D^2EPC Information Model for Next Generation EPCs v2

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Executive Summary

The main aim of the task *T2.5 D^2EPC Information model* is to extend current standards/protocols used for issuing certificates and include Smart Readiness, Human-Comfort and Wellbeing, Life Cycle Assessment and Cost and Economic indicators delivered under tasks T2.1-T2.4. This report presents the IFC parser framework guidelines in what way information for those indicators' calculations will be extracted.

Deliverable consists of two main parts:

i. State-of-the-art analysis.
ii. Guidelines for extracting required data (concerning KPIs: SRIs, HCWIs, EPIs, LCAIs and CEIs) from IFC.

The methodology part revealed the differences between asset and operational ratings. The main point is that operational rating is based on weighted measured amounts of delivered and exported energy, and asset rating is based on calculated values. Energy Performance of Buildings (EPB) Rating procedures are described in detail, which lets us understand the current situation in the evaluation process.

The state-of-the-art analysis disclosed IFC's importance in this project. It was decided to choose the IFC standard because it is an open BIM standard that provides information such as geometry, material, price, etc. In addition, it is recognized by ISO as the official international standard ISO 16739.

In D^2EPC project, it is crucial that IFC interoperability allows BIM to be integrated into the Internet of Things (IoT), and this data can improve this set of information by providing a dynamic real-time and recordable state of actual construction and performance. Some sensors can be described using IFC, but the IFC schema does not support the full description of monitoring information. It is important to know that using a standardized proxy server can cause you to lose semantic information. To avoid information loss, the design of the IFC schema extensions should consider enabling BIM-based descriptions of monitoring systems that will comply with the IFC schema.

Data exchange using various BIM software industry fund class (IFC) schemes was offered by Building Smart International. Although IFC can define and transmit the physical geometry of a building, including energy characteristics and construction products and its properties, interoperability problems arise during two-way data flow.

It is noted in the scientific literature that the discrepancy may be due to the fact that some software tools can only import or export IFC files, and only some of them can import and export IFC files related to the official IFC certification table. In this age of digitization, BIM interoperability problems with the IFC scheme are becoming more common with the application of numerous BIM software tools, especially when transferring complex buildings. However, the researchers point out that IFC-based data exchange across different BIM platforms remains practically possible, despite the inconsistencies that arise, while the IFC needs to be improved for a continuous and stable data transfer process.

In the next section, Key performance indicators that are considered important within the EPC issuance process were described. Cost and Economic indicators will be represented later.

For the extraction of the relevant data for indicators by using an open international standard, IFC parser guidelines presented in this report are written in Python programming language using open-source IfcOpenShell-Python and Pandas modules. IfcOpenShell-Python is an open source (LGPL-Lesser General Public License) software library that helps users and software developers work with the IFC file format. Pandas is a quick, vigorous and easy-to-use open source data analysis and manipulation tool, based on the Python programming language. The detailed definition and the code of the application are presented in the report as well. The additional file is added and belongs to the report as additional documentation.

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List of Acronyms and Abbreviations

Term	Description
BEPS	**Building Energy Performance Modelling**
BIM	**Building Information Model**
CEIs	**Cost and Economic Indicators**
D	**Deliverable**
dEPC	**Dynamic Energy Performance Certificate**
DT	**Digital Twin**
EPB	**Energy Performance of Buildings**
EPBD	**Energy Performance of Buildings Directive**
EPC	**Energy Performance Certificate**
EPIs	**Energy Performance Indicators**
EU	**European Union**
HCWIs	**Human-Comfort and Wellbeing Indicators**
IFC	**Industry Foundation Classes**
ISO	**International Organization for Standardization**
LCA	**Life Cycle Assessment**
LCAI	**Life Cycle Assessment indicators**
LGPL	**Lesser General Public License**
SRI	**Smart Readiness Indicators**
T	**Task**
WP	**Work Package**

1 Introduction

1.1 Scope and objectives of the deliverable

The main objective of WP2 is to analyse and define a set of indicators dedicated to the next generation EPCs schema, including SRI, LCA and financial indicators and considering user wellbeing aspects (thermal/vision comfort, air quality). The whole WP delivered the system's information model to optimally support information flow among the various components and necessary requirements and steps for ensuring a common way for auditing and implementation of next generation EPC format.

T2.5 task extended in a uniform manner all the new features proposed by the D^2EPC framework, including mainly the additional indicators delivered under T2.1-T2.4 tasks. This deliverable is the second and last version of the D^2EPC Information Model.

1.2 Structure of the deliverable

The purpose of the deliverable D2.10 of the D ^ 2EPC project is to gather all the information collected in updated deliverables D2.6 to D2.10 of the project, regarding the indicators that will describe the energy and environmental performance of the building in order to develop the appropriate environment to extract these indicators from BIM documents. For this purpose, both the indicators and their calculation procedure, as well as the IFC parcing proposed workflow, which is used to extract these indicators from BIM files are presented as part of this deliverable.

In this regard, this deliverable consists of five chapters.

- Following the introductory chapter of the deliverable, a chapter follows in which the methodology employed is analyzed. Specifically, aspects of the field research implemented under the program are presented. The certification procedures of the buildings are presented, as well as a targeted analysis of the current state of the art in the field.
- Second section of the deliverable presents State-of-the-Art analysis.
- The third section is dedicated for the key performance indicators, developed under T2.1-T2.4 tasks.
- The fourth section of this deliverable focuses on the presentation of the indicators that is used to enrich the information provided in the certificates. Specifically, the input, output and the process of calculating the indicators related to the intelligence of the building, the thermal comfort conditions, the life cycle analysis and the financial analysis of the buildings are presented in detail.
- The fifth chapter focuses on the presentation of the IFC parcing reference approach, which is used in the project for calculation of the indicators from BIM documents. The proposed IFC parser workflow developed for the purpose is given in detail in this section.

1.3 Relation to Other Tasks and Deliverables

T2.5 analysis, guidelines and conclusions used towards the development of a dynamic EPC for the building and further works of work package three (WP3), work package four (WP4) and work package five (WP5). The scheme (Figure 1) below shows the interactions with other tasks of work package two (WP2).

The T2.5 task, as shown in the diagram, is related and depends on D1.3, D1.6, D1.4 and D1.9 deliverables. The IFC parser guidelines developed under this task is highly dependent on indicators T2.1 to T2.4. The first version of the indicators was obtained in the D2.5 deliverable. D2.10 presents updated the D^2EPC information model upon receipt of the final D2.6-D2.9 deliverables.

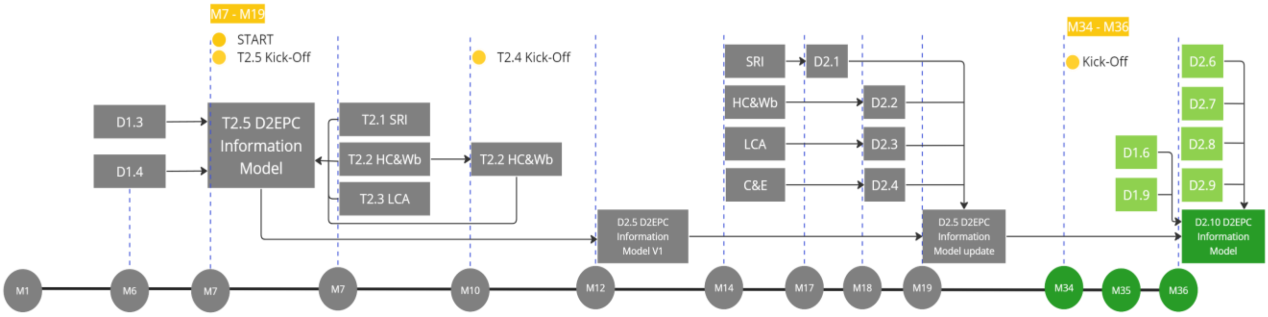


Figure 1. Task's T2.5 interactions with other tasks and deliverables

2 Methodology

D^2EPC aspires to deliver the next generation of dynamic EPCs for the operational and regular assessment of buildings' energy performance through a set of cutting-edge digital design and monitoring tools and services. D^2EPC relies upon and adjusts accordingly to the Smart-Readiness level of the buildings and the corresponding data collection infrastructure and management systems. It subsequently builds upon actual data and the "Digital Twin" concept to calculate energy, environmental, financial, and human comfort indicators and through them result in the final EPC classification of the building in question.

2.1 Objectives and actions

The main goal of the D^2EPC project is to evaluate the asset and the operational performance of a building. As described above, the existing system had shortcomings, such as differences between calculated and measured energy consumptions, which cause dissatisfaction with the certification system.

Within the project framework, the building will be assumed not as a single unit but as a set of separate premises (zones) with additional comfort and energy consumption values. Manual descriptions of distinct zones would require huge labour work efforts, but the automated processes could quickly solve this task.

The most popular format for data transfer between building models and other related software is IFC. In principle, IFC, or "Industry Foundation Classes", is a standardized, digital description of the built environment, referring both to buildings and civil infrastructure. The characterization of a building is based on an open, international standard (ISO 16739-1:2018) meant to be vendor-neutral, or agnostic, so that it can be used under several cases by a variety of hardware devices, software systems, and interfaces [1]. Even though, the IFC documentation can provide extensive documentation to support the building's description, only a predetermined set of data is required to perform the relevant calculations for the determination of the previously mentioned indicators. Based on these data, calculation methodologies will be applied to show-building key performance indicators. After defining the main indicators and establishing the methods for their calculation, it will be analysed what kind of data have to be obtained from the static model and which have to be taken from the sensors.

2.2 Field research

2.2.1 Definition of asset and operational ratings

Operational rating – energy performance based on weighted measured amounts of delivered and exported energy. The measured energy performance is the weighted sum of all energy carriers used by the building, as measured by meters or derived from measured energy by other means. It is a measure of the in-use performance of the building after correction or extrapolation. This is particularly relevant to the certification of actual energy performance [2].

Asset rating – energy performance based on calculated values related with the building's "after construction" data (prior to or during operation) and standard use data set. It refers to the calculated intrinsic annual energy use of a building under standardized conditions. This is particularly relevant for the energy performance certificate, as well as for regulation purposes (verification of compliance with requirements) [2].

2.2.2 Type of assessment

Depending on input data source there could be indicated few types of assessment procedures:

- Calculated design (asset rating);
- Calculated as built (asset rating);
- Measured actual (operational rating);
- Measured Standard (corrected for climate and use) (operational rating) [2].

2.2.3 Energy performance of buildings (EPB) Rating procedures

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 [2].

There are various ways to express the overall or partial energy rating of a building or a building feature and they can be defined based on the value of the energy performance indicator compared to reference values.

The following default energy rating methods are described in the Energy performance of buildings - Indicators, requirements, ratings, and certificates standard ISO 52003-1:2017:

- Default energy rating method with two reference points;
- Default energy rating method with a single reference point;
- Other energy rating methods [2].

These methods are elaborated in detail below.

2.2.3.1 Default energy rating method with two reference points

- The performance scale shall range from A (buildings of best energy performance) to G (buildings of worst energy performance).
- The energy performance regulation reference, R_r, shall be placed at the boundary between two classes, for instance, classes B and C.
- The building stock reference, Rs, shall be placed at the boundary between two classes, for instance, classes D and E.
- A building with a net delivered energy equal to 0 shall be placed at the top of one of the classes, for instance, class A.
- Subclasses may be defined in order to expand the classes, e.g., class A may be expanded with A+, A++, A+++ [2].

2.2.3.2 Default energy rating method with a single reference point

- The performance scale shall range from Class A to Class G.
- Subclasses may be defined in order to expand the classes, for instance class A may be expanded with A+, A++, A+++.
- The boundaries of the classes are based on a nonlinear scale ($Y = \sqrt{2}^{(n-n_{ref})}$).
- The energy performance regulation reference, Rr, shall be placed at the boundary between two classes, for instance classes 4 and 5 (n_{ref} = 4). The value of nref in formula $Y = \sqrt{2}^{(n-n_{ref})}$

determines the position of regulation reference, Rr, on the scale. The choice of the boundary, nref, is given in Table 1 (normative template) with an informative default choice given in Table 2 [2].

2.2.3.3 Other energy rating method

- Any other method for energy rating.
- This third choice can also be used to open up some of the details of the default energy rating method 1 or 2 for (national) choice by specifying another energy rating method that resembles the default method 1 or 2 but differs in some detail not foreseen in the default choices in Table 1 and Table 2.

Table 1. Energy rating methods [2].

Method	Choice[a]
Default energy rating method with two reference points	YES or NO
Default energy rating method with a single reference point	YES or NO
Other energy rating method	YES or NO
In case of method 1:	**Parameters**
Subclasses to expand the classes	**…**
Position of the energy performance regulation reference, R_r,	Between class .. and ..
Position of the building stock reference, R_s,	Between class .. and ..
Measure for the building stock reference	Median (50 %)
Position of $EP = 0$	Top of class ..
In case of method 2:	**Parameters**
Subclasses to expand the classes	…
Boundary for the reference position, n_{ref}	0 to 6
In case of method 3:	**Reference**
Reference to procedure:	<reference>
[a] Only one "YES" is possible.	

Table 2. Energy rating methods [2].

Method	Choice[a]
Default energy rating method with two reference points	NO
Default energy rating method with a single reference point	YES
Other energy rating method	No
In case of method 1:	**Parameters**
Subclasses to expand the classes	**A+**
Position of the energy performance regulation reference, R_r,	Between class B and C
Position of the building stock reference, R_s,	Between class D and E

Measure for the building stock reference	Median (50 %)
Position of $EP = 0$	Top of class A
In case of method 2:	**Parameters**
Numbering of the classes 1 to 7	A to G
Subclasses to expand the classes	A+ (EP < 0)
Boundary for the reference position, n_{ref}	4 (D)
In case of method 3:	**Reference**
Reference to procedure:	Not applicable
[a] Only one "YES" is possible.	

2.2.4 Energy certification procedures

According to ISO 52003-1:2017 standard, the following shall be included in a procedure for a building energy certificate:

- Energy performance assessment.
- Specification of the cases where the procedure for a building energy certificate applies.
- Specification of the type of Energy performance (EP) assessment used:
    - Calculated design (asset rating);
    - Calculated as-built (asset rating);
    - Measured actual (operational rating);
    - Measured Standard (corrected for climate and use) (operational rating).
- Specification of what the overall numerical indicator represents and specifically, which energy services are included and if renewable energy produced on-site is part of delivered energy or not and if exported energy is considered.
- Specification of whether and (if so) how the overall numerical indicator is normalized for the building.
- Specification of:
    - which energy performance requirements apply, and
    - how each of the requirements is expressed?
- Specification of the reference values and the procedure to define the values including the way the impact of certain parameters is modified.
- Specification of other information on the energy performance of main building and system elements required on the certificate (if any).
- Specifications and assessment procedures on additional indicators required on the certificate (if any).
- Processes to evaluate the recommendations for cost-effective improvements, and for which applications these are required on the certificate.
- Setup and processes to evaluate the energy performance rating presented on a scale or as a class.
- Specific additional content on the certificate to identify the building characteristics.
- Specification of any other additional information required on the certificate (if any).

- General procedures for the completion of the administrative and technical data required on the certificate.
- Format of the certificate, and which content is to be given in the certificate itself and which is to be given in an accompanying report.
- If this is part of the certification procedures, the purpose of this procedure is to ensure that the data obtained from the energy certificates describing the building stock are stored in an organized way and in a central place (one database) [2].

