D2.8 Life Cycle Indicators for next generation EPCs v2

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DELIVERABLE D2.8 Life Cycle Indicators for next generation EPCs v2

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2	Phoebe-Zoe Georgali Paris Fokaides	28.08.2023	Final version ready for submission

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Executive Summary

This deliverable is the result of Task 2.3 Energy Performance & Life Cycle Assessment (LCA) Indicators Analysis for Energy Performance Certificates (EPCs), which was created to provide environmental and energy indicators for the next generation of EPCs. The project's proposed set of indicators aims to improve EPC user-friendliness and raise user awareness by giving more knowledge.

A literature review was conducted in order to get an initial overview of the state-of-the-art, which included searching at existing standards, legislation, and schemes. On this foundation, the suggested approach was created. The goal was to give users a realistic view of the building's energy efficiency by comparing the conceptual design to the construction and operational stages, accounting for future needs and demands. Users will be able to evaluate the performance of their building based on this comparison. Environmental indicators will not only affect the building's energy class but will also be offered to the user as supplementary information. The guideline for obtaining required data concerning environmental and energy indicators and providing instructions for the calculation to all interested parties is the result of this task, as described in this deliverable.

The D^EPC indicators, which show how buildings perform in terms of energy and the environment, are proposed for inclusion in the next-generation EPCs. The Level(s) approach was used to develop the D^EPC environmental indicators. It's a useful foundation for improving environmental performance and resource usage, as well as reducing the impact of the built environment on global resources. The use of real-time data for the generation of energy indicators for EPCs contributes considerably to maximizing energy savings and achieving carbon reductions in buildings, as well as complementing SRIs, social, and economic indicators for the issuance of truly sustainable EPCs. The calculation of the energy indicators was conducted with the use of actual monitored values in the New Wing pilot building of Frederick Research Center (FRC), referring to the total power, heating, cooling, lighting, and electrical appliances of the building. The step-by-step representation of these indicators is shown in the Appendix.

In the second version of the deliverable, communication with leading partners of T4.4 and T5.4 of the project was held in order to define any needs that may have arisen concerning the dEPC tool and the environmental KPIs. During this time, the structure of the deliverable was adjusted based on the project's progress and the results of other activities. More specifically, more measurement data were available at this time, allowing the methodology to be thoroughly evaluated. Since the D^2EPC platform has already been demonstrated, any new requirements were established and addressed by reinforcing the current method and testing the methodology on a real-life example. Furthermore, additions have taken place in the section and sub-sections concerning (i) updates that have been made regarding the environmental indicators aspect in the standardization spectrum, (ii) the European framework for sustainable buildings - Level(s), (iii) the data and parameters for operational rating analysis, as well as (iv) the actual indicators based on the real-time measurements, and more specifically, the power consumption graphical representations of the Frederick Research Center pilot building.

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List of Acronyms and Abbreviations

Term	Description
BREEAM	BRE Environmental Assessment Method
CAT	Calculation and Assessment Tool
CEN	European Committee for Standardization
D.	Deliverable
EPC	Energy Performance Certificate
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
ETSI	European Telecommunications Standards Institute
EU	European Union
GWP	Global Warming Potential
IEC	International Electrotechnical Commission
ILCD	International Reference Life Cycle Data
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCCA	life cycle cost assessment
LCIA	Life Cycle Inventory Assessment
MS	Member State
NSB	National Standardization Body
PCR	Product category rules
PEF	Product Environmental Footprint
RSL	Reference Service Life
SC	Sub-committee
SDG	Sustainable Development Goals
SRI	Smart Readiness Indicators
T.	Task
TC	Technical Committee
VALERI	Valuation of Energy-Related Investments
WG	Working Group
WP.	Work Package

1 Introduction

WP2 aims to analyze and define a set of indicators to be included in the next generation EPCs, including SRI, LCA, and economic indicators, by taking into account user-driven models (thermal/vision comfort, occupancy). Task 2.3: Energy performance & Life Cycle Assessment Indicators Analysis for EPCs has specific operational objectives. In particular, the main objective is to propose additional indicators that demonstrate buildings' environmental performance for their introduction in the next-generation EPCs. For the development of the environmental indicators, Life Cycle Assessment (LCA) methodologies and tools will be employed; LCA enables the assessment of the environmental impact of any system throughout its life cycle by considering the required input and associated output resources of that system. For the delivery of this task, it is critical to first implement a comprehensive literature review on the LCA of the energy performance of buildings, the type and functional units of the LCA Indicators for EPCs to be used will be defined — — examples of LCA Indicators include "Energy savings", expressed in "Embodied energy/ m^2" and "Carbon reductions", expressed in "Carbon dioxide equivalent/ m^2". Under this task, the methodology for using the real-time data collected for the development of the LCA Indicators will also be formulated, as well as relevant guidelines will be developed. This task highlights the importance of employing LCA methodologies for the efficient energy design of buildings and for enabling the parameterization of its embodied energy and primary energy demand to be included in dynamic EPCs. The approach to be adopted under this task is found aligned and will be implemented in accordance with the content of the IEA EBC Annex 72 concerning the Assessment of Life Cycle Related Environmental Impacts Caused by Buildings.

1.1 Scope and objectives of the deliverable

T2.3 purpose is to create simplified environmental and energy indicators that will improve the information conveyed by issuing a building certificate. This deliverable summarizes T2.3 overall activities and includes a set of environmental and energy indicators based on literature analysis of well-established standards and methodologies. The environmental KPIs allow for the conversion of various parts of a building's energy performance into energy efficiency normalized results, as well as the use of EPCs for the life cycle assessment of building upgrades. This is the second and last version of the deliverable, which has been upgraded and adjusted in line with the project progress.

1.2 Structure of the deliverable

This report (D2.8) is the last part of the report on Energy performance & LCA Indicators Analysis for EPCs in national/regional certification schemes. Section 2 contains information on the current status of standardization. The methodology followed for identifying the set of indicators related to the environmental and energy performance of buildings is presented in Section 3. Section 4 refers to the Level(s) standard and the environmental indicators, while in Section 5 are introduced the energy indicators suggested through the D^2EPC project. Furthermore, in Section 6 is presented the calculation procedure of the energy indicators, and in Section 7 are presented the preliminary conclusions of this deliverable. Supplementary in the Appendix – Section 8, the calculations presented for the measurement of the energy indicators are followed with an example of the #4 pilot case – Frederick University New Wing pilot building. Compared to the previous version, additions have taken place in the section and sub-sections concerning (i) updates that have been made regarding the environmental indicators aspect in the standardization spectrum, (ii) the European framework for sustainable buildings - Level(s), (iii) the data and parameters for operational rating analysis, as well as (iv) the actual indicators based on the real-time measurements, and more specifically, the power consumption graphical representations of the Frederick Research Center pilot building.

1.3 Relation to Other Tasks and Deliverables

Task 2.3 for the issuing of truly sustainable EPCs will interact with T2.1, T2.2, T2.4, respectively, concerning the LCA Indicators for EPCs that will significantly contribute to the maximization of the energy savings and the achievement of carbon reductions of the buildings, as well as complement the SRIs, social and economic indicators.

In month thirty-four (M34), the annual review of data of T2.3 has been conducted based on the developments of the time and the new findings anticipated both by the project as well as from other EPC-related initiatives, such as research and innovation projects.

2 Current status of standardization

2.1 Introduction of the European building strategies and legislation

Standards are non-mandatory technical documents that define the parameters of a given product, material, component, system, or service; they may also provide in-depth descriptions of specific procedures or recommended practices. Expert technicians appointed by relevant stakeholders and other interested parties, such as businesses, consumers, and environmental groups, share their expertise and work toward consensus as standards are evolved and categorized. Technical Committees (TCs) serve as the overarching organizational structure for participation, with Subcommittees (SCs) and/or Working Groups (WGs) serving as the finer granularities. Each National Standardization Body (NSB) will create a similar group for these technical committees in order to establish a national stance.

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), as well as the Committee for European Normalization (CEN), and the European Telecommunications Standards Institute (ETSI) are all examples of such regional bodies. The standardization system is a resource for sharing pertinent methodologies and background information at the outset of a project, soliciting and incorporating feedback and critical analysis during the development of research results, and disseminating those results throughout the industry and public bodies.

Energy performance certificates (EPCs) have the potential to serve as a criterion for decision-making about energy efficiency property improvements. They do this by providing suggestions for the most cost-effective or cost-optimal ways to increase the energy performance of a building. When it comes to the energy performance of the EU's building stock, some of the most relevant information sources are the owners and occupants of buildings, as well as real estate stakeholders. As combined with SRIs, social and economic indicators, the use of real-time data for the formulation of energy indicators for EPCs greatly contributes to the maximization of energy savings and the attainment of carbon reductions in buildings.

Construction projects all across the globe rely on industry-driven standards and rules to ensure quality, safety, and sustainability. The increased demand for sustainable construction is a key problem for the global building sector nowadays. Green infrastructure is changing the way people plan, build, and run residential and commercial structures. As the sustainable construction industry gains momentum, European standards will continue to play a leadership role in accomplishing the aims of industry, government, consumers, and other stakeholders. Already, European standards contribute significantly to a more sustainable built environment. These standards, along with the actions of EU member states in this sector, form the foundation for the future of this expanding industry. In the sustainable development rating and certification systems adopted by the European construction sector, European standards influence the rise of sustainable buildings. By identifying sustainable construction qualities and implementing environmentally responsive behaviors, these initiatives assist stakeholders in navigating the complicated subject of sustainability.

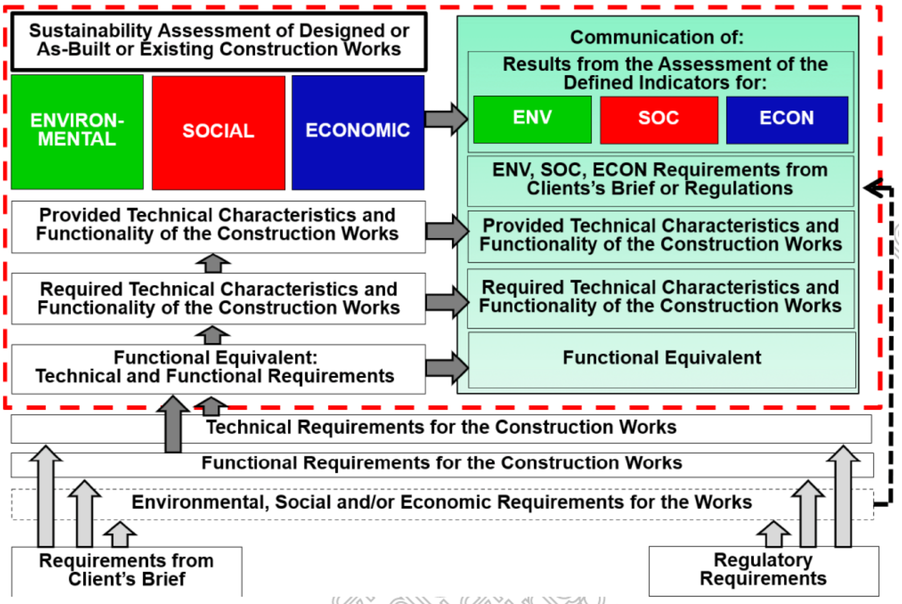
2.2 Sustainable construction performance techniques

The European Standard **EN 15643:2021** is one such initiative, which was established to promote more sustainable construction techniques. It is a group of a series written by CEN/TC 350 that provides a system for the sustainability assessment of buildings using a life cycle approach. The sustainability evaluation assesses the effects and elements of a building's environmental, social, and economic performance employing theoretical and practical metrics that are quantified without making conclusions. This set of European Standards enables the evaluation of sustainability to take place simultaneously and on equal terms, based on the same technical qualities and functioning of the examination object.

The outcomes of a sustainability assessment of the building provide values for the different types of indicators and information on the scenarios and building cycle stages included in the assessment.

As shown in **Figure 1**, evaluation at the building scale involves that the descriptive model of the building has been described in the client's request or the legislation, with the principal technical and operational specifications. Examinations can be carried out for the entire structure, for parts of the structure that can be used independently, or for individual components of the building. **Figure 1** illustrates how the operational equivalent, as well as technical and functional features that differ from those needed by the client's request or by guidelines, should be stated and presented with the performance assessment.

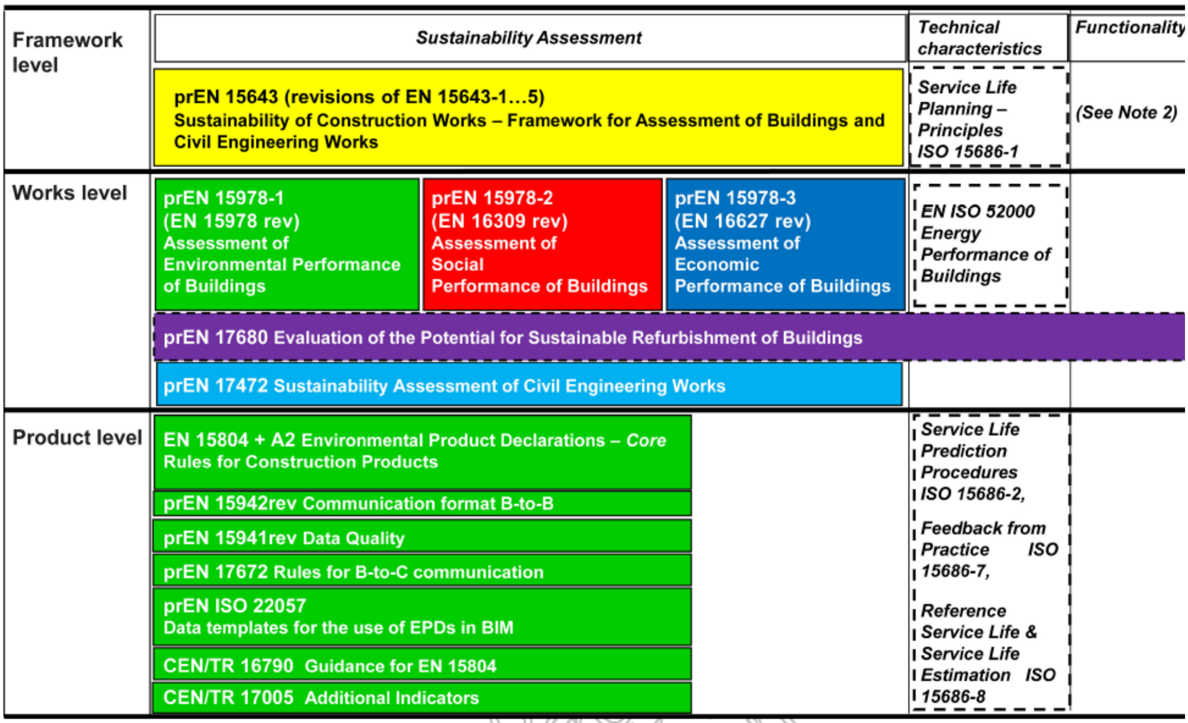
Although technical and functional performance evaluation is outside the choice of this series of standards, the practical and purposeful features considered within this approach are based on the functional equivalent, which incorporates theoretical and practical criteria and serves as the foundation for comparing outcome measures. The integrated design efficiency concept encompasses environmental, social, and economic performance and technical and functional efficiency, all of which are inextricably linked, as shown in **Figure 2**. Despite technical and functional efficiency are not included in this set of standards, its link with environmental, social, and economic performance is a requirement for assessing the sustainability of buildings and is therefore taken into account.



NOTE The outer box with the red dotted line represents the area standardized by CEN/TC 350.

Figure 1: The perception of sustainability assessment of construction works [1] (source: EN15643:2021)

When evaluating the long-term viability of a structure or a civil engineering project, the "framework level" in **Figure 2** is the one that will be used most frequently. The goal is to create a framework containing concepts, regulations, and recommendations for assessing the environmental, social, and economic performance of a building and/or civil engineering works or a combination thereof. The documents (EN 15978 [25], EN 16309 [26], EN 16627 [27], and EN 17472 [28]) developed under this framework for the evaluation of the construction works for buildings, and civil engineering projects contribute to the achievement of the United Nations Sustainable Development Goals (SDG).



NOTE 1 The coloured boxes represent the current work programme of CEN/TC 350.

NOTE 2 Functional requirements are part of client's brief and building regulations.

Figure 2: The work program of CEN/TC 350 (source: EN15643 2021)

This document replaces and improves upon earlier editions by:

- addressing the changes necessitated by the amended Mandate M530, especially those made as a result of the Mandate update to EN 15804+A2:2019.
- broadening the scope of Module D also to include "exported utilities" for both buildings and civil engineering activities and incorporating Module B8 into the modular framework of the analysis to account for the assessment of user actions related to the objective of the evaluation.
- providing a unified structure for evaluating the environmental, social, and economic performance of all construction projects (buildings and civil engineering works), while maintaining an awareness of the variations in methodology between evaluating structures and evaluating civil engineering projects.
- determining whether or not the sustainable renovation of already-existing structures is technically feasible.
- elaborating on and unifying the most important Terms and meanings used throughout the CEN TC350 standards.

