D^2EPC Information Model for Next Generation EPCs v1

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DELIVERABLE D2.5_ D^2EPC Information Model for next generation EPCs v1

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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 (API) guidelines in what way information for those indicators' calculation 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 this 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 (API) 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
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 economic indicators and considering user wellbeing aspects (thermal/vision comfort, air quality). The whole WP will deliver 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 will extend current standards/protocols used for issuing certificates including also 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.

1.2 Structure of the deliverable

The purpose of the deliverable 2.5 of the D ^ 2EPC project is to gather all the information collected in deliverables 2.1 to 2.4 of the project, regarding the indicators that will describe the energy and environmental performance of the building, and 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 architecture of an API, which will be used to extract these indicators from BIM files are presented as part of this deliverable.

In this regard, this deliverable consists of four 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.
- The third section of this deliverable focuses on the presentation of the indicators that will be 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 economic analysis of the buildings are presented in detail.
- The fourth chapter focuses on the presentation of the API architecture, which will be used in the project for calculation of the indicators from BIM documents. The code developed for the purpose is given in detail in this section.

In month thirty-four (M34) the review of data of T2.5 will be conducted based on the new findings as the project evolves, as well as from further research and innovation projects.

The second deliverable of T2.5 task D2.10: D^2EPC Information Model for next generation EPCs in month thirty-six (M36) will follow.

1.3 Relation to Other Tasks and Deliverables

T2.5 analysis, guidelines and conclusions will be 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 and D1.4 deliverables. The IFC parser (API) developed in this task is highly dependent on indicators T2.1 to T2.4. The first version of the indicators was obtained before the D2.5 deliverable (except for T2.4, as this task started later) and is summarized in this document. D2.1 - D2.4 deliverables are planned for months M17 and M18. Using the information provided in the deliverables mentioned above, updated the D^2EPC information model upon receipt of the final D2.6-D2.9 deliverables will form the basis for the final D2.10 deliverable prepared in M36.

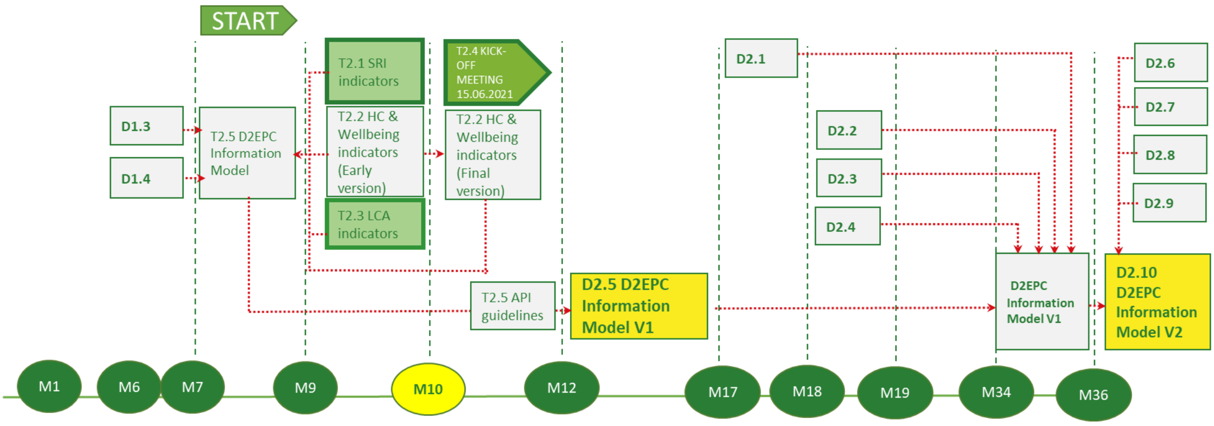

Figure 1. Task's T2.5 interactions with other tasks and deliverables.

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 principal, 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].

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 is 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 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 will be human-centric and oriented towards the whole life cycle of the building, will enable the evaluation of buildings in a holistic and cost-effective manner across several complementary dimensions which will consider both the envelope and the system performances of buildings. New elements including climate correction final energy consumptions and energy expenditure, comfort levels, expressed also in monetary terms are envisioned in the new scheme.

Key Performance Indicators are the set of indicators to be 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 Cost and Economic indicators. Results for the available list of indicators are presented in the indicated Annexes while for Cost and Economic Indicators, this is expected to be updated in the next version of this deliverable.

In the D^2EPC platform, KPIs will be the output according to which, a building will be assigned to a certain class based on a certain type of assessment.

3.1 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 [24].

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).

3.2 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 occupants wellbeing human health, life and productivity [25]. 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.

