# Final Report

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

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# Deliverable D8.3
# Final Project Report

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# Executive Summary

In this current document a comprehensive summary of the D^2EPC vision is provided in order to review the main scientific, technical and social objectives of the project. The main scientific and technological achievements of the project are detailed in Section 1.2 while the impact of the D^2EPC project has been further elaborated based on the evaluation methodology developed for assessing it from various perspectives – technical, economic, environmental, and social. Moreover, a section is devoted to the project's dissemination and exploitation strategies, identifying key exploitable results and exploitation plans for its main scientific and technological results to set the foundations for commercialization and market positioning of D^2EPC products. In the final section of the document, a summary of the use of resources is provided to depict all the efforts that have been made during the lifecycle of the project.

D^2EPC aspires to establish the next-generation dynamic EPCs for the operational and regular assessment of buildings energy performance through a set of cutting-edge digital design and monitoring tools and services. The project has analysed the quality and the drawbacks of the current EPC schemes, identifying technical challenges that currently exist and proposed means to overcome them in order to set the grounds for the next generation dynamic EPCs. At the same time, it has defined the required framework to empower the regular energy classification of buildings, based on their operational performance, establishing also a set of indicators which foster the reliability, user-friendliness and cost-effectiveness of energy certificates across Europe.

In particular, D^2EPC relies upon and adjusts accordingly to the smart-readiness level of the buildings and the corresponding data collection infrastructure and management systems. It subsequently builds upon actual data and the 'digital twin' concept to calculate energy, environmental, financial and human comfort indicators and through them the EPC classification of the building in question. The project is based on BIM literacy, integrating smart meters, actual performance-related data and activities profiling into the buildings' digital twins. The project delivers a holistic digital solution that not only issues the next generation EPCs, but also extends EPCs applications and usability. Added value services include the provision of customised recommendations for energy performance upgrades *(roadmapping tool)*, the provision of performance forecasting (*AI-driven forecasting tool)* in order to coordinate the operation of building's assets in the optimal comfort and efficient way as well as the provision of notifications and alerts *(notifications and alerts tool)* to avoid the risk of performance downgrade. Further to that, the project provides extended applications that include buildings performance comparison in more than one normalised metrics as per the SRI framework *(building energy performance benchmarking)* as well as verifying the credibility of the data collection and processing *(performance verification and credibility tool)*. The D^2EPC WebGIS tool visualises generated EPCs in a GIS environment, empowering users to perform various types of spatial and attribute queries.

The proposed scheme provides sufficient background for the redefinition of EPC-related policies, through regular benchmarking and upgrade of the reference buildings, as well as with the integration of geolocation and "polluter pay" practices into the EPC rationale. The implementation of the proposed project fosters the energy saving consciousness of buildings' users, through their regular information on the actual energy performance of their buildings and suitable incentivization. D^2EPC scheme has been validated and demonstrated under real-life conditions in six buildings (domestic, multifamily houses and tertiary buildings) in Greece, Germany, and Cyprus through piloting activities driven by CERTH, CLEO, FRC and SEC.

## Table of Contents

1 Final Publishable Summary Report ........ 13

**1.1 Project Summary ........ 13**

**1.2 Main Scientific and Technological Project Achievements ........ 16**

1.2.1 Comparative Assessment of current EPC methodologies towards the definition of the Dynamic EPC Scheme ........ 16

1.2.2 User Requirements and Market Needs ........ 18

1.2.3 Business Scenarios and Use Cases ........ 21

1.2.4 D^2EPC Framework Architecture & Specifications ........ 22

1.2.5 D^2EPC IoT Framework ........ 26

1.2.6 D^2EPC Asset rating methodology ........ 28

1.2.7 D^2EPC Operational rating methodology ........ 30

1.2.8 D^2EPC Set of additional Indicators ........ 34

1.2.9 D^2EPC Information Model ........ 46

1.2.10 Building Digital Twin ........ 48

1.2.11 D^2EPC Calculation Engine ........ 53

1.2.12 Added value services suite ........ 62

1.2.13 Extended dEPCs applications toolkit ........ 67

1.2.14 D^2EPC Web Platform ........ 71

1.2.15 D^2EPC WebGIS ........ 74

1.2.16 Contribution to standardization ........ 78

1.2.17 Policy-related implications ........ 81

1.2.18 D^2EPC Pilots ........ 87

1.2.19 Project's Data Management Plan & Open Knowledge ........ 100

**1.3 Impact ........ 103**

1.3.1 Addressing the expected impact set out in the Work Programme ........ 103

1.3.2 Socio-Economic Impact ........ 105

1.3.3 Value to Open Research Data ........ 106

1.3.4 Market Impact ........ 107

**1.4 Contact Details ........ 111**

1.4.1 Project Website ........ 111

1.4.2 List of Beneficiaries/ Consortium Composition ........ 112

2 Dissemination and Exploitation of Foreground ........ 121

**2.1 Dissemination Methodology & Objectives ........ 121**

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

**2.2 Exploitation of Results ........ 123**
2.2.1 Key Exploitable Results & Exploitation Foreground ........ 123
2.2.2 Business Innovation and Exploitation Plans ........ 125
2.2.3 Beyond D^2EPC ........ 131

## List of Figures

Figure 1. D^2EPC Layered Conceptual Architecture ........ 25
Figure 2: Asset Rating Calculation Overview ........ 28
Figure 3: D^2EPC AR dataset requirements ........ 29
Figure 4 D^2EPC SRI Calculation scheme ........ 37
Figure 5: Environmental indicators extraction ........ 42
Figure 6 The comparison of scenarios ........ 45
Figure 7 Process overview ........ 46
Figure 8. Proposed D^2EPC IFC Parser Workflow ........ 47
Figure 9: Building Digital Twin Functional Diagram, from D1.9 ........ 48
Figure 10: Digital Twin architecture implementation view ........ 49
Figure 11: BIM Parser conceptual level architecture ........ 50
Figure 12 BIM-based Digital Twin page ........ 52
Figure 13 Building collected measurements ........ 52
Figure 14: Calculation Engine- Architecture view ........ 53
Figure 15 Asset Rating page - validation ........ 54
Figure 16 Asset Rating page – results (CS1) ........ 55
Figure 17 Operational rating page - validation ........ 56
Figure 18 Operational rating page – results (CS1) ........ 56
Figure 19: SRI calculation procedure ........ 57
Figure 20 D^2EPC SRI Calculation subcomponent a) Assessor's Information; b) Assessor's Information; c) Domains; d) SRI Results ........ 58

Figure 21 Provision of HC&W indicators-related information ... 58

Figure 22: LCA submodule calculation procedure ... 59

Figure 23 LCA indicator impacts per material/life-cycle stage ... 60

Figure 24 LCA indicator impacts per material group ... 60

Figure 25: Financial Indicators calculation procedure ... 61

Figure 26 Results for cost & economic indicators ... 61

Figure 27: Added value services suite - Architectural view ... 62

Figure 28: Workflow of the Roadmapping tool ... 63

Figure 29: General overview of Roadmapping tool result in the Web Platform ... 64

Figure 30 Performance Forecasts page ... 65

Figure 31: Performance alerts & notifications component interactions ... 66

Figure 32: Performance alerts & notifications tool interface ... 67

Figure 33 Building Energy Performance Benchmarking Functional Diagram ... 68

Figure 34 Energy Benchmarking page – a) Building tab; b) Generic tab ... 69

Figure 35. Energy Performance Verification & Credibility Functional Diagram. ... 70

Figure 36. D^2EPC monitoring tool main dashboard ... 70

Figure 37 D^2EPC Credibility UI ... 71

Figure 38 Registration page ... 73

Figure 39 Main dashboard ... 74

Figure 40 Profile page ... 74

Figure 41: D^2EPC WebGIS Tool deployment diagram ... 75

Figure 42. D^2EPC WebGIS homepage overview ... 76

Figure 43. Provision of EPC statistics on a selected NUTS region ... 76

Figure 44. Visualisation of dEPC statistics for two regions in comparison mode ... 77

Figure 45. Attribute query and visualisation of dEPC for selected region ... 77

Figure 46. Provision of OGC services ... 78

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

Figure 47. 3d fully interactive visualisation for a pilot case building's BIM file ...................... 78

Figure 48 Overview of key features in the existing schemes ................................................ 84

Figure 49: nZEB Smart House (left); North - East View of Smart House building in a BIM environment (right) ........................................................................................................ 88

Figure 50 CS1 asset-based EPC results ....................................................................... 89

Figure 51 CS1 operation-based EPC results ................................................................. 89

Figure 52: Residential/ Multi-family building in Velten Germany ........................................ 90

Figure 53 CS2 asset-based EPC results ....................................................................... 91

Figure 54 CS2 operational-based EPC results .............................................................. 91

Figure 55: Tertiary building/Offices in Berlin Germany .................................................... 92

Figure 56 CS3 asset-based EPC results ....................................................................... 93

Figure 57 CS3 operation-based EPC results ................................................................. 93

Figure 58: IFC model of a FRC building ........................................................................ 94

Figure 59: CS4 asset-based EPC results ...................................................................... 96

Figure 60: CS4 operational-based EPC results ............................................................. 96

Figure 61 Front side of the renovated building (left); Aerial view of the building (photo credits eZeit Ingenieure GmbH) (right) ................................................................... 97

Figure 62 Dashboard energy management system ........................................................ 97

Figure 63 CS5 asset-based EPC results ....................................................................... 98

Figure 64 CS5 operational-based EPC results .............................................................. 98

Figure 65 Front and backyard Sonnenallee (left); 3D representation (right) ........................ 99

Figure 66 CS6 asset-based EPC results ..................................................................... 100

Figure 67 CS6 operational-based EPC results ............................................................ 100

Figure 68. D^2EPC Data Management ....................................................................... 101

Figure 69. Snapshot from the D^EPC official web site .................................................. 111

Figure 70. D^2EPC's exploitable assets. ..................................................................... 124

## List of Tables

Table 1. Summary of User Requirements .......... 18

Table 2. Technical needs and requirements .......... 19

Table 3. Volere –based documentation template .......... 22

Table 4. Proposed list of IoT devices .......... 27

Table 5. Energy Indicators .......... 31

Table 6 SRI functionality levels assessment in IFC schema .......... 36

Table 7. Thermal Comfort Indicators .......... 37

Table 8. Visual Comfort Indicators .......... 38

Table 9. IAQ KPIs according to Level(s) .......... 39

Table 10: LCA Indicators .......... 42

Table 11 D^2EPC Financial indicators .......... 45

Table 12 Benchmarking Dataset with building characteristics and energy performance indicators .......... 67

Table 13 Connection between D^2EPC components and BRP scheme .......... 85

Table 14 IoT deployment in Case study 2 .......... 90

Table 15 IoT deployment CS3 .......... 92

Table 16 Monitoring equipment characteristics .......... 94

Table 17. D^2EPC partners and contact details .......... 112

Table 18. SWOT Analyses. .......... 131

Table 19. PEST analysis .......... 132

Table 20. The Primary Exploitable outcomes and the partner in charge of each module .......... 134

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

## List of Acronyms and Abbreviations

| Term | Description |
|---|---|
| API | Application Programming Interface |
| BACS | Building Automation And Control Systems |
| BDT | Building Digital Twin |
| BEPS | Building Energy Performance Simulation |
| BIM | Building Information Model |
| BMS | Building Management System |
| BRP | Building Rennovation Passport |
| BS | Business Scenario |
| CS | Case Study |
| DBMS | DataBase Management System |
| dEPC | Dynamic Energy Performance Certificates |
| DHW | Domestic Hot Water |
| DMP | Data Management Plan |
| DoA | Description of Action |
| DT | Digital Twin |
| EMS | Energy Management System |
| EPB | Building Energy Performance Benchmarking |
| EPBD | Energy Performance of Buildings Directive |
| EPC | Energy Performance Certificate |
| EPD | Environmental Product Declaration |
| EPVC | Energy Performance Verification and Credibility |
| ESCO | Energy Services Company |
| ETS | Emission Trading System |
| FHW | Fernheizwerk Neukölln AG |
| GDPR | General Data Protection Regulation |
| GIS | Geographic Information System |
| GWP | Global Warming Potential |

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|---|---|
| **HC&W** | **Human Comfort and Wellbeing** |
| **HVAC** | **Heating, Ventilation and Air Conditioning** |
| **IFC** | **Industry Foundation Classes** |
| **IML** | **Information Management Layer** |
| **IoT** | **Internet of Things** |
| **IPR** | **Intellectual Property Rights** |
| **KER** | **Key Exploitable Results** |
| **KPI** | **Key Performance Indicators** |
| **LCA** | **Life Cycle Assessment** |
| **LCC** | **Life Cycle Costing** |
| **NG EPC** | **Next Generation Energy Performance Certificates** |
| **MS** | **Member State** |
| **PEST** | **Political, Economic, Social and Technological** |
| **RES** | **Renewable energy Sources** |
| **REST** | **REpresentational State Transfer** |
| **SEO** | **Search Engine Optimization** |
| **SRI** | **Smart Readiness Indicators** |
| **SWOT** | **Strengths, Weaknesses, Opportunities, and Threats** |
| **TC** | **Technical Committee** |
| **UI** | **User Interface** |
| **WG** | **Working Group** |
| **WP** | **Work Package** |

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# 1 Final Publishable Summary Report

## 1.1 Project Summary

The building sector is one of the largest energy consumers in the EU responsible for approximately 40% of the final energy demand and 36% of $CO_2$ emissions, and subsequently has a significant role in the EC's proposal for its energy-saving goal. Indicatively, an estimated 97% of the EU's building stock (close to 30 billion $m^2$) is considered energy inefficient, while up to 75-85% of it will continue to be utilized in 2050[1]. In this context, the EU has proposed a set of directives and policy tools towards phasing out inefficient buildings. Energy Performance Certificates (EPCs) comprise an essential part of the Energy Performance of Buildings Directive (EPBD), introduced in 2002[2] and revised in 2010[3] and in 2018[4]. EPBD is the legislative and policy instrument tool to improve the energy performance of buildings across Europe, focusing on both existing and new buildings.

The anticipated benefits of EPC systems can only be achieved through an appropriately endorsed management and control system. To ensure high quality, an independent control system was introduced in the EPBD (Art. 18, 2010/31)-MSs can delegate the task to apply the control system to a third party- while the energy assessor's competence needs to be considered in the accreditation procedure. The accuracy of the EPC results is determined by the national EPC calculation methodology's level of detail and its input data quality. The performance gap, i.e., the difference between estimated and actual energy performance may be hindering EPCs reliability[5]. Although significant progress has been achieved in the past decade in the field of buildings digital design with the use of advanced tools, most of the software used in EU MSs is based on simplified architecture. The calculation methods on which EPCs software rely, follow the monthly model of ISO 13790 standard, where the description of the building is simplified and based on aggregated values (in terms of building elements' areas, thermal zones, etc.) and look-up tables (in terms of material thermal properties, infiltration rates etc.), while correlation factors or predefined schedules are also used for the dynamic effects modelling. Moreover, the EPC delivery process can be subjective, as currently most EPC calculations rely on a range of standard inputs or default inputs[6] and, as a result, data quality can be easily influenced by the energy assessors because of the standard assumptions made in the process of producing the certificate.
The revised EPBD (2018/844/EU) requires the integration of human-centric elements to the energy performance calculations, which will provide to the building the ability to adapt its operational mode in response to the needs of the occupant by maintaining healthy and convenient indoor climate conditions. It is though a fact that human comfort aspects related to occupant well-being in inhabited spaces, are currently not considered by the existing EPC schemes. According to existing practices, energy performance certificates are issued at the early stages of the building construction, thus they fail to present the actual energy behaviour of the building over time. The availability of building energy-related data and recordings from the actual energy consumption of buildings through smart meters

[1] *BPIE – Buildings Performance Institute of Europe, The Concept of the Individual Building Renovation Roadmap – An in-depth case study of four frontrunner projects, iBRoad, January 2018.A*
[2] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings
[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)
[4] Directive 2018/844/EU of the European Parliament and of the Council of 19 June 2018 amending Directive 2010/31/EU on the energy performance of buildings (recast) and Directive 2012/27/EY on energy efficiency
[5] e Wilde, P. (2014). The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction*, *41*, 40-49
[6] Jenkins, D., Simpson, S., & Peacock, A. (2017). Investigating the consistency and quality of EPC ratings and assessments. *Energy*, *138*, 480-489.

and sensors, introduce several possibilities for integrating building management systems and digital twins into the certification process.

Industry 4.0, the digitisation of building operations and the growing ubiquity of data have resulted in the intensive development of massive datasets and data streams related to the urban environment[7]. Digitalization of the process of EPC issuing and updating through the integration of intelligent infrastructure in the certification process would support harmonization of EPC data collection, enable automatic upload to a central registry and makes the statistical analysis of data simple from a technical point of view[8]. Moreover, the use of advanced design models and tools such as Building Information Modelling (BIM), as well as inverse modelling through the creation of buildings' digital twins can turn EPC into a tool which would enable holistic technical, economic and environmental approaches for the design and operation of sustainable buildings.

Under this context, D^2EPC aspires to establish the next-generation of dynamic EPCs for the operational and regular assessment of buildings energy performance through a set of cutting-edge digital design and monitoring tools and services. D^2EPC relies upon and adjusts accordingly to the smart-readiness level of the buildings and the corresponding data collection infrastructure and management systems. It subsequently builds upon actual data and the 'digital twin' concept to calculate energy, environmental, financial and human comfort indicators and through them the EPC classification of the building in question. The project is based on BIM literacy, integrating smart meters, actual performance-related data and activities profiling into the buildings' digital twins. The proposed scheme provides sufficient background for the redefinition of EPC-related policies, through regular benchmarking and upgrade of the reference buildings, as well as with the integration of geolocation and "polluter pay" practices into the EPC rationale. The implementation of the proposed project fosters the energy-saving consciousness of buildings' users, through their regular information on the actual energy performance of their buildings and suitable incentivization.

**Objective 1: The introduction and establishment of the concept of the dynamic EPC (dEPC), an operational certificate to be calculated and issued on a regular basis**

Although cutting-edge monitoring technologies allow the real -time integration of measured data into the calculation process of EPCs, this has still not been regulated either by existing EPC tools or methodologies. D^2EPC project has defined the required framework to empower the regular energy classification of buildings, based on their operational performance. Building users can be informed about the actual energy performance of their buildings through the D^2EPC Web platform and manage this way to better regulate their energy habits. The dynamic character of the calculation procedure will also impose in the future the regular update of the reference values of the building stock, and thus the continuous update of the minimum energy performance requirements of buildings on a national level. Based on the continuous improvement of the minimum energy requirements of EU MSs for new buildings, and in view of the nearly Zero Energy Buildings era, this development will lead to the enhancement of the actual energy performance of EU MSs building stocks. In this manner a more active role of next generation EPCs into policy making is enabled. Finally, the visualization of EPCs in a GIS environment present a comprehensive overview of the actual performance of buildings which facilitates efficient energy planning.

**Objective 2: The definition of the drawbacks and discrepancies of the current EPC scheme, as well as the update of EU standards on the classification requirements of buildings**

[7] Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, *79*(1), 1-14.

[8] Arcipowska, A., Anagnostopoulos, F., Mariottini, F., & Kunkel, S. (2014). Energy performance certificates across the EU. A mapping of national approaches, 60.

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Current practices and tools of energy performance assessment and certification applied across Europe face several drawbacks and discrepancies[9]. D^2EPC has analysed the quality and the drawbacks of the current EPC schemes, identifying technical challenges that currently exist and proposing means to overcome them in order to set the grounds for the next generation dynamic EPCs. D^2EPC scheme is based on the relevant EU standards and the Energy Performance of Buildings Directive, in order to allow for an EU-wide deployment and has concluded to a specific series of proposals and measures to be used for the update of the ISO/CEN standards developed under Commission mandate M/480[10].

**Objective 3: The enhancement of EPCs through a novel set of indicators which cover environmental, financial, human comfort and technical aspects of new and existing buildings, aiming to simplify the understanding of buildings energy performance and to present a more comprehensive overview of the actual energy performance of buildings**

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

**Objective 4: The integration of actual operational data from buildings into the EPCs using advanced data collection infrastructure and BEPS tools integrated into BIM**

EPCs are currently issued with the use of verified software which are either open to the public or proprietary, depending on the legislation and requirements of the EU MSs. Although the quality and effectiveness of the available software cannot be questioned, there is still a significant gap between the state-of-the-art practices of Industry 4.0, digital construction tools and the existing Building Energy Performance Simulation (BEPS) tools. D^2EPC project bridges the gap with the introduction of the digital twin concept[11], which enriches BIMs with operational data taken from BEPS and/or an IoT-based data collection infrastructure. This way, the project injects an inverse modelling dimension into the BIM tools that allows building models (i.e., digital twins) to be evolved in line with the actual building performance. To this end, D^2EPC uses available building energy-related data from sensors, smart meters, connected devices and building systems and employs 6D Level 3 BIM, contributing to the improvement of the effectiveness of certificates, by demonstrating how these can be strengthened, modernised and best linked to the user needs and requirements.

**Objective 5: The integration of smart readiness rationale into the building's energy performance assessment and certification**

The ability of buildings to be smartly monitored and controlled and to get involved in demand-side management strategies is one of the new requirements envisioned in the 2018/844 directive on the energy performance of buildings. Smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency

[9] Sesana, Marta Maria, and Graziano Salvalai. "A review on Building Renovation Passport: Potentialities and barriers on current initiatives." *Energy and Buildings* 173 (2018): 195-205.

[10] M/480 Mandate of the European Commission to CEN, CENELEC and ETSI for the elaboration and adoption of standards for a methodology calculating the integrated energy performance of buildings and promoting the energy efficiency of buildings, in accordance with the terms set in the recast of the Directive on the energy performance of buildings (2010/31/EU)

[11] *'The vision of the Digital Twin itself refers to a comprehensive physical and functional description of a component, product or system together with all available operational data'*. _Source_: Boschert, Stefan, Christoph Heinrich, and Roland Rosen. "Next generation digital Twin." Proceedings of TMCE, Las Palmas de Gran Canaria, Spain Edited by: Horvath I., Suarez Rivero JP and Hernandez Castellano PM (2018).

and overall performance of buildings. D^2EPC scheme introduces an agreed list of parameters concerning the level of smartness of buildings which allow comparable good quality, in order to instil trust in the market and incite investments in energy efficient buildings. The assessment criteria of SRI are summarized on a set of criteria, including the heating, cooling, ventilation, lighting, electric vehicles as well as the smart grid integration potentials of buildings, while also considering the share of renewable energy used in the buildings.

**Objective 6: Intelligent operational digital platform for dynamic EPCs issuance and actual building performance monitoring and improvement, validated and demonstrated under realistic conditions:**

Current EPC schemes are based on a cradle-to-site rationale, completing their mission after the delivery of the certificate to the building user, overlooking user's behaviour and the actual energy performance of the building that might change dynamically over time. D^2EPC utilizes a multi-sensorial framework to collect multi-modal data from the buildings as related to energy consumption profiling and occupancy information, indoor environmental conditions, and air quality. The input data streams are aggregated and processed extracting meaningful intra-building information for calculating the necessary human-centric indicators in the dynamic EPC for the assessment of the building's actual energy performance. On top of that, the project delivers a holistic digital solution that not only issues the next generation EPCs, but also extends EPCs applications and usability. Added value services include the provision of customised recommendations for energy performance upgrades *(roadmapping tool)*, the provision of performance forecasting (*AI-driven forecasting tool)* in order to coordinate the operation of building's assets in the optimal comfort and efficient way as well as the provision of notifications and alerts *(notifications and alerts tool)* to avoid the risk of performance downgrade. Further to that, the project provides extended applications that include buildings' performance comparisons in more than one normalised metrics as per the SRI framework *(building energy performance benchmarking)* as well as verifying the credibility of the data collection and processing *(performance verification and credibility tool)*. The D^2EPC WebGIS tool visualises generated EPCs in a GIS environment, empowering users to perform various types of spatial and attribute queries. D^2EPC scheme has been validated and demonstrated under real-life conditions in six buildings (domestic, multifamily houses and tertiary buildings) in Greece, Germany, and Cyprus through piloting activities driven by CERTH, CLEO, SEC and FRC.

## 1.2 Main Scientific and Technological Project Achievements

### 1.2.1 Comparative Assessment of current EPC methodologies towards the definition of the Dynamic EPC Scheme

Task 1.1 "Comparative assessment of current EPC schemes and relevant emerging building performance paradigms" served as the foundational element for Task 1.3 "Definition of the dynamic EPC scheme" by concentrating on the joint analysis of data that exposed features of existing Energy Performance Certificate (EPC) schemes and practices. This analysis aimed to identify gaps and opportunities for improvement and set the stage for the subsequent development of dynamic EPCs. The methodology employed in T1.1 encompassed field research related to:

- EPC issuance, quality control, and quality assurance;
- EPC calculation software and tools;
- EPC indicators; and
- Competence and skills of qualified experts.

Additionally, desk research was conducted, which involved an examination of fifty-two (52) reports, followed by the extraction of twenty-five (25) statements relevant to multiple constraints and limitations present in the EPC procedure across the twenty-seven EU Member States.

The field research aspect utilized a questionnaire comprising ten questions, which was disseminated to a list of stakeholders identified and prioritized via the Stakeholder Circle® method. This method categorized stakeholders as those who influence, those who are influenced by, and those who may have an interest in practices, procedures, and policies related to EPCs. Stakeholder prioritization was done according to the recommended communication effort and in coordination with Task 1.2 partners to ensure consistency and avoid duplication of effort.

The desk research methodology entailed a review of fifty-two reports to discern the challenges, needs, and opportunities of current EPC schemes and a comparison of EPC schemes in the twenty-seven EU Member States. This review was followed by the extraction of twenty-five statements pertinent to various constraints and limitations within the EPC procedure. This work has been documented in the first version of the report Comparative assessment of current EPC schemes and relevant emerging building performance paradigms (D1.1) and updated within its second and final version (D1.5).

Due to the field's dynamic nature, revisions from D1.1 to D1.5 included a comprehensive progress overview that considered synergies with sister projects and the Energy Performance of Buildings Directive Recast.

Subsequently, Task 1.3 examined the aspects necessary for developing a dynamic EPC and laid the foundation for the work to be conducted in WP2 for the specification of the relevant indicators. These aspects encompass standardization, novel indicators like the smart readiness indicator, human comfort, life cycle environmental and economic performance attributes of buildings, geolocation practices, and the digital twin concept. Specifically, the content of the final report on the Aspects of Next generation EPC's definition (D1.8) outlined the following aspects:

- Analysis of existing information led to the conclusion that the new certification system should be user-friendly and compliant with national and European legislation, achievable through a standardized set of indicators based on a specific methodology.
- New indicators for the certification process were introduced, emphasizing a human-centric approach, inclusion of Life Cycle Assessment (LCA), financial and smart indicators, and connectivity to digital resources such as Geographic Information Systems (GIS), Building Information Modeling (BIM), and Digital Twins (DT).
- Integration of Smart Readiness Indicator (SRI) with building assessment and sustainability schemes will facilitate SRI calculation using data obtained during building digitization, employing digital logbooks or BIM files. This simplification is expected to aid in the establishment of the SRI, and assessments supported by online tools will provide users and owners with access to monitor SRI aspects.
- Data acquisition and processing still necessitate improvements and fresh insights regarding cyber-security and substantial data volume. DT implementation in construction offers promise, spanning the entire building lifecycle and encompassing energy performance simulations, predictions, and high-level transformative decisions.
- BIM holds promise for streamlining procedures, especially data collection. Although no BIM standards specific to EPC have been identified, BIM standards or projects applicable to energy efficiency-related elements will be considered. D^2EPC will strive to develop the necessary procedures for EPC implementation based on BIM. Given BIM's growing prominence, a BIM-based EPC standard would illuminate further possibilities and broaden tool usage.
- Incorporating new performance indicators and real, frequently updated measured data could enhance building energy performance, ensuring sustainable daily energy savings and thereby reducing energy costs for all citizens.
- Dynamic EPCs would facilitate ongoing monitoring of actual building user performance and the introduction of intelligent financial schemes tied to output-based assessments. These schemes could reward building owners exceeding EPC expectations or penalize "unconscious" users not meeting expected EPC classes, adhering to the "polluter pays" principle.

- Under the policy implication rationale, the D^2EPC project delivered a framework of proposals concerning the necessary upgrade of standards to facilitate the integration of the dynamic certificate concept into existing standards.

Related Submitted Deliverables:

- D1.1 Comparative assessment of current EPC schemes and relevant emerging building performance paradigms v1
- D1.3 Aspects of Next generation EPC's definition v1
- D1.5 Comparative assessment of current EPC schemes and relevant emerging building performance paradigms v2
- D1.6 Aspects of Next generation EPC's definition v2
- D1.8 Aspects of Next generation EPC's definition v3

### 1.2.2 User Requirements and Market Needs

Task 1.2 "Elicitation of user and stakeholder requirements & market needs" identified the needs and requirements of the major players and the market concerning the emerging next generation performance paradigms based on two main activities: (a) desk research including collection of reports from various reliable sources and (b) surveys/interviews addressing the project's stakeholders. The stakeholders' questionnaire was divided into two sub-groups; i) stakeholders defined as 'Directly or indirectly affected parties' (owners, users and real estate agents who can use EPCs for rental, sale, or normal use) and ii) stakeholders responsible for deploying the EPC service (Tool developers, EPC registries etc.) as well as service providers (ESCOs, Engineers, Building designers etc.). The stakeholder requirements have been collected and reported using a template based on the VOLERE methodology in order to be documented with the application of tools such as JIRA as part of T1.4 "System Technical Requirements, Specs & Architecture" for the definition of D^2EPC architecture. The results were summarized based on the findings of the stakeholder questionnaire as well as from the desk research in the following tables:

**Table 1. Summary of User Requirements**

| Users Requirements | Description |
|---|---|
| User-friendliness | The language used on the EPC must be simplified for easier understanding by an ordinary user. |
| Usability | • Information on a building's energy efficiency, comfort and cost savings, will impact the usability of EPCs as well as purchasing and rental decisions.<br>• Valuable guidance for energy renovation measures is needed. |
| Security | • Security surrounding the use of IoT devices, sensors and building management systems.<br>• Protection of sensitive data when sharing energy-related data with third parties.<br>• Exclusion of exact building location, i.e., only postcode, and personal data in a public database. |

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| | |
|---|---|
| Incentives | Incentives for installing smart building technologies for housing companies, real estate agencies and users, especially those who are not owners of the building. |
| Real time information | Users value receiving information on the actual performance of their buildings via a real time platform. |
| Human-centric comfort indicators | Provision of Comfort indicators including thermal conditions, air quality, visual and acoustic comfort. |
| Environmental impact indicators | Provision of environmental-related indicators. |
| Understanding smart building technologies | There is a need to further educate and inform people about the advantages of smart technologies especially for older age groups. |
| Indication of building smartness in the EPC | Introduction of smart readiness indicators (SRI) in EPCs. Users will be informed on the ability of buildings to process information and communication technologies and electronic systems and to adjust building operation to the needs of occupants and the grid. |
| Life Cycle Costing | Monetary indicators of the whole life cycle cost of heating, cooling, lighting and appliances. |
| Geo-location services | Visualization of generated EPCs in a GIS environment, empowering users to perform various types of spatial and attribute queries. |
| Control of building environment | User control of different building aspects especially indoor thermal comfort conditions, indoor air quality and building system's energy efficiency. |
| Visual Identity of EPCs | The use of a combination of graphical and text representation of information. |
| Renovation measures | Information on the estimated return of investments, cost of renovation measures, the impact of renovation options on thermal comfort conditions and information related to the maintenance and operational cost of renovation measures. |
| Renovation financing instruments | Available financing options presented with a brief description, application instructions or contact information, or a combination of any of these representations. |
| Indication of actual Energy class | The preferred frequency of building energy class indication ranges from annually, quarterly, monthly and upon request, with annually being the most preferred option. |

**Table 2. Technical needs and requirements**

| Technical Requirements | Description |
|---|---|
| Dynamic simulation methods | Capability of assessing individual apartments in multi-storey buildings. |

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| | |
|---|---|
| Defined building and system characteristics | • Defined input values for new technologies and systems.<br>• Easy-to-use collection tools that recognize more building characters. |
| Reliability | Complementary energy audit for existing and renovated buildings, and to assess energy performance of non-standard building use. |
| Inclusion of energy consumers | Energy consumption of lighting systems, electrical appliances calculated by use of actual (non-default) values. |
| Inclusion of energy flows | Internal gains calculated by appropriate means, e.g., solar gains. |
| Real time databases | • Dynamic energy consumption databases for operational rating.<br>• Data from utility providers or public authorities. |
| Objectivity | Use of both asset and operational methodologies. |
| Onsite data collection | Reduced delays due to incorrect project documentation. |
| Conducive legislation | Legislative frameworks that advance prior regulations. |
| Transparency | • User-friendly EPC data, consultation with EPC owner and an increased certification cost.<br>• Both building operators and owners informed about savings and efficiency. |
| Database accessibility | Authorization of further processing of user-owned consumption data. |
| Advanced control | Prioritization of quality checks linked to user behaviour and more onsite inspections. |
| Comparability | Through national EPC databases and a pan-European EPC database. |
| Database expansion | • Adaptation of data model to include input data, comfort indicators, statistics of building and technical characteristics, system fuel types, accompanying actual energy consumption and renovation dates and details where applicable.<br>• Categorization by building profile and number of occupants. |
| Connection | Digital links to other databases |
| Responsibility | Polluter pays penalties for both the user and the building designer after verification using a comparison tool to assess real consumption against the EPC. |
| Building monitoring | Through policy that registers energy data per VAT number, region and energy use. |

<u>Related Submitted Deliverables:</u>

- D1.2 Next-generation EPC's user and stakeholder requirements & market needs v1

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### 1.2.3 Business Scenarios and Use Cases

A business case or scenario (BS) captures the need or problem that enables the understanding of the business value. It may also capture the reasoning that facilitates a decision to start a project. A common practise that is followed for properly identifying and defining business scenarios, is that it has to be "SMART":

- **Specific**, by defining what needs to be done in the business.
- **Measurable**, through clear metrics for success.
- **Actionable**, by clearly segmenting the problem, and providing the basis for determining. elements and plans for the solution.
- **Realistic**, in that the problem can be solved within the bounds of physical reality, time and cost constraints.
- **Time-bound**, in that there is a clear statement of when the solution opportunity expires.

In order to further facilitate understanding of the business value offered by D^2EPC, three high-level business groups have been introduced, targeting specific market needs, as identified from Task 1.1 and Task 1.2 activities. Each of the business groups includes two business scenarios and multiple use cases as described below:

**Business Group A: EPC Issuance-** This business group is the main set of scenarios that aims to deliver the core functionalities of the D^2EPC framework. Focusing on two important aspects (asset and operational rating), these scenarios deliver an EU-based platform for issuing energy performance certificate.

- **Business Scenario 1:** Definition of buildings energy class and whether minimum requirements are met for Asset Rating;
- **Business Scenario 2:** Definition of buildings energy class and whether minimum requirements are met for Operational Rating.

**Business Group B: EPC Monitoring, Evaluation and Recommendation-** This group covers another critical business need, and therefore the business value of the D^2EPC platform, which is the capability to monitor and evaluate real-time information from the building. Hence, the performance of the infrastructure after the EPC has been issued can be dynamically re-evaluated and provide for the necessary notifications and recommendations in terms of deviations, improvements, or in general preventive and corrective actions.

- **Business Scenario 3:** Provision of (near) real-time building information, deviations and recommendations.

**Business Group C: Evaluation and Benchmarking of more certificates for policy making/ marketing/ business purposes (GIS included)-** Following the dynamic aspects introduced by D^2EPC, additional added value services are introduced. These are covered within this group of business scenarios, where energy performance is anonymized and is provided as a service in quantity. Other by employing GIS-based representation or statistics that are presented through enriched visual analytics, the two business scenarios introduced, cover added-value services that have been identified and can introduce quite a few potential business models and revenue streams.

- **Business Scenario 4:** Provision of district/area level information for third-party stakeholders.
- **Business Scenario 5:** Provision of dEPC statistics related to materials, assets, etc. for promoting "greener" equipment campaigns.

Related Submitted Deliverables:

- D1.4 D^2EPC Framework Architecture and Specifications v1
- D1.7 D^2EPC Framework Architecture and Specifications v2
- D1.9 D^2EPC Framework Architecture and Specifications v3

## 1.2.4 D^2EPC Framework Architecture & Specifications

D^2EPC framework architecture and specifications have been defined for all components at an initial stage and are reported as part of D1.4 “D^2EPC Framework Architecture and specifications v1” (M7). The activities that took place as part of Task 1.4 acted as the basis for the activities that were conducted as part of WP2, WP3 and WP4.

During the first iteration, the architecture definition process has involved at first a bottom-up process based on technologies and software modules brought by partners that have been considered necessary for the D^2EPC platform (collection and description of all the required technologies and software components). Following input derived from D1.2 and D1.3, an investigation of related projects, platforms and solutions were performed towards identifying core functionalities and components. This process allowed the initiation of a top-down approach towards more clearly defining the functionalities required for meeting the project’s objectives (clarification of each component’s role based on the business scenarios that were developed). Both phases have been complemented during the second and third iteration; on the one side, partners have been requested to provide updated plans for the D^2EPC components and information on how their existing solutions were adapted to be aligned with the advancements of the project. On the other side, the re-evaluation of the Business Scenarios and Technical Use Cases has been carried out towards completing the definition of the functionalities that were developed.

Preliminary user and system requirements come from the results of the other activities of WP1 “Foundations for next generation dynamic EPCs (dEPCs): Identifying challenges, needs and opportunities”. System requirements influence the architectural design process in that they frame the architectural problem and explicitly represent the stakeholders’ needs and desires. **Functional requirements** define what the system, or its components should do, i.e., the specific behaviour between inputs and outputs. **Non-functional requirements** describe criteria that can be used to judge the functions of a system, also known as quality attributes. Non-functional requirements might be further subcategorised to: Look&Feel, Usability, Accessibility, Performance, Accuracy, Scalability, Stability, Reliability, Interoperability, Security, Privacy, and Maintenance. Both Functional and Non-Functional requirements need to be carefully selected to ensure that they are clear and meaningful in the context of the outcome envisioned for meeting the project objectives, in accordance with the perspective of all technical partners. Requirements should be testable, consistent, unambiguous and rational; and should always keep the various actors in mind.

To enable easy logging and tracking of functional and non-functional requirements and business cases from definition to actual implementation, we opted for a specialised online platform – JIRA. CERTH has created a dedicated JIRA environment that will help partners create, assign, define dependencies and track business and user requirements. The template provided by the online platform was also linked to the Volere-enhanced template used in Task 1.2.