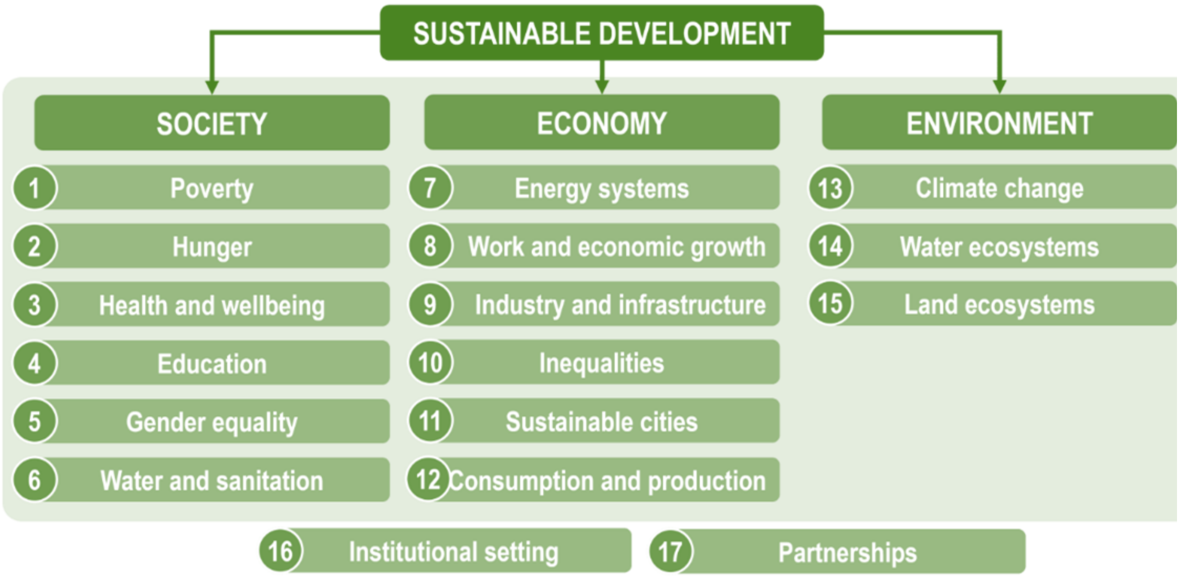


Figure 3: United Nations Sustainable Development Goals (Source: link)

All UN Member States endorsed the 2030 Agenda for Sustainable Development [29] in 2015, creating a universal framework for ensuring the future well-being of humanity and the planet. The 17 SDGs, depicted in **Figure 3**, are at the core of this global cooperation, and they represent an urgent call to action by all developed and developing countries to work towards a common goal. They understand that preventing and reversing climate change and protecting the world's oceans and forests are inextricably linked with one another and that these goals cannot be achieved without one another.

The document substitutes a series of standards aiming to devise a structure that will accommodate the following ideas, aims, and regulatory requirements:

- The first European Standard of this series (**EN 15643-1:2010**) **[1]** was released in 2010, which focuses on the general principles and requirements for assessing the environmental, social, and economic performance of a building, taking into account construction works to sustainable construction and development. The concept is applicable to all forms of structures. It is useful for evaluating the environmental, social, and economic performance of new structures over their whole life cycle, as well as older buildings' residual value life and end-of-life stages. In order to ensure verifiability, transparency, and comparability in the assessment outcomes, the assessment techniques must be trustworthy, clear, and methodical. The assessment methods for the environmental, social, and economic performance of buildings given in the standards under this framework take into account performance aspects and impacts that can be expressed with quantitative and qualitative indicators, which are assessed without making any value judgments and lead to a clear result for each indicator.
- The second European Standard of this series (**EN 15643-2:2011**) **[2]** was released in 2011 and it establishes particular concepts and procedures for evaluating a building's sustainability impact while considering its technological qualities and usefulness. The environmental component of sustainability is restricted to the evaluation of a building's environmental effects and features on the local, regional, and global environment. The evaluation is based on LCA and other measurable environmental data represented through defined indicators. It eliminates the evaluation of a building's contribution to environmental consequences and elements of local infrastructure outside of the construction site, as well as environmental consequences and characteristics deriving from the movement of the building's occupants. Environmental risk analysis is also not included. The third European Standard of this series (**EN**

15643-3:2012) **[3]** was released in 2012 and It establishes particular criteria and conditions for evaluating a building's performance outcomes while considering its technical qualities and operation. The social component of sustainability focuses on the evaluation of a building's characteristics and effects as indicated through measurable metrics. The indicators associated with social rating criteria are used to describe the social performance measures: accessibility, adaptability, health and comfort, loadings on the neighborhood, maintenance, safety/security, sourcing of materials and services, stakeholder involvement.

- The forth European Standard of this series (**EN 15643-4:2012**) **[4]** was released as well in 2012 and establishes particular concepts and conditions for evaluating a building's economic growth while considering its technical attributes and functioning. The financial performance of a building takes into account the life cycle expenses and several other economic factors, all of which are measured using quantitative information. It does not include a building's economic risk analysis or return on invested capital estimates. It involves financial implications of a building linked to the built environment within the vicinity of the construction site; it excludes financial implications of a building made in relation to the built environment outside of the construction site, such as economic effects of local infrastructural development, economic consequences arising from transportation of building users, and economic consequences of a construction project on the local community.
- The last European Standard of this series (**EN 15643-5:2017**) **[6]** was released in 2017 and is a system for assessing the long-term viability of civil engineering projects using a life cycle perspective. The sustainability evaluation uses quantifiable measures excluding value judgments to evaluate the environmental, social, and economic performance of civil engineering projects. The goal of this process is to allow assessment findings to be compared. It enables the evaluation of sustainability to take place simultaneously and on an equal basis due to the technical qualities and functionality of the assessment target. The findings of a civil engineering work sustainability evaluation disclose details on several types of indicators, associated civil engineering work scenarios, and life cycle stages covered in the analysis. Situations and a functional equivalent are established at the civil engineering projects phase while conducting assessments, which implies that the unique designs of the activities has been described in the client's brief, together with the primary technical and functional specifications or the regulations, as represented in **Figure 1** (where instead of a building is construction work).

2.3 Environmental performance of buildings

The European Standard **EN 15978:2011 [7]** (and the new but not published yet EN 15978-1:2021) follows the same logic with the EN 15643, prepared by the Technical Committee CEN/TC 350 “Sustainability of construction works”. This European Specification defines the calculating method to assess a building's sustainability impact using LCA and other quantifiable environmental data, as well as the mechanisms for documenting and communicating the results of the evaluation. The standard applies to both new and existing structures, as well as refurbished projects. This European Standard supports the decision-making process and documentation of the assessment of the environmental performance of a building. The evaluation method includes all aspects of the building life cycle and is based on information from the environmental product declaration (EPD), EN 15804, and additional information needed and suitable for the assessment to be completed. **Figure 4** is a visual representation of the seven distinct phases involved in creating an EPD.

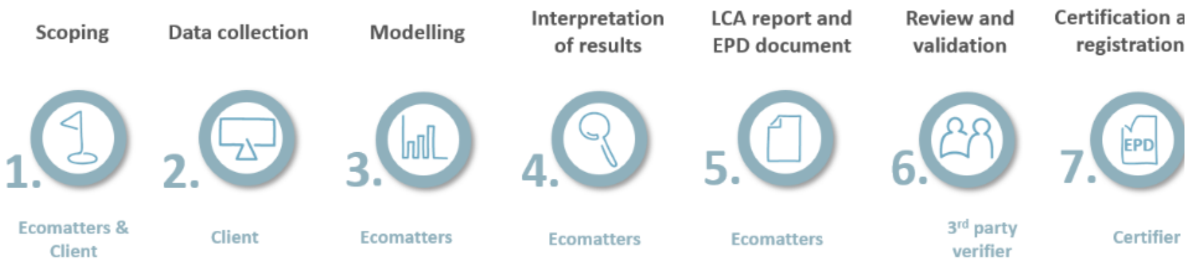


Figure 4: Seven distinct phases consisting of an EPD (Source: [30])

The stages illustrated in Figure 5 should be followed in order to carry out and complete the calculations necessary for the assessment of the environmental performance of buildings. This will help ensure that the essential information is gathered and treated in agreement with the requirements of this European Standard. The intended use of the assessment of this standard may include assistance in a decision-making process, declaring performance with respect to legal requirements, documenting the environmental performance of a building for use in, and support for policy development.

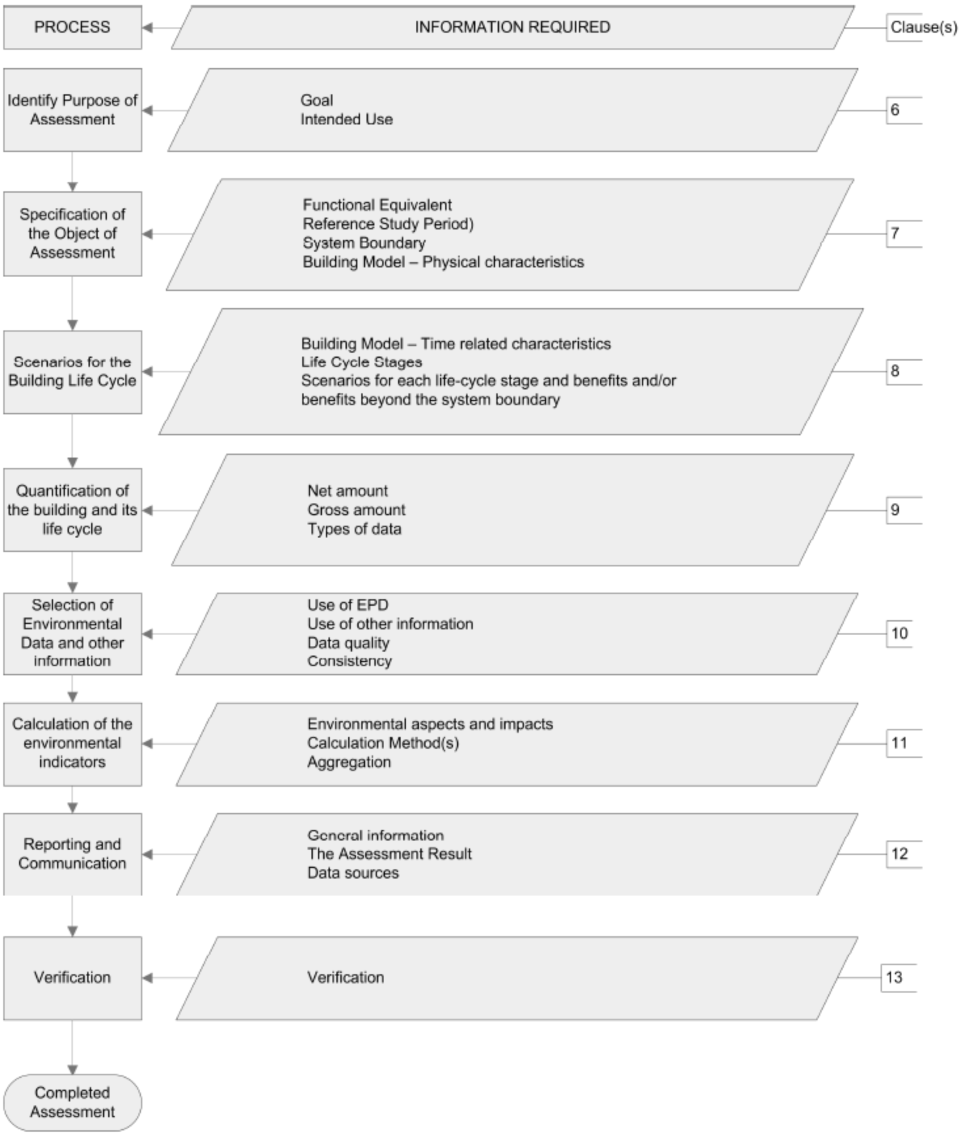


Figure 5: Flowchart of the process for the assessment of the environmental performance [7]

2.4 Product category rules

With the global expansion of sustainable building construction has come an increase in sustainable product claims from manufacturers and suppliers. It is becoming increasingly difficult to understand the significance and legitimacy of these claims, whether based on certification schemes or specific corporate declarations. When selecting items that claim to be sustainable, building designers, builders, customers, and regulatory inspectors want trustworthy information on environmental effects. Manufacturers require programs that will assist them in establishing credibility in this expanding industry while also raising knowledge of how their goods and operations affect the environment. The Environmental Product Declaration (EPD), a thorough report is documenting a product's influence on the environment during its lifetime, is one of the major instruments to assist producers in analyzing the genuine greenness of their goods. Product category rules (PCRs) are standards for creating environmental declarations for items that perform similar roles.

European Standards and other major organizations play an essential role in developing performance standards for green building certification systems such as BREEAM (BRE Environmental Assessment Method), the world's most commonly used method of analyzing and improving building environmental performance. Architects, contractors, material suppliers, realtors, and facility managers are relying heavily on technologies that identify best-in-class building practices and enable third-party verification in design, construction, and operation. The **EN 15804:2012+A2:2019/AC:2021** standard is a good example of a PCR document used to evaluate the environmental friendliness of building materials. The European Committee for Standardization (CEN) has adopted a significant update to this standard, so EPDs now better reflect the Product Environmental Footprint (PEF) established by the European Commission [31]. It explains how to create an EPD for any product or service in the building industry using BRE's methodology. These EPDs are environmental declarations of the ISO Type III, and they provide quantifiable environmental data for predefined indicators by applying LCA that has been independently validated. In Europe, EPDs for building supplies are determined in accordance with European Union guidelines such as EN 15804: Sustainability of Construction Works - Environmental Product Declarations - Core Rules for the Product Category of Construction Products. This regulation was created to ensure that construction works are sustainable. EN ISO 14025 [32] has been used as the basis for the standardization process.

There are three types of EPD based on this PCR document, as shown in **Table 1**. It is possible to have an EPD for a material e.g. cement, a product of component e.g. brick or bricks and mortar, and for an assembly of products or components, such as a building element e.g. an external wall, which can then be used at both product level and building level assessments. The EPD of an assembly of materials, products, and components can integrate the outcomes of the EPD of all the constituent materials and construction products. In principle, comparison of the environmental performance of construction products using EPD information shall only be carried out at the building level using the same functional unit in a complete life cycle (cradle to grave EPD), as it should be based on their use in and impacts on the building.

Table 1: The three types of EPD

EPD Type	Life cycle stages included	Units	Use for distinction
Cradle to gate	Covering product stage information A1 to A3 (raw material supply, transportation, manufacturing of products, and all upstream processes from cradle to gate). This encompasses the least of procedures	Declared unit	Shall not be used for comparison

	that shall be required in a declaration for compliance with EN15804:2012		
Cradle to gate with options	Covering product stage information as a minimum, plus any supplementary information components from mutually the use stage and the end-of-life stage (B1 through to C4). Benefits and loads outside the system boundary (Module D) may be involved.	Declared or functional unit	Should not be used as a benchmark
Cradle to grave	As a baseline, all life cycle phases should be covered, covering end-of-life at or after the research process. Benefits and loads that extend outside the system border (Module D) are possible to be involved.	Functional unit	If the functional unit is comparable, it could be employed comparative

The most significant changes compared to the **EN 15804:2014 [33]** are about covering all life-cycle stages, reporting on biogenic carbon and a broader set of environmental indicators, accounting for the loads and benefits of end-of-life recycling, as well as converting all data to ILCD format (with no requirement to share to third parties), allowing in this way product comparability [34]. Modules A1-A3, C1-C4, and D should now be declared on all products and materials used in the construction industry. A full cradle-to-grave (A1-A3) EPD analysis is now only feasible under extremely narrow circumstances. End-of-life (EOL) considerations are required in all other instances, requiring extensive effort. At the end of its life cycle, biomass will release the same quantity of carbon dioxide that it absorbed during its formation. This has a net zero Global Warming Potential (biogenic) across its entire life cycle (barring any methane or other gas conversions). It is now required that the amount of biogenic carbon contained inside the product and its packaging be disclosed separately. There will be a clearer picture of the strategy used by the various industries and the state-of-the-art in product category rules (PCR) in the future years. More comprehensive environmental indicators (13 core and 6 additional) will be recorded to adhere to the PEF's International Reference Life Cycle Data (ILCD) system. The ILCD format must be used to convert all past information. In spite of its seeming insignificance, this revision will have far-reaching consequences for major inventory systems like Ecoinvent and national building databases. Even though the PEF EOL strategy is now referenced as the basis for end-of-life evaluations, the updated EN 15804 standard continues to use an approach that relies on the 'end of waste' criterium. Thus, the LCA is made more comprehensive but also more difficult by factoring in the burdens and advantages of end-of-life recycling (module D).