Complete user profiles will comprise a set of comfort/wellbeing and behavioural indicators, along with the respective algorithms (for the extraction of the indicators values) and the expected range of desired values (per user segment). Behavioural profiles are directly translatable into building system utilization which plays an important role in energy consumption. More specifically, to extract these profiles, a customized sensor network will be designed and installed as physical sensors (IoT solution) deployed in the pilot buildings (to complement their existing data collection capacity) to capture the indoor environmental conditions and the occupant's activity (presence/absence). These profiles will subsequently be applied to measure the building system (e.g. heating/ cooling/lighting) utilization boundaries that fall within the comfort zone of the occupants. Beyond the static components and data related to the building envelope and systems can extract, the focus primarily on detailed information to understand why, how and under what varying usage constraints (operations, occupancy, end users' comfort preferences and behaviour) energy is consumed, so that accurate dynamic building performance measurement and monitoring can be realized by considering human-centric features related to wellbeing and comfort as per the SRI framework. Such enhanced and integrated profiles will incorporate all personalized and contextual (environmental, temporal) aspects of (energy-related) behaviour, focusing on visual and thermal comfort preferences of consumers (while performing specific activities), hygienic and healthy boundaries that need to be applied in the indoor environment, along with specific operational requirements for carrying special activities (ensuring business continuity, occupants' convenience and productivity). The defined human comfort and wellbeing indicators are listed in **Annex B**.

3.3 LCA Indicators

LCA indicators - additional indicators, which demonstrate the environmental performance of buildings for their introduction in the next-generation EPCs. To develop the environmental indicators, Life Cycle Assessment (LCA) methodologies and tools will be employed. 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/ m^2”.

These findings highlight the importance of employing LCA. The LCA Indicators for EPCs will significantly contribute to the maximization of the energy savings and the achievement of carbon reductions of the buildings and complement the SRIs, social and economic indicators - T2.1, T2.2, T2.4 respectively- for the issuing of truly sustainable EPCs. The defined LCA indicators are listed in **Annex C**.

3.4 Cost and economic indicators for EPCs

An economic indicator is a metric used to assess, measure, and evaluate the overall state of health of the macroeconomy. Economic indicators usually are retrieved within a census or survey that is performed by a government agency or private business intelligence organization, further analysed to result in an economic indicator [26]. One of the major concerns of the next-generation EPCs envisioned in the D^2EPC project is the establishment of simplified indicators that will enhance the building certificate's user-friendliness. In that sense, project partners will develop a set of financial indicators based on the well-established concept of whole life cycle costing to enable the interpretation of the individual elements of buildings energy performance into normalized monetary values. The delivery of such indicators will allow for the employment of EPCs for the financial assessment of buildings energy upgrade measures. It will enable the exploitation of the information produced by EPCs by energy audit processes, bridging the gap between the energy-related directives of EPBD and energy efficiency. The defined cost and economic indicators will be presented in the corresponding deliverable D2.4 and will be also included in the second version of the current deliverable.

4 IFC parser (API)

4.1 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

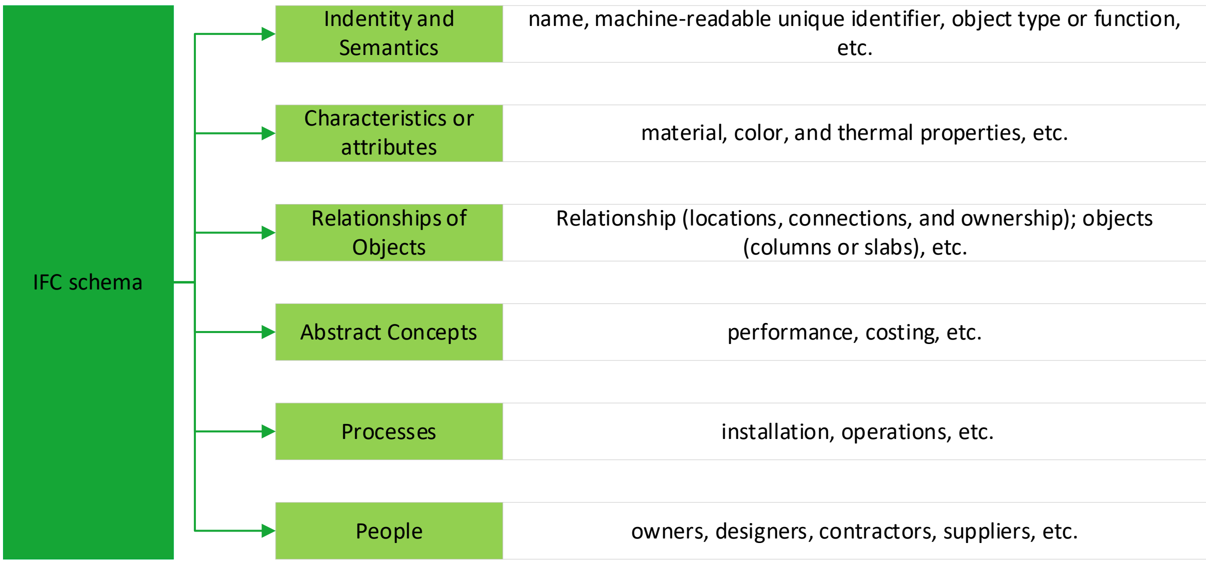

Figure 2. IFC Schema coding logic sequence

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 (API), IFC4 ADD2 TC1 used, published in ISO 16739-1:2018.

4.2 IFC parser 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 (API) is 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 IFC Parser, the structure of the API structure and the procedures are described in detail in section 4.4.

