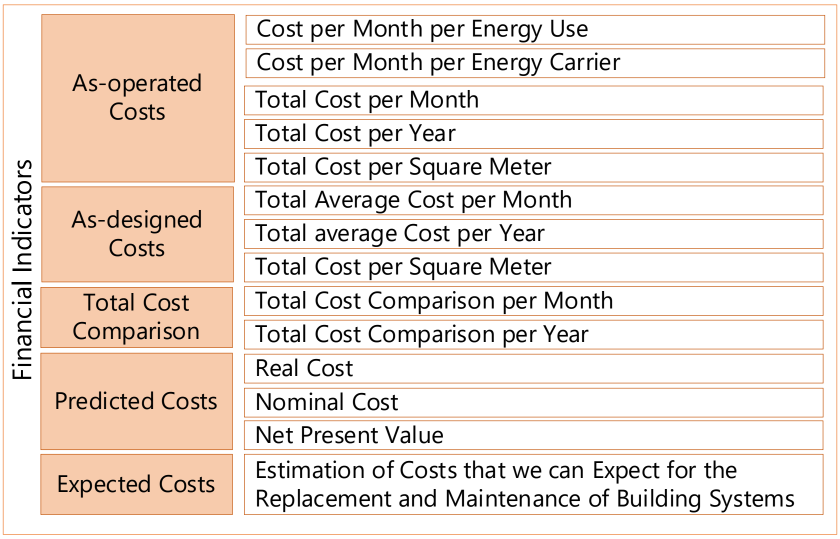


**Figure 7: Financial indicators**

## 2.3.5 D^2EPC Information Model

The D^2EPC information model aims to capture all the KPIs related to the fields that will characterise the energy and environmental performance of the building and to provide a suitable environment for extracting these indicators from the BIM documents. D^2EPC information model presents the indicators, the procedure for their calculation and the IFC Parser (API) architecture that will be used to extract these indicators from the BIM documents.

### 2.3.5.1 KPIs input development process

The D^2EPC information model development process aims to analyse and identify the set of indicators presented in the previous sections to be included in the next generation of EPCs, taking into account the work carried out by the D^2EPC project scope. The set of KPI inputs required for developing the next generation of EPCs is presented in a conceptual KPIs input development flowchart (Figure 8).

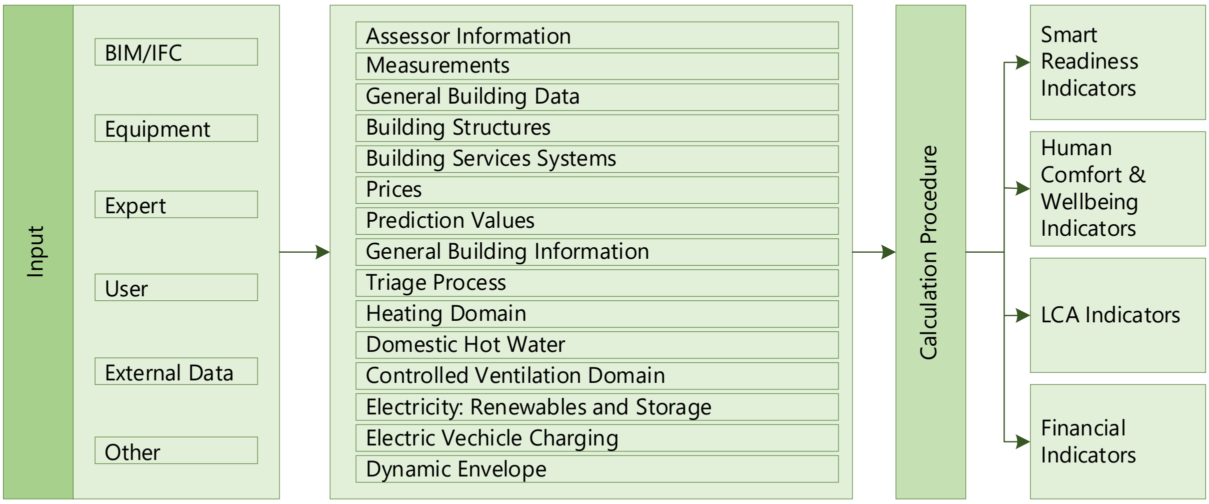


**Figure 8: Conceptual KPIs input development flowchart**

The detailed KPIs input table is presented to use for input extraction and calculation procedures to develop KPIs required for next -generation EPCs.

#### 2.3.5.2 Definition of IFC parser (API)

One way of exchanging data is through direct communication using application programming interfaces (APIs). An Application Programming Interface (API) is a connection between computers or computer programs. It is a type of software interface that allows communication between different software. BIM elements such as sensing, recognition, positioning, etc., can communicate through APIs.

#### 2.3.5.3 IFC parser workflow and required procedures

The BIM model of a building consists of various objects whose descriptive attributes and parameters are aligned with their geometry. Depending on the complexity of the building, the model may contain many objects with semantic data that may, in some cases, be irrelevant. In the D^2EPC project, information related to energy consumption, building envelope performance, occupant comfort, smart readiness indicators and other energy-related information is very important in the BIM model.

The workflow of the whole information extraction procedure is presented in Figure 9. The first step towards exchanging and extracting the required information is to export the building BIM file to an IFC file using the *BuildingSMART* IFC schema. The IFC reference file allows communication between software tools to extract and analyze the data further.

An IFC Parser can extract EPC relevant information stored in the BIM model, regarding to submitted needs i.e., a list of the material parameters of the building envelope for the energy calculations. Lexically parsed information can be presented in a structured way in various types of output formats suitable for further processing.

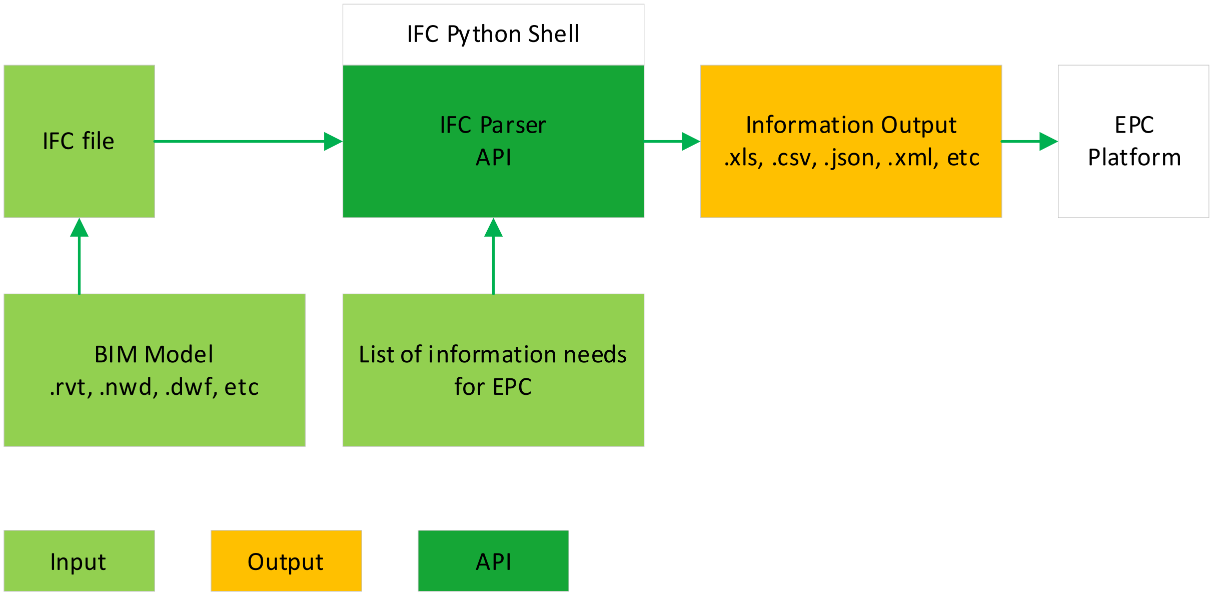


**Figure 9: D^2EPC IFC Parser Workflow**

To sum up, the IFC parser guidelines for the D^2EPC project were developed in the Python programming language; the IfcOpenShell-Python and Pandas modules were also used.

IfcOpenShell-Python is an open-source software library that allows users and software developers to use the IFC file format. The IFC file format is commonly used to describe the construction and as-built environment. Pandas is a fast, powerful and easy-to-use open-source data analysis and manipulation tool based of the Python programming language [7].

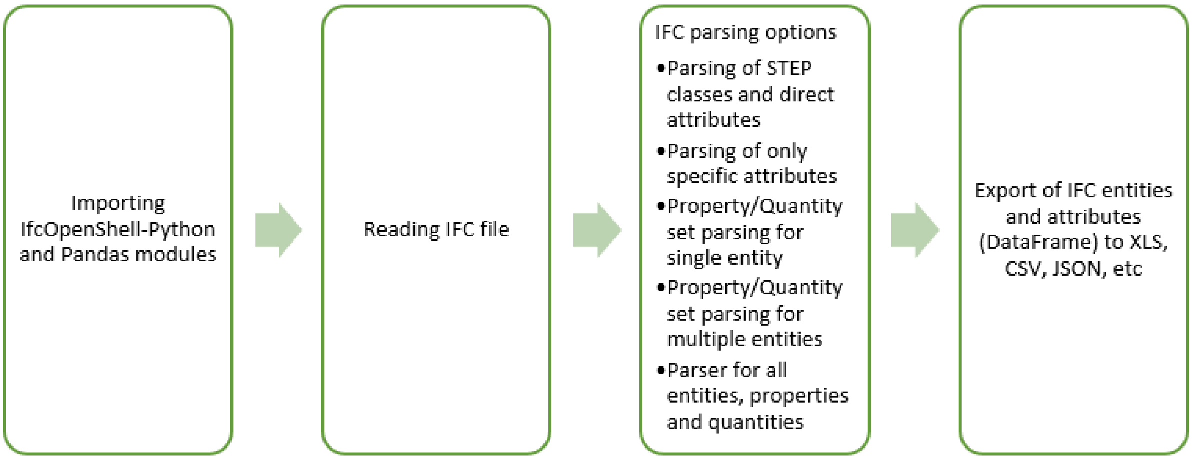


**Figure 10: D^2EPC IFC Parser procedures**

# 3 Calculation Engine implementation

This calculation engine is one of the primary components of the D^2EPC architecture (Figure 11). 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).

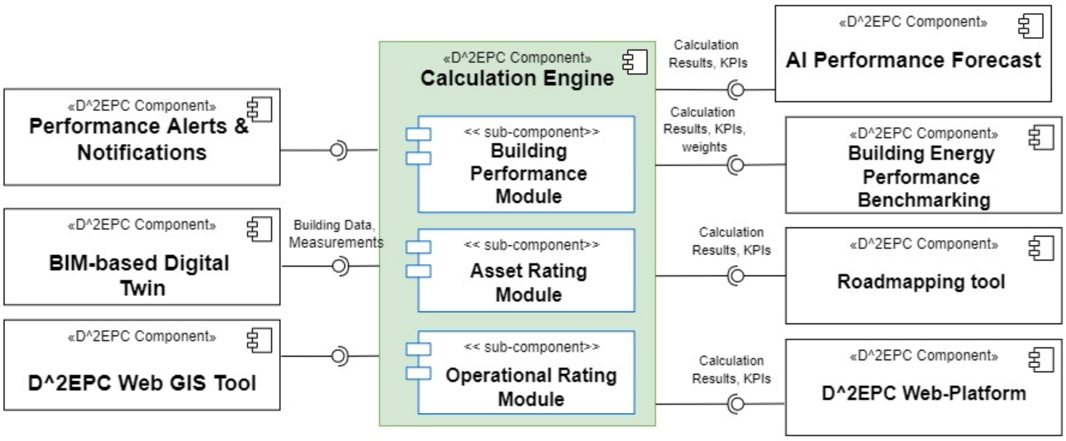


**Figure 11: Calculation Engine- Architecture view**

## 3.1 Asset Rating Module

The Asset Rating Module is the first calculation module that took place in the Calculation Engine's development procedure. It has the ability to estimate the asset's energy performance based on the building's documentation, as described in 2.1. The following sections present an overview of the component's operation methodology as well as the steps followed for its development.

### 3.1.1 Calculation Methodology

The European approach that D^2EPC followed for the development of the D^2EPC Asset Rating scheme is based on a set of commonly accepted standards among the EU 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 [8].
- **ISO 52003-1:2017**, Energy performance of buildings – Indicators, requirements, ratings and certificates – Part 1: General aspects and application to the overall energy performance [9].
- **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. The adoption of the monthly method, over the hourly one, lightens the building's documentation requirements and consequently the input data from the user, which typically introduces uncertainties and leads to loss of overall accuracy. On the other hand, the methodology requires a set of correlation or adjustment factors to account, in a kind of statistical way, for the dynamic effects of heat transfer that take place in a building.

The building's energy performance of an asset takes into consideration the following characteristics:

- Object type: whole building, building unit, part of a building or building element
- Building (and/or space) category (residential, office, etc.)
- Assessment types: design, as built, etc.
- Energy services: heating, cooling, ventilation, (de-)humidification, domestic hot water, lighting, building automation and control, PV and wind as energy sources, etc.

For each energy service, the energy need and the energy consumption must be calculated and then compared to the energy consumption of a reference building with identical geometric characteristics. The final EPC rating will result 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.

#### 3.1.1.1 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. The main set of services includes Heating, Cooling and DHW, while Lighting is calculated only in the case of tertiary buildings. Figure 12 illustrates the flow of calculations.

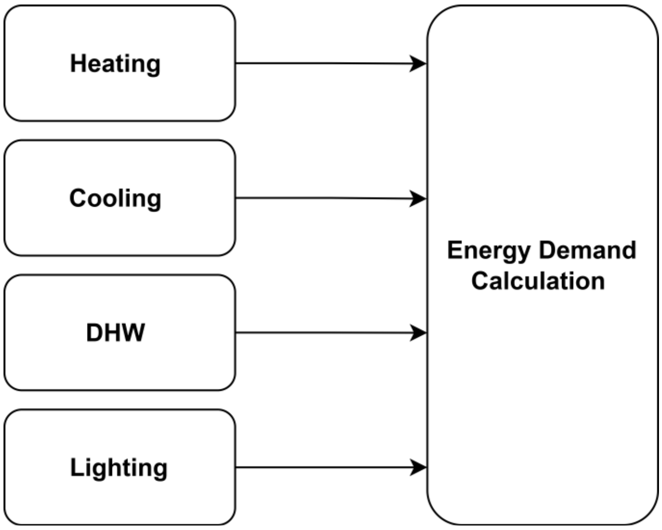


**Figure 12: Energy Demand**

Nevertheless, determining the monthly energy demand for heating and cooling requires an additional set of calculations that have to 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:

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

#### 3.1.1.2 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:

$$E_{HC;del} = \frac{E_{HC;nd}}{\eta} \quad (2)$$

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;
- $\eta$ 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 13.

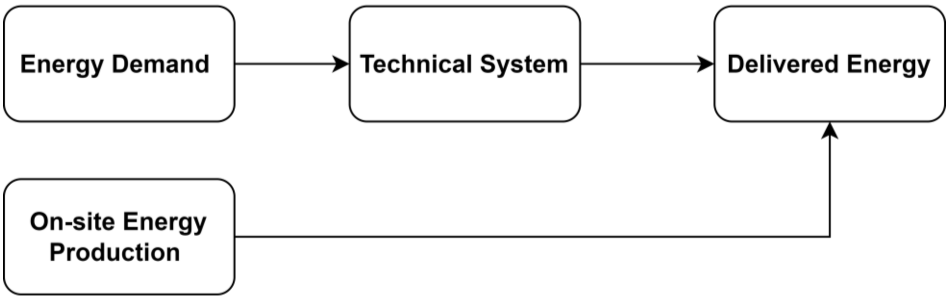


Figure 13: Delivered energy calculation flow.

Figure 14 presents an overview of the input sources of data utilized in the calculation procedure.

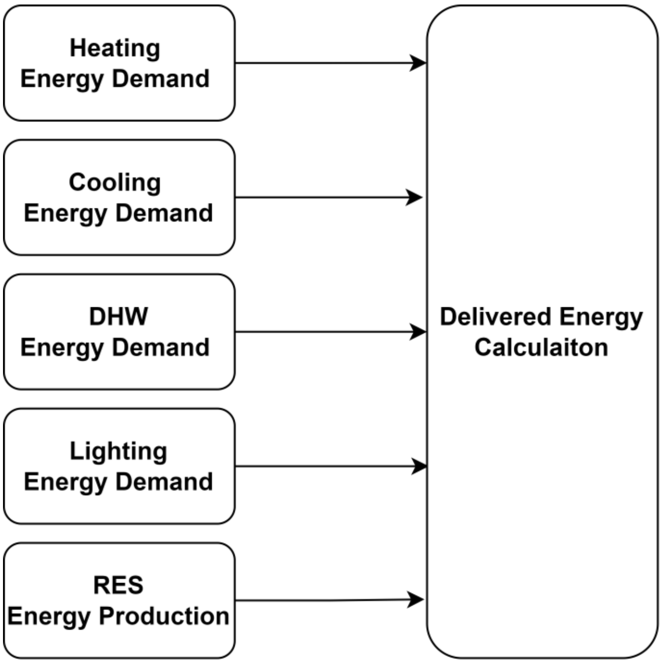


Figure 14: Delivered Energy Calculation

### 3.1.1.3 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 [8] the primary energy is calculated with the use of primary energy factors, as shown in the following equation:

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

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 3.1.3.3. Figure 15 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 [8].

$$E_{we} = E_{we;del;an} - E_{we;exp;an} \qquad (4)$$

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

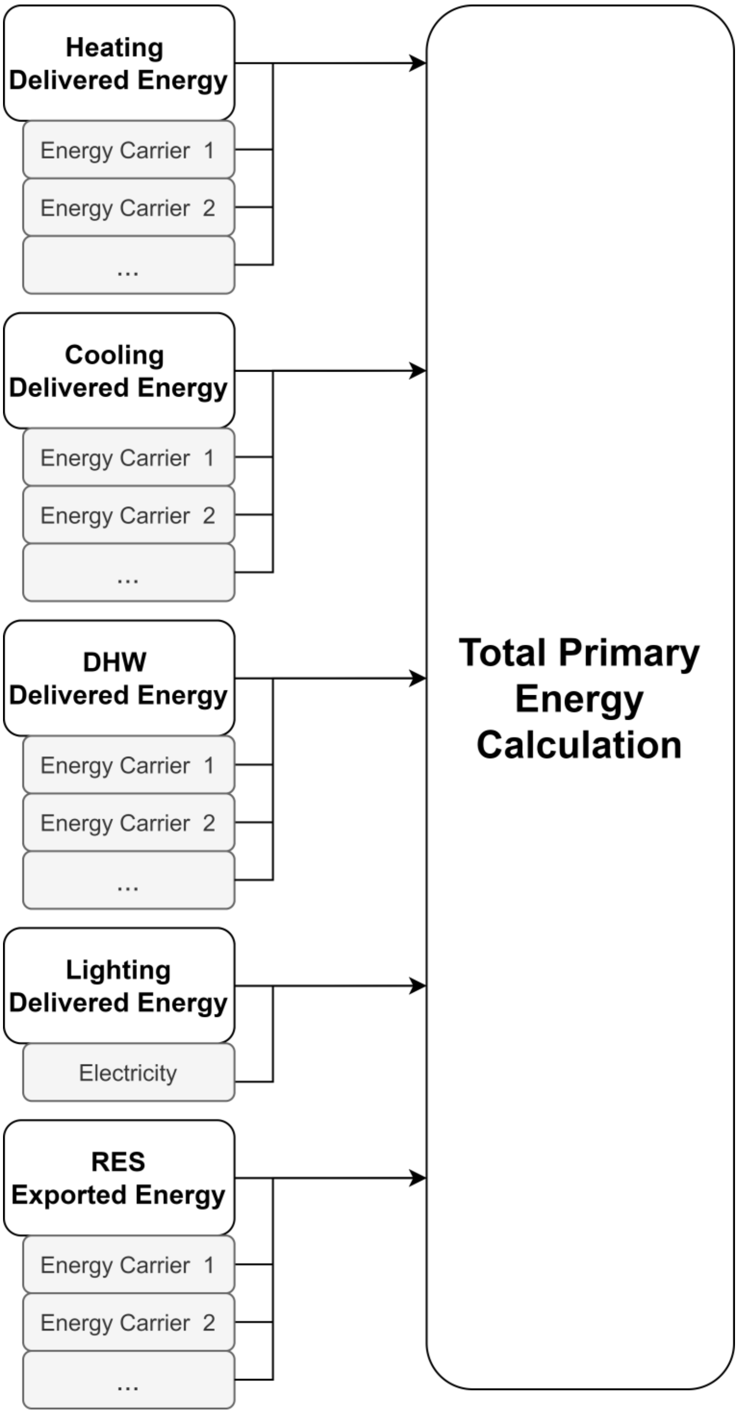


**Figure 15: Primary Energy Calculation**

### 3.1.1.4 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.

#### 3.1.1.5 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:

$$AR = f \cdot \frac{E_{we}}{E_{we;ref}} \tag{3}$$

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 7.