2.3 Targeted State-of-the-Art analysis

In order to empower the BIM model as the data source for the energy performance evaluation, several types of solutions can be distinguished:

- Integration of a simulation engine into the BIM tool or direct coupling using the Application Programming Interface (API) of such software.
- Export of the relevant information from the BIM tool to a file using the gbXML format and following import of this file into the simulation software.
- Export of the entire BIM (or preferably the relevant parts of it) to the Industry Foundation Classes (IFC) format and subsequent import of that file into the simulation software [3].

2.3.1 Definition of IFC

Building Information Modelling (BIM) is currently used by the construction sector in many countries as a relatively new design method [4]. BIM is usually coupled with Industry Foundation Classes (IFCs), which constitutes an official international standard, ISO 16739, since 2013 [5]. IFC is an open BIM standard containing information such as geometry, material, cost, etc. It is an object-based file format with a data model that enables architecture, engineering, and construction industry to interact and work together interoperably, and is commonly used in BIM-based projects [6].

The use of BIM exceeds the design and implementation phases of a project, reaching post-construction use in building lifecycle management and it has vital importance in smart buildings (structures). These smart buildings often are equipped with sensors for the monitoring and control of assets in real-time, using intelligent, networked processes [7]. The BIM-based approach towards describing monitoring-related information using the IFC is relatively new: there is a limited number of studies that have examined the relationship among physical objects, schedule, and quality management information relevant to inspection and real-time monitoring [7, 8].

IFC interoperability allows BIM integration with the Internet of Things (IoT) that enables a continuous flow of real-time data. BIM models represent valuable information concerning the building's functional and physical characteristics such as geometry, location, material properties, while, data coming from and sensors can further increase the set of information by providing dynamic real-time and recordable status from the actual operations in construction and operations [9]. These smart buildings (structures) consist a new engineering approach that incorporates the results from sensors, devices and actuators under a unified system that can respond in real-time to changes in the environment [10].

IFC can be used to describe single sensors, but a full description of the information coming from sensoring devices is not supported by the IFC schema. Generic IFC constructions, such as proxy elements and user-defined property sets, can be used to describe monitoring-related information with the IFC schema. However, using proxy standardized property sets might lead to a loss of semantic information. To avoid information loss, the IFC schema extensions should be designed in such a way to allow for BIM-based descriptions of sensoring systems, according to the IFC schema [7].

2.3.2 Definition of IFC parser (API)

The IFC schema targets a variety of different use cases and requirements. Model View Definitions (MVD) specify a subset of the IFC schema and are used to certify software applications for the import and export of IFC models. However, the official MVDs are perceived too general for the cases of a variety of tasks and need to be extended to allow for more specific exchange scenarios [11, 31].

One of the ways to exchange data is a direct link using application programming interfaces (APIs) [12]. An application programming interface (API) represents a connection between computers or between computer programs. It is a type of software interface, allowing communication between different pieces of software [13]. Through the API's BIM elements like sensing technologies, recognition, position technologies etc., are able to communicate [9].

IfcOpenShell is an open source (LGPL) software library that allows users and software developers to use the IFC file format. IfcOpenShell uses Open CASCADE (the Open CASCADE Community Edition) internally to convert the implicit geometry in IFC files into explicit geometry that can be readable by any software CAD or modelling package [14]. To handle IfcOpenShell IFC4 requires an I2M compatible IFC and the I2M-MVD as input [15].

2.3.3 Interoperability

Regarding the Industry 4.0 revolution in the construction sector, Building Information Modelling (BIM) software significantly increased in the past decade [16]. With the increased use of the BIM methodology, the interaction of different disciplines through BIM software is becoming a common process that results from various data formats, interfaces and disturbance in collaboration. The data exchange through various BIM software Industry Foundation Classes (IFC) schema was proposed by the "Building Smart International". Although IFC can define and transmit the physical geometry of the building, which entails energy characteristics and construction products and its properties, interoperability issues arise during bidirectional data flow. The discrepancy may occur because some software tools can only import or export IFC files, and just some of them can both import and export IFC files regarding the official IFC certification table [17].

The official IFC evaluation process consists of two steps [18]. In the first step, a range of object-level models such as walls, beams, slabs, columns are included. Concerning the intricacy of the building and the number of models, the software selects the most common models for the test in the certification process. Subsequently, several project models combined from the most objects initially are used for further certification. So, suppose the objects that are exchanged in IFC format are in high complexity. In that case, data exchange without loss of the properties, parameters, or similar isn't ensured even for the tools that have IFC certificate. It was stated [19] that the certification process is "more of a test of the ability to exchange information via IFCs rather than the quality of the exchange". A summarized table [19] of data interoperability in software tools using IFC schema reveals that data loss during the exchange process is a common problem in the data sharing process. While using the IFC schema for the exchange of information, missing objects and properties, varying object types, geometric inaccuracies, and similar discrepancies may occur. As for issues related to differences, some researchers [20] draw attention to the incomplete mapping between software native models and IFC models. In the experimental part of [19], the researchers point out that if the IFC model created with the tool or belonged to the same discipline that imports the model can perform the interpretation well. The re-exported model in the same tool also has a great consistency to the original one. In these cases, great interoperability is achieved regarding semantic compatibility. If the software imports an IFC model created with a third-party tool, a part of the model data can be lost/misrepresented.

Concerning BIM interoperability with energy analysis tools using the IFC schema, equivalent interferences may arise. As pointed out before, it may occur because of different definitions of the materials or the properties of the various software. Researchers [21] proposed to add Ashrae based material information library and perform the mapping of the materials by the different software. One of the analysed studies shows that when the building-related information (material properties, etc.) from the native model, which are subtracted into the IFC file, are mapped to the integrated material library (using a developed converter), can reduce discrepancies. Overall, "the data interoperability for the energy performance assessment is mapped to the material name to solve the interoperability problem" [21].

BIM interoperability issues using IFC schema are arising more frequently with the increasing use of different BIM software tools, especially when complex buildings are transferred. Nevertheless, the researchers point out that IFC-based data exchange through different BIM platforms remains feasible in practice regardless of arising discrepancies. However, the need for improvements for the IFC remains for the continuous and stable data transfer process. Researchers [19-23] proposes recommendations for the better interoperability of BIM. As a solution, it can use the same software tools or add-ins for all stakeholders, data converters that include the mapping between different platforms or similar. Also, effort should be made for the IFC schema improvement to minimize arising interoperability of BIM platforms.

3 Asset and Operational Ratings in D^EPC Framework

3.1 Asset rating in D^2EPC framework

The asset rating system assesses the energy performance of a building, taking into account post-construction data and a standard set of asset values. It aims to assess the quality of construction for first-time users such as buyers or tenants. The scheme calculates theoretical energy consumption based on the building envelope and services (e.g. heating, cooling and lighting), but does not take into account the actual operation, which leads to confusion and mistrust among stakeholders.

Efforts to develop a unified European energy rating system for buildings have resulted in regional implementation, leading to different Energy Performance Certificate (EPC) schemes. Some countries use a "reference building" approach, while others use reference values. In addition, building descriptions vary from country to country, making the EPC process more complex, lengthy and costly, and increasing the likelihood of errors.

It is clear that the EU needs to review and harmonise its property valuation system in order to better meet the decarbonisation targets for buildings. The proposed D^2EPC real estate valuation methodology offers a uniform approach to the valuation of the energy efficiency of buildings across the EU. It is based on established standards and incorporates insights from national EPC schemes. It uses Building Information Modelling (BIM) and literacy to simplify documentation tasks and reduce time, costs and errors. Despite automation, auditors remain crucial in verifying the building model and the final result.

This unified property valuation system helps to solve the problems caused by different methodologies, increases the value of EPCs in the European building market and facilitates strategic carbon planning [22].

The key performance indicators (KPI), which are used in asset rating calculation methodology under the D^2EPC framework are presented in Figure 2.

			Indicators	Units
Asset Rating	LCA Indicators	Environmental Indicators	Climate Change	kgCO_2 eq/kg
			Ozone Depletion Potential	kg CFC 11 eq
			Acidification Potential	kg SO_2 equivalents per kg
			Eutrophication Aquatic Freshwater	kg P equivalents
			Eutrophication Aquatic Marine	kg N equivalents
			Eutrophication Terrestrial	mol N eq.
			Photochemical Ozone Formation	kg NMVOC eq.
			Depletion of abiotic resources-minerals and metals	kg Sb eq.
			Depletion of Abiotic Resources-fossil Fuel	MJ
			Water Use	m^3
			Use Stage Energy Performance	kWh/m^2/yr
			Lyfe Cycle Global Warming Potential	kg CO_2 eq. per 1m^2 per year
			Bill of Quantities, Materials and Lifespans	Unit qt., mass & years
			Construction & Demolition Waste and Materials	kg of waste & materials for 1m^2
			Design for Adaptability & Renovation	Adaptability score
			Design for Deconstruction, Reuse and Recycling	Deconstruction score
			Use Stage Water Consumption	m^3/year of water per occupant
	Smart Readiness Indicators	Domain Scores	Domestic Hot Water	%
			Ventilation	%
			Lighting	%
			Dynamic Building Envelope	%
			Electricity	%
			Electric Vehicle Charging	%
			Heating	%
			Cooling	%
			Monitoring and Control	%
		Impact Scores	Energy Efficiency	%
			Energy Flexibility and Storage	%
			Comfort	%
			Convenience	%
			Maintenance and Fault Detection	%
			Information of Occupants	%
			Health and Wellbeing Accessibility	%

Figure 2. Asset Rating Indicators

3.2 Operational rating in D^2EPC Framework

The D^2EPC project plays an important role in improving methodologies for assessing the energy performance of buildings. It focuses on the operational energy rating of buildings, which calculates energy performance based on actual energy consumption. It recognises the key role of Building Energy Performance Modelling (BEPS) tools in calculating EPCs, particularly for determining buildings' heating and cooling loads.

Therefore, the D^2EPC project used BEPS tools to calculate the energy performance based on the actual energy consumption of the buildings, referred to as the operational assessment. The importance of this rating methodology has been underlined by the advocacy for its inclusion in dynamic EPCs. It is an invaluable tool for relevant stakeholders, practising engineers and EPC assessors responsible for implementing the D^2EPC principles in the certification of buildings. The methodology developed under the D^2EPC project follows a common approach for buildings across Europe, further standardising the assessment process.

Adopting the performance measurement methodology is a progressive step as it focuses on actual energy consumption data rather than theoretical calculations. The performance rating considers real factors such as building use, climatic conditions and the actual performance of building systems, giving a more accurate indication of the energy efficiency of the building. By incorporating real energy consumption data, targeted interventions can be taken to improve the energy performance of the building, thereby increasing energy efficiency and the comfort of the building occupants.

The methodology for assessing the energy performance of the D^2EPC project activities has been adapted to the next-generation D^2EPC tool, which uses a suite of advanced digital design and monitoring tools and services. These advanced tools increase the accuracy of energy performance assessments and provide detailed information on the energy performance of a building. As the building industry embraces digital transformation, using such tools becomes even more important for improving the energy performance of buildings and achieving sustainability objectives.

Further contributing to the energy performance assessment of buildings, the D^2EPC project aimed to increase the usability and efficiency of the next generation of EPCs. The project introduced several indicators of building intelligence, environmental performance, financial efficiency and occupant comfort. These indicators relate to different aspects of building energy performance and provide a holistic view of building energy efficiency and sustainability.

The D^2EPC project provides several indicators that cover aspects of smart readiness, thermal comfort and LCA, including monetary and cost-optimal key performance indicators (KPIs). These indicators include the Smart Readiness Indicator (SRI), which assesses the readiness of a building to use smart technologies; the Life Cycle Assessment (LCA) for environmental performance; the Life Cycle Costing (LCC) for financial performance; and the occupant comfort aspects (Figure 3).

Including these indicators further enhances the usefulness of the EPC by providing stakeholders with a comprehensive understanding of the energy performance of a building and allowing targeted interventions to improve energy efficiency. The inclusion of indicators reflects the project's commitment to enhancing methodologies for assessing the energy performance of buildings for the benefit of the construction industry, building occupants and the wider community.

The D^2EPC project focuses on actual energy consumption while introducing a range of indicators - a major advance in methodologies for assessing the energy performance of buildings. By taking a more comprehensive and data-driven approach, the project contributes to improving the energy performance of buildings and achieving sustainability objectives. The above-mentioned helps to address the growing global concern about energy consumption and environmental impact, paving the way for a more sustainable future.

Operational Rating	Group	Indicators list	Units
Human Comfort & Wellbeing Indicators	Thermal Comfort Indicators	Deviation from the Temperature Range	%
		Thermal Degree Hours	numeric
		Deviation from the Humidity Range	%
		Deviation from the Acceptable WBGT Levels	%
		Humidex Levels	%
	Visual Comfort Indicators	Deviation from the Set Illuminance Boudndary	%
		Deviation from the Standard Illuminance Levels	%
		Set Visual Degree Days	%
		Standard Visual Degree Days	%
	Indoor Air Quality Indicators	Ventilation Rate	%
		Total Volataile Organic Compuonds	$\mu g/m^3$
		Benzene	$\mu g/m^3$
		CO_2 Indoors	%
		Formaldehyde	$\mu g/m^3$
		Radon	Bq/m^3
		Particulate Matter (PM 2.5)	$\mu g/m^3$
		Particulate Matter (PM 10)	$\mu g/m^3$
Financial Indicators	As-operated Costs	Cost per Month per Energy Use	Eur
		Cost per Month per Energy Carrier	Eur
		Total Cost per Month	Eur
		Total Cost per Year	Eur
		Total Cost per Square Meter	Eur
	As-designed Costs	Cost per Month per Energy Use	Eur
		Cost per Month per Energy Carrier	Eur
		Total Cost per Month	Eur
		Total Cost per Year	Eur
		Total Cost per Square Meter	Eur
	Total Cost Comparison	Total Cost Comparison per Month	Eur
		Total Cost Comparison per Year	Eur
	Predicted Costs	The Real Costs	Eur
		The Nominal Cost	Eur
		The Net Present Value for the Next 10 years	Eur
	Expected Costs	Estimated Replacement Cost	Eur
		Estimated Maintenance Cost	Eur
LCA Indicators	Energy Indicators	Total Power/Occupancy	kWh/occupants
		Total Power/Occupancy Hours	kWh/h*occupants
		Total Power/Area	kWh/m^2
		Total Power/Volume	kWh/m^3
		Heating Consumption per Energy Carrier/Occupancy	kWh/occupants
		Heating Consump per Energy Carrier/Occupancy-hours	kWh/h*occupants
		Heating Consumption per Energy Carrier/Area	kWh/m^2
		Heating Consumption per Energy Carrier/Volume	kWh/m^3
		Cooling Consumption per Energy Carrier/Occupancy	kWh/occupants
		Cooling Consump per Energy Carrier/Occupancy-hours	kWh/h*occupants
		Cooling Consumption per Energy Carrier/Area	kWh/m^2
		Cooling Consumption per Energy Carrier/Volume	kWh/m^3
		Weather-Normalized Heating & Cooling Energy Cons.	---
		Lightning/Occupancy	kWh/occupants
		Lightning/Occupanc-Hours	kWh/h*occupants
		Lightning/Area	kWh/m2
		Lightning/Volume	kWh/m^3
		Electrical Appliances Energy Consumption/Occupancy	kWh/occupants
		Electrical Appliances Energy Cons./Occupancy-hours	kWh/h*occupants
		Electrical Appliances Energy Consumption/Area	kWh/m^2
		Electrical Appliances Energy Consumption/Volume	kWh/m^3
		DHW Consumption per Energy Carrier/Occupancy	kWh/occupants
		DHW Consump. per Energy Carrier/Occupancy-Hours	kWh/h*occupants
		DHW Consumption per Energy Carrier/Area	kWh/m^2
		DHW Consumption per Energy Carrier/Volume	kWh/m^3

Figure 3. Operational Rating Indicators

4 Key Performance Indicators

Although remarkable progress has been achieved in the past few years concerning energy efficiency indicators for buildings (e.g. IEA Annex 53), these have still not been integrated into the EPC on a European level. The D^2EPC project aims to establish a set of indicators that will foster the reliability, user-friendliness, and cost-effectiveness of energy performance certificates across Europe. These indicators, which are human-centric and oriented towards the whole life cycle of the building, enable the evaluation of buildings in a holistic and cost-effective manner across several complementary dimensions that consider both the envelope and the system performances of buildings. New elements, including climate correction, final energy consumption and energy expenditure, and comfort levels, expressed also in monetary terms, are envisioned in the new scheme.