**Table 3. Volere –based documentation template**

| **Obligatory fields** | |
|---|---|
| **Requirement Type** | Functional: Something the system should do<br>Non-functional: How the system works (several sub-types are pre-defined) |
| **Summary** | Clear and brief one-sentence description of the requirement |

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| | |
|---|---|
| **Rationale** | Why is the requirement important? What contributions does it make to the product's purpose? |
| **Originator/ Source** | Where did this requirement originate? E.g., the DoA, document XYZ, a workshop, the partner who raised this requirement etc. |
| **Fit Criterion** | The Fit Criterion must be measurable for testing/verification that the requirement is fulfilled |
| **Priority** | Priority defines the relevance of the requirement in relation to the other requirements |
| **Custom Labels - Linked Use Cases** | Custom labels are mainly intended for filtering purposes. Each requirement must have at least one label defining which use case(s) it is part of, e.g., BS3-UC3.1 |
| **Component (s)** | To which component(s) does this requirement belong?<br>Based on this association, the responsible assignee will be defined (after the requirement has passed Quality Check) - Please check the architecture for the D^2EPC Components |
| **Optional fields** | |
| **Description** | Extended text if needed presenting more information |
| **Conflicts** | Indicate if the requirement conflicts with other requirements |
| **Issue Links** | Indicate if the requirement is linked to other requirements, e.g., if one requirement is a precondition for another requirement or requirements |

Three main viewpoints have been considered for adequately describing all necessary aspects of the overall system architecture:

- **Functional View:** Describes the system's functional components and their responsibilities, interfaces, and interactions with other components. These components are represented as functional elements based on their responsibilities and their primary interactions with other elements. A functional model does not rely on operations that may occur during runtime since it can only express time-free and sequential execution semantics. This is usually the most important viewpoint, as it reflects the quality properties of the system and influences the performance, maintainability and extensibility of the system;
- **Deployment View**: Describes the physical environment into which the system is deployed and the dependencies the system has on its environment. Specifically, it captures (i) the hardware/software environment of the system (e.g., general-purpose hardware to execute the main functional elements of the system, storage hardware to support databases, hardware that allows users to access the system, network elements required to meet certain quality properties such as firewalls for security, etc.); (ii) the associated technical environment requirements (e.g. the type of operating system that run on the devices) and (iii) a mapping of the components to the runtime environment. The technical infrastructure used to execute the system is described by infrastructure elements like geographical locations, environments, computers, processors, channels and net topologies;
- **Information View:** Describes the way that the architecture stores, manages, and distributes information (information flow). Specifically, the information view documents information management, including storage and distribution within the system. Similarly, to a high-level ontology, the information view aims to provide a unique and consistent interpretation of the

lifecycles of the information objects handled by the infrastructure. The objective of this analysis is to answer the big questions around structure, content, ownership, and data migration.

The D^2EPC components are designed, implemented and integrated following a service-oriented architecture, exposing services at component and platform levels, towards allowing robust communication with each other and external entities, across different platforms, programming languages, execution environments, and development methods. Upon the finalisation of the D^2EPC architecture in the second reporting period, in total 32 functional and 10 nonfunctional requirements were defined and they were satisfied fully by the final architectural design reported in D1.9.

A brief explanation of the D^2EPC architecture layers follows:

- The **Infrastructure or Physical Layer** consists of one of the core layers for dynamic EPC, especially for the operational rating. Within this layer, all devices, sensors, actuators, and in general Internet of Things, and systems (i.e., Building Management System – BMS, Energy Management System – EMS, or even Supervisory control and data acquisition - SCADA) are included for collecting the necessary building information for all upper layers.
- The **Interoperability Layer** consists of one main D^2EPC component, i.e., *Information Management Layer*. This component is responsible for communicating with the building assets from the physical layer, retrieving the necessary information, translating it to a commonly accepted format and streaming it to the D^2EPC Repository through the Energy Performance & Credibility component to be further utilised in other D^2EPC layers.
- The **Service/Processing Layer** consists of most D^2EPC components and sub-components responsible for delivering all the main functionalities envisioned:
    - *BIM-based Digital Twin,*
    - *D^2EPC Calculation Engine*
        - *Building Performance Module*
        - *Asset Rating Module*
        - *Operational Rating module*
    - *Added-value Service Suite for D^2EPC*
        - *Roadmapping Tool for Performance Upgrade*
        - *AI-driven Performance Forecasts*
        - *Performance Alerts & Notifications*
    - *Extended dEPCs Applications Toolkit*
        - *Building Energy Performance Benchmarking*
        - *Energy Performance and Credibility*
- The **Representation Layer** constitutes the layer that is offered for interaction with the end-users (engineers, building owners, registries, etc.) or third-party platforms / tools (i.e., b-logbooks, BIM design tools, etc.). Within this layer, three D^2EPC components are included, namely:
    - *D^2EPC Web Platform*
    - *D^2EPC Web GIS, and*
    - *Credibility UI.*

The D^2EPC Web Platform provides redirected access to the two other components, with a common (D^2EPC Web GIS) or separate (Credibility UI) user authentication service. A more efficient and dynamic interaction with end-users is considered through the mobile-friendliness feature of the developed components.

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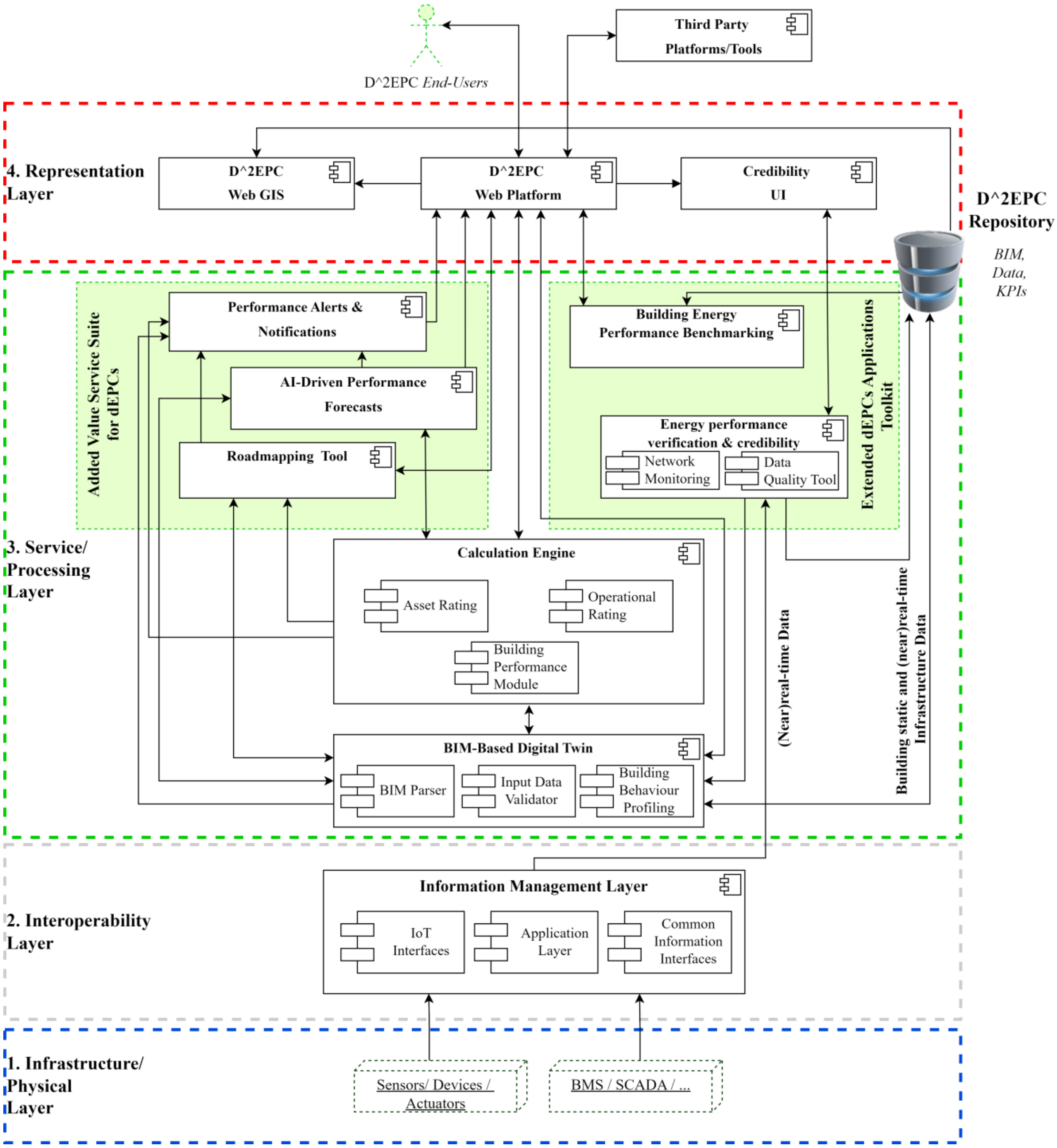


**Figure 1. D^2EPC Layered Conceptual Architecture**

All the above components and sub-components, along with their functionalities and high-level information exchange are explained in detail in the respective deliverables of Task 1.4.

Related Submitted Deliverables:

- D1.4 D^2EPC Framework Architecture and Specifications v1
- D1.7 D^2EPC Framework Architecture and Specifications v2
- D1.9 D^2EPC Framework Architecture and Specifications v3

### 1.2.5 D^2EPC IoT Framework

Task 3.1 "IoT and BMS interfaces to extract energy related data" was the dedicated task for the definition of the D^2EPC IoT Framework. The first step was to extract the metering and sensing requirements determined by the works conducted under WP2 (for the project's novel set of indicators) as well as under the working group (WG2) that was established within the project for the definition of the operational rating. Following the WG2 findings, a set of requirements has emerged related to the building typologies, submetering and weather corrections for the calculation of the building's operational rating. The outcome of WP2 and WG2 delivered the metrics expected to be measured in the D^2EPC pilots along with specific characteristics (i.e., spatial granularity, measuring frequency, format and corresponding building typology).

Beyond the drafting of dynamic data requirements, extended research has taken place in D^2EPC pilots to identify the already existing IoT infrastructure -through dedicated audit surveys. The focus was gathered on identifying the already-available information and the optimal way (i.e., data models and communication type) to acquire the relevant data from each of the demonstration cases in close collaboration with the pilot partners (CERTH, FRC, CLEOPA, SEC), under the works of WP5.

The main component materializing the D^2EPC IoT Framework is the Information Management Layer, a cloud-based component provided by Hypertech responsible for administrating the sensing and metering datasets extracted from the Wireless Sensor Network deployed at the pilot premises. The IML is equipped with the appropriate software modules that allow for gathering, pre-processing and forwarding energy consumption and ambient conditions data. It also includes a network monitoring tool which significantly facilitates the end-user in locating device miscommunications and malfunctions.
The IML component is therefore designed and developed in such a manner as to address various challenges related to big data directly linked to the IoT domain. More specifically:

- **Volumes of Data:** IML sets its grounds on cloud computing, enabling on-demand availability of computer system resources.
- **Security & Privacy:** Communication between the IML and other components is realized through the HTTPS protocol maximizing the security of data exchange. All data collected is anonymized following the EU GDPR (GDPR.EU n.d.), and to ensure maximum privacy, the access to data is strictly limited.
- **Transmission Speed:** The solution is designed based on modern, optimized, and open-source software components that minimize latency.
- **Selective Data Acquisition:** The recording strategy of data is event-based; hence, a new value is only registered if it fluctuates compared to the latest update. This type of filtering minimizes the overall storage load without significant loss of information. Furthermore, it reduces the number of messages sent, hence the number of operations, which ultimately leads to higher speed and lower power consumption.
- **Scalability:** The IML permits the registration of multiple pilot premises and prosumers to maintain high standards in terms of effective operation.
- **Data Extraction:** All datasets within the IML are transformed into a common structured format (JSON), facilitating the data extraction and analysis.

The role of the D^2EPC IML is not limited to simply collecting information coming from the Wireless Sensor Network and forwarding it to the D^2EPC repository. The component implements well-known and established algorithms responsible for cleansing and normalizing the various datasets related to energy consumption and ambient conditions. Furthermore, it is equipped with specialized tools capable of displaying and monitoring the respective datasets. The overall solution provides a high level of:

- **Data Quality:** The processing algorithms eliminate the inconsistencies and discontinuities in the vast sensorial and metering datasets and ensure that high-quality information is forwarded to the data-driven components.
- **Data Visualization & Monitoring:** The respective tools are optimized to deliver quality visualizations in a timely manner facilitating the user to identify patterns and monitor events within the collected datasets. In the context of D^2EPC, the visualization tool is not foreseen to be utilized. However, it will be offered to the pilot partners to facilitate the maintenance of the pilot sight equipment.

Within D^2EPC, the IML component was adjusted to enable the interfacing with the pilots' Web platforms which collect and stream the captured measurements. Different communication methods (i.e., RESTful or asynchronous communication) have been determined per case according to the corresponding data model. Furthermore, the IML was enhanced with a brand-new data quality component (i.e., EPVC), taking a step further in the validity of collected information.

In Table 4 the finalized list of proposed IoT equipment is presented, indicating the IoT devices that support pilots of different operation and spatial characteristics. Detailed specifications per device are included in Annex D of D3.4. Starting from consumption monitoring, the smart meters cover several installation topologies (din rails, clamp meters, plugs), power supply types (single-phase, 3-phase) and current amplitudes. Concerning indoor ambient sensing, the multitude of dynamic metrics requirements emerging from WP2 had to be satisfied in a cost-efficient and non-intrusive manner. The IoT equipment proposed corresponds to multisensing solutions that combine more than one sensor enclosed in a compact and discreet device. Those devices significantly facilitate the installation procedure and ensure wider end-user acceptance.  Lastly, regarding the gas concentrations to be measured within the project, an extensive market research was performed on the available off-the-shelf devices, addressing air quality. It was concluded that such measurements entail the need for multiple installations of distinct smart devices that may end up being highly intrusive with the prohibitive cost which surpasses the scope of D^2EPC. The IoT devices selected to capture indoor air quality manage to satisfy the most relevant and widely applicable requirements in line with the project restrictions and within the budget reserved.

**Table 4. Proposed list of IoT devices**

| Equipment Type | Installation Topology | Available Equipment |
|---|---|---|
| **Consumption Monitoring Devices** | DIN Rail Equipment | Z-Wave Qubino<br>Z-Wave Qubino 3-Phase |
| | Clamp Meters | Z-Wave Plus Aeotec Clamp Power Meter – 3 - Clamps (up to 200A)<br>Shelly EM 50A Clamp |
| | Smart Plugs | Qubino Smart Plug 16A |
| **Indoor ambient sensing** | Occupancy, Temperature, Humidity, Illuminance monitoring | Aeon Labs Multisensor 6 - Z-Wave Plus |
| **Indoor Air Quality** | $CO_2$, $PM_{2.5}$, VOC | MCO HOME A8-9 |

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Related Submitted Deliverables:

- D3.1 D^2EPC IoT platform &Interfaces v1
- D3.4 D^2EPC IoT platform &Interfaces v2

## 1.2.6 D^2EPC Asset rating methodology

In order to enable a wide EU deployment, the documentation of the asset rating calculation methodology and the development of the relevant tool according to existing European standards has been identified as one of the project's initial priorities, including the definition and collection of all the parameters, coefficients and data from EU Member States that will be used as inputs for the asset rating calculation. Special emphasis has been given to mapping the methodology input requirements with the existing building documentation in BIM modelling and parsing them into the calculation tool.

The European EN ISO 52000[12] series of standards laid the foundations for the development of the asset rating calculation module. EN ISO 52000 provides only the main set of equations for the calculation journey from the building's energy demand, to its energy consumption, primary energy and the resulting EPC rating. Figure 2 presents an overview of the calculations for the extraction of the building's EPC rating.

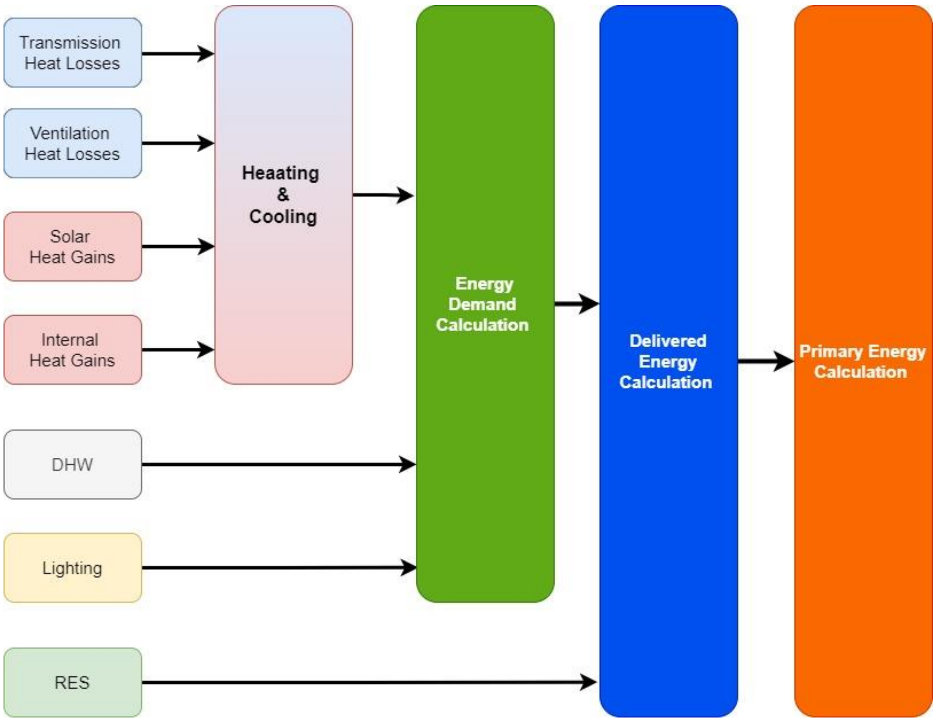


**Figure 2: Asset Rating Calculation Overview**

Despite the well-documented stepwise procedure, the standard doesn't provide the necessary documentation for the development of all the datasets that will support the calculation. More specifically, the missing information is related to the description of the Reference Building, climate and energy carrier data, as well as the parameters that describe the operation of a building. Figure 3 presents the role of the four sets of parameters in the overall calculation process. The referred parameters differ per country (or region) thus a systematic documentation procedure has been

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

followed, leading to the development of dedicated data-sets in a format that will facilitate the development of an EU-based Asset Rating calculation tool.

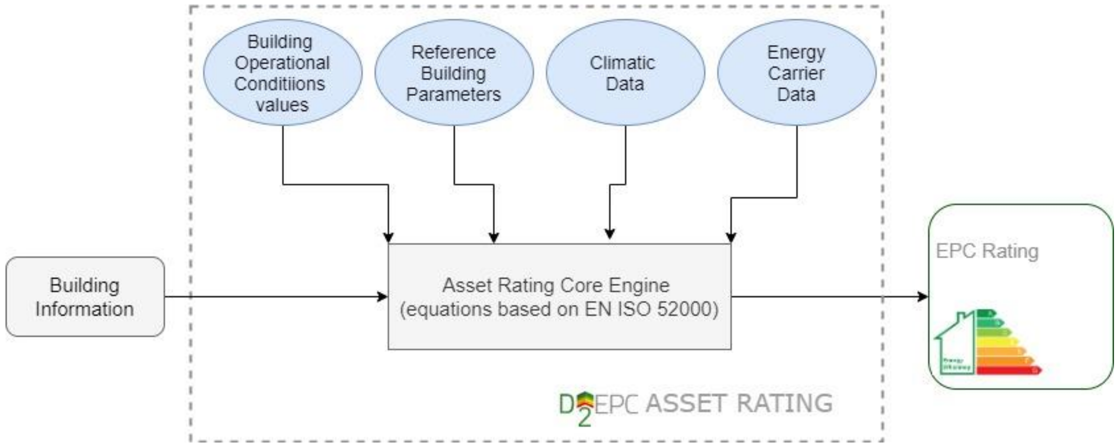


**Figure 3: D^2EPC AR dataset requirements**

The documentation process started with the delivery of a dedicated questionnaire to the D^2EPC partners for identifying and collecting the missing information from the national EPC frameworks of the involved countries (Cyprus, Germany, Greece, Lithuania, Netherlands, and Spain). The collected answers revealed an in-depth view of the backbone of the national certification schemes. On a building level, the questionnaire facilitated the collection of information related to the definition of the reference building in each country as well as the operational conditions that describe the various types of thermal zones. Moreover, information related to the energy carriers (primary energy factor, $CO_2$ emission factors, cost) has also been collected with the help of the questionnaire. Overall, the collected answers presented a high discrepancy in the availability of the requested information, reflecting the differences between the various national certification schemes.

In the case of climatic data collection, a hybrid approach has been followed to ensure a more expandable result. Each country's partition into climatic zones has been adopted from the national technical directives. Especially, the countries with smaller acreage, which aren't divided into thermal zones (Lithuania and the Netherlands), were considered one climatic zone. The extraction of the monthly average climatic values for each climatic zone has been conducted with the use of European climatic databases existing in the PVGIS tool. With this approach, a complete and uniform climatic database with the monthly average climatic values of each zone has been developed, having minimum variations between the D^2EPC database and the respective official national values. D4.5 and D5.6 analyse in detail the above issues and present the collected datasets.

The applied methodology has been tested on the six pilot buildings and compared with the results obtained from the respective national tools. In certain case studies, the results showed a close correlation, while in others, there was a noticeable variance in the calculated values, as outlined in D5.8. A larger sample of buildings would facilitate both a more thorough benchmarking of the methodology's outcomes, as well as the refinement of the calculations to align with the specific requirements of EU Member States.

<u>Related Submitted Deliverables:</u>

- D4.1 Building Performance Module v1
- D4.5 Building Performance Module v2
- D5.1 D^2EPC Manual v1
- D5.6 D^2EPC Manual v2

### 1.2.7 D^2EPC Operational rating methodology

The D^2EPC project plays a critical role in the advancement of building energy performance assessment methodologies. Its primary focus is on the operational energy rating of buildings, which calculates energy performance based on actual energy consumption. The project recognizes the essential role of Building Energy Performance Simulation (BEPS) tools in EPC calculation, primarily for determining buildings' heating and cooling loads.

In this regard, the D^2EPC project employed BEPS tools to derive energy performance calculations grounded on the actual energy consumption of buildings, which is referred to as the operational rating. This rating methodology's significance was underscored by advocating its inclusion in dynamic EPCs. It serves as an invaluable tool for relevant stakeholders, practicing engineers, and EPC assessors responsible for implementing the principles of D^2EPC in building certification. The methodology developed within the D^2EPC project adhered to a unified approach applicable to buildings across Europe, further standardizing the assessment process.

The adoption of the operational rating methodology is a forward-thinking move, as it shifts the focus from theoretical estimates to actual energy consumption data. The operational rating process accounts for real-world factors such as building usage, climatic conditions, and building systems' actual performance, providing a more accurate representation of a building's energy performance. The inclusion of actual energy consumption data enables targeted interventions to improve building energy performance, enhancing both energy efficiency and building occupants' comfort.

The D^2EPC project's methodology for operational energy performance ratings was employed in the context of the next-generation D^2EPC tool, which leverages a suite of cutting-edge digital design and monitoring tools and services. These advanced tools enhance the accuracy of energy performance assessments, providing comprehensive insights into building energy performance. As the construction industry embraces digital transformation, the application of such tools becomes even more crucial in improving building energy performance and achieving sustainability goals.

Furthering the project's contribution to building energy performance assessment, the D^2EPC project aimed to enhance the user-friendliness and effectiveness of next-generation EPCs. The project introduced multiple indicators related to building smartness, environmental performance, financial performance, and human comfort aspects. These indicators address various facets of building energy performance, providing a holistic perspective on building energy efficiency and sustainability.

The D^2EPC project presented a series of indicators that address smart readiness, thermal comfort, and LCA dimensions, incorporating monetary and cost-optimum Key Performance Indicators (KPIs). These indicators encompass the Smart Readiness Indicator (SRI), which assesses a building's readiness for smart technologies, Life Cycle Assessment (LCA) for environmental performance, Life Cycle Costing (LCC) for financial performance, and human comfort aspects.

The inclusion of these indicators further augments the utility of EPCs, providing stakeholders with a comprehensive understanding of building energy performance and enabling targeted interventions to improve energy efficiency. The indicators' inclusion reflects the project's commitment to advancing building energy performance assessment methodologies, benefiting the construction industry, building occupants, and the broader society.

The D^2EPC project's emphasis on actual energy consumption, coupled with the introduction of multiple indicators, represents a significant advancement in building energy performance assessment methodologies. By embracing a more comprehensive and data-driven approach, the project contributes to enhancing building energy performance and achieving sustainability goals. Doing so helps address the growing global concern about energy consumption and environmental impacts, paving the way for a more sustainable future.

Simplified energy indicators, such as total energy over area per annum, cannot adequately describe the energy performance of a building. Thus, the D^2EPC energy indicators covered 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 were based on the data retrieved by the building's regular measurements, where these were available. Implementing appropriate energy and environmental building evaluation techniques on a wide scale was required to stimulate market demand for sustainable practices in the built environment.

The operational rating scheme is used for the calculation, and a complete list of 25 data results is obtained from 4 categories. 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.

**Table 5. Energy Indicators**

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

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| | | | |
|---|---|---|---|
| Cooling Consumption | Cooling consumption per energy carrier/Occupancy | This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the total number of occupants | kWh/occupants |
| | Cooling consumption per energy carrier/Occupancy-Hours | This indicator shows the ratio of the cooling power consumption per energy carrier of the building in kWh over the total number of hours that occupants spend in the building | kWh/h*occupants |
| | Cooling consumption per energy carrier/Area | This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total surface area of the building | kWh/$m^2$ |
| | Cooling consumption per energy carrier/Volume | This indicator displays the ratio of the cooling power consumption per energy carrier of the building in kWh over the total volume of the building | kWh/$m^3$ |
| Weather Normalization | Weather-Normalized Heating & Cooling Energy Consumption [13] | A positive number means usage was added. It is good to have a Negative Number. When compared to the Weather Normalized Usage from the Baseline Year, it means that usage was avoided. A Positive Number, on the other hand, is unfavourable. It signifies that when compared to the Weather Normalized Usage from the Baseline Year, usage increased. | --- |
| Lighting Consumption | Lighting/Occupancy | This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of occupants | kWh/occupants |
| | Lighting/Occupancy-Hours | This indicator shows the ratio of the total lighting power consumption of the building in kWh over the total number of hours that occupants spend in the building | kWh/h*occupants |
| | Lighting/Area | This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total surface area of the building | kWh/$m^2$ |
| | Lighting/Volume | This indicator displays the ratio of the total lighting power consumption of the building in kWh over the total volume of the building | kWh/$m^3$ |
| Electri cal Applia | Electrical Appliances Energy Consumption /Occupancy | This indicator shows the ratio of the total energy consumption of the electrical appliances in the building in | kWh/occupants |

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

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

It is noted that the operational assessment of heating and cooling consumption, as well as domestic hot water (DHW) consumption, are conducted per energy carrier. In those cases where 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.

According to project D^2EPC, the main challenges that Member States will have to address in the process of creating and establishing a common operational rating scheme for buildings are mainly the following:

- The agreement on a joint concept for the reference building of an operational rating.
- The definition of a joint normalization approach for the various parameters affecting the actual performance of the building, mainly the climatic-related parameters.
- The determination of the performance indicators which will be calculated with the operational rating scheme.
- The minimum requirements in relation to the equipment and the quality of the measurement.

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In the context of T7.3, the initiative to develop a new standard was taken. According to this standardized approach – CEN/TC 371 WG5 – a robust, methodologically sound framework was established to comprehensively address the assessment of operational energy performance in buildings. This standard delineates the prerequisites and methodologies governing the evaluation of operational energy performance within the domain of building structures. Its primary objective is to systematize the procedures for calculating and disclosing the Operational Rating of buildings, a metric designed to portray energy efficiency in real-world operational scenarios. Comprehensive in scope, this standard encompasses a structured framework for operational energy assessment. It encompasses the overarching objectives of the assessment process, strategies for data acquisition, rigorous data analysis and validation protocols, calculation procedures, and the stipulated requisites for comprehensive reporting.

Of paramount importance, this document offers invaluable guidance pertaining to the types of data indispensable for this assessment, specifying their respective origins. These encompass a wide spectrum, including building-specific information, patterns of occupancy, energy consumption records, meteorological data, and indoor environmental quality data. Moreover, the standard expounds upon the methods and techniques imperative for measurement and monitoring, with explicit emphasis on quality assurance and the upkeep of monitoring equipment.

Furthermore, the standard articulates a repository of data analysis techniques, including comprehensive coverage of validation processes, uncertainty analysis, and sensitivity analysis. It introduces calculation models, algorithms, energy performance indicators, and correction factors that account for various factors, such as occupancy rates, climatic conditions, and service levels. A pivotal component of this standard encompasses the structuring of the assessment report and delineation of key discoveries and recommendations that merit inclusion.

It is imperative to note that the intended audience for this standard includes building owners, facility managers, energy auditors, and all other stakeholders actively engaged in the assessment of energy performance in buildings. Notably, this standard is universally applicable, encompassing a spectrum of building typologies, from residential and commercial to industrial..

Related Submitted Deliverables:

- D2.3 Life Cycle Indicators for next generation EPCs v1
- D2.8 Life Cycle Indicators for next generation EPCs v2
- D4.1 Building Performance Module v1
- D4.5 Building Performance Module v2
- D5.1 D^2EPC Manual v1
- D5.6 D^2EPC Manual v2
- D7.12 Report on the contribution to standardization v2

### 1.2.8 D^2EPC Set of additional Indicators

D^2EPC aims to enhance the user-friendliness and the effectiveness of the next generation EPCs, with the addition of multiple indicators, related to the smartness of the buildings (SRI), its environmental (LCA) and financial (LCC) performance, as well as to human comfort aspects. Under WP2, straightforward efforts are dedicated to the analysis and definition of a set of indicators including SRI, LCA and economic indicators and taking into account user-driven models (thermal/vision comfort, occupancy) and results are introduced in the following sections.

#### 1.2.8.1 Smart Readiness Indicators (SRIs)

The main target of D^2EPC project was to provide an enriched certificate that goes beyond energy considerations and includes aspects related to the sustainability of building units. Smart Readiness Indicator (SRI) is one of the various novel indicators D^2EPC was incorporated towards this goal. Task 2.1 was responsible to establish the framework and scope of SRIs integration in the dynamic EPC scheme. To achieve this, Task 2.1 analysed the possibility of extracting the SRI indicators from the following sources: (*a) Information included in EPC asset rating, in accordance with the European EN standards series 52000 and (b) Building Information models (BIM).* Given the fact that D^2EPC is a BIM based solution, the vendor neutral IFC schema developed by Building Smart International was utilized, in order to define and describe BIM models. This schema allows for the seamless sharing of information across various software platforms. Particularly, the analysis focused on the alignment of the individual SRI functionalities and the IFC attributes. The first version of the deliverable *D2.1 SRI indicators for next generation EPCs v1* provided a detailed analysis of the integration of SRI certification in Next-generation EPCs. The following information was presented as part of the analysis: **(a) Detailed Overview of the Current Status of SRI:** Identification of the level of development, methodology and related procedures needed for the issuance of SRI certification; **(b) Identification and extraction of SRI data based on IFC & EPC:** Definition of a set of SRIs which can be extracted based on the BACS related BIM input data and EPC according to EN 52000. **(c) Framework analysis of SRIs integration in the dynamic EPC**: Extraction of SRI-based data on BACS from IFC (Industry Foundation Classes) schema. **(d) Development of ''minimum modelling requirements'' for BIM models:** Development of the required procedures which defined guidelines for the realization of SRI certification. The analysis conducted under this Task, concluded with the following points:

- The current status of data for EPC assessment does not allow the extraction of the SRI. Some screening information for the SRI may be extracted, however, this information is not sufficient to extract the SRI indicator of the building. The information which can be extracted from EPC is namely:
    - Heating type, emission type;
    - Cooling type, emission type;
    - Ventilation type;
    - Domestic hot water system type;
    - Presence of renewable energy;
- A significant number of SRI functionality levels are currently not addressed in IFC-based documents. This limitation poses a major challenge in developing a comprehensive approach for extracting the SRI indicator from an IFC file. It is currently a fact that complete and comprehensive BACS modelling documentation can only be offered by hardware vendors for their specific products, making the process highly dependent when it comes to modify, modelling and management of BACS systems. Ideally, this information should be able to be presented in a vendor-free way, enabling building owners/facility managers to use third-party tools or technologies. Although the open BIM exchange format IFC, already features the Building Automation domain for the definition of building automation control functions, only specific functions within the BACS can be defined. The information supported by the current BIM formats is mainly limited to the field level supporting the definition of devices and wiring relations, disregarding the logical and operational aspects, such as control loops, bindings, or configuration management. According to the analysis presented in D2.1, the ''field level'' which is the lower part of the hierarchy of BACS, corresponds mostly to the ''default'' or Level 0 of the functionality levels in the SRI domains. Since some of the field-level entities are supported in IFC, the lower functionality levels of SRI can be adequately defined. However, when more complex automation and control functions are present within the ''Automation'' and ''Management'' levels (usually represented by Level 3 or Level 4 of SRI functionality levels),

the definition is incomplete or even completely unsupported. The SRI functionality levels assessment in IFC schema are shown in Table 6:

**Table 6 SRI functionality levels assessment in IFC schema**

| Domain | Complete | Partial | Not supported | Total functionalities |
|---|---|---|---|---|
| **Lighting** | 6 | 3 | 0 | 9 |
| **EV Charging** | 0 | 0 | 11 | 11 |
| **DHW** | 3 | 9 | 10 | 22 |
| **Dynamic Envelope** | 3 | 6 | 10 | 19 |
| **Electricity** | 4 | 3 | 21 | 28 |
| **Heating** | 7 | 14 | 21 | 42 |
| **Cooling** | 8 | 10 | 6 | 24 |
| **Ventilation** | 4 | 12 | 7 | 23 |

Concluding this analysis, IFC may be used for the definition of building systems required by the screening information required by the SRI. However, this information is not sufficient for the calculation of the SRI, and may be used only for activating the triage process, where services are to be included or excluded from the calculation engine. The information extraction can be realized within the BIM parser, by defining a minimum modelling requirement(s) for each of the screening questions. The minimum modelling requirements concern IFC entities that should be defined in the BIM model during its development. The features which can be defined in IFC for the purpose of the SRI screening questions are the following:

- **Heating:** Presence of Heating system, Emission Type, Production Type.
- **Domestic Hot Water (DHW):** Presence of Domestic Hot water, Production Type, Solar Collector.
- **Cooling:** Presence of cooling system, Emission Type.
- **Controlled Ventilation**: Presence of controlled ventilation system, System type, Heat Recovery
- **Dynamic Envelope**: Presence of dynamic Envelope system.
- **Electricity: Renewables & Storage:** Presence of Renewables, On-site renewable electricity generation, Storage of on-site generated renewable electricity, CHP (Combined Heat and Power).
- **Electric Vehicle Charging**: Not supported.

The analysis concluded that IFC schema may be used for the definition of building systems required by the screening information required by the SRI. However, this information is not sufficient for the calculation of the SRI, and may be used only for activating the triage process. The information extraction can be realized within the BIM parser, by defining a ‘’minimum modelling requirements’’ for each of the screening questions. The minimum modelling requirements concerning IFC entities that should be defined in the BIM model during its development were defined in the deliverable.

The second version of the deliverable *D2.6 SRI indicators for next generation EPCs v2* aimed to conclude the analysis of SRI integration in dEPCs by presenting the final D^2EPC SRI subcomponent based on the findings of D2.1. The SRI subcomponent is a part of the Building Performance Module which offers a comprehensive calculation suite that enables the assessment of various indicators in addition to the building's smart-readiness, such as indoor environment, environmental performance, and financial performance.

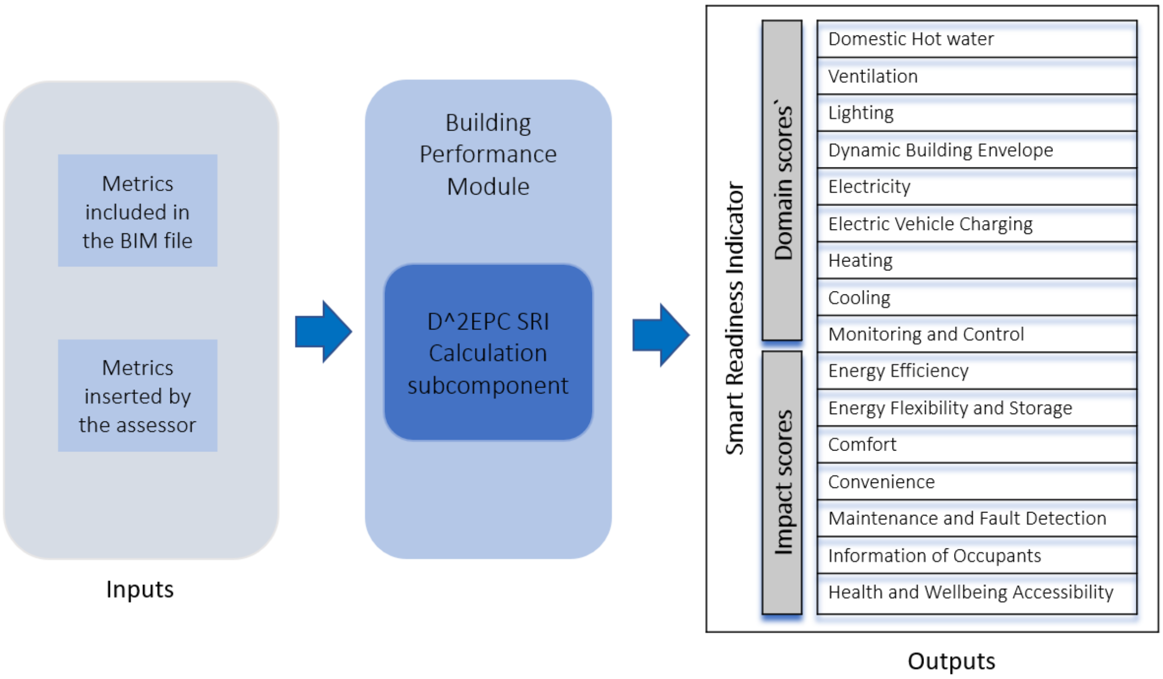


**Figure 4 D^2EPC SRI Calculation scheme**

Related Submitted Deliverables:

D2.1 SRI indicators for next generation EPCs v1

D2.6 SRI indicators for next generation EPCs v2

### 1.2.8.2 Human Comfort and Wellbeing Indicators

T2.1 was responsible for the definition of the Human Comfort and Well-Being (HC&W) indicators to be integrated in the next generation/dynamic EPC. Various European and International standards and frameworks have been considered during the process in order to extract recognised boundaries of building operation for each of the examined metrics and the D^2EPC HC&W KPI Framework has been concluded on the basis of three Indoor Environmental Quality (IEQ) pillars; the Thermal comfort, the Visual comfort and the Indoor Air Quality. Furthermore, for a more user-specific assessment of the indoor conditions, data-driven techniques on preceding data have been utilised towards analysing the occupant's preferences and delivering personalised boundaries (for spaces where it is deemed applicable). The outcome corresponded to a hybrid methodology characterised as part-static -in cases when the boundaries have been extracted from the literature- and part-dynamic -in cases when the boundaries have been extracted via data-driven processes.

