D^2EPC Manual v1

The D^2EPC project has received funding from the EU's Horizon 2020
research and innovation programme under grant agreement No 892984

Project Acronym:	D^2EPC
Project Full Title:	Next-generation Dynamic Digital EPCs for Enhanced Quality and User Awareness
Grant Agreement:	892984
Project Duration:	36 months (01/09/2020 – 31/08/2023)

DELIVERABLE D5.1 D^2EPC Manual v1

Work Package:	WP5 - Demonstration and Impact Assessment
Task:	T5.1- D^2EPC guidance for auditing and implementation
Document Status:	Final
File Name:	D^2EPC_D5.1_D^2EPC Manual v1_SGS
Due Date:	28.02.2022
Submission Date:	02.03.2022
Lead Beneficiary:	SGS

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

Authors List

Leading Author				
First Name		Last Name	Beneficiary	Contact e-mail
Adrián		Cano Cabañero	SGS	adrian.canocabanero@sgs.com
Stavros		Koltsios	CERTH	skoltsios@iti.gr
Co-Author(s)				
#	First Name	Last Name	Beneficiary	Contact e-mail
1	Óscar	Molins Teruel	SGS	oscar.molinsteruel@sgs.com
2	Antonio	Dominguez Mas	SGS	antonio.dominguezmas@sgs.com
3	Panagiota	Chatzipanagiotidou	CERTH	phatzip@iti.gr
4	Nikolaos	Katsaros	CERTH	nkatsaros@iti.gr
5	Paris	Fokaides	FRC	eng.fp@frederick.ac.cy
6	Phoebe-Zoe	Morsink-Georgali	FRC	res.gp@frederick.ac.cy
7	Ioannis	Maroufidis	GSH	i.maroufidis@geosystems-hellas.gr
8	Thanos	Kalamaris	HYP	t.kalamaris@hypertech.gr
9	Christiana	Panteli	CLEO	c.panteli@cleopa.de
10	Mija	Sušnik	DMO	mija@demobv.nl

Reviewers List

Reviewers			
First Name	Last Name	Beneficiary	Contact e-mail
Vasilis	Soulios	IsZEB	v.soulios@iszeb.gr
Karl	Grün	ASI	k.gruen@austrian-standards.at

Version History

v	Author	Date	Brief Description
0.1	Andrian Cano	25.10.2021	Initial draft (ToC)
0.3	Andrian Cano, Stavros Koltsios, Paris Fokaides	15.12.2021	Draft version with initial content for asset and operational rating
0.4	Andrian Cano	26.01.2022	Draft version with initial content for all sections
0.6	Andrian Cano	04.02.2022	Updates from all authors for relevant sections
0.8	Andrian Cano	22.02.2022	Final draft for internal review
1.0	Andrian Cano	28.02.2022	Final version ready for submission

Legal Disclaimer

The D^2EPC project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 892984. The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Climate, Infrastructure and Environment Executive Agency (CINEA) or the European Commission (EC). CINEA or the EC are not responsible for any use that may be made of the information contained therein.

Copyright

Executive Summary

This report presents the results of ***Task 5.1 D^2EPC guidance for auditing and implementation*** activities, aiming to provide guidance for the implementation of the D^2EPC methodology. The overall goal of this report is to provide an overview of the different aspects of the D^2EPC scheme and introduce the different steps for the implementation of the D^2EPC principles.

Starting with EPC calculation methodologies, an overview of the asset energy performance rating methodology has been presented based on the ISO 52000 series of standards while it has adopted several features from national asset rating calculation framework. The input parameters for the calculation have been described in detail documenting the

- Assessed object general information (Object type; Building/ space category; Climatic data);
- Thermal zones division: the spaces in a building or building unit should be grouped into thermal zones (according to their thermal characteristics), in order to proceed with the asset rating
- Analytical descriptions of the elements that comprise the building's envelope: Depending on their visual transparency, the building elements are divided into two main categories, the "opaque and transparent" building elements. A second distinction is done according to the placement of the element on the building topology (e.g., internal, external in contact with the ambient air or external in contact with the ground etc.)
- Installed technical systems: the different categories include technical systems for heating, cooling, domestic hot water, lighting, solar thermal collectors, photovoltaics and automation and control.

Following the asset rating, the methodology for the operational energy performance rating of buildings has been described. A key value for the EPCs' classification and issuance is the thermal energy per unit of conditioned building area (kWh/ (m^2a)). Apart from this value, the following values can also be given: (a) annual energy per unit of conditioned building area (kWh/(m^2a)), (b) annual electricity supply per unit of conditioned building area (kWh/(m^2a)), (c) annual primary energy for the operation of the building per unit of conditioned building area (kWh/(m^2a)), and (d) annual CO_2 emissions due to the operation of the building per unit of conditioned area of the building (kg /(m^2a)). An example of the Frederick University pilot building has been also included. In particular, the methodology proposed provides a well-defined process presenting:

- The indicators of the D^2EPC operational scheme (e.g., heating, cooling, lighting, appliances, domestic hot water, total),
- The reference values, based on which the rating will be calculated. The actual, degree-day-adjusted heat consumption and the annual real electricity consumption are used as the basis for the classification of each building on the energy label scale, instead of a reference value, which depends on building type with different demand of energy performance.
- Issuance frequency. Once issued, the operational energy dEPC is valid and should be renewed every six months according to weather normalization procedures. This allows an improved energy performance of buildings to be achieved.
- Normalization practices for operational values. The operational rating dEPC has a degree-day indicator for heating/cooling energy consumption.
- Methods of measurement of actual consumption and details (e.g. instruments, responsibilities, etc.).

The additional set of indicators to be included in the next generation EPCs, namely SRI, energy and LCA, human comfort and economic indicators have been introduced and documented. The extraction of those indicators through a BIM file has been discussed. In particular:

- The development of D^2EPC SRI assessment is based on ''Method B'' of the final SRI technical study conducted by a consortium consisting of VITO NV and Waide Strategic Efficiency and concluded in June 2020.
- The Human Comfort and Wellbeing indicators step on three pillars of indoor environmental quality i.e. the thermal comfort, the visual comfort and the indoor air quality.
- The development of the D2EPC environmental indicators is based on the Level(s) scheme, the EU sustainability assessment for constructions outline. The operational rating scheme is used for the calculation of the energy indicators and a complete list of 25 data results, from 4 categories, is presented.
- The set of financial indicators was developed based on the literature review of well-established standards and schemes, aiming to translate the individual elements of buildings' energy performance into monetary normalized values.

Finally, the major D^2EPC components that are utilised for the implementation of the D^2EPC framework have described. In particular, the D^2EPC BIM-based Digital Twin enables the unification of various forms of user-provided data with dynamic information while the WebGIS tool enables various analysis and visualisation options of the available data. The unified D^2EPC Web platform will host the presentation of all the results from the various components and sub-components, such as the EPCs, the KPIs, and the additional services. Through the web platform, the user will be able not only to adjust and configure certain components but also to request directly the execution of certain processes ad-hoc.

The technical features of the D2EPC framework will become clearer and more explicit as the project progresses and the technical activities proceed. As a result, the next version of this report is expected to have more detailed information, with certain elements being re-evaluated and refined.

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

Term	Description
ARM	Asset Rating Module
AR	Asset Rating
BAS	Building Automation System
BEPS	Building Energy Performance Simulation
BIM	Building Information Model
BIS	Building Information System
BMS	Building Management System
CEN	European Committee for Standardization
CHP	Combined Heat and Power
COP	Coefficient of Performance
D.	Deliverable
dEPC	dynamic Energy Performance Certificate
DHW	Domestic Hot Water
DSM	Demand Side Management
EBC	Energy in Buildings and Communities
EER	Energy Efficiency Ratio
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
EUR	Euro
EV	Electric Vehicle
GIS	Geographic Information System
HVAC	Heating, Ventilation and Air Conditioning
I.A.Q.	Indoor Air Quality
ICT	Information and communication technology
IDA-ICE	IDA Indoor Climate and Energy simulation tool

IEA	**International Energy Agency**
I.E.Q.	**Indoor Environmental Quality**
IFC	**Industry Foundation Classes**
IFC4	**The version of IFC that is an ISO standard, ISO 16739:2013**
ISO	**International Organization for Standardization**
LCA	**Life Cycle Assessment**
LCC	**Life Cycle Cost**
M/480	**Mandate M/480, standardization requests issued as the recast of the EPBD**
MS	**Member State**
NUTS	**Nomenclature of territorial units for statistics**
OGC	**Open Geospatial Consortium**
RES	**Renewable Energy Sources**
RH	**Relative Humidity**
SCOP	**Seasonal Coefficient of Performance**
SEER	**Seasonal Energy Efficiency Ratio**
SRI	**Smart Readiness Indicators**
T.	**Task**
TABS	**Thermal Activated Building Systems**
WP.	**Work Package**

1 Introduction

1.1 Scope and objectives of the deliverable

This deliverable is part of ***Task 5.1 D^2EPC guidance for auditing and implementation*** activities, aiming to provide guidance for the implementation of the D^2EPC methodology.

This report is mainly addressed to EPC assessors who wish to utilise the D^2EPC Web platform and benefit of its services. The aim of this document is to provide to the EPC assessor an overview of the different aspects of the D^2EPC scheme and familiarize them with the different steps that need to be followed.

In particular, this document provides a thorough analysis of the asset rating methodology, starting with the used terms and defining the assessed object, the different thermal zones, the building envelope and the various building technical systems. The same way, the operational rating methodology is introduced according to the ISO 52000 series and the operational rating parameters and information extraction are presented, including an example of the Frederick University pilot building. The additional indicators related to the smartness of the buildings (SRI), its environmental (LCA) and financial (LCC) performance, as well as to human comfort aspects are explained and introduced.

This report also presents the D^2EPC tools that incorporate the methodological steps for the calculation of the EPC rating and the indicators and describes the proposed WebGIS and additional services that are provided by the D^2EPC Web platform.

This report is expected to act as the technical manual that describes the different aspects of the project's framework and includes the theoretical background, the methodology and the calculation steps of the D^2EPC scheme.

1.2 Structure of the deliverable

The structure of this deliverable is divided in different chapters to cover all the aspects of the D^2EPC scheme:

- **Chapter 2** gives an overview of the asset rating methodology, providing general information on the assessed object, on the thermal zones that the spaces in a building can be grouped into thermal zones, the categories of the various building elements and the technical systems;
- **Chapter 3** introduces the operational rating methodology and describes the energy performance calculations based on the actual energy consumption of the building. A key value for the EPCs' classification and issuance is the thermal energy per unit of conditioned building area (kWh/ (m^2a)).
- **Chapter 4** presents the different types of the additional indicators that address smart readiness, thermal comfort and LCA dimensions, and financial KPIs.
- **Chapter 5** introduces the concept of BIM and Digital Twin serving as a core component of the D^2EPC Web platform.
- **Chapter 6** describes the D^2EPC WebGIS tool and its functionalities.
- **Chapter 7** introduces the D^2EPC Web Platform and the additional services deriving from the added value services suite (roadmapping tool for performance upgrade, AI-driven performance forecasts, performance notifications and alerts) and the Extended dEPCs applications toolkit.
- **Chapter 8** sums up the main conclusions and findings of this deliverable, and the next steps for the subsequent deliverables.

1.3 Relation to Other Tasks and Deliverables

This task elaborates all aspects and parameters of the D^2EPC scheme and provides guidance for the implementation of D^2EPC principles in building's specification, focusing on EPC assessors and engineers. This report will contain the whole methodology, theoretical background and calculation steps of the project, and as such, it is strongly related to the findings of WP2, WP3 and WP4. Additionally, this report can facilitate the deployment of the D^2EPC pilots and provide guidance to the relevant stakeholders of T5.3 while it can act as a reference document for the dissemination and exploitation of project results (WP7).

2 Asset Rating

2.1 Scope and Objectives

The Asset Rating Module (ARCM) is a dedicated tool for the calculation of the asset energy performance rating of the building under investigation. The information for the energy model of the building can be derived from the building's BIM file as well as through on-site inspection. Even if the use of BIM technology turns the building modeling process into an expeditious and straight forward procedure, the auditors' role remains critical throughout the Asset Rating process. Their main responsibility is to verify the compliance of the virtual model with the actual asset. Furthermore, they have to ensure that the building description follows the D^2EPC Manual's guidelines, as presented in this document. Lastly, it is important to note that the module's development is based on a European approach, applicable in each MS; its main core is the ISO 52000 series of standards [1] while it has adopted several features from national AR calculation frameworks.

2.2 Terms and Definitions

air conditioning: type of air treatment including controlling of the maximum or minimum temperature, probably coupled with ventilation, humidity and air cleanliness control.

air conditioning system: combination of all components required to provide air treatment in which supply air temperature is controlled, possibly in combination with the control of ventilation rate and humidity and air filtration.

assessed object: part of a building or portfolio of buildings that is the subject of an energy performance assessment (e.g., designed building, new building after construction, old building in use phase).

auxiliary energy: electrical energy used by technical building systems to support energy transformation to satisfy energy needs (e.g., energy for fans and pumps).

building: construction as a whole, encompassing the fabric and all technical systems, where energy can be utilised to control the indoor conditions, provide domestic hot water, light, and other services connected to the building's use.

building automation and control: products, software, and engineering services for automatic controls, monitoring and optimization, human intervention, and management of building services equipment to achieve energy-efficient, cost-effective, and safe operation.

building category/ unit category: The classification of a building and/or building units related to their main use or their special status, for the purpose of enabling differentiation of the energy performance assessment procedures and/or energy performance requirements.

building element: Integral component of the technical building systems or of the fabric of a building.

building fabric: all physical elements of a building, excluding technical building systems (e.g., roofs, walls, floors, doors). It includes elements both inside and outside of the thermal envelope, including the thermal envelope itself.

building portfolio: a collection of buildings and common technical equipment whose energy performance is influenced by their interactions.

building unit: section, floor or apartment within a building that has been designed or modified to be used independently from the rest of the building.

conditioned space: room or enclosure that is covered by one or more EPB services.

condition of use: requirement and/or restriction for the use of a building space category, related to the services for the energy performance assessment and/or the boundary conditions (e.g., the numbers are based on the number of occupants per m^2 per type of building space).

designed energy performance: energy performance with design data for the building and standard use and climate data set.

electricity grid: public electricity network.

energy carrier: substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.

energy performance: amount of energy (calculated or measured) needed to meet the energy demand of the assessed object associated with a typical use, which include energy used for specific services.

energy performance certificate: An assessed object's certificate, for instance recognized by a country or by a legal person designated by it, which highlights the energy performance of the assessed object, calculated or measured according to one or more particular methodologies.

energy rating/EPB rating: evaluation of the value of an energy performance indicator by comparison against one or more reference values, possibly including a visualization of the position on a continuous or discrete scale.

energy source: source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

external temperature: temperature of ambient air.

lighting: process of providing illumination.

ventilation: process of supplying or removing air by natural of mechanical means to or from a space or building.

heat balance ratio: monthly heat gains divided by the monthly heat transfer.

solar heat gain: heat provided by solar radiation entering, directly or indirectly (after absorption in building elements), into the building through windows, opaque walls and roofs, or passive solar devices such as sunspaces, transparent insulation and solar walls.

solar irradiation: incident solar heat per area over a given period.

space: room, part of a room or group of adjacent rooms that belongs to one thermal zone.

space category: classification of building spaces related to a specific set of use conditions.

thermal zone: internal environment with assumed sufficiently uniform thermal conditions to enable a thermal balance calculation.

thermal envelope area: total area of all elements of a building that enclose thermally conditioned spaces, except the area to adjacent buildings, through which thermal energy is transferred, directly or indirectly, to or from the external environment.

thermally conditioned space: heated or cooled space.

thermally unconditioned space: room or enclosure that is not part of a thermally conditioned space.

technical building sub-system: part of a technical building system that performs a specific function (e.g., heat generation, heat distribution, heat emission).

technical building system: technical equipment for heating, cooling, ventilation, humidification, dehumidification, domestic hot water, lighting, building automation and control and electricity production.

useful floor area: area of the floor of a building needed as a parameter to quantify specific conditions of use that are expressed per unit of floor area for EPB assessment and for the application of the simplification and the zoning and allocation rules.

2.3 Methodology

This section provides all the necessary information and guidelines to familiarize the energy assessor with the D^2EPC ARCM and allow the design of the building model according to the module's requirements. The building's documentation can be divided into four (4) main categories. The first category is an information set enclosing the general description of the building, while the second depicts its division into thermal zones according to the operational characteristics of each space. The last two categories include the analytical descriptions of the elements that comprise the building's envelope and the installed technical systems, respectively. All the information at the four categories can be derived either from its BIM model, or the auditor can insert them manually through the D^2EPC Web Platform. The resulted set of the building's data is stored in the D^2EPC Repository before proceeding with the energy performance calculation.