Key Performance Indicators are the set of indicators included in the Next Generation EPCs, including Smart Readiness Indicators (SRI) (Annex A), human comfort and Wellbeing indicators (Annex B), Life Cycle assessment indicators (Annex C) and Financial Indicators (Annex D). Results for the available list of indicators are presented in the indicated Annexes. In the D^2EPC platform, KPIs are the output according to which, a building will be assigned to a certain class based on a certain type of assessment.

The D^2EPC KPIs information table was developed under this task, which can be accessed by this **link**. It provides all the input required to calculate all the KPIs developed under the D^2 EPC framework.

4.1 Smart Readiness Indicators for EPCs

Smart technologies and their increasing uptake can induce remarkable, cost-effective energy savings, and on the same time enabling the improvement of indoor comfort leveraging on the increased capabilities of the building to adjust itself to the needs of the user. Smart buildings are considered as key enablers of future energy systems where a larger share of renewables will be available, including efficient supply distribution and increased demand-side energy flexibility [25].

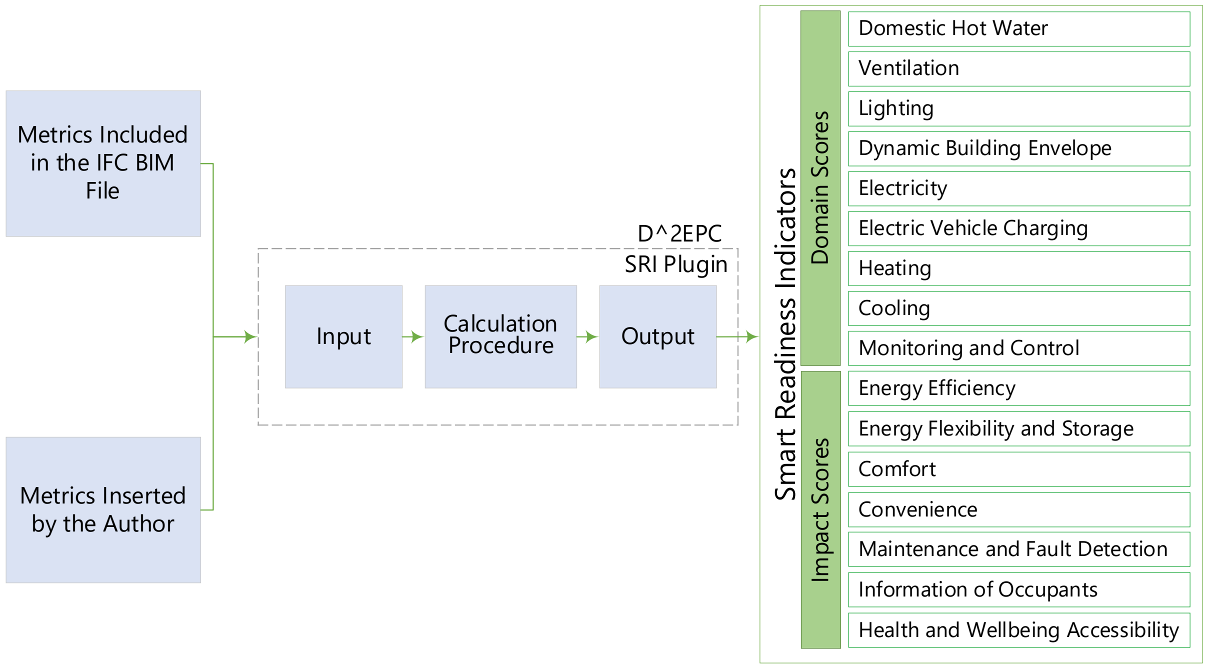


Figure 4. Smart Readiness Indicators Calculation Schema

According to the directive of (EU) 2018/844 of the European Parliament and Council of May 2018 on the energy performance of buildings, smart readiness indicators (SRI's) should be used to measure the capacity of buildings to use the information and communication technologies and electronic systems, to adapt its operation to both the needs of the occupants and the grid, including the improvement in energy efficiency and its overall performance (Annex A).

As a certification scheme, the SRI assesses the energy efficiency of a building, its interaction with the consumer and the reliability of the energy system in its interaction with the energy grid. It aims to encourage improvements through smart services and raise awareness of smart technologies and features among end-users and market actors. Thus, in the SRI scheme, the three main functions are the energy performance of the building, the responsiveness to user needs and the flexibility of energy demand. SRI aims to enable building users to optimise indoor comfort through dynamic and self-learning control systems. In smart buildings, cutting-edge ICT solutions are used to optimise the energy-efficient management of the building's technical systems and to control energy flexibility in daily operation [32]. The responsiveness of buildings to the grid is facilitated by real-time demand-side management systems, such as on-site energy storage and generation and e-mobility infrastructure. The SRI calculates the impact of all three of these features and provides a technology-neutral overview of the building's level of smart readiness.

Smart Readiness Indicators calculation scheme is provided in Figure 4.

4.2 Human-comfort and wellbeing indicators

The main purpose of a building is to provide a safe and comfortable environment for its users or occupants. During the last decades, the sector of building engineering is paying special interest in the part of human comfort and indoor environment conditions as they can have a great impact on the occupant's wellbeing human health, life and productivity [26]. More specific, several comfort parameters are under assessment, while buildings and their indoor environment have been improvised. Human comfort indicators vary from place to place, or seasonally according to climatic changes.

A set of comfort/wellbeing and behavioural profiles, along with the respective algorithms (for the extraction of the indicators values and user profiles) constitute the D^2EPC's Human Comfort & Wellbeing framework. Data from customised sensor networks (i.e., physical IoT sensors deployed in the pilot buildings) are utilised to capture the indoor ambient conditions and the occupant's activity (presence/absence). The acquired data enable the extraction of the user behavioral profiles which contribute to the determination of the building utilisation boundaries (e.g. heating/cooling/lighting operation to maintain the indoor conditions) that fall within the comfort zone of the occupants. Therefore, the HC&W framework provides context in regards to the constraints (i.e., operations, occupancy, end users' comfort preferences and behaviour) energy is consumed within a building taking into consideration human-centric features.

Under D^2EPC, three indoor environmental quality pillars have been examined. The thermal and visual comfort and indoor air quality. The personalised user profiles are extracted by a (thermal or visual) comfort profiling engine which acts upon historic data originating from regularly occupied spaces by the same occupants. Recommended boundaries -per environmental metric- have been also extracted by the literature and utilised in cases where the personalised profiling is not deemed applicable or relevant (lack of data or Wellbeing (IAQ) metrics). The overall approach generated a hybrid part-static, part-dynamic methodology presented in Figure 5. The defined human comfort and well-being indicators are listed in **Annex B**.

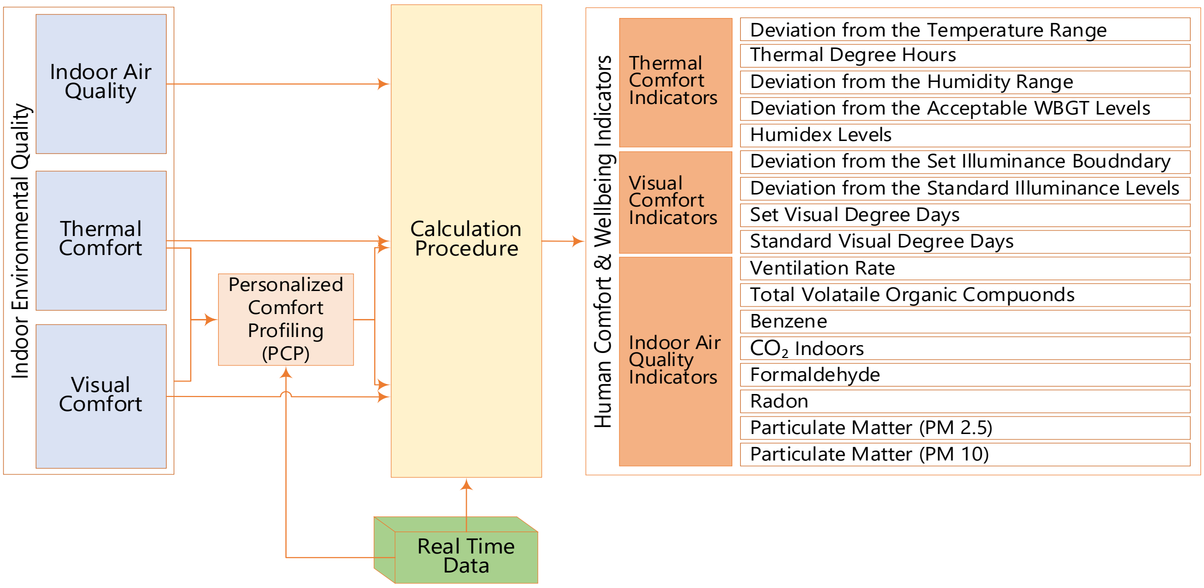


Figure 5. Human Comfort and Wellbeing Indicators calculation Schema

4.3 LCA Indicators

LCA indicators - additional indicators demonstrating the environmental performance of buildings for their introduction in the next-generation EPCs. Life Cycle Assessment (LCA) methodologies and tools are employed to develop the environmental indicators. LCA enables the evaluation of the environmental impact of any system throughout its lifecycle by considering the required input and associated output resources of that system. Following the implementation of a comprehensive literature review on the LCA of the energy performance of buildings, the type and functional units of the LCA Indicators for EPCs defined — examples of LCA Indicators include “Energy savings” expressed in “Embodied energy/ m2” and “Carbon reductions”, expressed in “Carbon dioxide equivalent/ m2”.

The above-mentioned highlights the importance of employing LCA. The LCA Indicators for EPCs significantly contribute to the maximization of energy savings and the achievement of carbon reductions of the buildings and complement the SRIs, social and financial indicators - T2.1, T2.2, T2.4, respectively- for the issuing of truly sustainable EPCs.

The LCA indicators under the D^2EPC framework are listed in Annex C and their calculation scheme is listed in Figure 6.

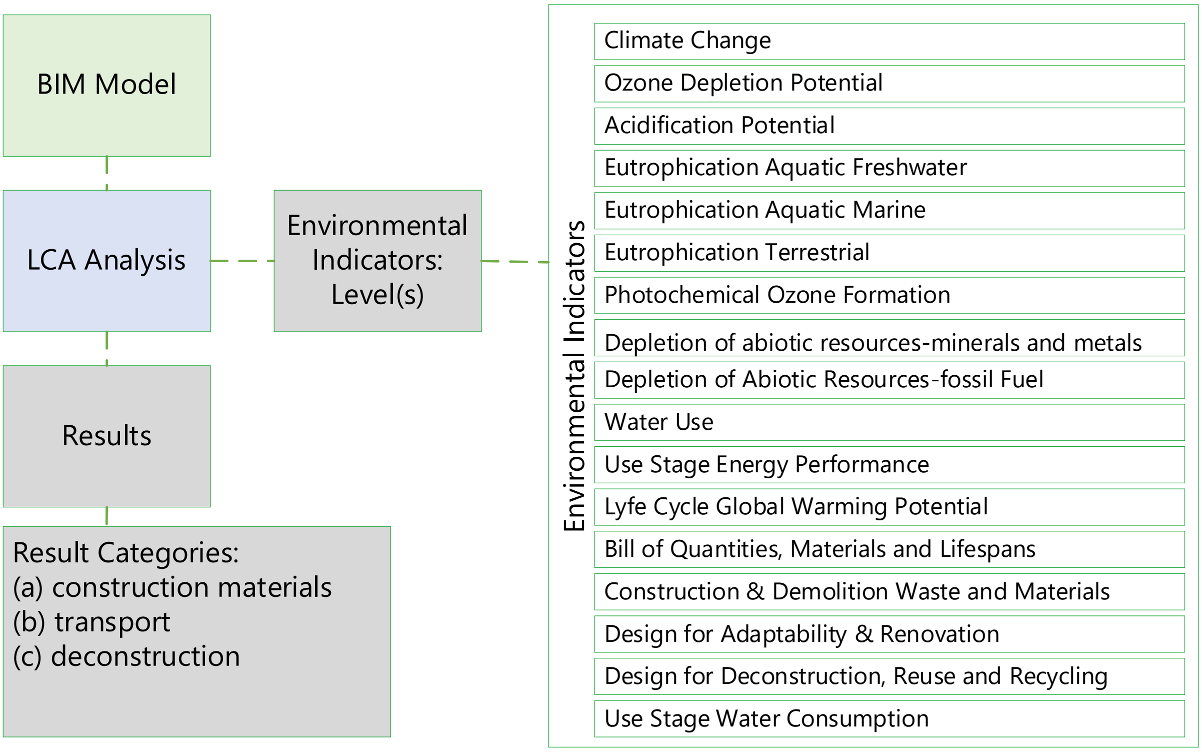


Figure 6. LCA Indicators calculation Schema

4.4 Financial Indicators for EPCs

A financial indicator is an indicator used to assess, measure and evaluate the overall macroeconomic situation. Economic indicators are usually obtained through a census or survey conducted by a government agency or private business information organisation and further analysed to produce an economic indicator [28]. One of the main concerns of the new generation of EPCs foreseen in the D^2EPC project is the identification of simplified indicators that increase the usability of the building certificate. In this respect, the project partners have developed a set of financial indicators based on the well-established concept of whole life costing to interpret the individual energy performance elements of buildings into normalised monetary values. The presentation of such indicators allows the use of EPCs for the financial assessment of energy retrofit measures for buildings. This allows the information obtained by the EPC to be used in energy auditing processes, bridging the gap between the energy-related EPBD directives and energy efficiency.

The financial indicators aim to raise consumer awareness of energy efficiency in buildings. This approach quantifies energy consumption in monetary terms, i.e., energy consumption is converted into euros. Tenants can see how much money they spend on energy and compare it with different scenarios (property value, operational value, predicted value). It is hoped that such indicators will allow for a financial evaluation of the building and thus provide additional information to the user. This could encourage them to adapt their behaviour to improve the energy efficiency of the building.

The development of financial indicators is based on the well-established Life Cycle Costing (LCC) concept. The LCC methodology is a decision-making tool that helps to evaluate different options over time. The indicators developed by D^2EPC are not intended for long-term planning or comparison of alternatives but are used as a reference for the LCC concept as it defines a representative range of costs throughout the construction, operation, maintenance and end-of-life phases. This approach estimates the relevant costs and presents them to the user as additional information for the next generation of dynamic EPCs.

The defined financial indicators (**Annex D**) have been presented in the relevant document D2.4 and updated in document D2.9.