**Table 7: EPC ratings [9]**

| 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 | 2.00$R_s$ ≤ AR |

Where

- $R_r$ is the energy performance regulation reference.

### 3.1.2 Development

The module's development follows the general approach of the project. The followed design philosophy enables the operation both as a stand-alone tool, as well as, integrated into the platform. The calculation engine takes as an input a building's data model from the D^2EPC repository. The results are also stored in the D^2EPC Repository and the user has access to them through the web platform module. Section 4.2.1 demonstrates the user interface and the results from the Asset Rating calculation. Furthermore, the integration into the D^2EPC platform enables additional components (e.g. Roadmapping) to access the module request for ad-hoc energy simulations to evaluate the energy impact of various renovation actions.

The 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

## 3.1.3 Databases

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. Despite the well-documented stepwise procedure, the EN ISO 52000 series of standards doesn't provide the necessary documentation for the development of the datasets that will support 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 databases for a systematic development approach.

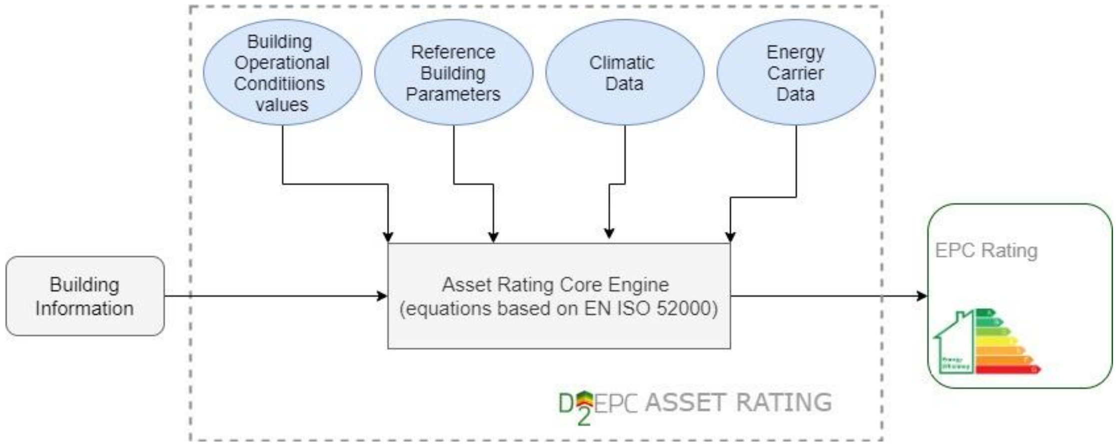


**Figure 16: Asset Rating data sets requirements**

### 3.1.3.1 Climatic Database

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 database that complies with national technical directives, a classification of each country's climatic zone is mandatory. Examined countries include Greece, Cyprus, Germany, Lithuania, and the Netherlands. Greece and Cyprus are divided into four climatic zones, and Germany has 15 climatic regions. Lithuania and the Netherlands, due to their smaller area, consist of a unified climatic zone.

Many data sources were examined, like PVGIS, NASA climatic databases, and commercialized databases. 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. Commercialized databases 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 database, named PVGIS-SARAH 2. PVGIS – SARAH 2 is the most updated database, 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 [8].

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 database. Requests' inputs are shown in Figure 1. 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.

```
URL_MONTHLY_TEMP=f"https://re.jrc.ec.europa.eu/api/v5_2/MRcalc?lat={lat}" \
                 f"&lon={lon}" \
                 f"&avtemp=1&outputformat=json" \
                 f"&startyear=2005&endyear=2020"
response=requests.get(URL_MONTHLY_TEMP)
```

Furthermore, another request is being made for monthly solar horizontal irradiation, which requires input latitude, longitude, the format of the output result, start year, end year, and a declaration that the wanted output result is solar horizontal irradiation. Results provide solar horizontal irradiation in $kwh/m^2$ per month and year. A data organization is being conducted to achieve mean values for each month in a similar way to the average temperature.

The final request refers to solar irradiation for a specific orientation and specific surface slope. The surface slope that is used for request input is 90 and 45 degrees. Orientations that are used for request input are shown in Table 1 with their respective orientation degrees. In total, sixteen 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 |
|---|---|
| SOUTH | 180 |
| NORTH-EAST | -135 |
| NORTH-WEST | 135 |
| EAST | -90 |
| WEST | 90 |
| SOUTH-WEST | 45 |
| SOUTH-EAST | -45 |
| SOUTH | 0 |

The final results of the requests are stored in an excel file and fed into the Asset rating module to perform the required calculations. A partial sample of the final results is shown in Table 1Table 9. With this approach, D^2EPC managed to develop a complete and uniform climatic database with the monthly average climatic values of each zone.

**Table 9: Partial sample of the final results**

| Month | Temperature | SR_H | SR_90_N | SR_90_S | SR_45_NW |
|---|---|---|---|---|---|
| january | 6,30833333 | 61,668125 | 12,143515 | 106,6027894 | 26,83053938 |
| february | 7,85 | 75,493125 | 15,39408407 | 96,30894805 | 39,31697681 |
| march | 10,7 | 121,119375 | 22,3490625 | 112,0949031 | 72,24540625 |
| april | 15,15 | 160,5425 | 30,31333938 | 102,3573175 | 108,1876725 |
| may | 20,1666667 | 198,22125 | 42,34519063 | 91,31374313 | 143,5692306 |
| june | 24,5 | 217,8925 | 48,3230425 | 82,52242625 | 162,8361394 |
| july | 26,8 | 233,77875 | 45,81229125 | 92,90074563 | 171,9291106 |
| august | 26,2 | 207,75125 | 31,767335 | 114,9274156 | 140,9361013 |
| september | 22,3416667 | 147,893125 | 24,06278688 | 120,3765081 | 90,287725 |
| October | 16,6916667 | 102,663125 | 19,07520063 | 119,8384663 | 55,67363875 |
| november | 11,875 | 65,05375 | 13,57455375 | 100,4967063 | 31,33624938 |
| december | 6,85833333 | 54,39375 | 11,48720875 | 101,14644 | 23,76783938 |

### 3.1.3.2 Reference Building Database

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 database includes information that describes the system’s efficiency.

The selection of the reference building values depends mostly on the type of the examined building, while it can also be affected by other parameters, like the location, according to the distinction inherited from the national methodologies.

The incorporated values derive from national EPC methodologies and have been collected through the “D^2EPC Questionnaire: Input Parameters for Asset Rating", Annex A.

### 3.1.3.3 Energy Carrier Database

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

- The primary energy factor, the conversion from delivered to primary energy
- 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 energy carrier values also derive from national official sources and have been collected with the *“D^2EPC Questionnaire: Input parameters for Asset Rating”*.

### 3.1.3.4 Database with Boundary Conditions for Thermal Zones

As the average desired indoor conditions differ per country or even per smaller regions depending on the climate conditions, a boundary Conditions Database has been constructed to incorporate the possible deviations. The following parameters are described in each case:

- Heating period
- Cooling period
- Heating set-point
- Cooling set-point
- Fresh air requirement
- Internal heat gains (people, equipment, lighting)
- Operational hours with available daylight

- Operational hours without available daylight
- DHW demand

The above parameters are essential mostly for the calculation of the building's energy demand.

The incorporated values derive from national EPC methodologies and have been collected through the "D^2EPC Questionnaire: Input Parameters for Asset Rating."

## 3.2 Operational Rating Module

### 3.2.1 Introduction

The introduction and establishment of the operational EPC (dEPC) concept, a calculating interface, empowers the regular energy classification of buildings based on their operational performance. In this manner, it will lead to the enhancement of the actual energy performance of EU Member States' building stocks, and a more active role of next-generation EPCs in policy making will be enabled.

The approach for next-generation EPCs follows an expanded, cohesive methodology and implementation of operational rating to all types of buildings, unrelated to their usage. A unified EPC operational rating for all the types of buildings - from residential and non-residential to offices and public buildings – detailed on the buildings' physical features provides the actual energy consumption of the buildings. For building extensions, measurements are made through the existing building's measurement system.

### 3.2.2 Calculation Methodology

In the following figure, the steps of the calculation methodology of the D^2EPC operational scheme are provided:

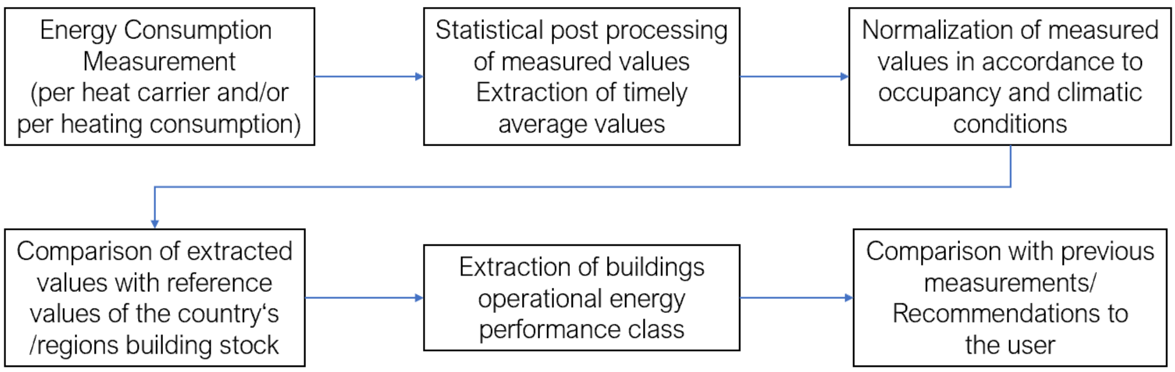


**Figure 17: Operational Rating flow of calculations**

### 3.2.3 Development

A first version of the Operational Rating Calculation Engine has been implemented based on Python 3.9. Functions for data retrieval (currently from CSV files) as well as for calculation of the different operational indicators have been developed. A preliminary example is provided in Section 4.2.2

## 3.2.4 Features of D^2EPC Operational Rating

### 3.2.4.1 Reference values

The D^2EPC operational rating will be conducted in accordance with the building stock as 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. An example of the Cypriot building stock is provided. The assessment of the Cypriot building stock was conducted, in accordance to the minimum requirements for class A buildings set by the competent authority in Cyprus, as well as on a JRC Technical Reports concerning the energy consumption of the building stock in Cyprus. The energy classification of the Cypriot building stock is presented in Table 10 and Table 11.

**Table 10: Energy rating class for residential building typologies (delivered energy)**

| Building type | Age | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Single house | < 1981 | 37 | 74 | 112 | 149 | 186 | 224 | 261 |
| | 1981 - 2006 | 37 | 62 | 87 | 112 | 137 | 162 | 187 |
| | > 2006 | 37 | 58 | 80 | 101 | 122 | 144 | 165 |
| Semi-detached + Rowhouses | < 1981 | 37 | 71 | 106 | 140 | 174 | 209 | 243 |
| | 1981 - 2006 | 37 | 60 | 82 | 105 | 128 | 150 | 173 |
| | > 2006 | 37 | 56 | 75 | 94 | 113 | 132 | 151 |
| Apartment blocks | < 1981 | 37 | 82 | 128 | 173 | 218 | 264 | 309 |
| | 1981 - 2006 | 37 | 70 | 102 | 135 | 168 | 200 | 233 |
| | > 2006 | 37 | 65 | 93 | 121 | 149 | 177 | 205 |
| Other types of building | < 1981 | 37 | 69 | 100 | 132 | 164 | 195 | 227 |
| | 1981 - 2006 | 37 | 58 | 79 | 100 | 121 | 142 | 163 |
| | > 2006 | 37 | 55 | 72 | 90 | 108 | 125 | 143 |

**Table 11: Energy rating class for non-residential buildings (delivered energy)**

| Building type | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Hotels and other accommodation | 46 | 155 | 264 | 373 | 482 | 591 | 700 |
| | 46 | 116 | 186 | 256 | 326 | 396 | 466 |
| Schools | 46 | 63 | 80 | 97 | 114 | 131 | 148 |
| | 46 | 53 | 59 | 66 | 73 | 79 | 86 |
| Public buildings | 46 | 63 | 81 | 98 | 115 | 133 | 150 |
| | 46 | 53 | 61 | 68 | 75 | 83 | 90 |
| Supermarkets and malls | 46 | 199 | 351 | 504 | 657 | 809 | 962 |
| | 46 | 146 | 245 | 345 | 445 | 544 | 644 |
| Hospitals and clinics | 46 | 163 | 281 | 398 | 515 | 633 | 750 |
| | 46 | 121 | 197 | 272 | 347 | 423 | 498 |
| Restaurants and taverns | 46 | 244 | 443 | 641 | 839 | 1038 | 1236 |
| | 46 | 176 | 307 | 437 | 567 | 698 | 828 |
| Private offices | 46 | 129 | 212 | 295 | 378 | 461 | 544 |
| | 46 | 98 | 149 | 201 | 253 | 304 | 356 |
| Retail shops | 46 | 111 | 175 | 240 | 305 | 369 | 434 |
| | 46 | 85 | 125 | 164 | 203 | 243 | 282 |
| Other | 46 | 261 | 477 | 692 | 907 | 1123 | 1338 |
| | 46 | 188 | 329 | 471 | 613 | 754 | 896 |

#### 3.2.4.2 Issuance frequency

An EPC needs to be revised in case the energy performance of the building is altered. Once issued, the operational energy dEPC is valid and could be renewed every six months according to weather normalization procedures. This allows an improved energy performance of buildings to be achieved. The consumption, production, and occupancy data are updated and displayed in a frequency of half-year as a continuous process. For the same period, the energy usage indicators are revised and subsequently stored in the EPC databases.

#### 3.2.4.3 Normalization practices

Since energy usage is weather dependent and heating/cooling energy consumption is substantial in most buildings, weather normalization is applied. Weather normalization is employed for the calculation of a building’s energy performance by defining a weather correction factor, for the time period deployed for the operational certificate issuance. Techniques for weather-normalization are based on regression analysis of historical energy usage data.

#### 3.2.4.4 Measurement equipment

For the D^2EPC operational rating classification, power and gas meters are employed to measure the energy consumption. The equipment should comply with competent EN standards with regard to its minimum requirements. Indicatively concerning the indoor temperature, the EN 17690-1:2022 standard - Components for BAC Control Loop - Sensors - Part 1: Room temperature sensors, is referred. Further information concerning the minimum requirements of the measuring equipment is provided under Deliverable 5.4.

### 3.2.5 Databases

The operational energy classification, conducted in accordance to the building stock as reference method, 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. 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

In addition, the regular extraction of the operational EPC, requires the recording of values related to the energy consumption of different building energy carriers, including, electricity, natural gas or heating oil, or even for different energy consumptions including heating, cooling, ventilation, domestic hot water, lighting, appliances, etc. These values should be kept on an hourly time step, and should be post-processed for extracting average values, specified on the time frame of the analysis (annually, biannually, quarterly etc).

Another database that will need to be developed concerns data related to normalization of the measured values, including weather data and occupancy data. These datasets should be developed and maintained, were according data is available, and post processed for the extraction of the necessary indicators for conducting the normalization of the operational energy assessment of the building.

## 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* [11]. The main classes are depicted in Figure 18 and Figure 19 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, 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.