This PCR covers two types of data that LCA does not obtain. The first kind of supplementary technical data entails physical information defining the product's functional performance during the product's life cycle phases that follow the manufacturing stage. These phases include construction, use, and end-of-life. This information is to be supplied by the producer in accordance with relevance. In order to evaluate various phases of a building's life cycle, this data is used to create consistent scenarios in their corresponding modules. Contingent upon the existence of standardized measurement techniques as supplied by the Technical Committees, the second category details emissions to indoor air, soil, and water during the usage stage, outlining the release of hazardous compounds not included in an impact assessment.

The environmental information that is included in a BRE EPD and covers all phases of a product's life cycle (from cradle-to-grave), as outlined in **Table 1**, must be segmented into the following categories: product, construction process, and use phase, as well as benefits and burdens that lie outside the system boundary. All the challenging steps from cradle to gate, encompassing sourcing raw materials to tally processing secondary material input to delivering raw and secondary material to the factory to finally constructing the building products are all part of the product stage. The construction phase consists of the transportation of building materials to the construction site and the actual construction of the building itself. The use phase of building fabric includes the use of the product, service, or appliance that has been installed, as well as the maintenance, repair, replacement, and even refurbishing of the item or the construction product. During the use stage, which is associated with the operation of the building, energy and water are consumed for that process. The destruction of the building or product, its inclusion in the destruction waste stream, its transfer to a waste processing center, the operations performed therein for the aim of reuse, recovery, or recycling, and its eventual disposal all fall under the end-of-life phase. Reuse, recovery, and recycling possibilities are counted as positive externalities that add to the benefits and reduce the burdens of the system overall. Scenarios should be developed to specify the precise settings and expectations of assessment, which are then used to assess the product's effects at each life cycle stage, which vary depending on the building context. In doing so, it will be guaranteed that the product information utilized in this product-level evaluation will also be appropriate in a building-level analysis.

In line with EN 15804+A2, it is considered good practice to make the content accessible to the verifier in order to facilitate verification while ensuring information security. This data consists of (a) an attributing of data on processes and life cycles to the datasets of an LCA software, (b) an analysis of the flows of both energy and material to support the inclusion or exclusion, along with a mass and water balance, (c) LCIA outcomes per modules of unit processes, (d) a quantifiable representation of the unit processes that have been specified as models for the activities and phases of the designated unit's life cycle, evidence that substantiates the percentages and values employed in (e) the calculations in the end-of-life scenario and Reference Service Life (RSL) parameters) and (f) the allocation process, if the procedure in question deviates in any way from the PCR, (g) LCIA findings for each production facility or product in the event that generalized data is reported from multiple factories or for a variety of goods that are very similar to one another.

In large part due to the obvious excellent calibre of the standards, ISO also chose to develop its own equivalent standard for EPDs. Many of EN 15804+A1's most crucial requirements are reflected in ISO 21930:2017 [35]. On the other hand, the effect categories reported by EN 15804+A2 are no longer in line with this ISO. This may serve as a barrier to trade until ISO 21930 is regulated [36].

2.5 Valuation of energy-related investments

More recently, another European Standard **prEN 17463:2020 [8]** released by the Technical Committee CEN/CLC/JTC 14 "Energy efficiency and energy management in the framework of the energy transition". This report lays forth the criteria for valuing energy-related investments (VALERI). It explains how to collect, calculate, assess, and data will be displayed in order to build good financial models for ERIs using Net Present Value calculations. The benchmark can be used to determine the value of any energy-related investment. The document is primarily concerned with valuing and documenting the economic implications of ERIs. However, non-economic effects (e.g. noise reduction) that could arise as a result of an expenditure are also taken into account. Therefore, qualitative effects (e.g. impact on the environment)– even though they are non-monetizable – are taken into account.

This European Standard aims to assist proposers of energy-related investments (ERIs) in evaluating their concepts financially and subjectively in a unified, clear, and coherent manner by creating all necessary significant data for a choice and to produce comparable outcomes (It is critical to verify that the cash flow approximation is performed in a comparable manner by applying correct price fluctuations, marginal pricing for all cash flows, etc.), its objective is to assist the valuation elaborator in producing assessment findings that are easily understandable from those who make decisions, to assist decision-makers and potential financial organizations who make decisions based on profitability outcomes and anticipate the outcomes to be accurate and reliable but also simple to comprehend, retraceable, and explicit (material), and to accompany other guidelines or policies and procedures that put emphasis on the technical perseverance of saving energy.

Organizations and households will be able to determine the economic benefit coming from ERIs by using straightforward formulas that include retraceable parameters that reveal the overall worth of ERIs. The proposed approach could be applied to energy audits and reviews (based on EN 16247-1) when prioritizing energy improvement potentials.

The valuation procedure of an ERI includes four phases, as it is depicted in **Figure 6**:

- setting up a model,
- calculation,
- assessment and
- reporting

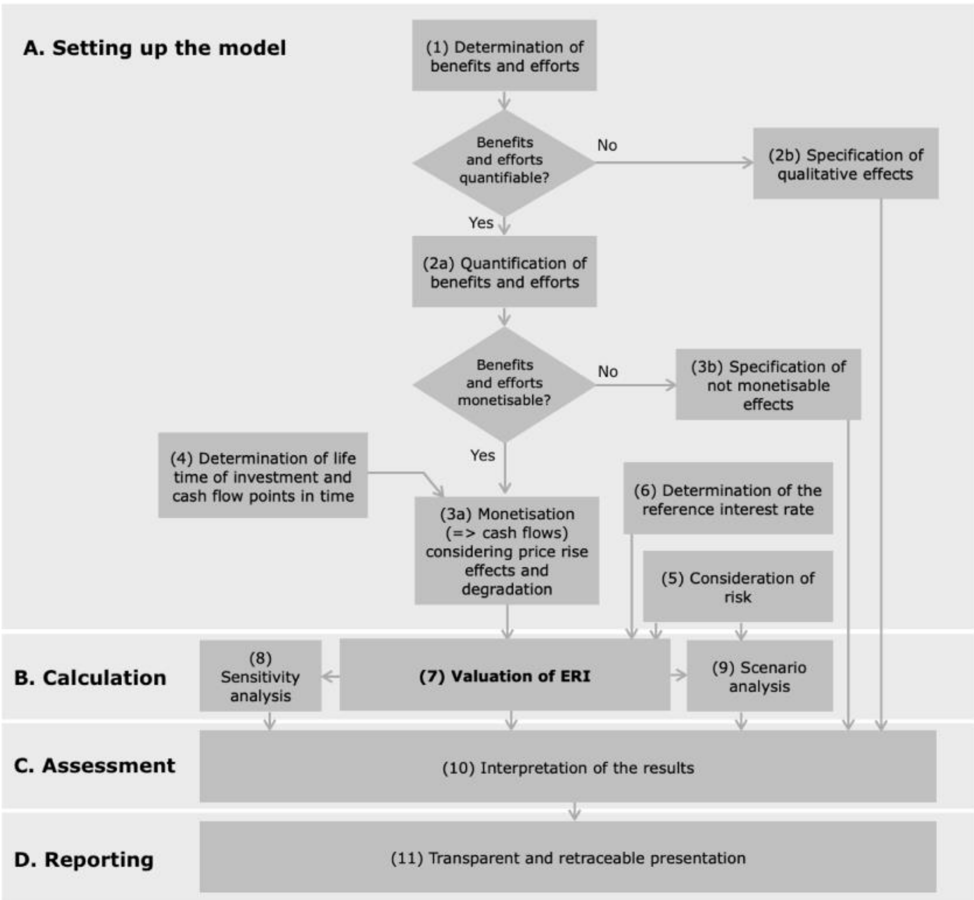


Figure 6: Valuation procedure [8]

2.6 Sustainability performance of buildings

The most recent European approach to assess and report on the sustainability performance of buildings throughout the entire life cycle of buildings is **Level(s) [13]**. Using existing standards, the Level(s) framework and, therefore, its indicators provide a shared identity for sustainable development that can be used effectively on construction projects and portfolios or as a foundation for other proposals, regulations, strategies, and actions, such as life cycle thinking and circularity. Level(s) delivers the fewest amount of indicators with the most potential to provide sustainability. It monitors performance throughout the varying phases of a development project to provide a full picture of the project's lifespan. Each indicator within the Level(s) framework is intended to correlate the effect of the specific building with European sustainability goals. Level(s) is separated into three sections, each having a subject and expected outcomes:

- resource use and environmental performance during a building's life cycle
- health and comfort
- cost, value, and risk

Level(s) introduces circularity and life cycle thinking, trying to make these subjects available to everybody. It is a helpful framework dedicated to enhancing environmental performance and resource utilization, as well as lowering the built environment's influence on global resources. The Level(s) approach enables customers to consider the entire life cycle of a building, offering a foundation for quantifying, analyzing, and understanding the life cycle, and targets a variety of circularity features, delivering indicators that can better clarify how to expand the functionality of the building.

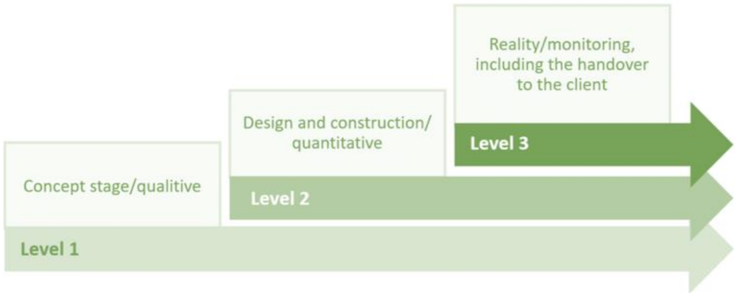


Figure 7: Level(s) structure

The development of a comprehensive nomenclature for sustainable construction practices is the objective of Level(s). It seeks to standardize a language for sustainable construction. With a common language in place, it should be feasible to implement building-level initiatives that advance European environmental policy as a whole. There are typically three 'levels' of participation (**Figure 7**) that correspond to the typical sequential phases of a project [37].

- Level 1: Simple level of the conceptual design of the construction project. Qualitative evaluation for design and reporting.
- Level 2: Intermediate level of detailed design and construction performance of the building. Quantitative evaluation of designed performance and construction monitoring according to standardized units and methods.
- Level 3: Advanced level of performance type as built and use of how the building performs after completion and delivery to the client. Quantitative assessment of design performance and construction tracking according to standardized units and methods.

Very recently, the EC has released a calculator application to teach those working in the built environment how to utilize the Level(s) scheme. Users can rely on the Level(s) Calculation and Assessment Tool (CAT) [38] throughout the building's life cycle, from planning and design to construction, maintenance, and eventual demolition. In accordance with the principles of Level(s), users can choose the granularity of each indicator.

2.7 Digitization of construction products

The design of environmentally friendly structures should also include careful consideration given to the use of environmentally friendly building materials. The business world is in dire need of a standardized approach to communicating accurate, machine-readable product data that can be used for a variety of purposes. When it comes to measuring and monitoring the environmental performance of built assets, having access to environmental information regarding building items that is accurate and suitable of being verified is of the utmost importance. EPDs are produced by manufacturers and convey this data in accordance with established norms.

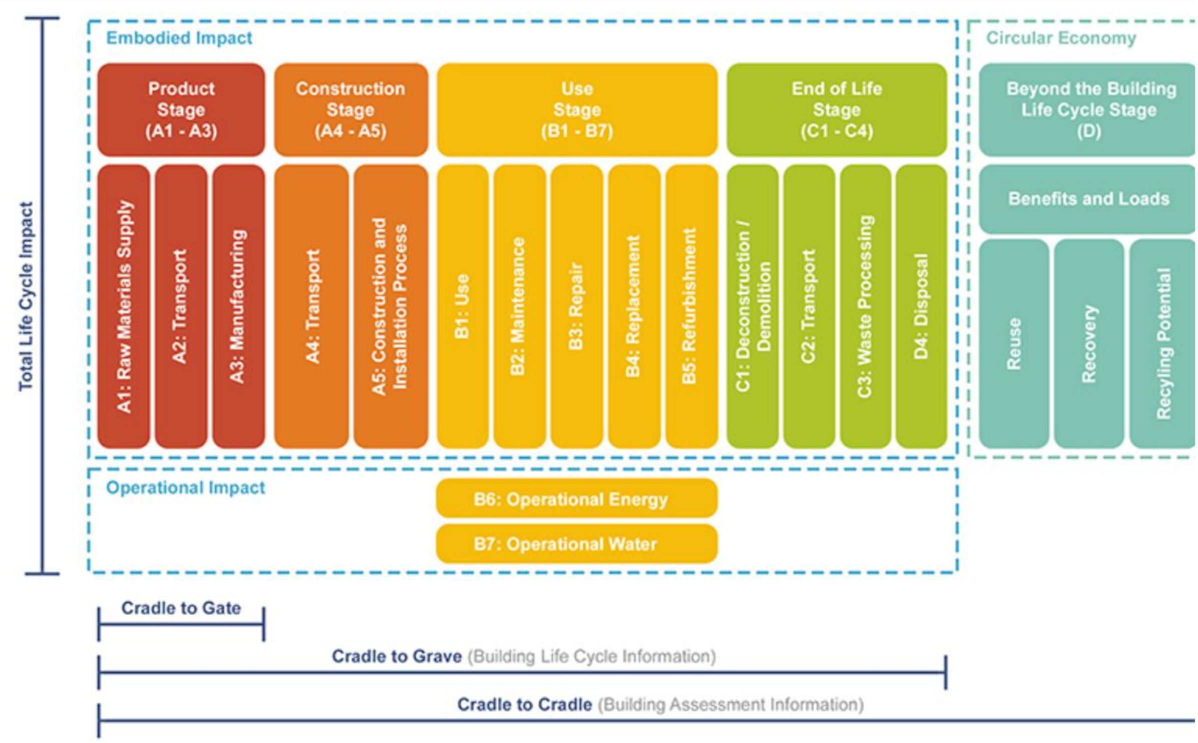


Figure 8: Life cycle stages (Source: ISO 15978:2011, [39])

The international standardization body released a new standard in April 2022, which paves the way for the usage and availability of such environmental information in a digital format expressly established for BIM [40]. The **ISO 22057:2022 [41]** was developed in response to the urgent need to drastically cut down on the embodied energy of the buildings by standardizing the provision of digitalized and digitized EPD and ensuring that EPD can be utilized to their highest capacity, as machine interpretable digitalized information. This procedure will allow all building LCA tools and tool creators to use the same, standardized digital data in the best possible manner when working with BIM. The mechanism used made possible through the employment of a data template and accompanying data sheet that were developed in accordance with ISO 23386:2020 [42] and ISO 23387:2020 [43]. In addition, this data architecture gives all stakeholders a shared technical vocabulary, a standardized way of organizing that material, and a standardized way of working with it for recording and exchanging factual data. It is also a crucial requirement for the development of a universal digital language that can be accurately understood by any program or BIM-authoring tool. Interaction among data, data templates, data sheets, BIM, and environmental evaluation at the building work levels is depicted in Figure 9.

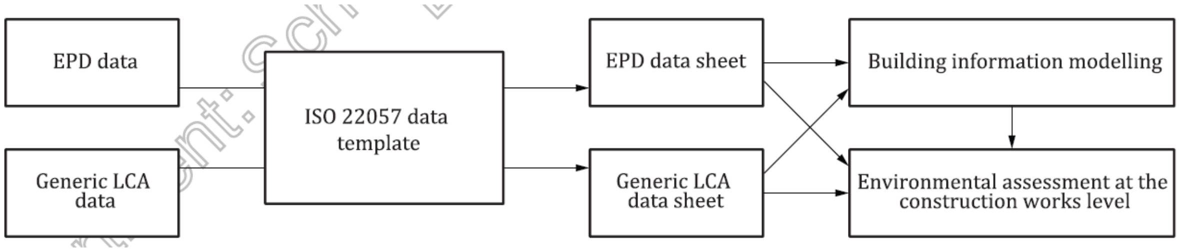


Figure 9: Interaction among data, data templates, data sheets, BIM, and environmental evaluation at the building work levels

This standard establishes a common database schema, known as a data template that may accommodate environmental information from EPDs. Any construction product can be described using the data layouts, and their descriptions will always include references to reliable sources like product standards that outline the procedures for declaring a product's performance and the processes it is assessed with [44]. As a result of the new framework, we will be capable of obtaining accurate and up-to-date information about each individual material or building component from the source. Data sharing and the industry-wide transition to digital processes are both aided by a standardized method for generating data models in construction. International and European standards, legislation, directives, and publications are reputable sources for product attributes.