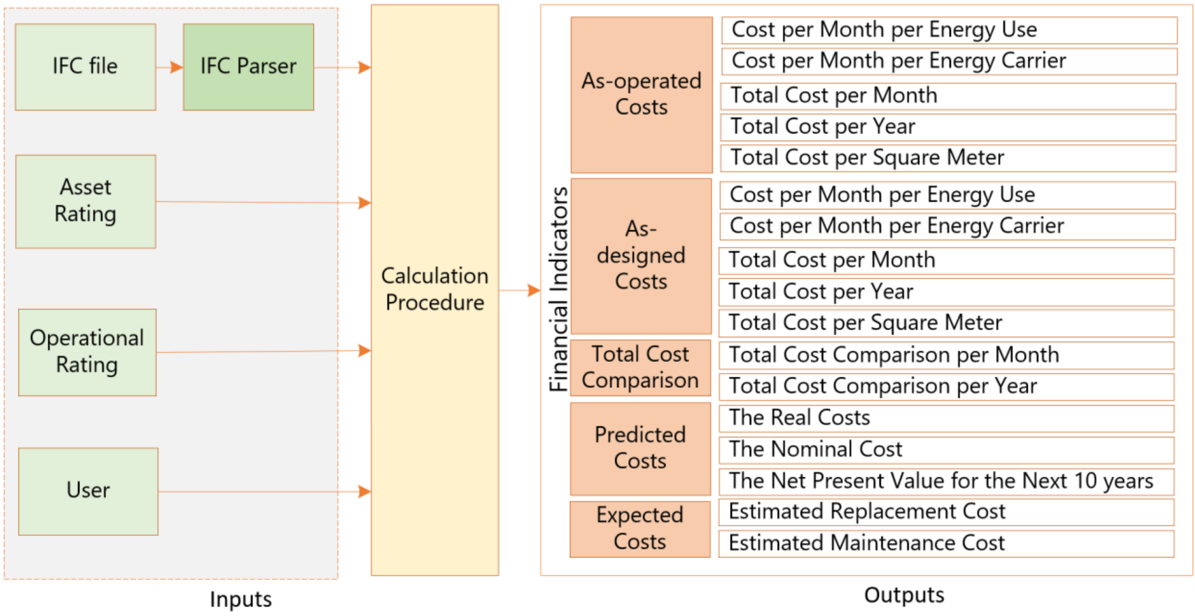


Figure 7. Financial Indicators Calculation Schema

5 IFC Parsing Reference Approach

5.1 IFC schema

The Industry Foundation Classes, IFC, is an open international standard for Building Information Model (BIM) data exchange and share. Commonly used software applications in the construction or facility management industry sector employ IFC [1].

The IFC schema specification is the primary technical deliverable of buildingSMART International, in view of promoting openBIM. In particular, the IFC schema is a standardized data model that codifies, in a logical way the following building elements and information (Figure 2):

- the identity and semantics
- the characteristics or attributes
- and relationships of objects
- abstract concepts
- processes
- people

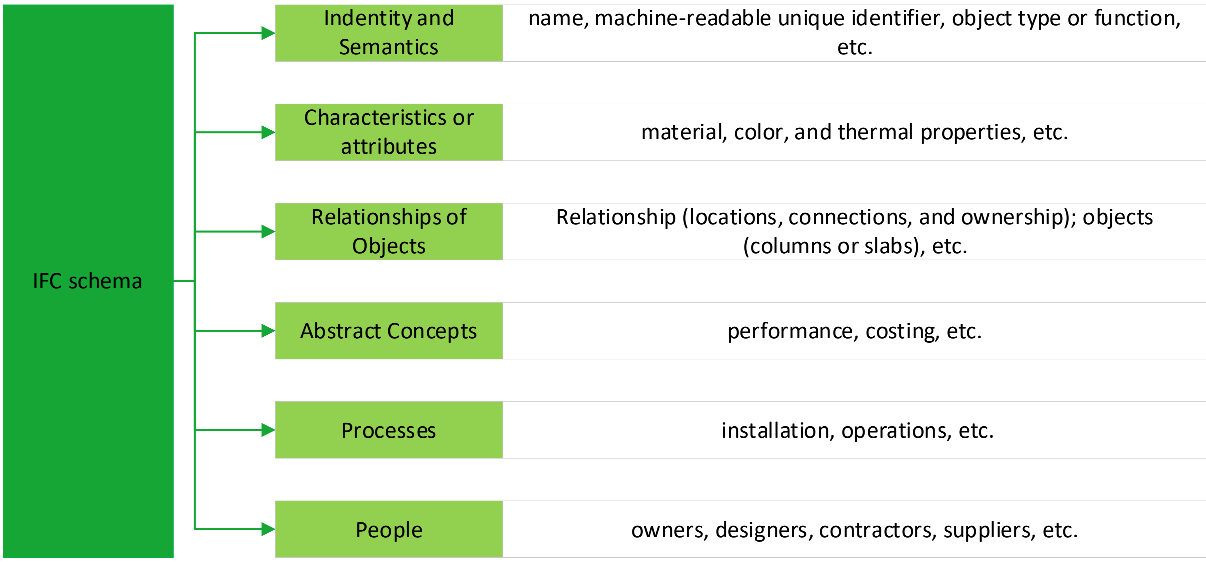


Figure 8. IFC Schema coding logic sequence

The schema specification can provide information on how a structure or installation is utilized, the way it's been constructed and how it performs. A non-exhaustive list of the information that can be defined with an IFC file includes

- physical components of buildings
- manufactured products
- mechanical/electrical systems
- more abstract structural analysis models
- energy analysis models
- cost breakdowns
- work schedules [5].

In D^2EPC project for IFC parser, IFC4 ADD2 TC1 used, published in ISO 16739-1:2018.

5.2 IFC parsing proposed workflow

The BIM model of the building contains various objects with descriptive attributes and parameters aligned to their geometry. Depending on the building complexity, a model can carry numerous objects with semantic data, which might not be relevant in some cases. For the D^2EPC project the information related to energy consumption, building envelope characteristics, human comfort, smart readiness indicators, and other energy-related information is crucial in the BIM model, while less relevant information cannot be considered.

The workflow of the overall information extraction procedure is presented in Figure 3. As a first step for the required information exchange and extraction, the BIM file of the building should be exported to an IFC file using the BuildingSMART IFC schema. The IFC reference file enables the communication between different software tools for further data extraction and analysis.

IFC file parsing application should be based on lexical analysis. The parsing process consists of the following steps:

- conversion of the character sequence into word sequence
- grammar check
- data structure construction of composed words and values.

An IFC Parser can extract EPC relevant information stored in the BIM model, regarding to submitted needs i.e., a list of the material parameters of the building envelope for the energy calculations. Lexically parsed information can be presented in a structured way in various types of output formats suitable for further processing. The proposed IFC Parser workflow (Figure 9, the structure and the procedures are described in detail in section 5.4.

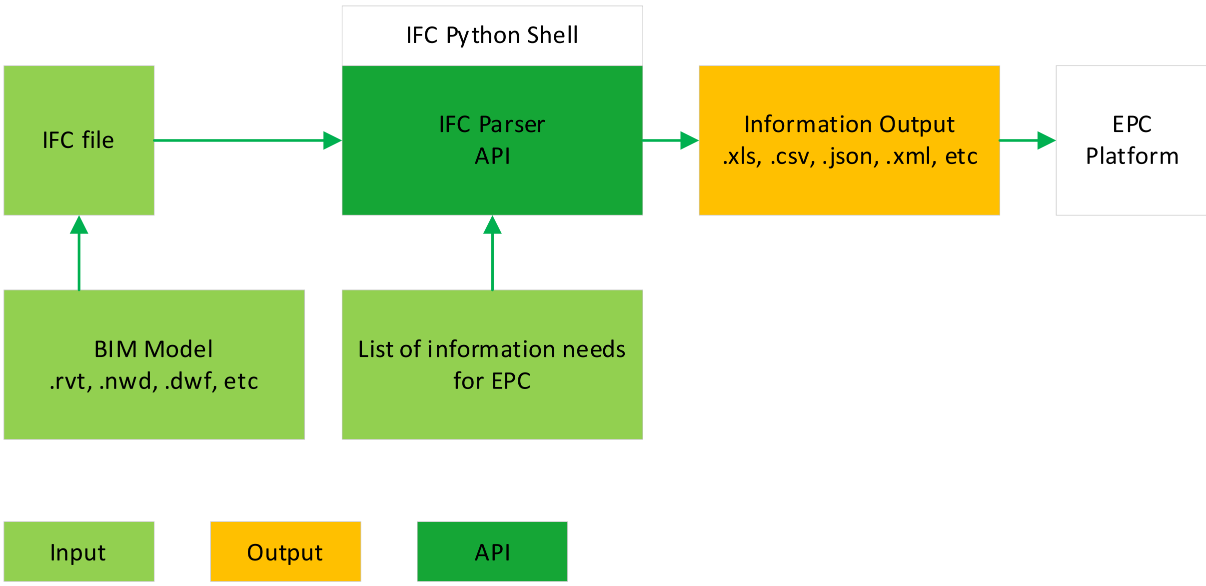
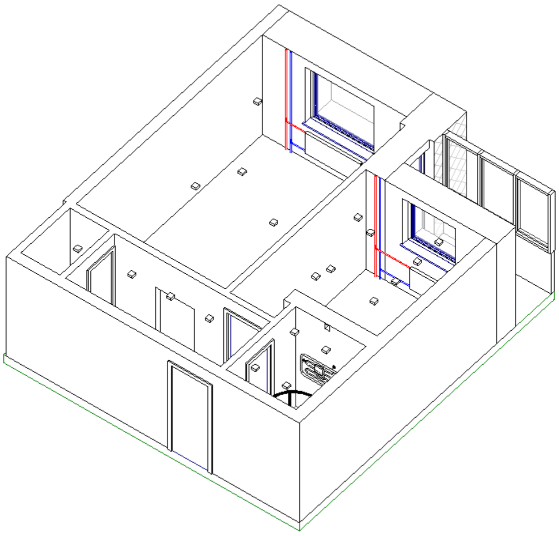


Figure 9. Proposed D^2EPC IFC Parser Workflow

5.3 Overview of the sample Apartment BIM and IFC model

The functionality of the proposed IFC Parser framework was tested through a case study. Particularly, the BIM model of a one living room apartment was considered. The apartment is located on the 2nd floor of a residential multistory building and it contains 5 spaces with a total area of 33,46 m^2. In the model, these 5 zones are defined as separate spaces with different properties and occupancy schedules. Depending on the aim of the work, various parameters can be added to the spaces-zones or to the objects located in them. Regarding the position in the apartment, the external and internal walls and the windows have different thermal and constructional parameters, which are specified in the model as well. The BIM model also includes many other objects with individually defined parameters, i.e., plumbing fixtures, heating appliances, pipes, doors, etc. The plan and the 3D views of the apartment in the BIM environment (Autodesk Revit 2020 software) are presented in Figure 10.



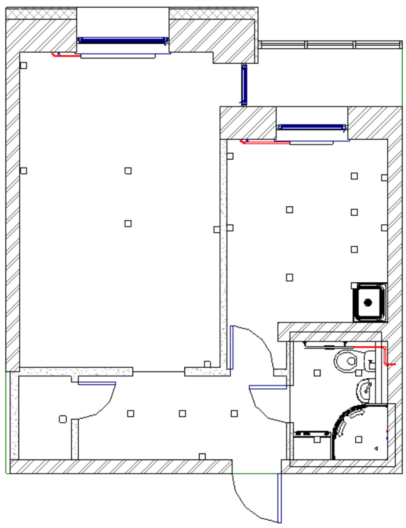


Figure 10. 3D view (left) and plan view (right) of the sample apartment

The aim of the IFC Parser is to select and extract only the EPC related information from the IFC file, which is realized from the BIM model. In order to test the IFC Parser, the element parameter named EPC_Parameter, with random numerical values, was added in the BIM model to the selected objects (walls, windows, heating appliances). The IFC file of the sample apartment carries a newly defined parameter (Figure 11).

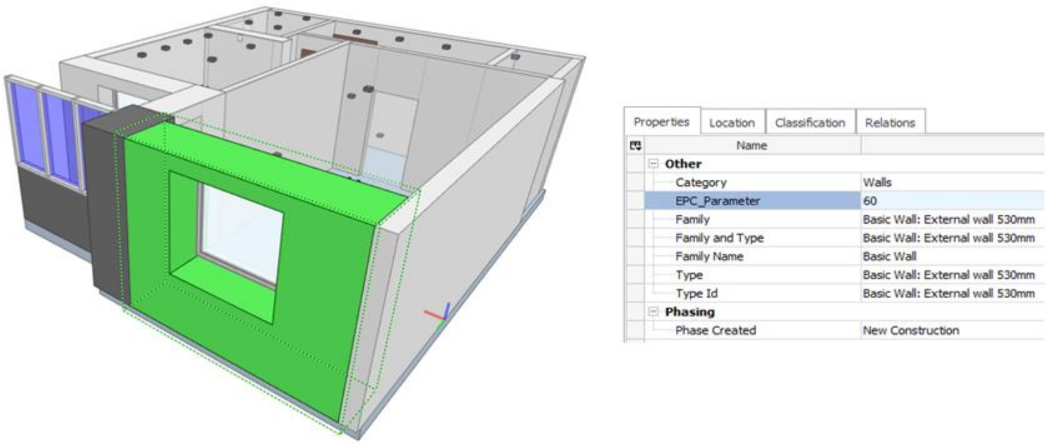


Figure 11. Selected wall (left), added parameter (right)

5.4 Application of IFC parsing in D^2EPC

The suggested IFC parser for the D^2EPC project is based on the Python programming language, utilizing the IfcOpenShell-Python and Pandas libraries. More details regarding the complete IFC parser component can be found in the deliverable 3.5 *Building Digital Twin v2*.

IfcOpenShell-Python is an open-source (LGPL- Lesser General Public License) software library that enables users and software developers to utilize the IFC file format[1]. The IFC file format is usually used to describe the construction and as-built environment. The format is commonly used for BIM. Pandas is a quick, vigorous and easy-to-use open-source data analysis and manipulation tool, built on top of the Python programming language[2].

The following subsections illustrate basic IFC parsing functionalities that can be combined towards forming a complete IFC parser component.

[1] http://ifcopenshell.org/python
[2] https://pandas.pydata.org/

5.4.1 Importing IfcOpenShell-Python and Pandas modules

Importing IfcOpenShell-Python and Pandas modules uses Python ***import*** command to load already installed modules. Command ***as*** is used for convenience as an abbreviation.

In [1]:

```
'''
Importing modules:
IfcPythonShell, http://ifcopenshell.org/python
Pandas, https://pandas.pydata.org/
'''

import ifcopenshell
import pandas as pd

print ('Importing successfully completed')
```

```
Importing successfully completed
```

5.4.2 Reading IFC file

Reading IFC file is intended for loading IFC-SPF (STEP physical file) format data from disk, server or another kind of source. Both, IFC 2x3 and IFC 4 schema versions are suitable for reading. Function's ***open*** argument, given in parenthesis and quotation marks, is a path and full IFC file name. The path is defined according to the syntax '/directory1/directory2/…/filename.ifc'.

In [2]:

```
ifc_file = ifcopenshell.open('Apartment_EPC.ifc') # reading IFC file

print ('IFC reading successfully completed')
```

```
IFC reading successfully completed
```

5.4.3 IFC parsing options

IFC parsing options provide several variants to parse IFC entities and attributes.

5.4.3.1 Parsing of STEP classes and direct attributes

Parsing of STEP classes and direct attributes mainly provide STEP definitions of IFC entities with tailored direct attributes in a dictionary format. For this task IfcOpenShell function ***.get_info()*** is used. Specific attribute of a given entity could be extracted by using function ***.attribute_name(0)*** , 0 denotes first attribute. Function ***.is_a()*** provide IFC entity name according to IFC schema (e.g. IfcWall, IfcWindow, etc.). Attribute ***PredefinedType*** returns predefined entity type.