The outcome of the analysis of the thermal comfort indicators resulted in five indicators presented below:

**Table 7. Thermal Comfort Indicators**

| Indicator Name | Indicator Description | Units |
|---|---|---|

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

The outcome of the analysis of the visual comfort indicators resulted in four indicators presented below:

**Table 8. Visual Comfort Indicators**

| Indicator Name | Indicator Description | Units |
|---|---|---|
| Deviation from the set | Summation of all the daylight hours of a regularly occupied space during which the illuminance was lower than the profiling engine bottom boundary, compared to the total hours of the period of interest. The | % |

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

For the D^2EPC project, the list of Indoor air quality (IAQ) indicators was created according to Level(s) and parameters (metrics) as presented below:

**Table 9. IAQ KPIs according to Level(s)**

| Indicator | Indicator Description | Units |
|---|---|---|
| Ventilation rate (airflow) | The ventilation rate is the magnitude of outdoor airflow to a room or building through the ventilation system or device. | $L/s/m^2$ |
| Total Volatile Organic Compounds (TVOCs) | TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air. | $\mu g/m^3$ |
| Benzene | Benzene concentration in the indoor air. | $\mu g/m^3$ |
| $CO_2$ indoors | CO2 concentration in the indoor air. | ppm |
| Formaldehyde | Formaldehyde concentration in the indoor air. | $\mu g/m^3$ |
| Radon | Radon concentration in the indoor air. | $Bq/m^3$ |
| Particulate matter <2,5 μm (PM 2.5) | Particles' that are 2,5 μm in diameter or smaller concentration in the indoor air. According to EN 16890-1, a particulate matter passes through a size-selective inlet with a 50% efficiency cut-off at 2.5μm aerodynamic diameter. | $\mu g/m^3$ |

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| | | |
|---|---|---|
| Particulate matter <10 µm<br>(PM 10) | Particles' that are 10 µm in diameter or smaller concentration in the indoor air.<br>According to EN 16890-1, a particulate matter passes through a size-selective inlet with a 50% efficiency cut-off at 10µm aerodynamic diameter. | µg/m$^3$ |

The air quality KPIs are formed on the following limits/categories:

- The ventilation rate categories (for diluting all emissions from the building) are presented according to CEN/TR 16798-1:2019. The ventilation rate can be estimated on a daily basis at specific timestamps and then averaged for the period of interest. The estimation of the ventilation rate is challenging due to several assumptions (e.g., no other $CO_2$ sources other than occupants). It is further influenced by many factors which may generate even worse results. In mechanically ventilated buildings, actual ventilation rates may be acquired by sensors of the ventilation system.
- The limits for total volatile organic compounds (TVOC) (the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air) are given according to EN 16798-1, 2019.
- The limits for Benzene concentration indoors are given according to EN 16798-1.
- The $CO_2$ concentration categories are given according to CEN/TR 16798-1/2:2019. CEN/TR 16798 defines four distinct categories for the differences between indoor/outdoor $CO_2$ concentrations.
- The limits of formaldehyde concentration in the indoor air are given according to EN 16798-1.
- The limits of radon are given according to WHO.
- The limits of PM 2.5 and PM 10 are given according to EN 16798-1.

Measuring and presenting data for all identified KPIs would give a comprehensive view of the current IAQ in the building and potential for improvement. However, within the D^2EPC project, strong focus is placed on three IAQ KPIs to be selected for the representation of the user's well-being point of view, in accordance with the findings of T3.1 which shed light on the measurability of I.A.Q. performance metrics:

- $CO_2$ indoors,
- TVOC (the sum of the concentrations of the identified and unidentified volatile organic compounds in the indoor air),
- PM 2.5 (particulate matter <2,5 µm).

The remaining indicators are considered as complementary.

Detailed description, units, calculation methodologies, relevant metrics, spatial granularities and measuring intervals of all indicators are presented in ANNEX A, B & C of the final deliverable D2.7.

Overall, a total of 17 indicators have been defined, five for Thermal Comfort, four for Visual Comfort and eight for the IAQ. The latter has been segmented into three 'main' and five 'complementary' IAQ indicators due to the complexity introduced into the overall pilot data acquisition by the significant amount of air quality metrics expected to be measured.

After the definition of human-centric indicators, a long validation period has taken place testing the KPIs into realistic scenarios with data originating from Hypertech's testbed and the project's demonstration cases. In addition, dedicated workshops have taken place with the participation of relevant stakeholders to provide feedback on the D^2EPC HC&W Framework. A specialised calculation engine has also been integrated into the D^2EPC Building Performance Module, a component responsible for delivering to the end-user results revolving around the D^2EPC calculated quantities.

Related Submitted Deliverables:

- D2.2 Human-Centric indicators and user profiles for next generation EPCs v1
- D2.7 Human-Centric indicators and user profiles for next generation EPCs v2

#### 1.2.8.3 LCA Indicators

Task 2.3, titled "Energy Performance & Life Cycle Assessment (LCA) Indicators Analysis for Energy Performance Certificates (EPCs)," delivered the framework for the integration of LCA indicators into the D^2EPC concept. The objective of this task was to generate environmental and energy indicators for the forthcoming generation of EPCs, with the goal of enhancing the user-friendliness of EPCs and increasing user awareness by providing more comprehensive information.

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 D^2EPC 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 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.

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 5Figure 5. 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.

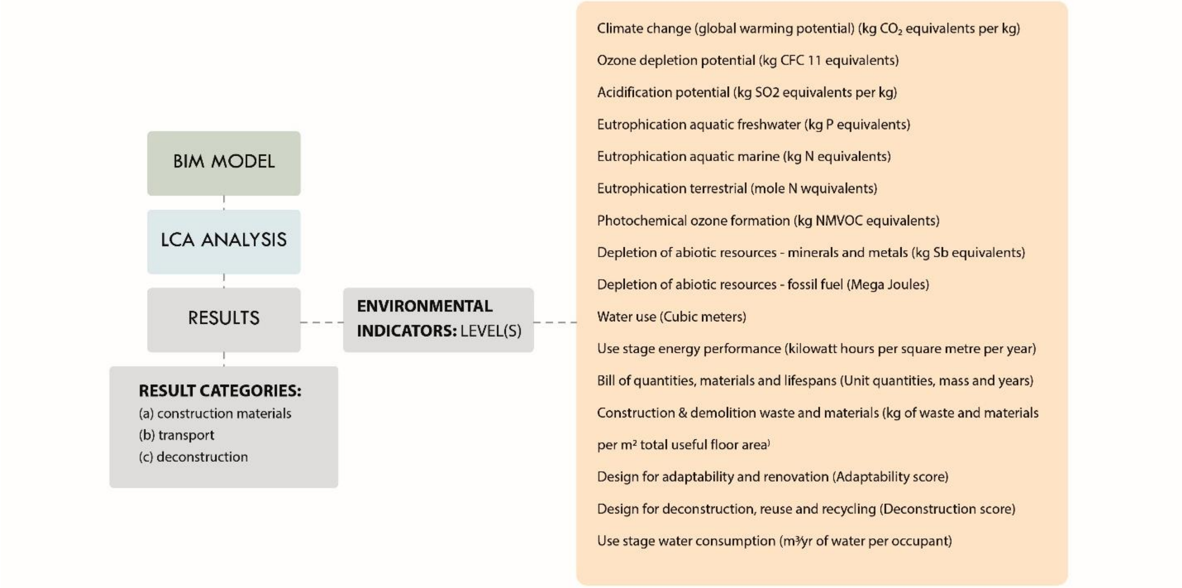


**Figure 5: Environmental indicators extraction**

LCA Level(s) tool is used in the assessment, and a complete list of 17 data result terms are presented in Table 10. These environmental indicators are asset indicators and may be calculated through the combination of materials bill of quantities, derived by a BIM document, and building materials EPDs.

**Table 10: LCA Indicators[14]**

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

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

| | | |
|---|---|---|
| | 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. 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 |

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| | | |
|---|---|---|
| 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 |

Distinctively, the environmental and energy indicators for the next-generation EPCs are based on actual data consumption, as opposed to current EPCs, which base some environmental indicators on design values and assumptions and do not include energy indicators at all.

Related Submitted Deliverables:

- D2.3 Life Cycle Indicators for next generation EPCs v1
- D2.8 Life Cycle Indicators for next generation EPCs v2

### 1.2.8.4 Financial Indicators

Task 2.4 “Analysis of cost and economic indicators for EPCs” focuses on developing cost and economic indicators, enabling the interpretation of the individual elements of a building’s energy performance into normalized monetary values.

The financial indicators aim to increase user awareness about the energy efficiency of buildings. The approach is to monetize the energy consumption, which means that the energy consumption is translated to EUR. Tenants will be able to see how much money they are spending on energy and compare it with different scenarios (asset values, operational values, prediction values). Such indicators are expected to enable the financial assessment of the building and thus provide additional information to the user. This could encourage them to adapt their behaviour to improve the energy efficiency of the building.

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

The idea of how to define the financial indicators is based on the comparison of the current state (as-operated) with different scenarios, for example, the as-designed state, the as-operated state at a different (past) time, the predicted model, and the building stock, as illustrated in Figure 6. The energy consumption of different scenarios is going to be monetized and compared to each other.

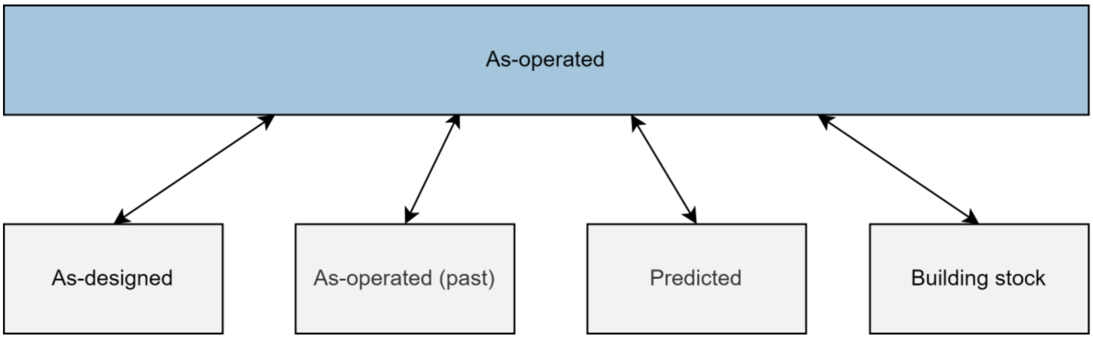


Figure 6 The comparison of scenarios

Besides the comparison between the monetized energy consumptions, the financial indicator will also include the expected cost for the replacement and maintenance of the building's systems and envelope. In this way, the user will be informed about the approximate expenses in the near future, which will allow him to better plan his expenditures.

The table below shows an overview of the D^2EPC financial indicators developed in the task.

Table 11 D^2EPC Financial indicators

| Indicator name | Indicator description | Units |
|---|---|---|
| As-operated costs | The "as-operated cost" indicator presents the following costs to the user:<br>- Cost per month per energy use<br>- Cost per month per energy carrier<br>- Total cost per month<br>- Total cost per year<br>- Total cost per square meter | EUR |
| As-designed costs | The "as-designed cost" indicator presents the following costs to the user:<br>- Cost per month per energy use<br>- Cost per month per energy carrier<br>- Total cost per month<br>- Total cost per year<br>- Total cost per square meter | EUR |
| Total cost comparison (graphically presented) | The "total cost comparison" indicator is comparing the as-designed and as-operated costs, namely the total costs per month and total costs for the whole year. | EUR |

| | | |
|---|---|---|
| | - Total cost comparison per month<br>- Total cost comparison per year | |
| Predicted costs | The "predicted costs" indicator presents the real cost, the nominal cost, and the Net Present Value for the next 10 years | EUR |
| Expected costs for building systems | The "expected costs for building systems" are an estimation of the costs that the user can expect for the replacement and maintenance of building systems | EUR |

The outcomes from the Asset Rating Module and the Operational Rating Module and contribution from the user, where applicable are the required inputs for the Building Performance Module to calculate the financial KPIs, as presented in Figure 7.

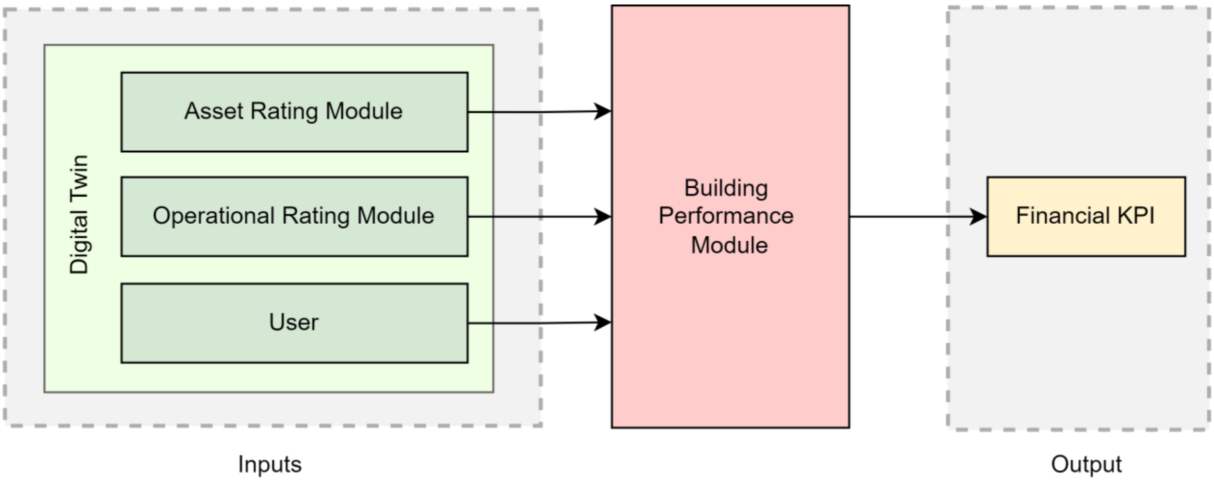


**Figure 7 Process overview**

Related Submitted Deliverables:

- D2.4 Financial indicators for next generation EPCs v1
- D2.9 Financial indicators for next generation EPCs v2

## 1.2.9 D^2EPC Information Model

Task 2.5 "D^2EPC Information Model" delivered the system's information model (link) to optimally support information flow among the various components and necessary requirements and steps for ensuring a common way for auditing and implementation of next generation EPCs.

The most popular format for data transfer between building models and other related software is IFC. In principle, IFC, or "Industry Foundation Classes", is a standardized, digital description of the built environment, referring both to buildings and civil infrastructure. The characterization of a building is based on an open, international standard (ISO 16739-1:2018) meant to be vendor-neutral, or agnostic, so that it can be used under several cases by a variety of hardware devices, software systems, and interfaces[15]. Even though, the IFC documentation can provide extensive documentation to support the building's description, only a predetermined set of data is required to perform the relevant calculations for the determination of the previously mentioned indicators.

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

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

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

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

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

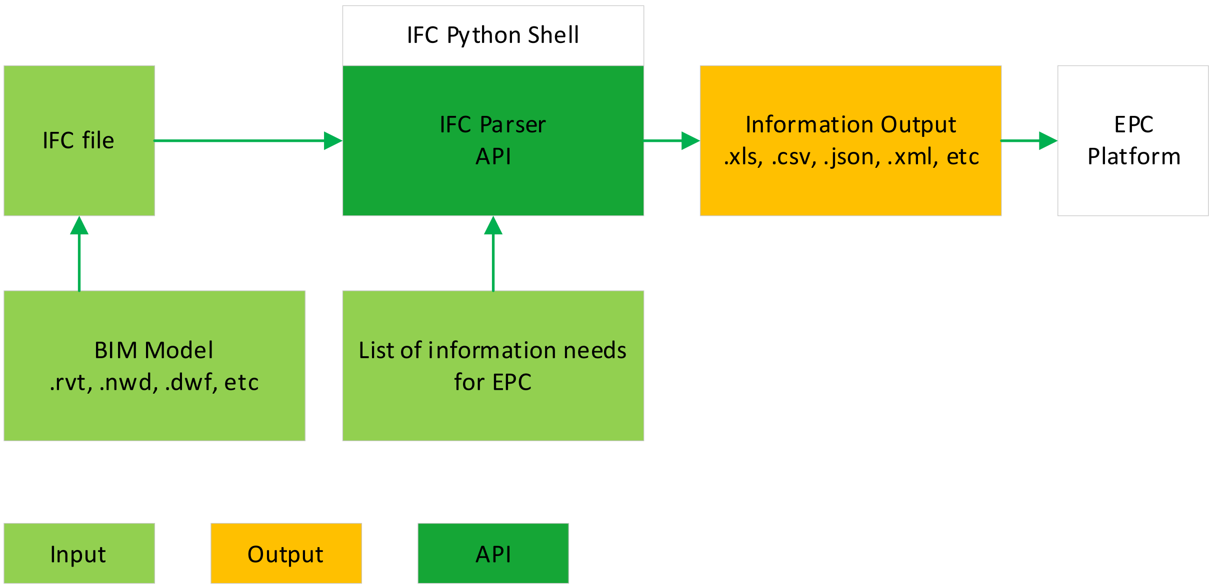


**Figure 8. Proposed D^2EPC IFC Parser Workflow**

The suggested IFC parser for the D^2EPC project is based on the Python programming language, utilizing the IfcOpenShell-Python and Pandas libraries. More details regarding the complete IFC parser component can be found in the deliverable D3.5 Building Digital Twin v2.

[15] ISO 16739-1:2018 (2018). Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema

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IfcOpenShell-Python is an open-source (LGPL- Lesser General Public License) software library that enables users and software developers to utilize the IFC file format[16]. The IFC file format is usually used to describe the construction and as-built environment. The format is commonly used for BIM. Pandas is a quick, vigorous and easy-to-use open-source data analysis and manipulation tool, built on top of the Python programming language[17].

Related Submitted Deliverables:

- D2.5 D^2EPC information model v1
- D2.10 D^2EPC information model v2

### 1.2.10 Building Digital Twin

The functional view of the BIM-based Digital Twin architecture, as documented in the D1.9 "D^2EPC Framework Architecture and Specifications v3", is presented in Figure 9. It includes three core sub-components, namely the BIM Parser, the Input Data Validator and the Building Behavior Profiling, while it is equipped with interfaces for other modules that require access to static and dynamic data. The BDT has been designed as a Python software package in a fully object oriented-based approach, allowing it to be embedded and utilized by any of the D^2EPC or other third-party tools.

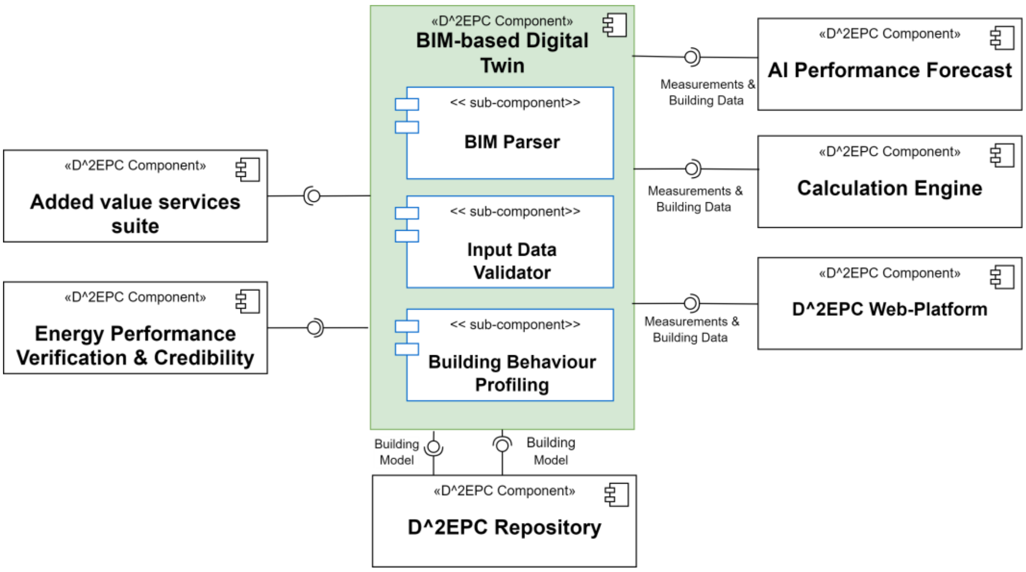


**Figure 9: Building Digital Twin Functional Diagram, from D1.9**

A more detailed view of the internal architecture is illustrated in Figure 10, along with the interactions with other external components and data sources. The initial creation of the BDT requires the provision of static building information, related to its geometry, underlying systems, structural elements etc. The BIM file is therefore utilized as the primary source of information, which is processed by the BIM Parser sub-component in order to be converted to a JSON-based model. However, as mentioned, considering that BIM files might lack essential data, additional user-derived input is expected in order to form more extended building models. On the other side, actual data from on-site sensing/metering infrastructure are also integrated (both historical and close to real-time) in order to encapsulate the past and present

[16] http://ifcopenshell.org/python
[17] https://pandas.pydata.org/

operational status of the building. All the aforementioned static and dynamic information is provided to the Input Data Validator subcomponent to ensure its integrity and produce the D^2EPC data model-based building representation. An interface with an external database is also considered (yet not required), which stores the generated model. Subsequently, the latter is provided to the Building Behaviour Profiling subcomponent, which structures the information and instantiates a building object, which external tools can then process.

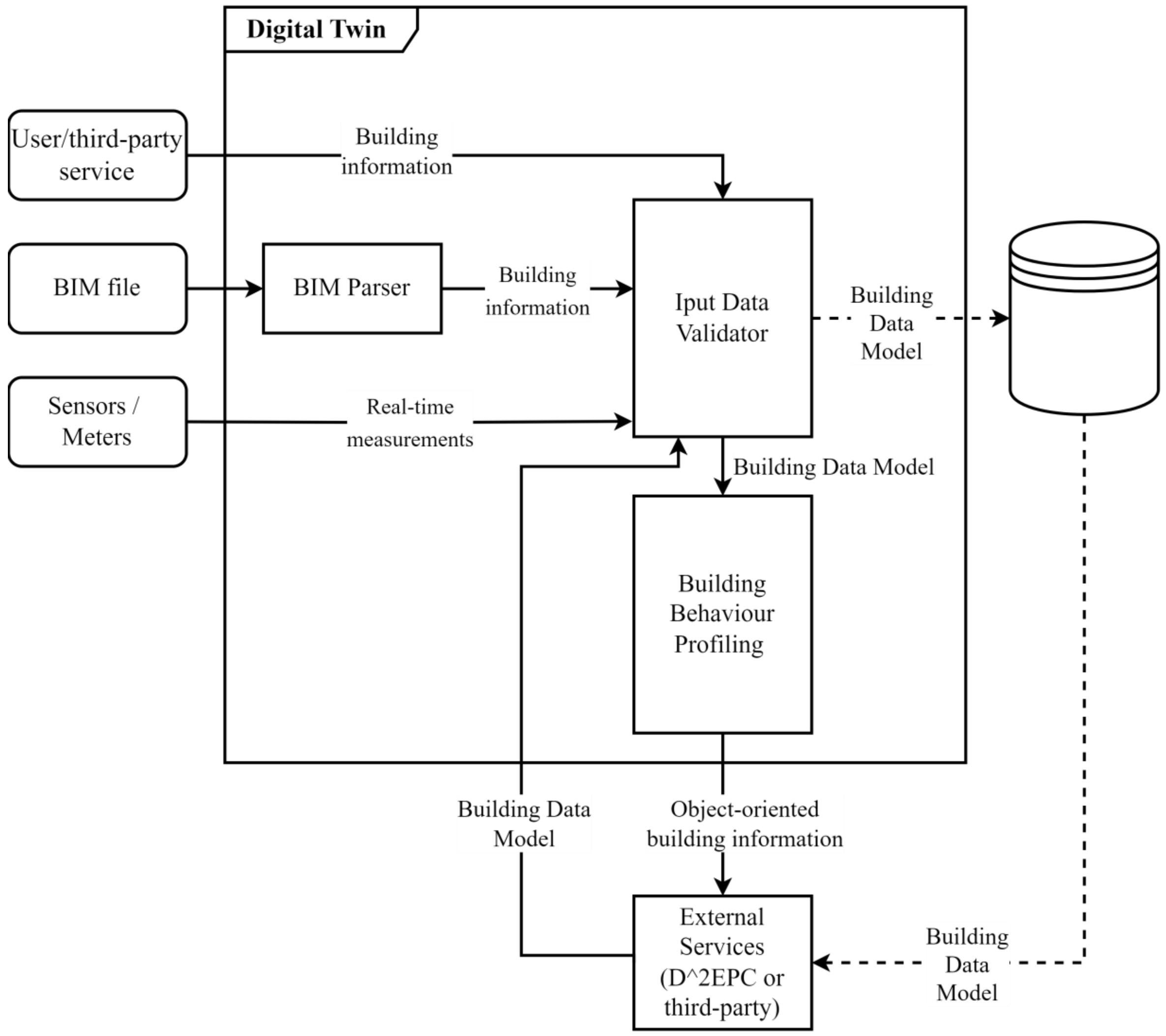


Figure 10: Digital Twin architecture implementation view

The following sections describe the consisting subcomponents of the BDT in further detail.

### 1.2.10.1 BIM Parser

The BIM Parser has been developed as a core component of the Digital Twin module, serving as a tool that enables the extraction of building information from an IFC file. For each file that is provided, an output in JSON format is generated containing all relevant information of the corresponding building in the context of the D^2EPC ecosystem, which is then forwarded to the validation tool.

In order to extract the entire information available in the IFC file, the parsing process is applied on four different levels (Figure 11), with each one containing:

- **First level:** The building, along with the information retrieved as a whole.

- **Second level:** The building-level technical systems, such as the Renewable Energy Sources (RES), the thermal zones and the building's location.
- **Third level:** The thermal zone usage information, the spaces that are part of the thermal zone, and the zone-level technical systems (heating, cooling, lighting).
- **Fourth level:** The structural elements and the monitoring equipment of the zone-consisting spaces, along with the information that is needed for calculations from other components.

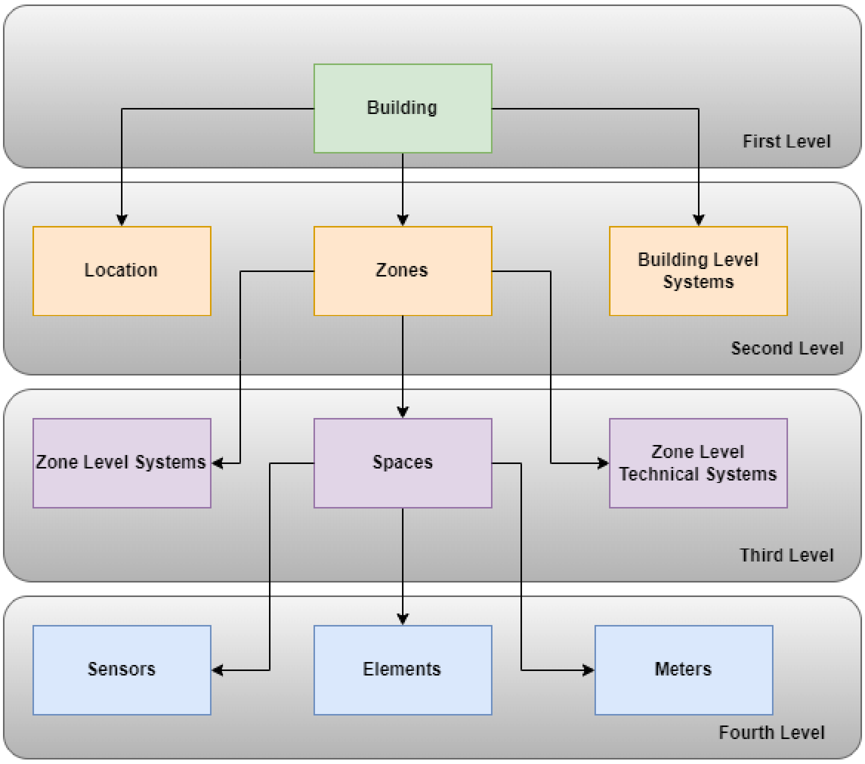


**Figure 11: BIM Parser conceptual level architecture**

### 1.2.10.2 Input Data Validator

As a second stage of input data handling, a component responsible for validation has been designed, following the BIM Parser. Data validation is the process of confirming the correctness and quality of data. It is accomplished by including multiple checks into a system or reports to ensure the logical consistency of input and stored data. As automated systems receive data inputs with little to no human oversight, it is critical to guarantee that the data entering the system is valid and satisfies the specified quality criteria.

There are several forms of data validation. Most data validation methods may execute one or more tests to confirm that the data is accurate before saving it in the database. During the registration procedure, the validation component performs the following validation checks on the input data:

- **Data Type verification** ensures that the data entered is of the right data type; for example, a field may only take numeric values. If this is not the case, the system should reject any data, including additional characters such as letters or special symbols.
- **Code verification** confirms that a field is chosen from a valid set of values or that specific formatting standards are followed.
- **Range verification** determines whether the input data is inside a preset range.

- **Uniqueness verification** validates that some data, such as IDs or physical addresses, are inherently unique. These fields in a database should most likely contain unique entries. A uniqueness check guarantees that an item is not stored in a database more than once.
- **Consistency verification** checks that data has been inserted in a logically consistent manner. For example, the collected measurement values from a sensor must contain the quantity and the unit of each value.

#### 1.2.10.3 Interface with external database

Although not an explicit part of the generic BDT architecture, a database management system (DBMS) for the storage and retrieval of the generated building data model can be utilized to eliminate the need for iterative provision of information (BIM file, user inputs). A DBMS stores data and responds to requests through a query language, such as SQL. At the same time, a DBMS interface facilitates the submission of queries to the database without the usage of the query language itself. In the DBMS, each entity of the building data model, such as a building, location, zone, systems, etc., is represented.

#### 1.2.10.4 Building Behavior Profiling

This subcomponent is mainly responsible for managing the data feed from the Digital Twin to other D^2EPC components. It provides access to structured information through a fully object-oriented interface. Based on the association of static, highly relational BIM data with actual data received from the building sensors/meters, as described in the previous section, it is able to identify common building operational patterns and provide insights in combination with other services.

Building information in the D^2EPC data model format is utilized in order to instantiate class objects that preserve the in-between logical relationships. Access to any data level as well as the combinational extraction of information, are supported through the designed class methods, which, on the one hand, serve the developed EPC assessment functionalities integrated into the BDT and, on the other hand, can support any third-party service that requires access to building data. As a digital copy of the building is provided, any modifications to the parameters can be exploited to perform sensitivity analysis and study further insights regarding the building's operation.

#### 1.2.10.5 Interfaces with other services

The BDT component has been developed as a software package, which allows easy installation and use by any other service. Consequently, the latter can either perform the entire BDT creation process, including the provision and parsing of a BIM file and the complete information validation or explicitly provide building data already in the D^2EPC data model format.

Following the successful setup of a building in terms of BIM file upload and device registration, the user is able to view a digital twin of the building on the corresponding page of the Web Platform (Figure 12). A 3D-rendered model is provided, in combination with useful, semantically enriched information by clicking any building element. Additionally, the selection of any sensor/meter device, either in the model or in the dropdown menu, displays the device's actual measurements for different time periods, as in Figure 13. All the data charts are interactive to allow toggling different data views.

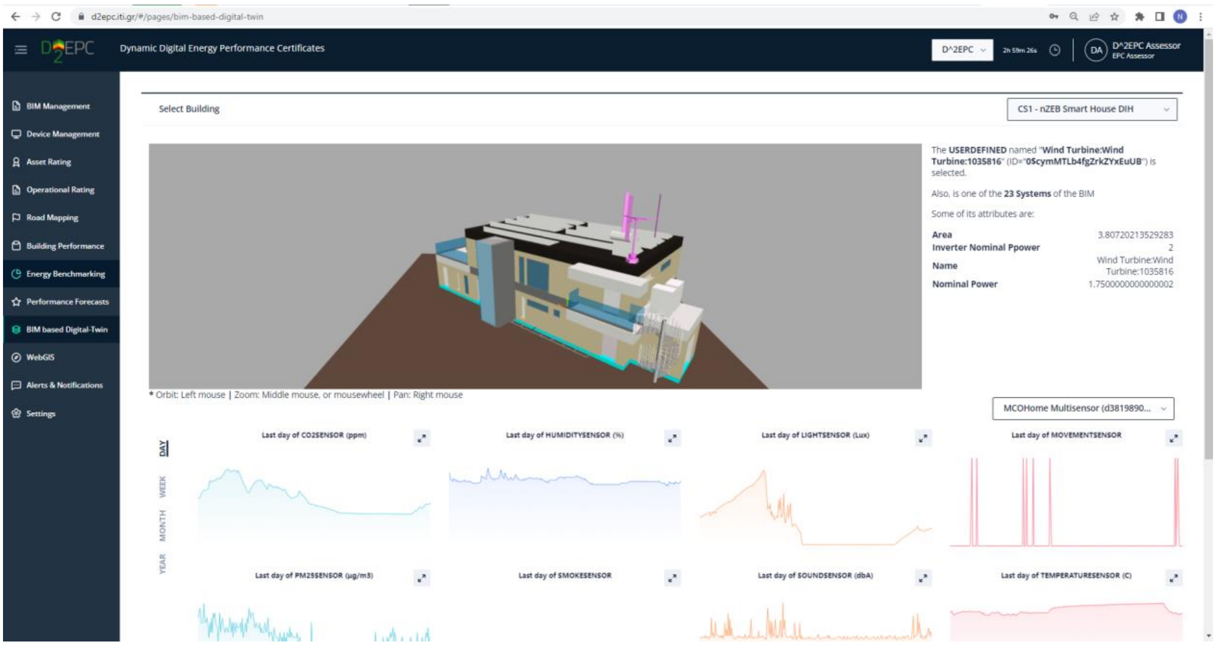


Figure 12 BIM-based Digital Twin page


Figure 13 Building collected measurements

<u>Related Submitted Deliverables:</u>

- D3.3 D^2EPC Building Digital Twin v1
- D3.5 D^2EPC Building Digital Twin v2
- D4.8 D^2EPC Digital Platform v2

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### 1.2.11 D^2EPC Calculation Engine

Task 4.1 "Building Performance Module" is one of the core development tasks in D^2EPC while the development of the calculation submodules is based on the work that has been done under WP2.

In more details, this calculation engine is one of the primary components of the D^2EPC architecture (Figure 14). This component is responsible for conducting all computations required for a precise evaluation of asset and operational performance. The existence of two different certification schemes triggered the development of two distinct sub-modules for each calculation. In addition, a third sub-module, the Building Performance Module, has been identified for the sole purpose of conducting the required calculations for a broad range of indicators that would enhance the EPC method (SRI, LCA, LCC, Human Comfort and Wellbeing).

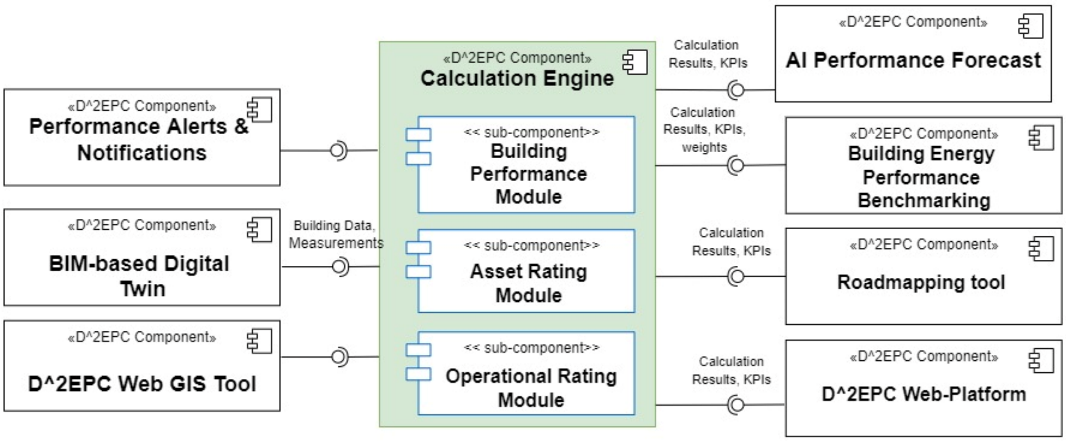


**Figure 14: Calculation Engine- Architecture view**

#### 1.2.11.1 Asset Rating Module

The development of the Asset Rating calculation engine followed the methodology described in Section 1.2.6. The calculation module receives as input the building information in a JSON file. This file is stored in the BIM-based Digital twin component and has been generated from the BIM parser sub-component. The module's operational philosophy can be described as an iteration between the listed thermal zones, technical systems, spaces and envelope elements. Each calculation phase iterates through the various entities to calculate the asset's energy performance.

Starting with the investigation of the heating and cooling demand, the module uses four functions to examine the energy exchange in each thermal zone. The *Transmission_Heat_loss* function calculates the energy loss per element from the transmission, while *Ventilation_Heat_Losses* calculates the part of energy losses through air exchange in the thermal zone. Additionally, the *Internal_Heat_Gains* calculates the thermal gains from the people and equipment in the zone and the *Solar Gains function* calculates the solar energy absorbed per building element. The resulting values from each function are weighted and summed in *the Heating_Demand* and *Cooling_Demand* functions.

To complete the energy demand calculation per thermal zone, two additional functions are also used. The *DHW* function calculates the DHW demand per thermal zone according to the DHW requirements from the zone's boundary conditions. In a similar manner, the *Lighting* function calculates the energy demand per thermal zone. The monthly results from all the above functions are expressed per zone, and per service. In parallel to the energy demand calculations for the examined boiling, the same functions calculate the energy demand for the Reference building, by replacing the values of the examined elements with the reference ones while maintaining the same geometrical characteristics.

Afterwards, the final energy is calculated taking as input all the above values. The *Q_deliver* function takes as an input the generated results, as described above. For each thermal zone, the function matches the energy demand per service with the respective technical system to calculate the theoretical energy consumption. In parallel, the same calculation procedure is repeated with the respective values of the reference building's technical systems. The resulting values are expressed per thermal zone, energy service and energy carrier.

In the third calculation phase, the *Q_primary* function takes the results generated from the *Q_deliver* function. Each set of results is weighted with the appropriate primary energy factor, according to the indicated energy carrier. In the same manner, the function also calculates the cost and $CO_2$ emissions per service.

Finally, the *EPC_class* function benchmarks the performance of the examined building in relation to the respective reference building and results to the energy class.

It is important to mention that the Asset Rating module has been developed with the use of the Python (3.9) programming language. Additionally, the following Python packages have been used to broaden the module's functionalities:

- Pandas 1.4.2
- Numpy 1.22.3
- XlsxWWriter 3.0.3

As part of the D^2EPC Web Platform, the Asset Rating page regards the issuance of the as-designed EPC for the building, assuming the corresponding BIM file has been uploaded successfully. In case additional information is required for the calculation of the EPC results, a validation error message appears along with an input form that includes the parameters that need to be provided (Figure 15). The form provides guidelines on the information that is required to be inserted, while an error report is also available for downloading.

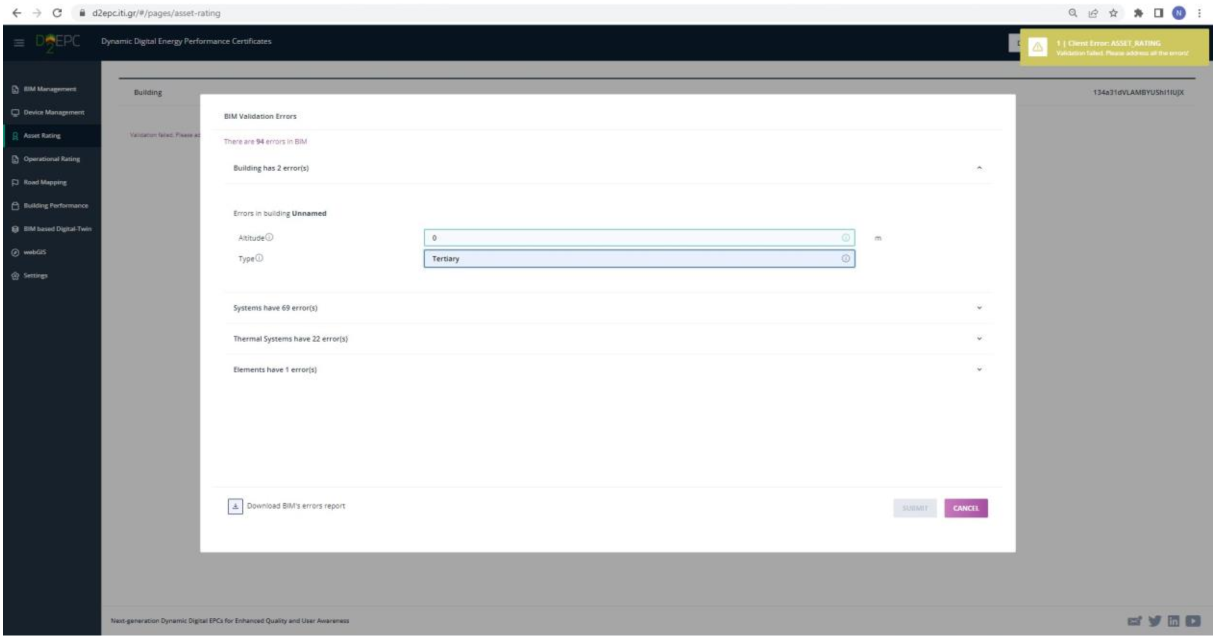


Figure 15 Asset Rating page - validation

Following the successful validation and EPC calculation process, the results are shown to the user as in Figure 16. They include the building-determined energy rating class as well as different performance indicators in terms of energy, $CO_2$ emissions and cost, which can be viewed by toggling the various data views.