2.3.1 Assessed Object General Information

2.3.1.1 Object Type

The assessed object can be a building, part of a building, or portfolio of buildings. The various buildings on a single location can be detached, connected, or even located widely apart. Table 1 lists the various types of objects according to their type, lifecycle stage, use and ownership.

Table 1: Building General Information

Object type	Categories				
Type	Whole building		Building Unit	Part of a building (lacking one or more features of building unit)	
Lifecycle Stage	New Building Design	Existing building as built (without long term use data)	Existing building after renovation (without long term use data)	Existing building extension (without long term use data)	Existing building in use
Use	Residential		Non-Residential		
Ownership	Private Building		Public Building		

2.3.1.2 Building/ Space Category

The assessed object is categorized according to its main use under one of the following types presented in Table 2.

Building Categories [1]	
Residential Buildings	
1	Single family
2	Apartment blocks

[1] The category of the building may influence the choices of the overarching document and in the other EPB standards. This property is therefore inherited by the other EPB standards where relevant.

3	For elderly and disabled
4	For collective use
5	Mobile home
6	Holiday home
Non-Residential Buildings	
6	Offices
7	Hospital
8	Hotel & Restaurants
9	Sport Facilities
10	Wholesale and Retail trade services buildings
11	Data centre
12	Industrial
13	Workshops

Table 2: Building Categories

It is a common phenomenon in building constructions to host several spaces with different uses. For this reason, the D^2EPC platform gives the opportunity to further categorize a building according to the use of its spaces. Firstly, the auditor (or the BIM file) specifies whether or not the building is divided into space categories and if so, the use category of each space is specified according to Table 3. Otherwise, the building's spaces have the same category with the building as a whole.

Space categories [2]	
1	Residential living space, kitchen, bed room, study, bath room or toilet
2	Residential Individual: hall, corridor, staircase inside thermal envelope, attic inside thermal envelope
3	Residential collective or nonresidential: hall, corridor, staircase inside thermal envelope
4	Thermally unconditioned adjacent space. such as storage room or unconditioned attic
5	Thermally unconditioned sunspace or atrium
6	Entrance hall/foyer Corridor
7	Hall, corridor outside thermal envelope
8	Office space
9	Educational space
10	Hospital bed room
11	Hospital other room
12	Hotels room
13	Restaurant space
14	Restaurant kitchen
15	Meeting or seminar space
16	Auditorium, lecture room
17	Theatre or cinema space
18	Server or computer room
19	Sport facilities, thermally conditioned
20	Sport facilities, thermally unconditioned

[2] Each space category requires a set of conditions (temperature settings, ventilation and lighting requirements, DHW needs, etc.). The category of the space may influence the choices of the overarching document and in the other EPB standards. This property is therefore inherited by the other EPB standards where relevant.

21	Wholesale and retail trade services space (shop)
22	Nonresidential bath room, shower, toilet, if inside thermal envelope
23	Spa area with sauna shower and/or relaxing area
24	Space with indoor swimming pool
25	Heated storage space
26	Cooled storage space
27	Non conditioned storage space
28	Engine room
29	Individual garage or collective indoor car park
30	Barn

Table 3: Space categories

2.3.1.3 Climatic data

The building's regional set of climatic data is a critical input parameter for the ARM. The construction's location defines the climatic zone, and the latter is used to assign the values of temperature, solar radiation etc. for the asset rating (AR) calculation process. The D^2EPC ARM incorporates a database with the monthly average values of climatic data for each climatic zone.

2.3.2 Thermal Zones

The spaces in a building or building unit should be grouped into thermal zones (according to their thermal characteristics), in order to proceed with the Asset Rating procedure. There are three main criteria that indicate the grouping procedure, which are related to the conditions of use over the spaces, their topology and technical systems. However, the assessed object should be considered as a single thermal zone, whenever it is possible. The building's division into thermal zones can derive from the BIM file, while at the same time the auditor has also the option to define them or make adjustments in the D^2EPC Web Platform environment.

A **thermal zone** is defined as a group of spaces that have similar operational characteristics, which are used for the calculation of their thermal balance. The latter is performed separately for each thermal zone and not directly for the whole assessed object. It is important to point out that the unheated (or unconditioned) spaces are also included in the thermal zoning procedure. The zoning process concludes to a number of thermal zones with a total area equal to the whole area of the examined building.

2.3.2.1 Thermal Zoning Guide

The spaces in a building are grouped into thermal zones according to the below-described stepwise process. The auditor has to keep in mind that the model should be constructed with the minimum required number of thermal zones.

Step 1: Assessment of space categories

Each space is assigned to a specific category, taking into account the overall energy performance assessment procedures.

Certain thermally unconditioned spaces, for reasons of simplicity, may be assumed to have the same conditions of use as the adjacent thermally conditioned spaces and then joined (e.g., attic. staircase, atrium, and garage). The following spaces are typically characterized as thermally unconditioned:

- spaces that are highly ventilated, such as: car garage or indoor car park. A highly ventilated space is defined as a space with a permanent ventilation capacity of at least 3 dm^3/s per m^2 of useful floor area of that space.
- spaces with large openings to the outdoor air. A large opening in a space to the outdoor air is defined as one or more permanent openings with at least 0.003 m^2 of openings per m^2 of useful floor area of that space.

Step 2: Grouping according to space category

A space category is characterized by a specific set of conditions of use. Therefore, all adjacent spaces belonging to the same space category are grouped into one thermal zone.

Thermally unconditioned spaces, adjacent to thermally conditioned spaces, are as a rule modelled in a simplified way. However, if a thermally unconditioned zone has a strong effect on the overall calculation, it can be considered as a thermally conditioned zone (with zero heating and cooling power).

Step 3: Grouping in case of large openings in between

If large openings exist between two spaces, the spaces are combined into one thermal zone. Doors that are likely to remain open frequently are considered as permanent large openings. A large opening in a space to a space or spaces inside the thermal envelope is defined as one or more permanent openings with a total area of at least 0,003 m^2 per m^2 of useful floor area of that space.

The thermal conditions of use are in this respect the minimum and maximum temperature and/or moisture settings and the period(s) of the settings, such as the number of hours per day and days per week.

Step 4: Further grouping according to similar thermal conditions of use

Adjacent thermally conditioned zones may be combined if the thermal conditions of use[3] are the same or similar. The two following criteria determine if the conditions of use are similar:

- the temperature set-points difference for heating and cooling is less than 4K
- the difference in minimum and maximum moisture content settings (if applicable) is less than 0,2 kg/kg (dry air)
- the daily operation periods are not differentiated by more than three hours

Step 5: Split according to specific system or subsystem properties

In case of system specific calculations ((taking into account specific heating, cooling, ventilation or (de-humidification) system properties)), a thermal zone may need to be split up in the relevant system standards, aiming at certain homogeneity in the system or subsystem within a thermal zone.

Step 6: (Further) split to have sufficient homogeneity in thermal balance

A thermal zone is to be split in such a way that a thermal zone is to some degree homogeneous in the thermal balance. The criteria are more stringent if cooling is involved.

For each of the following criteria, two different sections of the thermal zone are considered, covering each at least 25% of the useful floor area of the considered zone.

The thermal zone has to be split if:

[3] The thermal conditions of use are defined as the minimum and maximum temperature and/or moisture settings and the period(s) of the settings, such as the number of hours per day and days per week.

- between the two sections the monthly mean internal gains (including recoverable system losses) plus solar gains in a representative cold month are estimated to differ more than a factor of three. This does not apply if the average value is below 15 W per m^2 of useful floor area.

In addition, if the calculation involves the calculation of cooling needs or load or indoor temperature calculation, the thermal zone has to be split if:

- the difference of internal effective heat capacity between the two spaces is larger than two classes.
- the monthly mean internal gains, including recoverable system losses plus solar gains, in a representative warm month are estimated to differ more than a factor of three. This does not apply if the average value is below 30 W per m^2 useful floor area.

Step 7 (Further) grouping of thermally unconditioned zones

Adjacent thermally unconditioned zones may be combined into one thermally unconditioned zone.

Step 8: Simplification in case of small thermal zones

A thermal zone may be combined with an adjacent thermal zone if it has the same combination of services (Step 4), but different thermal conditions of use (Step 5) or different thermal balance properties (Step 7), provided that it has a useful floor area of less than 5% of the total useful floor area of the assessed object.

In that case the thermal conditions of use of the adjacent thermal zone (larger zone) apply. In case of more than one adjacent thermal zones, the combination of services and thermal conditions of use are adopted from the adjacent zone with more similar services and/ or conditions of use.

Step 9: Simplification in case of very small thermal zones

A thermal zone may be combined with an adjacent thermal zone even if it has different combination of services (Step 4), provided that it has a useful floor area of less than 1% of the total useful floor area of the assessed object.

In this case, the combination of services and thermal conditions of use of the adjacent thermal zone apply. If multiple zones are in contact with the unconditioned space, then the adjacent zone with more similar services and/ or conditions of use is selected.

2.3.2.2 Parameters per thermal zone

Type: the type of the thermal zone is selected according to the use of its spaces. The resulting category of the spaces is also the type of the zone (Table 3).

An extra set of parameters related to the zone's operational characteristics (e.g., temperature and Relative Humidity (RH) set-points, internal heat gains, scheduling) is created automatically, and the attribute values are defined from the Type of the zone.

Useful floor area: the sum of the useful floor areas from all the spaces in the zone.

Volume of air: the sum of the volume of air from all the spaces in the zone.

Internal Effective Capacity: this attribute is used to determine the internal heat capacity of the zone. The value is selected from the table below, according to the construction type of the building envelope.

Class	Internal Effective Heat Capacity [J/(K×m²) × m²]
Very Light	$80.000 \times A_{use}$
Light	$110.000 \times A_{use}$

Medium	165.000 × A_{use}
Heavy	260.000 × A_{use}
Very Heavy	370.000 × A_{use}

Table 4: Default values for internal effective heat capacity

2.3.3 Building Envelope

2.3.3.1 General

The BIM file contains all the information about the various building elements of the building fabric. The various BIM software solutions utilize standardized sets of information to describe the elements of the building fabric. Nevertheless, these solutions may be insufficient for the ARM. All the required attributes that each building element should have in order to be able to perform the Asset Rating calculation are presented in the following section. The attributes can be either inserted at the initial BIM model or at a later stage in the D^2EPC Web platform, before proceeding to the Asset Rating calculation. The auditor is responsible for the plentitude and the validity of the information in both cases.

The various building elements are categorized in two ways. Firstly, depending on their visual transparency, the building elements are separated under two main groups, the “opaque and transparent” building elements. A second distinction is conducted according to the placement of the element on the building topology, for instance an element can be internal, external in contact with the ambient air or external in contact with the ground etc. Each category (or sub-category) requires a different set of information which reflects their thermal characteristics. All the building element categories are presented in the following sub-sections, along with their set of attributes.

2.3.3.2 Opaque Elements

2.3.3.2.1 In contact with the external environment

This category includes all the opaque building elements placed at the outside layer of the building. The required attributes from each element are the following:

Type: the type of external opaque element (external wall, roof, pilotis, door).

Orientation (*γ*): the orientation of the external opaque building element is obtained from the geometric data of the BIM model. It is expressed as the geographical azimuth of the horizontal projection of the element and its value is in degrees. The angle is calculated starting from the North ($N=0^o$) measuring eastwards positive and westwards negative.

Tilt (*β*): the tilt angle of a building element expresses its inclination and it is measured in degrees. The angle is measured from the horizontal level measuring facing upwards. A vertical wall has a tilt angle equal to 90^o, while the tilt angle of a horizontal slab’s tilt is zero. The tilt angle of the building element obtained from the geometric data of BIM model.

Area: the total area of the opaque external building element, without the area of the openings that it might include, expressed in m^2. The value is obtained from the geometric data of the BIM model.

U-Value: the thermal transmittance of the opaque building element expressed in [W/m^2K].

a: the dimensionless absorption coefficient to the solar radiation, at the external surface of the element. It ia determinded by the type of the builfing element the material and the colour of its final layers.

Colouring	a
Light colour	0,3
Intermediate colour	0,6
Dark colour	0,9

Table 5: Absorbance coefficient typical values

F_{sh}: dimensionless shading reduction factor due to the existence of external obstacles and the horizon. In the case of a clear horizon without obstacles the shading factor is equal to 1, while for instances with complete shading the factor is zero. This parameter is defined for each element by the auditor.

2.3.3.2.2 External Elements in contact with the ground

External building elements can also be in contact with the ground. In this case the calculations that determine the thermal behavior of the spaces require the following set of parameters.

Type: the type of the opaque building element (e.g., wall (basement wall), floor (slab-on-ground floor)).

Area: the total area of the opaque external building element, without the area of the openings that it might include, expressed in m^2. The value is obtained from the geometric data of the BIM model.

U-Value: the thermal transmittance of the opaque building element expressed in [W/m^2K].

Depth (m): the depth in the soil that the surface of the building element lies. For walls there are two values the upper and the lower depth. For the ground floor the depth is described by one value, while the floors with are in contact with the ground surface the depth is considered equal to 0.

Perimeter (m): the exposed perimeter of the floor slab. This parameter is not defined for the case of basement walls.

2.3.3.2.3 Internal Element in contact to adjacent external/internal type or thermally unconditioned zone

In the case that an opaque element is in contact with unconditioned spaces, the ARM requires the following three parameters.

Type: the type of opaque elements in contact with the unconditioned spaces (e.g., wall (internal), roof, floor, door).

Area: the total area of the opaque building element, without the area of the openings it might include, expressed in [m^2]. The value is obtained from the geometric data of the BIM model.

U-Value: the thermal transmittance of the opaque building element expressed in [W/m^2K].

2.3.3.2.4 Internal Elements

The elements that belong inside a thermal zone or divide two conditioned thermal zones, are considered adiabatic and characterized as internal elements. For these elements there is no information needed for the ARM.

2.3.3.3 Transparent Elements

2.3.3.3.1 In contact with the external environment

Type/ Description: the type of the external transparent element (e.g., opening window, non-opening window, opening glass façade, non-opening glass façade).

Orientation (*γ*): the orientation of the external transparent building element. Its value is obtained from the geometric data of the BIM model. It is expressed as the geographical azimuth of the horizontal projection of the element and its value is in degrees. The angle is calculated starting from the North ($N=0^o$) measuring eastwards positive and westwards negative.

Tilt (*β*): the tilt angle of an element expresses its inclination and it is measured in degrees. The angle is measured from the horizontal level measuring facing upwards. The tilt angle of the building element is obtained from the geometric data of BIM model.

Area: the total area of the transparent element, expressed in [m^2]. The value is obtained from the geometric data of the BIM model.

U-Value: the thermal transmittance of the opaque building element expressed in [W/m^2K].

F_{sh}: dimensionless shading reduction factor due to the existence of external obstacles and the horizon. In the case of a clear horizon without obstacles the shading factor is equal to 1, while for instances with complete shading the factor is zero. This parameter is defined for each element by the auditor either in the BIM model or in the Web Platform.

g_w: the dimensionless monthly mean effective total solar energy transmittance, for heating/ cooling. This value can derive from the manufacturer of the window or from the table with typical values. This parameter is defined for each element by the auditor either in the BIM model or in the Web Platform.

2.3.3.3.2 In contact with unconditioned space

Type: the type of the transparent element (opening window, non-opening window).

Area: the total area of the transparent element, expressed in [m^2]. The value is obtained from the geometric data of the BIM model.

U-Value: the thermal transmittance of the opaque building element expressed in [W/m^2K].

2.3.3.4 Thermal Bridges

The ARM supports the calculation of thermal losses through thermal bridges. The auditor can insert them in the model through the Web Platform. Up to now, it has not been identified whether they can be inserted in the BIM file or automatically detected from the building's geometry.

Two parameters need to be specified for the description of a linear thermal bridge

- the **length** of the thermal bridge, expressed in [m].
- the value of **Linear Thermal Transmittance**, expressed in [W/m·K]. This value depends on the geometry and the construction type of the joined building elements.

2.3.4 Technical Systems

2.3.4.1 Heating

The various heating systems are distinguished according to their source of energy, the location of the equipment, the heat carrier and the method of heat transfer in heated spaces. A heating system is broken down to three main parts: the heart production unit, the distribution system and the terminal units.

The heating system is defined in the level of a thermal zone. A thermal zone can have multiple heating systems.

2.3.4.1.1 Production units

Type: the type of the production unit

- Local
  - Fireplace: Open | with rom air circulation chamber | with embedded heat exchangers (flue to gas-to-water or flue gas-to-air)
  - Stove: Wood burning | Pellet burning
  - Electric: convention oil-fired | radiant electric heater| electric panel heater | electric thermal storage heater
  - Room Air Conditioners
- Central: Hydronic or forced air system
  - Boiler: Oil-fired | Gas-Fired | Pellet |
  - HP: Air-to-Air | Air-to-Water | Water-to-Water | Ground-to-Water (geothermal)
  - District Heating

Energy Source: the source of energy that fuels the production unit.