In [3]:

```
objects = ifc_file.by_type('IfcWallStandardCase', include_subtypes=True)  #STEP list of objects

for entity in objects:                        # iterating through objects
  print(entity.is_a())                        # print class (entity) name
print("Type:",entity.ObjectType)              # print entity object type (attribute)
  print(entity.get_info())                    # all direct attributes in dict data type
  print(entity.attribute_name(0))             # specific attribute based on index (e.g. 0 -
                                              GlobalID)
  print(entity, '\n')                         # entity STEP line representation
```

Out [3]:

```
IfcWallStandardCase
Type:  Basic Wall:External wall 530mm 2
{'id': 1265, 'type': 'IfcWallStandardCase', 'GlobalId': '24bRgmt7L2LhcdIQMW2OGj', 'OwnerHistory': #41=IfcOwnerHistory(#3
8,#5,$,.NOCHANGE.,$,$,$,1629964586), 'Name': 'Basic Wall:External wall 530mm 2:785873', 'Description': None, 'ObjectTyp
e': 'Basic Wall:External wall 530mm 2', 'ObjectPlacement': #1237=IfcLocalPlacement(#32,#2652524), 'Representation': #1263
=IfcProductDefinitionShape($,$,(#1243,#1261)), 'Tag': '785873'}
GlobalId
#1265=IfcWallStandardCase('24bRgmt7L2LhcdIQMW2OGj',#41,'Basic Wall:External wall 530mm 2:785873',$,'Basic Wall:External w
all 530mm 2',#1237,#1263,'785873')

IfcWallStandardCase
Type:  Basic Wall:Internal wall 240mm
{'id': 1662, 'type': 'IfcWallStandardCase', 'GlobalId': '24bRgmt7L2LhcdIQMW2OQD', 'OwnerHistory': #41=IfcOwnerHistory(#3
8,#5,$,.NOCHANGE.,$,$,$,1629964586), 'Name': 'Basic Wall:Internal wall 240mm:786289', 'Description': None, 'ObjectType':
'Basic Wall:Internal wall 240mm', 'ObjectPlacement': #1642=IfcLocalPlacement(#32,#2652527), 'Representation': #1660=IfcPr
oductDefinitionShape($,$,(#1647,#1658)), 'Tag': '786289'}
GlobalId
#1662=IfcWallStandardCase('24bRgmt7L2LhcdIQMW2OQD',#41,'Basic Wall:Internal wall 240mm:786289',$,'Basic Wall:Internal wal
l 240mm',#1642,#1660,'786289')
```

5.4.3.2 Parsing of only specific attributes

Parsing of only specific attributes mainly provide attribute name and value within the whole IFC file. Usually, properties are instantiated within IfcPropertySingleValue entity. Attribute ***Name*** provides entity name, ***NominalValue*** return attribute value including data type, ***wrappedValue*** clear datatype and quotation marks.

In [4]:

```
# Pick STEP objects (e.g. IfcPropertySingleValue holds various properties as distinct entities)
objects2 = ifc_file.by_type('IfcPropertySingleValue')
```

`listN = []`	`# make a list`
`listV = []`	`# make a list`
`for attr in objects2:`	`# iterating through objects`
`    Name = attr.Name`	`# assigning variable to attribute name`
`    Value = attr.NominalValue.wrappedValue`	`# assigning variable to attribute value`
`    if Name == "EPC_Parameter":`	`# making condition equal to required attribute name`
`       print(Name, ": ", Value,'\n')`	`# print attribute name and value`
`       listN.append(Name)`	`# append attribute name to list`

`        listV.append(Value)`	`# append attribute value to list`
`print('List for Names:',listN)`	`# print list of attribute names`
`print('List for Values:',listV)`	`# print list of attribute values`

Out [4]:

```
EPC_Parameter :  55.0

EPC_Parameter :  144.0

EPC_Parameter :  25.0

EPC_Parameter :  30.0

EPC_Parameter :  57.0

EPC_Parameter :  45.0

EPC_Parameter :  0.5

EPC_Parameter :  64.0

EPC_Parameter :  15.0

EPC_Parameter :  80.0
```

5.4.3.3 Property/Quantity set parsing for single entity

Property/Quantity set parsing for single entity is accessible by the inverse IsDefinedBy relationship of IFC schema. This option returns property set or quantity set name.

In [5]:

`space = ifc_file.by_type('IfcCurtainWall')[0]`	`# assign variable for particular IFC entity`
`for definition in space.IsDefinedBy:`	`# iterating through objects`
`        if definition.is_a('IfcRelDefinesByProperties'):`	`# condition "defined by properties"`
`            Pset = definition.RelatingPropertyDefinition`	`# assign variable for property set`
`            print(Pset.Name)`	`# print property set (Pset) name`

Out [5]:

```
Pset_CurtainWallCommon
Pset_ProductRequirements
Pset_QuantityTakeOff
Constraints
Dimensions
Horizontal Grid
Other
Phasing
Structural
Vertical Grid
```

5.4.3.4 Property/Quantity set parsing for multiple entities

Property/Quantity set parsing for multiple entities is related to iterating through assigned objects (entities, e.g. IfcWall), printing names and IDs. The next iteration is intended for returning property set or quantity set name.

In [6]:

```
objects3 = ifc_file.by_type('IfcWallStandardCase')     # assign variable to IFC entities
i = 0                                                   # iterator

for entity3 in objects3:                                # iterating through objects
    print("  ")                                         # separator
    print(entity3.is_a())                               # print entity name
    print(entity3.id())                                 # print entity ID
    print("---------")                                  # separator
    wall = ifc_file.by_type('IfcWall')[i]               # assign variable to particular entity

    for definition in wall.IsDefinedBy:                 # iterating through a particular entity's
properties

            if definition.is_a('IfcRelDefinesByProperties'):      # condition "defined by properties"
                    Pset = definition.RelatingPropertyDefinition  # assign variable for property set
                    print(Pset.Name)                              # print property set (Pset) name
i += 1                                                  # iterator, next step
```

Out[6]:

```
IfcWallStandardCase
1265
---------
Constraints
Dimensions
Other
Phasing
Structural
Pset_ElementShading
Pset_ProductRequirements
Pset_QuantityTakeOff
Pset_ReinforcementBarPitchOfWall
Pset_WallCommon

IfcWallStandardCase
1662
---------
Constraints
Dimensions
```

5.4.3.5 Parser for all entities, properties and quantities

Parser for all entities, properties and quantities aggregates several pieces of code by iterating through all objects (entities, properties, quantities), parsing names and values of IFC elements, property/quantity sets and distinct properties/quantities. The first part of the code is intended to print out each element name and ID, assign it to particular variables. Next, print out property/quantity set name. The main condition (if RelData.is_a('IfcElementQuantity')) checks, is the iterating entity is quantity (assigned to IfcElementQuantity) or property (assigned to IfcPropertySingleValue). In addition, this option creates and append parsed data into the Pandas DataFrame.

In [7]:

```
df= pd.DataFrame({'Element':[],'ID':[],
                  'Property': [], 'Value': []})      # create Pandas DataFrame

objects4 = ifc_file.by_type('IfcWallStandardCase')   # assign variable to IFC entities (e.g. IfcWall)
i = 0                                                # iterator

for entity4 in objects4:                        # iterating through objects
```

```
    print('\n-----------', end=' ')         # separator
    print(entity4.is_a(), end=' ')         # print class (entity) name
    print(entity4.id(), end=' ')           # print class (entity) ID
    print('-----------')                   # separator
    kl = entity4.is_a()                    # assign variable for entity name
    ID = int(entity4.id())                 # assign variable for entity ID
    wall = ifc_file.by_type('IfcWall')[i]  # assign variable for particular entity

    for definition in wall.IsDefinedBy:    # iterating through a particular entity's properties or
quantities

        if definition.is_a('IfcRelDefinesByProperties'):       # condition: defined by properties
            RelData = definition.RelatingPropertyDefinition    # assign variable for property set
            print('\n<<Pset/Qto>>',RelData.Name)               # print property/quantity set name
            z
# quantities parsing

            if RelData.is_a('IfcElementQuantity'):             # condition: if object is quantity
                for quantity in RelData.Quantities:            # iterating through objects
                    print('    ', end=' ')                     # identation
                    print(quantity.Name, end=' ')              # printing quantity name
                    if quantity.is_a('IfcQuantityLength'):     # condition regarding quantity value
datatype
                        print(': ', quantity.LengthValue)      # printing quantity value(if length)
                    elif quantity.is_a('IfcQuantityArea'):     # condition regarding quantity value
datatype
                        print(': ', quantity.AreaValue)        # printing quantity value (if area)
                    else:                                      # condition regarding quantity value
datatype
                        print(': ', quantity.VolumeValue)      # printing quantity value (if volume)

# properties parsing

            else:
                for property in RelData.HasProperties:                   # iterating through objects
```

```
                    if property.is_a('IfcPropertySingleValue'):         # condition: if object is 
property
                        print('    ', end=' ')                          # identation
                        print(property.Name, end='')                    # printing property name
                        print(': ', property.NominalValue.wrappedValue) # printing property value

                        if property.Name == "EPC_Parameter":            # condition regarding attribute 
name
                            epc = property.Name;                        # assign variable for property 
name
                            value = property.NominalValue.wrappedValue  # assign variable for property 
value

# append properties to Pandas DatFrame (df)

                            df=df.append({'Element':kl, 'ID':int(ID),'Property':epc,'Value':value}, 
ignore_index=True)
# iterator
    i += 1
```

Out [7]:

```
----------- IfcWallStandardCase 1265 -----------

<<Pset/Qto>> Constraints
     Base Offset:  0.0
     Base Constraint:  Level: Level 1
     Base Extension Distance:  0.0
     Base is Attached:  False
     Location Line:  Core Face: Interior
     Related to Mass:  False
     Room Bounding:  True
     Top Constraint:  Level: Level 2
     Top Extension Distance:  0.0
     Top is Attached:  False
     Top Offset:  0.0
     Unconnected Height:  2450.0

<<Pset/Qto>> Dimensions
     Area:  4.63100000000001
     Length:  2780.0
```

5.4.4 Export of IFC entities and attributes (DataFrame) to XLS, CSV, JSON, etc.

Export of IFC entities and attributes (DataFrame) to XLS, CSV, JSON, etc. is intended to export parsed data into desired data format (e.g. XLS, CSV, JSON, etc.).

In [8]:

```
df.to_excel('IfcAttributes.xlsx')
df.to_csv('IfcAttributes.csv')
df.to_json('IfcAttributes.json')
df
```

Out [8]:

	Element	ID	Property	Value
0	IfcWallStandardCase	1265.0	EPC_Parameter	55.0
1	IfcWallStandardCase	1662.0	EPC_Parameter	25.0
2	IfcWallStandardCase	1988.0	EPC_Parameter	30.0
3	IfcWallStandardCase	2138.0	EPC_Parameter	57.0
4	IfcWallStandardCase	2311.0	EPC_Parameter	45.0
5	IfcWallStandardCase	3087.0	EPC_Parameter	0.5
6	IfcWallStandardCase	3313.0	EPC_Parameter	64.0
7	IfcWallStandardCase	3400.0	EPC_Parameter	15.0
8	IfcWallStandardCase	3487.0	EPC_Parameter	80.0
9	IfcWallStandardCase	3824.0	EPC_Parameter	60.0

6 Conclusions

This deliverable (D2.10) is the second version of two documents delivered for the definition of D^2EPC Information Model for the next generation EPCs. The report describes the scope, process, and primary methodology for defining the key performance indicators that will be integrated into EPC, as well as developed IFC Parser framework.

KPIs lists and definitions concerning the additional indicators that are part of the Next Generation EPCs were updated in this deliverable as the results of the activities of WP2 during the M34-M36 period of the project. In this version, the four groups of key performance indicators were updated:

- Smart Readiness Indicators (SRI) – define the ability of a building to utilize information and communication technologies and adapt to the behaviour and needs of the occupants.
- Human comfort and well-being indicators – are used for the measurement and evaluation of building systems utilization boundaries that lie within the occupants' comfort zone.
- Life Cycle Assessment (LCA) – enable environmental impact assessment of any system or material throughout its lifecycle.
- Financial indicators – raise consumer awareness of energy efficiency in buildings.

The relevant data for indicators will be extracted using the open international standard IFC. For this purpose, the IFC parser framework is written in Python using open-source IfcOpenShell-Python and Pandas modules. The detailed definition and the code guidelines of the application are also presented in the report.

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ANNEX A: Smart Readiness Indicators

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata	
				Metric			Attribute name	Attribute value Datatype
Heating-1a	**Heat Emission Control**	**Level 0** No automatic control	complete	Valves/switches/ controls (0)	IfcFlowController	6.2.3.12	HE-1a	Integers, [0]
Heating-1a	**Heat Emission Control**				IfcSwitchingDevice	7.4.3.41	HE-1a	
Heating-1a	**Heat Emission Control**	**Level 1** Central automatic control (e.g. central thermostat)	complete	Central thermostat/central control unit (1)	IfcUnitaryControlElement	7.2.3.11	HE-1a	Integers, [1]
Heating-1a	**Heat Emission Control**	**Level 2** Individual room control (e.g. thermostatic valves, or electronic controller)	partial	thermostatic valves, or electronic control units (2)	IfcActuator	7.2.3.1	HE-1a	Integers, [2]
Heating-1a	**Heat Emission Control**	**Level 3** Individual room control with communication between controllers and to BACS	partial	Control element depending on heat emission type (2,3,4)	IfcFlowController	6.2.3.12	HE-1a	Integers, [2,3,4]
Heating-1a	**Heat Emission Control**	**Level 4** Individual room control with communication and occupancy detection	partial	controllers (3,4)	IfcController	7.2.3.5	HE-1a	Integers, [3,4]
Heating-1a	**Heat Emission Control**			Temperature sensor (3,4)	IfcSensorType	7.2.3.9	HE-1a	Integers, [3,4]
Heating-1a	**Heat Emission Control**			Occupancy sensors (4)			HE-1a	
Heating-1b	**Emission control for TABS (heating mode)**	**Level 0** No automatic control	complete	Valve or other manual controls (0)	IfcFlowController	6.2.3.12	HE-1b	Integers, [0]
Heating-1b	**Emission control for TABS (heating mode)**				IfcSwitchingDevice	7.4.3.41	HE-1b	

		Level 1 Central automatic control	partial	Supply water temperature sensor (1,2,3)	IfcSensorType	7.2.3.9		Integers, [1,2,3]
		Level 2 Advanced central automatic control	partial	Outside air temperature sensor, (1,2,3)				Integers, [1,2,3]
				Room temperature sensor (2,3)				Integers, [2,3]
		Level 3 Advanced central automatic control with intermittent operation and/or room temperature feedback control	partial	Supply water valve (2,3)	IfcValve	7.5.3.63		Integers, [2,3]
Heating-1c	**Control of distribution fluid temperature (supply or return air flow or water flow)-Similar function can be applied to the control of direct electric heating networks**	**Level 0** No automatic control	complete	Default equipment (0)	IfcUnitaryEquipment	7.5.3.61	HE-1c	Integers, [0,1,2]
		Level 1 Outside temperature compensated control	partial	Outside air temperature sensor, water temperature sensor (1)	IfcSensorType	7.2.3.9		Integers, [1]
				Flow sensor (2)				Integers, [2]
		Level 2 Demand based control	partial	Flow control unit (1,2)	IfcFlowController	6.2.3.12		Integers, [1,2]
				Demand switches/controllers (1,2)	IfcController	7.2.3.5		Integers, [2]
Heating-1d	**Control of distribution pumps in networks**	**Level 0** No automatic control	complete	Default equipment (0)	IfcPumpType	7.5.3.54	HE-1d	Integers, [0,1,2,3,4]
		Level 1 On off control	Partial	Supply and return water temperature (1) Pressure sensors (4)	IfcSensorType	7.2.3.9		Integers, [1]