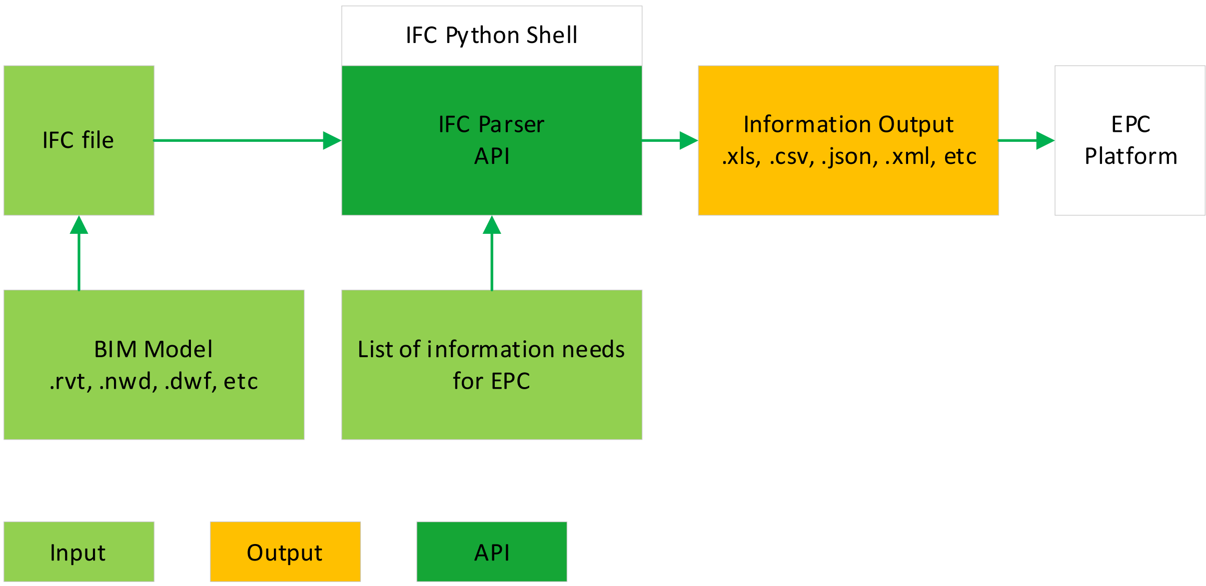

Figure 3. D^2EPC IFC Parser Workflow

4.3 Overview of the sample Apartment BIM and IFC model

The functionality of the developed IFC Parser API 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 4.

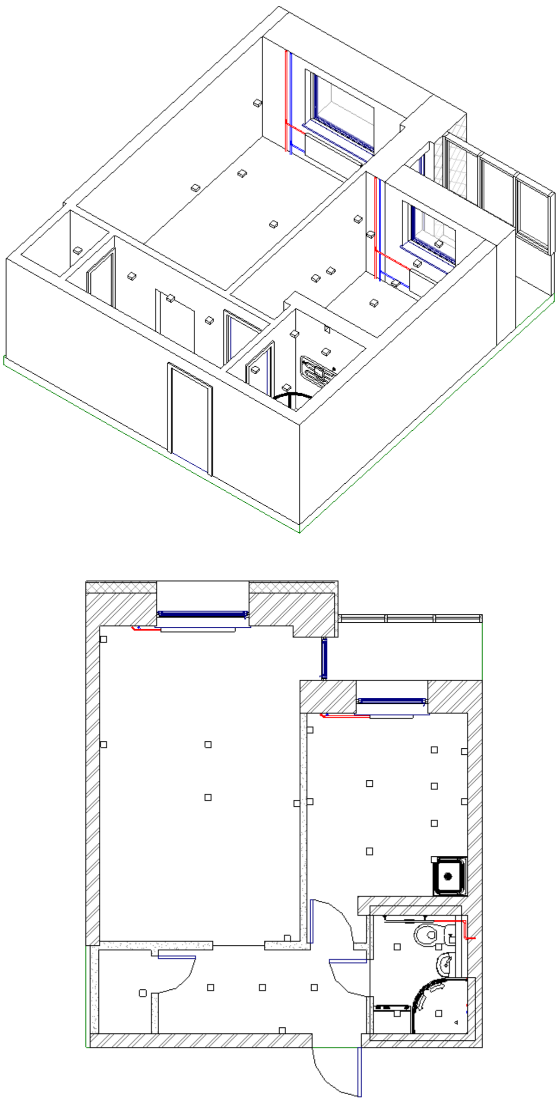

Figure 4. 3D view (left) and plan view (right) of the sample apartment

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 5).

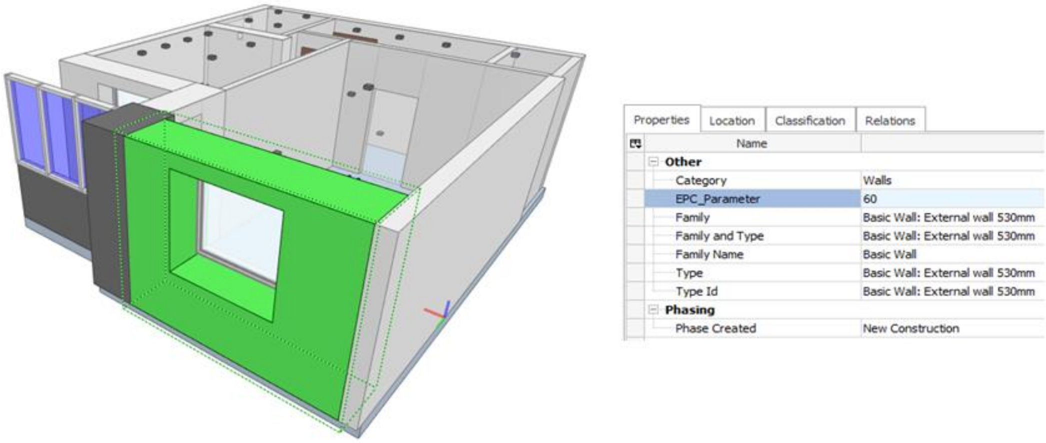

Figure 5. Selected wall (left), added parameter (right)

4.4 IFC parser (API) for D^2EPC

The IFC parser for the D^2EPC project is developed in Python programming language; the IfcOpenShell-Python and Pandas modules were also used.