Power: the nominal power of the production unit, expressed in [Kw]. The value is obtained for the technical characteristics in the manufacturer's datasheet, or from the maintenance report.

Efficiency: the efficiency of the production unit taking into account its technical characteristics as well as the sizing[4] of the unit.

SCOP[5]: in the case that the production unit is a heat pump with Energy Labelling, the Seasonal Coefficient of Performance is documented. If the SCOP value is not available, then the COP value is documented.

Coverage Ratio: the annual average ratio of the total heating load covered by the heating production unit, at the examined thermal zone.

2.3.4.1.2 Distribution System

This section is completed only in the case of central heating systems.

Type: the type of the distribution system according to the heating medium. In the case that the heating medium is water, the distribution system's type is characterized as "Hydronic", and in the case that the medium is air the characterization is "Air-Forced".

Power: the distribution system's nominal power, expressed in [kW].

Efficiency: the efficiency of the system.

Insulation: the existence of insulation in the distribution system (*Yes* or *No*).

Passage: description of the distribution system's passage through the building (*Internal* or *External*).

2.3.4.1.3 Terminal Units

This section is completed only in the case of central heating systems.

Type: the type of the heating terminal unit.

Power: the total power of the installed terminal units in the examined thermal zone.

Efficiency: the efficiency of the terminal units in the examined thermal zone.

---

[4] Pm/Pgen

[5] In the case that the heating production unit is a heat pump, the Efficiency value is replaced with the SCOP value, and the Efficiency field is not filled in. Respectively, the SCOP field is omitted when the heating system isn't a heat pump.

2.3.4.1.4 Ancillary Units

This section is completed only in the case of central heating systems.

Type: the type of ancillary unit (e.g., pump, circulator, ventilator, electric valve).

Power: the nominal power of each ancillary unit.

2.3.4.2 Cooling

A cooling system is reported in the same way as the heating system indicated above. The cooling system is declared in the level of a thermal zone. A thermal zone can have multiple cooling systems.

2.3.4.2.1 Production Units

Type: the type of the production unit

- Local
  - Room Air Conditioners
- Central: Hydronic or forced air system
  - HP: Air-to-Air | Air-to-Water | Water-to-Water | Ground-to-Water (geothermal)

Energy Source: the source of energy that fuels the production unit.

Power: the nominal power of the production unit, expressed in [kW]. The value is obtained for the technical characteristics in the manufacturer's datasheet, or from the maintenance report.

Efficiency: the efficiency of the production unit, taking into account its technical characteristics as well as the sizing of the unit.

SEER[6]: in the case of a heat pump with Energy Labelling, the Seasonal Energy Efficiency Ratio (SEER) is documented. If the SEER value is not available, then the EER value is documented.

Coverage Ratio: the annual average ratio of the total heating load covered by the heating production unit, at the examined thermal zone.

2.3.4.2.2 Distribution System

This section is completed only in the case of central cooling systems.

Type: the type of the distribution system according to the medium.

Power: the distribution system's nominal power, expressed in [kW].

Efficiency: the efficiency of the system.

Insulation: the existence of insulation in the distribution system (*Yes* or *No*).

Passage: description of the distribution system's passage through the building (*Internal* or *External*).

2.3.4.2.3 Terminal Units

This section is completed only in the case of central cooling systems.

Type: the type of the cooling terminal unit (e.g., cassette, fan coil, blower units).

Power: the total power of the installed terminal units in the examined thermal zone.

Efficiency: the efficiency of the terminal units in the examined thermal zone.

[6] In the case that the cooling production unit is a heat pump, the Efficiency value is replaced with the SCOP value, and the Efficiency field is not filled in. Respectively, the SCOP field is omitted when the cooling system isn't a heat pump.

2.3.4.2.4 Ancillary Units

This section is completed only in the case of central cooling systems.

Type: the type of ancillary unit (e.g., pump, circulator, ventilator, electric valve).

Power: the nominal power of each ancillary unit.

2.3.4.3 DHW

The DHW system is declared in the level of a thermal zone. A thermal zone can have multiple sources for DHW production or utilize solar thermal collector to cover part of its demand.

2.3.4.3.1 Production Unit

Type: the type of the production unit (e.g., boiler, district heating, heat pump, local electric heater – boiler, local electric heater – speed heater, local natural gas unit).

Energy Source: the source of energy that fuels the production unit.

Power: the nominal power of the production unit, expressed in [kW]. The value is obtained from the technical characteristics in the manufacturer's datasheet, or from the maintenance report.

Efficiency: the efficiency of the production unit taking into account its technical characteristics as well as the sizing[7] of the unit.

SCOP[8]: in the case that the production unit is a heat pump with Energy Labelling, it is documented the Seasonal Coefficient of Performance. If the SCOP value is not available, then the COP value is documented.

Load Coverage Ratio: the annual average ratio of the energy need for DHW covered from this specific heat production unit. The value range is from 0 to 1, and typically for local units the value is equal to 1.

2.3.4.3.2 Distribution System

This section is completed only in the case of central DHW systems.

Type: the type of the distribution system according to the medium.

Power: the distribution system's nominal power, expressed in [kW].

Efficiency: the efficiency of the system.

Insulation: the insulation existence in the distribution system (*Yes* or *No*).

Passage: description of the distribution system's passage through the building (*Internal* or *External*).

2.3.4.3.3 Storage

This section is completed in the case of a water storage tank, either in a local or central system.

Placement: the placement of the system, inside or outside of the building.

Efficiency: the efficiency of the storage system.

[7] Pm/Pgen

[8] In the case that the DHE production unit is a heat pump, the Efficiency value is replaced with the SCOP value, and the Efficiency field is not filled in. Respectively, the SCOP field is omitted when the DHW system isn't a heat pump.

2.3.4.3.4 Ancillary Units

This section is completed only in the case of central DHW systems.

Type: the type of ancillary unit (e.g., pump, circulator, ventilator, electric valve).

Power: the nominal power of each ancillary unit.

2.3.4.4 Lighting

The Lighting system's technical characteristics are described in the following format, at the level of the thermal zone. The energy demand for lighting is examined only in the case of tertiary buildings.

Installed Capacity: the total installed capacity of the lighting devices in a thermal zone, expressed in [kW].

Automation: the percentage of the lighting devices controlled by presence sensors.

Lighting Capacity controlled by Presence Sensor: the percentage of the installed lighting capacity controlled by human presence detection sensors.

Lighting Capacity controlled by natural Lighting Sensor: the percentage of the installed capacity lighting controlled by natural lighting sensors.

Lighting Capacity controlled by Natural Lighting and Presence Sensor: the percentage of the installed lighting capacity the combination of the two above-described categories.

2.3.4.5 Solar thermal collectors

The existence of solar thermal collectors is defined at the thermal zone level that they provide energy.

Type: the type of the solar thermal collector (e.g., without cover plate, flat plate, selective, vacuum tubes).

Application: the solar thermal collector can be utilized for Heating, DHW or both.

Area: the total absorber area of the collectors, expressed in [m^2].

Orientation (*γ*): the orientation of the collectors (usually South). The value is obtained from the geometric data of the BIM model. It is expressed as the geographical azimuth of the horizontal projection of the element and its value is in degrees. The angle is calculated starting from the North ($N=0^o$) measuring eastwards positive and westwards negative.

Tilt (*β*): the tilt angle of a solar collector expresses its inclination in degrees. The angle is calculated from the horizontal level measuring facing upwards. The tilt angle of the solar collectors is obtained from the geometric data of BIM model.

F_{sh}: the shading reduction factor at the area of the solar collectors due to the existence of external obstacles in the surrounding environment. In the case of a clear horizon without obstacles, the shading factor is equal to 1, while for instances with complete shading the factor is zero.

Exploitation factor: the percentage of solar radiation exploitation is defined at the percentage of the absorbed solar radiation from the collector that is converted to thermal energy for the production of DHW or space heating. In other words, it is the solar collector's average annual efficiency. The value depends on the type of the collector, the use and the system's losses.

2.3.4.6 Photovoltaics

The PV installation is declared on the building level, unlike the above-mentioned technical systems which are declared on a thermal zone level.

Type: the technology of the photovoltaic panels (e.g., monocrystalline, polycrystalline, thin film μ-Si, thin film a-Si, thin film CIS-CIGS, thin film Cd-Te, triple junction).

Installation Year: the date of the system's installation.

Area: the total area of the PV panels, expressed in [m^2].

Power: the total nominal power of the system, expressed in [kW].

Exploitation factor: the annual exploitation factor of the available solar radiation. It indicates the average annual efficient, according to which the PV installation converts the solar radiation to electrical energy. Its value depends on the nominal efficiency of the PV panels, their age and the total nominal efficiency of the rest of the installation (inverters, storage systems etc.).

Orientation (*γ*): the orientation of the panel's installation. The values are obtained from the geometric data of the BIM model. It is expressed as the geographical azimuth of the horizontal projection of the element and its value is in degrees. The angle is calculated starting from the North ($N=0^o$) measuring eastwards positive and westwards negative.

Tilt (*β*): the tilt angle of a PV panels expresses their inclination in degrees. The angle is measured from the horizontal level measuring facing upwards. The tilt angle of the building element is obtained from the geometric data of BIM model.

F_{sh}: the shading reduction factor at the area of the PV panels due to the existence of external obstacles in the surrounding environment. In the case of a clear horizon without obstacles the shading factor is equal to 1, while for instances with complete shading the factor is zero.

Connection: the connection type of the PV installation with the electricity grid. Two types are possible, with or without the Net Metering scheme.

2.3.4.7 Automation and control

- It could be described in levels
- Each system could have a level from a predefined list
- An extra category for the automation and control system (BMS)
- Interconnection with SRI

2.3.4.8 Theoretical system

- In the cases that there is no system in a category and its existence is obligatory the auditor should insert the theoretical system.

3 Operational Rating

3.1 Terms and Definitions

For the purposes of this document, the terms and definitions given below are presented according to the ISO 52000-1:2017 - Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures.

3.1.1 Building

Assessed object: part of a building or portfolio of buildings that is the subject of an energy performance assessment.

Building: construction as a whole, encompassing the fabric and all technical systems, where energy can be utilised to control the indoor conditions, provide domestic hot water, light, and other services connected to the building's use.

Building category, unit category: classification of buildings and/or building units related to their main use or their special status, for the purpose of enabling differentiation of the energy performance assessment procedures and/or energy performance requirements.

Building element: integral component of the technical building systems or of the fabric of a building.

Building fabric: all physical elements of a building, excluding technical building systems

Building thermal zone, thermal zone: internal environment with assumed sufficiently uniform thermal conditions to enable a thermal balance calculation according to the procedures in the standard under EPB module M2-2.

Building unit: section, floor or apartment within a building that has been designed or modified to be used independently from the rest of the building.

Reference floor area: floor area used as a reference size.

Reference size: relevant metric for comparing against benchmarks and normalizing total or partial energy performance and energy performance standards to the size of the structure or component of a building.

Thermally conditioned space: heated and/or cooled space.

Thermally unconditioned space: room or enclosure that is not part of a thermally conditioned space.

Useful floor area: area of the floor of a building needed as a parameter to quantify specific conditions of use that are expressed per unit of floor area and for the application of the simplifications and the zoning and (re-)allocation rules.

3.1.2 Indoor and outdoor conditions

Design condition: interpretation according to a particular environmental element such as indoor air quality, satisfactory lighting, thermal and acoustical comfort, energy efficiency, and associated system controls to be deployed for the assessment of the operation of a building, part of the building, and technical building systems.

External temperature: temperature of outdoor air.

Internal temperature: weighted average of the air temperature and the mean radiant temperature at the center of the thermal zone.

3.1.3 Technical building systems

Air conditioning system: combination of all components required to provide air treatment in which supply air temperature is controlled, possibly in combination with the control of ventilation rate and humidity and air filtration.

Building service: service delivered by technical building systems and by appliances to enable acceptable indoor environment conditions, domestic hot water, illumination levels, and other services that are associated with the building use.

Technical building sub-system: component of a technical building system that carries out a specific function (e.g. heat generation, heat distribution, heat emission).

Technical building system: technical tool for heating, cooling, ventilation, humidification, dehumidification, domestic hot water, lighting, building automation and control, and electricity production.

3.1.4 Energy

Air conditioning: type of air treatment including controlling of the maximum or minimum temperature, probably coupled with ventilation, humidity and air cleanliness control.

Building automation and control: products, software, and engineering services for automatic controls, monitoring and optimization, human intervention, and management of building services equipment to achieve energy-efficient, cost-effective, and safe operation.

Delivered energy: energy, expressed per energy carrier, supplied to the technical building systems through the assessment boundary to satisfy the uses taken into account or to produce the exported energy.

Energy carrier: substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.

Energy from non-renewable sources, non-renewable energy: energy from a source that is depleted by extraction.

Energy from renewable sources, renewable energy: energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogases.

Energy need for domestic hot water: heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point without the losses of the domestic hot water system.

Energy need for heating or cooling: heat to be provided to or withdrawn from a thermally conditioned room in order to maintain the desired temperature conditions in the space for a period of time.

Energy source: a source of useful energy that can be harvested or recovered directly or through a conversion or transformation process.

Energy use for lighting: electrical energy input to a lighting system.

Energy use for other services: energy input to appliances providing services not included in the EPB services.

Energy use for space heating or cooling or domestic hot water: energy input to the heating, cooling, or domestic hot water system in order to meet the energy requirements for heating, cooling (including dehumidification), or domestic hot water, respectively.

Energy use for ventilation: electric energy input to a ventilation system for air transport and heat recovery.

Primary energy: energy that has not been subjected to any conversion or transformation process.

Total energy: energy from both renewable and non-renewable sources.

3.1.5 Energy performance

Actual measured energy: measured energy without any correction for standard climate and use.

As built energy performance: energy performance calculated with data for the building after construction (prior to or during operation) and standard use.

Calculated energy performance: energy performance based on calculations of the weighted net delivered energy for the EPB services.

CO_2 emission coefficient: coefficient that describes the amount of CO_2 that is released from doing a certain activity, such as burning one tonne of fuel in a furnace.

Design energy performance: energy performance with design data for the building and standard use and climate data set.

Measured energy indicator: energy performance indicator based on measured energy performance.

Measured energy performance: energy performance based on weighted, measured amounts of delivered and exported energy.

Numerical indicator of primary energy use: primary energy use per unit of reference floor area.

Reference value: standard legal or calculated value against which an energy indicator is compared.

Total primary energy factor: sum of renewable and non-renewable primary energy factors for a given energy carrier.

3.1.6 Energy calculation

Assessment period: period of time during which the energy performance is assessed.

Calculation interval: discrete time interval for the evaluation of the energy performance.

Calculation period: period of time during which a calculation is performed.

Heating or cooling season: the time of year over which a large amount of energy for heating or cooling is required.

3.2 D^2EPC operational rating approach

The core process for the EPCs calculation lies in the calculation of buildings' heating and cooling loads, with the use of Building Energy Performance Simulation (BEPS) tools. D^2EPC, with the use of BEPS tools, examines energy performance calculations based on the actual energy consumption of the building (known as the operational rating). The importance of employing the operational rating methodology approach for assessing the energy performance of buildings is emphasized for its enclosure in the dynamic EPCs, mainly addressed to relevant stakeholders, as well as to practicing engineers and EPC assessors, implementing the principles of D^2EPC in buildings certification. More specifically, the developed methodology in D^2EPC follows a unified approach for the buildings located in Europe, and the improvement of the D^2EPC operational energy rating parameters is recommended for its introduction in the next-generation EPCs.

D^2EPC project develops and delivers a methodology for the operational energy performance ratings of buildings, which will be used in the framework of the next-generation D^2EPC tool through a set of cutting-edge digital design and monitoring tools and services. The Operational Rating Module will allow calculating the operational EPC, based on the methodology defined as follows.

3.2.1 Definition of operational rating parameters

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.

This document contributes to the reinterpretation of EPC-related policies and the updating of current standards, as well as implementation advice, and incorporates incentivization and restriction practices into the EPC reasoning. Thus, operational rating methodology is recommended to include the following parameters:

- Types of buildings to which the D^2EPC operational rating will apply;
- Indicators of D^2EPC operational scheme (e.g. heating, cooling, lighting, appliances, domestic hot water, total);
- The reference values, based on which the rating will be calculated;
- Normalization practices for operational values;
- Frequency of issuance;
- Methods of measurement of actual consumption and details (e.g. instruments, responsibilities, etc.).

3.2.2 D^2EPC operational energy rating parameters

3.2.2.1 Building type

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. A key value for the EPCs' classification and issuance is the thermal energy per unit of conditioned building area (kWh/ (m^2a)). Apart from this value, the following values can also be given: (a) annual energy per unit of conditioned building area (kWh/(m^2a)), (b) annual electricity supply per unit of conditioned building area (kWh/(m^2a)), (c) annual primary energy for the operation of the building per unit of conditioned building area (kWh/(m^2a)), and (d) annual CO_2 emissions due to the operation of the building per unit of conditioned area of the building (kg /(m^2a)).The calculation of each building's energy amount is made in a more transparent way by indicating the genuine rating i.e., how efficient the building is with the undertaken recommended improvements. The aim of this rating method is the reduction of energy-intensive constructions by utilizing a unique calculating approach and a more legible design.