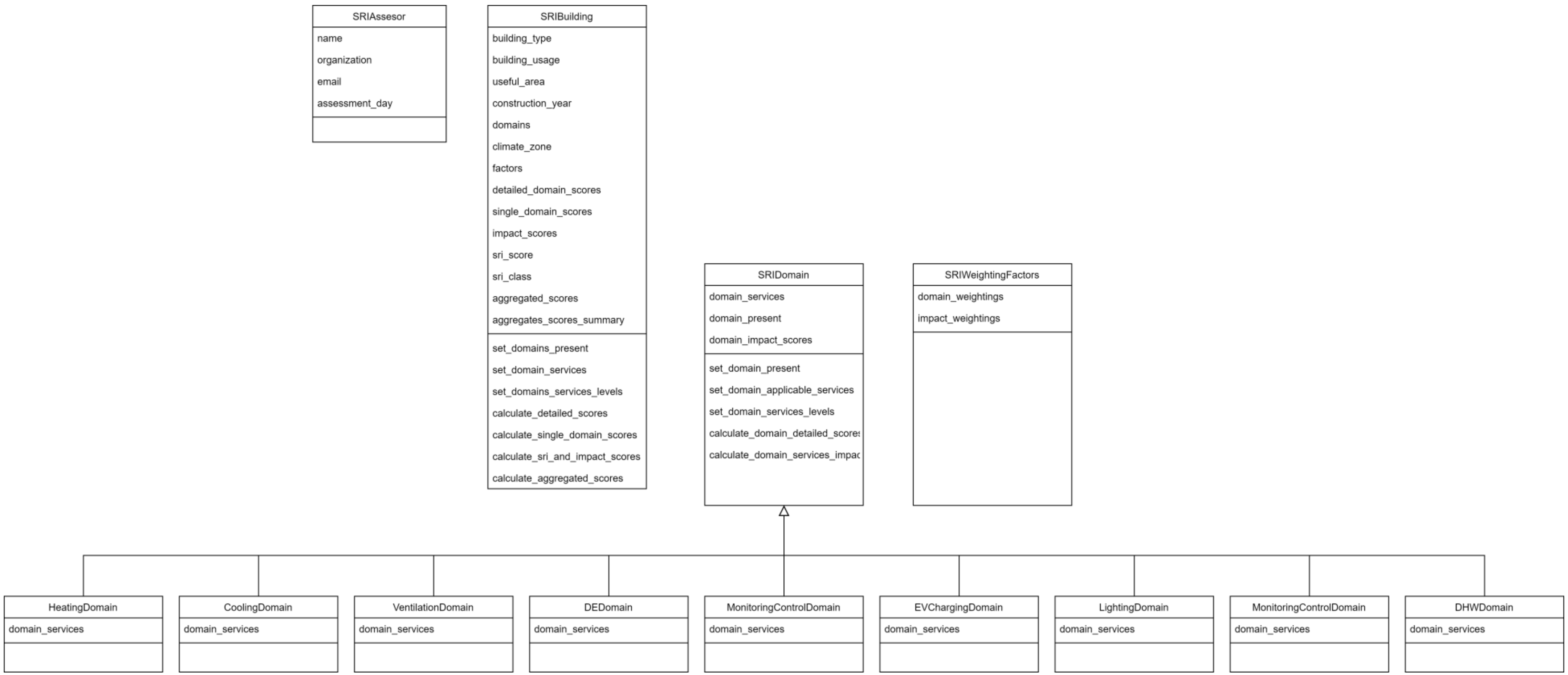


Figure 18: SRI calculation submodule main object classes

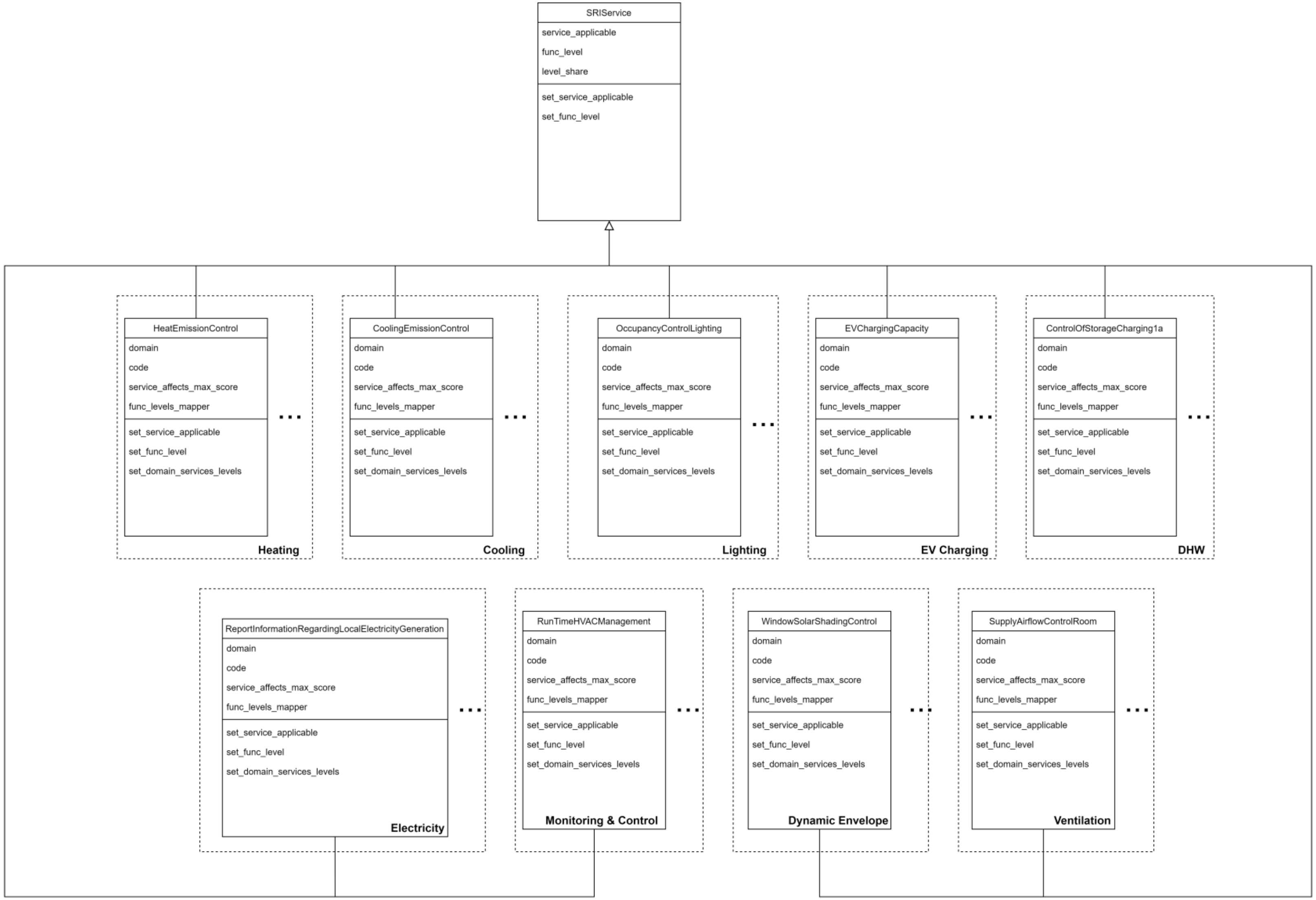


Figure 19: SRI calculation submodule services object classes

The *SRIAssessor* and *SRIBuilding* classes enclose information regarding the assessor and the building, respectively. The latter includes variables that store data useful for the calculations, such as the building type/usage. 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 20 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 is provided either by extraction from the BIM file or through the D^2EPC Web Platform.

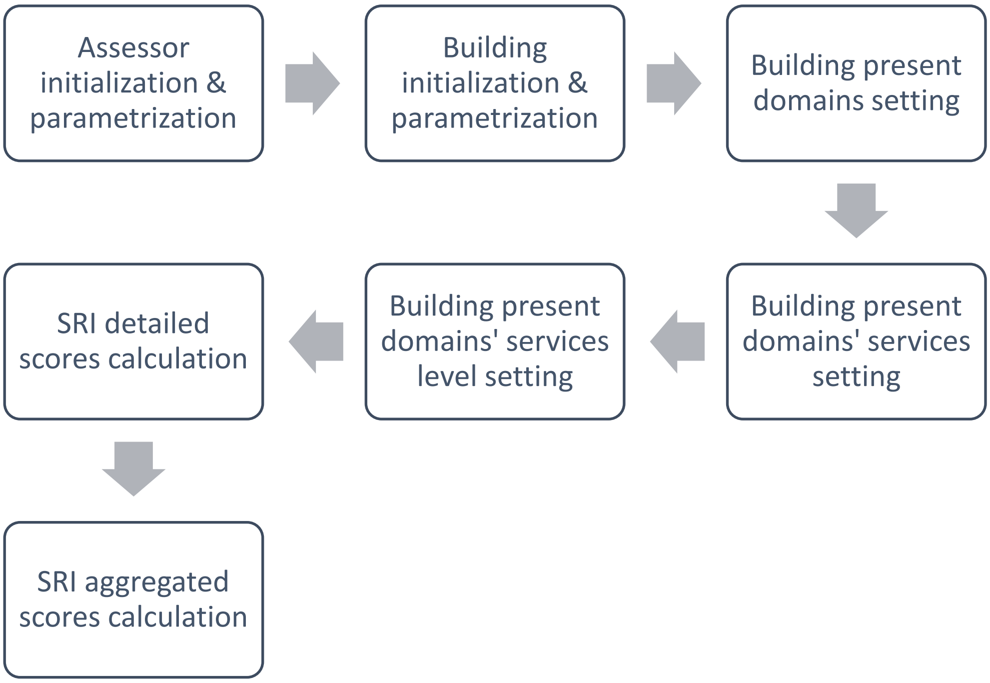


Figure 20: SRI calculation procedure

## 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". The main object classes are outlined in Figure 21 below.

The main class is the *HCWIndicators*, which contains all the relevant variables that are commonly utilized by the 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 relation to the time period and desired space) 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. This class is inherited by the three child classes that represent each subset of human comfort indicators.

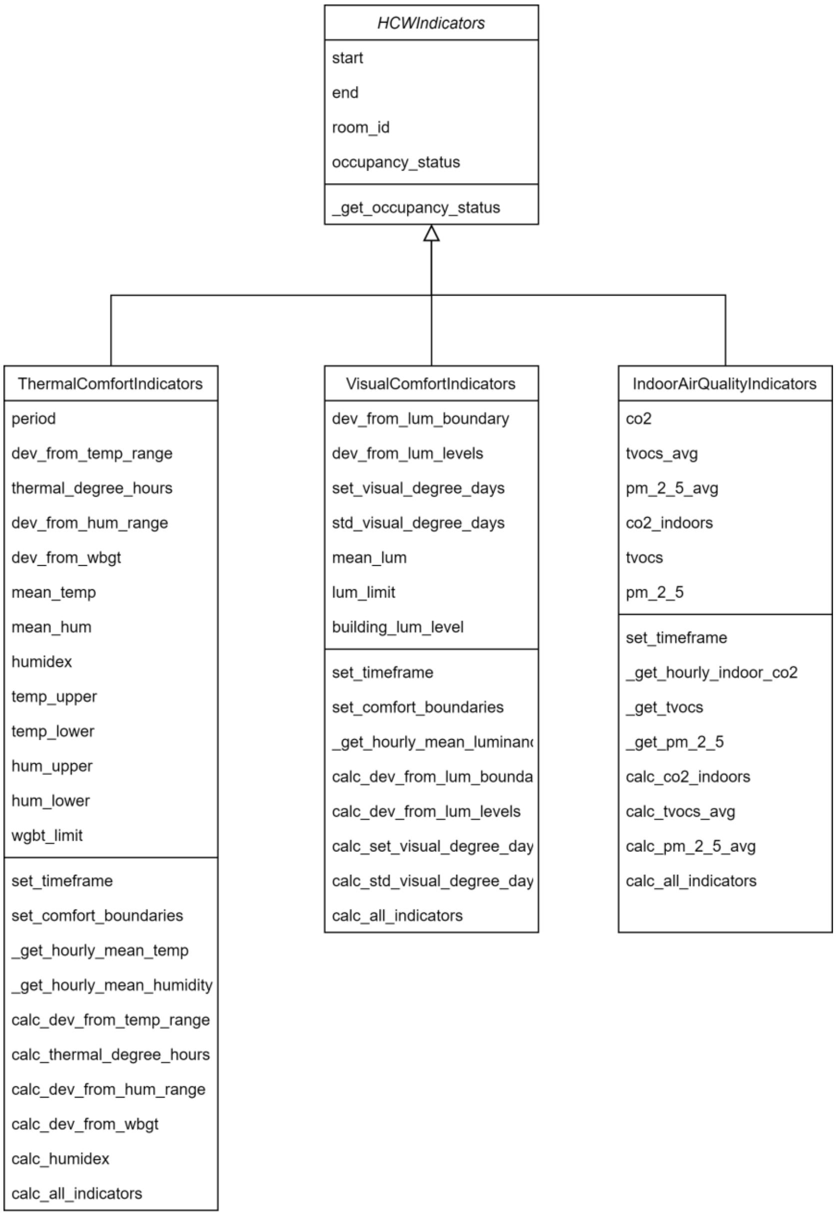


**Figure 21: HC&W Indicators calculation submodule main object classes**

The *ThermalComfortIndicators* class includes all the necessary parameters and methods to calculate the four thermal comfort indicators (deviation from the temperature range, thermal degree hours, deviation from the humidity range and deviation from the acceptable WBGT levels). The comfort boundaries (minimum/maximum temperature/humidity, WGBT level limits) as well as the necessary data series (mean temperature/humidity) are provided by functions that will be linked to the Comfort Profiling Engine and the D^2EPC Repository, respectively.

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 illuminance boundary) as well as the necessary data series (mean luminance) are provided by functions that will be linked to the Comfort Profiling Engine (or are already available through relevant standards) and the D^2EPC Repository, respectively.

Finally, the *IndoorAirQualityIndicators* class includes all the necessary parameters and methods to calculate the three indoor air quality indicators (CO2 indoors, average TVOCs, and average PM 2.5).

The level limits are set by relevant standards the necessary data series (CO2/TVOCs/PM2.5 concentrations) are provided by a function that will be linked to the D^2EPC Repository.

The procedure followed to calculate the indicators is straightforward and only requires the indication of the desired time period and the id of the building space. The internal functions fetch the corresponding data from the D^2EPC Repository and perform the necessary calculations.

### 3.3.3 LCA Indicators calculation submodule

This subcomponent's internal calculations follow the guidelines and relevant standards that were elaborated in the deliverable 2.3 "Life Cycle Indicators for next generation EPCs v1". The main object classes are outlined in Figure 22 below. Each life-cycle stage is represented by an *LCAStage* class object, which includes all the methods needed for the collection of the required data and the execution of the calculations. The necessary input information mainly regard the materials' bill of quantities (mapped to building elements) along with their corresponding EPDs, which are stored in the D^2EPC Repository. Consequently, the calculation process is simple as depicted in Figure 23.

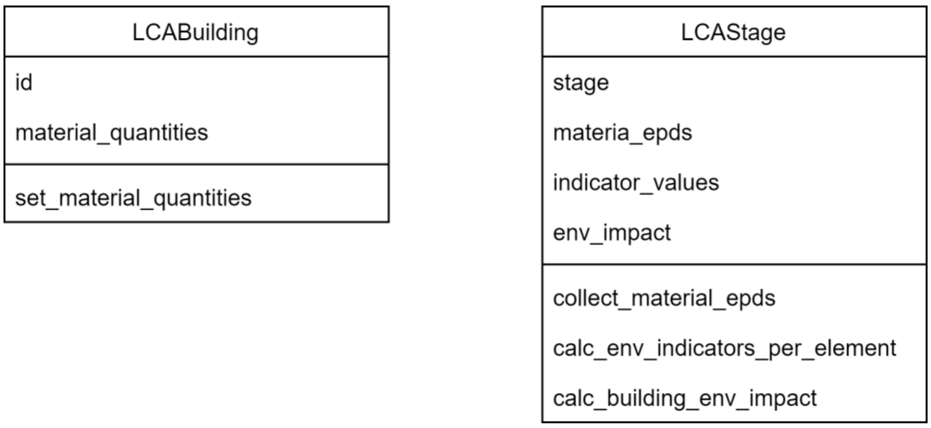


**Figure 22: LCA submodule main object classes**

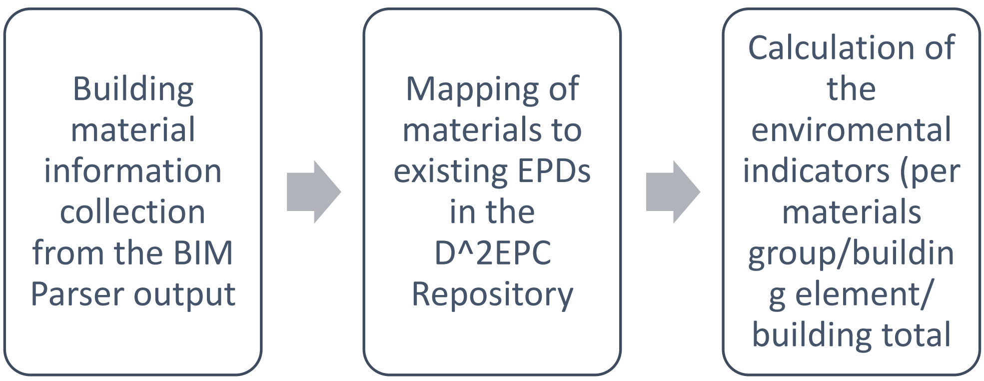


**Figure 23: LCA submodule calculation procedure**

### 3.3.4 Financial Indicators calculation submodule

This subcomponent's internal calculations follow the guidelines and relevant standards that were elaborated in the deliverable 2.4 "Financial indicators for next generation EPCs v1". The main object classes are outlined in Figure 24 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 area, the mapping of each existing energy use to an energy carrier and the corresponding energy carrier price. Additionally, several class methods are supplied 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. Each of these classes includes a method for fetching the necessary data from the D^2EPC Repository.

Finally, the *AsPredictedCosts* class calculates the nominal cost and the net present value for the next 10 years, while the *SystemCosts* class yields the expected maintenance and replacement costs of the building systems.