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 current version of the IFC parser consists of several parts (pieces of code) intended for a specific function and parse option (ref. to Appendix 1 – IFC parser for D^2EPC).

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

4.4.1 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
```

4.4.2 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
```

4.4.3 IFC parsing options

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

4.4.3.1 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')
```

4.4.3.2 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)
print('List for Names:',listN)
print('List for Values:',listV)
```

```
# append attribute value to list
# print list of attribute names
# 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
```

4.4.3.3 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]

for definition in space.IsDefinedBy:
         if
definition.is_a('IfcRelDefinesByProperties'):
             Pset =
definition.RelatingPropertyDefinition
             print(Pset.Name)
```

```
# assign variable for particular IFC entity

# iterating through objects
# condition "defined by properties"
# assign variable for property set
# print property set (Pset) name
```

Out [5]:

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

4.4.3.4 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
```

4.4.3.5 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
```

4.4.4 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

5 Conclusions

This deliverable is the first version of two documents to be 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 application programming interface (API).

Primary lists and definitions concerning the additional indicators that will be part of the Next Generation EPCs were presented as the initial results of the activities of WP2 during the M6-M12 period of the project. In total four groups of energy and human related indicators were proposed together with detailed description and evaluation requirements:

- 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 wellbeing 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.
- Cost and economic indicators – the definition of these indicators will be submitted with the second WP2 report.

Extraction of the relevant data for indicators will be performed using open international standard IFC. For this purpose, the IFC parser is written in Python programming language using open-source IfcOpenShell-Python and Pandas modules. The detailed definition and the code of the application are presented in the report as well.

6 References

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ANNEX A: Smart Readiness Indicators

Indicator Name	Indicator Description	Units	Static/Dynamic	Category	Calculation Procedure	Input Data				Data format	Type of the building
						Metric	Unit	Spatial Granularity **	Temporal Granularity **		
SRI-Lighting 1a	Occupancy control for indoor lighting	N/A	Static	SRI	**level 0** Manual on/off switch | **level 1** Manual on/off switch + additional sweeping extinction signal | **level 2** Automatic detection (auto on / dimmed or auto off) | **level 3** Automatic detection (manual on / dimmed or auto off)	Type of lighting switch sweep time control device (0,1) Occupancy Sensor (2,3)	-	-	-	-	
SRI-Lighting 2	Control artificial lighting power based on daylight levels	N/A	Static	SRI	**level 0** Manual (central) | **level 1** Manual (per room/zone) | **level 2** Automatic switching | **level 3** Automatic dimming | **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)	Type of lighting switch –central (0) Type of lighting switch –per zone/room (1) Brightness/photoelectric/occupancy sensors (2,3,4) *Colour Temperature Sensors, light intensity sensor (4)*					
EV-15	EV Charging Capacity	X Units	Static	SRI	**level 0** Not present | **level 1** Ducting (or simple power plug) available | **level 2** 0-9% of parking spaces has recharging points | **level 3** 10-50% of parking spaces has	Presence and type of power plugs available (0,1) Percentage of parking spaces with charging points (2,3,4)					

					recharging points | **level 4** >50% of parking spaces has recharging points							
EV-16	EV Charging Grid Balancing	N/A	Static	SRI	**level 0** Not present (uncontrolled charging) | **level 1** 1-way controlled charging (e.g., including desired departure time and grid signals for optimization) | **level 2** 2-way controlled charging (e.g., including desired departure time and grid signals for optimization)	Presence of EV charging control (0) Unidirectional chargers (1) Bidirectional chargers with internal converters, from DC to AC (2)						
EV-17	EV Charging Information and connectivity	N/A	Static	SRI	**level 0** | No information available |**level 1** Reporting information on EV charging status to occupant | **level 2** Reporting information on EV charging status to occupant AND automatic identification and authorization of the driver to the charging station (ISO 15118 compliant)	Availability of EV charging Information and connectivity (0) Powered charging apps (IoT platforms with advanced data analytic systems (1,2) – users can access all real time information about charging process						
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	N/A	Static	SRI	**level 0** | Automatic control on/off | **level** 1 Automatic control on/off and scheduled charging enable | **level 2** Automatic control on/off and scheduled charging enable and multi-sensor storage management | **level 3** Automatic charging control based on local availability of renewables or information from electricity grid (DR, DSM).	Thermostat (0,1) Multi-sensors (2) Real time clock or multi-sensing buffer (3)						
DHW-1b	Control of DHW storage charging (using hot	N/A	Static	SRI	**level 0** Automatic control on/off | **level 1** Automatic control on/off and scheduled charging enable | **Level 2**	Thermostat (0) Control equipment with real time clock (1)						

	water generation)				Automatic on/off control, scheduled charging enables and demand-based supply temperature control or multi-sensor storage management | **level 3** DHW production system capable of automatic charging control based on external signals (e.g. from district heating grid)	Control equipment with real time clock or multi-sensors (2)					