2.8 Energy Performance of Buildings Directive Recast

The update of standards for minimum energy performance in existing buildings as proposed by EPBD aids in eliminating the least efficient structures across the Union, with the use of MEPS; (i) residential buildings must achieve at least EPC class F by 2030 and E by 2033, and (ii) public and other non-residential buildings must achieve at least EPC class F by 2027 and class E by 2030. Building renovation plans in MSs need to include timeframes for future upgrades to the existing infrastructure. Concerning the National Building Renovation Plans, while there is a universal framework with predetermined national objectives and a primary required indicator, many of the items that expand the focus beyond energy are opt-in (accessibility, safety). On the other hand, EPBD's proposed new building regulations include (i) distributed generation, energy efficiency, and energy communities, as well as (ii) zero-emission and nearly-zero-energy structures where climate zone-specific benchmark updates will be implemented by 2030 (2027 for public buildings). As of the year 2030, the Level(s) framework necessitates that the GWP of new buildings is assessed in order to provide information on total life-cycle carbon emissions (2027 for large buildings). All EPCs will use the same harmonized scale of energy performance classes by 2025 (from A to G, with A=ZEB and G=15% of the worst buildings) and will share a common template with energy and GHG indicators, while other indicators will remain voluntary. According to the Regulated Delegation 244/2012 [45], the buildings and their components should meet minimum energy performance standards established by the MSs. Cost-effectiveness should be taken into account when determining the specifications. The final result of the cost-optimal calculations may be based on a national benchmark determined either from a macroeconomic viewpoint (considering the costs and benefits of energy efficiency investments for society as a whole) or a strictly financial viewpoint (considering only the investment itself).

The European Commission proposed a revision of the Energy Performance of Buildings Directive (EPBD) [46] as part of the "Fit for 55" Package of measures in December 2021. This package of policies has the overarching goal of putting Europe on track to cut its carbon emissions by 55% by the year 2030 compared with 1990 levels. "Fit for 55" Package [47] has a more promising target than the previously agreed upon 40% reduction goal for 2030, is part of the EU's effort to become climate-neutral by the year 2050 – and to urge the world's other nations to act under the 2015 Paris Agreement to combat climate change. A new procedure for life-cycle emission measurement methods for new builds, modifications to the principles of energy performance standards, and changes made to national building restoration plans are all included in the recast version of the EPBD. These changes are being made in order to bring about new standards for energy efficiency that will help decrease carbon dioxide emissions in the built environment. The proposal includes a number of supplementary terms that establish higher standards for restoration efforts [48], like the zero-emission building, the nearly zero-energy building, and the extensive refurbishment until 2030 or after 2030. These definitions are included in the proposal (Articles 2 and 6). By the years 2030, 2040, and 2050, the National Building Renovation Plans, formerly referred to as "Long-Term Renovation Strategies", will require to be revised in order to include a timeframe as well as national goals (Article 3).

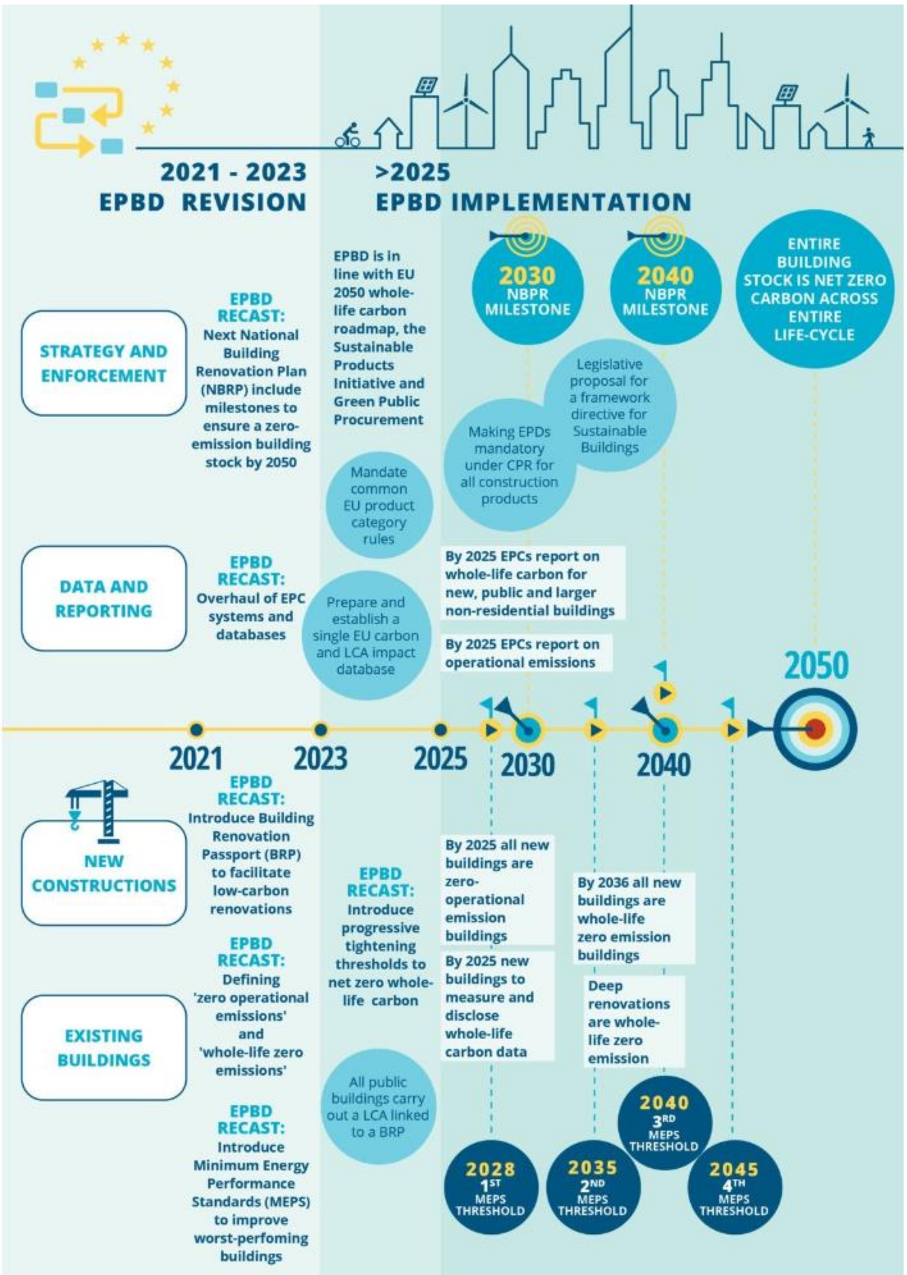


Figure 10: Roadmap to climate-proof buildings and construction. (Source: [49])

In addition, the Member States (MSs) are obligated to ensure that all public and non-residential buildings meet the requirements of at least class F or E by the year 2027 and that all residential buildings meet these requirements by the year 2033 (Article 6). In order to accomplish these goals, it would be necessary to renovate 15% of the existing building stock, which is projected to consist of more than 40 million structures across the EU. By the year 2030, all newly constructed buildings will be required to have zero emissions, whereas the deadline for zero emissions in publicly owned structures is 2027 (Article 7). This will consider the total amount of carbon emissions produced by the buildings during their entire life cycle, including the phases of manufacture and construction, usage, and disposal at the end of their useful lives. Moreover, the revised EPBD intends to prevent all forms of financial aid for fossil fuel boilers by 2025, and it offers MSs the legal justification they need to do so (Article 11). Among the overall objectives of this recast are new guidelines that aim to enhance the Smart Readiness Indicator (SRI) and Energy Performance Certificates (EPCs). Other goals include providing the information to owners and buyers and preserving homogeneity across the EU in terms of ensuring that all EU member states follow the same standards (Articles 13-19).

The decarbonization of the building stock is already underway, but it will take time and will require residents' input and municipal policies. There is not one set of policies that can bring about a reduction in CO2 emissions per square meter in the construction industry. The role of legislation is limited to providing a facilitating framework. Careful framing of the EPBD amendment is needed to prevent unintended repercussions on affordability. With regard to EPCs, the issues are twofold. Despite the fact that from 2027 it will be mandatory to calculate the GWP on the certificates, the relevant procedures have not yet been developed. In addition, the aspects of cycle analysis are not taken into account in the calculation of the economically optimal minimum requirements (Regulation 244/2012). Efforts need to be made in that direction since this regulation still does not take into account LCA and embodied energy issues in its analysis.

3 Methodology

D^2EPC includes a set of indicators which is related to the environmental and energy performance of buildings. The importance of employing LCA methodologies for the efficient energy design of buildings and for enabling the parameterization of its embodied energy and primary energy demand are highlighted for their inclusion in the dynamic EPCs, mainly addressed to relevant stakeholders, as well as to practicing engineers and EPC assessors, anticipating to implement the principles of D^2EPC in buildings certification. It is proposed that the energy and environmental D2EPC indicators, which illustrate building sustainability impact, be included in the next-generation EPCs.

The progress of the D^2EPC environmental indicators is based on the Level(s) scheme, the EU sustainability assessment for constructions outline. Level(s) is the most recent European approach to assessing and reporting on the sustainability performance of buildings throughout their entire life cycle, correlating the effects with European sustainability goals. Using existing standards, the Level(s) approach provides a shared identity for sustainable development, offering a foundation for quantifying, analyzing, and understanding the life cycle, and targets a variety of circularity features, delivering indicators that can better clarify how to expand the functionality of the building. It is a helpful framework dedicated to enhancing environmental performance and resource utilization, as well as lowering the built environment's influence on global resources. The usage of real-time data collected for the development of the energy indicators for EPCs is significantly contributing to the maximization of the energy savings and the achievement of carbon reductions of the buildings, as well as complementing the SRIs, social and economic indicators for the issuing of truly sustainable EPCs.

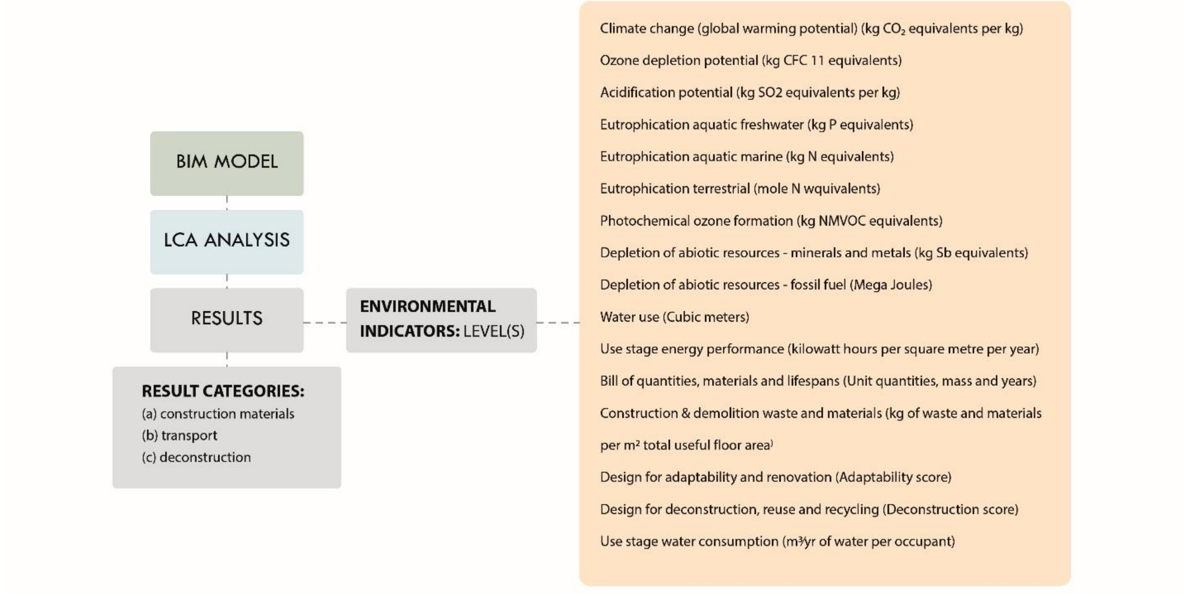


Figure 11: Environmental indicators extraction

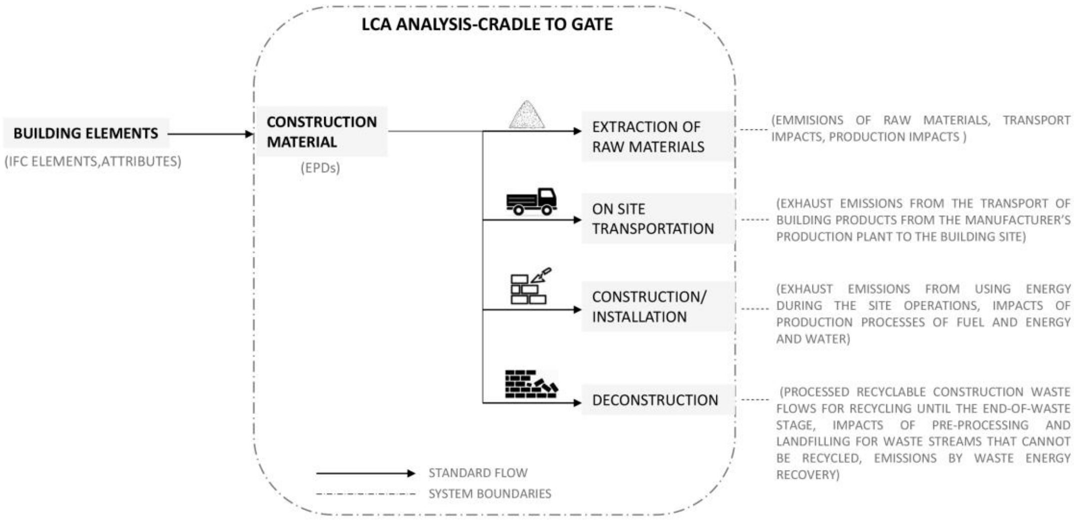


Figure 12: System's boundaries for the LCA analysis materials

3.1 Calculation of Energy and Environmental D^2EPC indicators

The extraction of the LCA results (construction materials, transportation, construction/installation, and deconstruction) of the environmental indicators for a building through a BIM file is presented in **Figure 11**. The results are extracted based on the environmental indicators of Level(s). Through this analysis, the values of the environmental indicators depicted above are shown in detail for stages of (a) construction materials, (b) transportation to site, (c) construction/installation process, and (d) end of life, as well as the total values for each indicator. As a values' result, the environmental footprint for each construction material and each category of the structural element is observed.

Simplified energy indicators, such as total energy over area per annum, cannot describe thoroughly the energy performance of a building adequately. Thus, the D^2EPC energy indicators are intended to cover present gaps in building performance indicators that can be utilized in conjunction with the increasingly accessible system-level data from the growing use of sensors and meters in buildings to quantify and analyze energy performance. The methodology used for creating energy indicators values is the operational rating, and the calculations are based on the data retrieved by the building's regular measurements, where these are available. Implementing appropriate energy and environmental building evaluation techniques on a wide scale is required to stimulate market demand for sustainable practices in the built environment.

3.1.1 Energy Indicators

The operational rating scheme is used for the calculation, and a complete list of 25 data results, from four categories, is presented in **Table 2**. These energy indicators are a result of measurement values – where these are available- retrieved by the building automation and control systems, as well as by smart meters.