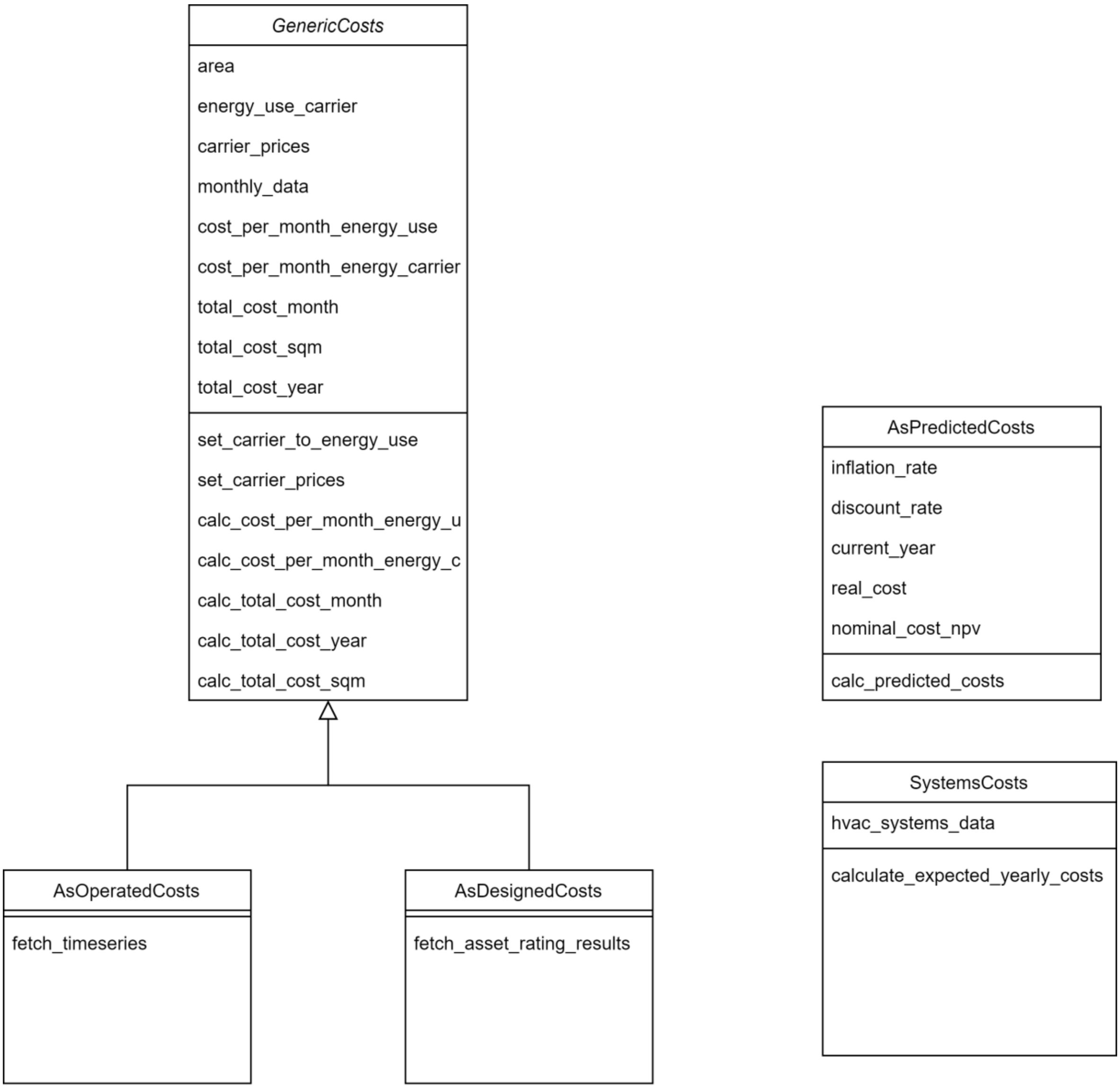


**Figure 24: Financial Indicators submodule main object classes**

The procedure followed to extract the financial indicators is depicted in Figure 25 below. The required information is provided either by extraction from the BIM file or through the D^2EPC Web Platform.

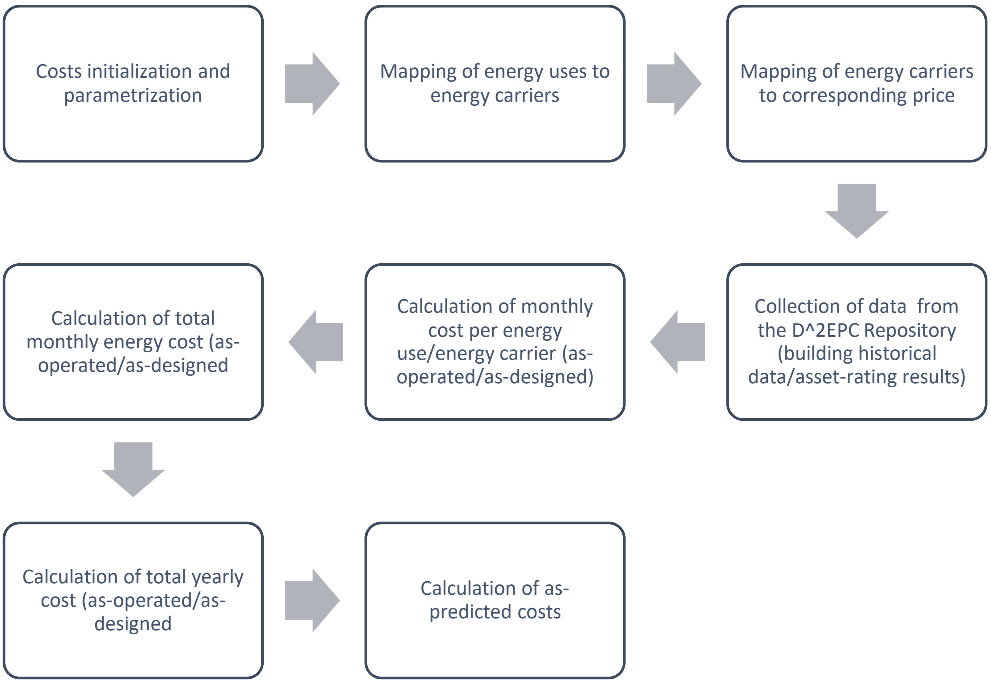


Figure 25: Financial Indicators calculation procedure

# 4 Component validation

## 4.1 Test cases

### 4.1.1 Asset Rating Module – Building Performance module

CERTH's nZEB Smart House (i.e. Pilot Case Study 1) has been used for the validation of the Asset Rating Module, as well as of the developed subcomponents of the BPM up to this day. Its existing BIM file contains a large amount of information required for the calculation of the EPC rating and the static indicators and has been extensively studied for the development of the BIM parser module. Furthermore, the on-site survey and the study of relevant building documentation have provided valuable information to complete the input data requirements. Finally, actual measurements of different indoor conditions variables have been retrieved from the existing IoT platform and were used to calculate the dynamic human comfort & wellbeing indicators.

### 4.1.2 Operational Rating Module

Data from Case Studies 4 and 5 were used for the validation of this first version of the Operational Rating Module. Data corresponded to 12 months of measurements of the two buildings' delivered energy in different parts of each infrastructure, in the form of CSV files. The results (delivered energy and resulted EPC class) were presented through a simplified user interface, where data selection is available using input forms, and through appropriate graphs, respectively.

## 4.2 Results

### 4.2.1 Asset Rating Module

The validation results of the Asset Rating Module are presented through the D^2EPC Web Platform, which has been designed carefully to deliver as much information as possible to the EPC assessor in an effective way. 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. Lastly, 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 26). 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 27), download it as an image, or view the numeric values in a tabulated form (Figure 30). Lastly, the provision of the calculation can be presented either as normalised values [kWh/m$^2$] or as absolute values (Figure 31), to enhance even more the end-user experience and the conceptualization of the building's energy performance.

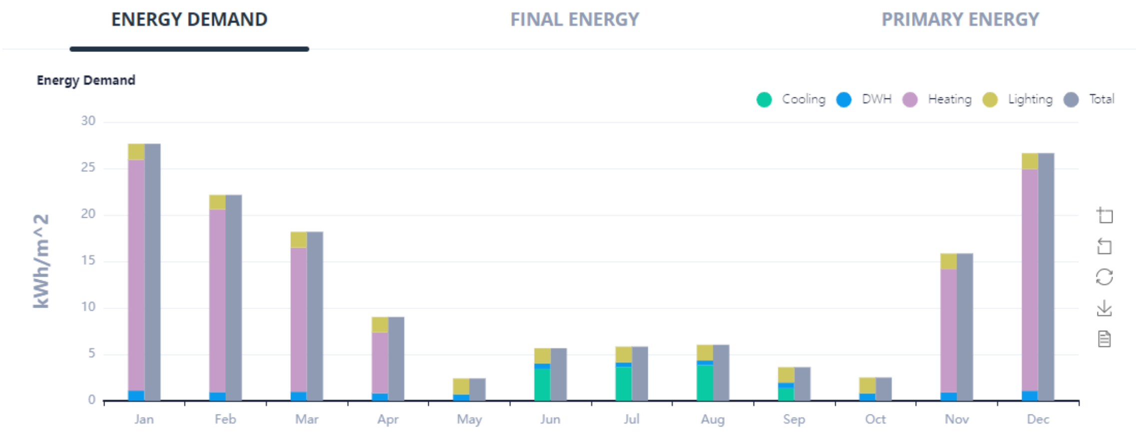


Figure 26: Energy Demand diagram [kWh/m$^2$]

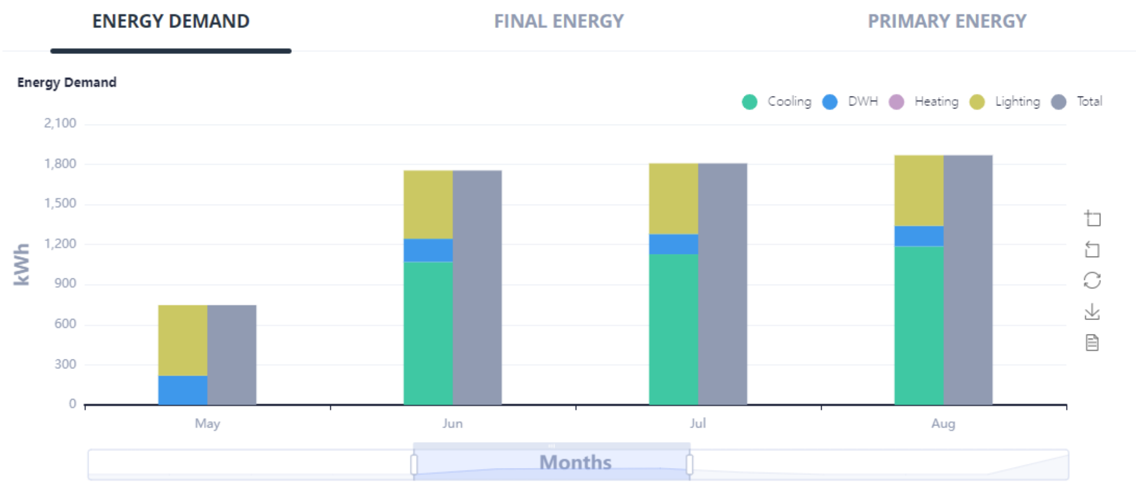


Figure 27: Energy Demand diagram - summer months' isolation

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 28: Energy demand - data view

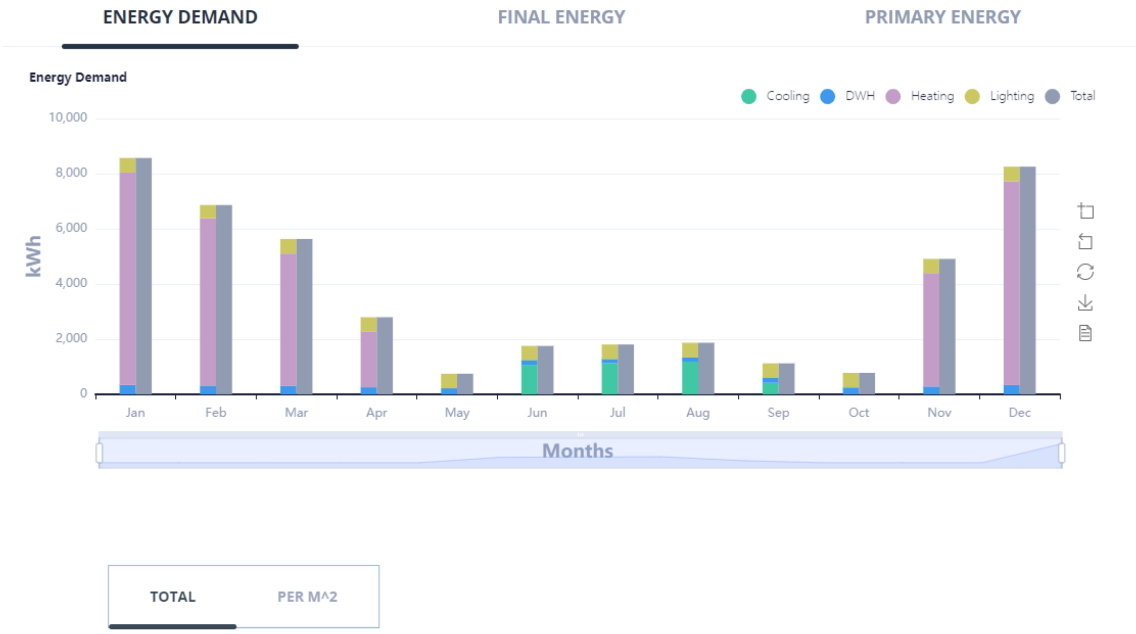


Figure 29: Energy Demand Diagram – absolute energy values

All the above-described functionalities are also available for the calculation steps of final energy (Figure 30) and primary energy (Figure 31). 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).

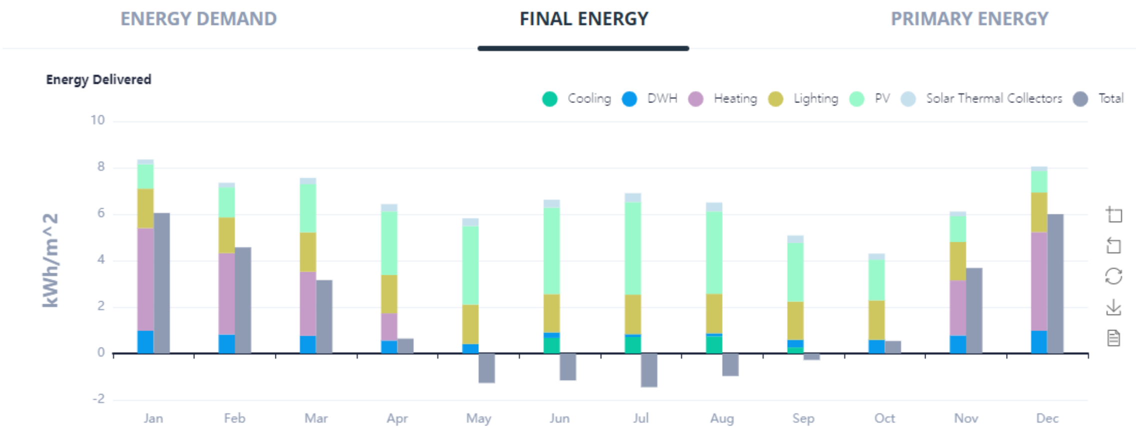


Figure 30: Final Energy Diagram

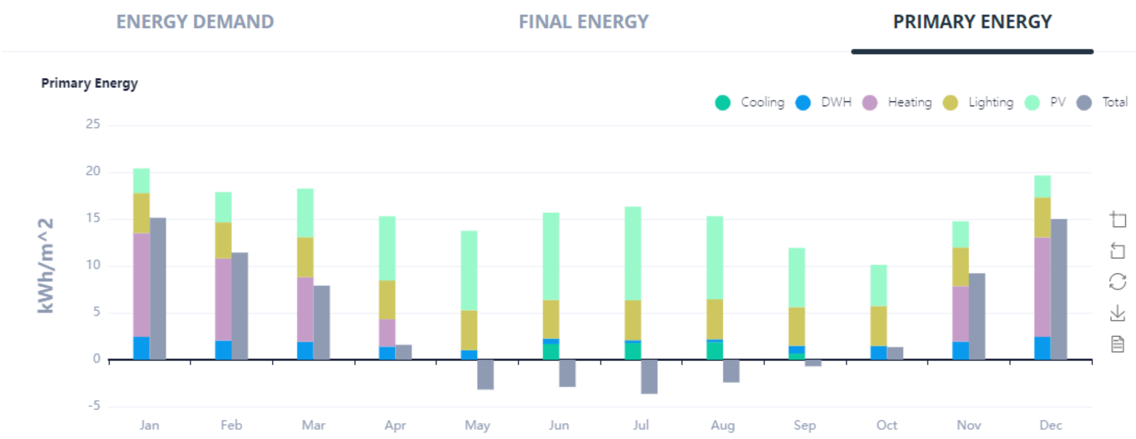


Figure 31: Primary Energy Diagram

Proceeding to the section with the KPIs, the end-user can find the total annual values of energy consumption. Figure 32 presents the annual energy consumption per energy service, while Figure 33 presents it per energy carrier. A small set of financial and environmental indicators is also included in the Asset Rating demonstration. Figure 34 presents the total cost of the building's annual energy consumption per energy carrier, and Figure 35 demonstrates the annual $CO_2$ emissions per energy carrier. All the KPIs can be presented as absolute or normalised values.


Figure 32: Annual energy consumption per energy service

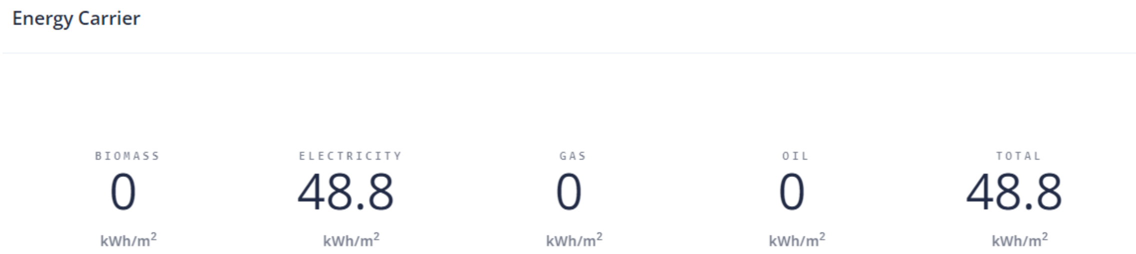


Figure 33: Annual energy consumption per energy carrier

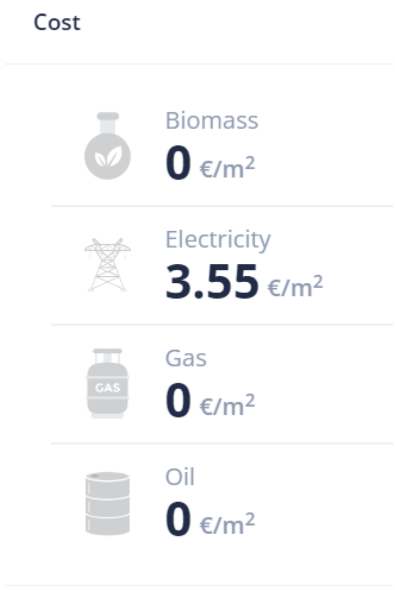


Figure 34: Financial Indicators

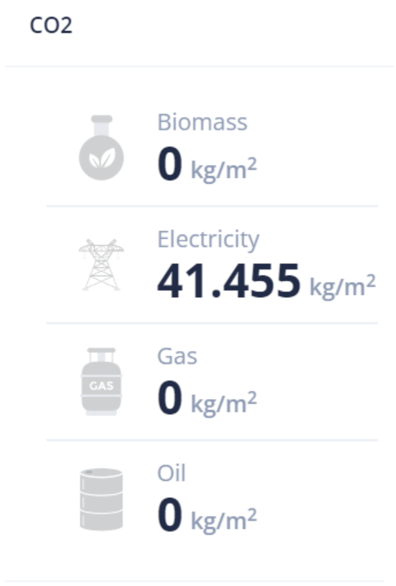


Figure 35: Environmental Indicators

The final and most important indicator is the building's energy class. Figure 36 presents the resultant energy class. At the bottom of the scheme, the "Energy Efficiency Rating" value shows 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 in each class.