DHW-1d	Control of DHW storage charging (with solar collector and supplementary heat generation)	N/A	Static	SRI	**level 0** Manual selected control of solar energy or heat generation | **level 1** Automatic control of solar storage charge (Prio.1) and supplementary storage charge | **level 2** Automatic control of solar storage charge (Prio.1) and supplementary storage charge and demand-oriented supply or multi-sensor storage management | **level 3** Automatic control of solar storage charge (Prio.1) and supplementary storage charge, demand-oriented supply and return temperature control and multi-sensor storage management	Thermostat (with preselected generator) (0) Automatic switch to supplementary loading of buffer with other Heat generations (1) Control equipment with real time clock or multi sensing buffer (2,3)					
DHW-2b	Sequencing in case of different DHW generators	N/A	Static	SRI	**level 0** Priorities only based on running time | **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	Sequence coordination device with communication/connection to all DHW generators (0,1,2,3,4)					

					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)						
DHW-3	Report information regarding domestic hot water performance	N/A	Static	SRI	**level 0** None |**level 1** Indication of actual values (e.g., temperatures, submetering energy usage) | **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	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about DHW production, forecasting, benchmarking					
DE-1	Window solar shading control	N/A	Static	SRI	**level 0** No sun shading or only manual operation | **level 1** Motorized operation with manual control | **level 2** Motorized operation with automatic control based on sensor data | **level 3** Combined light/blind/HVAC control | **level 4** Predictive	Blind Switches to manually operate blinds, motorized blinds (0,1) Solar sensor, communication to solar brightness sensor, motorized blinds (2) Motorized shades, motorized blinds and					

					blind control (e.g., based on weather forecast)	other window coverings which are operated from commands sent by either remote controls or adjacent wall switches (3,4)				
DE-2	Window open/closed control, combined with HVAC system	N/A	Static	SRI	**level 0** Manual operation or only fixed windows | **level 1** Open/closed detection to shut down heating or cooling systems | **level 2** Level 1 + Automized mechanical window opening based on room sensor data | **level 3** Level 2 + Centralized coordination of operable windows, e.g., to control free natural night cooling	Manual/fixed windows operation (0) Zone thermostatic controls (1) Mechanical ventilation with temperature/humidity sensor (2) Central mechanical demand control ventilation system (3)				
DE-4	Reporting information regarding performance	N/A	Static	SRI	**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…)	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about dynamic shading systems position, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature)				
Electricity-2	Reporting information regarding local electricity generation	N/A	Static	SRI	**level 0** None | **level 1** Current generation data available | **level 2** Actual values and historical data | **level 3** Performance evaluation	apps and/or IoT platforms with advanced data analytic systems – users can access all real time				

					including forecasting and/or benchmarking | **level 4** Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	information about electricity generation – electricity generation data, historical values, forecasting, benchmarking, performance evaluation, predictive management and fault detection					
Electricity-3	Storage of locally generated energy	N/A	Static	SRI	**level 0** None | **level 1** Limited: small scale storage (batteries, TES…) | **level 2** Storage which can supply self-consumption for > 3 hours | **level 3** Dynamically operated storage which can also feed back into the grid	No local storage available (0) On site electric battery (1) On site electric battery or thermal storage with controller based on grid signals (2) On site electric battery or thermal storage with controller optimising the use of locally generated electricity and possibility to feed back into the grid (3)					
Electricity-4	Optimizing self-consumption of locally generated energy	N/A	Static	SRI	**level 0** None | **level 1** Short term optimization | **level 2** Long term optimization including predicted generation and/or demand						
Electricity-5	Control of combined heat and power plant (CHP)	N/A	Static	SRI	**level 0** CHP control based on scheduled runtime management and/or current heat energy demand | **level** 1 CHP runtime control influenced by the fluctuating availability of RES; overproduction will be fed into the grid | **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					
Electricity-8	Support of microgrid operation modes	N/A	Static	SRI	**level 0** None | **level 1** Local battery usage | **level 2** Autonomous energy consumption control					
Electricty-11	Reporting information regarding energy storage	N/A	Static	SRI	**level 0** None | **level 1** Current state of charge (SOC) 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	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about energy storage – actual and historical values, forecasting and/or benchmarking, predictive management, fault detection				
electricity-12	Reporting information regarding electricity consumption	N/A	Static	SRI	**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	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about electricity consumption – real time feedback, benchmarking, recommendations				
Heating-1a	Heat emission control	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Central automatic control (e.g. central	Thermostat, central control unit (0,1)				

					thermostat) | **level 2** Individual room control (e.g. thermostatic valves, or electronic controller) | **level 3** Individual room control with communication between controllers and to BACS | **level 4** Individual room control with communication and occupancy detection	thermostatic valves, or electronic control units, occupancy sensors (2,3,4)					