3.2.2.2 Indicators

The operational energy rating calculation follows specific guidelines and includes demands for indicators, such as heating, cooling, lighting, appliances, domestic hot water, total, etc. The next-generation EPC includes a scheme of heating systems and domestic hot water systems, possibly but not necessarily, powered by one type of energy (natural gas or district heating), and cooling, based on the physical attributes of the building (insulation quality, heating system, type of windows, etc.). Furthermore, the estimation of energy consumption also takes into consideration the lighting and ventilation systems, as this provides a total perspective of the energy efficiency of the buildings. As an additional and more advanced approach, the dEPC interface involves as well a division between renewable and non-renewable energy consumption.

3.2.2.3 Reference values

The dEPC is formed based on the absolute consumption of each building and a comparison based on the statistics of each country. The actual, degree-day-adjusted heat consumption and the annual real electricity consumption are used as the basis for the classification of each building on the energy label scale, instead of a reference value, which depends on building type with different demand of energy performance. By following this rationale, monitoring a building’s energy consumption provides an overall understanding of where the building is over-using and over-spending on electricity and absolute clarity in where and how the energy rates can be reduced.

3.2.3 Issuance frequency

It is undeniable that 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 should 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 documented in the databases.

3.2.4 Normalization practices

Since a lot of energy usage is weather dependent and heating/cooling energy consumption is substantial in most buildings, weather normalization is applied in all the EU Member States. Weather normalization is employed for the calculation of a building’s energy performance by defining an energy index. Techniques for weather-normalization are based on regression analysis of historical energy usage data. With degree days, this approach is used to (a) quantify or prove energy savings following the adoption of specified measures (like installing new insulation), (b) monitor ongoing energy usage for signs of waste (excess consumption or “overspend”), as well as (c) track ongoing progress at reducing it. The operational rating dEPC has a degree-day indicator for heating/cooling energy consumption. This means that, for example, there is a number of kWh/m^2 for a number of degree-days, and depending on whether the kilo Watt-hours are increased or decreased. Respectively, the same happens for the energy consumption of the building and the adjustment.

3.2.5 Measurement methods

For the operational energy rating dEPCs to be issued, a list of power and gas meters is formed to measure the energy consumption. Additionally, guidance for measuring the savings produced by energy efficiency initiatives is provided to compile best practices for determining the degree to which efficiency measures produce savings. By this way, the invoices show the actual energy consumption of each building and not an annual rate. In the standardized data, descriptions of inhabitants, illumination profiles, small power equipment, operating times, and indoor climatic conditions are information that is included in the dEPC. The power and gas meters allow the accurate collection of the consumption data to give ultimate clarity on the building usage. This helps make informed and intelligent decisions on how to start saving energy while simultaneously ensuring EU citizens pay only for what they use across gas and electricity.

3.3 Information extraction

3.3.1 Pilot example calculation

The measurements of the following example were taken from the sensors and relevant equipment installed in the Frederick University pilot building. The average usage values of power, heating, and cooling, lighting, as well as electrical appliances energy consumption for the months from June to November are presented in Table 6. These values were deduced for the entire year (12 months).

The building introduced in this case study is a multi-use building with quite a diverse set of spaces, systems, and assets. The entire New Wing building covered is divided into three separate zones monitored in detail. The entire building is also covered in terms of energy monitoring, providing a complete data flow that fully depicts the building's status. The building was constructed in 2017 and is operating during the usual office hours of a University as it includes offices as well as seminar halls.

The building in Cyprus is located in the area of Palouriotissa, Nicosia, Y. Frederickou Str. (Longitude and Latitude 33°22'46.70 "E, 35°10'46.20 "N), Frederick University's new wing building is a two-story 2100 m^2 building, its volume is approximately 7100 m^3 (including the basement floor/parking area), and it was built in 2007. The understudy building does not border with any other building. The building consists of a basement (area of 450m^2), ground floor (area of 545m^2), and two floors (area of 545m^2 on each floor). The cafeteria of the University is located on the ground floor; three seminar halls of 220 students' capacity are located on the first floor, and on the second floor there are offices. The building can accommodate up to 390 occupants. The height of the building is 15.60m in total from the basement floor to the terrace. The individual heights of the floors are 4.10 m for the typical floors and the ground floor. The services delivered within the building include heating, cooling, ventilation, lighting, and electrical appliances.

The examined area for this example refers to the second floor of the New Wing building, which is 487 m^2, has a volume of 1450 m^3. The occupancy of the floor is around 25 occupants and the working hours are equal to 1920 hours annually (20 days per month * 8 hours per day = 160 h per month *12 months).

Table 6: Data collection for Electrical Appliances consumption of the second floor

	Heating consumption [kWh]	Cooling consumption [kWh]	Lighting consumption [kWh]	Electrical appliances energy consumption [kWh]	Total Power consumption [kWh]
Total Average Annual Consumption	5.168,4	12.059,4	10.227,6	13826,0	41.281,4

3.3.1.1 Total power consumption

The first energy indicators are concerning the total power consumption of the building.

3.3.1.1.1 Total Power/Occupancy

$$\frac{\text{total power consumption}}{\text{total number of occupants}} = \frac{41281.4\ kWh}{25\ p} = 1651{,}3\ \text{kWh/occupants}$$

3.3.1.1.2 Total Power/Occupancy-Hours

$$\frac{\text{total power consumption}}{\text{total number of occupants} * \text{hours of the occupants in the building}} = \frac{41281.4\ kWh}{25p * 1920\ h} = 0.9\ \text{kW/occupant}$$

3.3.1.1.3 Total Power/Area

$$\frac{\text{total power consumption}}{\text{total surface area}} = \frac{41281.4\ kWh}{487\ m^2} = 84.8\ kWh/m^2$$

3.3.1.1.4 Total Power/Volume

$$\frac{\text{total power consumption}}{\text{total volume of the building}} = \frac{41281.4\ kWh}{1450\text{m}^3} = 28.5\ \text{kWh/m}^3$$

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

3.3.1.2 Power consumption for heating

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

3.3.1.2.1 Heating consumption/Occupancy

$$\frac{\text{heating power consumption per energy carrier}}{\text{total number of occupants}} = \frac{5168.4\ kWh}{25\ p} = 206.7\ \text{kWh/occupants}$$

3.3.1.2.2 Heating consumption/Occupancy-Hours

$$\frac{\text{heating power consumption per energy carrier}}{\text{total number of occupants} * \text{hours of the occupants in the building}} = \frac{5168.4\ kWh}{25p * 1920h} = 0.11\ \text{kW/occupant}$$

3.3.1.2.3 Heating consumption/Area

$$\frac{\text{heating power consumption per energy carrier}}{\text{total area of the building}} = \frac{5168.4\ kWh}{487\ m^2} = 10.6\ kWh/m^2$$

3.3.1.2.4 Heating consumption/Volume

$$\frac{\text{heating power consumption per energy carrier}}{\text{total volume of the building}} = \frac{5168.4\ kWh}{1450\ \text{m}^3} = 3.6\ \text{kWh/m}^3$$

3.3.1.3 Power consumption for cooling

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

3.3.1.3.1 Cooling consumption/Occupancy

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total number of occupants}} = \frac{12059.4\ kWh}{25\ p} = 482.4\ \text{kWh/occupants}$$

3.3.1.3.2 Cooling consumption/Occupancy-Hours

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total number of occupants} * \text{hours of the occupants in the building}} = \frac{12059.4\ kWh}{25p * 1920h} = 0.25\ \text{kW/occupant}$$

3.3.1.3.3 Cooling consumption/Area

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total area of the building}} = \frac{12059.4\ kWh}{487\ m^2} = 24.8\ kWh/m^2$$

3.3.1.3.4 Cooling consumption/Volume

$$\frac{\text{cooling power consumption per energy carrier}}{\text{total volume of the building}} = \frac{12059.4\ kWh}{1450\ \text{m}^3} = 8.32\ \text{kWh/m}^3$$

3.3.1.3.5 Weather-Normalized Heating & Cooling Energy Consumption

Following the steps below to compare the Weather Normalized Usage from the Baseline Year. For both the evaluation and baseline year, we take the cooling degree days (CDD) for the cooling period and then calculate the percentage between the evaluation year and baseline year.

$$\frac{\text{Evaluation Year CDD}}{\text{Base Year CDD}}$$

Multiply the degree day percentage between the Evaluation year and Baseline year times the Actual cooling energy usage in the Baseline year.

$$\frac{\text{Evaluation Year CDD}}{\text{Base Year CDD}} * \text{Actual cooling energy usage in Baseline year}$$

Subtract the amount from step 3 of the baseline from Actual Usage in the cooling period of the Evaluation Year. The net difference is Usage Avoidance. A positive number means usage was added.

It is good to have a Negative Number. When compared to the Weather Normalized Usage from the Baseline Year, it means that usage was avoided. A Positive Number, on the other hand, is unfavourable. It signifies that when compared to the Weather Normalized Usage from the Baseline Year, usage increased [10].

The same procedure will be used for the heating degree days (HDD) in the heating period.

3.3.1.4 Power consumption for lighting

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

3.3.1.4.1 Lighting/Occupancy

$$\frac{\text{total lighting power consumption}}{\text{total number of occupants}} = \frac{10227.6\ kWh}{25\ p} = 409.1\ \text{kWh/occupants}$$

3.3.1.4.2 Lighting/Occupancy-Hours

$$\frac{\text{total lighting power consumption}}{\text{total number of occupants} * \text{hours of the occupants in the building}} = \frac{10227.6\ kWh}{25p * 1920h} = 0.21\ \text{kW/occupant}$$

3.3.1.4.3 Lighting/Area

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

3.3.1.4.4 Lighting/Volume

$$\frac{\text{total lighting power consumption}}{\text{total volume of the building}} = \frac{10227.6\ kWh}{1450\ \text{m}^3} = 7.1\ \text{kWh/m}^3$$

3.3.1.5 Energy consumption of electric appliances

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

3.3.1.5.1 Electrical Appliances Energy Consumption /Occupancy

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total number of occupants}} = \frac{13826.0\ kWh}{25\ p} = 553.0\ \text{kWh/occupants}$$

3.3.1.5.2 Electrical Appliances Energy Consumption /Occupancy-Hours

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total number of occupants} * \text{hours of the occupants in the building}} = \frac{13826.0\ kWh}{25\ p * 1920h} = 0.29\ \text{kW/occupant}$$

3.3.1.5.3 Electrical Appliances Energy Consumption /Area

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total area of the building}} = \frac{13826.0\ kWh}{487\ m^2} = 28.4\ kWh/m^2$$

3.3.1.5.4 Electrical Appliances Energy Consumption /Volume

$$\frac{\text{total energy consumption of the electrical appliances}}{\text{total volume of the building}} = \frac{13826.0\ kWh}{1450\ \mathrm{m}^3} = 9.53\ \mathrm{kWh/m}^3$$

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

3.3.1.6 Power consumption for DHW

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

In the pilot case of Frederick University there is no measurement for DHW power consumption, so for that reason no actual values are presented as an example.

3.3.1.6.1 DHW consumption/Occupancy

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

3.3.1.6.2 DHW consumption/Occupancy-Hours

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

3.3.1.6.3 DHW consumption/Area

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total area of the building}} = kWh/m^2$$

3.3.1.6.4 DHW consumption/Volume

$$\frac{\text{DHW power consumption per energy carrier}}{\text{total volume of the building}} = \mathrm{kWh/m}^3$$

4 D^2EPC Set of Indicators

D^2EPC aims to enhance the user-friendliness and the effectiveness of the next generation EPCs, with the addition of multiple indicators, related to the smartness of the buildings (SRI), its environmental (LCA) and financial (LCC) performance, as well as to human comfort aspects. The following sections introduce a set of indicators that address smart readiness, thermal comfort and LCA dimensions, while on the same time monetary and cost-optimum KPIs.

4.1 Smart Readiness Indicator (SRI)

One of the main purposes of D^2EPC, is to deliver an indicator enriched certificate, including aspects beyond energy, which are related to the sustainability of building units. One of this class of indicators concerns the smart readiness indicators (SRIs). The development of SRI align with the EU energy transition 2030 targets [1] and supports the provisions of EPBD recast [2] for the energy transformation of EU building stock. The SRI scheme measures the 'intelligence' of a building by evaluating the extent to which a building can adapt its operation to the needs of its occupants, the energy grid while maintaining energy efficiency and operation. Consequently, the main purpose of the SRI is to increase the awareness of the benefits of smart technologies and increase the adoption of Information and communication technology (ICT)-based products for monitoring and control of building energy use. The SRI scheme was entered into force in December 2020 as a voluntary scheme for EU MSs for rating the smart readiness of buildings. The SRI is expected to create added value to the EPC assessment, by providing an enriched building certificate for the user's benefit.

The development of D^2EPC SRI assessment is based on ''Method B'' of the final SRI technical study conducted by a consortium consisting of VITO NV and Waide Strategic Efficiency and concluded in June 2020 [3]. The current SRI Method B is calculated based on a ''check-list'' approach which includes the documentation of asset data concerning the operation of the building systems. The SRI building systems which can be assessed are: (1) Heating, (2) Cooling, (3) Ventilation, (4) Domestic Hot Water, (5) Electricity, (6) Lighting, (7) Dynamic Building Envelope (8) Electric Vehicle Charging, (9) Monitoring and Control. In general, the SRI Method B can assess up to 54 functionality levels (or level of advancement of operation) of building systems, if all SRI domains are present.

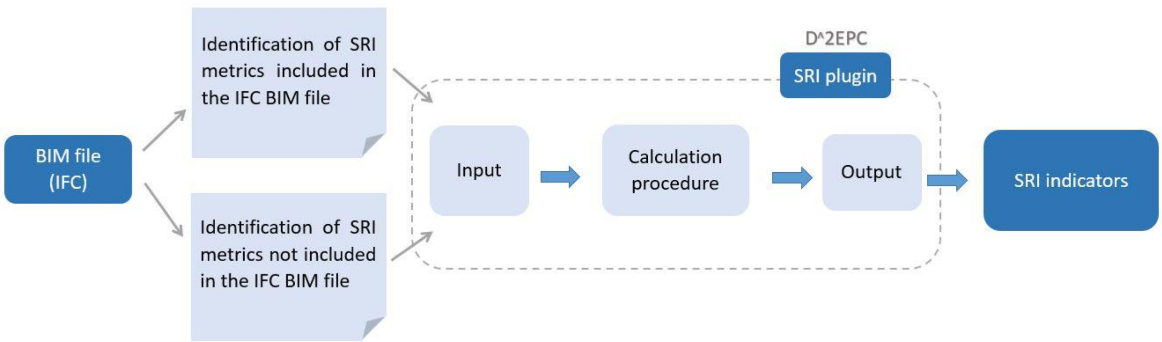

Figure 1. D^2EPC SRI Indicators Extraction

4.1.1 Calculation of D^2EPC SRI

The process of extracting the SRI indicators for a building through an IFC BIM file is presented in

Figure 1. D^2EPC SRI Indicators Extraction. Given the fact that D^2EPC solution aims to implement all the assessment procedures within BIM environment, the SRI assessment will utilize the vendor-neutral Industry Foundation Classes (IFC) schema, developed by Building Smart International for sharing information through various software. According to IFC4 current ability to define building automation systems, the first layer of SRI can be assessed mainly automatically by the D^2EPC plugin. For the successful assessment of the SRI first layer, the assessor is requested to ensure the presence of the 'minimum modelling requirements. These 'minimum modelling requirements' act as an activation of the triage process, where services are to be included or excluded from the calculation engine. According to the services activated from the first SRI layer, the assessment of functionality levels of the available services will be done in the later phase. To this end, due to the limitations of 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 which needs to be defined in 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.

4.1.2 SRI Indicators

The SRI indicators to be used in the D^2EPC solution are predefined in the ''Method B'' of the final SRI technical study. These SRI indicators 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 to the assessed domain.

Table 7. 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, or heat pump and solar heating. The functionality levels of each service vary between on/off, to 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 lighting and artificial lighting in a space
Dynamic Building Envelope	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 the units' control. The smartness scales take into account 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 for 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 includes also 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 8. 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 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 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 and visual comfort.	%
	Convenience	’’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	’’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 improve occupants’ health and well-being.	%
	Maintenance and fault detection	’’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	’’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.	%

4.2 Human Comfort and Wellbeing Indicators

As envisioned within D^2EPC, the new age certification covers aspects beyond the building’s energy performance by integrating a novel set of indicators. Towards this direction, human-centric features have been introduced to the state-of-the-art assessment, as they are considered crucial factors for the building’s operation.