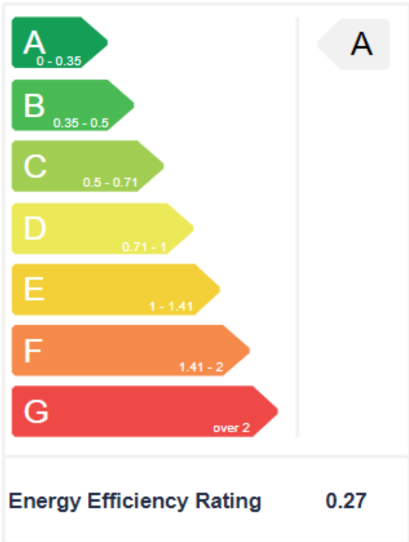


Figure 36: Energy Class

## 4.2.2 Operational Rating Module

The Operation Rating Module has been tested throughout the course of T4.1 at different development stages.

### 4.2.2.1 Case Study 5

A preliminary version of the tool has been tested based on data collected from Case Study 5 (Multi-family home in Berlin, Germany). The implementation aimed to apply the proposed rating scheme and provide a first prototype of user interface for the operational EPC visualization. With the provided tool, the user is able to visualise the asset's energy consumption, using the received data from csv files. The structure of the energy flows is shown in this input form of the research prototype in Figure 39.

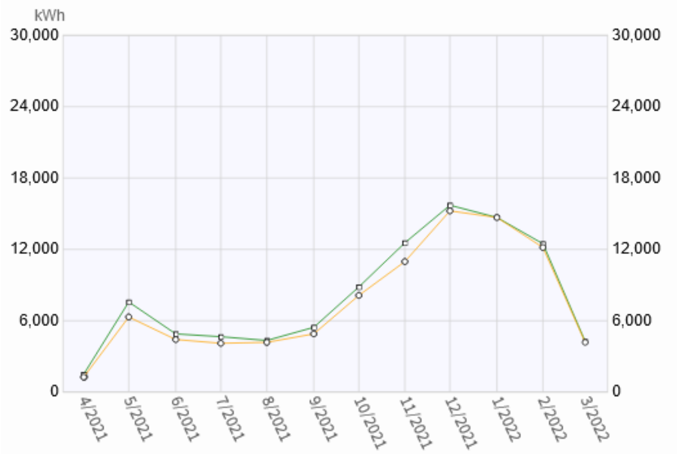


Figure 37: Energy demand for the observation period

Furthermore, the platform provides the assessor the ability to correlate the data streams of energy consumption with their corresponding energy carriers according to the type of system that provides each energy service, Figure 38. This step is crucial for the calculation of the Operational Rating Indicators included in the D^2EPC scheme.

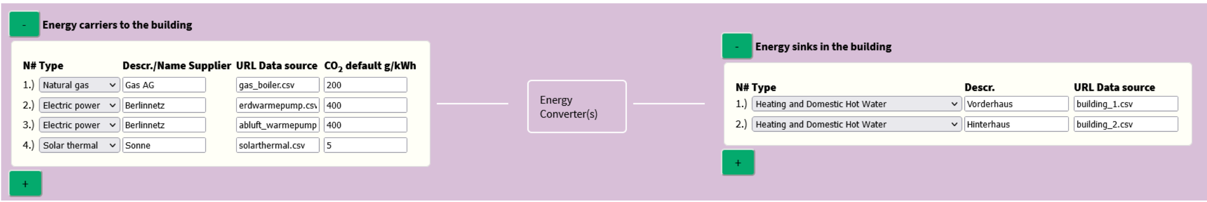


Figure 38: Input form representing the energy influx to the energy converter and the energy outflow

At the end of the operational rating process, the asset's energy class is provided to the end-user, as presented in Figure 39.

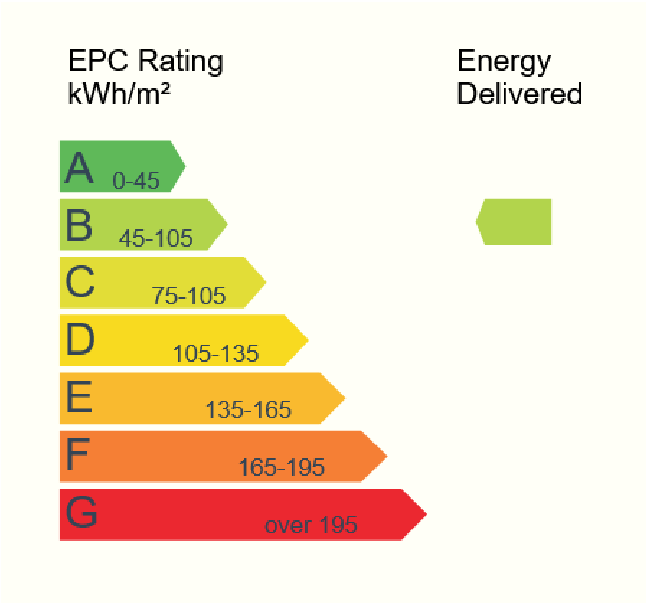


Figure 39: Example simplest output for the operational EPC

### 4.2.2.2 Case Study 4

An updated version of the Operational Rating module was tested using collected data from Case Study 4 (Mixed-use building in Nicosia Cyprus). The second stage of the module's development process included several additional features to the tools interface. The aim of these additions is to enhance the users' experience and facilitate their engagement with the platform. The improvised interface not only provides a holistic visual representation of the methodology's calculated indicators, but it also adds extra functionalities to the already existing ones. For instance, depicts the heating and cooling energy consumption for heating and cooling per floor of the building, Figure 40: Heating and cooling energy, per floor [kWh]Figure 40. As a result, the assessor has now the ability to isolate the energy consumption streams per energy service and per part of the building.

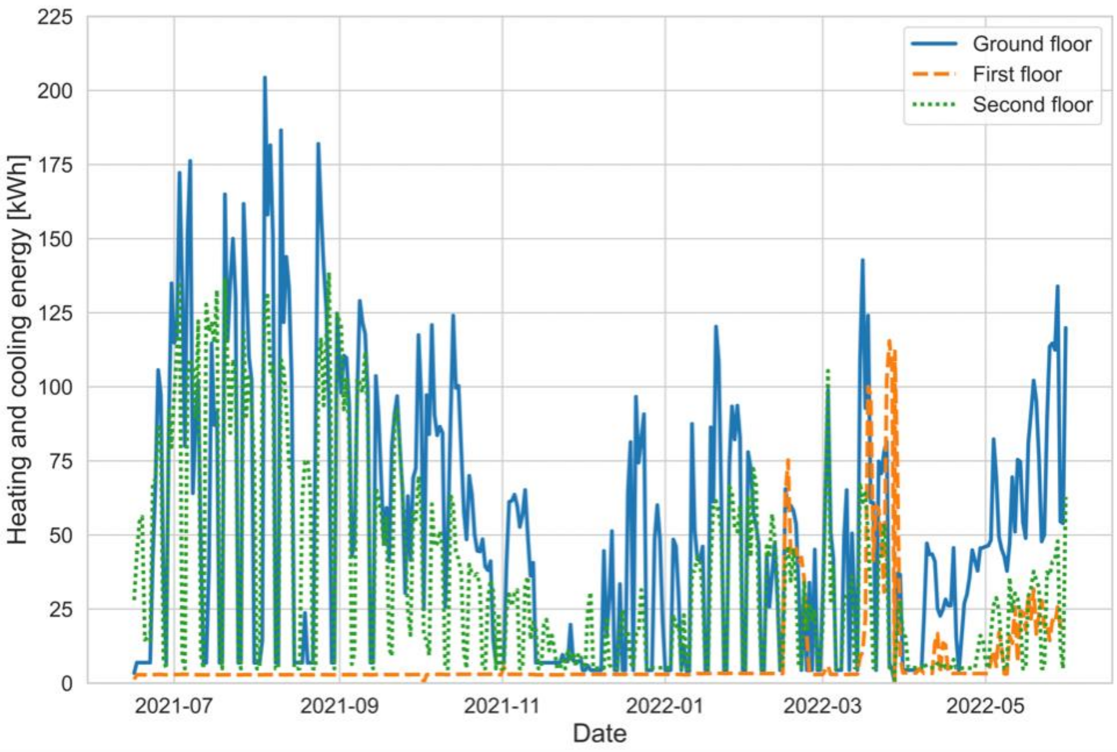


**Figure 40: Heating and cooling energy, per floor [kWh]**

Figure 41 provides a heat map of the energy consumption per occupant indicator on the three floors of the examined building. Lastly, Figure 42 provides a calendar heat map for the energy consumption on each day of the last two years, so the end-user can compare the energy consumption of each day with the respective value from the previous year. Based on values from Table 11, and the fact that the total annual energy consumption of FRC pilot was measured to be 128 kWh/m2, the performance of FRC pilot for year 2021-2022 was rated at class B, considering it as an office building.


**Figure 41: Heat map for indicators [kWh/occupants]**

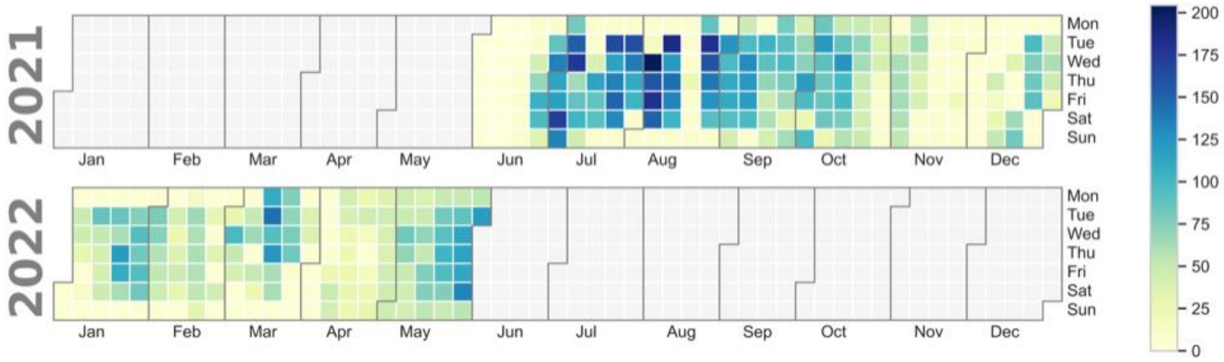


**Figure 42: Calendar heat map [kWh/Day/Degree Day]**

## 4.2.3 Building Performance Module

### 4.2.3.1 SRI calculation submodule

The output of the BIM Parser tool, concerning information relevant for the calculation of the SRI is shown below. The tool mainly contributes to the triage process, identifying the domains that are applicable for the building (where possible) along with a number of included services for each domain and their estimated functional level. However, as the extensive investigation in WP2/D2.1 has revealed, some information might be missing or cannot be included, and revisions/additions might be required by the assessor. 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.

```
{
    "BuildingInfo": {
        "building_type": null,
        "building_usage": null,
        "construction_year": null,
        "location": "NA",
        "useful_area": 297.5488372213181,
        "state": null
    },
    "Heating": {
        "Presence": 1,
        "heating_1a": 2,
        "heating_1b": 1,
        "heating_1c": 0,
        "heating_1d": 0,
        "heating_1f": null,
        "heating_2a": null,
        "heating_2b": 0,
        "heating_2d": null,
        "heating_3": null,
        "heating_4": null,
        "cooling_1c": 1
    },
    "Cooling": {
        "Presence": 1,
        "cooling_1a": 2,
        "cooling_1b": 2,
        "cooling_1c": null,
        "cooling_1d": 1,
        "cooling_1f": 0,
        "cooling_1g": null,
        "cooling_2a": 0,
        "cooling_2b": null,
        "cooling_3": null,
        "cooling_4": null
    },
    "Ventilation": {
        "Presence": 1,
        "ventilation_1a": 0,
        "ventilation_1c": 0,
        "ventilation_2c": 0,
        "ventilation_2d": 1,
        "ventilation_3": null,
        "ventilation_6": null
    },
    "Lighting": {
        "Presence": 1,
        "lighting_1a": 0,
        "lighting_2": 1
    },
    "DHW": {
        "Presence": 1,
        "DHW_1a": 3,
        "DHW_1b": 0,
        "DHW_1d": 0,
        "DHW_2b": null,
        "DHW_3": null
    },
    "Electricity": {
        "Presence": 1,
        "Electricity_2": null,
        "Electricity_3": 0,
        "Electricity_4": 0,
        "Electricity_5": 1,
        "Electricity_8": 0,
        "Electricity_11": null,
        "Electricity_12": null
    },
    "DE": {
        "Presence": 1,
        "DE_1": 0,
        "DE_2": 0,
        "DE_4": null
    },
    "EV_Charger": {
        "Presence": 0
    }
}
```

Following the collection of the necessary input data, the SRI subcomponent performs the necessary calculations. The overall SRI score achieved is **38%**, corresponding to **class E**. Figure 43 and Figure 44 below particularize the results in terms of single-impact and single-domain performance, respectively. It is worth mentioning that cross-validation of the results with the output of the SRI calculation package has been successfully carried out.

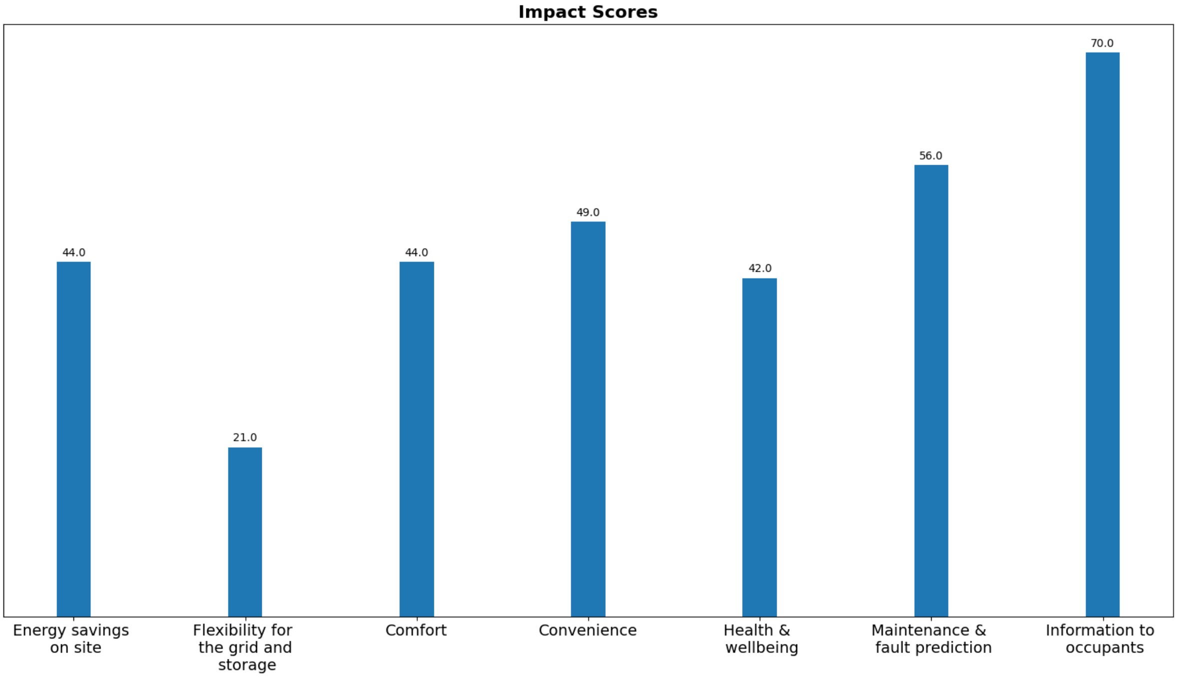


Figure 43: Smart House SRI impact scores

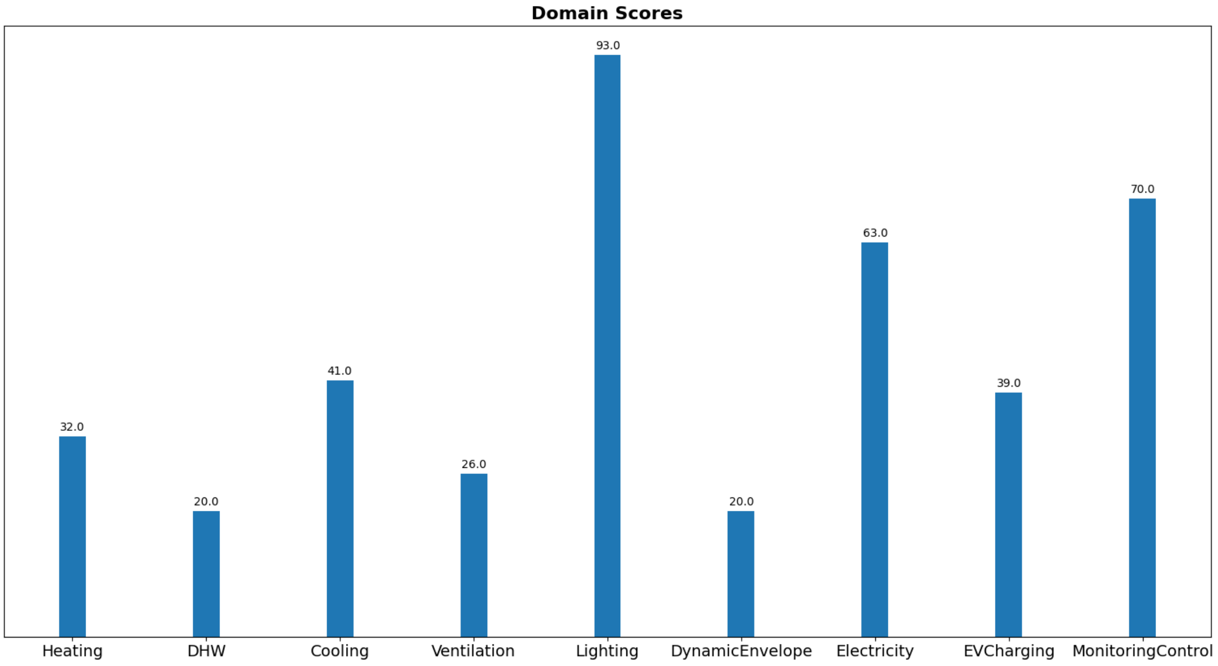


Figure 44: Smart House SRI domain scores

### 4.2.3.2 Human Comfort & Wellbeing Indicators calculation submodule

Towards validating the functionalities of this subcomponent, actual data collected from the on-site sensors of the Smart House were used. The period studied to extract the different metrics was September 2021. However, it should be mentioned that the tool is expected to perform the calculations over a wider timeframe, which corresponds to the issuance frequency of the operational rating (i.e. at least every six months).

Figure 45-Figure 48 show the variation of the hourly mean temperature, hourly mean humidity, hourly mean luminance and hourly mean CO2 concentration. It is important to highlight that any missing values are considered a result of sensors disconnection/communication problems, yet demonstrate a real-life scenario that is likely to take place in the actual pilot deployment. Such issues are not elaborated here and will be addressed by the Energy Performance Verification & Credibility tool.