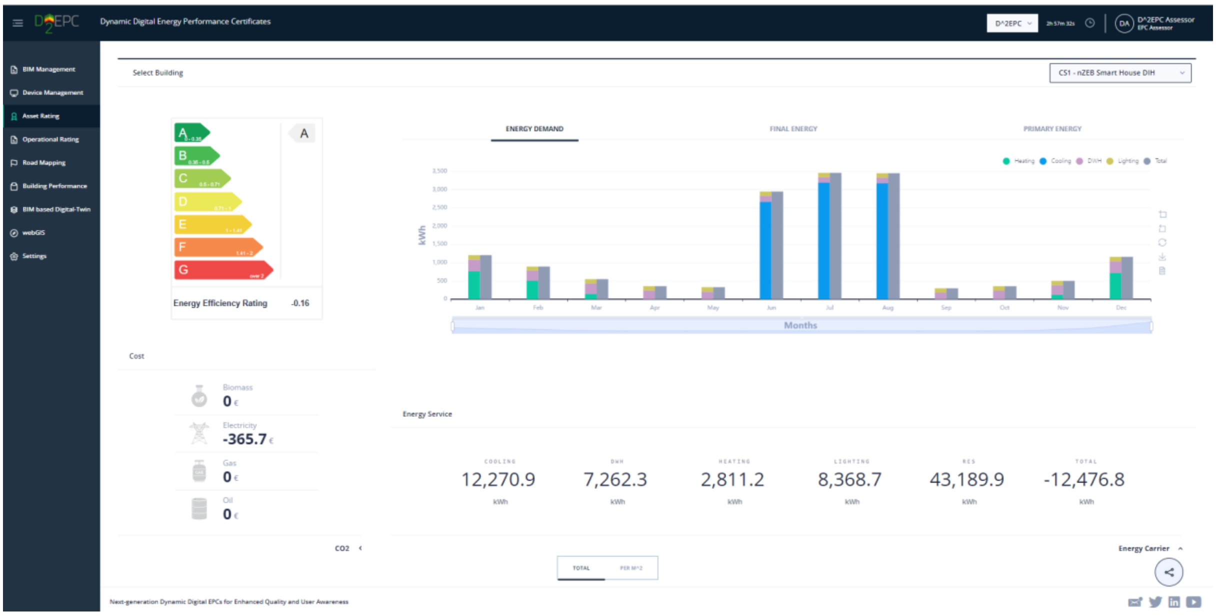


Figure 16 Asset Rating page – results (CS1)

### 1.2.11.2 Operational Rating Module

In contrast to the Asset Rating, the Operational Rating (OR) module evaluates the *as-operated* energy performance of the examined building taking as a main input the measurements of energy consumption. The module utilizes the static and dynamic information, derived from the BIM-based Digital Twin, to evaluate the operational performance of the building on daily, monthly and yearly horizon. The EU-based calculation methodology for the Operational Rating has been developed within the D^2EPC project and aims to bridge the gap created by the variety of existing national methodologies, as described in Section 1.2.7.

According to the requirements of the proposed methodology, the tool facilitates the dynamic and automated issuance of the Operational rating Report. The issuance frequency is six months. Each Operational Rating report will be delivered to the Digital Twin module and stored at the D^2EPC Repository. The tool's main functionalities consist of data pre-processing from digital twin, conversion to daily values, timestamp homogenization, organization on different time steps (daily, monthly, annual), and energy classification. It is worth mentioning that every tool's functionality differs significantly in order to produce specific results.

The Operational Rating Module follows the rationale of the project architecture. Operational Rating is based on structured programming and the flow is divided into multiple sub-functions. The module can operate as a stand-alone tool, and it is designed as a package in order to extend the applicability of the module to third-party members. The current version of the Operational Rating module has been implemented in Python programming language, version 3.9. Towards the development of the module, the following packages were used:

- Pandas
- Collections
- Datetime
- NumPy

Operational Rating can produce results both from historical data in a CSV format or real-time data in a JavaScript Object Notation format (JSON) format. Finally, the produced results are saved in the D^2EPC repository in JSON format to be used as input to the D^2EPC Web Platform for visualization purposes.

Similar to the Asset Rating page, in the Operational Rating page of the D^2EPC Web Platform the as-operated EPC results are presented. A validation process might be required prior to the calculation (Figure 17). Apart from the correct BIM file upload, the service required historical energy data to be available in the D^2EPC Repository, linked to the devices that had been registered earlier.

The provided results are illustrated in Figure 18. They include the energy rating class as well as several energy indicators that can be viewed by switching between the different tabs.

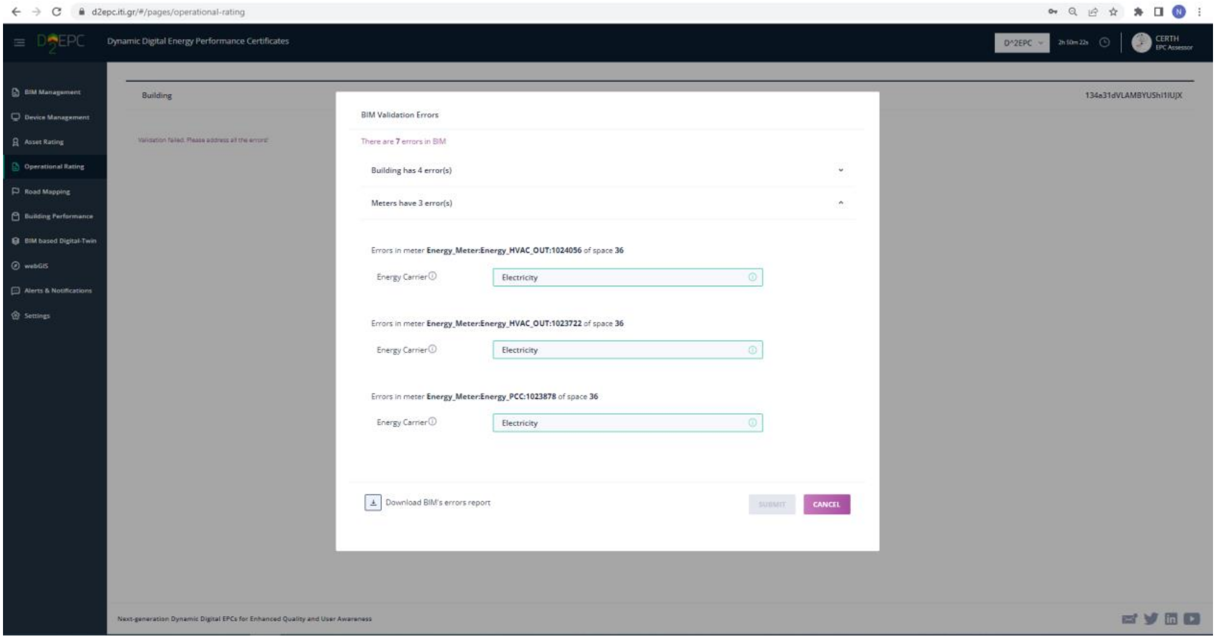


Figure 17 Operational rating page - validation

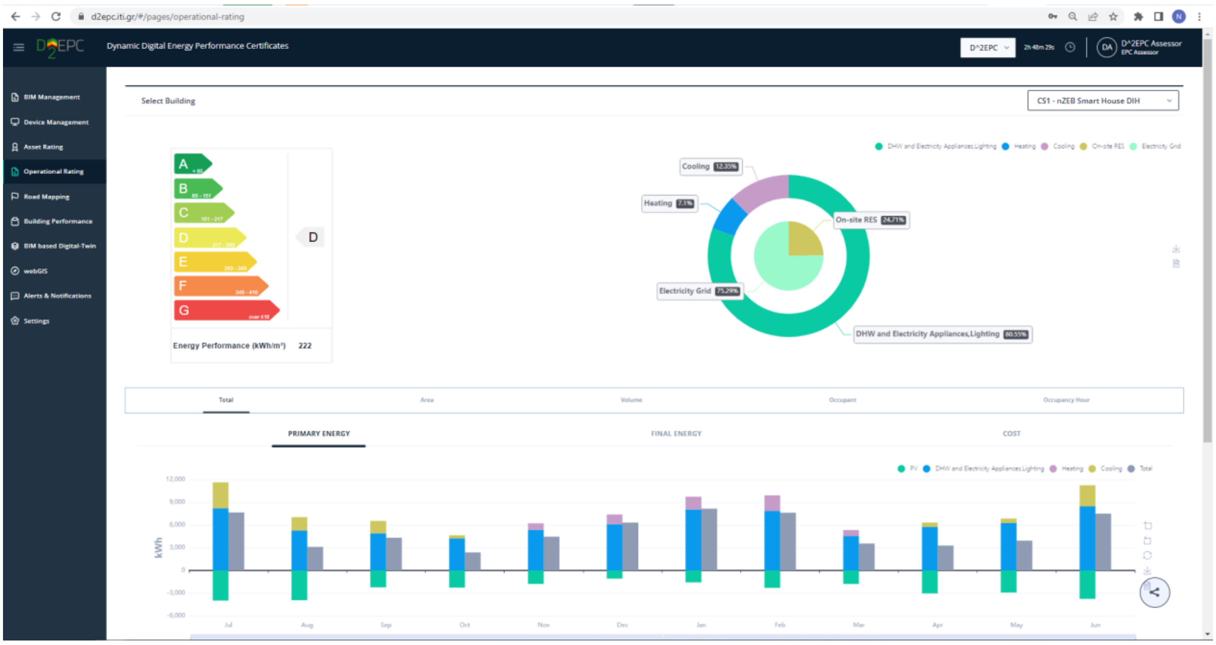


Figure 18 Operational rating page – results (CS1)

## 1.2.11.3 Building Performance Module

This module is responsible for calculating the enriched set of D^2EPC KPIs, including the ones that are already included in current EPC practices. The BPM is further divided into 4 dedicated submodules for each indicator category. Firstly, the SRI and LCA modules receive static information from the BIM-based DT to calculate the smart-readiness and life cycle sets of KPIs, respectively. The Cost & Economic (C&E) indicators submodule utilizes both static and dynamic data to calculate the financial KPIs at the various operational stages of a building's life span. Lastly, the Human Comfort and Wellbeing (HC&W) submodule receives the indoor environment measurements to evaluate the occupant's well-being. The co-existence of the above modules in a common environment enhances the interoperability of the produced information and paves the way for further enrichment of the performance indicator's set through the combinations that can be generated.

The procedure followed to extract the SRI overall and specific scores is depicted in Figure 19 below. The first step towards the SRI calculation is providing the assessor's and the studied building's parameters, as displayed earlier. Following, the building's present domains must be specified, along with their presence status (present, not present but mandatory, not present but not mandatory) and the services that they include. Finally, the input services' levels must be provided. The module is then able to calculate the SRI detailed scores as well as the aggregated ones, which yield the SRI overall score and class, the impact scores and the domain scores.

The required information should be provided using the JSON format.

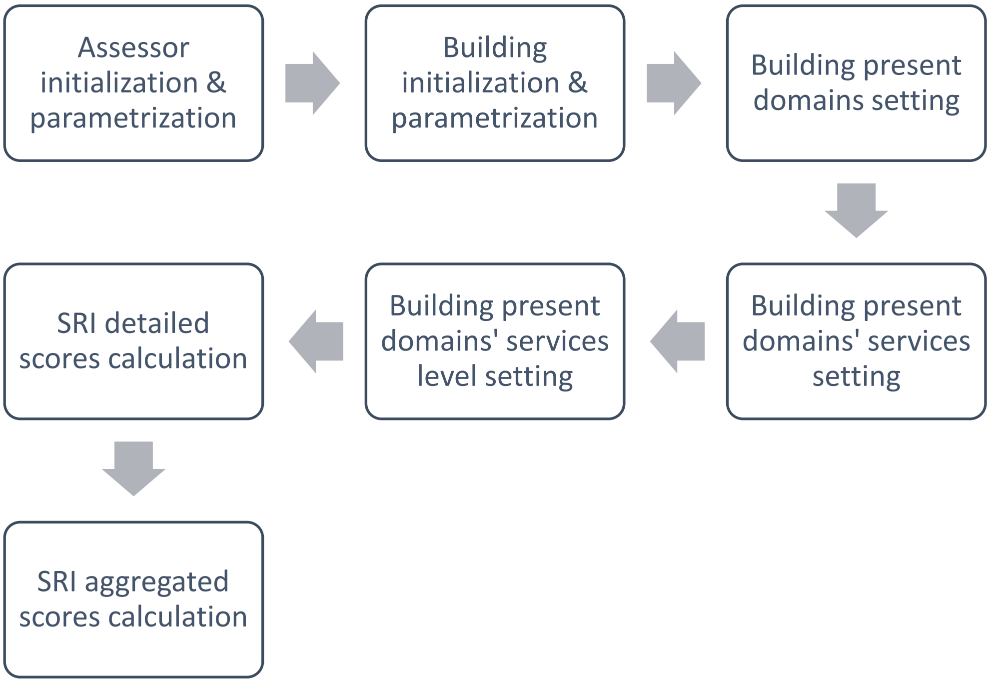


**Figure 19: SRI calculation procedure**

The tool was tested and validated to all pilots during the demonstration activities. The SRI tool was designed to operate as an online service accessible through the D^2EPC Web Platform. EPC assessors or/and users can upload building information directly into the SRI web environment, streamlining the documentation process. Given that the information required for the calculation of the SRI cannot be extracted fully from existing Building Information Models (BIM), the tool can extract specific information from the BIM model in addition to manual user inputs. The SRI ''Wizard'' was developed as a guidance for the assessor through the various information required for the SRI calculation in the D^2EPC platform.

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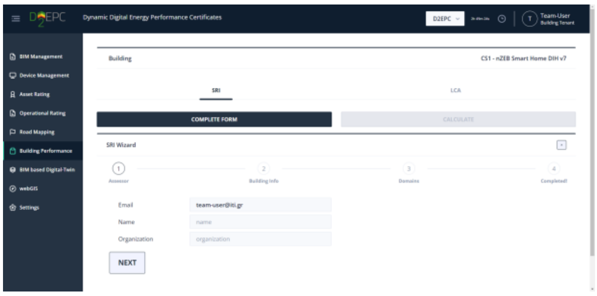
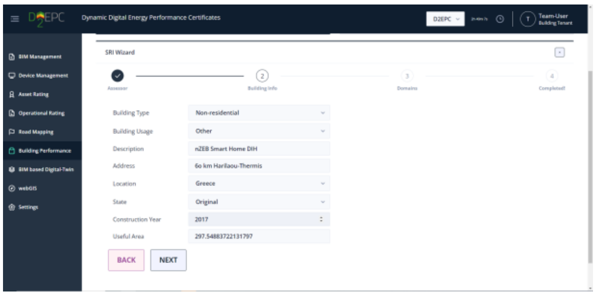


a)



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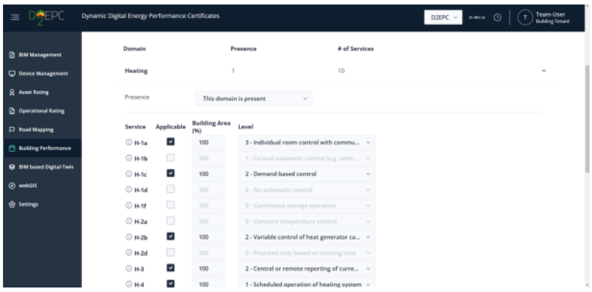
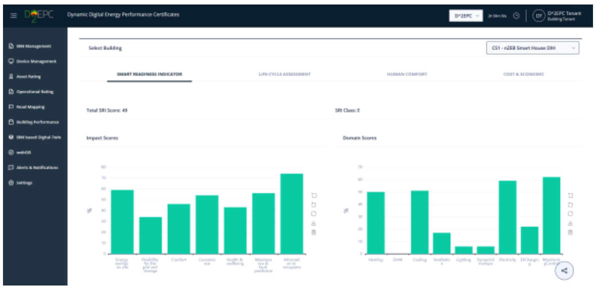


c)



d)

**Figure 20 D^2EPC SRI Calculation subcomponent a) Assessor's Information; b) Assessor's Information; c) Domains; d) SRI Results**

The Human Comfort & Wellbeing Indicators calculation submodule follows the guidelines and relevant standards that were elaborated in the D2.2 and finalized in its updated second version as described in Section 1.2.8.2. The user is able to select among the different building spaces where at least one group of indicators has been calculated. By default, all the indicators are calculated over a six-month time scale, though the option for selecting another timeframe (e.g., one year) is also available. The tool utilizes actual building measurements for each space, which are retrieved from the D^2EPC Repository through the Building Digital Twin. Figure 21 shows the initial parametrization of the HC&W calculation.

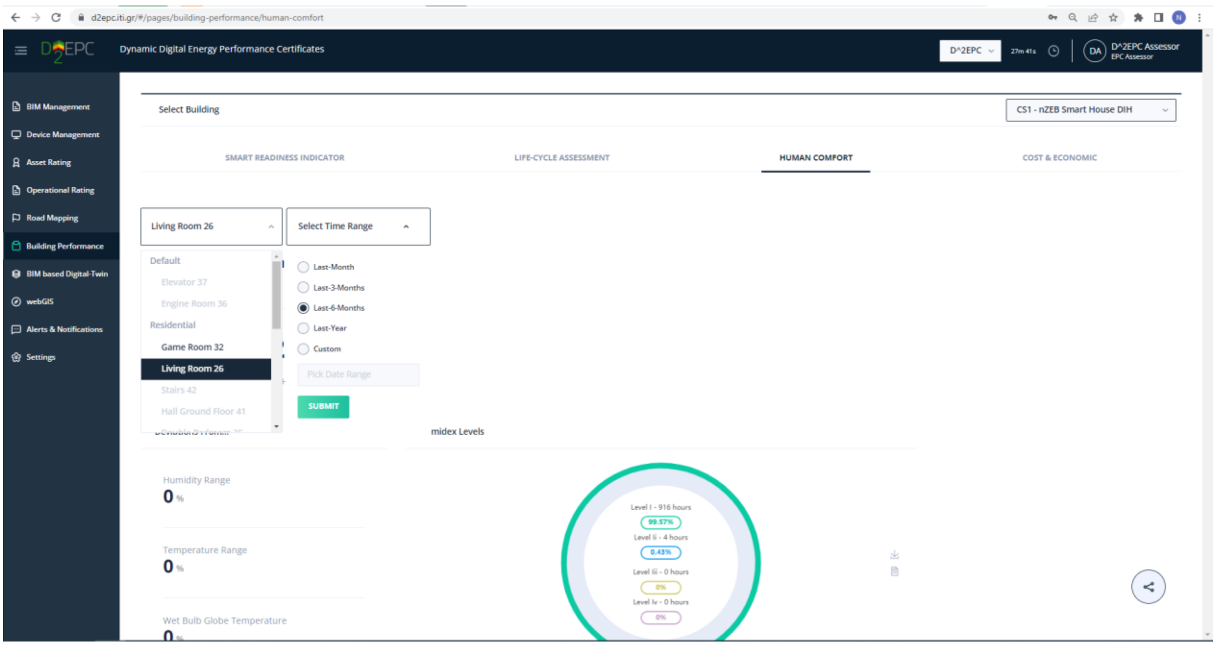



**Figure 21 Provision of HC&W indicators-related information**

The LCA Indicators calculation submodule follows the guidelines and relevant standards that were elaborated within the activities of Task 2.3 and described in Section 1.2.8.3. The calculation process is depicted in Figure 22. The first step regards the formulation of the bill of materials for the building under study. Each material entry in the aforementioned list should include the name, the structural group under which it is categorized (External walls, internal walls, slabs, roofs, doors, windows) and the quantity of the material and its corresponding unit. Following next, the source of the EPD-related data for each material has to be defined by selecting at least one of the options:

- Auto-searching the required information within the component. A dataset has been included within the tool, which contains EPD data for common materials and allows their quick parametrization;
- Providing the URI of a material EPD, which belongs to the open data set network that is supported by the ECO PORTAL[18]. The latter serves as a central access point for retrieving EPD data from many providers in a common digital format, namely the ILCD+EPD. Within the LCA subcomponent, dedicated methods were developed for properly accessing the platform's corresponding API and post-processing of the fetched data, which established easy access to more than 6000 EPDs.
- Providing the required EPD indicator data explicitly in a specific input format.

The last requirement concerns the provision of additional material properties, mainly in the case that the EPD indicator data are provided directly. Herein, at least the defined declared unit must be present, which enables the calculation of each indicator based on the material's quantity. Additional material properties may need to be provided, i.e., its density, default thickness or mass per unit of area, which are utilized for converting the quantity's unit to the declared one.

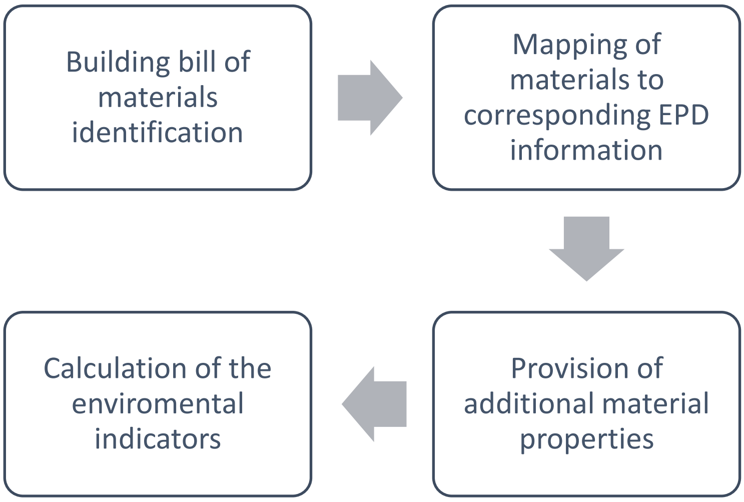
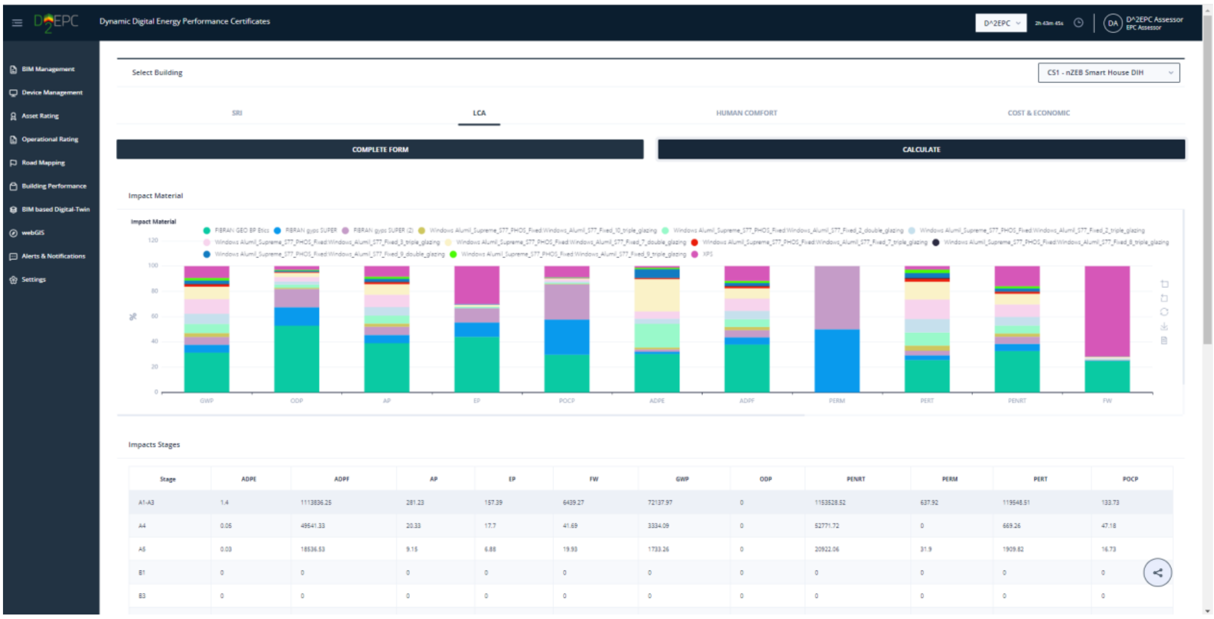



**Figure 22: LCA submodule calculation procedure**

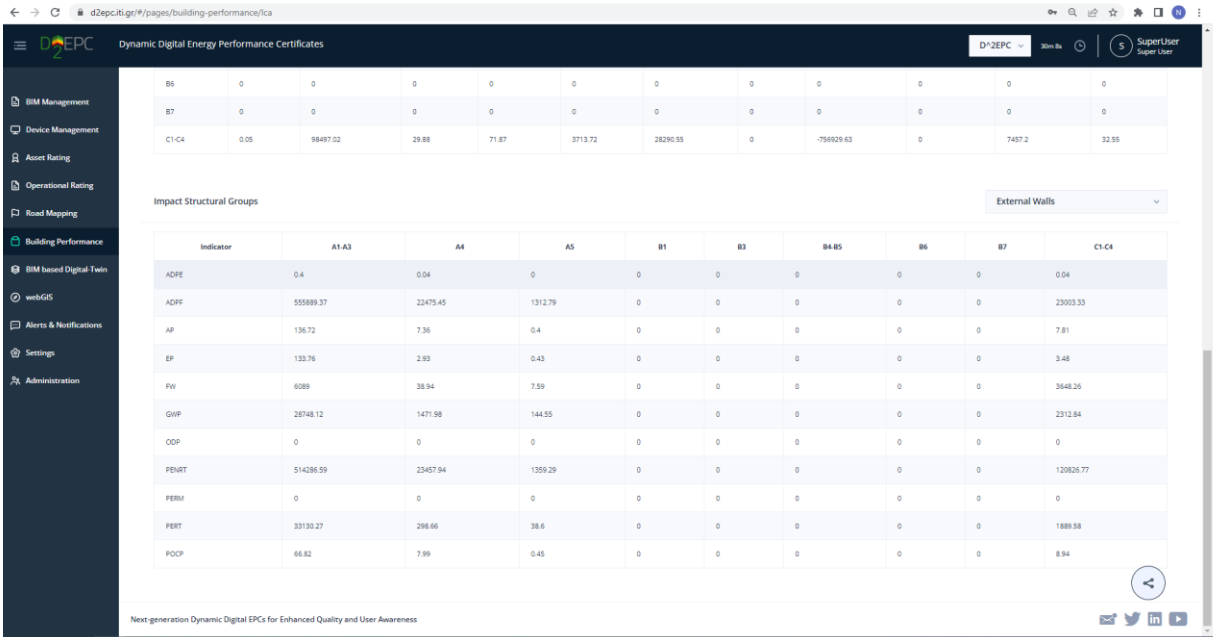
Upon completion of the aforementioned setup process, the calculation of the LCA indicators can be performed. Figure 23 and Figure 24 present the environmental impacts for Case Study 1, per material/ life-cycle stage and per material structural group, respectively.

[18] https://www.eco-platform.org/eco-portal-access-point-to-digital-product-data




| Stage | ADPE | ADPF | AP | EP | FW | GWP | ODP | PENRT | PERM | PERT | POCP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1-A3 | 1.4 | 1113836.25 | 281.23 | 157.39 | 6439.27 | 72137.97 | 0 | 1153528.52 | 637.92 | 119548.51 | 133.73 |
| A4 | 0.05 | 49541.33 | 20.33 | 17.7 | 41.69 | 3334.09 | 0 | 52771.72 | 0 | 669.26 | 47.18 |
| A5 | 0.03 | 18536.53 | 9.15 | 6.88 | 19.93 | 1733.26 | 0 | 20922.06 | 31.9 | 1909.82 | 16.73 |
| B1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 23 LCA indicator impacts per material/life-cycle stage




| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1-C4 | 0.05 | 98497.02 | 29.88 | 71.87 | 3713.72 | 28290.55 | 0 | -756929.63 | 0 | 7457.2 | 32.55 |

| Indicator | A1-A3 | A4 | A5 | B1 | B3 | B4-B5 | B6 | B7 | C1-C4 |
|---|---|---|---|---|---|---|---|---|---|
| ADPE | 0.4 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 |
| ADPF | 555889.37 | 22475.45 | 1312.79 | 0 | 0 | 0 | 0 | 0 | 23003.33 |
| AP | 136.72 | 7.36 | 0.4 | 0 | 0 | 0 | 0 | 0 | 7.81 |
| EP | 133.76 | 2.93 | 0.43 | 0 | 0 | 0 | 0 | 0 | 3.48 |
| FW | 6089 | 38.94 | 7.59 | 0 | 0 | 0 | 0 | 0 | 3648.26 |
| GWP | 28748.12 | 1471.98 | 144.55 | 0 | 0 | 0 | 0 | 0 | 2312.84 |
| ODP | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PENRT | 514286.59 | 23457.94 | 1359.29 | 0 | 0 | 0 | 0 | 0 | 120826.77 |
| PERM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PERT | 33130.27 | 298.66 | 38.6 | 0 | 0 | 0 | 0 | 0 | 1889.58 |
| POCP | 66.82 | 7.99 | 0.45 | 0 | 0 | 0 | 0 | 0 | 8.94 |

Figure 24 LCA indicator impacts per material group

The Financial Indicators calculation submodule follows the guidelines and relevant standards that were elaborated within the activities of Task 2.4 as described in Section 1.2.8.4. Similarly to the HC&W indicators calculation subcomponent, the D^2EPC BIM-based Digital Twin has been integrated in order to ease the actual data collection and post-processing, regarding the as-operated costs calculation. The asset rating calculation engine is also incorporated in order to retrieve the as-designed energy values. Instantiation

The procedure followed to extract the financial indicators is depicted in Figure 25.

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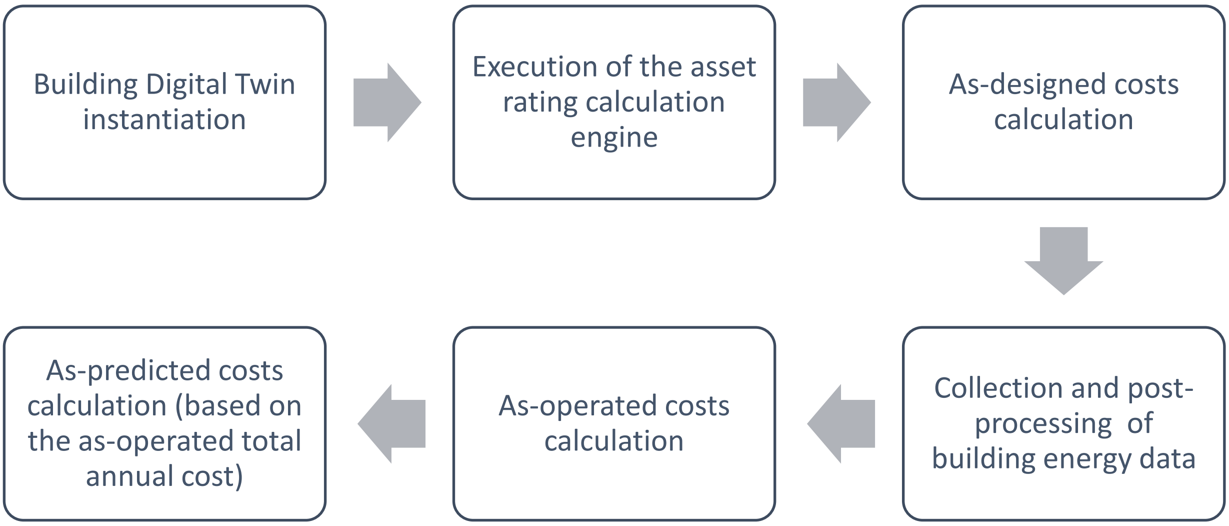


**Figure 25: Financial Indicators calculation procedure**

When the calculation has finished, results can be presented as follows. Three different graphs are presented as a result. The top ones show the results for the as-designed building and the as-operated building. The user can choose between four different options on these graphs, namely the monthly cost per energy carrier (electricity, natural gas…), the monthly cost per use (cooling, heating, lighting…), the monthly total cost and the monthly total cost per square meter. Lastly, the third graph shows the as-predicted values for the building, representing the real energy cost (green), the nominal cost (blue), and the net present value of the costs (purple).


**Figure 26 Results for cost & economic indicators**

<u>Related Submitted Deliverables:</u>

- D4.1 Building Performance Module v1
- D4.5 Building Performance Module v2
- D4.8 D^2EPC Digital Platform v2

### 1.2.12 Added value services suite

The Added value services suite component consists of 3 different subcomponents with different objectives. The first subcomponent, the Roadmapping tool, creates potential recommendations for the building's asset-based data. The second subcomponent, AI-driven performance forecast is responsible for building operational suggestions based on monthly load predictions. The final subcomponent, the Alerts and Notifications Module provides alerts and notifications to the end-user based on the results of the Roadmapping tool and AI-driven performance forecast.

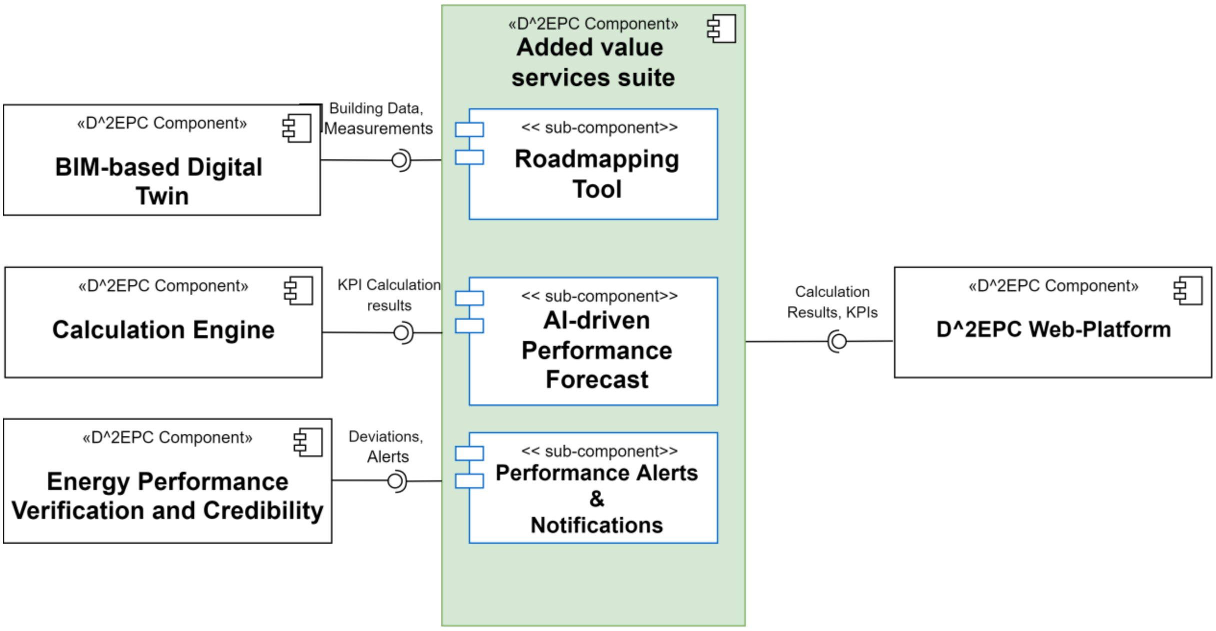


Figure 27: Added value services suite - Architectural view

In more detail, the purpose of the Roadmapping tool is to evaluate and assess the building as a whole in terms of energy performance, emission, and cost carrier in order to provide building-specific recommendations and user-centred suggestions. The suggestions can further enhance the building's energy performance and upgrade its EPC classification within an indicative timeframe. This BIM-based decision support tool identifies the optimal course of action towards improved energy efficiency and can further feed the relevant building renovation passport.

The overall workflow can be described in Figure 28, where the main objective of improving the EPC classification can be achieved through three main categories. Each category consists of several actions to improve the building's energy efficiency. The diagnosis procedure includes the identification of the element and the element's specific characteristics. The technical characteristics of each building element category (e.g., U-values of walls) are compared with the respective values of specified standards. In the case that there is a "Violation of Standards," the diagnosis ends, and a renovation action is proposed, as indicated in Figure 28.

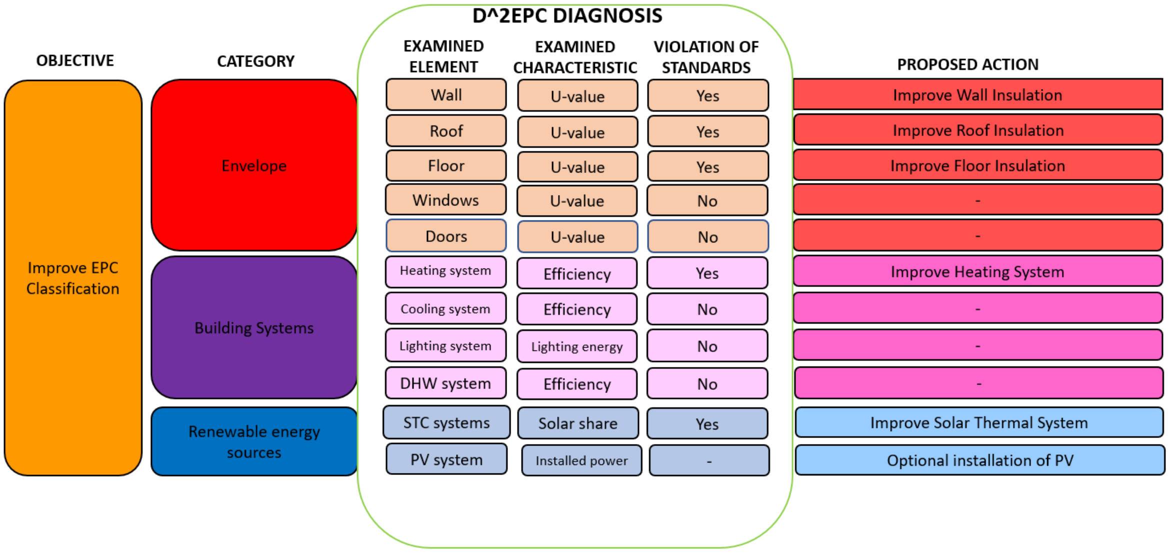


**Figure 28: Workflow of the Roadmapping tool**

Once the relevant actions are identified, they need to be evaluated regarding the effect they have on the improvement of the building's energy performance class. This means that for each action, a scenario is generated to evaluate how much the energy performance has improved. Based on that, a priority list is formed, indicating which action will result in the highest performance improvement with the most efficient economic return. Such prioritisation is valuable information for the user as it provides a guideline for energy and economically efficient EPC improvement.