The Human Comfort and Wellbeing indicators developed within the project step on three pillars of indoor environmental quality (I.E.Q.). The thermal comfort, which corresponds to level of satisfaction of the occupant with the thermal environment, the visual comfort, which relates to the quantity and quality of light offered to the occupant and lastly the indoor air quality (I.A.Q.) which examines the amount of fresh air provided within a space in order to guarantee the proper functioning of the human respiratory system [1]. This set of indicators enables the evaluation of a building’s energy performance, considering both functional and human-centred attributes that potentially affect the overall building energy demand and savings. The development of the comfort and well-being indicators is based on a data-driven, user-profiling approach -where applicable- and the Level(s) scheme [2] [3] [4], which is the EU's common voluntary framework adopted by building professionals to measure, report and communicate the building's environmental performance. The scheme steps on existing standards and provides context on the methodologies and environmental parameters to be integrated in the D^2EPC comfort and wellbeing assessment.

4.2.1 Calculation of the Human Comfort and Wellbeing Indicators

To extract the novel set of thermal and visual comfort indicators, a hybrid, data-driven and non-intrusive methodology is applied, based both on static and dynamic elements. The methodology utilises real-life measurements on the building's ambient conditions to extract personalised user profiles - via a specially designed comfort profiling engine- that showcase the occupant's preferred boundaries in regards to several environmental parameters. The comfort indicators are ultimately built upon the personalised boundaries, quantifying the building's comfort performance. In cases when the user profile extraction is not feasible or relevant, the building codes are obtained by the level(s) framework and other national environmental and sustainability standards. (**Figure 2**). Regarding the indoor air quality, only the static approach is considered as the optimal air conditions within a space are determined based on several factors not always perceived by the occupant. Level(s) provides a multitude of air quality metrics which are reported on predefined intervals and limits/categories. The most critical parameters are integrated in the D^2EPC I.A.Q. assessment.

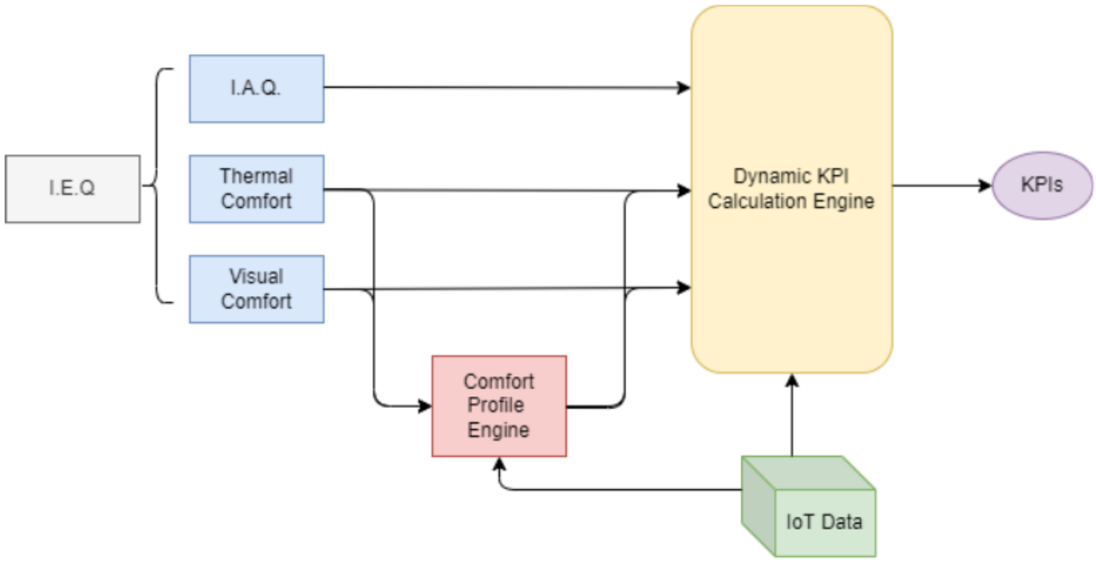

Figure 2. Human comfort and wellbeing hybrid methodology

4.2.2 Thermal Comfort indicators

The thermal comfort indicators have been formulated based on well-elaborated and measurable metrics captured by the sensing infrastructure of a building. Two different methodologies from EN 15251 are utilised for the calculation based on the extracted or predefined boundaries, the time out of range and the degree hours. Regarding the indicators expressed on specific categories/limits, a reporting method from CEN/TR 16798-2 is applied.

Table 9. Thermal Comfort Indicators

Indicator Name	Indicator Description	Units
Deviation from the temperature range	Calculates the % of hours (during which the building is occupied) when the temperature is outside a specified range from the personalized comfort boundaries (EN 15251) [5] compared to the number of hours of the period of interest. The scope of the indicator concerns both residential and commercial buildings	%
Thermal Degree Hours	The time during which the actual temperature exceeds the personalized range (occupied hours) is weighted by a factor which is a function depending on by how many degrees, the range has been exceeded (EN 15251). The scope of the indicator concerns both residential and commercial buildings	numeric
Deviation from the humidity range	Calculates the number or % of hours (during which the building is occupied) when the relative humidity is outside a specified range from the personalized comfort boundaries (EN 15251). The scope of the indicator concerns both residential and commercial buildings Humidity boundary: [40-60%] (level(s))	%
Deviation from the acceptable WBGT levels	Calculates the % of hours (during which the building is occupied) when the thermophysiological parameter 'Wet-Bulb Global Temperature' (as defined in ISO 7243:2017) [6] [7] is greater than a specified value based on the workload and metabolic rate. The scope of the indicator concerns commercial buildings where heavy tasks of high workload and human metabolic rate take place during the heating period. A specific threshold is applied per case.	%
Humidex levels	The Humidex is thermophysiological parameter (defined in ISO 7243:2017). The indicator is reported based on the % of hours of each level compared to the total hours of the period of interest. The scope of the indicator concerns both residential and commercial buildings. Humidex levels Level I: 20 to 29 -> Little to no discomfort Level II: 30 to 39 -> Some discomfort Level III: 40 to 45 -> Great discomfort Level VI: Above 45 -> Dangerous	%

4.2.3 Visual Comfort Indicators

The definition of the visual comfort indicators is carried out in an analogous way with the thermal comfort in terms of information retrieval and calculation methodologies.

Table 10. Visual Comfort Indicators

Indicator Name	**Indicator Description**	**Units**
Deviation from the set Illuminance boundary	Summation of all the daylight hours of a regularly occupied space during which the illuminance was lower than the profiling engine bottom boundary, compared to the total hours of the period of interest. The scope of the indicator concerns residential buildings taking into consideration that the occupant's visual comfort during home activities is purely subjective	%
Deviation from the standard Illuminance levels	Summation of all the daylight hours of a regularly occupied space during which the illuminance was lower than the acceptable levels determined within EN 12464, compared to the total hours of the period of interest. The scope of the indicator concerns commercial buildings where the illuminance levels for different spaces and activities must adhere to international standards. Within D^2EPC, the illuminance levels for different spaces from EN 12464, are utilised.	%
Set Visual Degree Days	The daylight hours during which the space is occupied and the measured illuminance remains below the profiling engine bottom boundary. The calculation is weighted by a factor that is a function considering how many degrees the average hourly illuminance was below the bottom boundary (EN 15251). The scope of the indicator concerns residential buildings taking into consideration that the occupant's visual comfort during home activities is purely subjective	%
Standard Visual Degree Days	The daylight hours during which the space is occupied and the measured illuminance remains below the building code level provided within EN 12464. The calculation is weighted by a factor which is a function depending on by how many degrees the average hourly illuminance was below the acceptable level. The scope of the indicator concerns commercial buildings where the illuminance levels for different spaces and activities must adhere to international standards. Within D^2EPC, the illuminance levels for different spaces from EN 12464, are utilised.	%

4.2.4 Indoor Air Quality Indicators

The set of indoor air quality indicators concerns the concentrations of specific pollutant gases which have been proven to be toxic to the human respiratory system when they surpass predefined limits. The gas concentrations are captured by specialised sensoring equipment expected to be put in the building. The I.A.Q. set further includes an indicator that reports the rate of the indoor air renewal.

Table 11. Indoor Air Quality Indicators

Indicator Name	Indicator Description	Units
Ventilation rate	The ventilation rate (l/s*m^2) is the magnitude of outdoor air flow to a room or building through the ventilation system or device. The indicator is reported based on the % of hours that correspond to each	%

	ventilation rate category compared to the total hours of the period of interest Ventilation rate limits (For diluting all emissions from building) According to CEN/TR 16798-1:2019: I category – 2 l/(s*m^2) II category – 1,4 l/(s*m^2) III category – 0,8 l/(s*m^2) IV category – 0,55 l/(s*m^2)	
Total Total Volatile Organic Compounds (TVOCs)	TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air. The TVOC measurements are reported on a 28-day basis TVOC Limits According to EN 16798-1, 2019: <1000 μg/m^3 (low emitting building) <300 μg/m^3 (very low emitting building)	μg/m^3
Benzene	Benzene concentration in the indoor air. The Benzene measurements are reported on a 28-day basis Benzene Limits According to EN 16798-1 [6]: 3.25 μg/m3	μg/m^3
CO_2 indoors	The CO2 concentration of a space along with the respective outdoor concentration are measured for a period of interest (occupied hours). CEN/TR 16798 defines four distinct categories for the differences between indoor/outdoor CO2 concentrations. Categories according to CEN/TR 16798-1/2:2019: I – 500 ppm when the air flow rate is 10 l/s II– 800 ppm when the air flow rate is 7 l/s III– 1350 ppm when the air flow is 4 l/s IV– 1550 ppm when the air flow is 4 l/s	%
Formaldehyde	Formaldehyde is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air. The formaldehyde measurements are reported on a 28-day basis Formaldehyde Limits According to EN 16798-1 <100 μg/m^3 (low emitting building)	μg/m^3

	<30 μg/m³ (very low emitting building)	
Radon	Radon is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air. The radon measurements are reported on a 28-day basis Radon limits According to WHO 100 Bq/m³	Bq/m³
Particulate matter <2,5μm (PM 2.5)	Particles' that are 2,5μm in diameter or smaller concentration in the indoor air. According to EN 16890-1, particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5μm aerodynamic diameter. The PM 2.5 measurements are reported per 24h and yearly PM2.5 Limits According to EN 16798-1: <25 μg/m³ (per 24 h) <10 μg/m³ (per year)	μg/m³
Particulate matter <10μm (PM 10)	Particles' that are 10μm in diameter or smaller concentration in the indoor air. According to EN 16890-1 [7], particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 aerodynamic diameters. The PM 10 measurements are reported per 24h and yearly PM10 Limits According to EN 16798-1: <50 μg/m³ (per 24 h) <20 μg/m³ (per year)	μg/m³

4.3 Energy and Environmental D^2EPC indicators

D^2EPC includes a set of indicators which is related to the environmental and energy performance of buildings. The importance of employing LCA methodologies for the efficient energy design of buildings and for enabling the parameterization of its embodied energy and primary energy demand [1] are highlighted for their inclusion in the dynamic EPCs, mainly addressed to relevant stakeholders, as well as to practicing engineers and EPC assessors, anticipating to implement the principles of D2EPC in buildings certification. The energy and environmental D^2EPC indicators are considered to be introduced as part of the next generation EPCs, illustrating the environmental performance of buildings.

The development of the D2EPC environmental indicators is based on the Level(s) scheme [8], the EU sustainability assessment for constructions outline. Level(s) is the most recent European approach to assessing and reporting on the sustainability performance of buildings throughout their entire life cycle, correlating the effects with European sustainability goals. Using existing standards [9] [10], the Level(s) approach provides a shared identity for sustainable development, offering a foundation for quantifying, analysing, and understanding the life cycle, and targets a variety of circularity features, delivering indicators that can better clarify how to expand the functionality of the building. It is a helpful framework dedicated to enhancing environmental performance and resource utilization, as well as lowering the built environment's influence on global resources. The usage of real-time data collected for the development of the energy indicators for EPCs is significantly contributing to the maximization of the energy savings and the achievement of carbon reductions of the buildings, as well as complementing the SRIs, social and economic indicators for the issuing of truly sustainable EPCs.

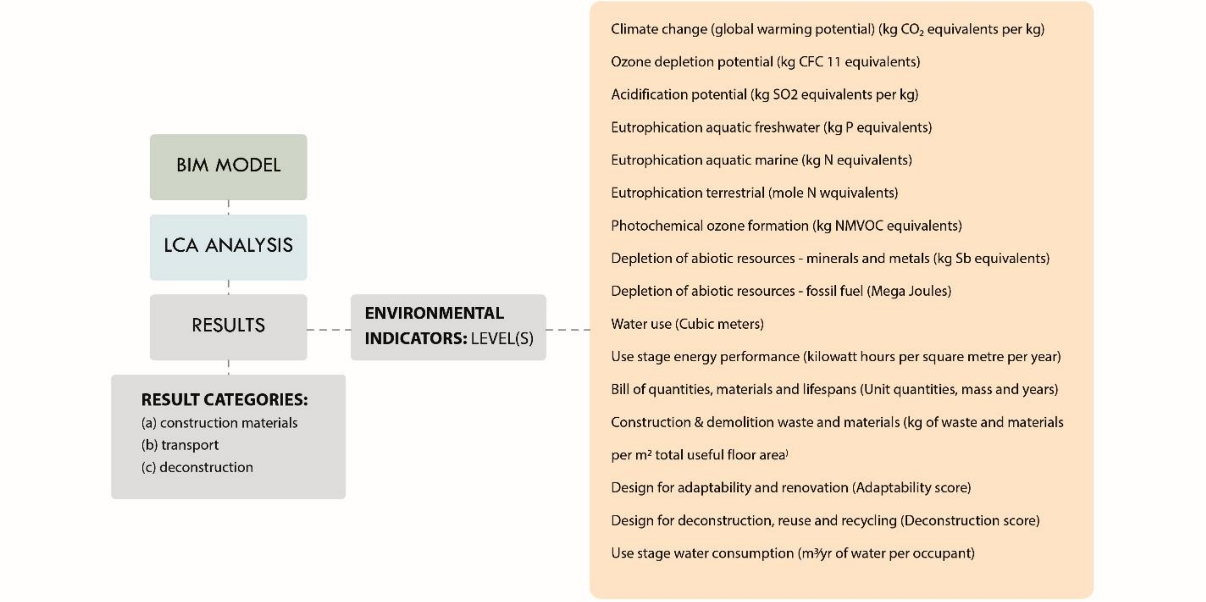

Figure 3. Environmental Indicators Extraction

4.3.1 Calculation of Energy and Environmental D^2EPC Indicators

The extraction of the LCA results (construction materials, transportation, construction/installation, and deconstruction) of the environmental indicators for a building through a BIM file is presented in **Figure 3**. The results are extracted based on the environmental indicators of Level(s). Through this analysis, the values of the environmental indicators depicted above are shown in detail for stages of (a) construction materials, (b) transportation to site, (c) construction/installation process, and (d) end of life, as well as the total values for each indicator. As a values' result, the environmental footprint for each construction material and each category of the structural element is observed.

Simplified energy indicators, such as total energy over area per annum, cannot describe thoroughly the energy performance of a building adequately. Thus, the D2EPC energy indicators are intended to cover present gaps in building performance indicators that can be utilized in conjunction with the increasingly accessible system-level data from the growing use of sensors and meters in buildings to quantify and analyse energy performance. The methodology used for creating energy indicators values is the operational rating, and the calculations are based on the data retrieved by the building's regular measurements, where these are available. Implementing appropriate energy and environmental building evaluation techniques on a wide scale is required to stimulate market demand for sustainable practices in the built environment.

4.3.2 Energy Indicators

The operational rating scheme is used for the calculation, and a complete list of 25 data results, from 4 categories, is presented in Table 6. These energy indicators are a result of measurement values – where these are available- retrieved by the building automation and control systems, as well as by smart meters.