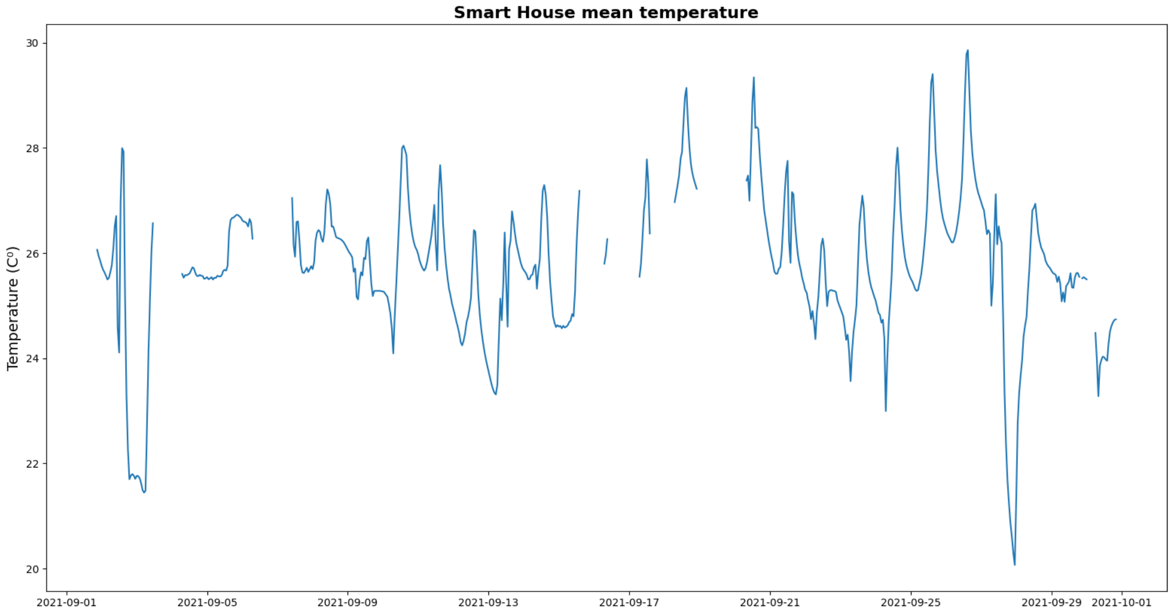


**Figure 45: Smart house mean temperature sample**

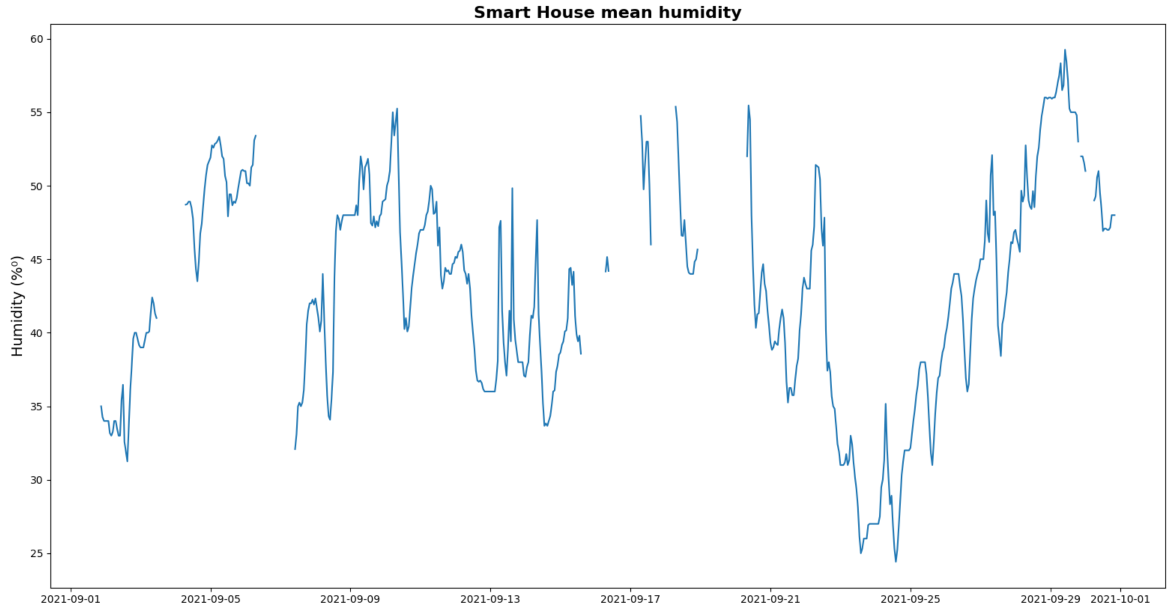


**Figure 46: Smart House mean humidity sample**

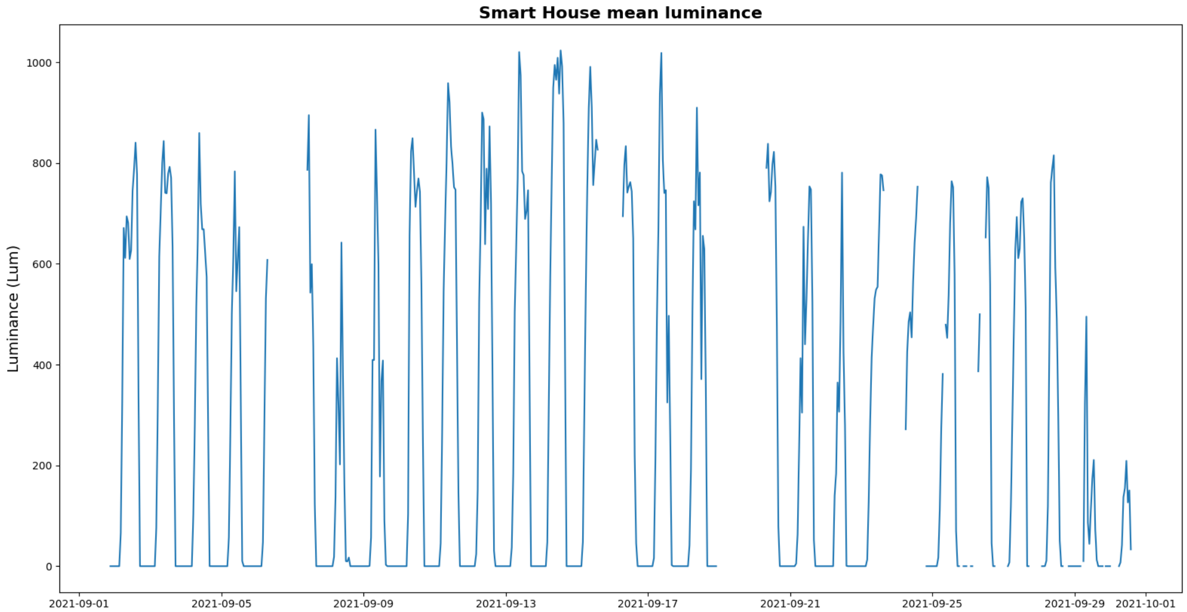


**Figure 47: Smart House mean luminance sample**

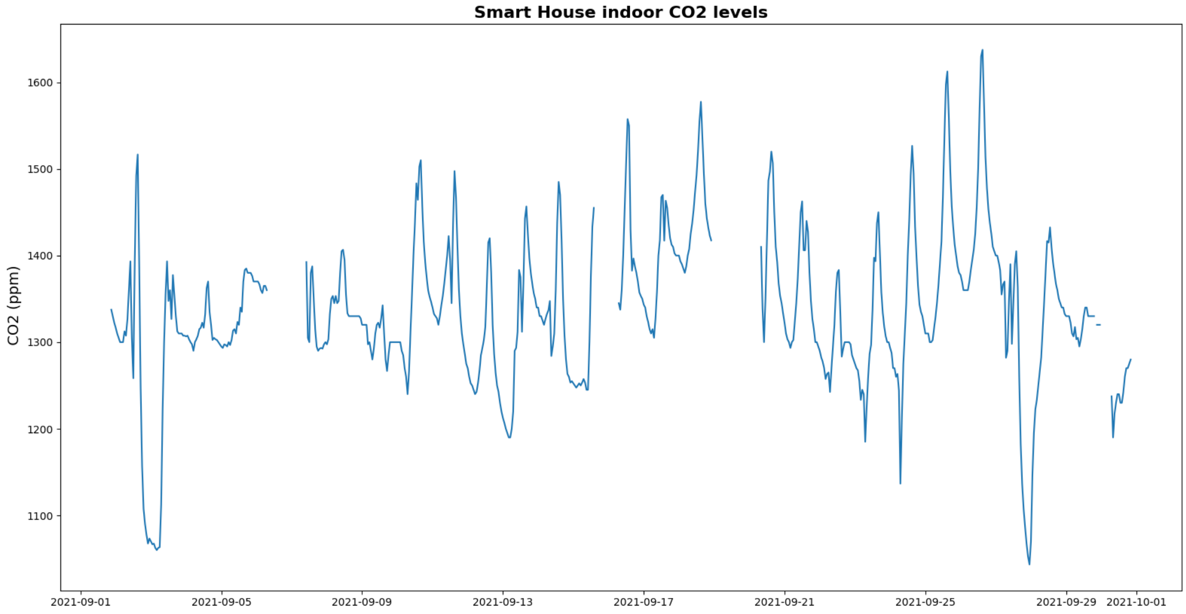


**Figure 48: Smart House indoor CO2 concentration sample**

Table 12 outlines the main assumptions/boundaries that were used in the calculations, while Table 13 displays the calculated indicators. Unit tests have been performed for each function and, in case of more complex calculations (e.g. humidex levels), the results have been validated against the output of corresponding online tools.

**Table 12: HC&W Indicators calculation assumptions**

| Indicators Group | Assumptions/boundaries | Value(s) | Comments |
|---|---|---|---|
| THERMAL COMFORT | Temperature comfort levels [upper, lower] (°C) | 27.7, 19.4 | Provided from ASHRAE 55:2017. Will also be provided by the Comfort Profiling Engine upon integration and availability of sufficient data. |
| | Humidity comfort levels [upper, lower] (%) | 60, 40 | Provided from Level(s) |
| | WGBT limit (°C) | 28 (moderate metabolic rate) | Provided from BS EN ISO 7243:2017 |
| VISUAL COMFORT | Luminance casual comfort limit (lux) | 100 | Provided from BS EN 12464-1:2021. Will also be provided by the |

| | | | |
|---|---|---|---|
| | | | Comfort Profiling Engine upon integration and availability of sufficient data. |
| | Building activity luminance level (lux) | 300 (Visual tasks moderately easy) | Provided from BS EN 12464-1:2021 |
| INDOOR AIR QUALITY | $CO_2$ outdoor level (ppm) | 400 | |

**Table 13: Calculated HC&W Indicators**

| Indicators Group | Indicator | Metric | Value |
|---|---|---|---|
| THERMAL COMFORT | Deviation from temperature range | Hours of range | 13 |
| | | Frequency of deviation (%) | 6.8 |
| | Deviation from humidity range | Hours out of range | 66 |
| | | Frequency of deviation (%) | 34.6 |
| | Deviation from WBGT | Hours out of range | 14 |
| | | Frequency of deviation (%) | 7.33 |
| | Thermal degree hours | | 19.7 |
| | Humidex levels | Level I [Hours per level, level proportion (%)] | 154, 80.1 |
| | | Level II [Hours per level, level proportion (%)] | 38, 19.9 |
| | | Level III [Hours per level, level proportion (%)] | 0, 0 |
| | | Level IV [Hours per level, level proportion (%)] | 0, 0 |
| VISUAL COMFORT | Deviation from luminance boundary | Hours out of range | 41 |
| | | Frequency of deviation (%) | 21.7 |
| | Deviation from luminance levels | Hours out of range | 41 |

| | | | |
|---|---|---|---|
| | | Frequency of deviation (%) | 21.7 |
| | Set visual degree days | | 1412.5 |
| | Standard visual degree days | | 1412.5 |
| INDOOR AIR QUALITY | CO2 indoors | Category I [Hours per category, category proportion (%)] | 0, 0 |
| | | Category II [Hours per category, category proportion (%)] | 6, 3.1 |
| | | Category III [Hours per category, category proportion (%)] | 184, 96.3 |
| | | Category IV [Hours per category, category proportion (%)] | 0 ,0 |

#### 4.2.3.3 LCA Indicators calculation submodule

As the collection of the necessary material EPDs is an ongoing process, the complete validation of the submodule is not documented in this version of the deliverable, considering only the main inputs. The output of the BIM Parser tool, concerning information relevant to the building materials of Case Study 1 is shown below. The tool extracts the type of materials used in different building elements as well as their volumetric quantity.

```
{
    "External_walls": {
        "Finishing Coating": 6.221748208752428,
        "FIBRAN GEO BP Etics": 34.843890821462736,
        "Lightweight Perlite Concrete": 20.33468922315777,
        "Concrete, Cast In Situ": 7.951800844786199
    },
    "Internal_walls": {
        "Finishing Coating": 0.3615032213360071,
        "FIBRAN gyps SUPER": 5.422548320040103,
        "FIBRAN GEO B-570": 9.136188285269473,
        "Glass, Clear Glazing": 1.8232856928262482
    },
    "Doors": {
        "Aluminum alloy-AIMgSi(EN AW 6060)": 0.0836754440301898,
        "Glass": 0.49651459772717477,
        "Door - Hardware": 0.933117462227615,
        "My aluminium exterior door": 0.752403070803605,
        "Aluminum alloy-AIMgS(EN AW 6060)": 0.82567830739397,
        "Aluminum": 0.8167231427234326,
        "Cherry": 0.8167231427234326
    },
    "Windows": {
        "Aluminum alloy-AIMgSi(EN AW 6060)": 0.2567637432660758,
        "Glass": 1.283818716330378
    },
    "Slabs": {
        "Ceramic tiles": 3.9718146237208836,
        "cement mortar": 36.5658062542453,
        "Reinforced Concrete 2%": 119.15443871162648,
        "Damp-proofing": 0.0,
        "FIBRAN xps seismic 400": 30.58831145037064,
        "Air": 299.8400527218592,
        "Ceiling Tile 600 x 600": 39.84075288402698,
        "unreinforced concrete (gross beton) (C12/15)": 5.746821964916353,
        "FIBRAN GEO B-570": 11.493643929832706,
        "Exterior Tread Stair": 0.4185636502688822
    },
    "Roofs": {
        "grc": 0,
        "concrete": 0,
        "gfrc": 0,
        "ceramic": 0
    },
    "Columns": {
        "220 x 240mm": 0.4687366670502785,
        "260 x 260mm": 1.070196054963605,
        "475 x 475mm": 4.598856956292815,
        "200 x 400mm": 1.8805534020467611,
        "column 200x700 mm": 0.9688442125739021,
        "column 300 x 1400 m": 1.752978056553332,
        "column 300 x 900": 0.8985600000001,
        "TRON219x6.3": 0.0345451046024008,
        "300 x 450mm": 1.781999999999998
    }
}
```


The collected EPDs are pre-processed and the extracted information for each material is stored in the format shown in Figure 49 below. Consequently, the tool collects the available data to perform the required calculations.

| | Parameter | | Unit | A1-A3 | A4 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|---|---|
| | **ENVIROMENTAL IMPACT** | | | | | | | | |
| | **Parameter** | | **Unit** | **A1-A3** | **A4** | **C2** | **C3** | **C4** | **D** |
| 1 | Global warming potential | GWP | [kg $CO_2$-Eq.] | | | | | | |
| 2 | Depletion potential of the stratospheric ozone layer | ODP | [kg CFC11-Eq.] | | | | | | |
| 3 | Acidification potential of land and water | AP | [kg $SO_2$-Eq.] | | | | | | |
| 4 | Eutrophication potential | EP | [kg $(PO_4)$3--Eq.] | | | | | | |
| 5 | Formation potential of tropospheric ozone photochemical oxidants | POCP | [kg ethene-Eq.] | | | | | | |
| 6 | Abiotic depletion potential for non-fossil resources | ADPE | [kg Sb-Eq.] | | | | | | |
| 7 | Abiotic depletion potential for fossil resources | ADPR | [MJ] | | | | | | |
| | **RESOURSE USE** | | | | | | | | |
| | **Parameter** | | **Unit** | **A1-A3** | **A4** | **C2** | **C3** | **C4** | **D** |
| 1 | Renewable primary energy as energy carrier | PERE | [MJ] | | | | | | |
| 2 | Renewable primary energy resources as material utilization | PERM | [MJ] | | | | | | |
| 3 | Total use of renewable primary energy resources | PERT | [MJ] | | | | | | |
| 4 | Non-renewable primary energy as energy carrier | PENRE | [MJ] | | | | | | |
| 5 | Non-renewable primary energy as material utilization | PERNRM | [MJ] | | | | | | |
| 6 | Total use of non-renewable primary energy resources | PENRT | [MJ] | | | | | | |
| 7 | Use of secondary material | SM | [kg] | | | | | | |
| 8 | Use of renewable secondary fuels | RSF | [MJ] | | | | | | |
| 9 | Use of non-renewable secondary fuels | NRSF | [MJ] | | | | | | |
| 10 | Use of net fresh water | FW | [$m^3$] | | | | | | |
| | **OUTPUT FLOWS AND WASTE CATEGORIES** | | | | | | | | |
| | **Parameter** | | **Unit** | **A1-A3** | **A4** | **C2** | **C3** | **C4** | **D** |
| 1 | Hazardous waste disposed | HWD | [kg] | | | | | | |
| 2 | Non-hazardous waste disposed | NHWD | [kg] | | | | | | |
| 3 | Radioactive waste disposed | RWD | [kg] | | | | | | |
| 4 | Components for re-use | CRU | [kg] | | | | | | |
| 5 | Materials for recycling | MFR | [kg] | | | | | | |
| 6 | Materials for energy recovery | MER | [kg] | | | | | | |
| 7 | Exported electrical energy | EEE | [MJ] | | | | | | |
| 8 | Exported thermal energy | EET | [MJ] | | | | | | |

**Figure 49: EPD collected information template per material**

#### 4.2.3.4 Financial Indicators calculation submodule

The validation of this subcomponent requires both actual historical data from Case Study 1 as well as the results from the Asset Rating Module calculations that were described in the previous sections. In order to calculate the as-operated energy costs, load consumption and PV production data from the year 2021 were collected from the existing IoT platform, as depicted in Figure 50 - Figure 52.