		Level 2 Multi-Stage control	Not supported	Pump with electronic staging device (2)	N/A	-		Integers, [2]
		Level 3 Variable speed pump control (pump unit (internal) estimations)	Not supported	Variable speed drive pump (3,4)	N/A	-		Integers, [3,4]
		Level 4 Variable speed pump control (external demand signal)			N/A	-		
Heating-1f	**Thermal Energy Storage (TES) for building heating (excluding TABS)**	**Level 0** Continuous storage operation	Not supported	--			HE-1f	
		Level 1 Time-scheduled storage operation						
		Level 2 Load prediction-based storage operation						
		Level 3 Heat storage capable of flexible control through grid signals (e.g. DSM).						
Heating-2a	**Heat generator control (all except heat pumps)**	**Level 0** Constant temperature control	complete	Outdoor temperature sensor (0)	IfcSensorType	7.2.3.9	HE-2a	Integers, [0]
		Level 1 Variable temperature control depending on outdoor temperature	Partial	Outdoor temperature sensor, flow temperature sensor, flow sensors (1, 2)				Integers, [1,2]
				possible variant: temperature sensor included in generator (1)				Integers, [*1]
		Level 2 Variable temperature control depending on the load (e.g. depending on supply water temperature set point)	Partial	Communication to distribution/heat consumer (2)	N/A	-		Integers, [2]

Heating-2b	**Heat generator control (for heat pumps)**	**Level 0** On/Off-control of the heat generator	complete	Single-stage heat generator/default heat generator equipment (0)	IfcUnitaryEquipmentType	7.5.3.62	HE-2b	Integers, [0,1,2,3]
		Level 1 Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)	Partial	Multi-stage heat generator (1)	N/A	-		Integers, [1]
		Level 2 Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	Partial	Variable-control heat generator (2,3)	N/A	-		Integers, [2,3]
		Level 3 Variable control of heat generator capacity depending on the load AND external signals from grid	Partial	By pass valve, inverter frequency control (2,3)	IfcFlowController	6.2.3.12		Integers, [2,3]
				Communication from grid signals (3)	N/A	-		Integers, [3]
Heating-2d	**Sequencing in case of different heat generators**	**Level 0** Priorities only based on running time	**Not supported**	--			HE-2d	Integers, [0,1,2,3,4]
		Level 1 Control according to fixed priority list: e.g. based on rated energy efficiency						
		Level 2 Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat,						

		cogeneration plant, fossil fuels)				
		Level 3 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)				
		Level 4 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)				
Heating-3	**Report information regarding HEATING system performance**	**Level 0** None **Level 1** Central or remote reporting of current performance KPIs (e.g. temperature, submetering energy usage) **Level 2** Central or remote reporting of current performance KPIs and historical data **Level 3** Central or remote reporting of performance evaluation including forecasting and/or benchmarking **Level 4** Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also	**Not supported**	---	HE-3	Integers, [0,1,2,3,4]

		including predictive management and fault detection				
Heating-4	**Flexibility and grid interaction**	**Level 0** No automatic control **Level 1** Scheduled operation of heating system **Level 2** Self-learning optimal control of the heating system **Level 3** Heating system capable of flexible control through grid signals (e.g. DSM) **Level 4** Optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control)	**Not supported**	---	HE-4	Integers, [0,1,2,3,4]

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata	
							Attribute Name	Attribute Value Datatype
Cooling-1a	**Cooling Emission Control**	**Level 0** No automatic control	**complete**	Valve/ switch or electronic control (0)	IfcFlowController	6.2.3.12	COL-1a	Integers, [0]
		Level 1 Central automatic control	**complete**	Central control unit (1)	IfcUnitaryControlElement	7.2.3.11		Integers, [1]
		Level 2 Individual room control	**Partial**	Thermostatic valves or electronic control units (2)	IfcActuator	7.2.3.1		Integers, [2]

		Level 3 Individual room control with communication between controllers and to BACS	**Partial**	Room control units and communication, (3,4)	IfcController	7.2.3.5		Integers, [3,4]
		Level 4 Individual room control with communication and occupancy detection	**Partial**	Occupancy sensor (4)	IfcSensorType	7.2.3.9		Integers, [4]
Coolin g – 1b	**Emission control for TABS (cooling mode)**	**Level 0** No automatic control	**complete**	Manual control (e.g. valve) (0)	IfcFlowController	6.2.3.12	COL-1b	Integers, [0]
		Level 1 Central automatic control	**complete**	Outside air temperature sensor, water temperature sensor (1)	IfcSensorType	7.2.3.9		Integers, [1]
		Level 2 Advanced central automatic control	**Partial**	Outside air temperature sensor, room setpoint device (2,3)				Integers, [2,3]
		Level 3 Advanced central automatic control with intermittent operation and/or room temperature feedback control	**Partial**	Room temperature sensor (3)				Integers, [3]
				Room setpoint device (2,3)	IfcUnitaryControlElem ent	7.2.3.11		Integers, [2,3]
				Supply water valve (2,3)	IfcValve	7.5.3.63		Integers, [2,3]
Coolin g-1c	Control of distributio n network chilled water temperatur e (supply or return)	**Level 0** Constant temperature control	**complete**	Presence of distribution network (0)	IfcDistributionElemen t	5.4.3.8	COL-1c	Integers, [0]
		Level 1 Outside temperature compensated control	**Partial**	Flow temperature sensor, outside temperature sensor (1)	IfcSensorType	7.2.3.9		Integers, [1,2]
		Level 2 Demand based control	**Partial**	Temperature sensor and communication (2)				

				Control unit (1,2)	IfcUnitaryControlElement	7.2.3.11		
Cooling-1d	Control of distribution pumps in networks	**Level 0** No automatic control	**complete**	Pump (0)	IfcPump	7.5.3.53	COL-1d	Integers, [0]
		Level 1 on/off control	**complete**	Flow temperature sensor, return temperature sensor (1)	IfcSensorType	7.2.3.9		Integers, [1]
				Pressure sensors (3,4)				Integers, [3,4]
		Level 2 Multi-Stage control	**Partial**	Multi-speed pump(e.g. multi-stage, electrical/electronic staging equipment) (2)	N/A	7.5.3.53		Integers, [2]
		Level 3 Variable speed pump control (pump unit (internal) estimations)	**Partial**	Variable speed pump drive (3,4)				Integers, [3,4]
		Level 4 Variable speed pump control (external demand signal)	**Partial**					
Cooling-1f	Interlock: avoiding simultaneous heating and cooling in the same room	**Level 0** No interlock |	**complete**	No equipment (0)	No equipment	-	COL-1f	Integers, [0]
		Level 1 Partial interlock (minimizing risk of simultaneous heating and cooling e.g. by sliding setpoints)	**Not supported**	Communication/connection between heating control, cooling control, and air temperature control (1,2)	--			Integers, [1,2]
		Level 2 Total interlock (control system ensures no simultaneous heating and cooling can take place)						
Cooling-1g	Control of Thermal	**Level 0** Continuous storage operation	**Not supported**	Presence of thermal energy storage	--		COL-1g	Integers, [0.1,2,3]

	Energy Storage (TES) operation	**Level 1** Time-scheduled storage operation		passive systems in building envelopes, phase change materials (PCM) in active systems, sorption systems, and seasonal storage				
		Level 2 Load prediction-based storage operation						
		Level 3 Cold storage capable of flexible control through grid signals (e.g. DSM)						
Coolin g-2a	**Generator control for cooling**	**Level 0** On/off-control of cooling production	**Complete**	Default mode/presence of cooling generator	IfcUnitaryEquipment	7.5.3.61	COL-2a	Integers, [0.1,2,3]
		Level 1 Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors)	**Partial**	Outdoor temperature sensor, flow temperature sensor, Multi stage equipment, demand switches/controllers (1)	IfcSensorType	7.2.3.9		Integers, [1,2,3]
		Level 2 Variable control of cooling production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	**Partial**	Communication to distribution/cooling consumer, flow sensor, demand switches/controllers, direct grid signal (2,3)	IfcController	7.2.3.5		Integers, [1,2,3]
		Level 3 Variable control of cooling production capacity depending on the load AND external signals from the grid.	**Partial**	External signals from grid (3)	N/A	-		Integers, [,3]
Coolin g-2b	**Sequencin g of different cooling generators**	**Level 0** Priorities only based on running times	**Not supported**	---			COL-2b	Integers, [0.1,2,3,4]
		Level 1 Fixed sequencing based on loads only: e.g. depending on the generator's characteristics						

		such as absorption chiller vs. centrifugal chiller				
		Level 2 Dynamic priorities based on generator efficiency and characteristics (e.g. availability of free cooling)				
		Level 3 Load prediction based sequencing: the sequence is based on e.g. COP and available power of a device and the predicted required power				
		Level 4 Sequencing based on dynamic priority list, including external signals from grid.				
Cooling-3	**Report information regarding cooling system performance**	**Level 0** None	Not supported	--	COL-3	Integers, [0.1,2,3,4]
		Level 1 Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)				
		Level 2 Central or remote reporting of current performance KPIs and historical data |				
		Level 3 Central or remote reporting of performance evaluation including forecasting and/or benchmarking |				

		Level 4 Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection.				
Coolin g-4	**Flexibility and grid interaction**	**Level 0** No automatic control **Level 1** Scheduled operation of cooling system **Level 2** Self-learning optimal control of cooling system **Level 3** Cooling system capable of flexible control through grid signals (e.g. DSM) **Level 4** Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)	**Not supported**	---	COL-4	Integers, [0.1,2,3,4]

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata: Attribute Name	Entity attribute metadata: Attribute Value / Datatype
Ventilatio n-1a	**Supply airflow at**	**Level 0** No ventilation system or manual control	**complete**	Manual operated control/no ventilation (0)	No equipment or ventilation equipment present	-	VEN-1a	Integers, [0]

	the room level	**Level 1** Clock control	**Partial**	Existence of scheduling for the specific room/zone or functional test (1)	N/A	-		Integers, [1]
		Level 2 Occupancy detection control	**Partial**	Presence detection with occupancy sensor (2)	IfcSensorType	7.2.3.9		Integers, [2]
				Air quality sensors (CO2 sensors, VOC sensors) (3,4)				Integers, [3,4]
		Level 3 Central Demand Control based on air quality sensors (CO2, VOC, humidity…)	**Partial**	Central demand switches/controllers (3) Demand switches/controllers, zone/room level (4)	IfcController	7.2.3.5		Integers, [3,4]
		Level 4 Local Demand Control based on air quality sensors (CO2, VOC, …) with local flow from/to the zone regulated by dampers						
Ventilation-1c	**Air flow or pressure control at the air handler level**	**Level 0** No automatic control: continuously supplies of airflow for a maximum load of all rooms	**complete**	Constant Air Volume system (CAV) (0)	IfcUnitaryEquipmentType	7.5.2.31	VEN-1c	Integers, [0,1]
		Level 1 On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	**Partial**	Constant Air Volume system with scheduling/time clock (CAV) (1)				
				Occupancy sensor (1)	IfcSensorType	7.2.3.9		Integers, [1]

		Level 2 Multi-stage control: to reduce the auxiliary energy demand of the fan	**Partial**	Ventilation system with multi-speed fan motor (2)	IfcFanType	7.5.3.38		Integers, [2]
		Level 3 Automatic flow or pressure control without pressure reset: load dependent supplies of air flow for the demand of all connected rooms	**Partial**	Variable Air Volume (VAV) systems with Variable frequency drive (VFD) (4)	IfcUnitaryEquipment Type (USERDEFINED)	7.5.2.31		Integers, [4]
		Level 4 Automatic flow or pressure control with pressure reset: load-dependent supplies of air flow for the demand of all connected rooms (for variable air volume systems with VFD)	**Partial**	Variable fan speed motor (3,4)	N/A	-		Integers, [3,4]
				Pressure sensing equipment (3,4)	IfcSensorType	7.2.3.9		Integers, [4]
				Demand-based sensors (temperature, air quality, occupancy, humidity etc.) (3,4)				Integers, [3,4]
				Demand/communication controller	IfcController	7.2.3.5		Integers, [2,3,4]
Ventilation-2c	Heat recovery control: prevention of overheating	**Level 0** Without overheating control	**complete**	Heat recovery equipment (0)	IfcAirToAirHeatRecovery	7.5.3.5	VEN-2c	Integers, [0,1,2]
		Level 1 Modulate or bypass heat recovery based on sensors in air exhaust	**Partial**	Temperature Sensor for Supply Air (1,2)	IfcSensorType	7.2.3.9		Integers, [0,1,2]
		Level 2 Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control	**Partial**	Multiple room temperature sensors (2)				
				Actuators (1,2)	IfcActuator	7.2.3.1		Integers, [1,2]
				Communication controller (1,2)	IfcController	7.2.3.5		Integers, [1,2]

Ventilation-2d	Supply air temperature control at the air handling unit level	**Level 0** No automatic control	**complete**	No controls to a fixed temperature value/default ventilation equipment (0)	IfcUnitaryEquipmentType	7.5.2.31	VEN-2d	Integers, [0,1,2,3]
		Level 1 Constant setpoint: a control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action	**Partial**	Room/zone temperature sensor (1)	IfcSensorType	7.2.3.9		Integers, [1,2,3]
		Level 2 Variable setpoint with outdoor temperature compensation	**Partial**	Outside air sensor (2)				
		Level 3 Variable setpoint with load dependant compensation. A control loop enables to control the supply air temperature. The setpoint is defined as a function of the loads in the room	**Partial**	Flow/air quality control, communication/connection to static heating/cooling (3)				
				Controllers (1,2,3)	IfcController	7.2.3.5		Integers, [2,3]
Ventilation-3	Free cooling with mechanical ventilation system	**Level 0** No automatic control	**Complete**	Default ventilation system (0)	IfcUnitaryEquipmentType	7.5.2.31	VEN-3	Integers, [0]
		Level 1 Night cooling	**Partial**	Outside temperature sensor (or communication to outside air sensor) / Room/zone temperature Sensor (1,2)	IfcSensorType	7.2.3.9		Integers, [1,2]
		Level 2 Free cooling: air flows modulated during all periods of time to	**Partial**	Integrated economizer coil (2)	N/A	-		Integers, [2]

		minimize the amount of mechanical cooling						
		Level 3 H,x – directed control: the amount of outside air and recirculation air are modulated during all periods of time to minimize the amount of mechanical cooling. The calculation is performed on the basis of temperature and humidity.	**Partial**	Humidity sensor, humidifier/dehumidifier actuators, room/zone temperature sensor (3)	IfcSensorType	7.2.3.9		Integers, [3]
Ventilation-6	Reporting information regarding IAQ	**Level 0** None **Level 1** Air quality sensors (e.g. CO2) and real time autonomous monitoring **Level 2** Real-time monitoring & historical information of IAQ available to occupants **Level 3** Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)	**Not supported**	--			VEN-6	Integers, [0,1,2,3]