Heating-1b	Emission control for TABS (heating mode)	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Central automatic control | **level 2** Advanced central automatic control | **level 3** Advanced central automatic control with intermittent operation and/or room temperature feedback control	Air temperature sensor, supply water temperature sensor (1) Room temperature sensor, supply water valve, outside air temperature sensor, room setpoint device (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	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Outside temperature compensated control | **level 2** Demand based control	Outside air temperature sensor, water temperature sensor, demand switches/controllers (1,2)					
Heating-1d	Control of distribution pumps in networks		Static	SRI	**Level 0** No automatic control | **level 1** On off control | **level 2** Multi-Stage control | **level 3** Variable speed pump control (pump unit (internal) estimations) | **level 4**	Multi speed equipment – pump with multi-stage, electrical/electronic staging equipment (2)					

					Variable speed pump control (external demand signal)	Variable speed drive, pressure sensors (3,4)					
Heating-1f	Thermal Energy Storage (TES) for building heating (excluding TABS)		Static	SRI	**Level 0** Continuous storage operation | **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)		Static	SRI	**Level 0** Constant temperature control | **level 1** Variable temperature control depending on outdoor temperature | **level 2** Variable temperature control depending on the load (e.g. depending on supply water temperature set point)	Manual temperature setpoint (0) Outdoor temperature, flow temperature sensor (1) Flow sensors (requires communication to other parts of the system (2)					
Heating-2b	Heat generator control (for heat pumps)		Static	SRI	**Level 0** On/Off-control of heat generator | **level 1** Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors) | **level 2** Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control) | **level 3** Variable control of heat generator capacity depending on the load AND external signals from grid						
Heating-2d	Sequencing in case of different heat generators	N/A	Static	SRI	**Level 0** Priorities only based on running time | **level 1** Control according to fixed priority list: e.g. based on	Sequence coordination device with communication/connection to all heat					

					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)	generators, flow temperature sensors, efficiency measurement ouput (1)					
Heating-3	Report information regarding HEATING system performance	N/A	Static	SRI	**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 including predictive management and fault detection	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about heating system performance – performance KPI's, historical data, forecasting and/or benchmarking, predictive management and fault detection.					

Heating-4	Flexibility and grid interaction	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Scheduled operation of heating system | **level 2** Self-learning optimal control of 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)						
Cooling-1a	Cooling emission control	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Central automatic control | **level 2** Individual room control | **level 3** Individual room control with communication between controllers and to BACS | **level 4** Individual room control with communication and occupancy detection	Central control unit, temperature sensor (1) Thermostatic valves or electronic control units, temperature sensor (2) Room control units and communication, temperature sensor (3) Room control units and communication, temperature sensor, occupancy sensor (4)					
Cooling-1b	Emission control for TABS (cooling mode)	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Central automatic control | **level 2** Advanced central automatic control | **level 3** Advanced central automatic control with intermittent operation and/or room temperature feedback control	Manual control (e.g valve) (0) Outside air temperature sensor, water temperature sensor (1) Room temperature sensor, supply water valve, outside air temperature sensor, room setpoint device (2,3)					
Cooling-1c	Control of distribution	N/A	Static	SRI	**Level 0** Constant temperature control | **level 1** Outside	Presence of distribution network (0)					

	network chilled water temperature (supply or return)				temperature compensated control | **level 2** Demand based control	Control unit, flow temperature sensor, outside temperature sensor (1) Control unit, temperature sensor and communication (2)						
Cooling-1d	Control of distribution pumps in networks	N/A	Static	SRI	**Level 0** No automatic control | **level 1** On off control | **level 2** Multi-Stage control | **level 3** Variable speed pump control (pump unit (internal) estimations) | **level 4** Variable speed pump control (external demand signal)	Multi-speed equipment (e.g mult-stage, electrical/electronic staging equipment) (2) Variable speed drive, pressure sensor (3,4)						
Cooling-1f	Interlock: avoiding simultaneous heating and cooling in the same room	N/A	Static	SRI	**Level 0** No interlock | **level 1** Partial interlock (minimizing risk of simultaneous heating and cooling e.g. by sliding setpoints) | **level 2** Total interlock (control system ensures no simultaneous heating and cooling can take place)	Communication/connection between heating control, cooling control and air temperature control (1,2)						
Cooling-1g	Control of Thermal Energy Storage (TES) operation	N/A	Static	SRI	**Level 0** Continuous storage operation | **level 1** Time-scheduled storage operation | **level 2** Load prediction-based storage operation | **level 3** Cold storage capable of flexible control through grid signals (e.g. DSM)							
Cooling-2a	Generator control for cooling	N/A	Static	SRI	**Level 0** On/off-control of cooling production | **level 1** Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors) | **level 2** Variable control of cooling	Outdoor temperature sensor, flow temperature sensor, Multi stage equipment, demand switches/controllers (1) Communication to distribution/cooling						