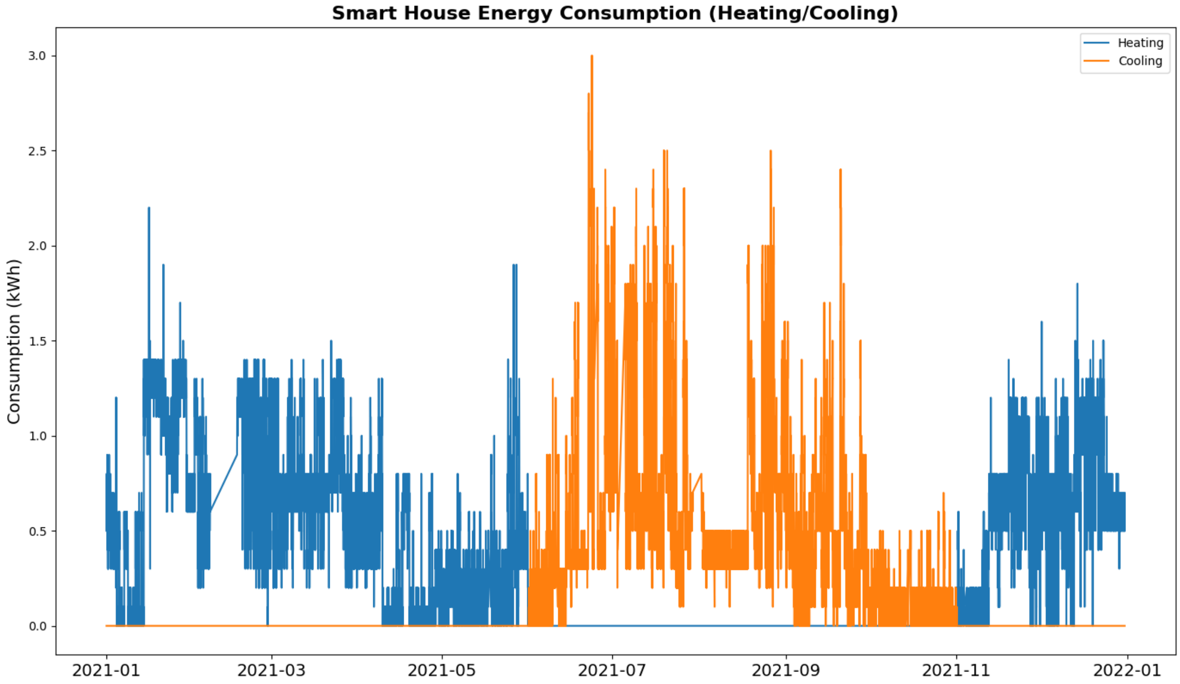


Figure 50: Smart House heating/cooling energy consumption of year 2021

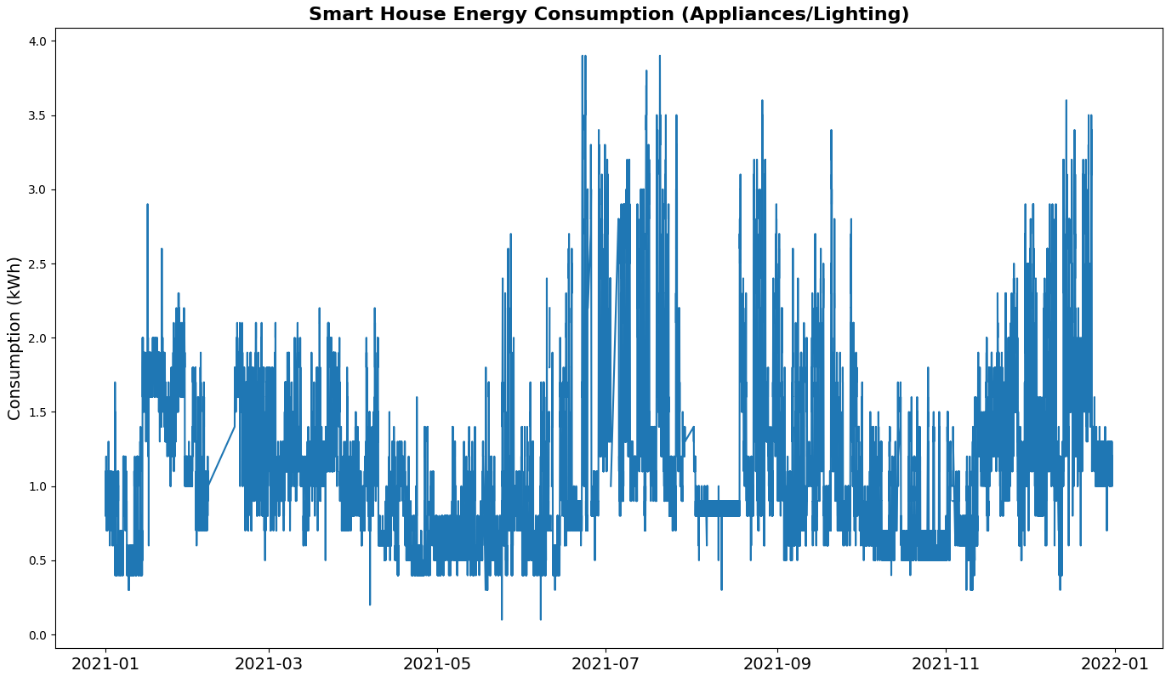


Figure 51: Smart House appliances/lighting energy consumption of year 2021

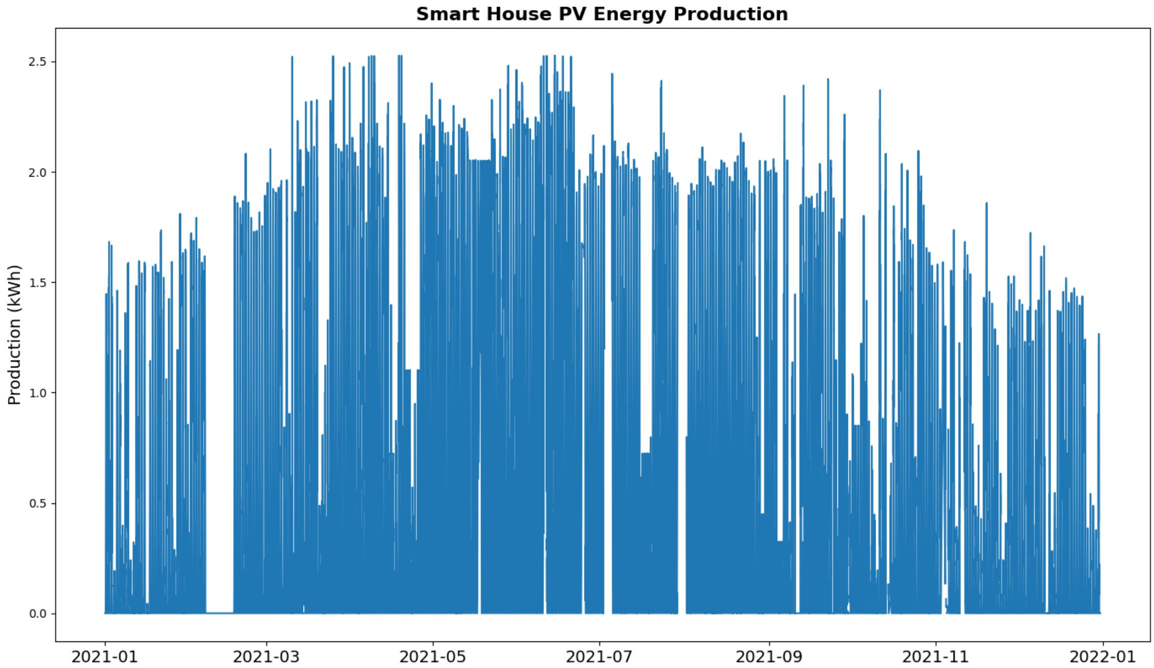


**Figure 52: Smart House PV energy production of year 2021**

Upon collection and pre-processing, the data were provided as input to the tool for the execution of the calculations. The following assumptions were considered:

- The simplified energy tariff used is equal to 0.1 €/kWh.
- A net-metering scheme applies to the PV energy generation (i.e., any excess energy production that is fed to the utility grid is then subtracted from the energy consumption on a monthly basis).
- The building area is equal to 317.7 $m^2$.

The graphical results representing the as-operated costs per energy use and energy carrier are shown in Figure 53 and Figure 54, respectively.

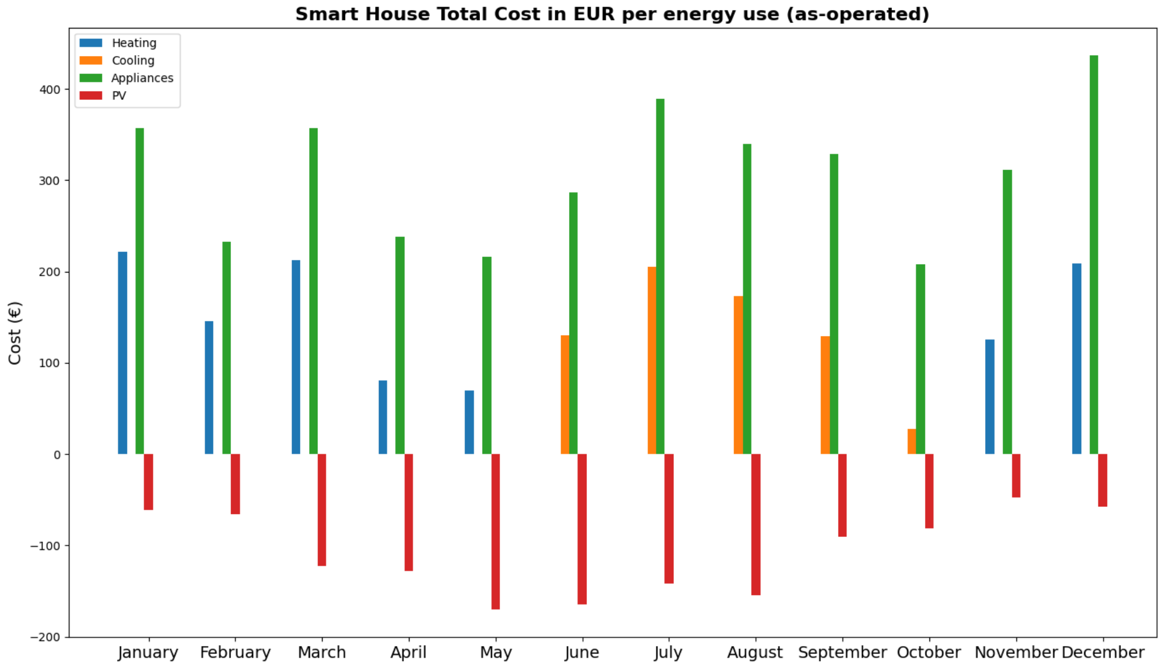


Figure 53: Smart House as-operated total cost per energy use

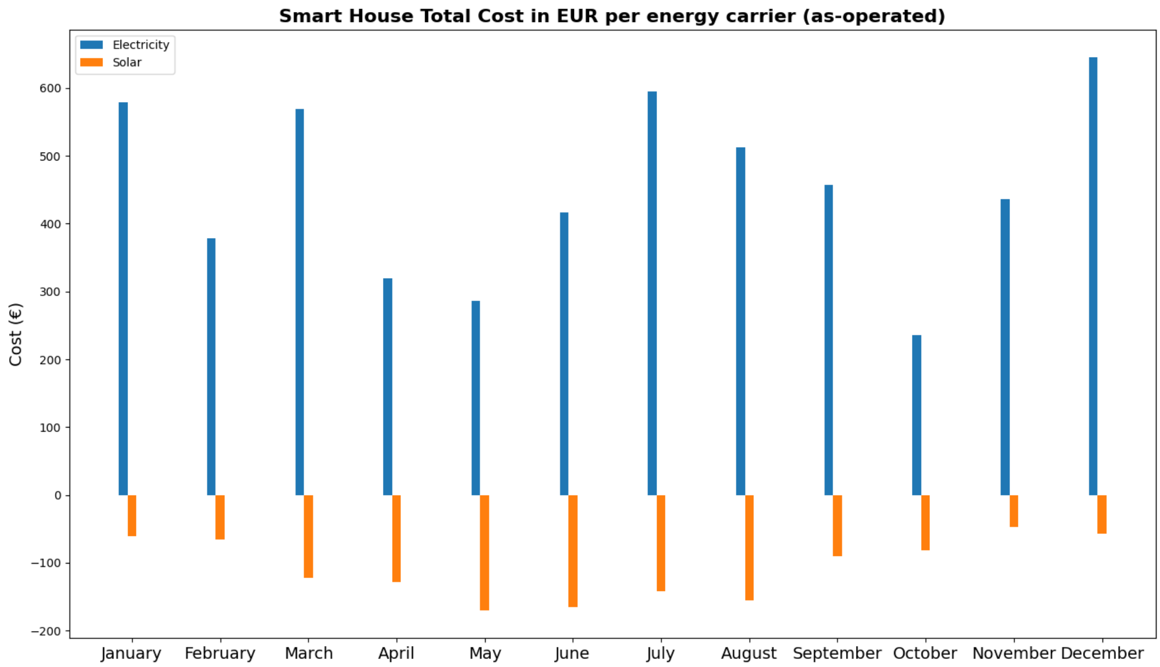


Figure 54: Smart House as-operated total cost per energy carrier

Following, the results from the Asset Rating module were retrieved (already grouped per month) and they were used to calculate the as-designed energy costs, which were compared against their as-operated counterparts, considering the same assumptions. Figure 55-Figure 59 depict the comparison between the monthly total costs (absolute/per m$^2$) and the yearly costs in each case. The as-operated costs are significantly higher than the as-designed costs, 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.