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

Table 2: Energy Indicators

Usage	Indicator Name	Indicator Description	Units
Power consumption of the building	Total Power/Occupancy	This indicator shows the ratio of the total power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Total Power/Occupancy-Hours	This indicator shows the ratio of the total power consumption of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Total Power/Area	This indicator displays the ratio of the total power consumption of the building in kWh over the total surface area of the building	kWh/m^2
	Total Power/Volume	This indicator displays the ratio of the total power consumption of the building in kWh over the total volume of the building	kWh/m^3
Heating	Heating consumption per energy carrier/Occupancy	This indicator shows the ratio of the heating power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Heating consumption per energy carrier/Occupancy-Hours	This indicator shows the ratio of the heating power consumption of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Heating consumption per energy carrier/Area	This indicator displays the ratio of the heating power consumption of the building in kWh over the total surface area of the building	kWh/m^2
	Heating consumption per energy carrier/Volume	This indicator displays the ratio of the heating power consumption of the building in kWh over the total volume of the building	kWh/m^3
	Weather-Normalized Heating Energy Consumption	A positive number means usage was added. A Negative Number is good. It means usage was avoided compared to the Weather Normalized Usage from the Baseline Year. Furthermore, a Positive Number is unfavorable. It signifies that use increased when in comparison to the Baseline Year's Weather Normalized Usage.	---
Cooling	Cooling consumption per energy carrier/Occupancy	This indicator shows the ratio of the cooling power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Cooling consumption per energy	This indicator shows the ratio of the cooling power consumption of the building in kWh	kWh/h*occupants

	carrier/Occupancy-Hours	over the total number of hours that occupants spend in the building	
	Cooling consumption per energy carrier/Area	This indicator displays the ratio of the cooling power consumption of the building in kWh over the total surface area of the building	kWh/m²
	Cooling consumption per energy carrier/Volume	This indicator displays the ratio of the cooling power consumption of the building in kWh over the total volume of the building	kWh/m³
	Weather-Normalized Cooling Energy Consumption	A positive figure indicates that consumption has increased. It's better to have a negative number. When compared to the Weather Normalized Usage from the Baseline Year, it means that usage was averted. Moreover, a Positive Number is unfavorable. It signifies that use increased when in comparison to the Baseline Year's Weather Normalized Usage.	---
Lighting	Lighting/Occupancy	This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of occupants	kWh/occupants
	Lighting/Occupancy-Hours	This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Lighting/Area	This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total surface area of the building	kWh/m²
	Lighting/Volume	This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total volume of the building	kWh/m³
Electrical Appliances Energy Consumption	Electrical Appliances Energy Consumption /Occupancy	This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of occupants	kWh/occupants
	Electrical Appliances Energy Consumption /Occupancy-Hours	This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total number of hours that occupants spend in the building	kWh/h*occupants
	Electrical Appliances Energy Consumption /Area	This indicator displays the ratio of the total energy consumption of the electrical appliances in the building in kWh over the total surface area of the building	kWh/m²

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

3.1.2 Environmental Indicators

LCA Level(s) tool is used in the assessment, and a complete list of 17 data result terms are presented in **Table 3**. These environmental indicators are asset indicators and may be calculated through the combination of materials bill of quantities, derived by a BIM document, and buildings materials EPDs.

Table 3: LCA Indicators [11]

Indicator Name	Indicator Description	Units
Climate change (global warming potential)	Indicator of potential global warming due to emissions of greenhouse gases to the air. Climate change is defined as the impact of human emissions on the radiative forcing (i.e. heat radiation absorption) of the atmosphere. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise, i.e. the greenhouse effect. The areas of protection are human health, the natural environment, and the man-made environment.	kg CO_2 equivalents per kg [kg CO_2 eq/ kg]
Ozone depletion potential	Indicator of emissions to air that causes the destruction of the stratospheric ozone layer.	kg CFC 11 equivalents [kg CFC 11 eq]
Acidification potential	Decrease in the pH-value of rainwater and fog measure, which has the effect of ecosystem damage due to, for example, nutrients being washed out of soils and increased solubility of metals into soils. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological	mole H+ equivalents [mol H+ eq] kg SO_2 equivalents per kg [kg CO_2 eq/ kg]

	organisms, ecosystems, and materials (buildings). The major acidifying pollutants are SO2, NOx, and NHx. Areas of protection are the natural environment, the man-made environment, human health, and natural resources.	
Eutrophication aquatic freshwater	Excessive growth of aquatic plants or algal blooms as a result of increased nutrient levels in freshwater. Freshwater ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.	kg P equivalents [kg P eq]
Eutrophication aquatic marine	Marine ecosystem reaction measurement to an excessive availability of a limiting nutrient.	kg N equivalents [kg N eq]
Eutrophication terrestrial	Increased nutrient availability measurement in soil as a result of input of plant nutrients.	mole N equivalents [mol N eq]
Photochemical ozone formation	Emissions of nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection. Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health, and ecosystems may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environment, and natural resources.	kg NMVOC equivalents [kg NMVOC eq.]
Depletion of abiotic resources - minerals and metals	Indicator of the depletion of natural non-fossil resources. "Abiotic resources" are natural sources (especially energy resources) such as iron ore, crude oil, and wind energy are examples. Among the most commonly mentioned impact categories is abiotic resource depletion, which has resulted in a wide range of solutions available for characterizing contributions to this category. To a large extent, these different methodologies reflect differences in problem definition. Depending on the definition, this impact category includes only natural resources, or natural resources, human health and the natural environment, among its areas of protection.	kg Sb equivalents [kg Sb eq]
Depletion of abiotic resources – fossil fuel	Indicator of natural fossil fuel resource depletion.	Mega Joules [MJ]
Water use	Indicator of the amount of water required to dilute toxic elements emitted into water or soil.	Cubic meters [m^3]
Use stage energy performance	"Operational energy consumption": primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.	kilowatt-hours per square meter per year (kWh/m^2 /yr)
Life cycle Global Warming Potential	"Carbon footprint assessment" or "whole life carbon measurement": building's contribution to greenhouse gas (GHG) emissions measurement associated with earth's global warming or climate change.	kg CO_2 equivalents per square meter per year (kg CO_2 eq./m^2/yr

Bill of quantities, materials, and lifespans	The quantities and mass of construction products and materials, as well as estimation of the lifespans measurement important to finish specific elements of the structure.	Unit quantities, mass, and years
Construction & demolition waste and materials	The overall quantity of waste and materials generated by construction, renovation, and demolition activities; used to calculate the diversion rate to reuse and recycling, harmonized with the waste ladder.	kg of waste and materials per m^2 total useful floor area
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.	Adaptability score
Design for deconstruction, reuse, and recycling	Building design extent assessment of facilitation prospective material reclamation for reuse and recycling, including assessment of deconstruction for a limited range of building components ease, followed by the reuse and recycling of these components, as well as the sub-assemblies and substances that go along ease.	Deconstruction score
Use stage water consumption	The overall water use of a typical building user with the ability to break this amount into potable and non-potable water consumption, supplied water, as well as support measurement of the water-scarce locations identification.	m^3/yr of water per occupant

4 European framework for sustainable buildings - Level(s)

Level(s) provides a set of indicators and common metrics for measuring the environmental performance of buildings along their life cycle. It allows for the assessment of other essential types of building performance, such as health and comfort, life cycle cost, and possible future vulnerabilities to effectiveness, in addition to environmental performance.

The goal of Level(s) is to create a general terminology for building sustainability. This shared vocabulary should make it possible to conduct measures at the building level that contribute to greater European environmental policy goals. It is organized in this manner:

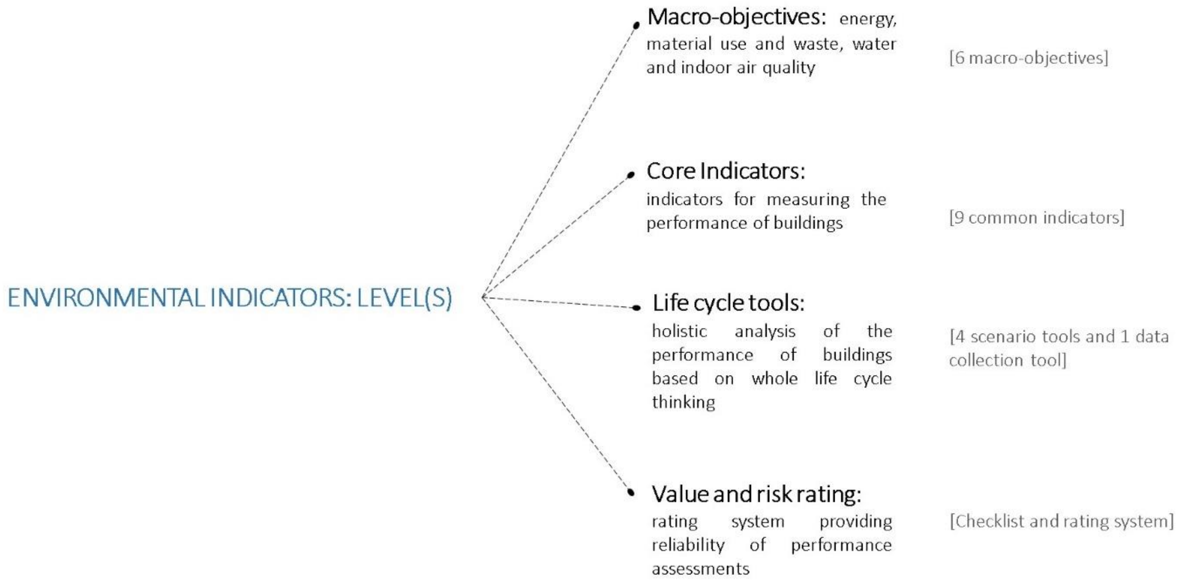


Figure 13: Diagram of Level(s) objectives

The Level(s) approach also makes an effort to promote life cycle thinking. The end goal is to increase the acceptance of LCA and life cycle cost assessment (LCCA) across Europe. It does this by guiding users from a narrow viewpoint on a certain building performance development process to a more holistic perspective.

Level(s) is at an early stage of development, and it needs a lot of actions to establish itself in the market. As a result, relevant tools should be developed, as well as training techniques and procedures that will encourage general visibility by the engineers. Currently, there is no EC system to verify the use of Level(s). In addition, the life cycle Global Warming Potential (GWP) of new buildings will have to be calculated as of 2030 in accordance with the Level(s) framework, informing on whole life-cycle carbon emissions and of 2027 for large buildings. Companies with a global presence may face difficulties as a result of stricter energy efficiency standards in MSs if national approaches to compliance are not standardized. Legislation addressing carbon emissions throughout the life cycle may vary by country in a number of ways. In the event of widespread adoption, Level(s) could function as a standard against which national assessments of sustainability performance can be compared. The alignment of national rating systems to Level(s) is crucial for public procurement procedures and private activities to achieve European goals for climate adaptation and circularity in the building sector. Contributions made by Level(s) include making it simpler to further define and reduce the scope of the sustainability of construction activities (specified in the standard EN 15978:2011). What Level(s) could do next is develop a tool for connecting the climate targets set at the European and national levels with those set at the project level. This linkage is supported by the Level(s) system, which provides definitive information on whether or not a construction project meets national climate targets for the built environment [50].

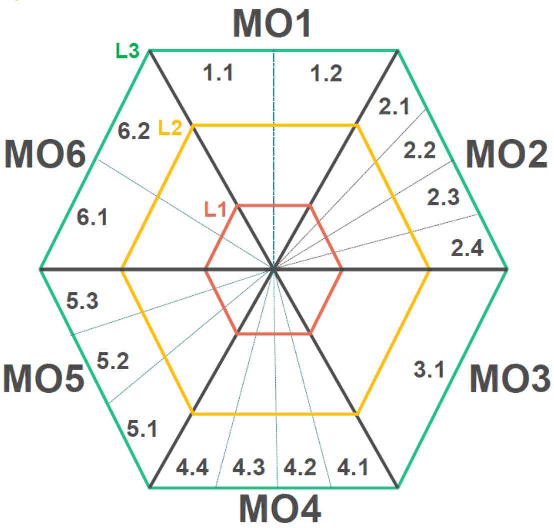


Figure 14: Diagram of indicators' levels in Level(s)

Each of the indicators has three levels, which represent the following [51]:

- Level 1 is the "entry level", for design concepts
- Level 2 requires detailed calculations/estimations based on designs
- Level 3 requires real-life measurements

The establishment of European standards and the ongoing work of EU MSs in this field lay the framework for the industry's further expansion in the years to come. The purpose of each indicator contained within the Level(s) framework is to establish a connection between the impact of a certain structure and the sustainability objectives of Europe. **Currently, the criteria currently in use for assessing improvements are not effectively reflected at the system level.**

The Level(s) concept tries to encourage life cycle thinking. It leads users from a narrow perspective on particular process of developing building performance to a more holistic view, with the ultimate goal of increasing the adoption of Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) across Europe (LCCA).

In this case study of the New Wing building, the LCA analysis and results will be extracted for the environmental indicators defined by the Level(s) database.

4.1 Environmental indicators

The indicators are explained in more detail below:

Climate change (global warming potential) (kg CO_2 equivalents per kg): Indicator of probable global warming linked to greenhouse gas releases into the environment. Climate change is defined as the impact of human emissions on the radiative forcing (i.e. heat radiation absorption) of the atmosphere. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise, i.e. the greenhouse effect. The areas of protection are human health, the natural environment, and the man-made environment.

Ozone depletion potential (kg CFC 11 equivalents): Indicator of pollutants into the atmosphere that cause the stratospheric ozone layer to deplete.

Acidification potential (kg SO_2 equivalents per kg): Reduced pH value of precipitation and fog measurement, which has the consequence of ecosystem degradation due to nutrients being rinsed out of soils and increased metal absorption in soils, for example. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems, and materials (buildings). The major acidifying pollutants are SO_2, $NO_{x,}$ and NH_x. Areas of protection are The natural environment, the man-made surroundings, public health, and environmental assets.

Eutrophication aquatic freshwater (kg P equivalents): Excessive growth measurement of aquatic plants or algal blooms, because of the high quantities of nutrients in freshwater. Fresh water ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.

Eutrophication aquatic marine (kg N equivalents): marine ecosystem reaction measurement to an excessive availability of a limiting nutrient.

Eutrophication terrestrial (mole N equivalents): increased nutrient availability measurement in soil as a result of input of plant nutrients.

Photochemical ozone formation (kg NMVOC equivalents): emissions of nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection. The creation of reactive chemical compounds such as ozone by the impact of sunlight on some of these major air pollutants is known as a photo-oxidant formation. These energetic chemicals have the potential to harm human health as well as ecosystems may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environment, and natural resources.

Depletion of abiotic resources - minerals and metals (kg Sb equivalents): Indicator of the depletion of natural non-fossil resources. "Abiotic resources" are natural sources (including energy resources) such as iron ore, crude oil, and wind energy, which are regarded as non-living. Among the most widely mentioned impact categories is abiotic resource depletion, which has resulted in a wide range of solutions available for characterizing contributions to this category. To a large extent, these different methodologies reflect differences in problem definition. Depending on the definition, this impact category includes only natural resources, or natural resources, human health, and the natural environment, among its areas of protection.

Depletion of abiotic resources – fossil fuel (Mega Joules): Indicator of natural fossil fuel resource depletion.

Water use (Cubic meters): Indicator of the amount of water required to dilute toxic elements emitted into water or soil.

Use stage energy performance (kilowatt-hours per square meter per year): 'operational energy consumption': primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.

Life cycle Global Warming Potential (kg CO_2 equivalents per square meter per year): 'carbon footprint assessment' or 'whole life carbon measurement': building's contribution to greenhouse gas (GHG) emissions measurement associated with eearth'sglobal warming or climate change.

Bill of quantities, materials, and lifespans (Unit quantities, mass, and years): 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.

Construction & demolition waste and materials (kg of waste and materials per m^2 total useful floor area): The overall quantity of waste and materials generated by construction, renovation, and demolition activities; used to calculate the diversion rate to reuse and recycling, coordinated with the waste pyramid.

Design for adaptability and renovation (Adaptability score): Building design extent assessment of facilitation upcoming adjustment to evolving occupant desires and property market conditions; a building proxy capacity o continue to serve its purpose and to have the option of extending its effective service future life.

Design for deconstruction, reuse, and recycling (Deconstruction score): Building design extent assessment of facilitation future recovery of materials for reuse of recycling, including assessment of the disassembly for a minimum scope of building parts ease, followed by the pieces and their accompanying sub-assemblies and materials can be reused and recycled with simplicity. **Use stage water consumption** (m^3/yr of water per occupant): The entire water usage of an average building inhabitant is measured, with the possibility of splitting this figure into potable and non-potable supplied water, as well as support measurement of the identification of the water-scarce location.

The results relate to the **life stages of the building**: (a) construction materials A1-A3, (b) transportation to site A4, (c) construction/installation process A5, (c) use phase (B1), (d) repair (B3), (e) material replacement and refurbishment (B4-B5), (f) energy use (B6), (g) water use (B7), (h) end of life C1-C4. Based on the specific process of exporting prices of environmental indicators, results are obtained basically for the four life stages of the building: construction materials (A1-A3), transportation to site (A4), construction and installation (B5), and end of life (C1-C4). Description of the main life cycle stages and analysis scope are provided in the table below.