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

Table 12. Energy Indicators

Usage	Indicator Name	Indicator Description	Units
Power consumption of the building	Total Power/Occupancy	This indicator shows the ratio of the total power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Total Power/Occupancy-Hours	This indicator shows the ratio of the total power consumption of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Total Power/Area	This indicator displays the ratio of the total power consumption of the building in kWh over the total surface area of the building	kWh/m^2
	Total Power/Volume	This indicator displays the ratio of the total power consumption of the building in kWh over the total volume of the building	kWh/m^3
Heating Consumption	Heating consumption per energy carrier/Occupancy	This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of occupants	kWh/occupants
	Heating consumption per energy carrier/Occupancy-Hours	This indicator shows the ratio of the heating power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Heating consumption per energy carrier/Area	This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total surface area of the building	kWh/m^2
	Heating consumption per energy carrier/Volume	This indicator displays the ratio of the heating power consumption per energy carrier of the building in kWh over the total volume of the building	kWh/m^3
Cooling Consumption	Cooling consumption per energy carrier/Occupancy	This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the total number of occupants	kWh/occupants
	Cooling consumption per energy carrier/Occupancy-Hours	This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the	kWh/h*occupants

		total number of hours that occupants spend in the building	
	Cooling consumption per energy carrier/Area	This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total surface area of the building	kWh/m^2
	Cooling consumption per energy carrier/Volume	This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total volume of the building	kWh/m^3
Weather Normalization	Weather-Normalized Heating & Cooling Energy Consumption [9]	A positive number means usage was added. It is good to have a Negative Number. When compared to the Weather Normalized Usage from the Baseline Year, it means that usage was avoided. A Positive Number, on the other hand, is unfavourable. It signifies that when compared to the Weather Normalized Usage from the Baseline Year, usage increased.	---
Lighting Consumption	Lighting/Occupancy	This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Lighting/Occupancy-Hours	This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Lighting/Area	This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total surface area of the building	kWh/m^2
	Lighting/Volume	This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total volume of the building	kWh/m^3
Electrical Appliances Energy	Electrical Appliances Energy Consumption /Occupancy	This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of occupants	kWh/occupants

9 https://help.dudesolutions.com/Content/Documentation/Energy/UtilityDirect/Reporting/Weather%20Normalization%20Report%20Explanation%20Sheet.htm

	Electrical Appliances Energy Consumption /Occupancy-Hours	This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Electrical Appliances Energy Consumption /Area	This indicator displays the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total surface area of the building	kWh/m^2
	Electrical Appliances Energy Consumption /Volume	This indicator displays the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total volume of the building	kWh/m^3
Domestic Hot Water Consumption	DHW consumption per energy carrier/Occupancy	This indicator shows the ratio of the DHW power consumption per energy carrier of the building in kWh over the total number of occupants	kWh/occupants
	DHW consumption per energy carrier/Occupancy-Hours	This indicator shows the ratio of the DHW power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	DHW consumption per energy carrier/Area	This indicator displays the ratio of the DHW power consumption per energy carrier of the building in kWh over the total surface area of the building	kWh/m^2
	DHW consumption per energy carrier/Volume	This indicator displays the ratio of the DHW power consumption per energy carrier of the building in kWh over the total volume of the building	kWh/m^3

4.3.3 Environmental Indicators

LCA Level(s) tool is used in the assessment, and a complete list of 17 data result terms are presented in Table 13. These environmental indicators are asset indicators, and may be calculated through the combination of materials bill of quantities, derived by a BIM document, and buildings materials EPDs.

Table 13. 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	kg CO_2 equivalents per kg [kg CO_2 eq/ kg]

	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.	
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 SO_2, NOx, and NHx. Areas of protection are the natural environment, the man-made environment, human health, and natural resources.	mole H+ equivalents [mol H+ eq] kg SO_2 equivalents per kg [kg CO_2 eq/ kg]
Eutrophication aquatic freshwater	Excessive growth measurement of aquatic plants or algal blooms due to high levels of nutrients in freshwater. Freshwater ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.	kg P equivalents [kg P eq]
Eutrophication aquatic marine	Marine ecosystem reaction measurement to an excessive availability of a limiting nutrient.	kg N equivalents [kg N eq.]
Eutrophication terrestrial	Increased nutrient availability measurement in soil as a result of input of plant nutrients.	mole N equivalents [mol N eq]
Photochemical ozone formation	Emissions of nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection. Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health, and ecosystems may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environment, and natural resources.	kg NMVOC equivalents [kg NMVOC eq]
Depletion of abiotic resources - minerals and metals	Indicator of the depletion of natural non-fossil resources. "Abiotic resources" are natural sources (including energy resources) such as iron ore, crude oil, and wind energy, which are regarded as non-living. Abiotic resource depletion is one of the most	kg Sb equivalents [kg Sb eq]

	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 extent 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 water consumption for an average building inhabitant, with the choice of splitting this value under potable and non-potable, supplied water, as well as support measurement of the water-scarce locations identification.	m^3/yr of water per occupant

4.4 D^2EPC Financial Indicators

D^2EPC includes a set of simplified financial indicators which will enhance the user-friendliness of the building certificate. The set of financial indicators was developed based on the literature review of well-established standards [15] [16] and schemes [17] [18]. The financial KPIs enable the interpretation of the individual elements of buildings' energy performance into monetary normalised values and employment of EPCs for the financial assessment of building upgrade measures.

The financial indicators aim to increase user awareness about the energy efficiency of buildings. 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 (asset values, operational values, prediction values…). Such indicators are expected to enable the financial assessment of the building and thus provide additional information to the user. This could encourage them to adapt their behaviour in order to improve the energy efficiency of the building.

The development of financial indicators is based on the well-established concept of whole life cycle costing (LCC). The LCC methodology is a decision-making tool that helps assess different options over a certain period of time. The indicators, developed in D^2EPC are not intended for the long-term planning or comparison of alternatives; nevertheless, the LCC concept is used as a base, as it defines a typical scope of costs throughout the construction, operation, maintenance, and end-of-life phase. Therefore, the approach is to evaluate the relevant costs and present them to the user as additional information in next-generation dynamic EPCs.

The idea of financial indicators is based on the comparison of the current state (as-operated) with different scenarios, for example the as-designed state, the as-operated state at a different (past) time, the predicted model, and the building stock, as presented in Figure 4**.** The energy consumption of different scenarios is monetized and compared to each other.

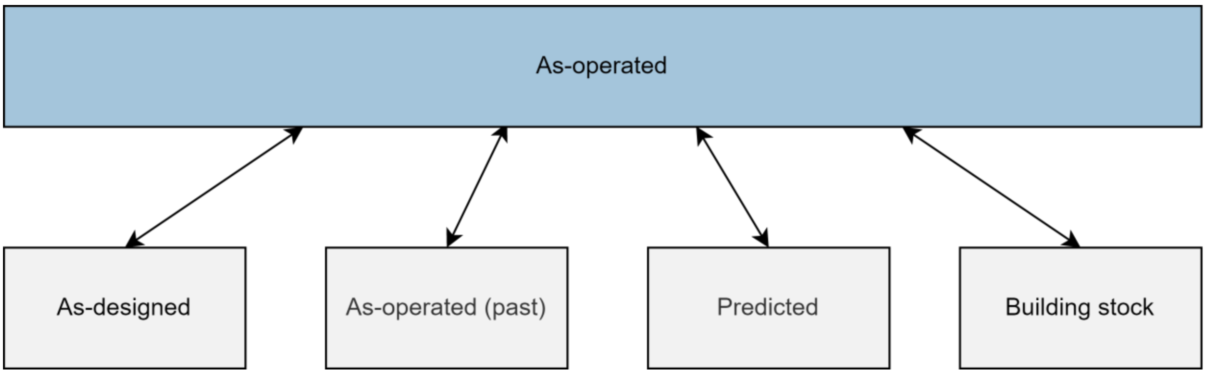

Figure 4. The comparison of scenarios

The outcomes from the Asset Rating Module and the Operational Rating Module and contribution from the user, where applicable are the required inputs for the Building Performance Module to calculate the financial KPIs, as presented Figure 5.

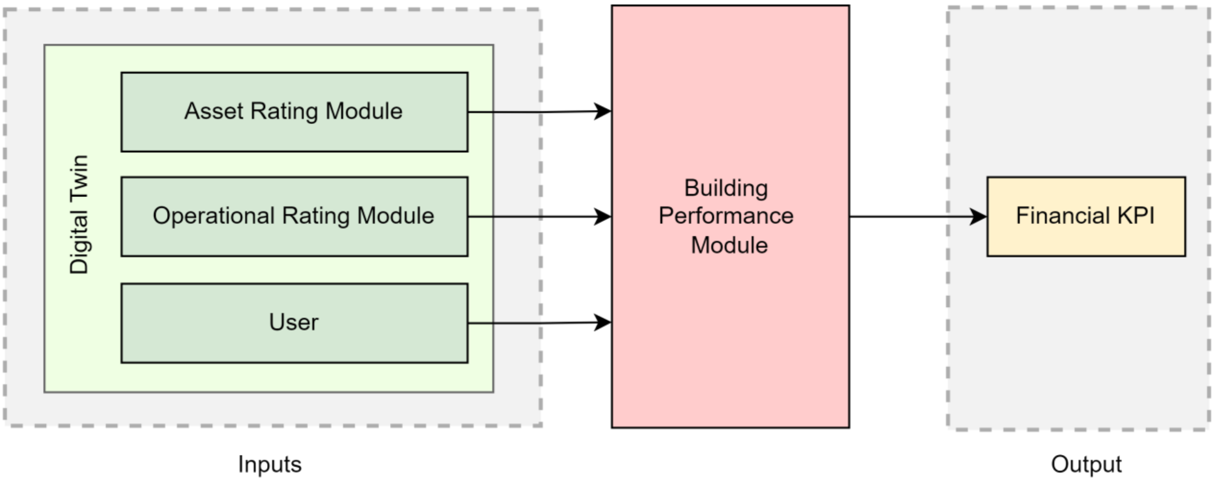

Figure 5. Process overview

4.4.1 The Inputs

Crucial information for this KPI calculation is the price of the energy carriers. Even though the intent is to deliver universal KPIs, no uniform price that can be used, which would be valid for all member states. It was therefore decided that the price information will be provided by the user. This way, the results can be more accurate and provide better information to the user. The price that will be entered will be used for all the scenarios, since only this way will the comparison be reasonable. Different countries define their electrical tariffs in different ways. In some cases, there are more tariffs, while in others, there is only one. To overcome this discrepancy, it was decided to perform the calculation with an average value of all the tariffs entered without tax.

In order to evaluate the future values, the prediction model requires information regarding the inflation rate and the discount rate. The average expected rates for the next 10 years are provided by the user as they differ from country to country, but it also allows the user to compare different possible scenarios by using different rates.Lastly, the financial indicator aims to list all the expected future costs related to the maintenance and replacement of the building's systems. The systems' information will be retrieved from the BIM model of the building and through the inputs from the user. Based on that, the expected costs for maintenance and replacements per year will be calculated and presented to the user which will allow better planning of their expenditure.

4.4.2 As-operated and as-designed

Based on the acquired inputs, the calculation follows the simple formula of multiplying the energy consumption with the energy price.

The as-designed asset values follow the Energy Performance of Buildings (EPB) standards with main core the EN ISO 52000 family of standards and divide the consumption into heating, cooling, domestic hot water (DHW) and lighting. On the other hand, the as-operated energy consumption values depend on the measurements that take place in the building, for example, heating and cooling can be combined due to having only one system present for both, while there might be additional values such as energy consumption of appliances.

The outcomes of the as-operated scenario therefore include:

- Cost in EUR per month per energy use
- Cost in EUR per month per energy carrier

- Total cost in EUR per month
- Total cost in EUR per year
- Total cost in EUR per square meter

The separation of costs per energy use and energy carrier can be beneficial for the user, as it indicates where improvements can be made in case the building is performing poorly.

The outcomes of the as-designed scenario include:

- Total cost in EUR per month
- Total cost in EUR per year
- Total cost in EUR per square meter

Due to above-mentioned differences in what values are available in the asset and operational rating, the comparison between both scenarios shows the total cost in EUR per month and per year, providing additional information, and thus increasing user awareness regarding energy consumption. The comparison can clearly indicate whether the performance of the building is better or worse than the design values. The as-operated yearly cost in EUR is a true reflection of the monetarized energy use in the building, although it does not match the bills that the residents receive because the additional costs and taxes are, in this case, omitted.

4.4.3 Prediction Model

The prediction model tries to evaluate the future costs, based on the inflation rate and discount factor provided by the user. The basis for the calculation is the monetized annual energy consumption from the measurements, to which the inflation rate and discount factor are applied. The prediction looks into the next 10 years, and it calculates:

- the real cost, which is adjusted for inflation, meaning that it can be compared as if the prices have not changed on average
- the nominal cost, which indicates the expected price in the future considering changes in price such as inflation
- the Net Present Value (NPV), which represents the future price in today's value, that is determined with the discount rate

The comparison between the real value, nominal value and the NPV is an approximation and aims to illustrate to the user the impact of time on the value of money they will be paying for the energy use in their building.

4.4.4 Expected costs for building systems

Expected yearly costs for building's systems are calculated based on the inputs from the BIM model and inputs from the user, by simply summing up the expected costs for the maintenance and replacement of the systems in the next few years.

It was also considered to include the expected costs for the building's envelope (façade and windows). However, the idea was dropped after taking into consideration different systems that are present in the MS in this regard. For example, in some countries to perform maintenance work on the façade, all building's residents need to agree on it, while in other countries residents are already paying monthly contributions to the fund which is later used for the maintenance works on the building's envelope.

.

4.4.5 Financial Indicators (Summary)

Table 14. Summary of D^2EPC Financial Indicators

Indicator name	Indicator description	Units
As-operated costs	The “as-operated cost” indicator presents the following costs to the user: - Cost per month per energy use - - Cost per month per energy carrier - Total cost per month - Total cost per year - Total cost per square meter	EUR
As-designed costs	The “as-designed cost” indicator presents the following costs to the user: - Total cost per month - Total cost per year - Total cost per square meter	EUR
Total cost comparison (graphically presented)	The “total cost comparison” indicator is comparing the as-designed and as-operated cost, namely the total costs per each month and total costs for the whole year. - Total cost comparison per month - Total cost comparison per year	EUR
Predicted costs	The “predicted costs” indicator presents the real cost, the nominal cost, and the Net Present Value for the next 10 years	EUR
Expected costs for building systems	The “expected costs for building systems” are an estimation of the costs that the use can expect for the replacement and maintenance of building systems	EUR

5 BIM & Digital Twin

The D^2EPC BIM-based Digital Twin serves as a core component, which enables the unification of various forms of user-provided data with dynamic information collected from the building's field devices, under a common, digital building model.

Static building information may be provided through the D^2EPC User Interface. The main source is the BIM file, uploaded by the user, in IFC format (*.ifc*), which contains necessary information regarding the building's geometry, materials, underlying systems etc. To this end, a specifically designed tool, namely the *BIM Parser*, is utilized to extract any available data from the aforementioned file and store them in the *D^2EPC Repository*, a common database that is designed to securely contain the provided information. A graphical representation of the previously described process is displayed below.

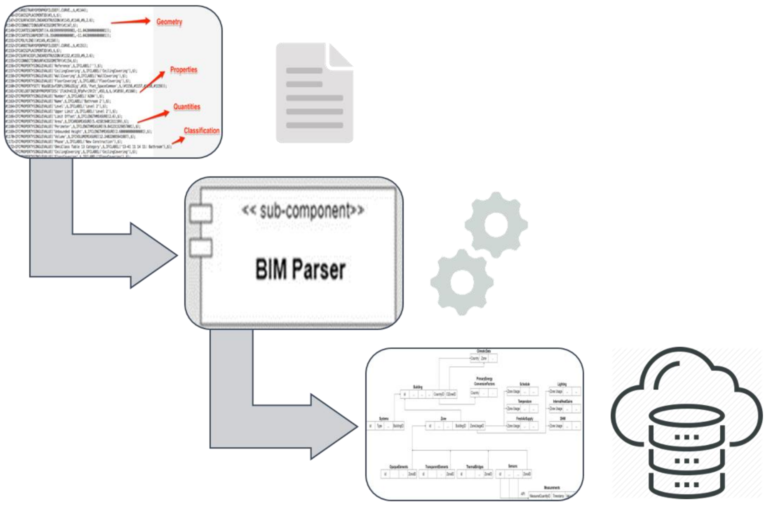

Figure 6. Graphical representation of the D^2EPC BIM-based Digital Twin

A minimum amount of input data has been determined, in order to perform the required calculations regarding the asset and operational ratings, as well as the desired set of indicators. Depending on the user preference, additional static information regarding the studied building may be requested, should the retrieved one from a provided BIM file is not sufficient. The user will be able to insert any required data through the web platform, following the upload of the building's IFC file.

On the other side, dynamic building information, which are collected by field-level devices and sensors, is also stored in the D^2EPC Repository, after pre-processing for cleansing and structuring purposes. Any received data are linked with the building digital entity based on common IDs, and therefore, to other existing static data from the sources that were previously described, finally forming the building's Digital Twin.

Although unperceived by the user, the Digital Twin is utilized by all the components of the D^2EPC for the calculation of indicators, the asset and operational rating and the Added value services suite and the Extended dEPCs application toolkit.

6 D^2EPC WebGIS Tool

6.1 WebGIS architecture

The D^2EPC WebGIS Tool is an independent sub-component of the D^2EPC Platform. The WebGIS introduces an added value service and a potential revenue stream to the D^2EPC project. Third party platform end users such as authorities, public or standardisation bodies and others are empowered with useful tools such as enriched analytics, comparisons and visualisations of dEPC statistics across EU countries and regions. Furthermore, the users can visualise the pilot buildings in 3d mode through the enriched BIM on the same platform.