					production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control) | **level 3** Variable control of cooling production capacity depending on the load AND external signals from grid.	consumer, flow sensor, demand switches/controllers, direct grid signal (2,3)					
Cooling-2b	Sequencing of different cooling generators	N/A	Static	SRI	**Level 0** Priorities only based on running times | **level 1** Fixed sequencing based on loads only: e.g. depending on the generators 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.	Sequence coordination device with communication/connection to all cooling generators, flow temperature sensors, efficiency measurement ouput (1,2,3)					
Cooling-3	Report information regarding cooling system performance	N/A	Static	SRI	**Level 0** None | **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	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about cooling system performance – performance KPI's, historical data, forecasting and/or benchmarking,					

					benchmarking | **level 4** Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection.	predictive management and fault detection					
Cooling-4	Flexibility and grid interaction	N/A	Static	SRI	**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)						
Ventilation-1a	Supply air flow at the room level	N/A	Static	SRI	**Level 0** No ventilation system or manual control | **level 1** Clock control | **level 2** Occupancy detection control | **level 3** Central Demand Control based on air quality sensors (CO2, VOC, humidity…) | **level 4** Local Demand Control based on air quality sensors (CO2, VOC, …) with local flow from/to the zone regulated by dampers	Manual operated switch (0) Existence of scheduling for the specific room/zone or functional test (1) Presence detection with occupancy sensor, manual occupancy switch, etc. or functional tests (2) Air quality sensors (CO_2 sensors, VOC sensors), central demand switches/controllers, multistage or variable speed Control of fun speed (3) Air quality sensors (CO_2 sensors, VOC sensors),					

						demand switches/controllers, zone/room demand switches/controllers, mixing dampers for circulated air, (4)					
Ventilation-1c	Air flow or pressure control at the air handler level	N/A	Static	SRI	**Level 0** No automatic control: continuously supplies of air flow for a maximum load of all rooms | **level 1** On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time | **level 2** Multi-stage control: to reduce the auxiliary energy demand of the fan | **level 3** Automatic flow or pressure control without pressure reset: load dependent supplies of air flow for the demand of all connected rooms | **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)	Existence of scheduling for the specific air handler (1) Control equipment for multi-step control for the fan(s) (2) Equipment for variable fan speed, pressure sensing equipment and Demand Communication/Connection to rooms/zones (3,4)					
Ventilation-2c	Heat recovery control: prevention of overheating	N/A	Static	SRI	**Level 0** Without overheating control | **level 1** Modulate or bypass heat recovery based on sensors in air exhaust | **level 2** Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control	Temperature Sensor for Supply Air (1,2)					

Ventilation-2d	Supply air temperature control at the air handling unit level	N/A	Static	SRI	**Level 0** No automatic control | **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 | **level 2** Variable setpoint with outdoor temperature compensation | **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	Room/zone temperature sensor (1) Room/zone temperature sensor, outside air sensor (or communication to outside air sensor) (2) Room/zone temperature sensor, flow/air quality control, communication/connection to static heating/cooling (3)					
Ventilation-3	Free cooling with mechanical ventilation system	N/A	Static	SRI	**Level 0** No automatic control | **level 1** Night cooling | **level 2** Free cooling: air flows modulated during all periods of time to 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. Calculation is performed on the basis of temperature and humidity.	Outside temperature sensor (or communication to outside air sensor) / Room/zone temperature Sensor (1,2) Humidity sensor, humidifier/dehumidifier actuators, room/zone temperature sensor (3)					
Ventilation-6	Reporting information regarding IAQ	N/A	Static	SRI	**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	apps and/or IoT platforms with advanced data analytic systems – users can access all real time information about IAQ – real time air quality,					

					time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)	historical air quality values, warning on maintenance needs or occupant actions					

** Spatial & Temporal Granularities will be based on the Data Model

ANNEX B: Human-Comfort and Wellbeing Indicators [27,28].

Indicator Name	Indicator Description	Units	Static/Dynamic	Category	Calculation Procedure	Input Data				Data format	Type of the building	Indicator calculated based on asset rating	Indicator calculated based on operational	Comments
						Metric	Unit	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.	L/s/m2	Dynamic	Indoor air quality	***Basic ventilation rates*** (for diluting emissions (bio effluents) from people): I category – 10 l/s/person II category – 7 l/s/person III category – 5 l/s/person IV category – 2,5 l/s/person V***entilation rates*** (for diluting all emissions from building) ***According to CEN/TR 16798-1:2019:*** I category – 20 l/s/person II category – 14 l/s/person III category – 8 l/s/person IV category – 5,5 l/s/person Or I category – 2 $l/(s*m^2)$ II category – 1,4 $l/(s*m^2)$ III category – 0,8 $l/(s*m^2)$ IV category – 0,55 $l/(s*m^2)$								X	Recommended to measure ventilation rates at building scale
Total Total Volatile Organic Compounds (TVOCs)	TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air.	µg/m3	Dynamic	Indoor air quality	As defined in 3.1.3.11 (of EN 16516), calculated by summing the reference room concentrations of every individual compound (target and non-target, identified and unidentified) eluting between n-hexane and n-hexadecane inclusively using the specified column, and calculated using the TIC response factor for toluene after subtracting the blank values and after excluding compounds								X	