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data / Metric	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata: Attribute name	Entity attribute metadata: Attribute value / Datatype
SRI-Lighting 1a	**Occupancy control for indoor lighting**	**Level 0** Manual on/off switch	**complete**	Manual on/off switch [0]	IfcFlowController (IfcSwitchingDevice)	7.4.3.41	SRI-L-1a	Integers, [0,1,3]
		Level 1 Manual on/off switch + additional sweeping extinction signal	**complete**	Manual on/off switch with sweep time control device [1]	IfcElectricTimeControl	7.4.3.23		Integers, [1,3*]
		Level 2 Automatic detection (auto on / dimmed or auto off)	**partial**	Occupancy Sensor, automatic switch [2]	IfcSensorType	7.2.3.9		Integers, [2,3]
		Level 3 Automatic detection (manual on / dimmed or auto off)	**partial**	Manual on switch, occupancy sensor or timer [3]				
SRI-Lighting 2	**Control artificial lighting power based on daylight levels**	**Level 0** Manual (central)	**complete**	Influence zone – central, room (0,1)	IfcSpatialZone	5.4.3.60	SRI-L-2	Integers, [0,1]
		Level 1 Manual (per room/zone)	**complete**	Manual lighting switch (0,1)	IfcFlowController (IfcSwitchingDevice)	7.4.3.41		Integers, [0,1]
		Level 2 Automatic switching	**complete**	Lighting sensors, occupancy sensors (2,3)	IfcSensorType	7.2.3.9		Integers, [2,3,4]
		Level 3 Automatic dimming	**complete**	Brightness/occupancy sensors, Colour Temperature Sensors, light intensity sensor (4)				
		Level 4 Scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated colour temperature (CCT) and the possibility to change the light distribution within the space according to e.g., design, human needs, visual tasks)	**partial**	Controller (keypad) (4)	IfcController	7.2.3.5		Integers, [4]

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data Metric	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata Attribute name	Entity attribute metadata Attribute value Datatype
Electricity-2	**Reporting information regarding local electricity generation**	**Level 0** None	**Not supported**	---			ELE-2	Integers, [0,1,2,3,4]
		Level 1 Current generation data available						
		Level 2 Actual values and historical data						
		Level 3 Performance evaluation including forecasting and/or benchmarking						
		Level 4 Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection						
Electricity-3	Storage of locally generated energy	**Level 0** None	**complete**	local storage available (0)	No equipment	-	ELE-3	Integers, [0]
		Level 1 Limited: small scale storage (batteries, TES…)	**partial**	On site electric battery (1)	IfcElectricFlowStorageDevice	7.4.3.17		Integers, [1,2]
		Level 2 Storage which can supply self-consumption for > 3 hours	**partial**	On site electric battery > 3hrs(2)				
		Level 3 Dynamically operated storage which can also feed back into the grid	**Not supported**	Thermal storage with controller based on grid signals (3)	N/A	-		Integers, [3]

Electricity-4	Optimizing self-consumption of locally generated energy	**Level 0** None	**complete**	No optimization (0)	No equipment	-	ELE-4	Integers, [0]
		Level 1 Short term optimization	**Not supported**		N/A	-		Integers, [1]
		Level 2 Long term optimization including predicted generation and/or demand	**Not supported**	Predictive generation based on historical data (2)	N/A	-		Integers, [2]
Electricity-5	Control of combined heat and power plant (CHP)	**Level 0** CHP control based on scheduled runtime management and/or current heat energy demand	**complete**	Presence of CHP (0)	IfcElectricGenerator	7.43.19	ELE-5	Integers, [0]
		Level 1 CHP runtime control is influenced by the fluctuating availability of RES; overproduction will be fed into the grid	**Not supported**	Renewable energy sources (1,2)	IfcSolarDevice	7.4.3.39		Integers, [1,2]
		Level 2 CHP runtime control influenced by the fluctuating availability of RES and grid signals; dynamic charging and runtime control to optimise self-consumption of renewables	**Not supported**	Grid signal response (1,2)	N/A	-		Integers, [1,2]
Electricity-8	Support of microgrid operation modes	**Level 0** None	**complete**	No equipment (0)	No equipment	-	ELE-8	Integers, [0]
		Level 1 Local battery usage	**partial**	Local battery presence (1)	IfcElectricFlowStorageDevice	7.4.3.17		Integers, [1]
		Level 2 Autonomous energy consumption control	**Not supported**		N/A	-		Integers, [2]
Electricty-11	Reporting information regarding	**Level 0** None **Level 1** Current state of charge (SOC) data available	**Not supported**	---				

	energy storage	**Level 2** Actual values and historical data **Level 3** Performance evaluation including forecasting and/or benchmarking **Level 4** Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection		
electricity -12	Reporting information regarding electricity consumption	**Level 0** None **Level 1** reporting on current electricity consumption on building level **Level 2** real-time feedback or benchmarking on building level **Level 3** real-time feedback or benchmarking on appliance level **Level 4** real-time feedback or benchmarking on appliance level with automated personalized recommendations	**Not supported**	---

Indicator Name	Indicator Description	Calculation Procedure	IFC coverage	Input Data	Relation with IFC entity	Reference to IFC schema contents	Entity attribute metadata	
				Metric			Attribute name	Attribute value Datatype
DE-1	**Window solar shading control**	**Level 0** No sun shading or only manual operation	**complete**	No sun shading (0)	No equipment	-	DE-1	**Integers, [0]**
		Level 1 Motorized operation with manual control	**complete**	Manual control (0)	IfcShadingDevice	6.1.3.36		**Integers, [0]**
		Level 2 Motorized operation with automatic control based on sensor data	**partial**	Electrical Motor for mechanical operations (1,2,3,4)	IfcElectricMotor	7.4.3.21		**Integers, [1,2,3]**
		Level 3 Combined light/blind/HVAC control	**partial**	Solar sensor, brightness sensor, temperature sensor (2,3)	IfcSensorType	7.2.3.9		**Integers, [2,3,4]**
		Level 4 Predictive blind control (e.g., based on weather forecast)	**partial**	Weather station (4)				**Integers, [4*]**
				Controller (3,4)	IfcController	7.2.3.5		**Integers, [3,4]**
DE-2	Window open/closed control, combined with HVAC system	**Level 0** Manual operation or only fixed windows	**complete**	Manual/fixed windows operation (0)	IfcWindow	6.1.3.50	DE-2	**Integers, [0,1,2,3]**
		Level 1 Open/closed detection to shut down heating or cooling systems	**partial**	Contact sensors (1)	IfcSensorType	7.2.3.9		**Integers, [1]**
		Level 2 Automized mechanical window opening based on room sensor data	**partial**	Light sensor, temperature sensors, CO2 (2)				**Integers, [2,3]**
				actuators (2)	IfcActuator	7.2.3.1		**Integers, [2,3]**
		Level 3 Centralized coordination of operable windows, e.g., to control free natural night cooling	**partial**	Controller connecting sensors with and HVAC (1,2)	IfcController	7.2.3.5		**Integers, [1,2]**
				Central controller connecting windows (3)				**Integers, [3]**

`DE-4	Reporting information regarding performance	**Level 0** No reporting **Level 1** Position of each product & fault detection **Level 2** Position of each product, fault detection & predictive maintenance **Level 3** Position of each product, fault detection, predictive maintenance, real-time sensor data (wind, lux, temperature… **Level 4** Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature…)	**Not supported**	---	DE-4	**Integers, [0,1,2,3,4]**

ANNEX B: Human-Comfort and Wellbeing Indicators [28,29].

Thermal Comfort Indicator Name	Indicator Description	Units	Static/Dynamic	Category	Calculation Procedure	Input Data				Type of the building	Comments
						Metric	Unit	Spatial Granularity	Temporal Granularity		
Deviation from the temperature range	Calculate the number or % of hours (during which the building is occupied) when the temperature is outside a specified range from the personalized comfort boundaries (EN 15251)	%	Dynamic	Thermal Comfort	**Total Hours of building occupation in the period of interest:** $\sum_{i=t_0}^{t_n} 1$ **Hours out of range:** $\sum_{i=t_0}^{t_n} 1,\ [\text{if } T_{upper} - \overline{T}_i < 0 \text{ or } \overline{T}_i - T_{bottom} < 0]$ **Frequency of Deviation:** (Hours out of range / Total Hours) *100	Indoor hourly mean Temperature: $\overline{T}_i$	°C	Room level	1 hour	Residential/Commercial	The personalised comfort boundaries are extracted from the comfort profiling engine. If that's not feasible, building code boundaries found from literature, are utilised
						Upper Temp Limit: T_{upper}	°C	Room level	1 hour		
						Bottom Temp Limit: T_{bottom}	°C	Room level	1 hour		
						First timestamp: t_0	datetime	Room level	1 hour		
						Last timestamp: t_n	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		

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	Numeric	Dynamic	Thermal Comfort	**Weighting factor:** $W_f = \lvert \overline{T}_i - T_{limit} \rvert$ **Hours out of range (Warm period):** $\sum_{i=t_0}^{t_n} W_{fw},\ [\text{if } T_{upper} - \overline{T}_i < 0]$ **Hours out of range (Cold period):** $\sum_{i=t_0}^{t_n} W_{fc},\ [\text{if } \overline{T}_i - T_{bottom} < 0]$	Indoor hourly mean Temperature: $\overline{T}_i$	^oC	Room level	1 hour	Residential/Commercial	The personalised comfort boundaries are extracted from the comfort profiling engine. If that's not feasible, building code boundaries found from literature, are utilised
						Upper Temp Limit: T_{upper}	^oC	Room level	1 hour		
						Bottom Temp Limit: T_{bottom}	^oC	Room level	1 hour		
						First timestamp: t_0	datetime	Room level	1 hour		
						Last timestamp: t_n	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		
Deviation from the humidity range	Calculates the number or % of hours (during which the building is	%	Dynamic	Thermal Comfort / Indoor air quality	**Total Hours of building occupation in the period of interest:**	Indoor hourly mean relative Humidity: $\overline{RH}$	%	Room level	1 hour	Residential/Commercial	The building code boundaries according to

	occupied) when the relative humidity is outside a specified range (EN 15251)				$\sum_{i=t_0}^{t_n} 1$ **Hours out of range:** $\sum_{i=t_0}^{t_n} 1 \; [\text{if } \mathrm{RH_{upper}} - \overline{\mathrm{RH}} < 0 \text{ or } \overline{\mathrm{RH}} - \mathrm{RH_{bottom}} < 0]$ **Frequency of Deviation:** (Hours out of range / Total Hours) *100	Upper relative Humidity Limit: $\mathbf{RH_{upper}}$	%	N/A	N/A		Level(s) correspond to [40-60%])
						Bottom relative Humidity Limit: $\mathbf{RH_{bottom}}$	%	N/A	N/A		
						First timestamp: $\mathbf{t_0}$	datetime	Room level	1 hour		
						Last timestamp: $\mathbf{t_n}$	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		
Deviation from the acceptable WBGT levels	Calculate the % of hours (during which the building is occupied) when the thermophysiological parameter 'Wet-Bulb	%	Dynamic	Thermal Comfort	**Calculate T_{wb} based on T_{db} and RH:** $T_w = T \operatorname{atan}[0.151\,977(\mathrm{RH}\% + 8.313\,659)^{1/2}] + \operatorname{atan}(T + \mathrm{R}$ $+ 0.003\,918\,38(\mathrm{RH}\%)^{3/2} \operatorname{atan}(0.023\,101\mathrm{RH}\%) - 4.686$ **Calculate WGBT based on T_{db} and T_{wb}:** $WGBT = 0.7 * T_{db} + 0.3 * T_{wb}$	Indoor hourly air dry-bulb temperature $\mathbf{T_{db}}$	°C	Room level	1 hour	Commercial	Based on the metabolic rate of several work catergories along with the
						Indoor hourly relative temperature **RH**	%	Room level	1 hour		

	Global Temperature' (as defined in ISO 7243:2017) is greater than a specified value based on the workload				**Total Hours of building occupation in the period of interest (cooling):** $\sum_{i=t_0}^{t_n} 1$ **Hours out of range of the proposed WBGT taking into account the workload of the space:** $\sum_{i=t_0}^{t_n} 1\,,\ \ [\text{if WBGT} > \text{threshold}]$ **Frequency of Deviation:** (Hours out of range / Total Hours) *100	**WBGT** threshold	constant	Room level	1 hour		percentage of work effort, specific levels are generated tailored to each building's usage. The wet bulb temperature is estimated based on the dry bulb temperature and the relative humidity. The WBGT is calculated for the cooling period
						First timestamp: $\mathbf{t_0}$	datetime	Room level	1 hour		
						Last timestamp: $\mathbf{t_n}$	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		

<table>
<tr>
<td rowspan="5">Humidex levels</td>
<td rowspan="5">The Humidex is physiological 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</td>
<td rowspan="5">% per level</td>
<td rowspan="5">Dynamic</td>
<td rowspan="5">Thermal Comfort</td>
<td rowspan="5">Calculate T_{dew} based on T_{db} and RH:
$L = \ln\left(\frac{RH}{100}\right)$
$M = 17.27 * T_{db}$
$N = 237.3 + T_{db}$
B = (L+(M+N))/17.27
$T_{dew} = (237.3 * B)/(1 - B)$
Calculate Humidex based on T_{db} and T_{dew}:
$H = T_{db}\frac{5}{9}\left[6.11 \times e^{5417.7530(\frac{1}{273.16}-\frac{1}{273.15+T_{dew}})} - 10\right]$
Total Hours of building occupation in the period of interest:
$\sum_{i=t_0}^{t_n} 1$
Total Hours corresponding to each level for the period of interest:</td>
<td>Indoor hourly air dry-bulb temperature T_{db}</td>
<td>ºC</td>
<td>Room level</td>
<td>1 hour</td>
<td rowspan="5">Residential/Commercial</td>
<td rowspan="5">The Humidex index is calculated separately for the cooling and heating period</td>
</tr>
<tr>
<td>Indoor hourly relative Humidity : RH</td>
<td>%</td>
<td>Room level</td>
<td>1 hour</td>
</tr>
<tr>
<td>Hourly Humidex: H</td>
<td>constant</td>
<td>Room level</td>
<td>1 hour</td>
</tr>
<tr>
<td>Humidex level's bottom limit: $H_{bot,level}$</td>
<td>constant</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Humidex level's upper limit: $H_{up,level}$</td>
<td>constant</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</table>

					$Hours\ per\ level: \sum_{i=t_0}^{t_n} 1,\ [If\ H_{bot,level} \le H \le H_{up,level}\ ]$ **Level proportion:** (Hours per level / Total Hours) *100 **Humidex levels** Leve I: 20 to 29 -> Little to no discomfort Leve II: 30 to 39 -> Some discomfort Leve III: 40 to 45 -> Great discomfort Leve VI: Above 45 -> Dangerous	First timestamp: t_0	datetime	Room level	1 hour		
						Last timestamp: t_n	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		

Visual Comfort Indicator Name	**Indicator Description**	**Units**	**Static/Dynamic**	**Category**	**Calculation Procedure**	**Input Data**				**Type of the building**	**Comments**
						Metric	**Unit**	**Spatial Granularity**	**Temporal Granularity**		
Deviation from the set Illuminance boundary	Summation of all the daylight hours of a regularly	%	Dynamic	Visual Comfort	**Total Daylight Hours of**	Indoor hourly mean Illuminance: $\overline{Ev_i}$	Lux	Room level	1 hour	Residential/Commercial	The bottom set illuminance boundary is determined by the personalised

	occupied space during which the illuminance was lower than the profiling engine bottom boundary, compared to the total hours of the period of interest				**building occupation in the period of interest :**	Bottom set Illuminance Limit: $\boldsymbol{Ev_{set}}$	Lux	Room level	1 hour		comfort profiling engine, applied in the visual comfort. Only the bottom limit is examined, assuming
					$\sum_{i=t_0}^{t_n} 1$	First daylight timestamp: **t_0**	datetime	Room level	1 hour		
					Hours under the bottom boundary: $\sum_{i=t_0}^{t_n} 1\ ,\ [if\ \overline{Ev_i} - Ev_{set} < 0]$	Last daylight timestamp: **t_n**	datetime	Room level	1 hour		
					Frequency of deviation: (Hours out of Range / Total Hours) *100	Occupancy Status	Binary	Room level	1 hour		
Deviation from the standard Illuminance levels	Summation of all the daylight hours of a regularly occupied	%	Dynamic	Visual Comfort	**Total Daylight Hours of building**	Indoor hourly mean Illuminance: $\boldsymbol{\overline{Ev_i}}$	Lux	Room level	1 hour	Commercial	The illuminance levels obtained from the literature are separately examined as