Table 4: Table of life-cycle stages description [OneClick LCA]

A1-A3 Construction Materials	Raw material supply (A1) includes emissions generated when raw materials are taken from nature transported to industrial units for processing and processed. Loss of raw material and energy are also taken into account. Emissions from the transit of all goods from suppliers to the manufacturer's production plant are included in the transportation impacts (A2) as well as impacts of the production of fuels. Production impacts (A3) cover the manufacturing of the production materials and fuels used by machines, as well as handling of waste formed in the production processes at the manufacturer's production plants until the end-of-waste state.
A4 Transportation to site	A4 includes exhaust emissions from the transportation of building products from the manufacturer's production plant to the building site along with the environmental effects of the production of the used fuel.
A5 Construction/installation process	A5 covers the exhaust emissions resulting from using energy during the site operations, the environmental impacts of production processes of fuel and energy and water, as well as handling of waste until the end-of-waste state.
B1-B5 Maintenance and material replacement	The environmental impacts of maintenance and material replacements (B1-B5) include environmental impacts from replacing building products after they reach the end of their service life. The emissions cover impacts from raw material supply, transportation, and production of the replacing new material as well as the impacts from manufacturing the replacing material as well as handling of waste until the end-of-waste state.
B6 Energy use	The considered use phase energy consumption (B6) impacts include exhaust emissions from any building level energy production as well as the environmental impacts of production processes of fuel and

	externally produced energy. Energy transmission losses are also taken into account.
B7 Water use	The considered use phase water consumption (B7) impacts include the environmental impacts of production processes of fresh water and the impacts from wastewater treatment.
C1-C4 Deconstruction	The impacts of deconstruction include impacts for processing recyclable construction waste flows for recycling (C3) until the end-of-waste stage or the impacts of pre-processing and landfilling for waste streams that cannot be recycled (C4) based on the type of material. Additionally, deconstruction impacts include emissions caused by waste energy recovery.
D External impacts/end-of-life benefits	The external benefits include emission benefits from recycling recyclable building waste. Benefits for re-used or recycled material types include positive impact of replacing virgin-based material with recycled material and benefits for materials that can be recovered for energy cover positive impact for replacing other energy streams based on average impacts of energy production.

5 Operational rating and energy indicators

Quantifying building energy performance via the formulation and use of key performance indicators (KPIs) is a critical step in attaining energy-saving targets in both new and existing structures. However, the current methods for evaluating improvements are not adequately reflected at the system level (e.g., lighting, plug-loads, HVAC, service water heating). Instead, they are usually only measured at the aggregated equipment level (e.g., energy use intensity) or at the equipment level (e.g., chiller efficiency coefficient of performance (COP)) with limited insights for benchmarking and diagnosing deviations in pooled technology that delivers a certain function to a building in terms of effectiveness (e.g., space heating, lighting). The expanding installation of sensors and meters in buildings through enhanced data gathering makes evaluating building performance at the system level more realistic.

The energy indicators proposed in this work are intended to cover present gaps in building performance indicators that can be utilized in conjunction with the increasingly accessible system-level data from the growing use of sensors and meters in buildings to quantify and analyze energy performance. For instance, in performance benchmarking, system-level KPIs might be a suitable supplement to the whole-building EUI since they give additional insight into how a system performs in comparison to the same system in other buildings.

5.1 Data and Parameters for Operational Rating Analysis

According to EN ISO 52000-1:2017, the measured energy indicator and the measured energy performance are the energy performance indicator based on measured energy performance and the energy performance based on weighted, measured amounts of delivered and exported energy, respectively. The measured energy performance, also known as operational 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. Operational performance is only applicable to existing buildings in the use phase. Buildings' energy operational indicators are essential for measuring and evaluating the energy performance of buildings, which is critical for achieving energy efficiency and sustainability goals. By tracking these indicators, building owners and managers can identify areas where energy efficiency improvements can be made, which can reduce energy consumption, lower operating costs, and mitigate the environmental impact of building operations.

Energy consumption indicators are one of the most common and straightforward indicators used to measure building energy performance. They can measure the total energy used by a building, a specific system, or individual equipment. Energy consumption indicators can provide valuable insights into overall energy usage trends, which can help building owners and managers identify opportunities for reducing energy consumption and optimizing energy use. Energy consumption indicators can also deliver information related to the efficiency of building components, such as heating and cooling systems, lighting, and insulation, among others. By measuring the energy efficiency of these components, building owners and managers can identify areas where upgrades or replacements may be necessary to improve overall energy efficiency and reduce energy consumption.

Greenhouse gas emissions indicators are also critical for measuring the environmental impact of building operations. These indicators can track emissions from building operations, including energy consumption, transportation, and waste management. By measuring greenhouse gas emissions, building owners and managers can identify opportunities for reducing emissions and mitigating the environmental impact of building operations.

Finally, renewable energy production indicators can assess the contribution of renewable energy sources to a building's energy mix. These indicators can help building owners and managers determine the feasibility of implementing renewable energy technologies, such as solar or wind power, to meet their energy needs.

In conclusion, buildings' energy operational indicators play a crucial role in evaluating building energy performance, identifying opportunities for energy efficiency improvements, and reducing the environmental impact of building operations. By tracking these indicators, building owners and managers can optimize energy use, reduce operating costs, and achieve their sustainability goals.

Table 5: Energy performance of buildings assessment types [ISO 52000-1:2017]

Type	Sub-type	Input data			Type of application
		Use	Climate	Building	
Calculated (asset)	Design	Standard	Standard	Design	Building permit, certificate under conditions
	As built	Standard	Standard	Actual	Energy performance certificate, regulation
	Actual	Actual	Actual	Actual	Validation
	Tailored	Depending on purpose			Optimization, validation, retrofit planning, energy audit
Measured (operational)	Actual	Actual	Actual	Actual	Monitoring
	Climate corrected	Actual	Corrected to standard	Actual	Monitoring or energy audit
	Use corrected	Corrected to standard	Actual	Actual	Monitoring
	Standard	Corrected to standard	Corrected to standard	Actual	Energy performance certificate, regulation

5.2 Energy performance indicators in general

In theory, an energy indicator might be purely based on raw data on energy consumption in kWh, MJ, and other units for a certain time period. In most situations, however, the energy indicator should be defined as a key-value for energy performance, with energy consumption normalized to a constant reference to account for variations in production or climate conditions. A theoretical ideal energy indicator offers stable information about the energy performance of a given process without being influenced by circumstances other than the actual operation. However, in reality, such an indication is unlikely to be practical because the majority of indicators are impacted by external variables, sometimes to such an extent that the indicator becomes unstable and useless as a management tool.

5.3 The numerator

The motivating factor behind applying environmental assessment methodologies is energy efficiency. This is owing to the fact that the global construction sector is putting a strain on natural resources, which is reflected in the massive demand for energy. Environmental assessment techniques created in the manner outlined above, it might be claimed, can lead to a new understanding of climate impact on the built environment. The implementation of appropriate environmental building evaluation techniques on a wide scale is required to stimulate market demand for sustainable practices in the built environment **[18]**.

The energy consumption per area per year is the primary metric now employed in the field of building energy consumption (kWh/ m^2a). According to Fokaides et al. (2017) **[19]** analysis, this indicator is not the best suitable measurement for determining a building's real energy performance in certain situations. It should be highlighted that neither the European Commission's State of the Energy Union report (European Commission, 2017) **[20]** on key energy indicators nor the International Energy Agency's Energy Efficiency Indicators report (International Energy Agency, 2016) **[21]** include this indication. Furthermore, a more holistic approach to building energy efficiency should be derived by taking into account energy usage per person for the period the spaces were occupied. When analyzing the energy behaviour of the inhabitants, end-energy and primary-energy usage should be taken into account. The true parameter that should be addressed in order to give a consistent correlation about the lifestyle and energy habits of inhabitants is the end-energy, as this represents the occupants' actual utilization habits. Since the energy mix of each country affects the macroeconomics of energy consumption and the extraction of national indicators, primary energy usage should only be evaluated for these two indications. However, studies focused on building energy performance and the influence of new policies or initiatives that should utilize the energy spent on-site.

Many problems remain in the realm of energy efficiency indicators, according to Boemi and Tziogas (2016) **[22]** research, including more accurate KPIs that account for building characteristics, occupant behavior, and environmental context. A few criteria to consider in energy analytical techniques for both existing buildings and under construction include (i) accuracy; (ii) sensitivity; (iii) speed; (iv) reproducibility; (v) ease of use and level of detail; (vi) availability of required data; (vii) output quality; and (viii) project stage (for structures during the construction phase).

Building energy consumption is frequently represented in terms of kWh of yearly supplied energy - final energy; primary energy; energy cost; or, in terms of a climate effect, in units of CO_2 equivalent. These can also be broken down by energy sources, such as on-site and off-site renewables.

5.4 The denominator

The numerator (kWh, kgCO2, cost, etc.) per time interval (typically a year) must be divided by something to develop an energy-use indicator (EUI). In **Table 6** are listed some of the most often used denominators, as well as some of their strengths and weaknesses, based on Bordass (2020) **[23]** research. Internal floor space is a common starting point since it is more easily recorded (e.g. in leases) and auditable than occupancy, though it is still susceptible to uncertainty.

Table 6: Denominators often used in energy-use indicators

Denominator	Strengths	Weaknesses	Comments
Floor area (m2)	Measure of useful space. Frequently documented, though not usually appropriate.	Buildings that are not heavily used may be rewarded unless the degree of use is accounted for in a certain manner.	Floor area resolutions (e.g. gross, net, usable, internal, external, treated (heated), etc.) and definitions can vary widely between sector and country
Volume (m3)	Used in some sectors	Not routinely recorded. Tall ceilings help with natural ventilation and light. Lower ceilings exacerbate inequalities in EUI when there is air conditioning.	Typically, this is not very useful. It may be appropriate for industries (e.g., warehouses) wherein volume can be contained by height. It is often preferable to have unique sector criteria for each location.
Number of occupants or occupant-hours	In some sectors, the building's productivity is indicated.	It is challenging to track occupants (and occupant-hours) accurately. Overestimation has frequently been employed to enhance EUIs.	It is best used as a backup indicator or in situations where capacity data are solid (e.g. school rolls). As occupation tracking technology progresses, it will become increasingly beneficial.

The differences in area definitions between sectors and jurisdictions make comparisons challenging. While standard units are important, common usage must also be considered.

Standard EN 15203 (CEN 2005) **[14]** defines Operational Ratings for EU energy certificates as the total of the weighted yearly consumption of each kind of energy provided (imports fewer exports) per m2 of usable floor space. Member states of the EU might set their own weightings for the EPBD, depending on primary energy factors, energy costs, CO2 emission factors, or other policy drivers. A new amendment (European Parliament and Council 2018) **[16]** now mandates uniform reporting in primary energy units.

6 Calculation of Energy Indicators

6.1 Power

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

6.1.1 Total Power/Occupancy

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

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

6.1.2 Total Power/Occupancy-Hours

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

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

6.1.3 Total Power/Area

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

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

6.1.4 Total Power/Volume

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

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

6.2 Heating

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

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

6.2.1 Heating consumption/Occupancy

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

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

6.2.2 Heating consumption/Occupancy-Hours

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

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

6.2.3 Heating consumption/Area

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

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

6.2.4 Heating consumption/Volume

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

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

6.2.5 Weather-Normalized Heating Energy Consumption

Following the steps below to compare the Weather Normalized Usage from the Baseline Year.

1. For both the evaluation and baseline year, we take the heating degree days (HDD) for the heating period
2. Then calculate the percentage between the evaluation year and baseline year.

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

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

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

4. Subtract the amount from step 3 of the reference point from Actual Usage in the heating period of the Evaluation Year. The main distinction is Usage Avoidance, and a positive figure indicates that consumption has increased.

   It is better to have a negative number. When tried to compare to the Weather Normalized Usage from the Baseline Year, it implies that utilization was averted. Furthermore, a Positive Number is unfavorable, and it signifies that usage increased when contrasted to the Weather Normalized Usage from the Baseline Year **[10]**.

6.3 Cooling

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

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

6.3.1 Cooling consumption/Occupancy

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

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

6.3.2 Cooling consumption/Occupancy-Hours

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

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

6.3.3 Cooling consumption/Area

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

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

6.3.4 Cooling consumption/Volume

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

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

6.3.5 Weather-Normalized Cooling Energy Consumption

Following the steps below to compare the Weather Normalized Usage from the Baseline Year.

5. For both the evaluation and baseline year, we take the cooling degree days (CDD) for the cooling period
6. Then calculate the percentage between the evaluation year and baseline year.

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

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

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

8. Subtract the amount from step 3 of the baseline from Actual Usage in the cooling period of the Evaluation Year. The main distinction is Usage Avoidance, and a positive figure indicates that consumption has increased.
   It is better to have a negative number. When tried to compare to the Weather Normalized Usage from the Baseline Year, it implies that utilization was averted. Furthermore, a Positive Number is unfavorable. It signifies that usage increased when contrasted to the Weather Normalized Usage from the Baseline Year. **[10]**.

6.4 Lighting

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

6.4.1 Lighting/Occupancy

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

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

6.4.2 Lighting/Occupancy-Hours

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

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

6.4.3 Lighting/Area

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

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

6.4.4 Lighting/Volume

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

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

6.5 Electrical Appliances Energy Consumption

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

6.5.1 Electrical Appliances Energy Consumption /Occupancy

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

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

6.5.2 Electrical Appliances Energy Consumption /Occupancy-Hours

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

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

6.5.3 Electrical Appliances Energy Consumption /Area

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

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

6.5.4 Electrical Appliances Energy Consumption /Volume

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

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

6.6 Domestic Hot Water

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

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

6.6.1 DHW consumption/Occupancy

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

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

6.6.2 DHW consumption/Occupancy-Hours

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

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

6.6.3 DHW consumption/Area

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

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

6.6.4 DHW consumption/Volume

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

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

7 Conclusions

The aim of the deliverable was to examine the potential of integrating environmental and energy indicators into the next generation of EPCs. The project's proposed set of indicators aims to improve EPC user-friendliness and raise user awareness by giving more knowledge.

Following a thorough literature review, existing knowledge, and method designing, the guideline for obtaining required data concerning environmental and energy indicators and providing instructions for the calculation to all interested parties was the result of this deliverable. By creating and implementing energy and environmental key performance indicators (KPIs) an essential step in achieving energy-saving targets is related to both new and existing structures. Additionally, the conversion of various parts of a building's energy performance into energy efficiency normalized results, as well as the use of EPCs for the life cycle assessment of building upgrades, are allowed. This information can encourage the user to compare and estimate their expenses related to building systems each month and be aware of the overall energy consumption of their building.

The European standards, as well as the efforts of EU member states in this area, lay the groundwork for the industry's future growth. Each indicator in the Level(s) framework is meant to link the impact of a particular structure to European sustainability goals. Currently, the present criteria for assessing advances are not adequately reflected at the system level. Conversely, they are typically only measured at the aggregated equipment level or the equipment level, with limited insights for benchmarking and troubleshooting performance aberrations in aggregated equipment that offers a particular service to a structure.

In contrast to existing EPCs, which depend on certain environmental indicators on designed values and assumptions and do not include energy indicators at all, the next generation EPCs present energy efficiency ratings based on actual data consumption.

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8 Appendix

8.1 Pilot case's brief description and the indicators

The measurements of the following example were taken from the sensors and relevant equipment installed in the Frederick University pilot building. The average usage values of power, heating, and cooling, lighting, as well as electrical appliances energy consumption for the months from June to May are presented in **Table 7.** These values were deduced for the entire year (12 months).

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

The building in Cyprus is located in the area of Palouriotissa, Nicosia, Y. Frederickou Str. (Longitude and Latitude 33°22'46.70 "E, 35°10'46.20 ""), Frederick University's new wing building is a two-story 2100 m2 building, its volume is approximately 7,100m3 (including the basement floor/parking area), and it was built in 2007. The understudy building does not border with any other building. The building consists of a basement (area of 450 m2), ground floor (area of 545 m2), and two floors (area of 545 m2 on each floor). University's cafeteria is on the ground floor; on the first floor, there are three seminar halls of 220 students' capacity, and offices are found on the second floor. The building can host up to 390 people. The total height of the building is 15.60 m from the basement floor to the terrace. The individual heights of the floors are 4.10 m for the typical floors and the ground floor. The services that are provided within the building include heating, cooling, ventilation, lighting, and electrical appliances.

Based on the real-time measurements of the FRC's pilot case, the related to heating and cooling, lighting, and electrical appliances indicators are documented in **Table 7** -

Table 9: Seasonal Indicators. The time step of the KPIs calculation is annual (June 2021-May 2022), biannual (June 2021-November 2021 and December 2021-May 2022) and per semester. These indicators have been calculated concerning occupancy, the surface area, and the volume per floor of the building.