The results are forwarded to the D^2EPC Web Platform to depict meaningful indicators to the end user in a user-friendly way. Figure 29 illustrates the general overview of Roadmapping's tool results.

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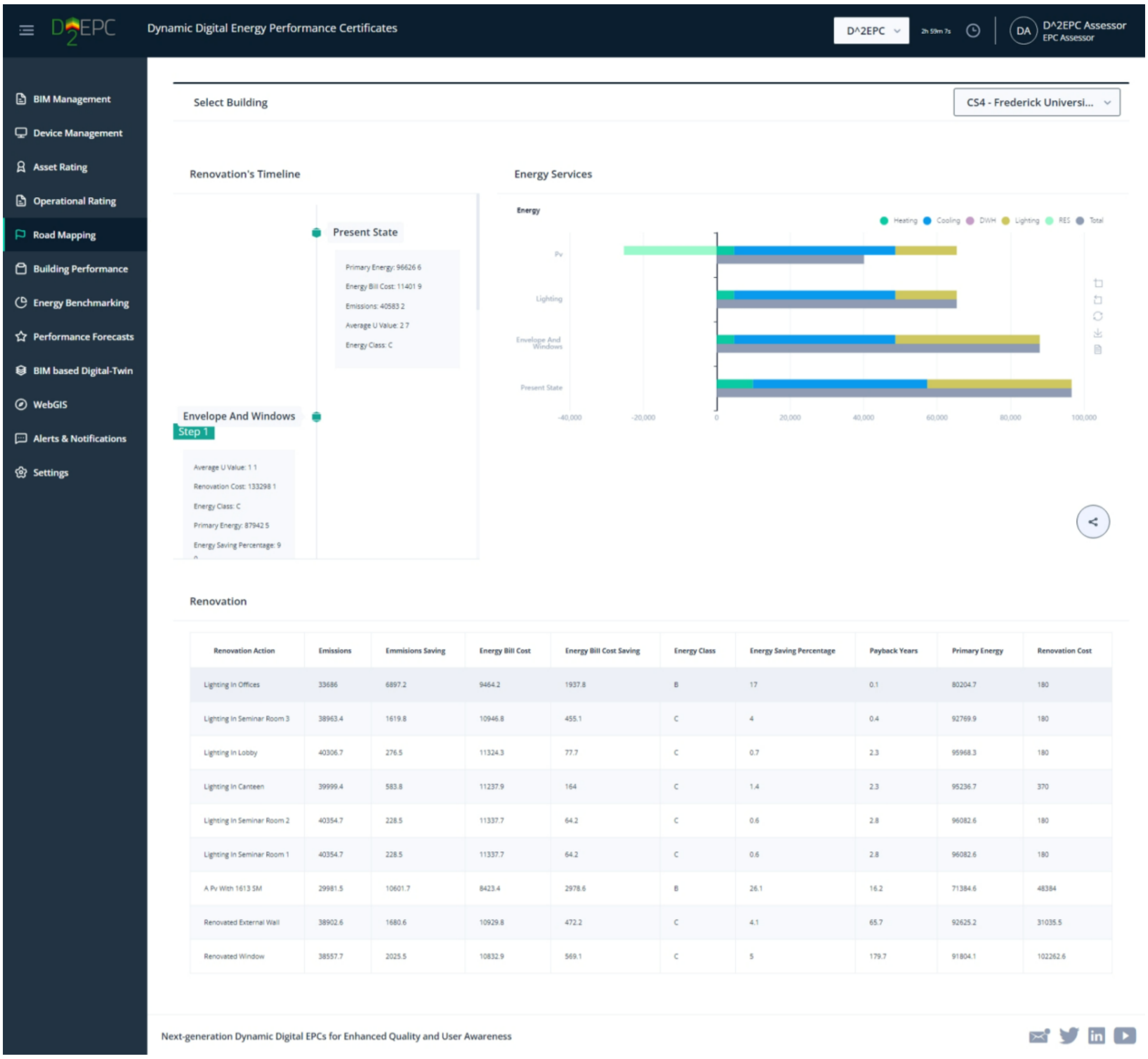


Figure 29: General overview of Roadmapping tool result in the Web Platform

In the last couple of years, great strides have been made towards increasing the accuracy and the algorithmic complexity of Artificial Intelligence methods that aim to predict the energy consumption or the electrical load of residential and industrial buildings. These methods can be categorised as short-term, mid-term, and long-term energy consumption forecasting. In the context of D^2EPC, the main idea concerning the AI-driven performance forecast is to implement a method for long-term load forecasting with monthly intervals. To that end, various architectures were tested using GRUs, LSTMs, Fully Connected Layers, and the XGBoost algorithm. Apart from energy consumption, weather and temporal data were used. For the initial experiments, the data used include:

- The energy consumption (in KWh)
- The average outdoor temperature (in Celsius)
- The maximum outdoor temperature (in Celsius)
- The minimum outdoor temperature (in Celsius)
- The day of the week
- Binary mask for weekends
- The month of the year

The goal of the AI-driven performance forecast module is to forecast the energy consumption of the following month. Its output will be forwarded to the Operational Rating module where it will estimate how much the excess or lesser energy consumption will impact the building's Operational Rating in a 6-month or 12-month window. The operational rating has been integrated into the AI-driven performance forecasts, and the tool can inform the user about changes in the rating of their property depending on his consumption patterns, for better or worse.

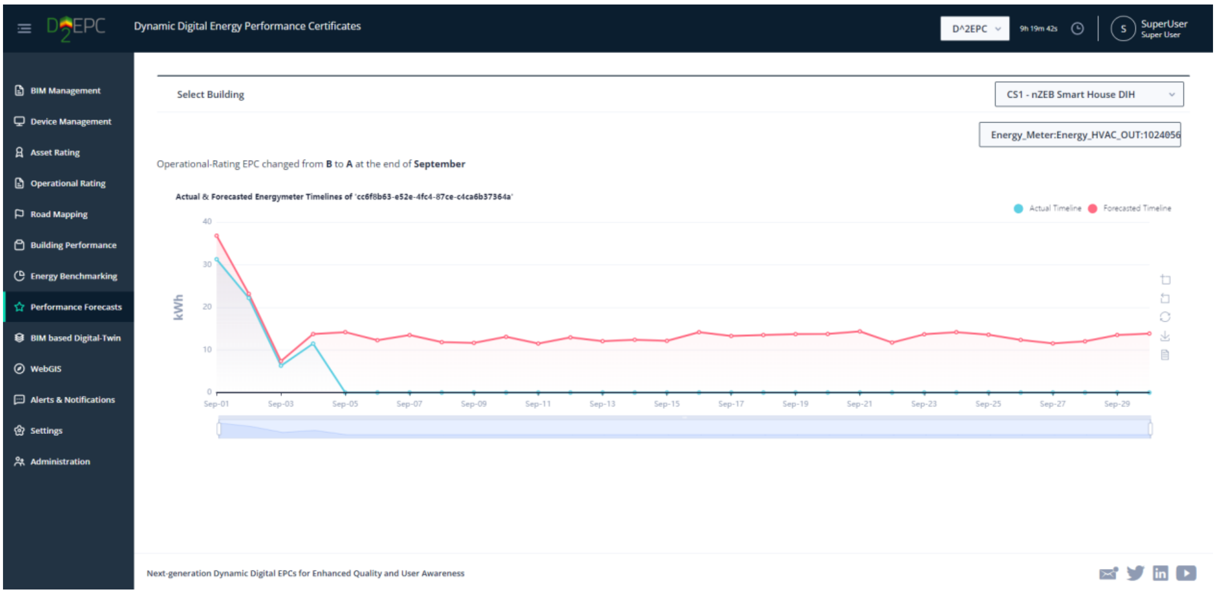


Figure 30 Performance Forecasts page

Figure 30 showcases the AI driven Performance Forecast page as part of the D^2EPC Web Platform. A graph for each metering device of the building displays the predicted and actual daily energy consumption for the current month. Additionally, a message allocated on top of the chart informs the user about any potential change of the as-operated EPC class, based on the aforementioned prediction.

Last, the Alerts and Notifications sub-component seeks to provide notifications or alerts to the end-user. The Notification context depends on the interaction with the Roadmapping tool or AI-driven Performance. Interaction with the Roadmapping tool message contains information about optimal energy performance recommendations. In contrast, the AI-driven performance forecast depicts the impact of end-users' energy behaviour. Each D^2EPC tool supports the following notifications:

| | |
|---|---|
| Roadmapping Tool: | • Issuance of new renovation suggestions with high efficiency that are expected to have a direct impact on the building's performance.<br>• Warnings/ errors regarding the input information and the output of the asset rating calculation engine. |
| AI Performance Forecasts | • Issuance of an updated forecast of the building's as-operated energy performance.<br>• Predicted alteration of the buildings as operated energy performance (upgrade/downgrade) regarding the one included in the last issued EPC. |

| | |
|---|---|
| | • Warnings/ errors regarding the input information and the output of the operational rating calculation engine. |
| Calculation engine | • Issuance of an updated asset-based/operation-based EPC.<br>• Issuance of an updated set of calculated static or dynamic indicators.<br>• Warnings/ errors regarding the input information and the calculation processes.<br>• Suggestions towards improving any detected unfavourable building conditions in terms of human comfort. |
| Energy Performance Verification & Credibility | • Warnings/ errors regarding real-time data quality. |

The operation of the component and its information exchange with other components is illustrated in Figure 31.

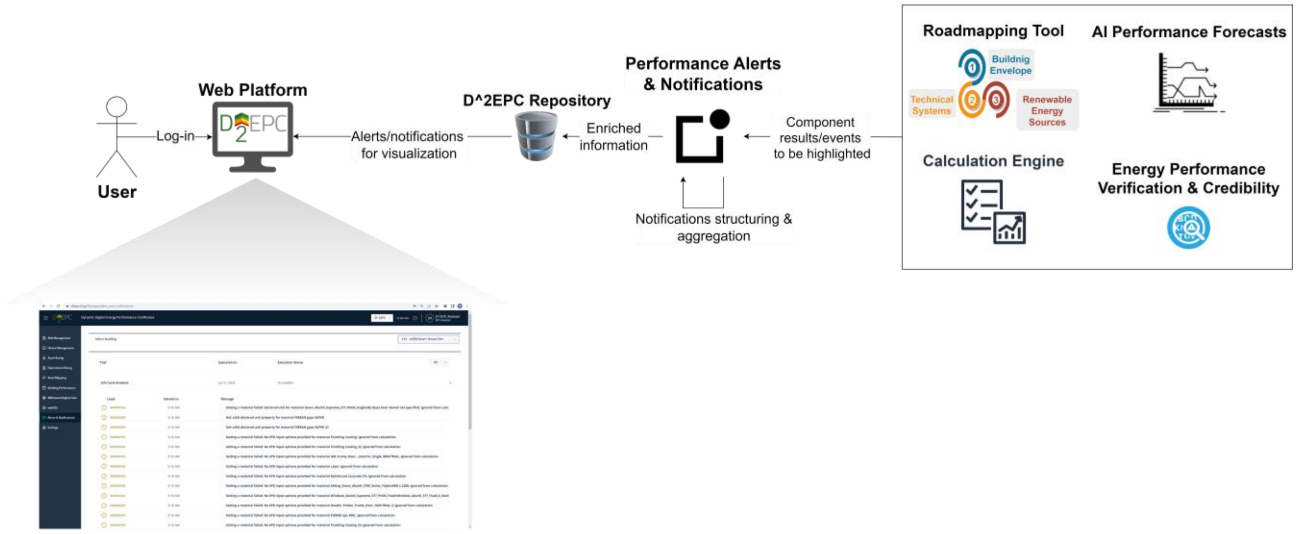


**Figure 31: Performance alerts & notifications component interactions**

Collecting and visualising available notifications is based on periodic data retrieval from the D^2EPC Repository. This asynchronous design stems from the fact that the output of the tools, based on the gathered real-time and static data, is not expected to be updated in high frequency rather than over a wider timeframe.

Figure 32 displays the designed web interface. The produced notifications are organized per tool, annotating the corresponding execution time. Within each expanded list, the notifications generated by the corresponding tool are provided, indicating the alert level, the time that the alert was recorded and the included message. The user can filter the notifications based on the aforementioned alert level.

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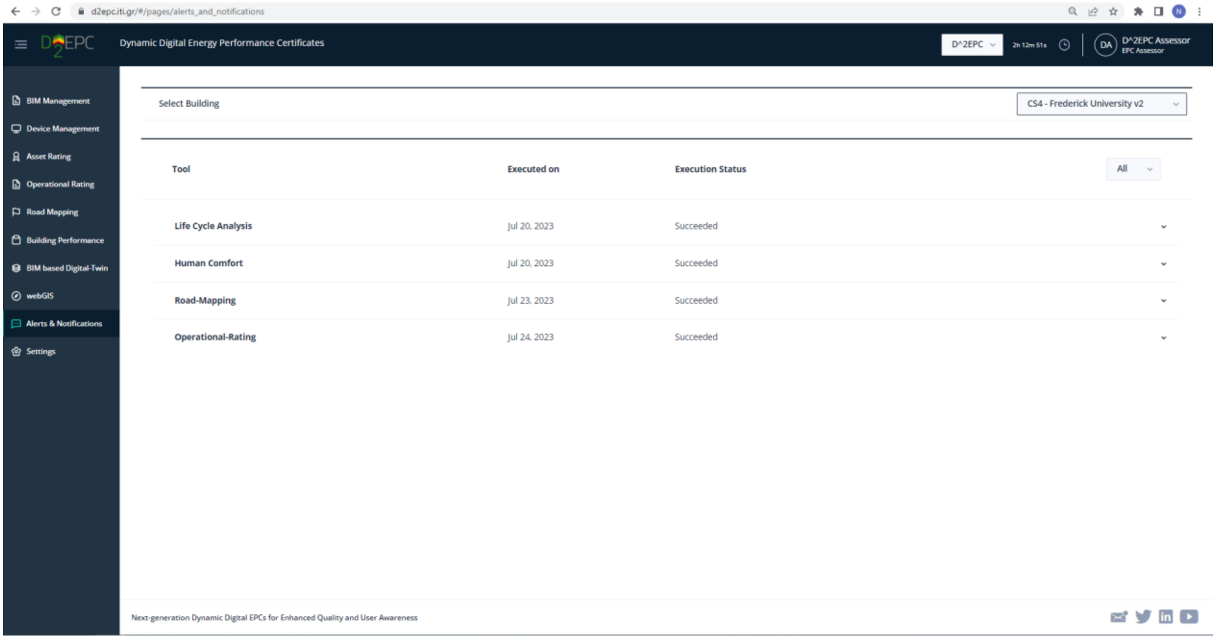


**Figure 32: Performance alerts & notifications tool interface**

Related Submitted Deliverables:

- D4.2 Added value services suite v1
- D4.6 Added value services suite v2
- D4.8 D^2EPC Digital Platform v2

## 1.2.13 Extended dEPCs applications toolkit

T4.3 "Extended dEPCs applications toolkit" is the task focusing on the design and development of the Extended dEPCs applications toolkit. The latter is a composite component including tools that deliver various services to the end-users of D^2EPC platform. The task is segmented into two subtasks offering two different modules, the T4.3.1 Building Energy Performance Benchmarking (EPB) and T4.3.2 Energy Performance Verification & Credibility (EPVC). For the completion of the task, CERTH/SEC took over the delivery of EPB and Hypertech the EPVC.

Within T4.3.1, a classification mechanism is delivered to benchmark the buildings under study based on configuration data and KPI results. This mechanism steps on data-mining techniques to enable the categorization of buildings, taking into account metrics linked to the building's operation and human-centric features. The main purpose of the module is to act as a basis for informing future dynamic EPC users whether they meet the set performance criteria or not and which paths should be followed for performance improvements.

To classify buildings, a proper dataset was constructed in order to test the most suitable clustering algorithms. The dataset consists of building metadata, including primary space use labels and the other essential building characteristics and data related to the SRI framework, Operational Rating Class and contributing factors and Asset Rating Class, as described in the following table.

**Table 12 Benchmarking Dataset with building characteristics and energy performance indicators**

| DATASET COLUMNS | | |
|---|---|---|
| Heating (SRI Domain) | SRI Score | Total GWP (kg $CO_2/m^2$) |

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| | | |
|---|---|---|
| Cooling (SRI Domain) | SRI EPC Class | Total GWP category |
| Ventilation (SRI Domain) | Asset Rating EPC Class | Country |
| Lighting (SRI Domain) | Operational Rating EPC Class | European Region |
| DHW(SRI Domain) | Cooling(Operational Rating Annual Primary Energy) | Building Category |
| Electricity(SRI Domain) | Heating(Operational Rating Annual Primary Energy) | Primary usage |
| Dynamic Envelope(SRI Domain) | Electrical Appliances & Lighting (Operational Rating Annual Primary Energy) | Construction Year |
| Monitoring & Control (SRI Domain) | On-site RES (Operational Rating Annual Primary Energy) | Construction Decade |
| Electric Vehicle Charging (SRI Domain) | On-site RES Label | Building Area |
| Building Area Label | - | - |

To continue with, clustering results are analyzed, and a general report is composed after post-processing for each one of the clusters. Apart from computing building categories, the classification mechanism is utilized for functionality conducted by the other benchmarking sub-components as well.

EPB communicates with the appropriate components within D^2EPC to extract the necessary information and deliver the calculated results. More specifically, it interfaces with the Digital Twin to retrieve the building information as well as the project's common Repository to obtain KPIs, weightings and reference values. Finally, the component provides the benchmarking results to the D^2EPC Web Platform while any updated reference values are stored in the project's Calculation Engine. Figure 33 presents a functional diagram that includes the entirety of the EPB's interactions.

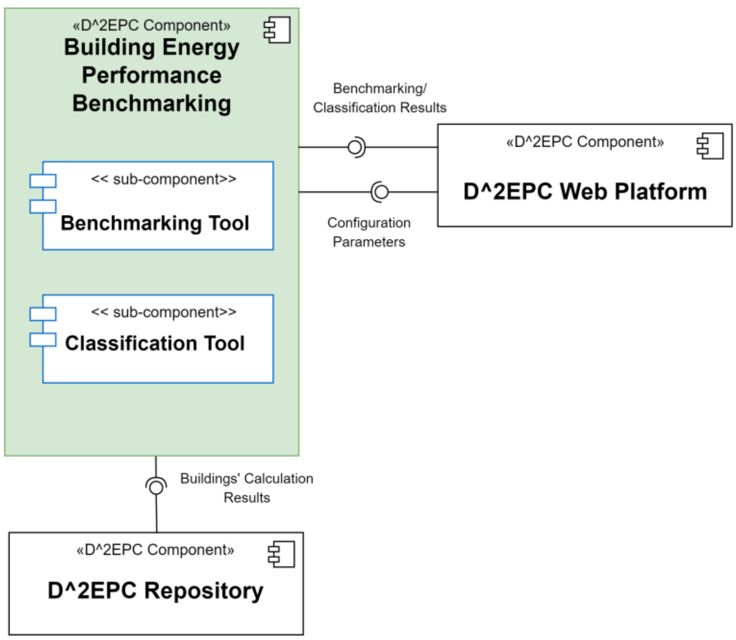
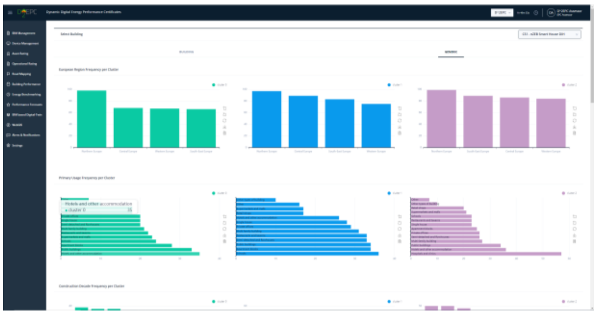



Figure 33 Building Energy Performance Benchmarking Functional Diagram

The results of the EPB tool are provided in the Energy Benchmarking page of the D^2EPC Web Platform, depending on the user access rights. Figure 34 a) displays the first tab that is available for all users and demonstrates the building's performance against other buildings that belong to the same generic cluster group that has been defined by the designed classification mechanism, in terms of asset-based and operation-based EPC results, SRI scores and total GWP. The user is also able to select custom classification parameters (construction decade, primary usage, European region, country and building area) in order to limit the comparison of the building's performance to be applied to buildings with specific similar characteristics. The second tab of this page is shown in Figure 34 b) which provides a generic overview of the entire building dataset and is designed to be accessed only by users with an *Authority* role. Based on the provided classifications, useful results can be extracted towards correlating energy performance with smart readiness, European region, construction year and primary usage. A subset of buildings can also be examined, based on the classification parameters that were mentioned above.

a)



b)

**Figure 34 Energy Benchmarking page – a) Building tab; b) Generic tab**

Within T4.3.2, a component is delivered to undertake the verification process for the entirety of dynamic data captured by the IoT infrastructure in the D^2EPC pilots and guarantee the reliability of the data collection. The Energy Performance Verification and Credibility (EPVC) module is designed to constantly monitor the status of deployed devices and check specific data quality features in an automatic and continuous manner.

EPVC is a composite component that comprises two separate sub-components: the Data Quality and the Network Monitoring Tool. The former takes the data quality assessment a step further, by introducing a new set of data quality checks (shape, range, missing values, positivity, monotonicity) on the streaming dataset (beyond the outlier detection and treatment already implemented in the IML component). Its purpose is to identify errors that jeopardize the adequacy and usability of dynamic data utilized for the EPC calculation. The tool includes the necessary scripts that identify extreme, missing or stuck values and is also able to infer the operational status of all IoT devices in the project's demonstration cases (device status is not foreseen in the D^2EPCs information model). Combined with the already-available network monitoring tool (in Hypertech's solution) a Credibility UI has been delivered (updating the previously available Network Monitoring Tool) informing the user for any disruptions in the operation of smart devices. Additionally, the UI includes information about the captured measurements covering specific characteristics along with the overall quality of the examined metrics.

EPVC communicates with the Information Management Layer, which gathers all data extracted from the D^2EPC pilots. After a series of checks performed on the datasets, EPVC streams the processed information to the D^2EPC BIM-based Digital Twin (DT), which corresponds to a virtual representation of the project's demonstration cases. If the data quality is not acceptable, an alert is generated and sent to the Performance Alerts and Notification module, which is responsible for connecting and pushing notifications to the D^2EPC platform. In parallel, EPVC forwards the credibility alerts and other related information to the Credibility UI to be presented to the end-user.

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In Figure 35, a functional diagram is presented, highlighting the interactions between the EPVC and other D^2EPC components as described in the project's architecture.

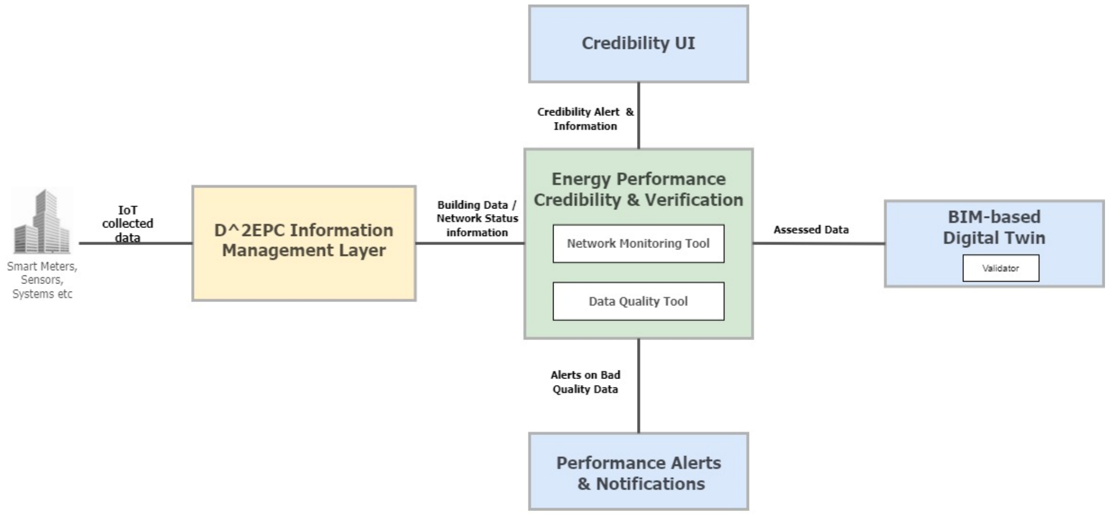


**Figure 35. Energy Performance Verification & Credibility Functional Diagram.**

In Figure 36, the main dashboard of the monitoring tool is provided. Starting from the left, a list of the available prosumers (per pilot) is presented, along with the overall status of the corresponding network and the number of devices that remain active. In the upper middle and right part of the dashboard, the percentages of active IoT gateways and devices in total are offered via pie charts. Finally, an interactive map is also delivered to the user, indicating the location per prosumer (in a GDPR-compliant manner).

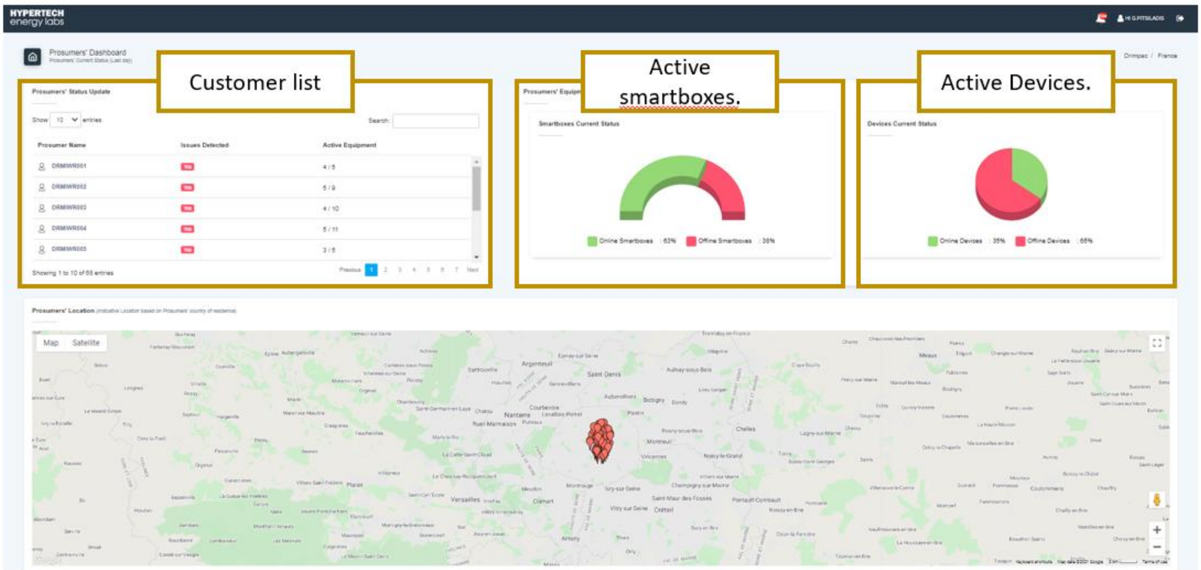


**Figure 36. D^2EPC monitoring tool main dashboard**

In addition, the Credibility UI delivered by the EPVC tool has a dedicated interface, where the user is being redirected when selecting the appropriate button in the Web Platform. A new user login is required, as different user roles are considered for the two platforms. Following next, the operational status of the deployed meters and sensors along with various data quality metrics can be viewed for building devices of interest, as in Figure 37.

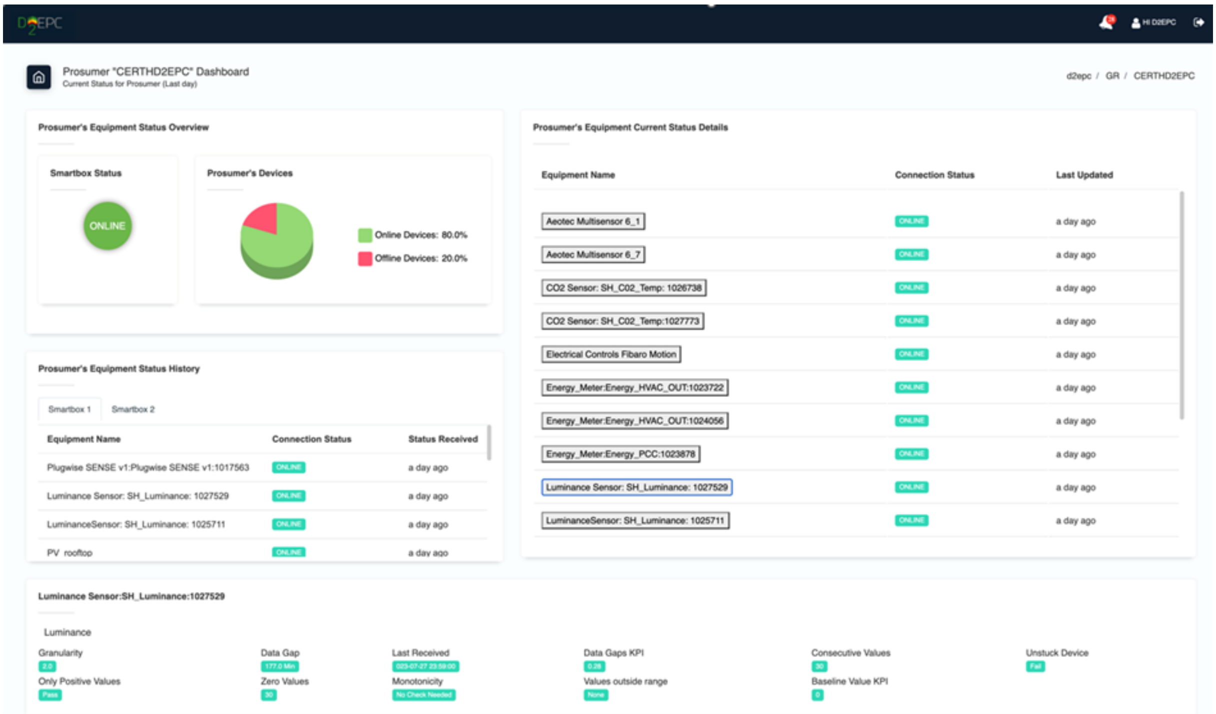


**Figure 37 D^2EPC Credibility UI**

<u>Related Submitted Deliverables:</u>

- D4.3 Extended dEPCs applications toolkit v1
- D4.7 Extended dEPCs applications toolkit v2
- D4.8 D^2EPC Digital Platform v2

## 1.2.14 D^2EPC Web Platform

The D^2EPC Web Platform hosts the parametrization of the processes as well as the presentation of all the results from the various components and sub-components, such as the EPCs, the KPIs, recommendations and notifications, etc. The D^2EPC platform, as part of the presentation layer, queries information from the D^2EPC Repository. Employing visual analytics, the platform delivers a user-friendly and information-reach environment for the D^2EPC end-users to interact with.

Given the dynamic aspects introduced by the D^2EPC, through the Web Platform the user is able not only to adjust and configure certain components, but also to directly request the execution of certain processes ad-hoc, for updating the EPC results.

From an end-user perspective, the Web Platform provides a personalized environment to facilitate interaction with the D^2EPC ecosystems. Firstly, the EPC assessor has extended access to the provided functionalities, as they can insert information required by the assessment process and authorize the various calculations. As a typical building BIM file usually lacks all the documentation required to perform the whole spectrum of the D^2EPC calculations, the Web Platform provides the necessary interfaces that show the missing information and enable the assessor to easily add them. Furthermore, they allow to check the building's existing documentation in the BIM file and make modifications to correct any inconsistencies or update the building information in the case of a renovation action. At the building owner level, the Web Platform offers a demonstration of the results from all the performance assessment calculations, as well as, of all the high-level (non-technical) information that assist them to reduce their energy consumption and improve the overall rating. Finally, access to a third-party user (authorities, market, or research/academia) is also considered, providing aggregated

EPC results and KPIs to gain a clear picture of the building stock's energy performance. In particular, following the SaaS approach, SEC has developed an experimental server-based service to test the third-party integration of the D^2EPC services. The service, which is implemented using the PHP language and capable of processing JSON input and outputting SVG graphics, has demonstrated the integration and use of the operational rating calculation engine

The software *Backend* comprises the common structure under which the D^2EPC services are provided. Its development is based on Python[19] 3, which is one of the most adopted programming languages, simplifying software development both during the creation and maintenance phases. In addition, many open-source packages are available, which can be used to build extended functionalities in any application. Within the D^2EPC backend, these include:

- Flask[20], which has been used to design the various API routes that correspond to platform functionalities. It is a micro web flexible framework that provides customizable functionality to the developer through extensions. Available extensions support form validation, upload handling, object-relational mapping, several authentication technologies and other framework tools.
- SQLAlchemy[21], an open-source SQL toolkit and object-relational mapper (ORM), which has been used to link the backend with the D^2EPC Repository.
- Marshmallow[22], an ORM/ODM/framework-agnostic library for converting complex datatypes, such as objects, to and from native Python datatypes. The package has been used for developing the validation features of the Web Platform.
- Pandas[23], a data analysis and manipulation tool, which has been used for data structuring and post-processing.

Since all the *D^2EPC tools* have been developed as Python software packages, they have been integrated into the backend similarly to the aforementioned libraries. On the other side, the *D^2EPC Repository* serves as the common storage location for user input data (personal information, BIM files, calculation parameters etc.), configuration parameters, device measurements and service outputs. It is based on PostgreSQL[24], which is an open-source DBMS.

The software *Frontend* is the main presentation layer of the D^2EPC solution and features all the designed user interfaces, which will be described in the following section. Its development relies on the Angular[25] web development framework.

When initially accessing the platform, the user is provided with a registration page, as shown in Figure 38, where the required parameters can be inserted to create a new account and select the appropriate user role. Following the administrator's approval, an email is automatically sent to the provided address to announce the successful registration. The user is then able to log in to the platform through the provided sign-in page. Apart from sign-in and registration, the initial user interfaces include a password recovery page, where an email is sent to enable the password update.

[19] https://www.python.org/
[20] https://flask.palletsprojects.com/en/2.3.x/
[21] https://www.sqlalchemy.org/
[22] https://marshmallow.readthedocs.io/en/stable/
[23] https://pandas.pydata.org/
[24] https://www.postgresql.org/
[25] https://angular.io/

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**Figure 38 Registration page**

Three main user roles for the Web Platform have been determined as described above, which entail different granted access privileges and can be selected during the registration process. The *EPC Assessor* is eligible to perform all the available actions related to building performance assessment. Such users are able to:

- Upload and validate BIM files;
- Share BIM files with other users;
- Register new sensing/metering devices;
- Issue an EPC;
- Calculate the building performance indicators;
- Manually insert historical data measurements;

On the other side, the *Building Tenant* role is not able to edit the assessment parameters of the different provided services and is limited to viewing the calculated results.

The third user role is the *Authority*, which is reserved for accessing parties with a wider overview of the building assessment results, e.g., within a region or a country. Such users are also allowed to execute extended functionalities of the Energy Performance Benchmarking tool, in order to gain insights into multiple building performance data.

Apart from the latter, a fourth user role has been determined and concerns the overall system's administration, which allows full access to all building performance data that have been uploaded to the Web Platform, as well as for user management purposes.

Figure 39 shows the first page that is shown to the user after log-in. The navigation panel on the left side allows to toggle between the different pages for each service/platform functionality, while the menu on the top right corner that appears by clicking on the username loads the Profile page (Figure 40). In the latter, the user is able to modify the appearing name and the login password, upload a profile picture and to view personal information including the user's unique identifier, which can be used for BIM file sharing. An API key management functionality has also been integrated, which enables the user to generate unique API keys and use the Web Platform's services without the need to log in via a web browser, e.g., via third-party applications.

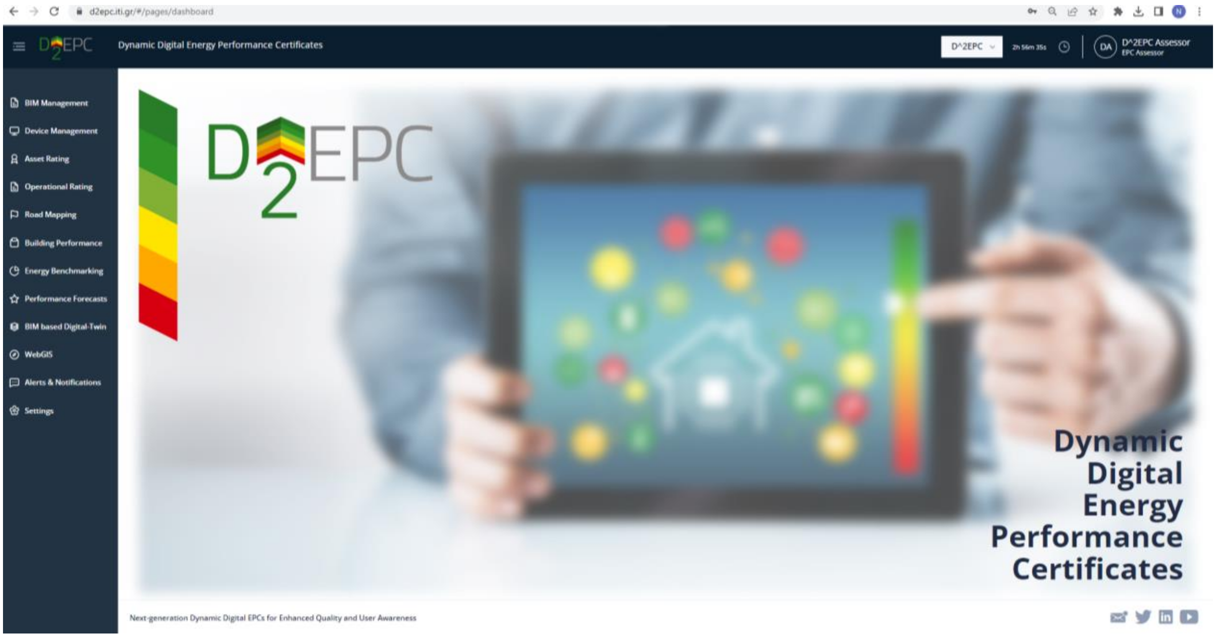


Figure 39 Main dashboard

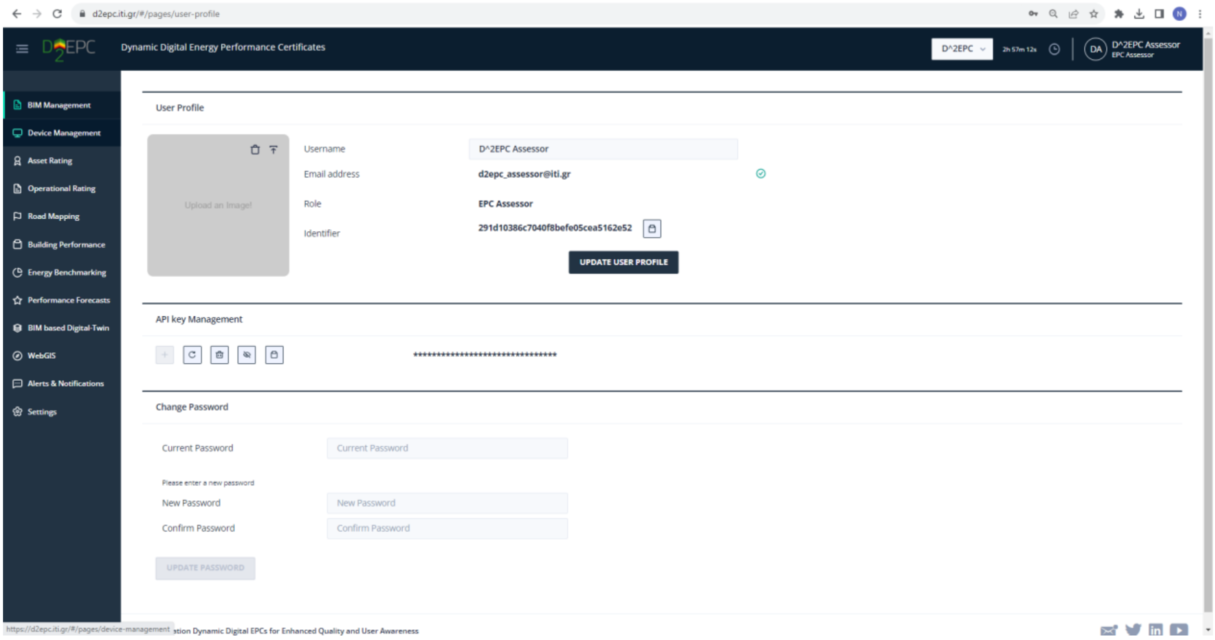


Figure 40 Profile page

<u>Related Submitted Deliverables:</u>

- D4.4 D^2EPC Digital Platform v1
- D4.8 D^2EPC Digital Platform v2

## 1.2.15 D^2EPC WebGIS

The D^2EPC WebGIS tool has been designed and developed under task T3.2 “Development of a GIS scheme for EPC documentation”. As a sub-component of the representation layer, the WebGIS tool is an application that functions as an endpoint between end users and the D^2EPC platform providing

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EPC-related statistical data in regional level, 3D BIM models documentation and advanced querying and visualisation functionalities. The application is also designed to operate independently from the D^2EPC Web platform while also being able to connect to the main repository and the respective geospatial database (DB) for updating its contents. The D^2EPC WebGIS application incorporates the open-source RDBMS PostgreSQL for storing and handling the building-related generated data. Moreover, it employs postgres and PostGIS extension for handling the geospatial data. Additionally, towards optimizing the dissemination and map creation for the data contained in PostgreSQL the usage of the Geoserver web server has been deployed.