	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				**occupation in the period of interest :** $\sum_{i=t_0}^{t_n} 1$ **Hours under the bottom boundary:** $\sum_{i=t_0}^{t_n} 1\ , [if\ \overline{E}$ $- Ev_{code}$ $< 0]$ **Frequency of deviation:** (Hours out of Range / Total Hours) *100	Building code Illuminance level: $\boldsymbol{Ev_{code}}$	Lux	N/A	N/A		they have been proposed (EN 12464) for different types of spaces (and activities). The preferred illuminance levels of an occupant do not always coincide with the optimal ones.
						First daylight timestamp: $\mathbf{t_0}$	datetime	Room level	1 hour		
						Last daylight timestamp: $\mathbf{t_n}$	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		
Set Visual Degree Hours	The daylight hours during which the space is occupied and the	Numeric	Dynamic	Visual Comfort	**Weighting factor:**	Indoor hourly mean Illuminance: $\overline{\boldsymbol{Ev_i}}$	Lux	Room level	1 hour	Residential/Commercial	The set visual degree hours quantify the deviation of the measured illuminance from the minimum acceptable

	measured illuminance remains below the profiling engine bottom boundary. The calculation is weighted by a factor which is a function depending on by how many degrees the average hourly illuminance was below The bottom boundary (EN 15251)				$W_f = \lvert \overline{Ev_i} - Ev_{set} \rvert$ **Visual degree hours:** $\sum_{i=t_0}^{t_n} W_f$, [if $Ev_{set} - \overline{Ev_i} > 0$]	Bottom Set Illuminance Limit: $\boldsymbol{Ev_{set}}$	Lux	Room level	1 hour		illuminance as determined from the visual comfort profiling engine. They take into account not only the number of hours below the limit but also the magnitude of the difference between measured and acceptable illuminance
						First daylight timestamp: **t_0**	datetime	Room level	1 hour		
						Last daylight timestamp: **t_n**	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		
Standard Visual Degree Hours	The daylight hours during which the space is occupied	Numeric	Dynamic	Visual Comfort	**Weighting factor:**	Indoor hourly mean Illuminance: $\boldsymbol{\overline{Ev_i}}$	Lux	Room level	1 hour	Residential/Commercial	The standard visual degree hours quantify the deviation of the measured illuminance from the minimum

	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				$W_f = \lvert\overline{Ev_i} - Ev_{code}\rvert$ **Visual degree hours:** $\sum_{i=t_0}^{t_n} W_f, [\text{if } Ev$ $- \overline{\overline{Ev_i}} > 0]$	Building code Illuminance level: $\boldsymbol{Ev_{code}}$	Lux	Room level	1 hour		acceptable illuminance level as determined in EN 12464 for different spaces (and activities). They take into account not only the number of hours below the limit but also the magnitude of the difference between measured and acceptable illuminance
						First daylight timestamp: $\mathbf{t_0}$	datetime	Room level	1 hour		
						Last daylight timestamp: $\mathbf{t_n}$	datetime	Room level	1 hour		
						Occupancy Status	Binary	Room level	1 hour		

Main IAQ Indicator Name	Indicator Description	Units	Static/Dynamic	Category	Calculation Procedure	Input Data	Type of Building	Comments

						Metrics	Units	Spatial Granularity	Temporal granularity		
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. The indicator is reported based on the % of hours of each category compared to the total hours of the period of interest	% per category	Dynamic	IAQ	**Calculate the differences between indoor/outdoor CO2 concentrations:** $CO_2 = \ CO_{2,indoors} - CO_{2,outdoors}$ **Total Hours of building occupation in the period of interest:** $\sum_{i=t_0}^{t_n} 1$ **Total Hours corresponding to each category for the period of interest:** $Hours\ per\ category: \sum_{i=t_0}^{t_n} 1,\ [If\ C$ $\leq CO_{2_{cat}}\ ]$ **Category proportion:** (Hours per category / Total Hours) *100	Hourly outdoor CO_2 concentration: $\boldsymbol{CO_{2,outdoors}}$	ppm	Room level (Intake air duct, outdoor sensor, or the nearest measuring station)	1 hour	Residential/Commercial	The mentioned limits of CO_2 concentrations correspond to the deviation from outdoor air CO_2 concentration. It is further assumed standard CO_2 emission of a person 20L/(h/person). As mentioned in the Ventilation rate indicator, due to the challenges of its estimation, CO_2 levels will
						Hourly indoor CO2 concentration: $\boldsymbol{CO_{2,indoors}}$	ppm	Room level (Extract air duct or CO2 sensor mounted at least 1,5m above the floor)	1 hour		
						C02 category: $\boldsymbol{CO_{2_{cat}}}$	ppm	N/A	N/A		
						First timestamp: $\mathbf{t_0}$	Datetime	Room level	1 hour		

					Categories according to CEN/TR 16798-1/2:2019: I category – 500 ppm when the air flow rate is 10 l/s II category – 800 ppm when the air flow rate is 7 l/s III category – 1350 ppm when the air flow is 4 l/s IV category – 1550 ppm when the air flow is 4 l/s	Last timestamp: t_n	Datetime	Room level	1 hour		be examined irrespective to ventilation rate or air flow rates
						Occupancy Status	Binary	Room level	1 hour		
Total Volatile Organic Compounds (TVOCs)	TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air.	Numeric	Dynamic	IAQ	**Average TVOC** The TVOC measurements are reported on a 28-day basis. If data of smaller granularity are provided, the values are averaged per 28-day intervals. **Limits** According to EN 16798-1, 2019: <1000 μg/m³ (low emitting building) <300 μg/m³ (very low emitting building)	TVOC measurement	μg/m³	Room level (at supply air duct ideally)	28 days	Residential/Commercial	

Particulate matter <2,5 μm (PM 2.5)	Particles’ that are 2,5 μm 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.	Numeric	Dynamic	IAQ	**Average PM 2.5** The PM measurements when the space is occupied are grouped and averaged by day and then all days within the period of interest are averaged to produce a single value. The calculated value is compared with the per-24h limit. Alternatively, the same measurements are averaged on yearly basis and the calculated value is compared to the per-1year limit **Limits** According to EN 16798-1: <25 μg/m3 (per 24 h) 10 μg/m3 (per year)	PM2.5 measurement	μg/m³	Room level (at extract air duct ideally)	1 hour	Residential/Commercial	
						Occupancy status	binary	Room level	1 hour		
						Occupancy status	binary	Room level	1 hour		

Complementary IAQ Indicator Name	Indicator Description	Units	Static/Dynamic	Category	Calculation Procedure	Input Data	Type of Building	Comments

						Metrics	**Units**	**Spatial Granularity**	**Temporal granularity**		
Ventilation rate (air flow)	The ventilation rate 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 of each category compared to the total hours of the period of interest	% per category	Dynamic	IAQ	**Average ventilation rate** Rough estimation (naturally ventilated buildings) of air change rate with hourly CO_2 concentrations on the single zone approximation when no sources are present: $A = (\ln(CO2_{t_0}) - \ln(CO2_{t_n})) / (t_n - t_0)$ The first and second CO_2 measurements must correspond to occupied and unoccupied hours respectively. After conversion the ventilation rate in l/s/m^2: $Vr = \frac{A \times Vol \times 1000}{3600} / S$	Carbon Dioxide conentration measured at two different timestamps: $\boldsymbol{CO2_t}$	ppm	Room level (at supply air duct ideally)	1 hour	Residential/Commercial	The ventilation rate can be estimated on a daily basis at specific timestamps and then averaged for the period of interest. The estimation of ventilation rate is a challenging task due to several assumptions made (e.g., no other CO_2 sources other than occupants). It is further influenced by many factors (# of occupants, open/close windows etc.) which may generate
						First timestamp: $\mathbf{t_0}$	datetime	Room level	1 hour		
						Last timestamp: $\mathbf{t_n}$	datetime	Room level	1 hour		

					Total Hours of building occupation in the period of interest: $$\sum_{i=t_0}^{t_n} 1$$	Room surface: $\boldsymbol{S}$	m^2	Room level	N/A		even worse results. Based on the results it may be deemed out of scope. In mechanically ventilated buildings actual ventilation rates may be acquired by sensors of the ventilation system. It is generally recommended to measure ventilation rates at building scale
					Total Hours corresponding to each category for the period of interest: $Hours\ per\ category: \sum_{i=t_0}^{t_n} 1,\ [If\ V$ $\leq Vr_{cat}\ ]$	Room volume: $\boldsymbol{Vol}$	m^3	Room level	N/A		
					Category proportion: (Hours per category / Total Hours) *100	Ventilation category: $\boldsymbol{Vr_{cat}}$	$l/s/m^2$	N/A	N/A		
					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 $l/(s*m^2)$	Occupancy Status	Binary	Room level	1 hour		
Benzene	Benzene concentration in the indoor air.	Numeric	Dynamic	IAQ	**Average Benzene**	Benzene measurement	$\mu g/m^3$	Room level (at supply air	28 days	Residential/Commercial	

					The Benzene measurements are reported on a 28-day basis. If data of smaller granularity are provided, the values are averaged per 28 days intervals. **Limits** According to EN 16798-1: 3.25 μg/m3			duct ideally)			
Formaldehyde	Formaldehyde concentration in the indoor air.	Numeric	Dynamic	IAQ	**Average Formaldehyde** The Formaldehyde measurements are reported on a 28-day basis. If data of smaller granularity are provided, the values are averaged per 28-day intervals **Limits** According to EN 16798-1 <100 μg/m³ (low emitting building) <30 μg/m³ (very low emitting building)	Formaldehyde measurement	μg/m³	Room level (at extract air duct ideally)	28 days	Residential/Commercial	
Radon	Radon concentration in the indoor air.	Numeric	Dynamic	IAQ	**Average Radon** The Radon measurements are reported on a 28-day basis. If data of smaller granularity are	Radon measurement	Bq/m³	Room level (at extract air duct ideally)	28 days	Residential/Commercial	

					provided, the values are averaged per 28-day intervals 100 Bq/m³ (based on WHO)						
Particulate matter <10 μm (PM 10)	Particles' that are 10 μm 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 10 aerodynamic diameters.	Numeric	Dynamic	IAQ	**Average PM 10** The PM measurements when the space is occupied are grouped and averaged by day and then all days within the period of interest are averaged to produce a single value. The calculated value is compared with the per-24h limit. Alternatively, the same measurements are averaged on yearly basis and the calculated value is compared to the per-1year limit **Limits** According to EN 16798-1: <50 μg/m³ (per 24 h) <20 μg/m³ (per year)	PM2.5 measurement	μg/m³	Room level (at extract air duct ideally)	1 hour	Residential/Commercial	
						Occupancy status	binary	Room level	1 hour		

ANNEX C: Life Cycle Assessment Indicators [28, 30]

Indicator Name	Indicator Description	Unit of measurement	Static/ Dynamic	Category	Characterization factor
Climate change (global warming potential)	Indicator of potential global warming due to emissions of greenhouse gases to air	kg CO_2 equivalents [kg CO2 eq]	Static	Environmental	$CF_{x, TH, AOP}$= $GWP_{x, TH}$ $\delta TEMP_{CO2, TH}$·EF_{AOP} where GWP: Global Warming GWP of greenhouse gas x. TH: time horizon. δTEMP: temperature increase due to the release of 1 kg of CO2. EF: effect factor for a given Area of Protection (AOP), in this case Human Health.
Ozone depletion potential	Indicator of emissions to air that cause the destruction of the stratospheric ozone layer	kg CFC 11 equivalents [kg CFC 11 eq]	Static	Environmental	$CF_{x, TH}$= $ODP_{x, TH}$ $EF_{CFC-11, TH}$ where ODP: ODP of substance x. EF: effect factor of the reference substance CFC-11 for time horizon TH.
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.	mole H+ equivalents [mol H+ eq.]	Static	Environmental	Characterization factors are provided for emissions of nitrogen oxides (NOx), ammonia (NH3), and sulfur dioxide (SO2).
Eutrophication aquatic freshwater	excessive growth measurement of aquatic plants or algal blooms, due to high levels of nutrients in freshwater.	kg P equivalents [kg P eq.]	Static	Environmental	Characterization factors are provided for emissions to freshwater, emissions to soil, as well as erosion.
Eutrophication aquatic marine	marine ecosystem reaction measurement to an excessive availability of a limiting nutrient	kg N equivalents [kg N eq.]	Static	Environmental	CFend, ijk=∑j(FFijk)·(XFj)·(EFjj)·(VSj) where FFijk: Fate Factor [yr] for emissions from country i to receiving marine ecosystem j by emission route k.

					XFj: exposure factor [kgO2·kgN-1] in receiving ecosystem j. EFj: Effect Factor [PDF·kgO2-1] in receiving ecosystem j.
Eutrophication terrestrial	increased nutrient availability measurement in soil as a result of input of plant nutrients.	mole N equivalents [mol N eq.]	Static	Environmental	
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	kg NMVOC equivalents [kg NMVOC eq.]	Static	Environmental	CFx, i=∑j ((iFx, i→j) ·∑e (EFe, j·DFe, j)) This CF for human health damage is composed of a dimensionless intake fraction (iFx, i→j), providing the population intake of ozone in receptor region j (in kg/yr) following an emission change of substance x in source region i (in kg/yr), an effect factor (EFe), describing the cases of health effect e per kg of inhaled ozone, and a damage factor (DFe), which describes the years of life lost per case of health effect e.
Depletion of abiotic resources - minerals and metals	Indicator of the depletion of natural non-fossil resources	kg Sb equivalents [kg Sb eq.]	Static	Environmental	
Depletion of abiotic resources – fossil fuel	Indicator of the depletion of natural fossil fuel resources	Mega Joules [MJ]	Static	Environmental	
Water use	Indicator of the amount of water required to dilute toxic elements emitted into water or soil	Cubic meters [m^3]	Static	Environmental	
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 metre per year (kWh/m^2 /yr)	Static	Environmental	
Life cycle Global Warming Potential	'carbon footprint assessment' or 'whole life carbon measurement': building's contribution to greenhouse gas (GHG)	kg CO_2 equivalents per square metre per year (kg CO_2 eq./m^2/yr	Static	Environmental	

	emissions measurement associated with earth's global warming or climate change.				
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	Static	Environmental	
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	Static	Environmental	
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 fulfil its function and for the possibility to extend its useful service life into the future.	Adaptability score	Static		
Design for deconstruction, reuse and recycling	Building design extent assessment of facilitation future recovery of materials for reuse of recycling, including assessment of the disassembly for a minimum scope of building parts ease, followed by the reuse and recycling for these parts and their associated sub-assemblies and materials ease.	Deconstruction score	Static		
Use stage water consumption	the total consumption of water measurement for an average building occupant, with the option to split this value into potable and non-potable supplied water, as well as support measurement of the water scarce locations identification.	m^3/yr of water per occupant	Static		

ANNEX D: 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: - 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
Total cost comparison (graphically presented)	The "total cost comparison" indicator is comparing the as-designed and as-operated costs, namely the total costs per 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 user can expect for the replacement and maintenance of building systems	EUR