Table 7: Annual Indicators – June 2021-May 2022

Load	Annual Amount	Unit
Total for Heating and Cooling	25.22	(kWh/m²)
	330.33	(kWh/Occupants)
	8.34	(kWh/m³)
Total for Heating	7.31	(kWh/m²)
	95.76	(kWh/Occupants)
	2.41	(kWh/m³)
Total for Cooling	17.91	(kWh/m²)
	234.57	(kWh/Occupants)
	5.93	(kWh/m³)
Total for Lighting (1st and 2nd floor)	14.22	(kWh/m²)
	184.57	(kWh/Occupants)
	4.76	(kWh/m³)
Total for Electrical Appliances (1st and 2nd floor)	19.18	(kWh/m²)

	249.10	(kWh/Occupants)
	6.43	(kWh/m^3)
Total for the Ground floor (October 2021 – May 2022)	69.60	(kWh/m^2)
	928.76	(kWh/Occupants)
	22.42	(kWh/m^3)
Total Power of the building	128.22	(kWh/m^2)
	1692.76	(kWh/Occupants)
	41.95	(kWh/m^3)

Table 8: Biannual Indicators

Load	Amount		Unit
	Summer-Autumn	Winter-Spring	
Total for Heating and Cooling	15.42	9.80	(kWh/m^2)
	202.07	128.26	(kWh/Occupants)
	5.11	3.23	(kWh/m^3)
Total for Lighting (1st and 2nd floor)	6.84	7.38	(kWh/m^2)
	88.74	95.83	(kWh/Occupants)
	2.29	2.47	(kWh/m^3)
Total for Electrical Appliances (1st and 2nd floor)	10.93	8.25	(kWh/m^2)
	141.94	107.16	(kWh/Occupants)
	3.67	2.76	(kWh/m^3)
Total for the Ground floor (October 2021 – May 2022)	13.81	55.79	(kWh/m^2)
	184.30	744.46	(kWh/Occupants)
	4.45	17.97	(kWh/m^3)
Total Power of the building	47	81.22	(kWh/m^2)
	617.05	1075.71	(kWh/Occupants)
	15.52	26.43	(kWh/m^3)

Table 9: Seasonal Indicators

Load	Amount				Unit
	Summer	Autumn	Winter	Spring	
Total for Heating and Cooling	9.89	5.53	4.18	5.62	(kWh/m^2)
	129.59	72.48	15.54	73.51	(kWh/Occupants)
	3.28	1.83	3.55	1.85	(kWh/m^3)
Total for Lighting (1st and 2nd floor)	3.14	3.70	3.48	3.90	(kWh/m^2)
	40.77	47.97	18.33	50.61	(kWh/Occupants)
	1.05	1.24	2.66	1.30	(kWh/m^3)
Total for Electrical Appliances (1st and 2nd floor)	5.19	5.74	4.05	4.20	(kWh/m^2)
	67.39	74.55	22.35	54.61	(kWh/Occupants)
	1.74	1.93	3.03	1.41	(kWh/m^3)
Total for the Ground floor (October 2021 – May 2022)	-	13.81	24.32	31.47	(kWh/m^2)
	-	184.30	136.33	419.89	(kWh/Occupants)
	-	4.45	18.17	10.14	(kWh/m^3)
Total Power of the building	18.22	28.78	36.03	45.19	(kWh/m^2)
	237.75	379.3	192.55	598.62	(kWh/Occupants)
	6.07	9.45	27.41	14.7	(kWh/m^3)

The graphical representations of indicators are depicted below in Figure 15 to Figure 19.

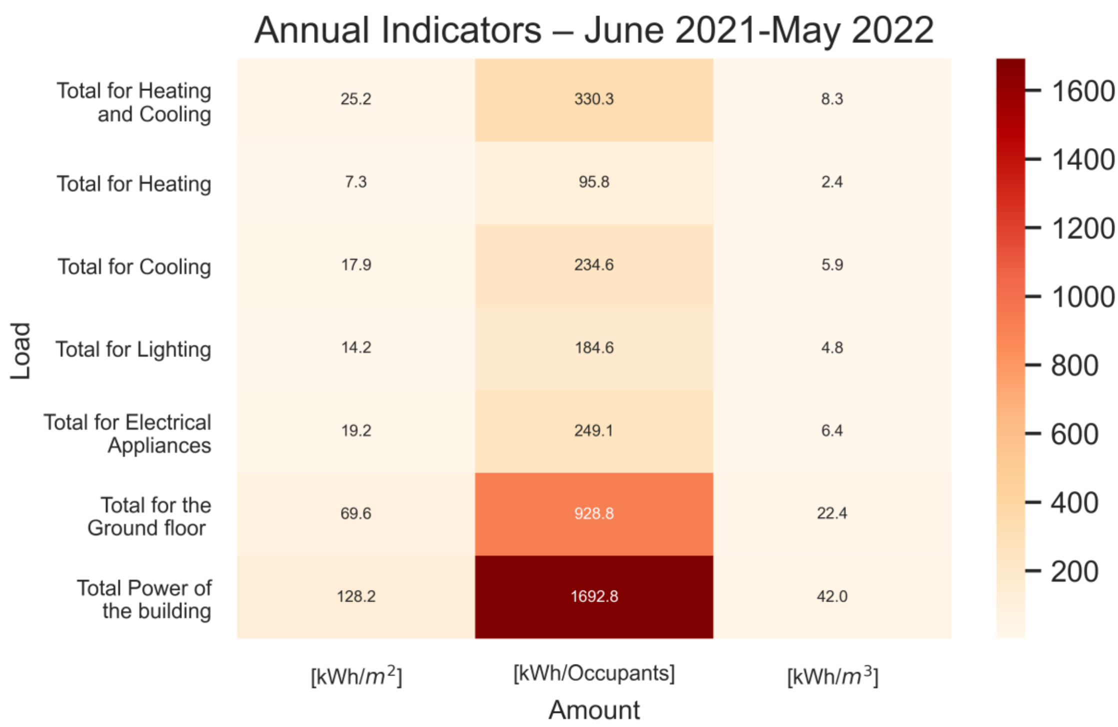

Figure 15: Annual Indicators – June 2021 - May 2022

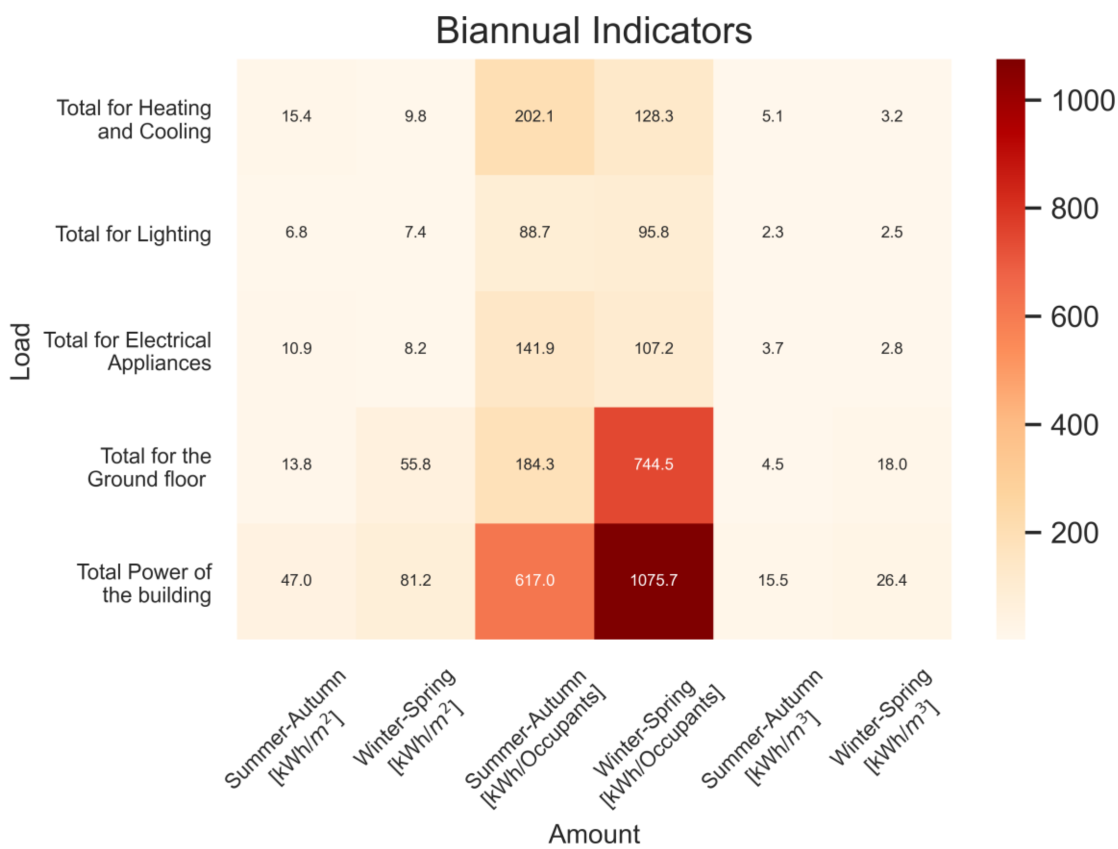

Figure 16: Biannual Indicators

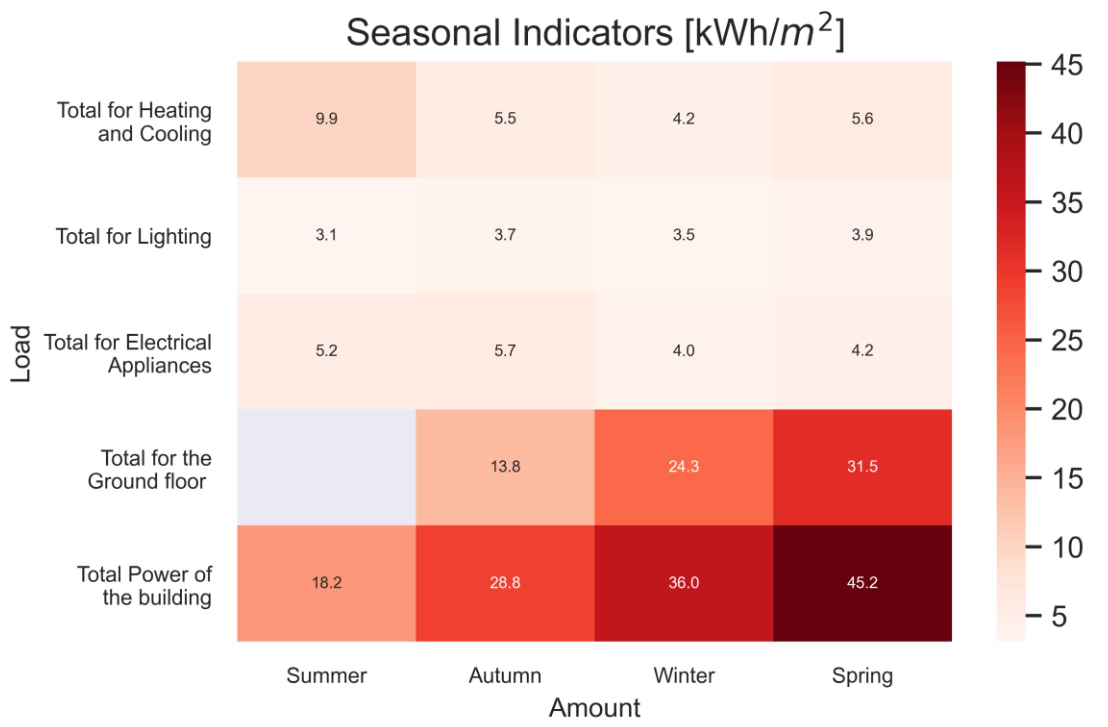

Figure 17: Seasonal Indicators [kWh/m²]

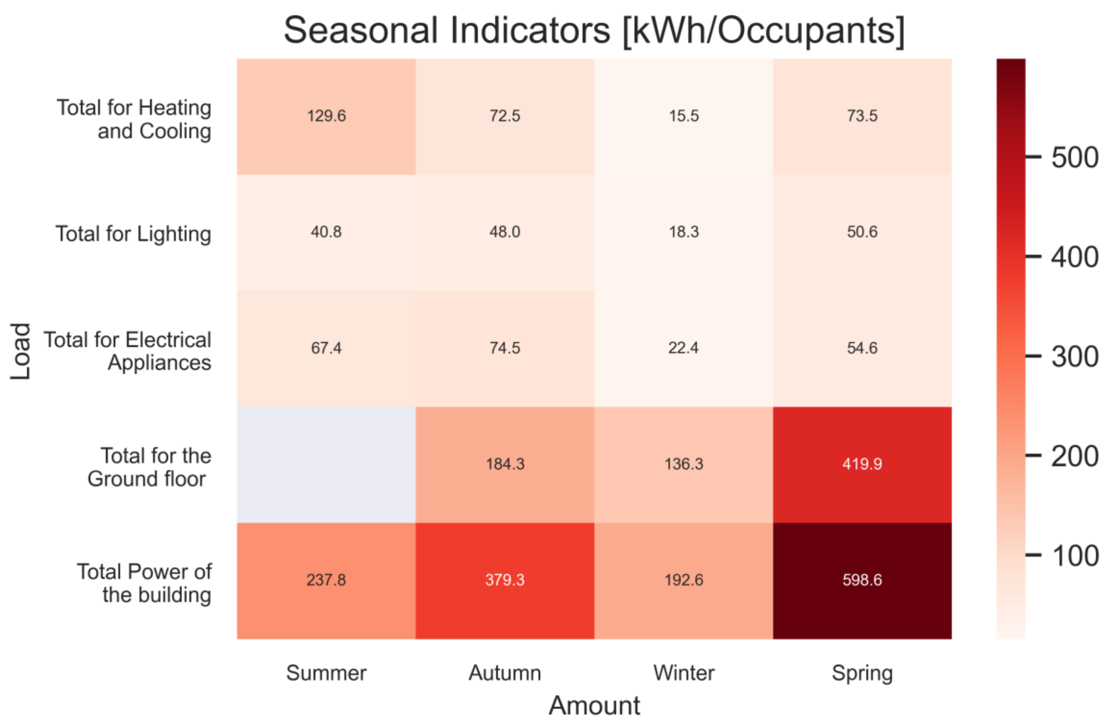

Figure 18: Seasonal Indicators [kWh/Occupants]

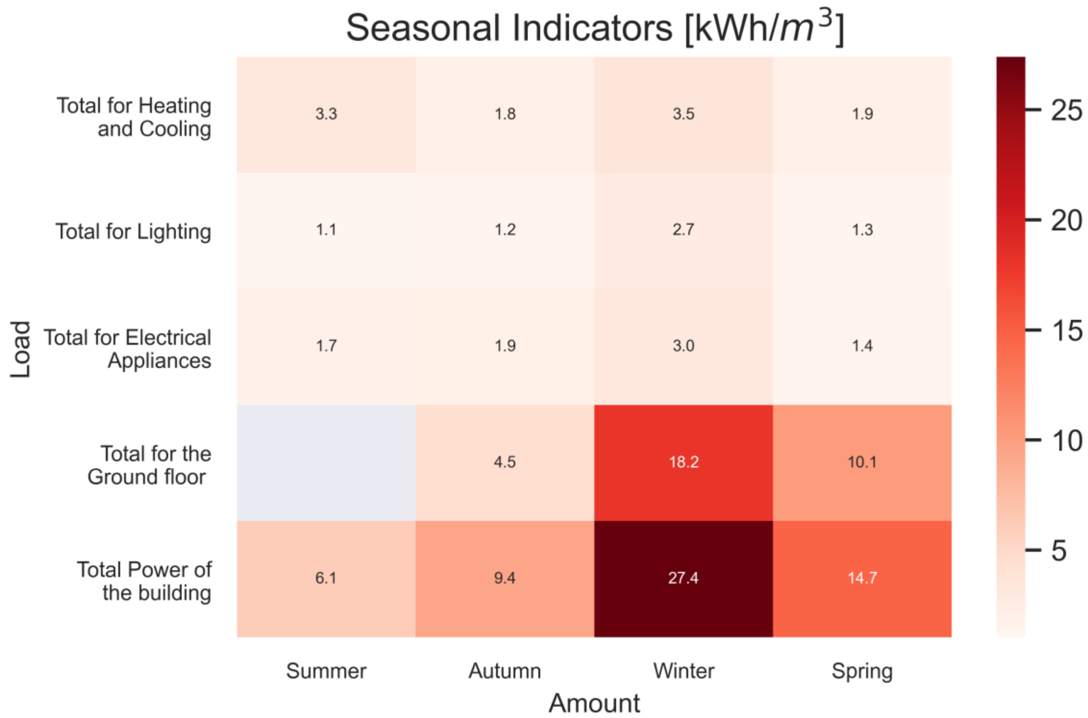

Figure 19: Seasonal Indicators [kWh/m³]

Table 10 and **Table 11** show biannual and seasonal indicators for the period from June 2022 to November 2022.