Based on the flexible dockerised design and implementation of the GIS framework it can be easily expanded to enable extra functionalities and data display based on the information stored per building (e.g., calculated economic indicators). For anonymisation and privacy protection purposes, the economic indicators statistics can be automatically calculated per NUTS region, as it has already been deployed in the corresponding PostGIS extension.

The D^2EPC GIS is a novel web application tool, built exclusively using open-source technologies, and is integrated into the main D^2EPC platform. Additionally, it can be easily expanded with extra functionalities in a possible future version and can be easily integrated into external hosts through nginx web server dockerization. It consists of a separate geodatabase, a server for exposing OGC services and a web application (front-end and backend). Below, some representative screenshots of the application are shown with the addition of dummy data for demonstration purposes.

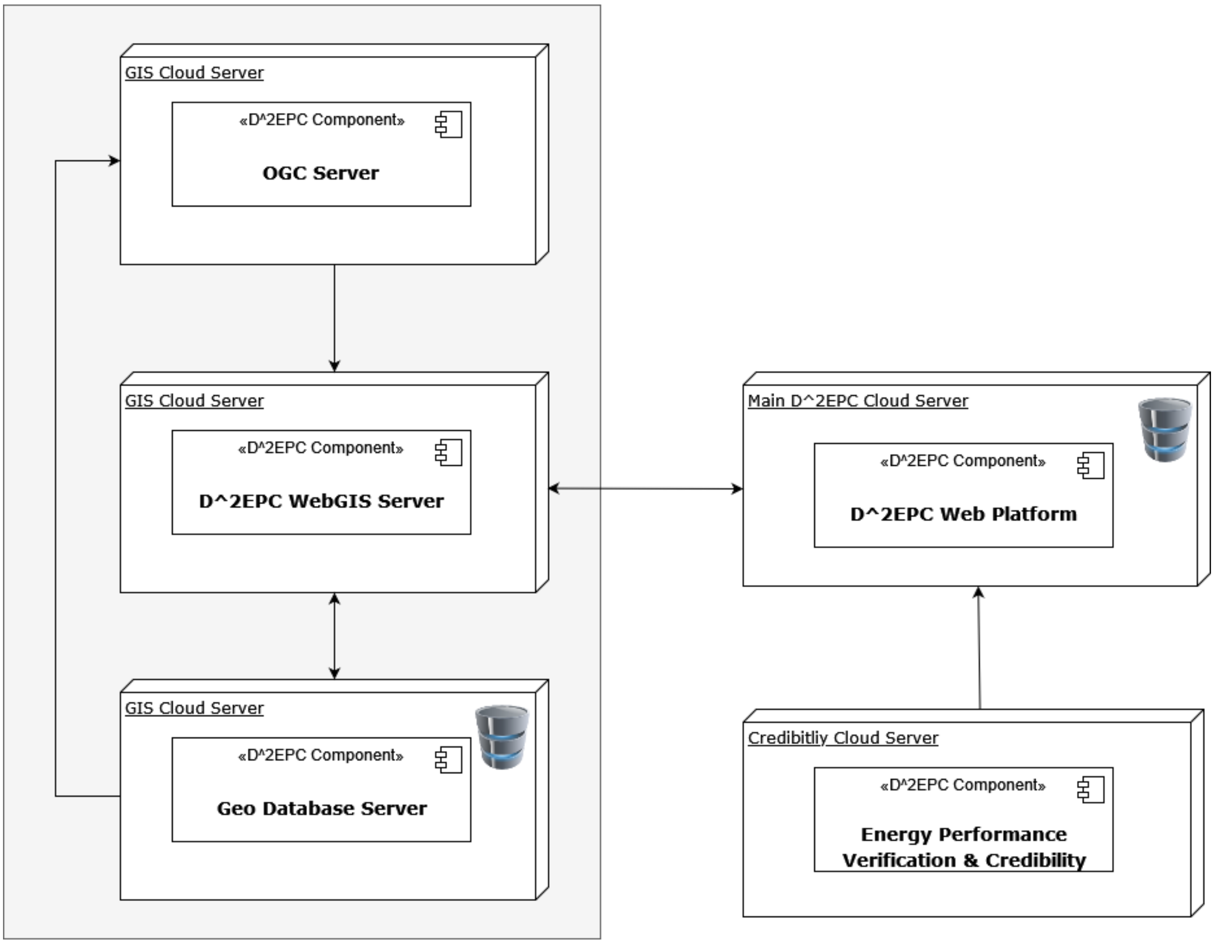


Figure 41: D^2EPC WebGIS Tool deployment diagram

The main functionalities of the D^2EPC WebGIS are mentioned below:

- Produce statistics for dEPC issued by D^2EPC framework for Nomenclature or territorial units for statistics as defined by Eurostat (NUTS).
- Visualize EPC statistics on map (WebGIS).
- Provide spatial & attribute EPC-related queries.
- Compare EPC statistics for different regions and geographical scales.
- Disseminate data via OGC (Open Geospatial Consortium) services.
- Visualize BIM models on map for pilot case buildings.


Figure 42. D^2EPC WebGIS homepage overview

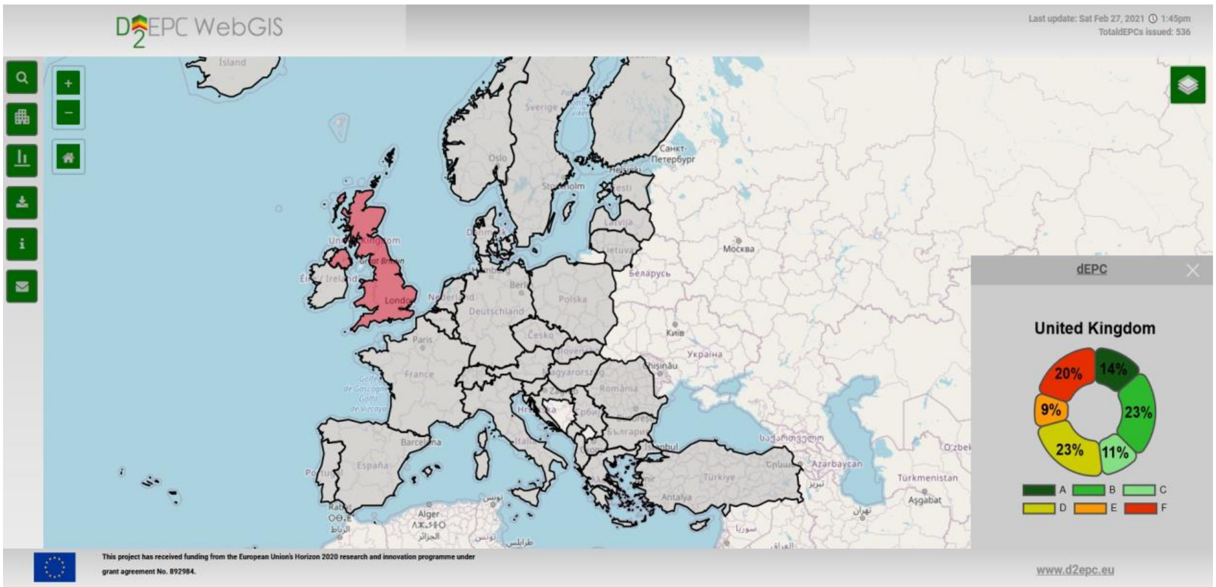


Figure 43. Provision of EPC statistics on a selected NUTS region


Figure 44. Visualisation of dEPC statistics for two regions in comparison mode

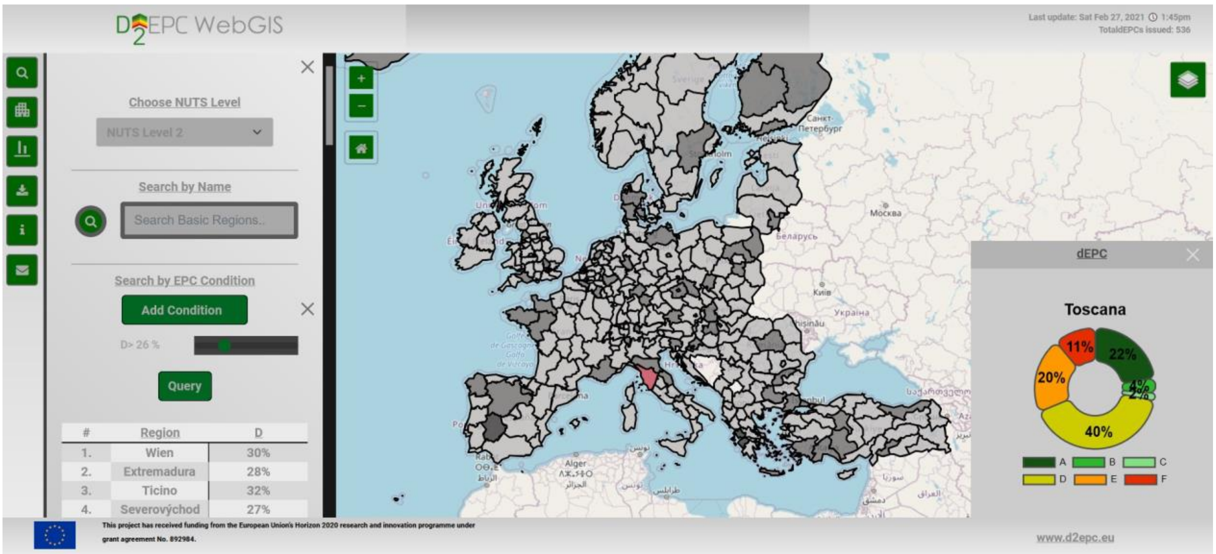


Figure 45. Attribute query and visualisation of dEPC for selected region

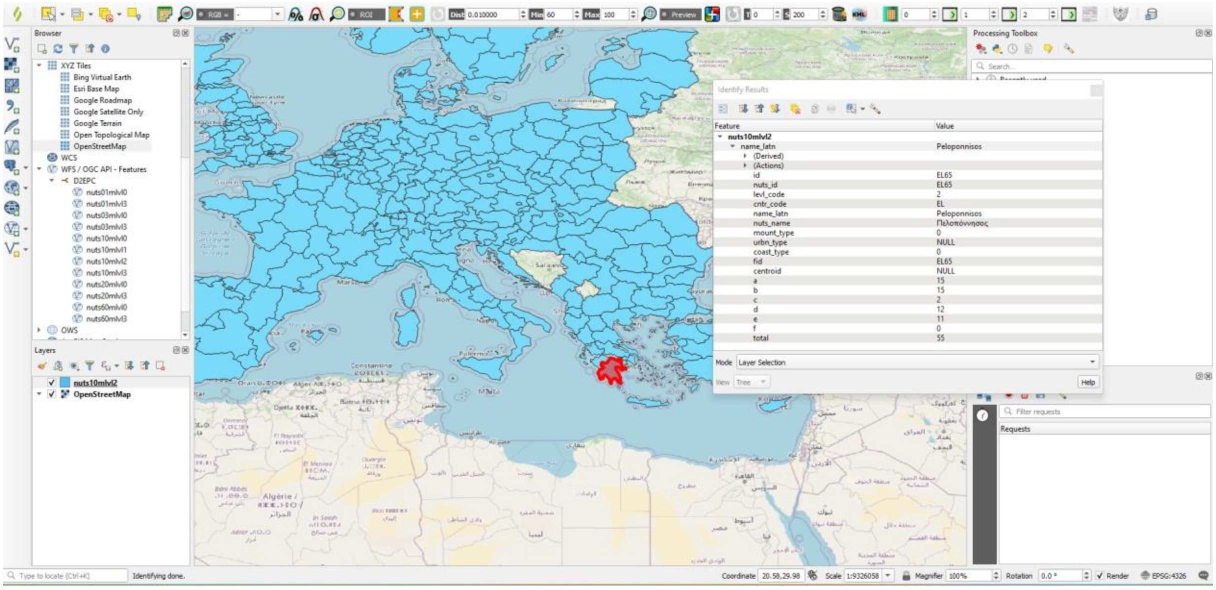

Figure 46. Provision of OGC services

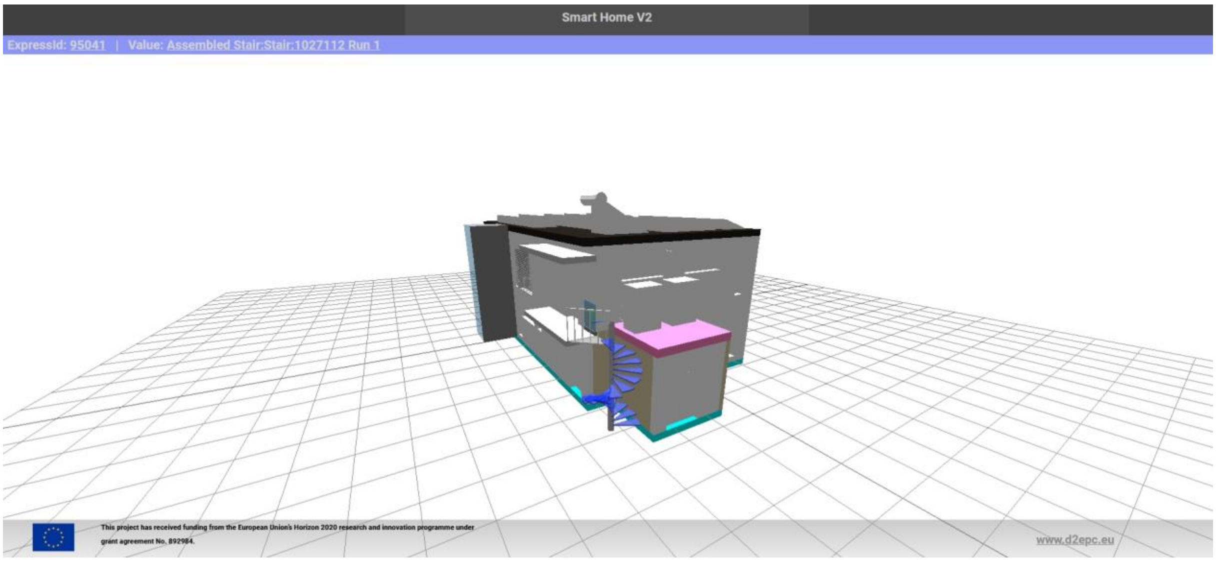


Figure 47. 3d fully interactive visualisation for a pilot case building's BIM file

<u>Related Submitted Deliverables:</u>

- D3.2 Design and Implementation of the D^2EPC GIS Tool
- D4.8 D^2EPC Digital Platform v2

## 1.2.16 Contribution to standardization

Two D^2EPC partners are standardization bodies, i.e., ASI (Austria) and UNE (Spain), leading two separated tasks: Task 6.1 "Updating of current standards towards dynamic EPCs" (ASI) and Task 7.3 "Contribution to standardisation activities" (UNE).

As part of Task 6.1, a survey has been developed to collect missing standardization elements and identify gaps. The survey was circulated to project partners as well as was made available to the public. The aim of the survey was to identify the standards, regulations and frameworks used by the respondents, to understand the shortcomings of the available standards, related to the Energy Performance Certificate, to reveal the areas that are lacking adequate standardization from the point of view of the respondents, and finally to identify any information (gaps) that the mentioned documents miss from the point of view of the respondents. A vast majority of the survey respondents supported the statement that standards from the following areas are useful and relevant for the Energy Performance Certificate in terms of applicability and being extensive:

- **Energy requirements and the thermal quality of buildings**: CEN/TC 089 "Thermal performance of buildings and building components", CEN/TC 371 "Energy Performance of Buildings", ISO/TC 163 "Thermal performance and energy use in the built environment" and ISO/TC 205 – Building environment design";
- **Heating and Cooling systems**: CEN/TC 228 "Heating systems and water-based cooling systems in buildings" and ISO/TC 86/SC 6 "Testing and rating of air-conditioners and heat pumps";
- **Control technology and automation systems**: CEN/TC 247 "Building Automation, Controls and Building Management" and ISO/TC 184 "Automation systems and integration";
- **Aspects influencing energy certificate**: CEN/TC 33 "Doors, windows, shutters, building hardware and curtain walling", CEN/TC 156 "Ventilation for buildings" and CEN/TC 169 "Light and lighting";
- **Sustainability**: CEN/CLC/JTC 10 "Energy-related products – Material Efficiency Aspects for Ecodesign", CEN/TC 350 "Sustainability of construction works" and ISO/TC 59/SC 17 Sustainability in buildings and civil engineering works";
- **BIM** (**Building Information Modelling**): CEN/TC 442 – Building Information Modelling (BIM).

In addition, the lack of European standards for operational rating of an Energy Performance Certificate was identified through this surveys as well as European standards for data exchange between CAD from planning and EPC software, EPC software and EPC registries and EPC Data repositories and need owners.

The result of the examination of the survey as well as the update of the standardization landscape (presented in D6.1, Strategic Standardization Plan v1) is included in D6.5.

To maximize synergies and enhance the impact of the project through standardization, the activities in Task 6.1 are aligned with the activities undertaken in Task 7.3 Contribution to standardisation activities, led by UNE.

Task 7.3 developed a study of the *state of the art* in order to draft the standardisation route for D^2EPC. D7.4 summarised these activities. Based on this route, Task 7.3 promoted regular contacts with the main committees (in particular CEN/TC 371) or working groups related with the activity and results of D^2EPC. This task also assessed relevant documents from CEN/TC 442 (BIM and digital twins) and CEN/TC 350 (sustainability in construction), in order to use this information for the development of D^2EPC methodologies and, in some cases, as a source of feedback and peer-review of the developments. As part of these activities, D^2PC proposed the inclusion of aspects of operational EPC in the guidance document for the Systematic Review of the EPB standards made by several international (ISO) and European (CEN) committees.

In addition, CEN/TC 371 was contacted to propose and succeed, in 2022, the creation of a **new standardisation working group** covering operational rating of the energy performance of buildings, with Paris A. Fokaides (FRC) as Convenor and Aitor Aragón (UNE) as Secretariat.

This CEN/TC 371/WG 5 "Operational rating of energy performance of buildings" had its first meeting in October 2022 and made a proposal for a **new standard on operational energy performance rating for buildings**. The ballot for approval of this new project finalised in February 2023, and it is currently registered in CEN system as WI=00371012, *Energy Performance of Buildings — Operational rating —* ***Requirements for assessing operational rating***.

It is important to note that the publication of this European standard will require around two more years. To ensure that proper resources are allocated to this important task, D^2EPC will transfer this standardisation activity to other research projects: **SmartLivingEPC** and **Chronicle**. The meeting for the handover of the standardisation activities is scheduled for September 28th. D^2EPC is thus a relevant example of cooperation between EU-funded research projects.

The standard on operational rating of energy efficiency, when published, will have a lasting impact on the building sector in Europe, which will *outlive* D^2EPC. The activities and research dissemination within the new standardisation WG will also promote innovations in this field and is, thus, considered very positive.

**D^2EPC has also been nominated** by CYS, Cyprus Organization for Standardisation, **for the Standards+Innovation Awards 2023 of CEN and CENELEC**, in the category **Project award** in June 2023. The nomination included the following statement:

> *The current Energy Performance Certificates (EPCs) play a crucial role in assessing the energy efficiency of buildings, primarily relying on the building's design. These certificates adhere to the European standards established by CEN/TC 371 for building-level evaluations. Additionally, various product or systems committees like TC 089, TC 156, TC 169, TC 228, and TC 247 contribute to different aspects of energy performance assessment, such as thermal performance, ventilation, lighting, and heating and cooling systems.*
>
> *D^2EPC's innovative approach proposes a new generation of EPCs that integrate dynamic sensors and Building Information Modeling (BIM). By leveraging these technologies, D^2EPC enables the creation of a digital twin that accurately represents the building's energy characteristics.*
>
> *D^2EPC takes a comprehensive perspective by introducing a novel rating system for assessing the energy performance of buildings. This new rating not only considers the energy efficiency aspects but also incorporates indicators related to economic factors, human comfort, and general well-being. By encompassing these broader aspects, D^2EPC aims to provide a more holistic evaluation of a building's energy performance.*
>
> *Recognizing the significance of operational energy performance, D^2EPC has played a pivotal role in establishing a specialized European working group known as CEN/TC 371/WG 5. This dedicated group focuses on addressing operational energy performance concerns and actively contributes to the advancement of EPCs in this domain.*
>
> *Through its dynamic approach, integration of sensors and BIM, and emphasis on comprehensive performance indicators, D^2EPC is poised to revolutionize the field of energy performance evaluation for buildings, paving the way for more efficient and sustainable built environments.*

The Secretariat of the working group proposed by D^2PEC (CEN/TC 371/WG 5 'Operational rating of energy performance of buildings'), Aitor Aragón (UNE) has also been nominated for these Awards in the category of **Technical Body Officer**.

More information about these nominations is available at CEN/CENELEC website: https://www.cencenelec.eu/get-involved/research-and-innovation/cen-and-cenelec-activities/s-i-awards/list-of-nominees-2023/

The evaluation of the nominees will take place during Q3 2023 and the award ceremony in Q4 2023.

These recognitions are an important result for the dissemination of the works developed by D^2EPC in the standardisation system.

Related Submitted Deliverables:

- D6.1 Strategic standardization plan V1
- D6.5 Strategic standardization plan V2
- D7.4 Report on the contribution to standardization v1
- D7.12 Report on the contribution to standardization v2

## 1.2.17 Policy-related implications

### 1.2.17.1 Recommendations on integration of Next Generation EPC in national/regional certification schemes

The EPC is an important and effective tool for informing end-users about the performance of a building. An EPC can be based on calculated pre-defined parameters or on actual energy consumption. A dynamic EPC based on real-time energy consumption can take the presentation of a building's performance to the next level by providing end-users with information on how behaviour affects energy consumption. Policy makers and public authorities can benefit from a reliable EPC based on real data when monitoring and enforcing building efficiency policies and renovation measures.

The D^2EPC scheme is based on the relevant EU standards and the Energy Performance of Buildings Directive, in order to allow for an EU-wide deployment. One of the main objectives of the project is to conclude with a specific set of proposals and actions to be used for the update of the ISO/CEN standards developed under Commission Mandate M/48014.

The implementation of the D^2EPC framework as a major innovation in EPC calculation, EPC issuance and quality control, providing services to policy makers all over the EU for the assessment of national and EU-wide building stock can potentially help to achieve the maximum reduction of energy consumption of the EU building stock. The following recommendations are provided:

**Collection of real energy consumption data:** In order to establish the concept of a dynamic EPC (including the operational information), it is necessary to understand the current EPC system in every country and to identify the existing gaps and discrepancies. The basis for the implementation of a dynamic EPC scheme should not only be based on filling the gaps but also on the adapted laws and regulations. Within the research activities carried out during the project, the main gap identified was the lack of real-time data collection (lack of monitoring equipment), compounded by the lack of enforcement of national regulations. Therefore, access to data for end-users (building owners, tenants, utilities, developers, authorities) – as in the revised EPBD – is the first step.

**User-friendliness**: In order to bring the energy efficiency closer to the user of a building, the EPC must provide information that is easy to understand and use. The use of actual energy consumption data to assess the performance of buildings will highlight opportunities for adaptation and fine-tuning of the heating system to meet the needs of the user. An EPC based on real energy consumption (as operated) can be calculated and issued on a regular basis. Building users can be informed about the actual energy performance of their buildings through a dedicated platform and can regulate their energy habits.

Additional information such as the indoor air quality and financial aspects of the energy use could support understanding and therefore, lead to changes and/or actions and implementing renovation measures. A dynamic EPC can be the basis for a renovation roadmap, based on the real situation of the building.

**Harmonization of EPCs with the smart city concept:** As the energy transformation of the EU building stock aims to ensure that all EU citizens have access to energy services regardless of their income, the Smart Readiness Indicator (SRI) is expected to become a low-cost measure to promote healthier, more comfortable, low carbon impact and low energy use buildings capable of integrating renewable energy sources (RES). Digital smart home systems optimise the use of RES installations, battery storage, heating systems and electric vehicle (EV) charging and thereby helping to integrate renewables into the power grid through data-driven energy services. The SRI is complementary to the EPC as both systems are applied to improve the energy efficiency of the EU building stock and thus sharing the goal of promoting decentralised, renewable-based, consumer-centric and interconnected, essentially, smarter buildings. The SRI could be a good monitor for understanding the potential of a building as it is, linked to the current EPC.

The visualisation of EPCs in a GIS environment will provide a comprehensive view of the actual performance of buildings, facilitating efficient energy planning.

**Integration of further infrastructure and indicators for human centric EPC**: To calculate a dynamic NG EPC, it is necessary to collect adequate information (real data) by monitoring tools and to define a set of new indicators. In D^2EPC these additional indicators are used: smart readiness, human comfort, and financial indicators. The use of 6D Level 3 BIM and a full integration (BIM) of the information in a cloud-based environment, as well as the use of advanced digital construction design tools, could improve the effectiveness of certificates. These tools could strengthen and modernise the EPC and can provide a better link to the user needs and requirements.

The information should be processed on a digital comprehensive and transparent platform for the actual performance of the building in order to monitor and apply improvement measures. All the solutions should be promoted to improve the European standards and include the link between digital data and operational energy assessment.

**Data quality:** The accuracy of the EPC is determined by the level of detail and the quality of the input data. Linking to IoT or other relevant information improves the potential for building evaluation of and comparison between the designed building and the actual as-built building. Therefore, the provision of BIM documentation and digital logbooks can improve the data quality.

**Software credibility and quality:** The calculation methods on which the EPCs software is based, follow the monthly model of the ISO 52000 standard, where the description of the building is simplified and based on aggregated values (in terms of areas of building elements, thermal zones, etc.) and look-up tables (in terms of thermal properties of materials, infiltration rates etc.), while correlation factors or predefined schedules are also used for the modelling of dynamic effects. The EPC calculation should be combined with the building energy performance simulation for the design of the HVAC equipment and the thermal comfort of the building.

This will ensure the quality of the EPC. In addition, BIM models need to include energy-related information, and a digital twin should be used to have an as-built model of the asset. The building-related information needs to be collected and managed in a consistent manner such as BIM and digital twin.

**Training of the EPC-assessors**: Currently, most EPC calculations are based on a set of standard inputs or default inputs. The process of delivering to EPC can be subjective, and, as a result, the data quality can be easily influenced by the energy assessors due to the default assumptions made in the process of producing the certificate. Regular training of energy consultants and assessors, especially in the area of digitalisation, is required to deliver the EPC and a high quality energy assessment of the building. Currently, the qualification and training requirement are defined differently by the EU Member States.

**Connection between sustainability assessment and energy performance:** As we move towards an era where resource efficiency receives greater attention and it is integrated into all major aspects of the energy sector, further progress in the field of EPCs with the integration of LCA-related indicators are of vital importance. D^2EPC proposes the introduction of a set of LCA-based indicators for the energy performance of buildings. These indicators will be based on well-established European databases on the environmental impact of building materials, with focus on the Level(s) scheme, and they will result in a life cycle assessment of buildings, as well as of individual building components (building envelope, building technical systems, building materials etc.). This assessment also provides the building designers with the opportunity to improve and optimise the environmental performance of the building, based on changes to be incorporated at the initial design stages of the building. To meet the requirement of a building shell and building technical system oriented approach, novel indicators could be divided into building shell and building technical system oriented indicators. This will also allow the extraction of additional indicators such as the proportion of renewable energy used.

**Harmonising the operational assessment of buildings across Europe**: The asset rating of the buildings at national level has been developed since the provision of an EPC became mandatory under the EPBD. Harmonising the asset rating method across EU-countries is a difficult task, due to calculation methods and national standards and specific terms. D^2EPC is one of the first tools developed for the dynamic calculation of the EPC. It has therefore paved the way for the development of a harmonised dynamic EPC.

D^2EPC envisages and proposes the development of all necessary structures that will allow for the development of standardised procedures, that can be used by all Member States (MS), or the development and adoption of operational rating systems for the energy assessment of buildings among all MS.

The proposed framework should provide specific answers regarding applicability, common methods for calculating the operational rating of buildings, minimum requirements and indicators that should be provided and the time step of the assessment, weather and occupancy normalisation practices as well as guidelines for reference values, on which the classification will be based. The development of this information requires the establishment of standardisation working groups in the field of operational rating.

**Motivational schemes:** There is concrete evidence of the need for stricter motivational schemes to combat buildings' energy consumption. The robust and rigorous motivational programmes can support compensating escalating energy consumption in buildings. EU Emissions Trading Scheme infrastructure could galvanize a tangible change by dint of financial penalties coupled with equally potent rewards. The efficacy of the penalty and award approach based on real energy consumption can orchestrate swift and transformative shifts in behaviour.

There have been many European projects for improvement of the EPCs, considering new indicators, features and uses. The results of these research projects can help the policy makers to redesign the national implementation of the EPBD. The practical implementation as enabled by the D^2EPC Web platform has the ability to cover all the needs and requirements arising from the research conducted in the project, to respond to current and future legislation and to unify in one tool the recommendations for the integration of Next Generation EPC in national/regional certification schemes as listed above.

The implementation of the D^2EPC framework as a major innovation in EPC calculation, EPC issuance and quality control, providing services to policy makers across the EU for the assessment of national and EU-wide building stock can potentially help to achieve a maximum reduction in energy consumption of the EU building stock.

### 1.2.17.2 EPCs, Building passports and Renovation roadmaps

In Task 6.3 “Linking EPCs with building passports and renovation roadmaps” an investigation was performed on how D^2EPC outcomes can be matched with Building Renovation Passports. In order to better understand the topic, a thorough literature has been performed. First, the *Energy Performance of Building Directive*[26] was studied to grasp the purpose and idea behind the definition of the BRPs.

[26] DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

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Then, the *Technical study on the possible introduction of optional building renovation passports*[27] and *Building renovation passports – Customised roadmaps towards deep renovation and better homes*[28] were reviewed in order to get familiar with the existing schemes. Three existing BRP cases from Belgium, France, and Germany were studied to facilitate a better understanding of the realization of BRP A report titled *Definition of the digital building logbook* offered an insight into the advantages of logbooks[29]. Finally, documents produced by *Deutsche Energie-Agentur*[30] were reviewed to better understand the German version of the Building Renovation Passport. A comparison between the identified schemes can be seen in Figure 48. When comparing whether different processes are present in the existing scheme or not, the German iSFP earns the highest score.

| Process | BE-Flanders (EPC+) | France (PEE) | Germany (iSFP) | Denmark (BetterHome) |
|---|---|---|---|---|
| Definitions (Deep or staged deep renovation and/or alternative definition) | √ | √ | √ | X |
| Long-term target for the existing building stock (2050) | √ | √ | √ | X |
| Identified barriers | √ | √ | √ | √ |
| Stakeholders mapping | √ | √ | √ | √ |
| Stakeholders engagement | √ | ! | √ | √ |
| Market analysis | √ | √ | √ | X |
| Energy Audit – On-site visit | X | √ | √ | √ |
| Auditors training | X | √ | √ | √ |
| Tailored solutions (renovation roadmap) | ! | √ | √ | √ |
| $CO_2$ reductions | √ | ! | √ | √ |
| Logbook/Database | √ | ! | X | ! |
| Integrated financial support | ! | N/A | √ | ! |

√ = Yes ! = Under development/consideration X = No

**Figure 48 Overview of key features in the existing schemes**

In order to do that, first an extensive literature review on Building Renovation Passports was performed, followed by a thorough investigation of D^2EPC components that match in properties with components of Building Renovation Passport. Similarities and differences were identified with the addition of a list of items that could be improved in the D^2EPC components.

[27] European Commission, Directorate-General for Energy, Volt, J., Fabbri, M., Zuhaib, S., Technical study on the possible introduction of optional building renovation passports: final report, Wouters, P.(editor), Publications Office, 2020
[28] BPIE, Building Renovation Passports - Customised roadmaps towards deep renovation and better homes > BPIE - Buildings Performance Institute Europe, 2016
[29] BPIE, DEFINITION OF THE DIGITAL BUILDING LOGBOOK - Report 1 of the Study on the Development of a European Union Framework for Buildings' Digital Logbook, 2020,
[30] Deutsche Energie-Agentur GmbH (dena), Factsheet iSFP / Basics / Grundlegendes

**Table 13 Connection between D^2EPC components and BRP scheme**

| D^2EPC components | BRP scheme |
|---|---|
| Information Management Layer | Data gathering, Pre-Processing the data |
| Energy performance verification & credibility | Pre-Processing the data |
| Roadmapping tool | Renovation roadmap |
| BIM-based digital twin, Repository (not a tool) | Building logbook |
| Building energy performance benchmarking | Building logbook |

The findings were demonstrated on two case studies, namely the CS1 and CS4. The data gathering and data processing do not differ per pilot, whereas the renovation roadmap looks at each building individually and forms a step-by-step process that leads to the improvement of the building.

Finally, two guidelines were developed, the generic guidelines and consultancy for decision and policy makers and the technical advisory for building professionals and end-user. The latter is further divided into advisory for building professionals and advisory for residential and non-residential end-users. The technical advisory is formed in a way that it lists the items that a guideline should include.

In general, the process for successful implementation of the building renovation passport can be divided into four steps: exploration, concept design, implementation and evaluation. Based on the four existing building renovation passports in Germany, France, Denmark, and Belgium, a list of success factors was identified:

- Include the right stakeholders, who can add value to the process.
- Ensure proper timing of each phase to avoid unnecessary stops.
- Guarantee the necessary funds for all phases of the implementation.
- Provide additional information about the building in the BRP besides the energy.
- Ensure user-friendliness and affordability.
- Promote the BRPs to ensure the demand, which can be driven by need, desire for service, or obligation.

The overall work is presented in D6.3 EPC and Building Renovation Passport to which all the partners of Task 6.3 contributed.

Related Submitted Deliverables:

- D6.3 EPC and Building Renovation Passport

### 1.2.17.3 Motivational schemes for conscious energy users

In the context of Task 6.4 “Development of motivational schemes for conscious energy users in the building sector,” an initial exploration was conducted into existing incentive and penalizing schemes in the building sector and in general. Preliminary findings from stakeholder engagement and an accompanying literature review informed this.

The development of motivational schemes for conscious energy users in the building sector incorporated information gathered through desk research and stakeholder interactions. International practices, such as the EU Emissions Trading Scheme and carbon pricing, were extensively documented and demonstrated their effectiveness in maintaining carbon emissions below certain thresholds for heavily polluting industries. The literature review also highlighted that disparities in carbon emissions are observed not only between countries but also among individuals within the same country. This phenomenon of differential pollution levels on a global scale is currently being addressed by the international price of carbon to deter heavy polluters from relocating their businesses to countries where they can afford penalties or lower carbon prices. This ideology was deemed appropriate for the project's motivational schemes, incorporating penalties and award schemes that drew on successful theories and practices of the EU ETS and the international price of carbon. In more details, the D^2EPC project lays forth a strategic framework encompassing four distinct award schemes. These devised schemes wield the potential to galvanize substantial reductions in energy consumption, thereby fostering a culture of conscious energy usage among households. The four proposed award schemes are:

- Tax Reductions
- Reduced Electricity Bill
- Cash Back
- Credit Transfer
- Common Pricing Principle and Customized Choice

Central to the ethos of these award schemes is their unified foundation upon a singular pricing principle. This pioneering approach underscores the adaptability and inclusivity of the proposed schemes, ensuring that households possess the autonomy to elect a scheme aligning with their preferences and aspirations. A noteworthy facet pertains to the provision of annual flexibility, granting households the prerogative to seamlessly transition from one scheme to another, thus tailoring their energy conservation strategy in accordance with evolving circumstances.

The pivotal facet anchoring these award schemes is their pricing architecture, intricately linked to the global panorama of carbon pricing. Inextricably tied to the international carbon market, the pricing of these schemes is irrefutably tethered to the pressing need for carbon emission reduction. This resonates profoundly with the overarching objectives of the European Union, which ardently aspires to attain carbon neutrality by the year 2050. A key tenet in this pursuit is the deliberate curtailment of carbon allowances, a quintessential facet of the EU Emission Trading System (ETS). This strategic reduction imparts an upward impetus to carbon prices, akin to the dynamics of demand and supply.

The synergy between these award schemes and global carbon pricing is of paramount significance. Envision a scenario where households, through judicious energy consumption, remain within their allocated carbon quotas. In this scenario, the escalating trajectory of carbon prices translates into tangible benefits for conscientious households. Financial incentives commensurate with their energy-efficient practices amplify their motivation to conform to their allocated energy bounds. Forecasts hint at an upswing in carbon pricing, projected to culminate in a zenith of 410 euros per ton by 2050, catalyzed by supplementary measures augmenting extant initiatives.

Acknowledging the nuanced predilections of diverse governments and member states, an element of customization is contemplated. Some jurisdictions might opt for a marginally divergent pricing structure, albeit within bounds that uphold the fundamental underpinning principle. This flexible latitude seeks to harmonize award schemes with regional variances while upholding the overarching objective of incentivizing energy-conscious behavior.

A further layer of sophistication is infused into the design by embracing differential pricing for surplus units of energy (kWh). This strategic maneuver empowers governments to calibrate the funds directed back into households finely. This control mechanism serves as a strategic instrument to wield influence over energy consumption patterns, thereby steering households toward optimal energy efficiency.

In summary, the architectural blueprint of the motivational award schemes, meticulously outlined by the project D^2EPC, weaves a tapestry of possibilities that synergistically intertwine global carbon dynamics with localized motivations. The envisioned confluence of global sustainability imperatives and household-centric awards is poised to be a transformative force, fostering a collective movement towards sustainable energy practices within the household.

The motivational schemes were tested using six different case studies from various pilot building locations accessible to consortium partners. The case studies included buildings in Thessaloniki,

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Greece; Velten, Germany; Berlin, Germany; and Nicosia, Cyprus. Data from June to December 2021 served as the baseline for energy consumption, with the same period in 2022 being used for comparison. The 2022 values were adjusted daily using degree days for a reliable comparison.