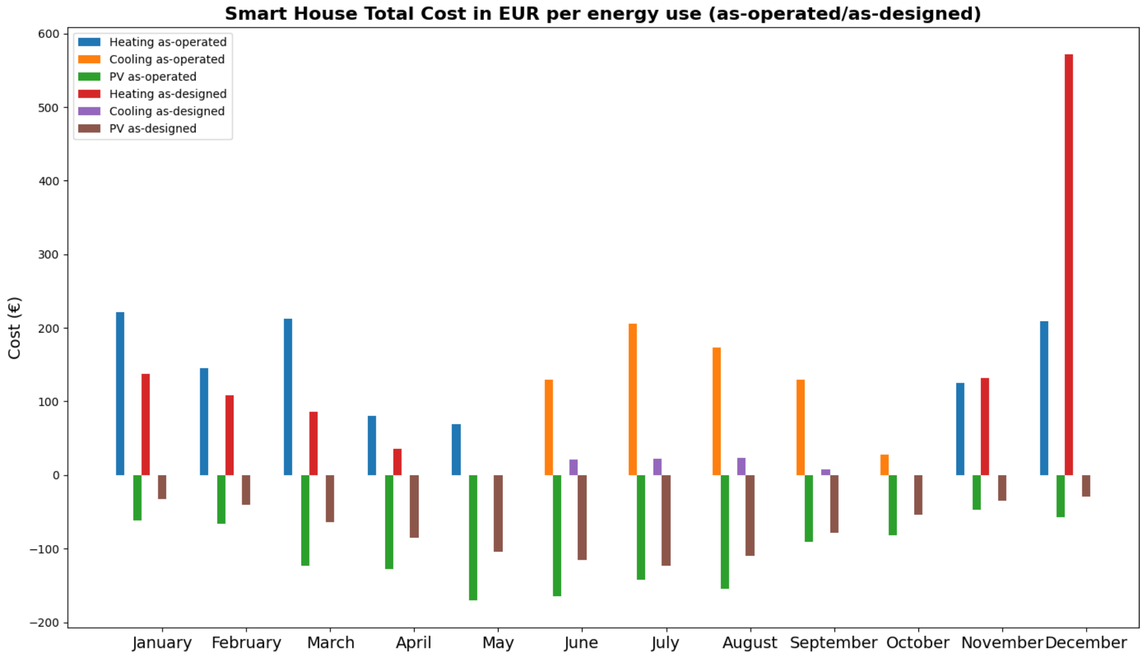


Figure 55: Smart House total cost per energy use comparison

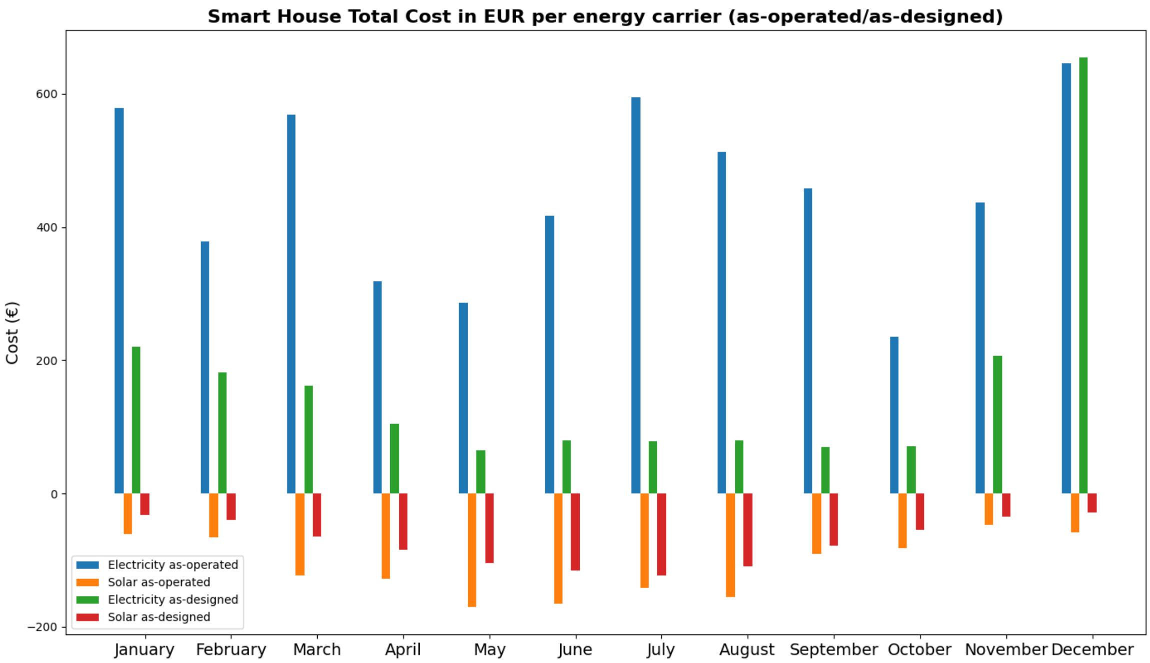


Figure 56: Smart House total cost per energy carrier comparison

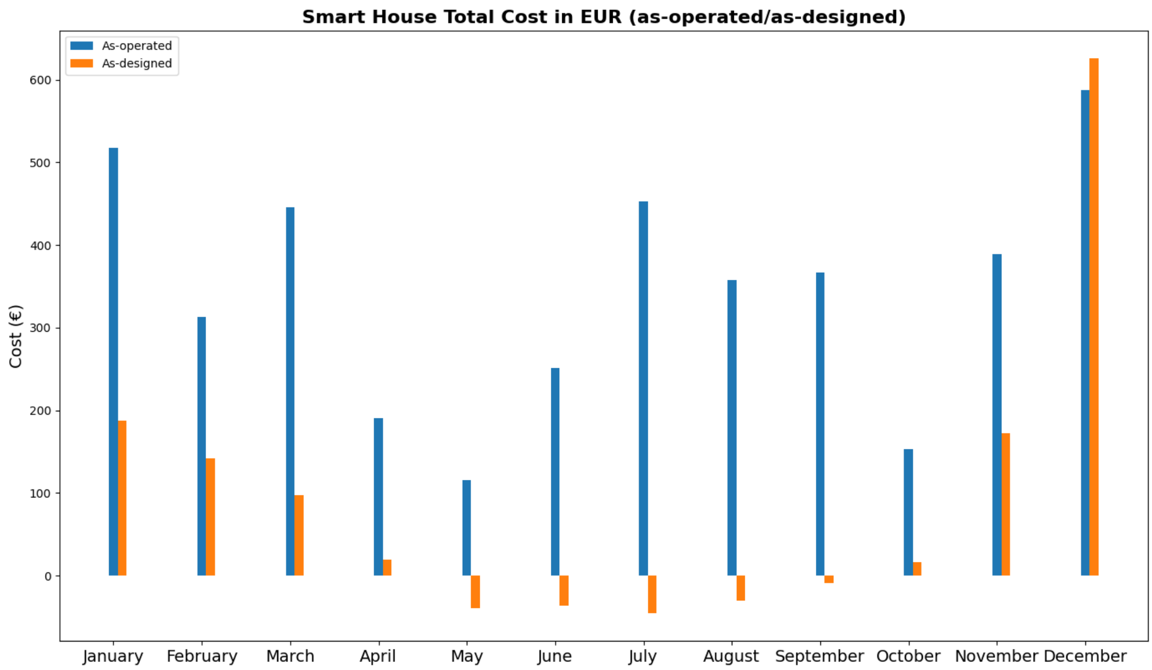


Figure 57: Smart House total monthly cost comparison

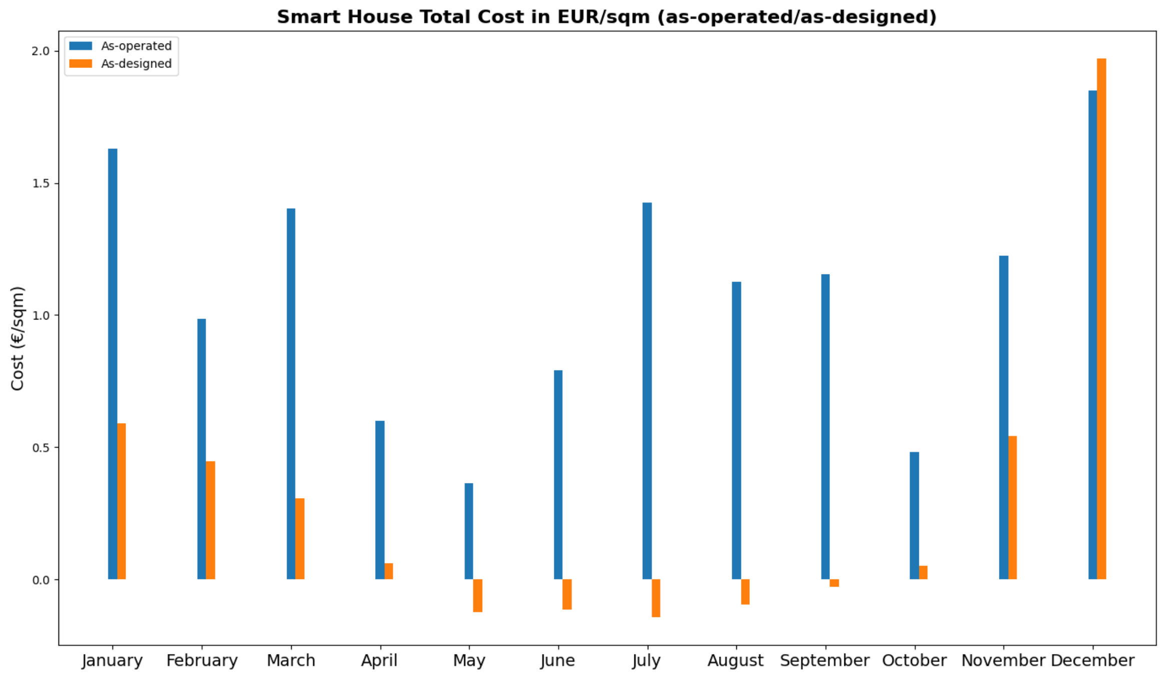


Figure 58: Smart House monthly total cost per sqm comparison

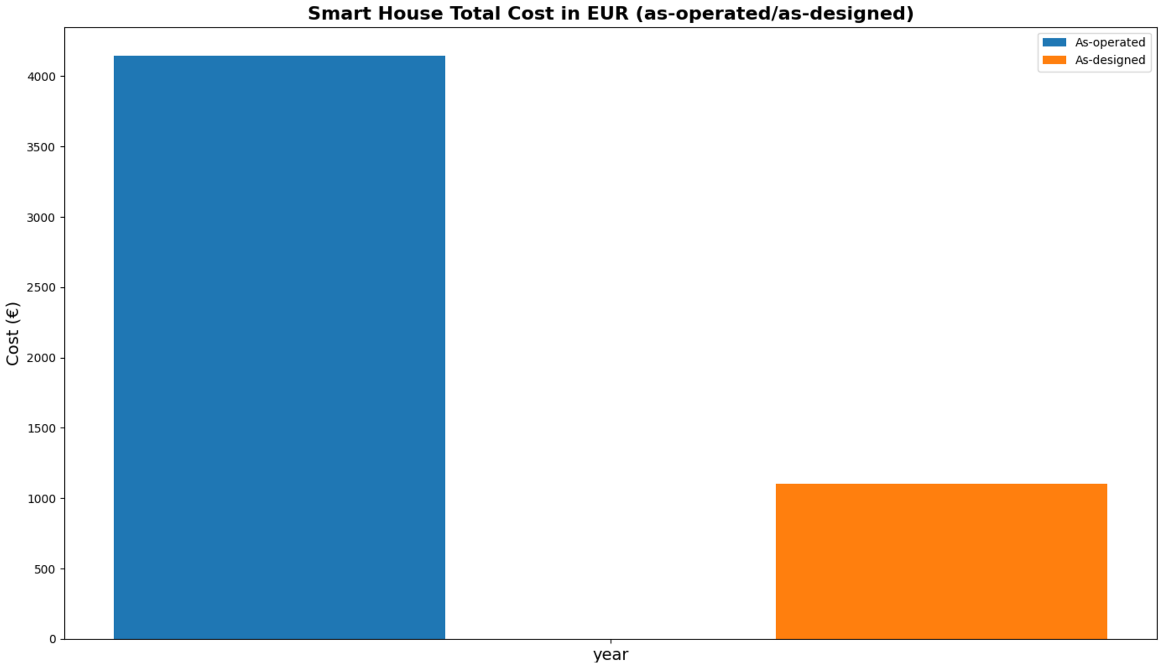


Figure 59: Smart House yearly cost comparison

Finally, the as-predicted costs are visualized in Figure 60. The real cost is equal to 4143€ (yearly as-operational cost), while the inflation and the discount rates were considered as 8% and 4%, respectively.

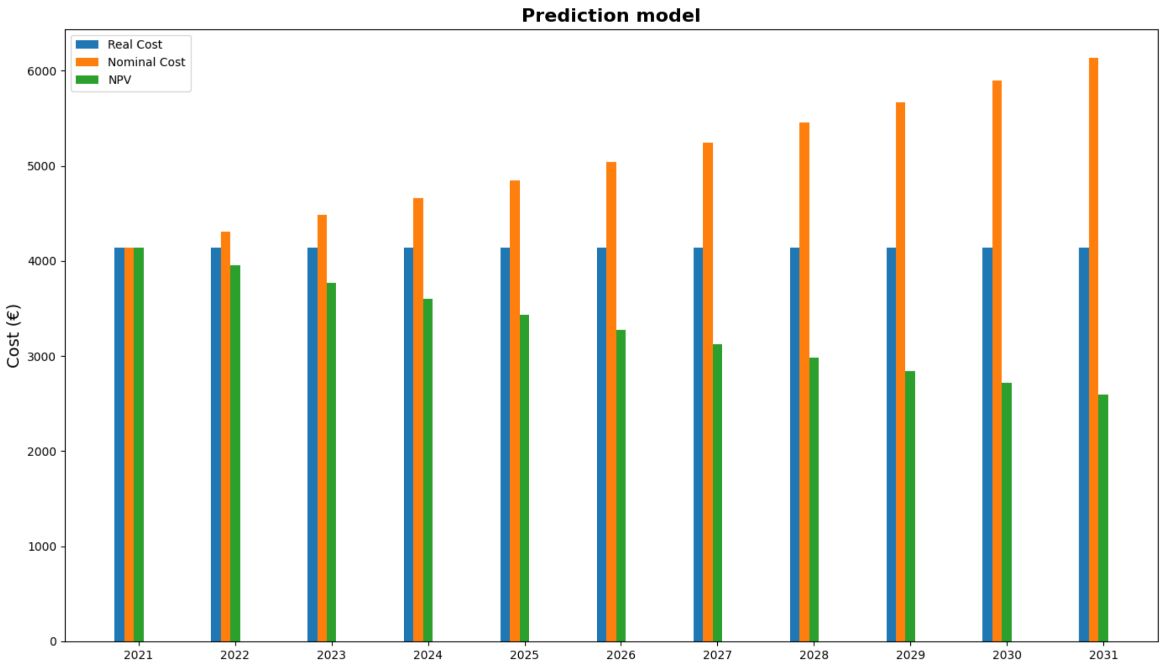


Figure 60: Smart House as-predicted costs

# 5 Conclusions

This report outlined the procedure followed for the development of D^2EPC's core engine and the application of its three principal submodules to specific pilot buildings. The successful completion of this task enabled the D^2EPC platform to perform the basic calculations required for a building's certification in accordance with the introduced holistic scheme. At the same time, the development of the tools hindered the limitations of the proposed functionalities, especially the limitations of BIM literacy for the calculation of the static indicators. Additionally, it indicated the requirements for future improvements and additions that need to be applied to the present module’s version. To this end, further actions are anticipated until the next version of this deliverable, to extend and finalize the functionalities of the developed calculation modules. The application on the remaining pilot buildings will indicate the possible paths for future enhancements and increase their adaptability to a variety of building types.

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# Annex: A Questionnaire: Input parameters for Asset Rating

The following form contains a description of the requested parameters that are used as inputs in the Asset Rating Calculation (ARC) Tool.

## Weather Data Input

| Weather Library | |
|---|---|
| **Location** | Longitude |
| | Latitude |
| **Temperature** | Average monthly temperature ($^{o}$C) of the ambient air |
| **Humidity** | Average monthly absolute humidity value (g/kg dry air) from the ambient air. |
| **Solar Radiation** | Average monthly value of total solar radiation, on the horizontal level (kWh/m$^2$) |
| | Average monthly value of total solar radiation (kWh/m$^2$), on the vertical surfaces with orientation N,NE,E,SE,S,SW,W,NW |
| | Average monthly value of total solar radiation (kWh/m$^2$), on the surfaces with inclination 45$^{o}$ and orientation N,NE,E,SE,S,SW,W,NW |
| **Ground Temperature** | Average monthly ground temperature values ($^{o}$C)<br>Otherwise, is it approximated with some mathematical formula? |
| **Water Temperature** | Average monthly water temperature values ($^{o}$C) (from the water distribution network. Otherwise, is it approximated with some mathematical formula? |
| **PV - kWh/kWp** | What is the expected annual energy production per installed kW of PV for each region. Only the average annual value for each region. |

Furthermore, it would be helpful to describe how the country, that you are providing information, is divided into regions or climatic zones in its current EPC scheme.

# Fuel Database

| Fuel Database | |
|---|---|
| $f_{Ptot}$ | The primary energy factors for the conversion from final delivered to primary energy, as defined at a national level. |
| $K_{CO2e}$ (g/kWh) | The $CO_2$ factors for the conversion from final energy to $CO_2$ emissions [kg $CO_2$/unit of fuel] |
| **Fuel Cost** | The current cost value of each fuel type. [€/kWh] |
| | |

**The data requested above should be delivered in the form of the following table, as it is defined from standard EN ISO 52000-1:2017**

| | **Energy carrier<br>Delivered from distant** | | $f_{Ptot}$ | $K_{CO2e}$ **(g/kWh)** | **Fuel cost , €/kWh** |
|---|---|---|---|---|---|
| 1 | Fossil fuels | Solid | | | |
| 2 | | Liquid | | | |
| 3 | | Gaseous | | | |
| 4 | Bio fuels | Solid | | | |
| 5 | | Liquid | | | |
| 6 | | Gaseous | | | |
| 7 | Electricity | | | | |
| | **Delivered from on - site** | | | | |
| 8 | Solar | PV electricity | | | |
| 9 | | Thermal | | | |
| 10 | Wind | | | | |
| 11 | Environment | Geo-, aero-, hydrothermal | | | |
| | **Exported** | | | | |
| 12 | Electricity | To the grid | | | |
| 13 | | To non EPB uses | | | |

# Reference Building

<table>
<tr><th colspan="2">Reference Building – Indicative Parameters</th></tr>
<tr><td>Basic Assumptions</td><td>What are the parameters that the reference building inherits from the actual building?<br>For example:<ul><li>size, shape, zoning arrangements, conventions relating to the measurement of dimensions</li><li>use/ activity of each space/thermal zone</li><li>Orientation</li><li>Technical systems per zone</li></ul></td></tr>
<tr><td>U-Values</td><td>For each type of building element are requested its reference U-Value. e.g. from Cyprus
<table>
<tr><th colspan="3">Table E1: U-values in the reference building</th></tr>
<tr><td>Exposed element U-value</td><td>U-value (W/m$^2$K) (residential)</td><td>U-value (W/m$^2$K) (non-residential)</td></tr>
<tr><td>Roofs[1] (irrespective of pitch)</td><td>0.6375</td><td>0.6375</td></tr>
<tr><td>External wall</td><td>0.7225</td><td>0.7225</td></tr>
<tr><td>Internal wall</td><td>Same as actual building</td><td>Same as actual building</td></tr>
<tr><td>Floor in contact with an enclosed adjacent space</td><td>Same as actual building</td><td>Same as actual building</td></tr>
<tr><td>Floor in contact with the external environment</td><td>0.6375</td><td>0.6375</td></tr>
<tr><td>Ground floors</td><td>1.6</td><td>1.6</td></tr>
<tr><td>Windows, roof windows, roof lights, and pedestrian doors</td><td>3.23</td><td>3.23</td></tr>
<tr><td>Vehicle access and similar large doors</td><td>Same as actual building</td><td>Same as actual building</td></tr>
<tr><td colspan="3">[1] Any part of a roof having a pitch greater or equal to 70° is considered as a wall</td></tr>
</table></td></tr>
<tr><td>Thermal Bridges</td><td>Is any assumption made for the calculation of thermal bridges?<br>Are there any reference values for linear thermal transmittance?</td></tr>
<tr><td>Thermal Capacity</td><td>Since we use the simplified table with construction types for the actual building, we will proceed with the same methodology for the reference building?<br>Values for thermal capacity of building elements</td></tr>
<tr><td>Rate of ventilation – Air Permeability</td><td>Is there any value for air exchange in the reference building [m$^3$/h/m$^2$] or [AC (air changes)/h]?<br>Does it differentiate according to the use of the thermal zone?</td></tr>
<tr><td>Glazing</td><td>Values for solar transmittance and daylight transmittance</td></tr>
<tr><td>Openings</td><td>restrictions for the area of openings, are they calculated as a percentage of the buildings total area?</td></tr>
<tr><td>Internal gains</td><td>Are there any specifications for internal heat gains (people, equipment) for each zone type of the reference building?</td></tr>
<tr><th colspan="2">Minimum requirements</th></tr>
<tr><td>Indoor conditions</td><td>Will the user has to define what the temperatures will be for winter and summer, as well as will they have to define which months are considered summer and winter?</td></tr>
</table>

| | |
|---|---|
| **Fuel Type** | The fuel type of each system of the reference building is predetermined or is the same as in the actual building? |
| **HVAC** | Are there any specifications for the installed capacity of HVAC in the reference building?<br>What are the reference values for the efficiency of each system in the reference building? (e.g., SCoP, SSEER) |
| **Lighting** | ▪ Installed power density specification / relevance with the activity<br>▪ Schedule / duration of lighting demand<br>▪ Can automation be involved in the calculation (in the case that the actual building has lighting automation) |
| **RES** | Is there any assumption about RES participation in the energy consumption of the reference building (e.g., In Greece it is assumed that 15% of the energy demand for DWH is covered from solar thermal collectors) |
| **Automation** | Can automation be involved in the calculation, in the case that the actual building automation systems installed |

## Typical Values Library

| **Library with Typical Values per Thermal Zone Use** | |
|---|---|
| **Schedule** | The typical operation schedule (timeschedule) of each thermal zone or building according to its use. For instance, in the Greek legislation, it is described by 3 values: hours per day, days per week and months per year. |
| **Indoor Temperature** | The typical values of required indoor temperature for each use of a building or thermal zone. There are usually two temperature values for winter and summer period respectively. |
| **Indoor Relative Humidity** | The typical values of required relative humidity for each use of a building or thermal zone. There are usually two RH values for winter and summer period respectively. |
| **Fresh Air** | The typical values of required fresh air for each use of a building or thermal zone. It is usually measured in [$m^3$/person/hour] or [$m^3$/hour/ $m^2$] |
| **DHW consumption** | The typical value for DHW consumption for each use of a building or thermal zone. It is usually measured in [lt/person/day] or [lt/ $m^2$ /day] |
| **Heat emissions from users** | For the calculation of internal heat gains it is used a typical value of heat emitted from occupants according to the use of the thermal zone. It is usually measured in [W/person] or [W/$m^2$] |
| **Thermal power from electric appliances/ equipment** | For the calculation of internal heat gains it is used a typical value of emitted heat from appliances according to the use of the thermal zone. |
| **Operational hours with natural lighting** | For the calculation of energy consumption from lighting it is used the maximum operational hours when there is available daylight. The number refers to the number of operational hours with daylight in a year. |
| **Operational hours without natural lighting** | For the calculation of energy consumption from lighting it is used the maximum operational hours during the night when |

| | |
|---|---|
| | there is not available daylight. The number refers to the number of operational hours without daylight in a year. |

## Constant Values Library

| Library with constant values | |
|---|---|
| | Correction factor of solar radiation from the sky. It is used in the solar gains calculation from the envelope's opaque elements. |
| | Numerical reference coefficient and standard value of reference time for heating & cooling. They are used for the calculation of use coefficient for heating cooling loads. |