Table 10: Biannual Indicators for the Year 2022

Load	Amount	Unit
	Summer-Autumn	
Total for Heating and Cooling	17.83	(kWh/m²)
	233.38	(kWh/Occupants)
	5.90	(kWh/m³)
Total for Lighting (1st and 2nd floor)	7.59	(kWh/m²)
	98.41	(kWh/Occupants)
	2.55	(kWh/m³)
Total for Electrical Appliances (1st and 2nd floor)	8.75	(kWh/m²)
	113.62	(kWh/Occupants)
	2.94	(kWh/m³)
Total for the Ground floor	73.08	(kWh/m²)
	975.03	(kWh/Occupants)
	23.55	(kWh/m³)
Total Power of the building (June 2022 - November 2022)	107.25	(kWh/m²)
	1420.44	(kWh/Occupants)
	34.94	(kWh/m³)

Table 11: Seasonal Indicators for the Year 2022

Load	Amount		Unit
	Summer	Autumn	
Total for Heating and Cooling	11.11	6.72	(kWh/m²)
	145.53	87.85	(kWh/Occupants)
	3.68	2.22	(kWh/m³)

Total for Lighting (1st and 2nd floors)	3.47	4.12	(kWh/m²)
	44.97	53.44	(kWh/Occupants)
	1.16	1.39	(kWh/m³)
Total Electrical Appliances	4.23	4.52	(kWh/m²)
	54.96	58.66	(kWh/Occupants)
	1.42	1.52	(kWh/m³)
Total Ground floor	34.66	38.42	(kWh/m²)
	462.34	512.69	(kWh/Occupants)
	11.17	12.38	(kWh/m³)
Total Power of the building (June-November 2022)	53.47	53.78	(kWh/m²)
	707.8	712.64	(kWh/Occupants)
	17.43	17.51	(kWh/m³)

8.2 Pilot example calculation

8.2.1 Power

8.2.1.1 Total Power/Occupancy

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

8.2.1.2 Total Power/Occupancy-Hours

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

8.2.1.3 Total Power/Area

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

8.2.1.4 Total Power/Volume

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

8.2.2 Heating

8.2.2.1 Heating consumption/Occupancy

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

8.2.2.2 Heating consumption/Occupancy-Hours

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

8.2.2.3 Heating consumption/Area

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

8.2.2.4 Heating consumption/Volume

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

8.2.3 Cooling

8.2.3.1 Cooling consumption/Occupancy

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

8.2.3.2 Cooling consumption/Occupancy-Hours

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

8.2.3.3 Cooling consumption/Area

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

8.2.3.4 Cooling consumption/Volume

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

8.2.4 Lighting

8.2.4.1 Lighting/Occupancy

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

8.2.4.2 Lighting/Occupancy-Hours

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

8.2.4.3 Lighting/Area

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

8.2.4.4 Lighting/Volume

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

8.2.5 Electrical Appliances

8.2.5.1 Electrical Appliances Energy Consumption /Occupancy

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

8.2.5.2 Electrical Appliances Energy Consumption /Occupancy-Hours

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

8.2.5.3 Electrical Appliances Energy Consumption /Area

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

8.2.5.4 Electrical Appliances Energy Consumption /Volume

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

8.3 Power consumption graphical representations

In **Figure 20** to **Figure 22**, the representation of heating and cooling is presented, per each floor of the building.

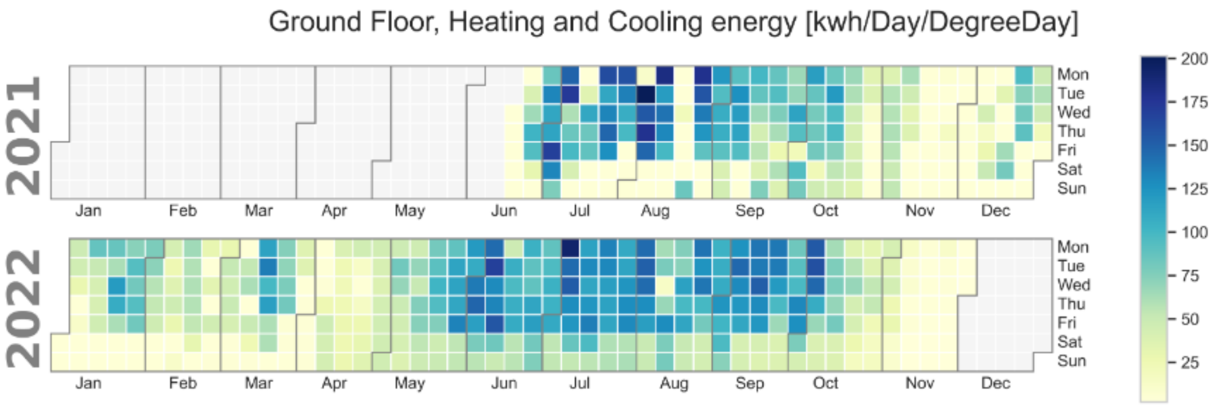

Figure 20: Ground Floor, Heating and Cooling energy [kWh/Day/DegreeDay]

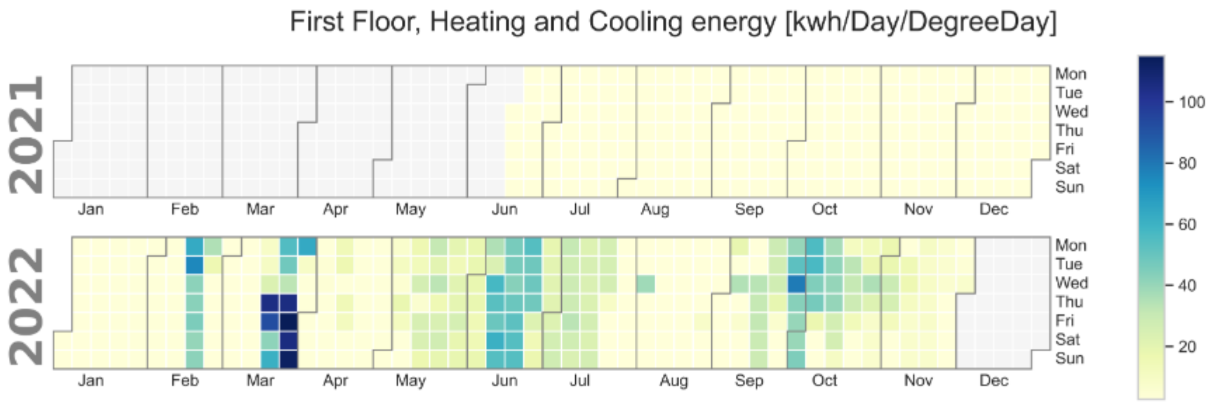

Figure 21: First Floor, Heating and Cooling energy [kWh/Day/DegreeDay]

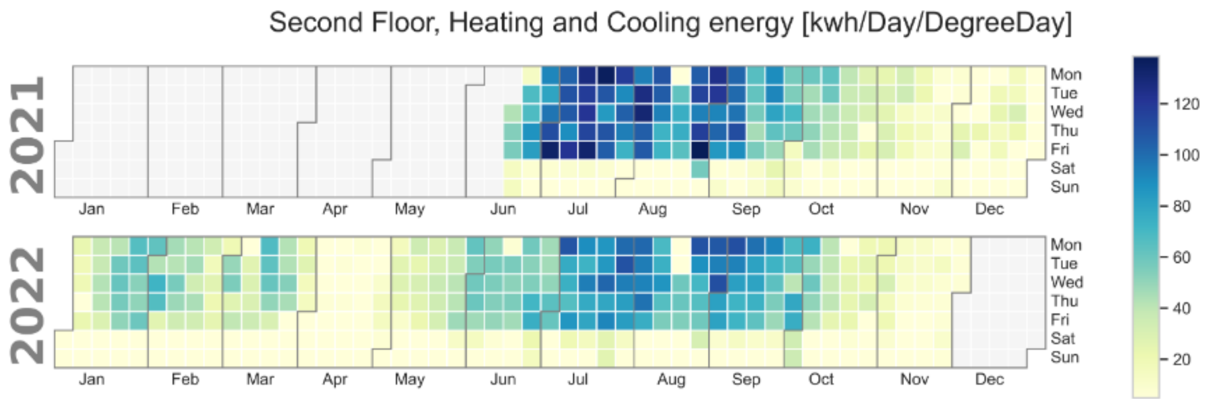

Figure 22: Second Floor, Heating and Cooling energy [kWh/Day/DegreeDay]

8.4 Power consumption graphical comparison 2021 - 2022

Figure 23 presents the total power consumption [kWh/Day/DegreeDay] of the FRC pilot building for 2021-2022. It is observed that the power consumption in 2022 was significantly higher compared to 2021, due to the COVID-19 pandemic, where the majority of employees were working from home. **Figure 24** shows the total power consumption [kWh/Day/DegreeDay] difference between 2021 – 2022 during Summer and Autumn seasons.

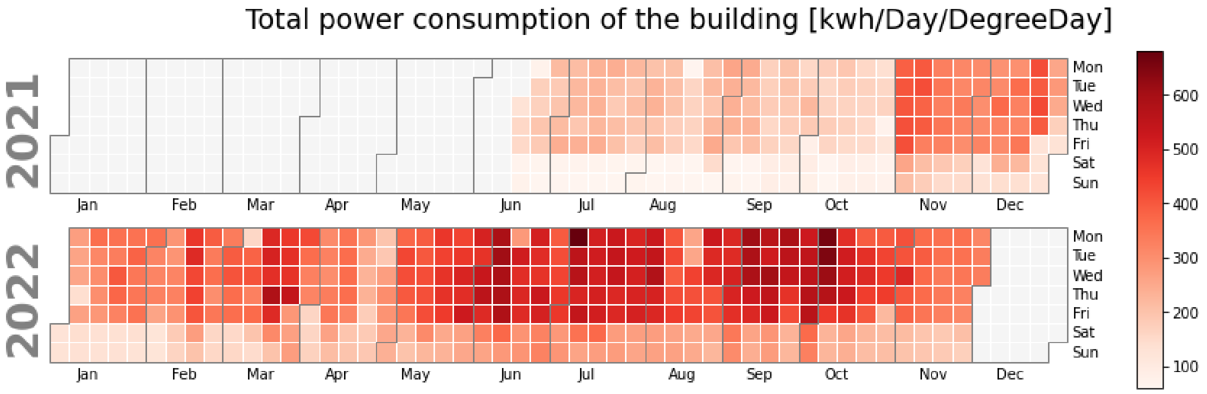

Figure 23: Total power consumption of the building [kWh/Day/DegreeDay]

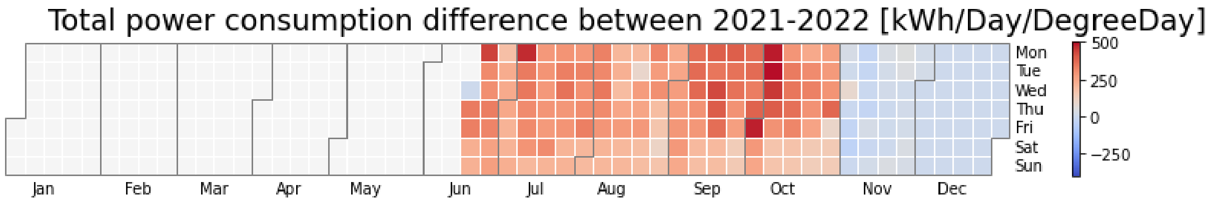

Figure 24: Total power consumption difference between 2021-2022 [kWh/Day/DegreeDay]

Figure 25 shows the power usage of the ground floor between 2021 and 2022. It is not possible to compare these two years due to a lack of measurements.

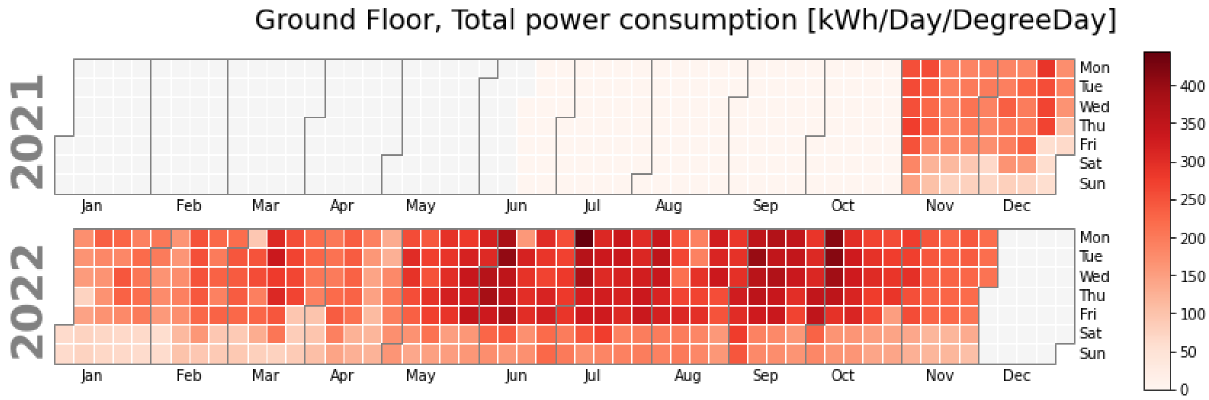

Figure 25: Total power consumption of ground floor[kWh/Day/DegreeDay]

Figure 26 shows the power usage of the first floor between 2021 and 2022. The first floor has a mixed occupation activity depending on the occasion, being used for seminars, examinations, and teaching purposes.

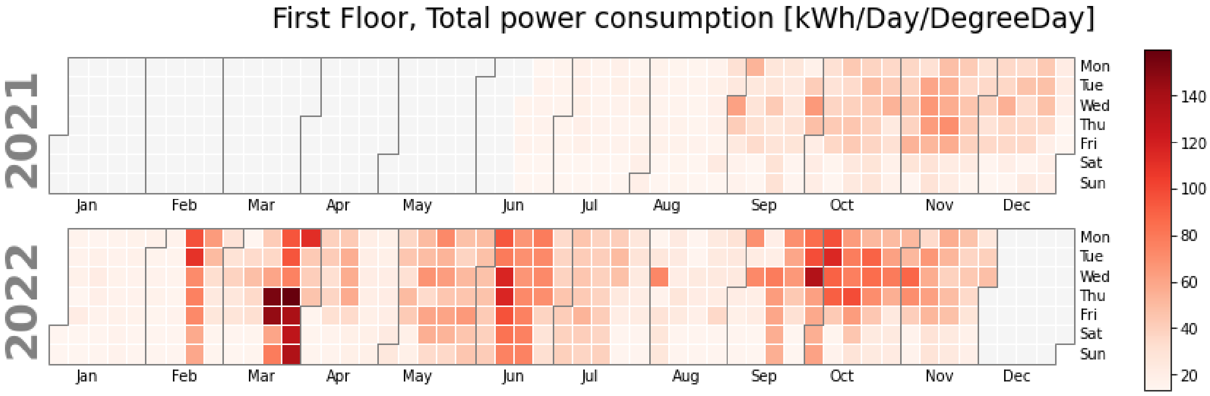

Figure 26: Total power consumption of first floor[kWh/Day/DegreeDay]

Figure 27 shows the power usage of the second floor between 2021 and 2022. It is observed that the power consumption in 2022 was significantly lower compared to 2021.

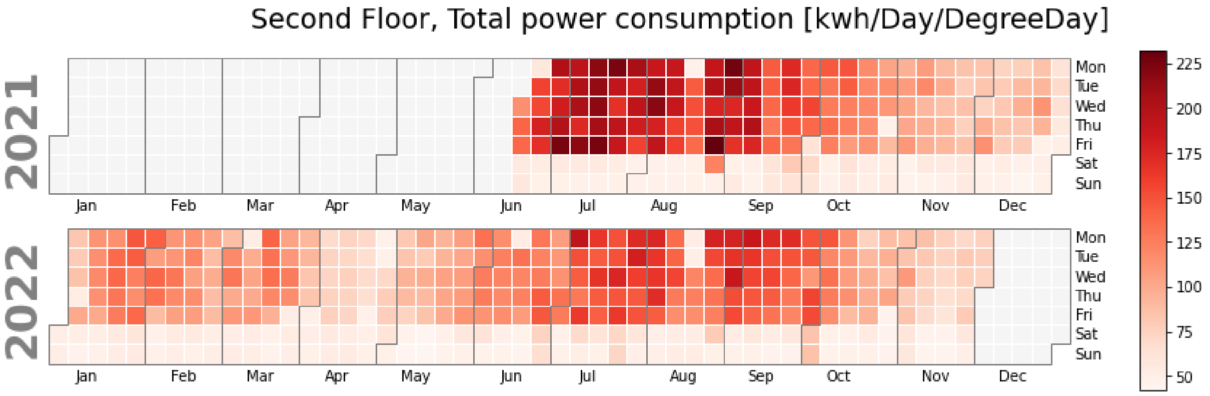

Figure 27: Total power consumption of second floor[kWh/Day/DegreeDay]