The architecture of the WebGIS application is shown in Figure 7. The application connects to the centralized D^2EPC Repository which stores useful data for each building. The WebGIS consumes the Asset & Operational Rating, the BIM file and the geolocation for each building. In the backend a separate geospatial database is deployed for the need of storing data in a dynamic manner. This database consists of two tables created for the two levels of NUTS (Nomenclature of territorial units for statistics) used: level-0 (countries) and level-3 (small regions for specific diagnoses). NUTS are preferred over administrative regions as they contain a uniform population (levels 1,2,3) and therefore better suited for statistic interpretation. In addition, the use of neighbourhoods is abandoned as they are vaguely defined.

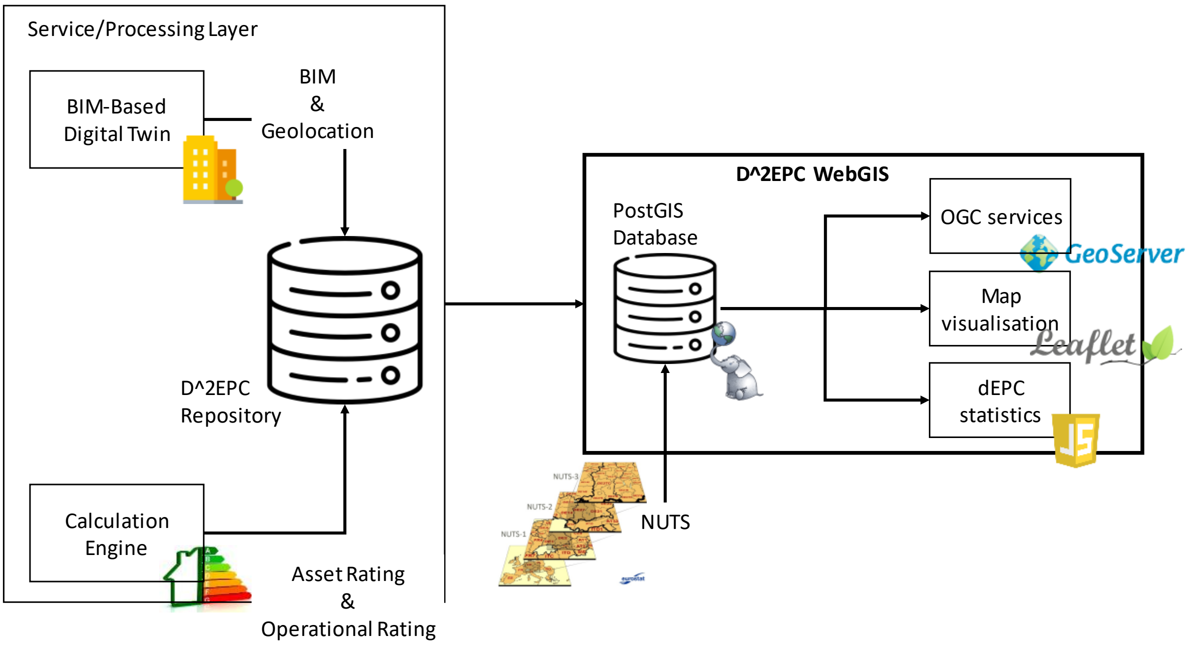

Figure 7: D^2EPC WebGIS architecture

6.2 Map Visualisation

To fully anonymize the data for the dEPC statistics, using a geospatial analysis each statistical region (country or level-3 NUTS) is correlated with aggregates of both Operational and Asset EPCs. The information contained in the geospatial database forms a vector layer which can be displayed in WebGIS as shown in Figure 8 and Figure 9. The initial view displays the countries or NUTS level-0.

However, the user can select manually between layers as shown in Figure 9. In addition, the transition from countries to level-3 NUTS takes place automatically when the user zooms into the map.

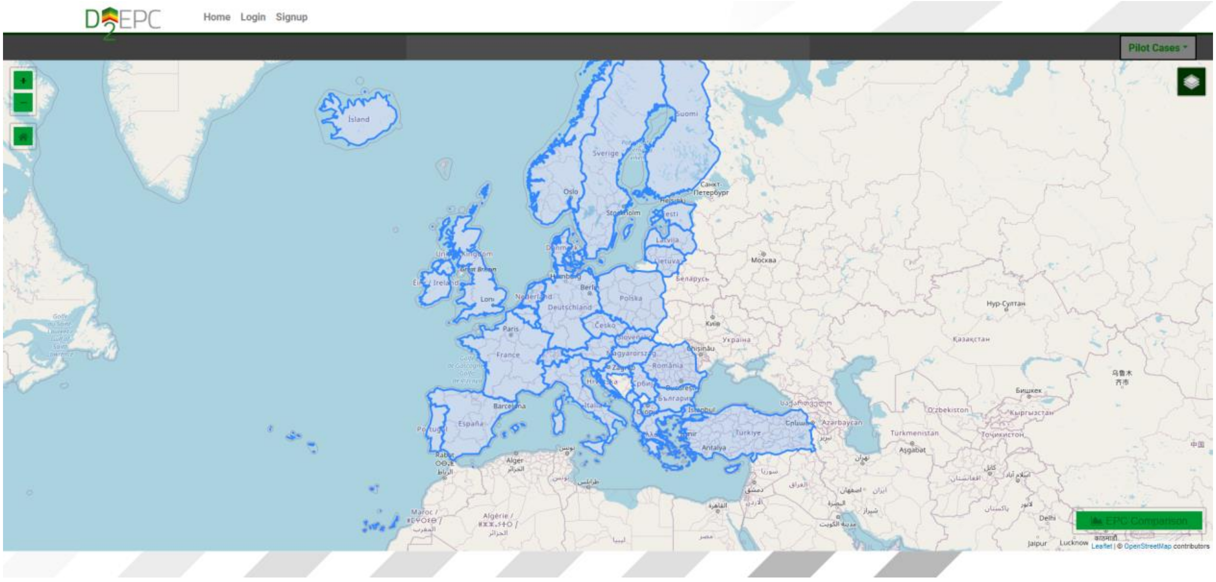

Figure 8: Initial view of the WebGIS map. View of the countries (NUTS level-0)

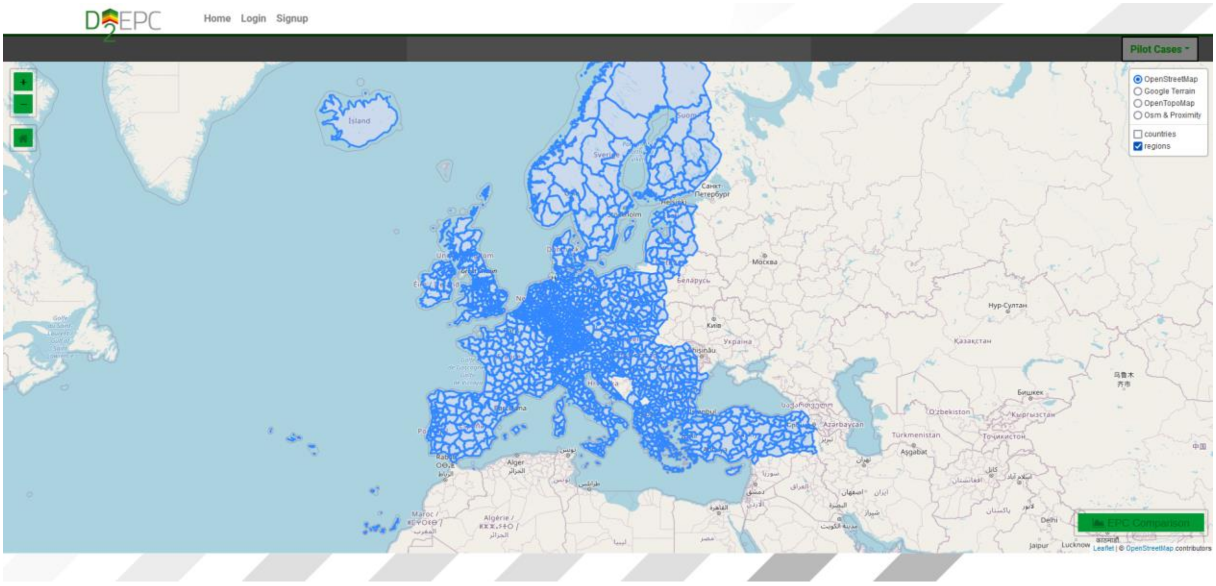

Figure 9: View of the level-3 NUTS in the WebGIS map

Moreover, for demonstration purposes, the six pilot cases of D^2EPC are also contained in the application. The user can select from a dropdown list on the right corner. When selected, the map "flies to" the exact location of the building represented by a marker. Clicking on the marker alters the view 2D to 3D and displays the BIM. The user has full 3D control and access to the BIM file with interaction when selecting parts of the building and displaying relevant information (Figure 10).

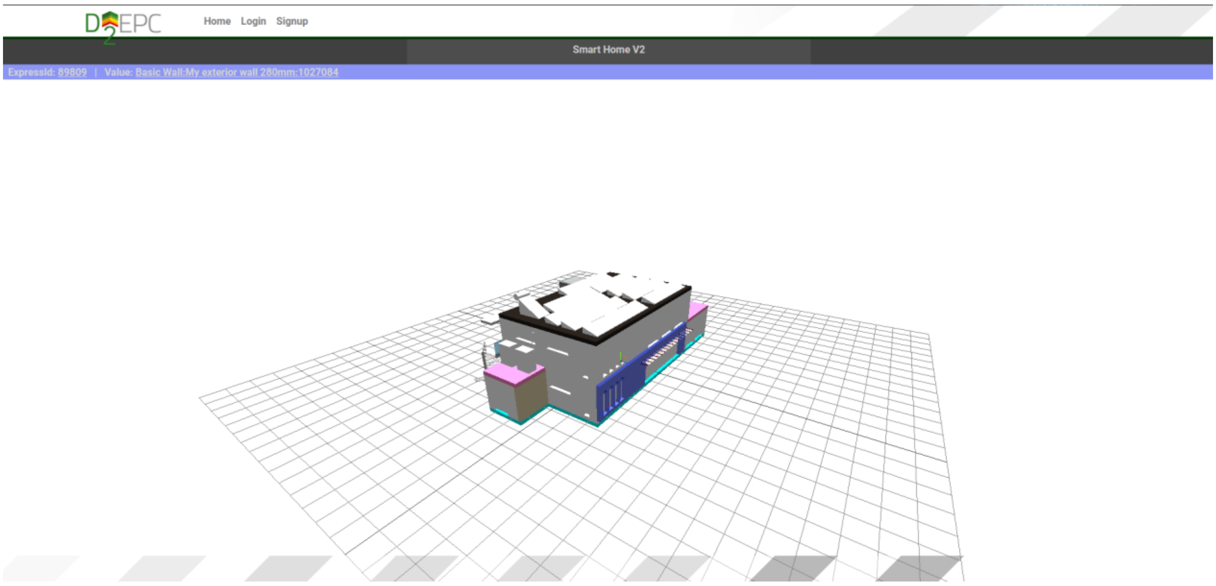

Figure 10: 3D visualisation of BIM for D^2EPC pilot case building

6.3 D^2EPC statistics

The provision of dEPC statistics is displayed on the map through graphics implemented by the application's front-end. The user selects the polygon of interest, which according to the level of the map zoom can be a country or a region. A pie chart is then displayed on top of the map, presenting percentages for each dEPC class as calculated from D^2EPC Asset/Operational Ratings for dwellings inside the selected polygon. Hovering above the percentages unveils the absolute number of dwellings belonging to each class.

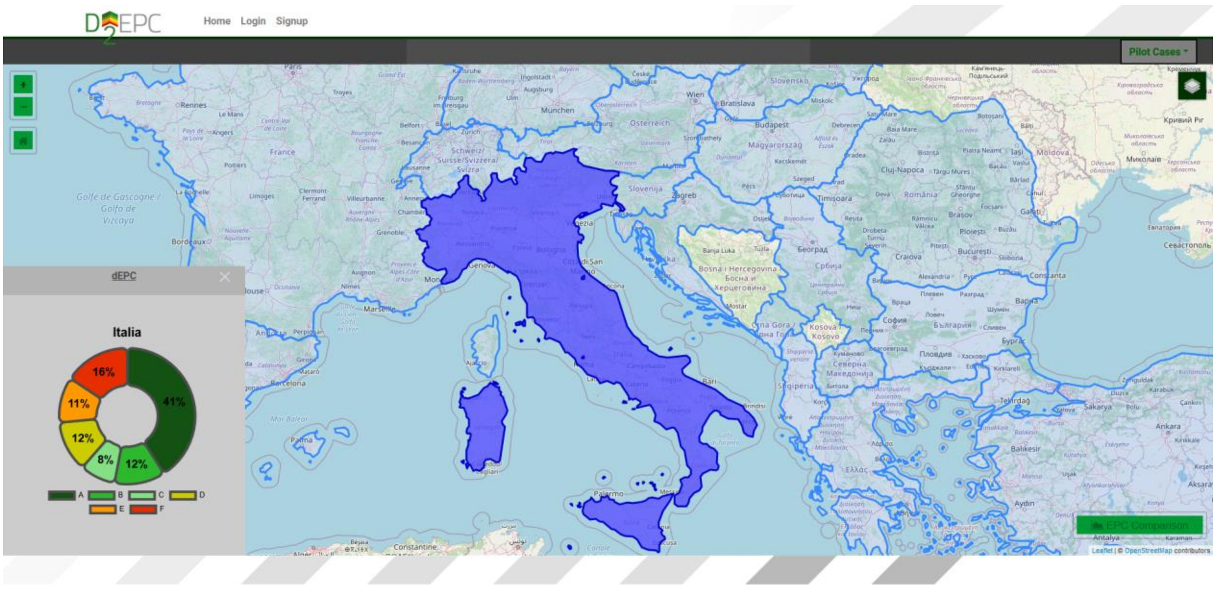

Figure 11: DEPC statistics visualisation for Italy (the values are set for demonstration purposes only and don't correspond to real values).

A second mode of statistics visualisation is the comparison between two regions. Selecting the "EPC Comparison" button, the user can select the first polygon of interest while the selection of a second displays a bar chart as shown in Figure 12.

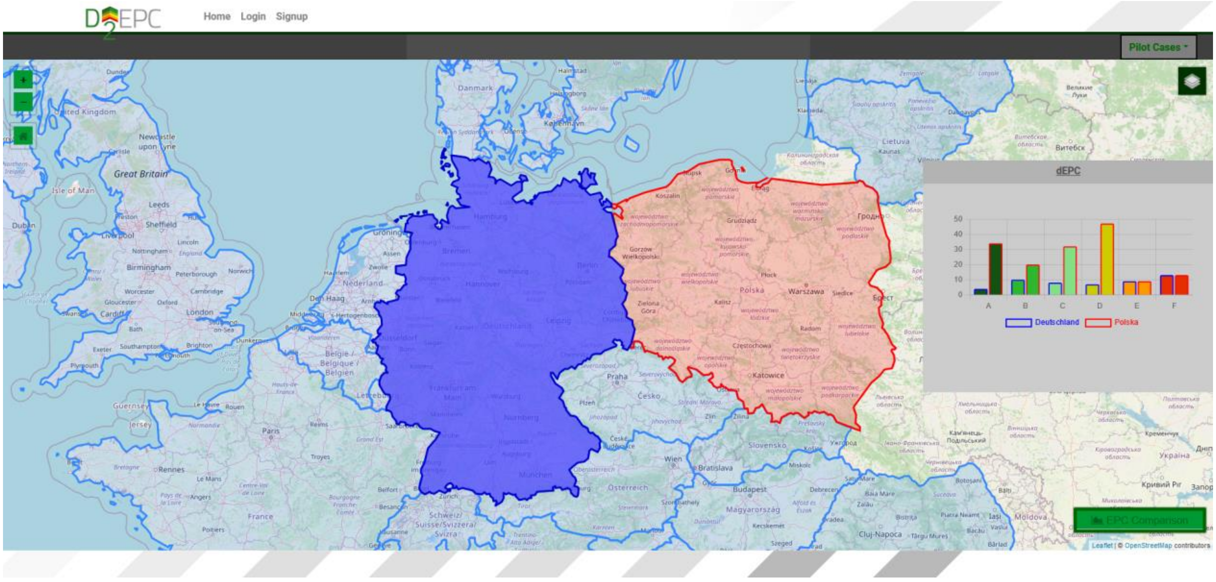

Figure 12. DEPC statistics comparison of Germany and Poland (the values are set for demonstration purposes only and do not correspond to real values).

6.4 OGC services

For dissemination purposes and to promote further analysis in GIS applications (e.g. QGIS, Erdas Imagine, ArcGIS). The analysis of the data can be useful to third party stakeholders. Vector layers produced in the context of D^2EPC are stored in the form of a PostGIS database and are served as Open Geospatial Consortium Web Feature Service (OGC WFS) through the webserver Geoserver (http://geoserver.org/). The users can add the service URL in a GIS tool of choice to proceed with further analysis.