The analysis highlighted the importance of considering all relevant information for each building to ensure data accuracy. In Case Study 4, the mixed-use building in Nicosia, Cyprus, did not alter its energy source, and 2022 appeared to be a more energy-consuming year based solely on energy consumption data adjusted for degree days. However, once COVID-19 restrictions for both years were factored in, energy consumption remained unchanged, and no penalties were required. In contrast, in Case Study 1, the nZEB Smart House DIH in Thessaloniki, Greece, significantly reduced energy consumption due to the installation of photovoltaic panels, reducing grid energy requirements and qualifying for award schemes.

Related Submitted Deliverables:

- D6.4 Motivational schemes for conscious energy users

### 1.2.18 D^2EPC Pilots

The validation of the D^2EPC prototype was based on the successful implementation of Architectural Use Cases in the D^2EPC Pilot demonstration sites. The D^2EPC pilot buildings include six buildings, namely, the nZEB Smart House DIH in Thessaloniki, Greece (Case Study 1); a residential multi-family building in Velten, Germany (Case Study 2); a tertiary building in Berlin, Germany (Case Study 3); the new wing building of Frederic's University in Nicosia, Cyprus (Case Study 4); and two multi-family buildings located in Berlin (Case Studies 5 and 6). The plethora of characteristics in this set of pilot buildings has set a challenging environment for the applicability and validity of the D^2EPC framework.

Related Submitted Deliverables:

- D5.1 D^2EPC Manual v1
- D5.2 D^2EPC User Training Workshops
- D5.3 Pilot Planning and Setup v1
- D5.4 D^2EPC Pilots Demonstration v1
- D5.6 D^2EPC Manual v2
- D5.7 Pilot Planning and Setup v2
- D5.8 D^2EPC Pilots Demonstration v2

#### 1.2.18.1 Case Study #1: nZEB Smart House DIH

The first pilot building is located in Thessaloniki, Greece and is owned by CERTH. The advanced building infrastructure, both in terms of energy-efficient technical systems and extended IoT installation, establishes its role as a fertile testbed to try out the methodologies developed within D^2EPC. CERTH's nZEB Smart House is a duplex apartment with a total area of 317.7 $m^2$, representative of a single-family residential building, and is already equipped with many IoT, Smart Home solutions that provide a lot of information about its operational characteristics. The construction of the building started in 2014 and was completed in 2016. Typically, the building has no actual residents, since it functions as an office during the usual office hours. However, except for the specific rooms that are officially used as offices (Control Rooms) the building has also common residential rooms, such as a living room, bedrooms etc. equipped with IoT devices.

**Figure 49: nZEB Smart House (left); North - East View of Smart House building in a BIM environment (right)**

The building spaces are equipped with several sensors collecting measurements of interest. The whole infrastructure is complemented with the Smart Home IoT Platform, where all data is gathered for real-time monitoring and control and conveniently accessed through a corresponding API. A detailed description of the existing infrastructure is also provided in D3.4. The current IoT infrastructure of the nZEB Smart Home enables the remote control of several building systems under a common Building Management System (BMS) and through different protocols. Residential loads, such as the air-conditioning terminal units can be adjusted regarding the desired temperature and operation mode, while the installed lights can be dimmed according to the user preferences. Control of the in-premises energy storage system is also possible. Upon these functionalities of the BMS, several control strategies and automated routines have been implemented and are constantly being tested in the building.

Towards effectively implementing the D^2EPC solution to the greatest extent possible, additional sensing equipment was installed within the project, which was proposed within T3.1 as the most suitable for the application and complements the existing infrastructure. To this end, a MCOHome multi-sensor was installed in the building's living room, measuring $CO_2$, PM2.5 and TVOCs levels, temperature, humidity, luminance, presence, loudness and smoke density. Additionally, an Aeotec Multisensor 6 device was installed in every space of the main building, namely:

- Living room
- Kitchen
- Guest room
- WC
- Hall
- Corridors
- Double bedroom
- Single bedroom
- Bathroom
- Playroom (serving as an office space)

The sensors measure temperature, humidity, luminance, presence, vibration and UV. The integration of the aforementioned sensors allowed CS1 to serve as a testing ground for completely assessing the Human Comfort & Wellbeing performance aspects, as determined within Task 2.2.

Thanks to its innovative building design in collaboration with the use of highly efficient technical systems and RES, the Smart House manages to minimize its energy consumption and, at the same time offer excellent indoor conditions. As a result, the Smart House has achieved the highest rating in the EPC evaluation process (A+) according to the National Asset Rating Methodology.

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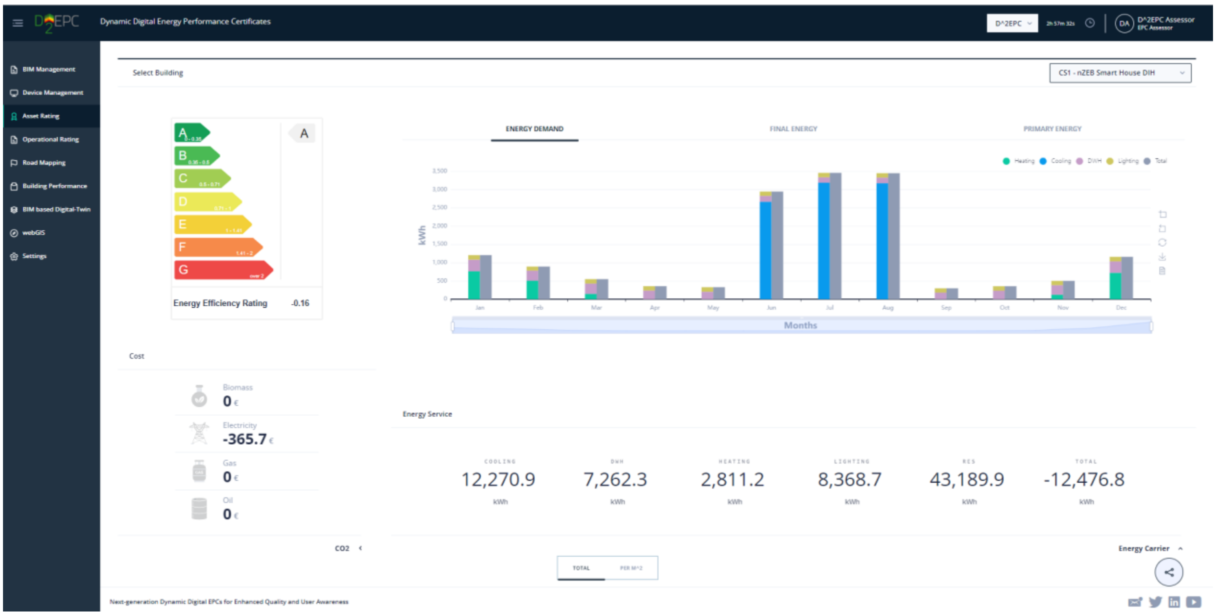


Figure 50 CS1 asset-based EPC results

The difference in the calculated primary energy as shown in Figure 50 is due to the differences in the two calculation standards (EN ISO 13790 and EN ISO 52016), as all other calculation parameters have been kept the same, although the resulted energy class (the highest possible) is not affected as the same conditions apply also for the reference building. An additional factor that slightly affects the primary energy results is also identified in the difference between the applied set of annual climatic conditions (external temperature and solar radiation).

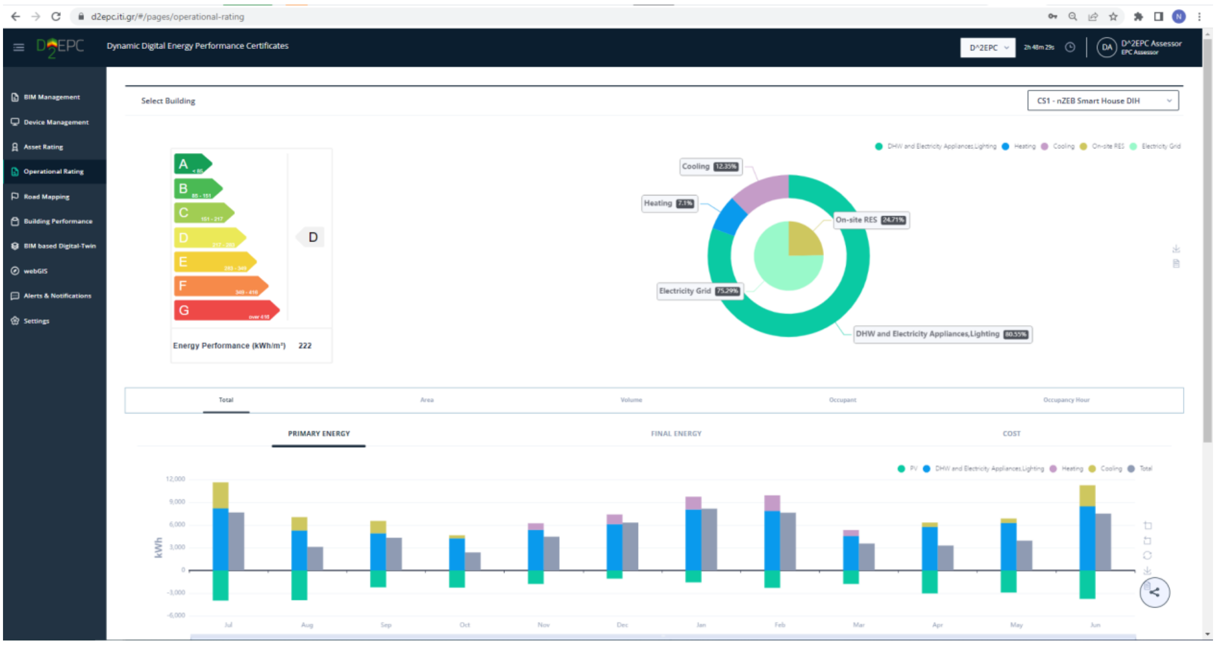


Figure 51 CS1 operation-based EPC results

Figure 51 shows that the majority of the consumption is attributed to the building's electrical appliances and lighting services, and, more specifically, to the numerous server computers that operate inside the building.

### 1.2.18.2 Case Study #2: Residential/ Multi-family building in Velten Germany

This pilot building was constructed in 1907 and is located in Velten, which is a city in the northwest of Berlin. The building includes apartments used for residential purposes. Currently, the building apartments are occupied by tenants. The total living area of this building is 335m2.

**Figure 52: Residential/ Multi-family building in Velten Germany**

For the purpose of the project, smart devices have been installed in the pilot building. The selection of the devices was based on the requirements of the indicators to be assessed as well as the consent of the building owner. Two apartments were examined in the scope of this project. The building was equipped with wireless sensors and smart meters that enable the close monitoring of electricity consumption, indoor air quality and environmental conditions. The scope, type and number of devices installed are presented in Table 14.

**Table 14 IoT deployment in Case study 2**

| Scope for the D^2EPC project | 2 apartments in a residential building |
|---|---|
| **Number of devices installed** | 9 |
| **Type of devices and sensing parameters** | |
| **CO2, Temperature and humidity sensors (indoor)** | 2 sensors measuring indoor CO2, temperature and humidity (1 per apartment) |
| **Temperature and humidity (indoor)** | 2 sensors measuring indoor temperature and humidity (stairways) |
| **Temperature and humidity (outdoor)** | 1 sensor measuring outdoor temperature and humidity |
| **Electrical smart meters - wireless** | 2 smart meters measuring electricity consumption in kWh among other parameters. |
| **Weather data from service provider** | Yes |
| **Communication/network protocols** | Sigfox and NB-IoT |
| **Data transfer to D^2EPC platform (external server)** | REST API, request method POST - authentication required[31] |

D^2EPC has been successfully validated for the designed test cases according to the deployment timeline and results are shown in the figures below for the use case of asset rating and operational rating respectively. The difference between the results from the asset-based assessment with the national methodology and the D^2EPC assessment is primarily due to possible differences in the building models used in each case.

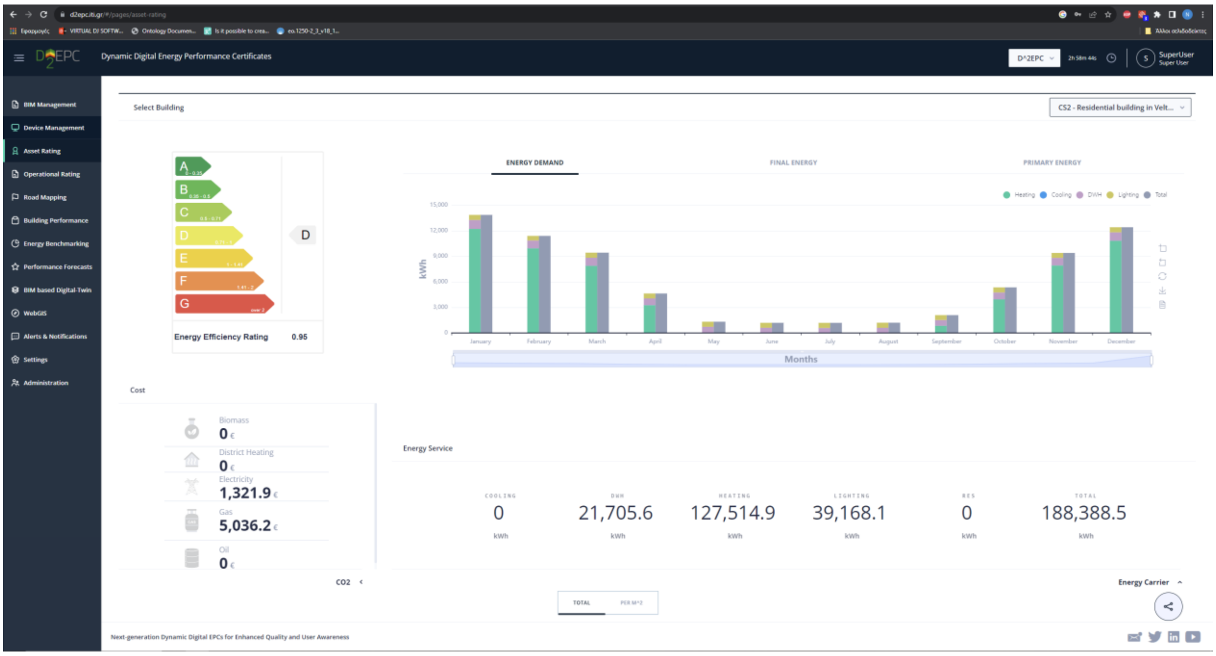

Figure 53 CS2 asset-based EPC results

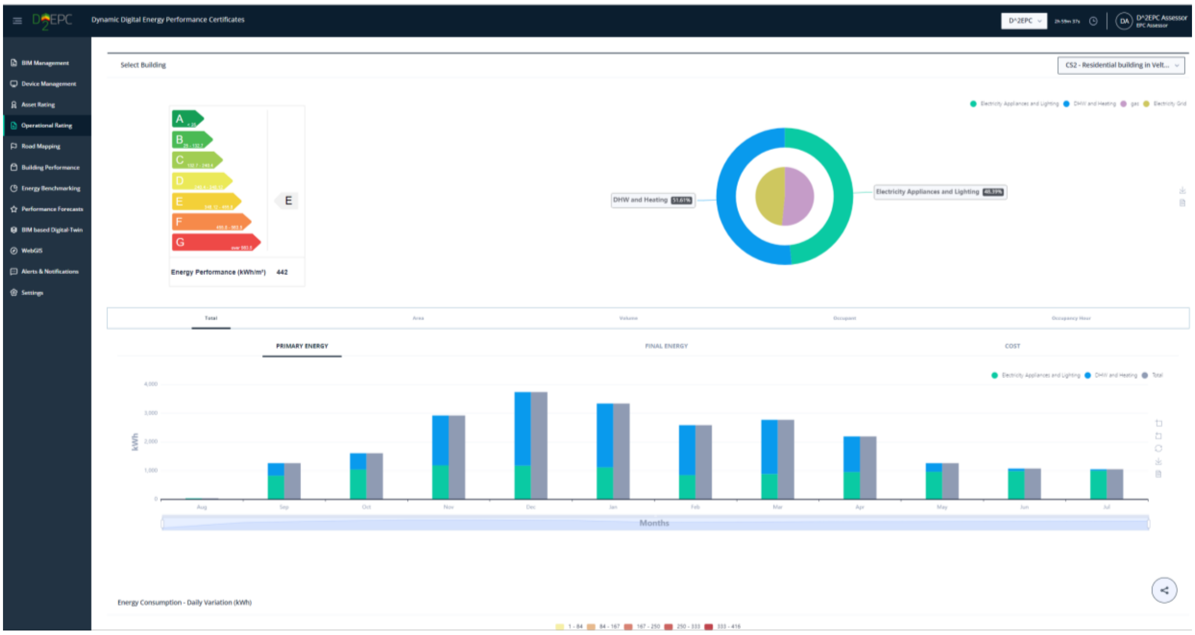

Figure 54 CS2 operational-based EPC results

## 1.2.18.3 Case Study #3: Tertiary building/ Offices in Berlin Germany

The pilot facility in Berlin is a typical industrial building occupied by a metalworking company. The object consists of two floors. On the first floor, there is only an office, the surface of which is 277 m2. The building can be divided into the following areas: the stainless-steel production hall 2, which also hosts a plasma cutting machine, the production hall 1, the staff room, the work equipment warehouse, the lathe and milling shop, the polish and paint shop and four warehouses. The company's offices are located on the first floor, above the work equipment warehouse and turning and milling shops. The

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other areas are designed as industrial halls. The whole building was included within the scope of the D^2EPC project. The main entrance is located next to a staircase, but each hall also has a large entrance. The building is divided into six thermal zones.

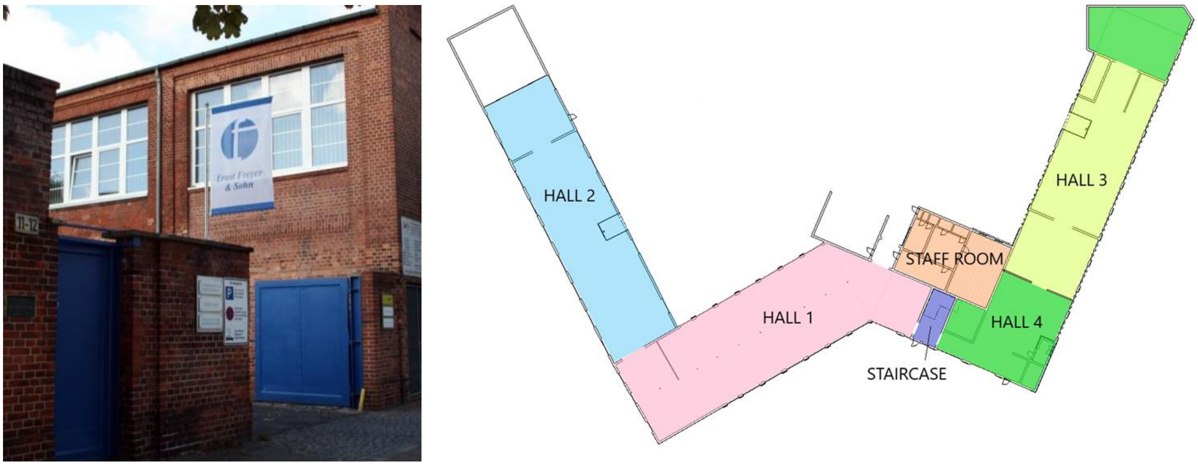



**Figure 55: Tertiary building/Offices in Berlin Germany**

For the purpose of the project, smart devices have been installed in the pilot building. The selection of the devices was based on the requirements of the indicators to be assessed as well as the consent of the building owner. The scope, type and number of devices installed are presented in Table 15. The devices that sense the indoor temperature, humidity and CO2 are located at different points in the production halls. The first device is located in Production Hall 1, the second in Production Hall 2, the third in the lathe and milling shop and the last one in the paint shop. The sensors communicate wirelessly using the Sigfox network.

In terms of the operational rating, historical data have been provided for the year 2021 for the whole building. The dataset provided includes electricity consumption as well as gas consumption (Heating and Domestic Hot water).

**Table 15 IoT deployment CS3**

| **Scope for the D^2EPC project** | **Industrial building in Berlin - metal working company** |
|---|---|
| **Number of devices installed** | 4 |
| **Type of devices and sensing parameters** | |
| **CO2, Temperature and humidity sensors (indoor)** | 2 sensors measuring indoor CO2, temperature and humidity |
| **Temperature and humidity (indoor)** | 2 sensors measuring indoor temperature and humidity |
| **Weather data from service provider** | Yes |
| **Communication/network protocols** | Sigfox |
| **Data transfer to D^2EPC platform (external server)** | REST API, request method POST[32] |

All pilot-related architectural use cases which have been demonstrated and validated for CS3 and results are shown in the following figures for asset-based and operational-based EPC. For the asset

[32] Method tested at the company (Cleopa GmbH) - process not implemented with D^2EPC partners yet. Authentication process is required before implementation of data transfer.

rating, the nationally issued EPC was conducted in accordance with the current EPC German legislation GEG which has been in force since 2020. The last EPC was issued in 2021 and compared to the D^2EPC assessment, the rating is considered satisfactory and in-line with the national legislation.

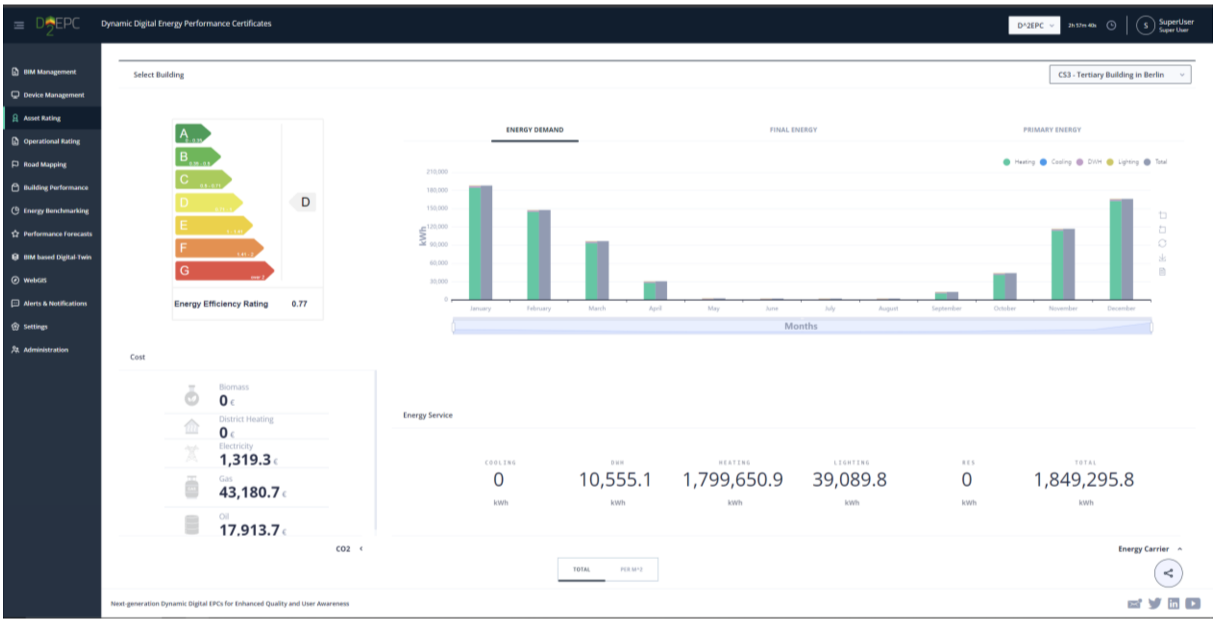



**Figure 56 CS3 asset-based EPC results**

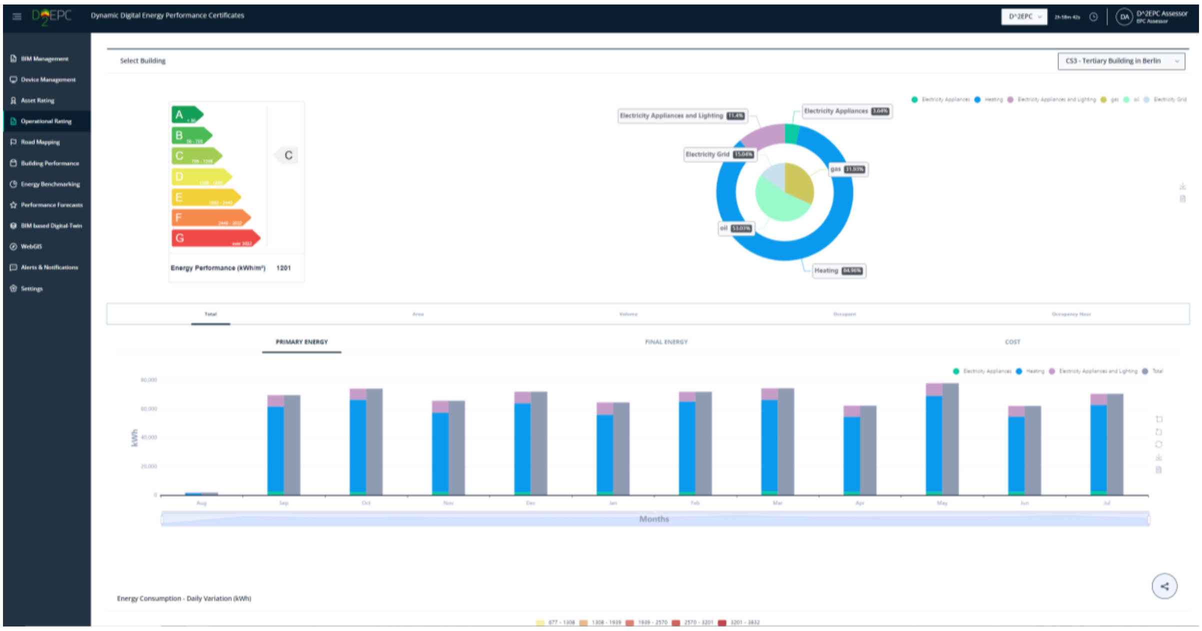



**Figure 57 CS3 operation-based EPC results**

## 1.2.18.4 Case Study #4: Mixed-use building in Nicosia Cyprus

Frederick University's pilot is a two-story 2,100 m$^2$ building, its volume is approximately 7,100 m$^3$ (including the basement floor/parking area), and it was built in 2007. The understudy building does not border with any other building.

The building 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 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.

**Figure 58: IFC model of a FRC building**

Smart meters installed throughout the building allow for real-time measurement of electricity, as well as of internal conditions, such as temperature, humidity, and carbon dioxide. Measurements and other data are available for monitoring, downloading, and analyzing. By the installed equipment, there are extracted measurements for the total power consumption of the pilot building, as well as HVAC data on the ground, first and second floor. Relevant information is extracted as well from the building's BIM file and other documentation sources, with dynamic data received from IoT devices, sensors, and meters deployed throughout the building. This results in a highly detailed building identification that serves as a common documentation approach for assessing the building's energy performance, operational conditions, and indoor environmental quality. During the previous period, the addition of the sensors presented in Table 16 took place.

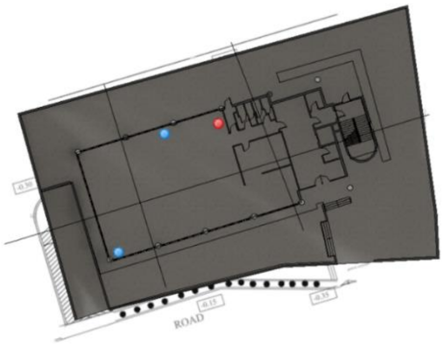
**Table 16 Monitoring equipment characteristics**

| Name | Accuracy | Qty | Picture |
|---|---|---|---|
| Hobo EG4115 Core Data Logger | 0.5% revenue-grade accuracy compliance | 3 |  |
| Hobo EG4130Pro Data Logger | 0.5% revenue-grade accuracy compliance | 1 | |
| Hobo T-EG-0630-0100 | Up to +/-1% | 21 |  |
| Hobo T-EG-0940- 0100 | Up to +/-1% | 3 | |
| Hobo T-EG-0940- 0200 | Up to +/-1% | 3 | |
| Hobo T-EG-0390-0050 | Up to +/-1% | 30 | |
| AM107-868M Milesight AM107 (LoRaWAN®) | Temperature sensing: -40°C - 85°C, ± 1°C accuracy<br>Humidity sensing: 0% – 100% RH, ± 3% accuracy<br>CO2 sensing: 400 – 5000 ppm, ±30 ppm or ±3 % | 7 |   |

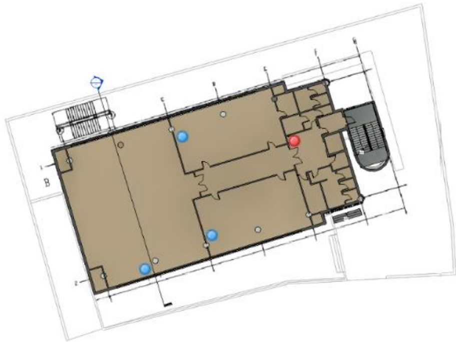
Presented herewith are the floor plans of the building, along with the precise locations of the measuring devices.

Power meters

Indoor Ambience Monitoring Sensor
(Milesight AM107 LoRaWAN® with E-Ink Display) – Temperature, Humidity, and CO2

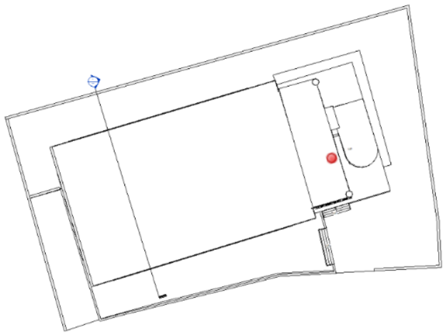


Ground Floor



First Floor

Second Floor



Roof

The installed equipment is connected to a system that allows monitoring, control, and remote sensing of the actual energy performance of the building, as well as enables the realization of the dynamic EPC scheme. The 3-Zone monitoring and remote sensing, as well as the power consumption of the building, are implemented with the use of equipment covering the following aspects indicatively:

- Temperature
- Humidity
- CO2
- Outdoor temperature, wind speed, and direction, rain concentration, solar irradiation (through a roof weather station)
- Energy Meters for electricity consumption

KPIs presenting the operational energy performance are relevant to:

- The definition of the drawbacks and discrepancies of the current EPC scheme, as well as the update of EU standards on the classification requirements of buildings
- Increasing partners' absorptive capacity
- Improving partners' market knowledge
- Contribution to standards

The energy consumption results include information about the energy consumption per energy service (e.g., heating, cooling) or any possible on-site energy production (e.g., solar thermal collectors, PV). The calculations (Figure 59) are presented to the three stages of energy conversion; energy demand, final and primary energy, as well as, the calculations for $CO_2$ emission and annual energy consumption cost have been included in the outcome final set of equations. With regard to the as-operated energy performance of the building, the main input is the measurements of energy consumption (Figure 60).

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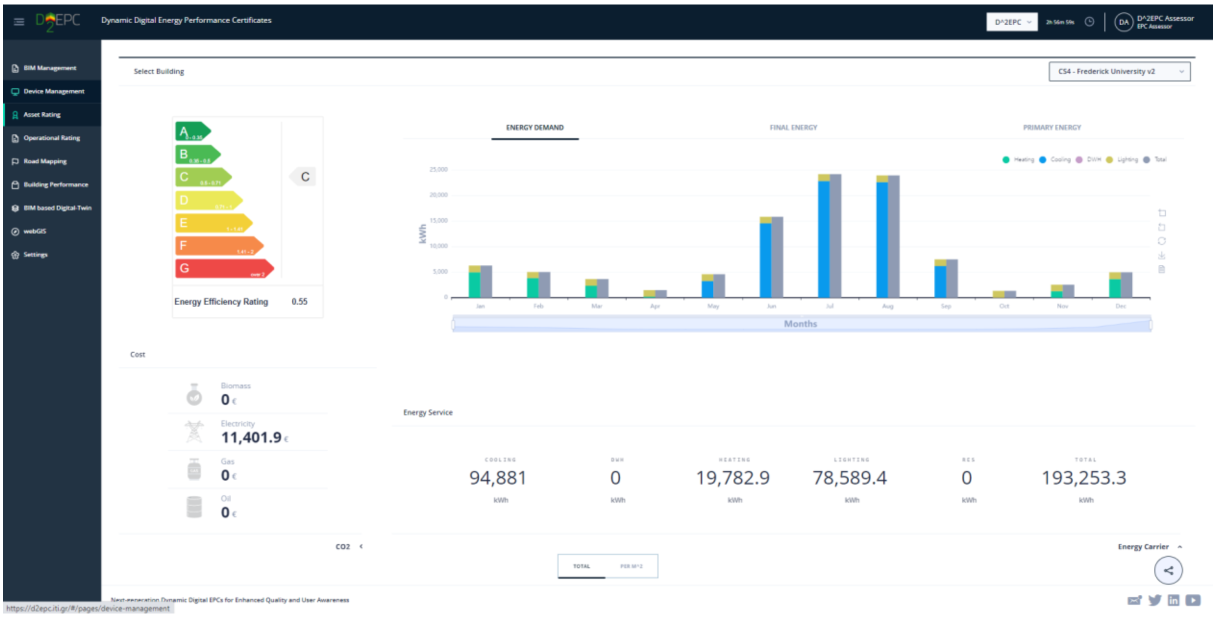


Figure 59: CS4 asset-based EPC results

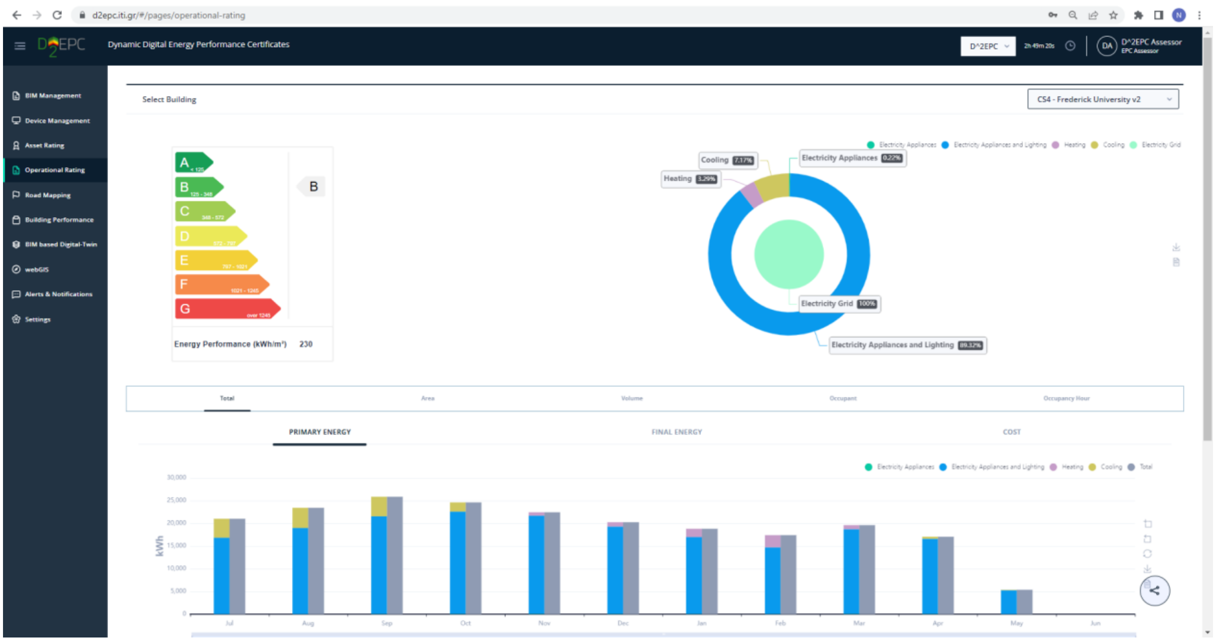


Figure 60: CS4 operational-based EPC results

## 1.2.18.5 Case Study #5: Multi-family home in Berlin Germany

The fifth pilot building is a multifamily building located at Berlin-Pankow, Mendelstraße 5. The building has a total area of 2,929 m$^2$ and 17 apartments are hosted in it with approx. 41 inhabitants. The distinctive characteristic of this case study is the building's age, as it was erected in 1900. In the last decade, the building has been renovated having:

- Geothermal heat pump
- Solar thermal appliance with storage tank
- Heat recovery from exhaust via heat pump
- Buffer tank
- PV

The remaining energy is provided by a condensing gas boiler. The building consists of two parts which are supplied by the same energy conversion system. The flats are equipped with ducts for the mechanical air exchange. The building also was insulated.

**Figure 61 Front side of the renovated building (left); Aerial view of the building (photo credits eZeit Ingenieure GmbH) (right)**

Those measures and reduced hull with heat loss lead to an excellent EPC rating following the national legislation at pre-pilot assessment. The asset-based EPC was calculated showing 29 kWh/m²a end energy demand equivalent to class A+ and 43 kWh/(m²a) primary energy demand equivalent to class A (SEnerCon 2020).

The existing energy management system (Figure 62) of the buildings comprises meters for:

- Solar thermal - heat
- Geothermal heat pump – power and heat
- Exhaust recovery heat pump – power and heat
- Gas furnace - gas
- Heat provided to the building - heat

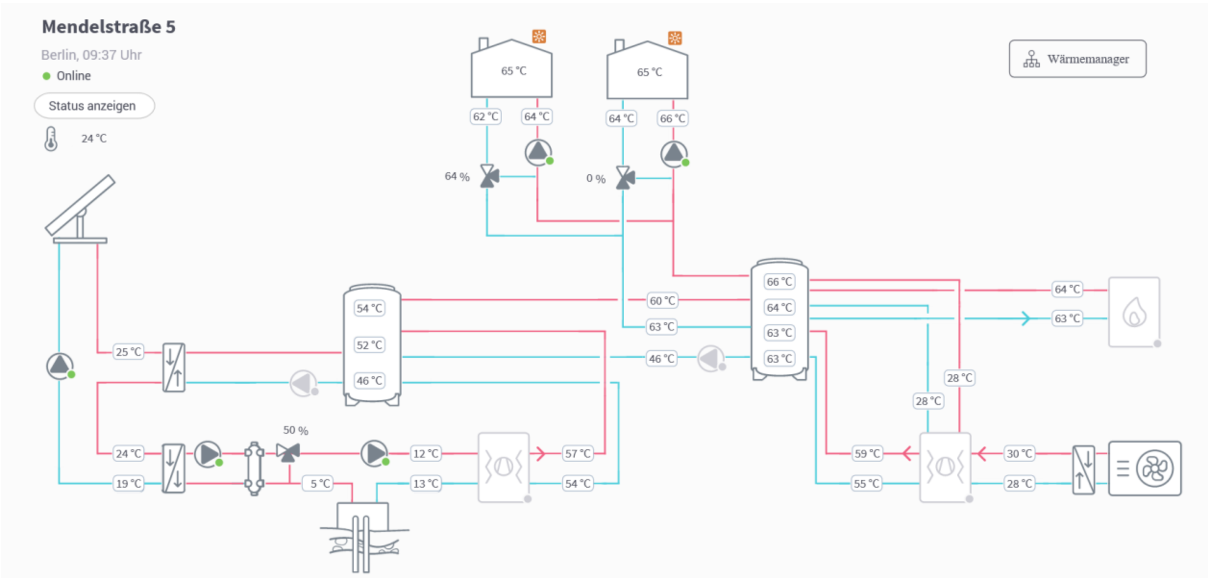


**Figure 62 Dashboard energy management system**

The information about the total heating demand can be acquired from the energy monitoring tool, which is provided by an external party (GREEN FUSION start-up company) and offers the possibility of AI-optimization.