					calculated to be below 5 µg/m3 in the air of the reference room using the TIC response factor for toluene, additionally all compounds listed in Annex G (of EN 16516) are included even if they elute after n-hexadecane or before n-hexane under the specific test conditions. ***According to EN 16798-1, 2019:*** Limits: <1000 µg/m^3 (low emitting building) <300 µg/m^3 (very low emitting building) $c_B = c_R \times L_{AB}/L_{AR} \times \frac{AC_R}{AC_B}$ *where:* *c_B is the mass concentration of compound a in the air of the actual building, in µg/m^3;* *c_R is the mass concentration of compound a in the air of the reference room, in µg/m^3;* *L_{AB} is the loading factor in the actual building, in square metre sample per cubic meter reference room;* *L_{AR} is the loading factor in the reference room, in square metre sample per cubic meter reference room;* *AC_R is the hourly air change rate in the reference room, in h^{-1};* *AC_R is the hourly air change rate in the actual building, in h^{-1}.*									
Benzene	Benzene concentration in the indoor air.	µg/m3	Dynamic	Indoor air quality	3.25 µg/m3								X	
CO_2 outdoors	CO_2 concentration in the outdoor air.	ppm	Dynamic										X	

CO_2 indoors	CO_2 concentration in the indoor air.	ppm	Dynamic	Indoor air quality	***According to CEN/TR 16798-2:2019 and CEN/TR 16798-1:2019:*** 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 – 1350 ppm when the air flow is 4 l/s Note: mentioned numbers of CO_2 concentrations are above outdoor air. Note: Assuming standard CO_2 emission of 20L/(h/person)								X	
Relative humidity	Indicates a present state of absolute humidity relative to a maximum humidity given the same temperature.	%	Dynamic	Indoor air quality	General: 30 – 75 % For human comfort: 40 – 60 %								X	
CMR VOCs	The mass of volatile organic compounds, in the formulation of the product in its ready to use condition. *VOCs classified as Carcinogenic, Mutagenic or toxic for Reproduction according to Regulation (EC) No 1272/20085.*	µg/m3	Dynamic	Indoor air quality	***According to EN 16798-1****:* Limits: <5 µg/m³ (low emitting building) <5 µg/m³ (very low emitting building) $c_B = c_R \times L_{AB}/L_{AR} \times \frac{AC_R}{AC_B}$ *where:* *c_B is the mass concentration of compound a in the air of the actual building, in µg/m³;* *c_R is the mass concentration of compound a in the air of the reference room, in µg/m³;* *L_{AB} is the loading factor in the actual building, in square metre sample per cubic meter reference room;* *L_{AR} is the loading factor in the reference room, in square metre*								X	

					sample per cubic meter reference room; *AC_R is the hourly air change rate in the reference room, in h^{-1};* *AC_R is the hourly air change rate in the actual building, in h^{-1}.*									
Formaldehyde	Formaldehyde concentration in the indoor air.	µg/m3	Dynamic	Indoor air quality	***According to EN 16798-1***: Limits: <100 µg/m³ (low emitting building) <30 µg/m³ (very low emitting building) $c_B = c_R \times L_{AB}/L_{AR} \times \frac{AC_R}{AC_B}$ *where:* *c_B is the mass concentration of compound a in the air of the actual building, in µg/m³;* *c_R is the mass concentration of compound a in the air of the reference room, in µg/m³;* *L_{AB} is the loading factor in the actual building, in square metre sample per cubic meter reference room;* *L_{AR} is the loading factor in the reference room, in square metre sample per cubic meter reference room;* *AC_R is the hourly air change rate in the reference room, in h^{-1};* *AC_R is the hourly air change rate in the actual building, in h^{-1}.*								X	
Radon	Radon concentration in the indoor air.	Bq/m3	Dynamic	Indoor air quality	100 Bq/m³ (based on WHO)								X	
Particulate matter <2,5 µm (PM 2.5)	Particles' that are 2,5 µm in diameter or smaller concentration in the indoor air.	µg/m3	Dynamic	Indoor air quality	***According to EN 16798-1:*** Limits: <25 µg/m³ (per 24 h) 10 µg/m³ (per year)								X	

	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.													
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.	μg/m3	Dynamic	Indoor air quality	***According to EN 16798-1:*** Limits: <50 μg/m³ (per 24 h) <20 μg/m³ (per year)								X	

** Spatial & Temporal Granularities will be based on the Data Model

ANNEX C: Life Cycle Assessment Indicators [27, 29]

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	$CF_{x, TH, AOP}= GWP_{x, TH}\ \delta TEMP_{CO2, TH} \cdot EF_{AOP}$ 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	$CF_{x, TH}= ODP_{x, TH}\ EF_{CFC\text{-}11, TH}$ 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	mole H+ equivalents [mol H+ eq.]	Static	Environmental	Characterization factors are provided for emissions of nitrogen oxides (NOx), ammonia (NH3), and sulfur dioxide (SO2).

	soils and increased solubility of metals into soils.				
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	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

	volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection				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	kilowatt hours per square metre per year (kWh/m^2 /yr)	Static	Environmental	

	renewable energy.				
Life cycle Global Warming Potential	‘carbon footprint assessment’ or ‘whole life carbon measurement’: building’s contribution to greenhouse gas (GHG) emissions measurement associated with earth's global warming or climate change.	kg CO_2 equivalents per square metre per year (kg CO_2 eq./m^2/yr	Static	Environmental	
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	kg of waste and materials per m^2 total useful floor area	Static	Environmental	

	demolition activities; used to calculate the diversion rate to reuse and recycling, in line with the waste hierarchy.				
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.	Adaptability score	Static		
Design for deconstruction, reuse and recycling	Building design extent assessment of facilitation future recovery of materials for reuse of	Deconstruction score	Static		

	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.				
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		