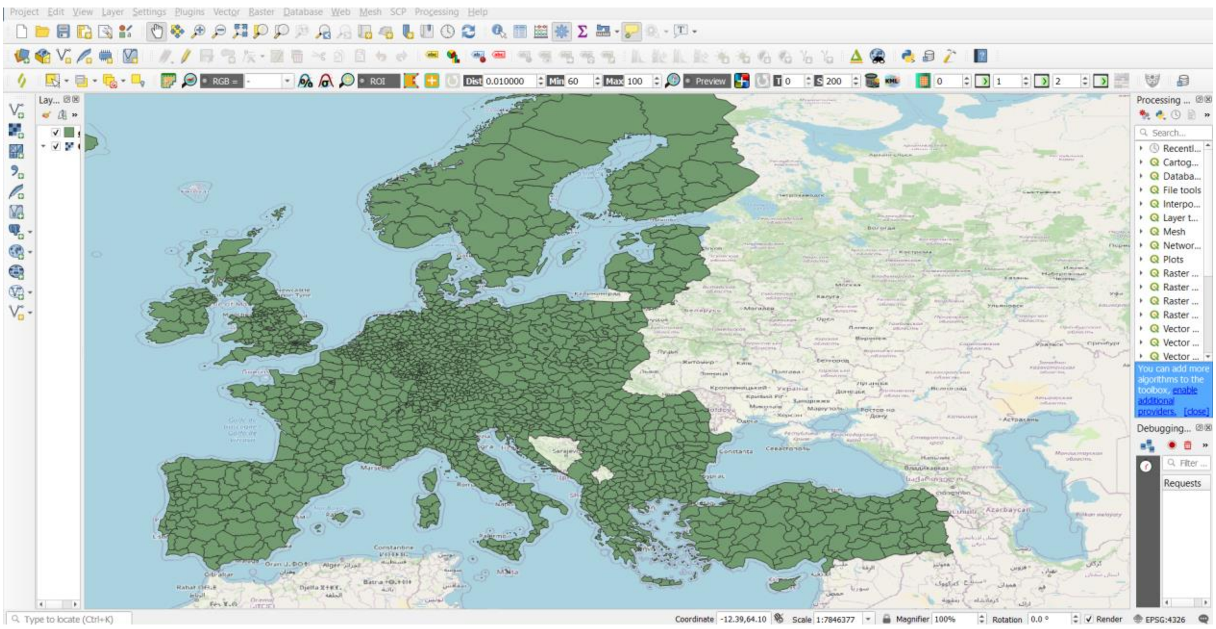

Figure 13: Integration of the WFS of countries in a QGIS environment

7 D^2EPC Web Platform & Additional Services

The D^2EPC Web Platform, along with the integrated additional services, will comprise an intuitive user interface, where the distinct D^2EPC developed functionalities will be accessible by users with different roles. As the development of the platform is in an early stage, some initial guidelines regarding the usage of the different embedded services are provided in the current version of the deliverable. The second and final version of the D^2EPC Manual, which is due M36, is expected to document all the functionalities that will have been integrated into the platform and provide a step-by-step, visual representation of their appropriate use.

The tools that will be interfaced through the platform will be listed below.

7.1 BIM Parser

The user will be able to upload the building's BIM file, if existing, in IFC format, which will then be processed by the BIM Parser. The functionality of this tool has been described in Chapter 5.

7.2 Calculation Engine

7.2.1 Asset & Operational Ratings

This subcomponent will utilize the information extracted from the uploaded BIM file through the Digital Twin. When the issuance of the asset rating-based or the operational rating-based EPC is requested, the user will be prompted to manually enter any data required for the calculations, which cannot be retrieved from the uploaded BIM file. An example of such a required action is shown in Figure 14, regarding the additional parameters for the calculations regarding the operational rating. Apart from the requested input data, the information collected from the BIM file will be clearly displayed to allow possible revision by the user. Following the completion of the necessary input actions, the user will be able to submit the provided information and issue either the asset rating-based or the operational rating-based EPC. Besides the visualization of the result, the export of the generated certificate to other formats (e.g. PDF) will also be considered.

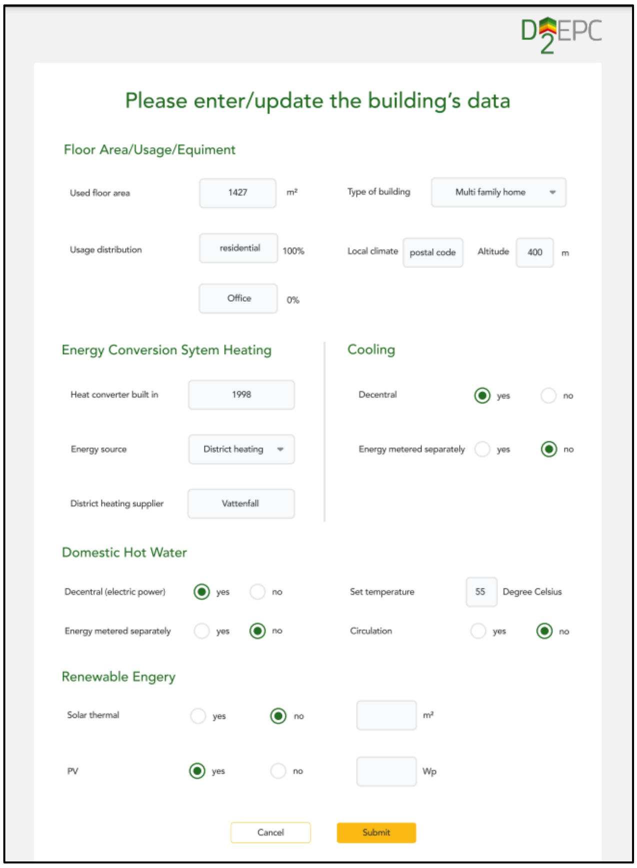

Figure 14: User requested input for the calculation of the operational rating-based EPC

7.2.2 Building Performance Module

Similar to the Calculation Engine, this module will also exploit any information contained in the uploaded BIM file, to complete the data required for the calculation of each set of indicators, as defined in Chapter 4. Additional data for each set of calculations may be requested as optional input by the user. After any data insertion, the execution of the calculations will generate a short report containing all the set of calculated indicators available.

7.3 Added Value Services Suite

7.3.1 Roadmapping Tool

This tool will be based on the existing building information, in order to provide specific recommendations regarding possible renovation actions that will facilitate the performance upgrade, both in terms of the asset-based rating as well as concerning specific sets of indicators. The user will be requested to enter specific calculation parameters, such as the expected cost range, the renovation depth etc. The visual output will include a list of the suggested renovations actions, along with the expected building performance upgrade.

7.3.2 AI Performance Forecasts

The AI Performance Forecasts module will be integrated in the D^2EPC Web Platform as a means of visualizing the predicted change in the building's energy performance. Utilizing historical data collected from the on-site electrical and thermal energy meters, the tool will provide a projection of the future energy consumption along with an estimation of the corresponding operational rating, for a horizon with a time scale of a few months.

7.3.3 Performance Alerts and Notifications

A customizable, constant feed of notifications will be provided through the Web Platform. By using the outputs of the AI Performance Forecasts module, as well as the monitored data from the on-site sensors, any expected performance downgrade will be communicated to the user, in order to offer insights and encourage self-induced behaviors towards appropriate counterbalancing. The user will have the option to adjust the frequency and the level of detail of the notifications to the desired extent.

7.4 Extended dEPCs applications toolkit

7.4.1 Building Energy Performance Benchmarking

Based on the user role, this tool will provide a ranking of the buildings that have been assessed using the Web Platform, in terms of EPC rating (both asset-based and operational-based), but also concerning several indicators. Furthermore, a number of visualization methods will be deployed, in order to present comparative results in various forms and to ensure that the user receives insightful combined information in an intuitive way.

7.4.2 Energy Performance Verification and Credibility Tool

This subcomponent takes over the data verification process applied on all data collected from metering/sensing infrastructure in the D^2EPC pilots. It enables the detection of connection losses and malfunctions based on the operation status of the devices. It further ensures the quantitative and qualitative reliability of the collected data by checking their completeness and whether their values fall within acceptable boundaries. In cases of communication disruptions or bad quality data, the tool generates alerts to warn the end-user through the D^2EPC platform. A dedicated verification UI also allows the user to request additional information regarding the issue -title and description- that resulted in the disqualification of the corresponding data.

8 Conclusions

This report is the first version of the D^2EPC manual, defining in detail the D^2EPC scheme in order to allow the implementation of the D^2EPC principles in buildings certification, focusing on the EPC assessor.

A detailed description of the asset energy performance rating methodology according to existing European standards has been included, documenting on the general description of the building, its division into thermal zones according to the operational characteristics of each space, the analytical descriptions of the elements that comprise the building's envelope as well as on the installed technical systems.

Accordingly, the methodology for the operational energy performance ratings of buildings, which will be used in the framework of the D^2EPC project has been described, elaborating on the main parameters to be considered indicators. In particular, the methodology proposed provides a well-defined process presenting the indicators of the D^2EPC operational scheme (e.g. heating, cooling, lighting, appliances, domestic hot water, total), the reference values, based on which the rating will be calculated, normalization practices for operational values as well as methods of measurement of actual consumption and details (e.g. instruments, responsibilities, etc.). An example of the Frederick University pilot building has been included considering the average usage values of power, heating, and cooling, lighting, as well as electrical appliances energy consumption for the months from June to November.

The additional set of indicators to be included in the next generation EPCs, namely SRI, LCA, human comfort and economic indicators have been introduced and documented. The incorporation of such indicators aims to raise awareness about the benefits of smart technologies and ICT in buildings, consider the entire life cycle of the building as a construction, focus also on the "human-centric" character of the next generation of EPCs and increase EPCs user-friendliness by means of terms which are widely understood and accepted by the public such as the monetary indicators related to the main operations of building's energy consumption (heating, cooling, lighting, appliances).

In the following sections, the major D^2EPC components that are utilised by the end-user in the implementation of the D^2EPC framework have described in terms of their application. In particular, the D^2EPC BIM-based Digital Twin serving as a core component, which enables the unification of various forms of user-provided data with dynamic information has been introduced as well as the WebGIS tool including the various analysis and visualisation options. Finally, the unified D^2EPC Web platform hosting the presentation of all the results from the various components and sub-components, such as the EPCs, the KPIs, and the additional services as provided by the Added value services suite and the Extended dEPCs application toolkit have been briefly described. Through the web platform, the user will be able not only to adjust and configure certain components but also to request directly the execution of certain processes ad-hoc.

The technical features of the D2EPC framework will become clearer and more explicit as the project progresses and the technical activities proceed. As a result, the next version of this report is expected to have more detailed information, with certain elements being re-evaluated and refined.

References

[1] *2030 climate & energy framework. Available at: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en.*

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

[3] *Final report on the technical support to the development of a smart readiness indicator for buildings.*

[4] *Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC).*

[5] *N. Dodd, S. Donatello and M. Cordella, "Level(s) indicator 4.1: Indoor air quality," JRC Technical Reports, European Commission, 2021.*

[6] *N. Dodd, S. Donatello and M. Cordella, "Level(s) indicator 4.2: Time outside of thermal comfort range," JRC Technical Reports, European Commission, 2020.*

[7] *N. Dodd, S. Donatello, M. Cordella, N. McLean and C. Casey, "Level(s) indicator 4.3: Lighting and Visual Comfort," JRC Technical Reports, European Commission, 2020.*

[8] *DIN EN 15251, "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics," 2012.*

[9] *BS EN ISO 7243:2017, "Ergonomics of the thermal environment. Assessment of heat stress using the WBGT (wet bulb globe temperature) index".*

[10] *BS EN 12464-1:2021, "Light and lighting. Lighting of work places Indoor work places".*

[11] *BS EN ISO 16890-1:2016, "Air filters for general ventilation Technical specifications, requirements and classification system based upon particulate matter efficiency.*

[12] *Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, JRC Science for Policy Report, Parts 1 and 2: Introduction to Level(s) and how it works (Beta v1.0).*

[13] *CEN (European Committee for Standardization), 2017. EN ISO 52000-1, Energy performance of buildings.*

[14] *CEN. (2005). Standard EN 15203: Energy performance of buildings—Assessment of energy use and definition of ratings. Brussels: Comité Européen de Normalisation (CEN).*

[15] *IEA EBC (2017). Methodology for Cost-Effective Energy and Carbon Emission Optimization in Building Renovation (Annex 56).*

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

[17] *Dodd N. & Donatello S., 2021. Level(s) indicator 6.2: Value creation and risk exposure user manual: introductory briefing, instructions, and guidance (Publication version 1.1).*

[18] *Dodd N., Donatello S. & Cordella M., 2021. Level(s) indicator 6.1: Life cycle costs user manual: Introductory briefing, instructions and guidance (Publication version 1.1).*

[19] *BS EN 16798-1:2019, "Energy performance of buildings. Ventilation for buildings Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.*

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

ANNEX A: Asset Rating- Allowable & Suggested Values for input parameters

INPUT PARAMETER	ALLOWABLE VALUES [10]		SUGGESTED VALUES	
	MIN	MAX	MIN	MAX
Building Level Information				
Total Area (m^2)	>0			≥ useful area
Useful Area (m^2)	>0	<Total area		
Total volume (m^3)			>0	> Useful volume
Useful volume (m^3)	>0			<Total volume
Typical floor height (m)	>0			
Ground floor height (m)	>0			
Zone Level Information				
Useful Area (m^2)	>0			≤Beneficial surface
Useful Volume (m^3)				
Specific heat capacity [kJ/(m^2·K)]	>0		80	300
Building Envelope				
Opaque Elements				
In contact with the ambient air				
Orientation- γ [deg]	0	359		
Tilt - β [deg]	0	180		
Area [m^2]	>0			
U- value [W/(m^2·K)]	>0			Wall: 6 Roof: 7.5 Garage: 5
a, Absorption coefficient	0	1		
External surface				

[10] Negative values are not allowable

INPUT PARAMETER	ALLOWABLE VALUES [10]		SUGGESTED VALUES	
	MIN	MAX	MIN	MAX
heat resistance- R_{se} [m²K/W]				
F_sh, Shading coefficient	0	1		
In contact with the ground				
Area (m²)	>0			
U- value [W/(m²·K)]	>0			
Depth [m]				
Perimeter [m]				
Internal in contact with unconditioned thermal zone				
Area (m²)	>0			
U- value [W/(m²·K)]	>0			
Transparent Elements				
In contact with the ambient air				
Orientation- γ [deg]	0	359		
Tilt - β [deg]	0	180		
Area [m²]	>0			
U- value [W/(m²·K)]	>0			
g_w, Permeability	0	1		
F_{sh}, Shading coefficient	0	1		
In contact with unconditioned space				
Area [m²]	>0			
U- value [W/(m²·K)]	>0			
Thermal Bridges				
Linear Thermal Transmittance [W/K]	>0			
Length [m]	>0			
Technical Systems				
Heating				
Production Unit				
Power	0			
Efficiency	>0			
SCOP	>1			
Coverage Ratio	0	1		

INPUT PARAMETER	ALLOWABLE VALUES [10]		SUGGESTED VALUES	
	MIN	MAX	MIN	MAX
Distribution System				
Power	0			
Efficiency	>0			
Terminal Units				
Power	0			
Efficiency	>0			
Ancillary Units				
Power	0			
Cooling				
Production Unit				
Power [kW]	0			
Efficiency	>0			
SEER	>1			
Coverage Ratio	0	1		
Distribution System				
Power [kW]	0			
Efficiency	>0	1		
Terminal Units				
Power [kW]	0			
Efficiency	>0			
Ancillary Units				
Power [kW]	0			
DHW				
Production Unit				
Power [kW]	0			
Efficiency	>0			
SCOP	>1			
Coverage Ratio	0	1		
Distribution System				
Power	0			
Efficiency	>0			
Storage				

INPUT PARAMETER	ALLOWABLE VALUES [10]		SUGGESTED VALUES	
	MIN	MAX	MIN	MAX
Efficiency	>0			
Ancillary Units				
Power	0			
Lighting				
Installed Capacity [kW]	>0			
Lighting Capacity controlled by Presence Sensor	0	≤ Installed Capacity		
Lighting Capacity controlled by natural Lighting Sensor	0	≤ Installed Capacity		
Lighting Capacity controlled by Natural Lighting and Presence Sensor	0	≤ Installed Capacity		
Solar Thermal Collectors				
Orientation- γ [deg]	0	359		
Tilt - β [deg]	0	180		
Area (m²)	> 0			
F_sh, Shading coefficient	0	1		
Exploitation factor	> 0	1		
Photovoltaics				
Orientation- γ [deg]	0	359		
Tilt - β [deg]	0	180		
Area [m²]	> 0			
F_sh, Shading coefficient	0	1		
Exploitation factor	> 0	1		