There were three approaches using data from the pilot to compile digital energy performance certificates:

- Manual export of CSV data from the energy management portal of the building.
- Monthly data was accessed via the internet from the energy management system of the building.
- Import of CSV for hourly data which had been provided off-line.

A networked air quality measurement device (Netatmo) was deployed after preparation period. Data was stored in a database and an API was developed to be used by the projects engines to calculate operational EPC. Secondly the hourly data was converted into a JSON representation offered via endpoint on the internet to the D^2EPC Repository.

CS5 satisfied the prerequisites for applying the asset-based and operation-based EPC methodologies, as well as to testing most of the considered UCs. Results are shown in the following figures.

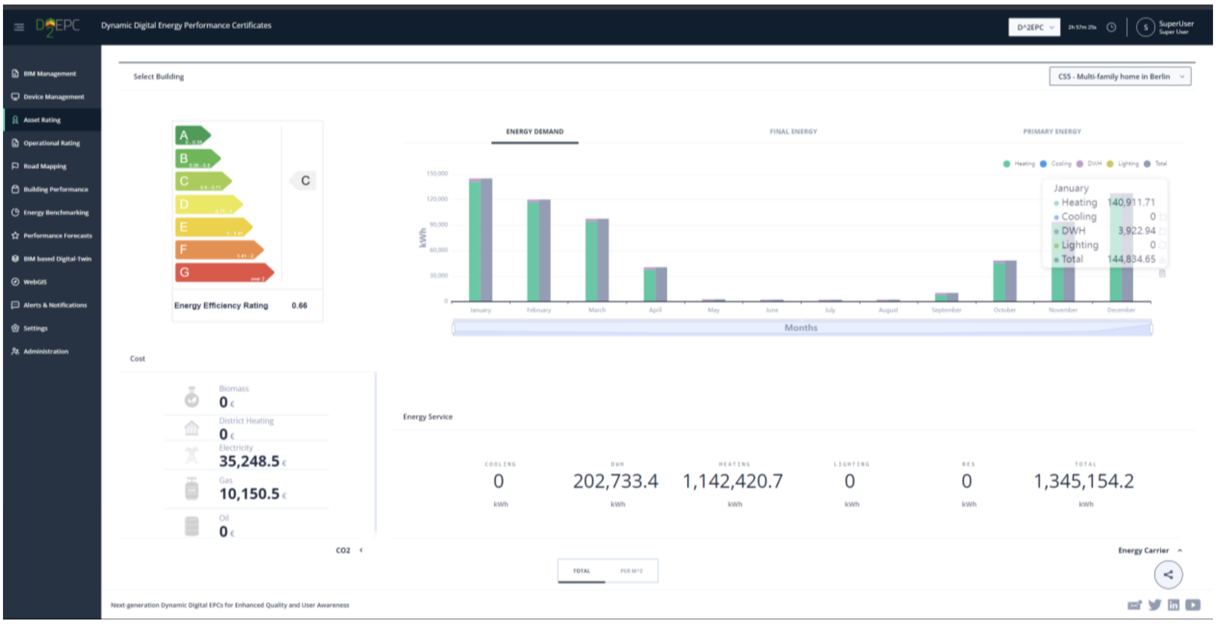


Figure 63 CS5 asset-based EPC results

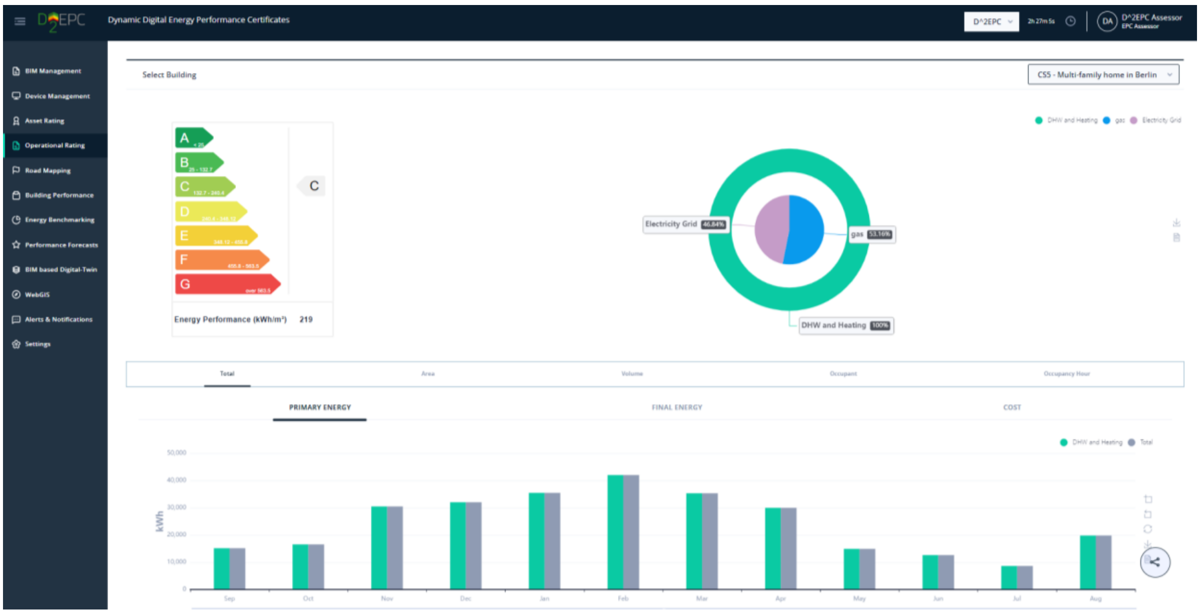


Figure 64 CS5 operational-based EPC results

### 1.2.18.6 Case Study #6: Multi-family home in Berlin Germany

This building is located in Neukoelln, Sonnenallee 159, in the center of Berlin. It is a historical building consisting of three parts with dominant residential usage. The building was constructed in 1918 with an overall building area 2,231 $m^2$ and includes a total of 29 rented apartments. The façade towards the street has partly balconies and a central building ledge located behind a tree. The old box-style windows consist of two separate windows with single glazing each, though most of them were exchanged by double glazed new windows with internal shading. District heating was installed in 1989 and supplied by Fernheizwerk Neukölln (FHW) while there is no central infrastructure for cooling and ventilation. Because of the hight density of the ground area usage there are adiabatic hull parts where the building connects to other heated volumes. This is shown in the 3D representation.

**Figure 65 Front and backyard Sonnenallee (left); 3D representation (right)**

Starting with 2019, digital meters were rolled out by FHW, transmitting metering data and temperature of the primary feed and return. The heat is produced from combined heat and power plants. An API has been made available for providing the aforementioned information, also including historical data. In addition, data acquisition devices, namely the Netatmo Homecoach, were proposed to building tenants for installation. In one flat they were accepted and data was acquired via wireless modem, providing several indoor conditions-related variables for a few months.

CS6 was the only pilot site with operational EPC assessment prior to pilot deployment. CS6 was assessed as residential apartment blocks. Total primary consumption was calculated 83 kWh/$m^2$, which is comparable to the calculated 111 kWh/$m^2$ based on the German national legislation.

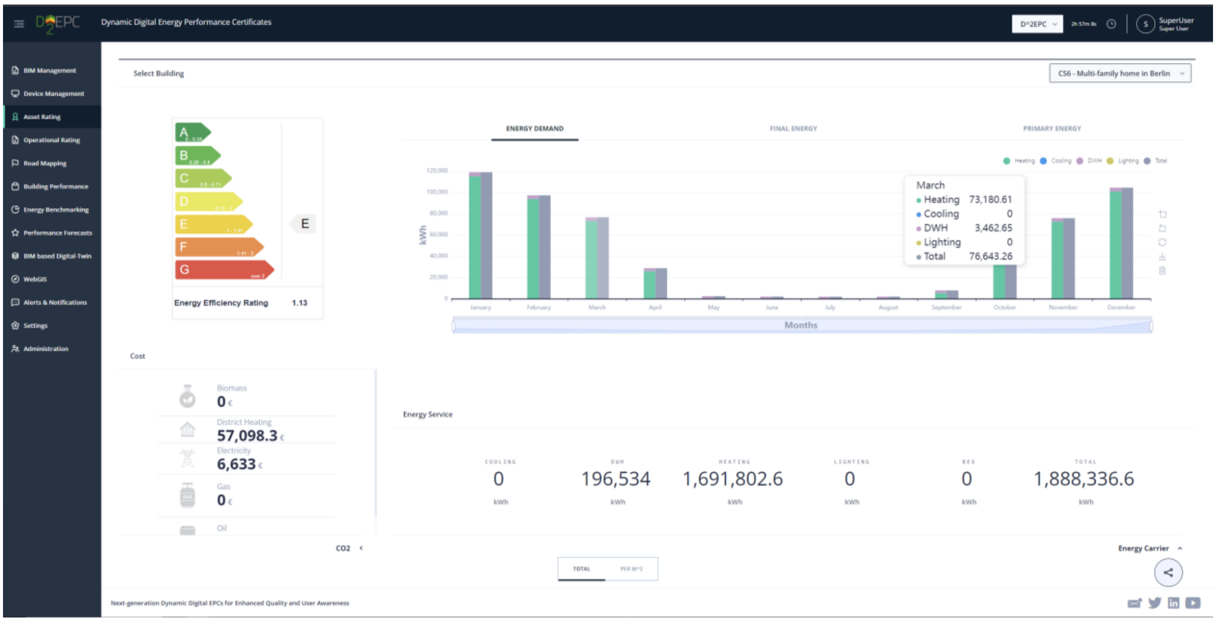


Figure 66 CS6 asset-based EPC results

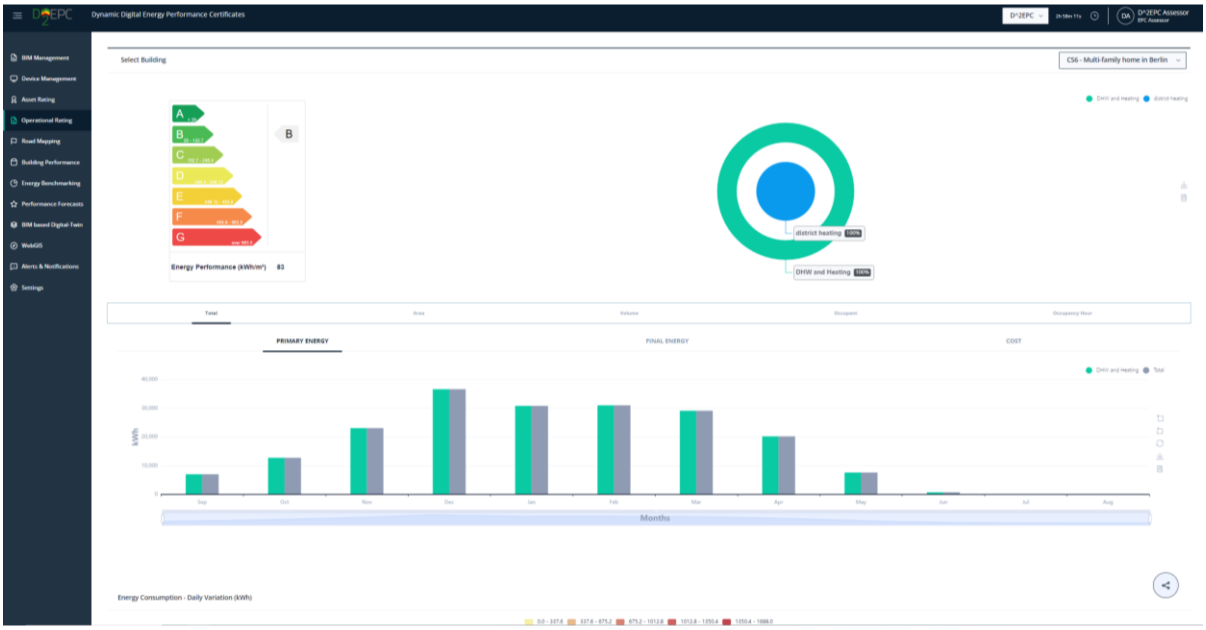


Figure 67 CS6 operational-based EPC results

## 1.2.19 Project's Data Management Plan & Open Knowledge

A Data Management Plan was developed based on the datasets for procedures and infrastructure that were anticipated by the end of the project. A key conclusion is that each partner was responsible for particular type of dataset. The D^2EPC Data Management Plan has provided the infrastructure required for the proper collection, dissemination and storage of metadata. Each data producer was in charge of this metadata, which has been made available based on their classification (i.e., Open, Consortium, and Private).

Within the D^2EPC project, datasets are subdivided as follows:

- Pilot sites generated datasets shared between the Consortium partners (Consortium)
- Pilot sites generated datasets that are used for individual partner purposes (Private)
- Pilot sites generated datasets shared to the public (Open Data)
- Research findings and outcomes that should be publicly disseminated (Open Data)

The data controllers and the data processors are the two main roles introduced by D^2EPC when it comes to data handling operations. The data controllers are the ones who set the goals and rules of data processing, while the processors are the ones who process the personal data on the controller's behalf. In D^2EPC, the Pilot Responsible and the Data Protection Officers (DPOs) acted as data controllers, while all technical partners, who needed to perform pilot-related data analysis, were considered as data processors.

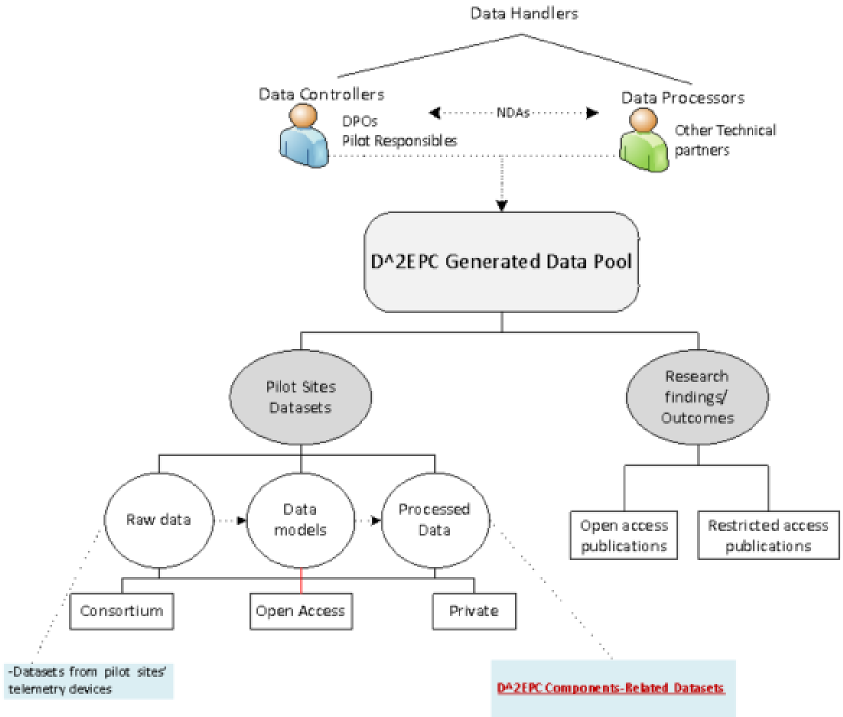


Figure 68. D^2EPC Data Management

In more detail, D^2EPC collected data from six pilot sites, which were conducted in Greece, Germany, and Cyprus. Both EU and national legislations and guidelines were followed closely according to the D^2EPC Ethical Management procedures as defined in D8.4 Data Management Plan v1 & Ethics. D^2EPC addressed any ethical and other privacy issues during the lifetime of the project, reviewing the design, development and deployment of the D^2EPC solutions for data management, privacy and security.

Following the Open Access principles while also complying with EU and national legislations and regulations, data that are deemed as Open Data are published to the Zenodo online repository.

Concerning the collected data from the sensing/metering infrastructure of the case studies, the project's consortium, including the pilot responsible partners, has agreed to preserve them in the D^2EPC Web Platform that is maintained by CERTH for future demonstration and exploitation purposes. The partners ensured that no sensitive data, as described in the previous sections, have been included in the stored datasets, while CERTH restricted the access to the latter only to consortium members, depending on their role.

The guidelines below were adopted for all cases of data protection and privacy:

- Protective principles against penetration were followed;
- Physical protection of major system components and access control measures were employed;
- Logging of D^2EPC system(s) and proper auditing of the peripheral components is available.

Apart from Zenodo, the project team ensures visibility of the D^2EPC public knowledge included in public deliverables, open data and scientific publications by sharing them in the project's website and project's social media pages.

Related Submitted Deliverables:

- D8.4 Data management plan v1 & ethics
- D8.9 Data management plan v2
- D8.10 Data management plan v3

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

## 1.3 Impact

### 1.3.1 Addressing the expected impact set out in the Work Programme

The information in Section 2.1 of the DoA continues to be relevant and, in general, does not need to be updated. Considering the methodology developed for evaluating and assessing the impact of the D^2EPC project from various perspectives – technical, economic, environmental, and social, the following updates can be made based on the results of the qualitative assessment:

**Improved user-friendliness of EPCs in terms of clarity and accuracy of the information provided**

To evaluate the improved user-friendliness of EPCs, a survey was organised for EPC assessors and pilot end-users to assess their perception of NG EPCs. EPC assessors' opinions are divided regarding the energy performance information provided by the improved EPC format. Most of the EPC assessors who took part perceived that the information provided was concise and clear, while others may not perceive it as fully concise and easily comprehensible. Despite differences of opinion, the information clarity rate is still relatively high at the rate 75.89%.

Considering the intuitiveness and the functional arrangement of the D^2EPC tool features, most of EPC assessors evaluated it positively or strongly positively, which resulted in the intuitiveness acceptance rate of 78.13%. All respondents were positive about the layout of D^2EPC tool, as well as the use of graphical elements and its colour schemes. The 75% of strong agreement resulted in an outstanding visual acceptance rate of 93.75%.

To summarize the EPC assessors' perception of user-friendliness of the D^2EPC Web platform, the total acceptance rate was calculated to be 82.59%.

The results of the pilot end-users survey suggest that improvements to the EPC format and the D^2EPC tool features have improved the clarity of the information provided in the EPCs. In particular, information clarity rate was calculated to be 81.25%, which is higher than EPC assessors rate for the same criteria. End-users provided their strongly positive opinion that revised EPC scheme is more user-friendly compared to the previous version. When converted into numerical values, the user-friendliness rate was 87.50%. Considering the intuitiveness and the functional arrangement of the D^2EPC tool features, most of the respondents evaluated it positively or strongly positively, which resulted in the intuitiveness acceptance rate of 82.14%.

All respondents were very positive about the layout of D^2EPC tool, as well as the use of graphical elements and its colour schemes. The 85.71% of strong agreement resulted in an outstanding visual acceptance rate of 96.43%.

Summarising the feedback from the EPC assessors on the ease of use of the NG EPC and the views of the pilot end-users, it can be concluded that the improvements proposed by D^2EPC have been evaluated very positively by all stakeholders. EPC assessors' feedback resulted in 82.59% of improved user-friendliness rate, while end-users had a better opinion on the improvements with 86.83%. The overall value of the improved user-friendliness of the EPCs indicator is calculated to be 84.71%.

**Enhanced user awareness of building energy efficiency**

The user awareness indicator for the D^2EPC service is derived from a comprehensive questionnaire targeting pilot users. Considering end-user's motivation towards monitoring their building's energy consumption, most of the responders evaluated it positively or strongly positively, which resulted in the motivation rate of 85.71%. A strong positive opinion was recorded with regards to the level of information provided by D^2EPC. In particular, all responders evaluated positively that improved EPCs are providing more information on building's energy efficiency. Based on the end-users' perception improved information rate was calculated to be 96.43%.

Similarly, most of the responders (82.14%) evaluated positively or strongly positively that D^2EPC project improved their awareness towards the importance of building's energy efficiency.

To summarize the end-user's awareness of building energy efficiency, the total enhancement rate was calculated to be 88.10%.

### Primary energy savings triggered by the project (in GWh/year).

To quantify energy savings, the simulated energy consumption of the building with energy-efficient measures (e.g., better insulation, energy-efficient appliances) is compared to a baseline scenario, representing the building's energy consumption without these measures.

The primary energy savings are derived from the reduction in energy consumption achieved by implementing the recommended energy-efficient measures.

Following the methodology presented in Section 2.1 of the DoA, assumptive calculations were made for two scenarios:

**Scenario 1 – Calculations based on EU Statistics**

Considering an average energy consumption of 85.75 kWh/m2 (European Commission[33]), a minimum 45% energy savings potential from deep renovation, a 70% renovation rate triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the annual future savings induced by D^2EPC, can be estimated at 32.58 GWh per year. According to Annex IV of the Directive 2012/27/EU[34] , a default coefficient of 2.5 can be applied for savings in kWh of electricity, whereas the respective value for fossil fuels can be taken as 1.171. Assuming that the energy savings come originally from 30% electricity and 70% fossil fuels, the total PES triggered by D^2EPC will reach **49.52 GWh/year.**

**Scenario 2 – Calculations based on D^2EPC Pilots**

Considering an average energy consumption of 163.15 kWh/m2 (which is the average consumption for residential D^2EPC Pilots), a minimum 45% energy savings potential from deep renovation, an 89% renovation rate (data obtained from questionnaires, D5.5) triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the annual future savings induced by D^2EPC, can be estimated at 78.93 GWh per year. According to Annex IV of the Directive 2012/27/EU[35], a default coefficient of 2.5 can be applied for savings in kWh of electricity, whereas the respective value for fossil fuels can be taken as 1.171. Assuming that the energy savings come originally from 30% electricity and 70% fossil fuels, the total PES triggered by D^2EPC will reach **119.38 GWh/year.**

On top of those assumptive calculations based on the approach introduced according to DoA, the results of the end-user survey confirm that all asked users believe that implementing the renovation plans presented by the D^2EPC tool will lead to energy savings and improved energy performance of their buildings. In particular, 71.43% of the users strongly confirmed that opinion while, in relation to the question about if the customised recommendations provided by the road mapping tool will encourage users to consider renovation plans, 85.72% evaluated it very positively or positively.

[33] https://building-stock-observatory.energy.ec.europa.eu/database/
[34] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027
[35] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027

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### Investments in sustainable energy triggered by the project (in million Euro).

Following the same approach as in the previous expected impact, assumptive calculations were made for two scenarios to assess potential investment in sustainable energy triggered by the project.

**Scenario 1 – Calculations based on general EU data**

Considering a 70% renovation rate triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the building renovation decisions induced by D^2EPC after entering the market – full development, can be estimated at 5,869 buildings. According to a report on European building stock renovation potential[36], the average renovation cost in the EU is 11.724 €/building. Considering that cost, an investment in sustainable energy of **68,8 million € per year** can be triggered by the project.

**Scenario 2 – Calculations based on D^2EPC Pilots**

Considering an 89% renovation rate (data obtained from questionnaires, D5.5) triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the building renovation decisions induced by D^2EPC after entering the market – full development, can be estimated at 7,474 buildings. According to the European building stock renovation potential report, the average renovation cost in the EU is 11.724 €/building. Considering that cost, an investment in sustainable energy of **87,6 million € per year** can be triggered by the project.

### Reduction of the greenhouse gases emissions (in $tCO_2$-eq/year) and/or air pollutants (in kg/year) triggered by the project.

As in the previous expected impact, the following assumptive calculations were made for two scenarios to assess the potential reduction of GHG emissions and air pollutants triggered by the project.

**Scenario 1 – Calculations based on EU Statistics**

Considering an average energy consumption of 85.75 kWh/m2 (European Commission, 2023[37]), a minimum 45% energy savings potential from deep renovation, a 70% renovation rate triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the annual future savings induced by D^2EPC after entering market – full development, can be estimated at 32.58 GWh per year. Applying the previous percentages for energy distribution per application in households and the corresponding emission factors for electricity, heating oil and natural gas, an estimated **10.57 tons CO2-eq/year** can be saved due to D^2EPC implementation.

**Scenario 2 – Calculations based on D^2EPC Pilots**

Considering an average energy consumption of 163.15 kWh/m2 (which is the average consumption for residential D^2EPC Pilots), a minimum 45% energy savings potential from deep renovation, an 89% renovation rate (data obtained from questionnaires, D5.5) triggered by EPCs and a 0.2% penetration rate of the D^2EPC in the EU certification market, the annual future savings induced by D^2EPC after entering market – full development, can be estimated at 78.93 GWh per year. Applying the previous percentages for energy distribution per application in households and the corresponding emission factors for electricity, heating oil and natural gas, an estimated **25.60 tons CO2-eq/year** can be saved due to D^2EPC implementation.

## 1.3.2 Socio-Economic Impact

**Boosting energy efficiency** impact assessment methodology included evaluation of end-users' perception of the improvement of energy efficiency through observing the energy used and monitoring activities. Based on the survey results, the users indicated that participating in the piloting

[36] https://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf
[37] https://building-stock-observatory.energy.ec.europa.eu/database/

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activities of the project motivated them to reduce their energy consumption and make behaviour changes in their daily routine. Most of the end-users (answers “likely” and “very likely” together 85%) are ready to reduce their energy consumption. All have indicated that have started to change their behaviour, at least moderately by 85%. This shows the effectiveness of monitoring the use of energy and involving the end users. Positive end-user perception of the D^2EPC solution resulted in 87.50% of energy reduction contribution rate, with a contribution to user behaviour change at 78.57%. In total, end-users’ contribution in boosting energy efficiency rate is calculated to be 83.04%.

**Upgrading Indoor Environmental Quality & Comfort** - As one of the aims of the project was to shift the focus of the NG EPC towards a user-centred approach and to improve the quality and comfort of the indoor environment, IEQ indicators were also included in the updated EPC scheme. The assessment took into account the EPC assessors' perception of the IEQ indicators in the context of the general indoor conditions, as well as the effectiveness in identifying potential problems. EPC assessors rated the IEQ indicators to be effective at the rate of 78.57%. The level of acceptance by building end-users was higher at 88.39%, resulting in an overall acceptance rate of 83.48% for the IEQ indicators.

**Improving renovation rate** indicator assessment methodology included evaluation of EPC assessors’ answers regarding the implementation of the solutions by the project in the processes of policy-making regarding renovation policies. More than 51% EPC assessors indicated that the outcomes has high influence on renovations policies and a further 25% of the respondents were of the opinion that the influence is very high. Almost 74% of the EPC assessors that responded to the questionnaire indicated that the recommendations provided in the NG EPCs would motivate the building owners to undertake energy renovation measures to improve energy efficiency and therefore, reduce the maintenance costs during the life cycle of the buildings and raise the comfort of the users. After EPC assessors’ perceptions are converted to total numerical values it is expected that D^2EPC solution will have an impact to improve the renovation rate by up to 72.97%. Almost 50% of the respondents to the end-users’ questionnaire indicated that the recommendations provided in the NG EPCs would motivate the building owners to undertake energy renovation measures to improve energy efficiency and therefore, reduce the maintenance costs during the life cycle of the buildings and raise the comfort of the users. This respond can be linked to the challenges, ownership structure and costs that will occur during the renovation work, and therefore, scoring the lower agreement rates of the end users. Users’ answers converted into improved renovation rate was calculated to be 70.83%. End-users’ and EPC assessors’ perception of improved renovation rate are very similar in value and in total, it is calculated to be 71.90%. It is worth mentioning that based on the results of the surveys it is visible that end-users’ and EPC assessors’ perception differs, EPC assessors have a more positive view on the project impact. This may be the result of their experience in building energy.

### 1.3.3 Value to Open Research Data

D^2EPC is a participant in the Pilot on Open Research Data, initiated by the European Commission along with the Horizon2020 program. The participants of the D^2EPC consortium respect the concepts and the values of open science and recognize the benefits of reusing and reviewing previously produced data for promoting and supporting European research and innovation projects. Selected data produced and collected throughout the duration of the project are made publicly available in open access for future research. In order to ensure the proper usage of data, all necessary principles for data handling have been outlined. At the same time, the perspective of the D^2EPC partners complies fully with the EU legislation and national regulations for data protection.

Towards ensuring the proper usage of data, all the relevant principles for data handling have been described. In particular, data availability within D^2EPC can be divided in three categories, as mentioned below:

- **Open Data**: Data that are publicly shared for re-use and exploitation.
- **Consortium:** Confidential data that are available only to members of the D^2EPC consortium and the EU Commission services and is subject to the project Non-Disclosure Agreement (NDA)
- **Private:** Data that are retained by individual partners for their own processes and tests.

The D^2EPC Data Management Plan focuses on providing the necessary infrastructure for the appropriate collection, publication and storage of metadata, especially during pilot execution. Each technical partner and pilot managers are responsible for following the guidelines presented by the Data Management Plan (DMP).

The D^2EPC Data Management Plan was covered by three deliverables, D8.4, D8.9 and D8.10, with the latter updating the former after the first prototypes were made available and a clearer understanding of the envisioned solutions was available.

The generated datasets were defined, considering certain interactions between the various modules of the D^2EPC architecture. In the light of the required information and taking into account the guidelines for reports related to "Pilot on Open Research Data in Horizon 2020", an appropriate dataset template was created and sent to partners who were responsible for specific components and their corresponding produced datasets. More specifically, the datasets were classified into the following categories: i) datasets belonging to the architecture components of D^2EPC (DS_01 - DS_11); ii) raw datasets from the pilot sensors/meters (DS_12 – DS_17). The final version of this deliverable was uploaded on M36. Within the D^2EPC DMP, the final versions of the 17 datasets were presented along with the following information:

- Type and short description of the datasets that were produced, collected and processed;
- Management processes of research data during and after the completion of the project;
- Standards and formats concerning the metadata;
- Information about data sharing, exploitation and preservation.

### 1.3.4 Market Impact

D^2EPC offers a groundbreaking solution in the field of energy performance assessment. Its innovative tools provide real-time monitoring and evaluation of energy efficiency in buildings, catering to a wide range of audiences, including private sector organizations, public bodies, policymakers, real estate owners, energy consultants, and academic institutions. D^2EPC platform is designed with scalability, allowing it to adapt to the specific needs and requirements of different stakeholders. This flexibility enables the system to cater to a wide range of stakeholders, ensuring that the solution remains effective and relevant over time, adapting to changing patterns.

D^2EPC taps into a substantial market potential, driven by the growing importance of energy efficiency and environmental sustainability. With its user-friendly web platform, standalone tools, and strategic partnerships, D^2EPC solution lies in the potential revenue streams that it can generate securing its commercial viability. Exploitation options include licensing the system to stakeholders as a software-as-a-service (SaaS) model, offering subscription-based access (monthly or yearly), or providing tailored solutions and consulting services. D^2EPC solution system can also use a model to charge for customer service or system update and maintenance. This can be charged as a monthly or yearly fee, to get the support- customer service when they need it, and for some customers can be a 24/7 (operational) that can have a different value.

A well-crafted business plan plays a pivotal role in enhancing D^2EPC's market impact. It provides a strategic roadmap that guides the project's distribution, sales, marketing, and financial efforts. D^2EPC business plan outlines clear objectives, target audiences, distribution channels, and revenue streams, while it empowers D^2EPC to effectively position itself in the market, attract investors and partners, and drive widespread adoption of its innovative energy performance assessment tools and additional services.

### 1.3.4.1 D^2EPC Business Models

The business plan for D^2EPC is designed to facilitate the widespread acceptance and successful commercialization of its innovative energy performance assessment tools and additional services. The plan includes a distribution strategy with a focus on objectives, target audiences, and diverse distribution channels, encompassing an online web platform, standalone tools, and strategic partnerships. It also outlines a sales strategy that combines direct sales efforts with collaborations to expand market reach and credibility.

Complementing these strategies are marketing initiatives, including SEO and pay-per-click campaigns, aimed at enhancing online visibility. The plan includes a detailed cost structure analysis covering development, distribution, marketing, and maintenance expenses. Moreover, it provides a sales forecast to estimate future revenue and incorporates Key Performance Indicators (KPIs) for tracking the success of sales and marketing efforts, ensuring data-driven decisions to optimize distribution and promotional activities. In summary, the D^2EPC business plan is a roadmap that encompasses distribution, sales, marketing, cost analysis, sales forecasting, and KPI analysis to drive the project's commercial success.

### 1.3.4.2 Value Proposition of D^2EPC

By delivering improved multi-parameter assessment and combining additional metrics like energy, smart readiness (SRI), sustainability, human comfort, and financial factors, the D^2EPC solution delivers a distinctive value proposition. Building energy efficiency can be better-understood thanks to this all-encompassing approach supporting decision-making. Moreover, it offers near-real-time asset and operational energy assessment of buildings, delivering more precise and up-to-date information. It does this by introducing BIM-based Digital Twins coupled with an advanced Internet of Things (IoT) system.

One unique aspect of D^2EPC is the enhanced AI-driven assessment recommendations that encourage energy conservation and the highest level of comfort. This tool promotes energy-saving awareness by offering practical advice that is adapted to the specific needs of each facility. Additionally, by including geolocation and "polluter pays" principles in the EPC’s perspective, it provides a solution with a greater positive impact on the environment and gives guidelines to the formulation of legislation. Last but not least, the Performance Alerts & Notifications feature and the Energy Performance and Credibility are two more components of the D^2EPC value proposition. D^2EPC can set itself apart by providing tailored recommendations both during the issuance of EPCs and throughout actual building operations. Moreover, the D^2EPC Web platform can automatically and continuously verify the data that has been collected, ensuring the accuracy of the information. The increased confidence in the platform's accuracy strengthens the case for energy performance assessments, elevating D^2EPC to the status of a highly dependable and innovative solution. These elements work in unison to transform the energy performance certification process and distinguish D^2EPC as the industry's premier platform. This connection promotes the unification of EPC data collection and transforms EPCs into useful policy-feeding mechanisms.

The EPC process is being revolutionized by the use of cutting-edge design models and tools like Building Information Modelling and the development of digital twins, which enable up-to-date approaches in sustainable building design and operation. The digitalization of EPC issuance and updating simplifies the procedure, reduces the mistake rates, and properly depicts the structural and operational aspects of a building. EPC data of all EU member states are uniformly documented and visualized thanks to the centralized EPC register provided by the D^2EPC WebGIS platform. This unified strategy enables accurate policy impact analyses, assists in the development of efficient energy efficiency award programs, and promotes targeted building materials and energy efficiency regulations. Policymakers can use the WebGIS tool to gain access to relevant statistics, to examine the location of EPCs, and conclude energy-related funding, rules for responsible energy use, and comparisons of regional energy performance.

In summary, the D^2EPC solution's value proposition lies in its ability to deliver comprehensive multi-parameter assessment, leverage advanced technologies like BIM and IoT, offer AI-driven recommendations, Performance Alerts & Notifications and the Energy Performance Benchmarking and Verification and Credibility, integrate geolocation and environmental practices, and provide a centralized EPC register through the WebGIS. These features set the D^2EPC solution as a powerful tool for improving building energy performance and supporting well-documented decision-making in the field of sustainable building construction and operation.

#### 1.3.4.3 Market Reach

Market research is a vital component of every company or project strategy, including the D^2EPC project's exploitation plan. Getting a meticulous analysis of the market environment entails a methodical study of market circumstances, industry trends, customer demands, and the competitive landscape. This analysis enables the participants to make properly formulated decisions, uncover opportunities, and devise successful methods for achieving their goals.

The following sections included in the D^2EPC Exploitation Report and IPR Protection Plan provide a detailed explanation of all the components that are included in the concept of Market research:1) The challenges of the current EPC schemes and the solution of the D^2EPC 2) Value Proposition 3) Key Exploitable Results 3) SWOT Analysis 4) PEST Analysis 5) Target Audience 6) Competitors Analysis and 7) Risk Management.

Firstly, the analysis reinforces the detection of the project's important exploitable findings, new services and solutions that address the market gaps and create value for the market by further assessing the state and the problems of EPCs, as described in the supplied overview. The primary exploitable findings should be explicitly specified and discussed in this part to emphasize the D^2EPC project's distinctive offerings.

The value proposition describes the advantages and the value of the project to its target audience. It explains the project's unique saleable features, and competitive advantages. It should clearly describe the project's value to the potential consumers, stakeholders, and other relevant parties. The target audience analysis is critical for determining the groups of consumers who might benefit from the project. This analysis entails investigating and determining the target audience's traits, requirements, preferences, and habits. Understanding their needs and expectations allows the project to modify its products and marketing methods to effectively reach and interact with the target audience.

Another important aspect of market analysis is the competitor analysis. It requires the detection and analysis of existing and future market rivals. It elaborates the comprehension of their advantages, disadvantages, market share, plans, and offers. The D^2EPC project can successfully position itself, distinguish its services, and uncover possibilities to beat the competition by examining the competitive landscape.

In addition, risk management analysis is also a vital part of market analysis. It involves identifying and assessing potential risks and uncertainties that could impact the success of the project. By analyzing these risks, the project can develop mitigation strategies, and contingency plans, and ensure that appropriate risk management measures are in place.

By conducting an in-depth market analysis encompassing these sections, the D^2EPC project gains valuable insights into the market dynamics, customer needs, competitive landscape, and potential risks. This information forms the foundation for effective exploitation strategies, targeted marketing efforts, and successful implementation of the project's objectives.

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#### 1.3.4.4 Key Stakeholders of the D^EPC Digital Platform

A wide spectrum of building industry stakeholders makes up the D^2EPC solution's target audience. The primary target group includes building professionals, building tenants/ owners, real estate agents, and various industries. Important audience segments also include early adopters such as service providers, academic institutions, and governmental organizations/public officials.

The target audience for the D^2EPC solution can be categorized into the following groups:

- Building Professionals/Construction companies (e.g., engineers, retrofitting/construction businesses, and real estate brokers): The different available data by D^2EPC, regarding energy usage profiling, occupancy data, and interior environmental conditions, can be useful to these experts. The solution provides individualized guidance and suggestions for energy performance improvements, assisting experts in enhancing performance evaluation, certifications, and integrating energy efficiency measures into building design and construction.
- Building Tenants/ Owners: D^2EPC can give this target audience useful knowledge and suggestions on how to reduce energy use, better indoor air quality, and improve their comfort and well-being. D^2EPC encourages energy efficiency knowledge and behavior change at the individual level by arming building users with tailored instructions and insights.
- Real estate agents: Real estate agents have a big impact on the housing market and their opinion is important regarding adopting energy-efficient techniques. D^2EPC can increase awareness of the value of energy performance evaluations, energy certifications, and the advantages of energy-efficient homes by specifically targeting real estate brokers as an audience. This supports the market value of energy-efficient structures and motivates real estate brokers to place an emphasis on energy efficiency in their listings and deals.
- Various Industries: D^2EPC's wider approach and set of applications can be easily expanded/applied also to different case studies other than the pilot buildings (residential, industrial, research buildings). Such case studies could include hotels, factories, and other commercial structures. It promotes energy efficiency projects and aids in the optimization of energy performance in a variety of building types by offering specialized advice and insights catered to the unique energy issues and requirements of these businesses.

Additionally, the D^2EPC solution targets early adopters who can drive the initial adoption and implementation of the technology. These early adopters include:

- Service Providers: The most important service providers in the energy efficiency industry are engineers, EPC Assessors, and Energy Service Companies (ESCOs). These specialists may improve their abilities and deliver more precise and thorough energy performance analyses, certifications, and retrofit suggestions by integrating D^2EPC into their businesses.
- Academic Institutions: Academic institutions are essential for research, development, and instruction on sustainable construction practices and energy efficiency. D^2EPC may work with academic institutions as early adopters to validate and improve the system, carry out research, and educate the next energy efficiency specialists.
- Governmental Agencies/Public Policy Makers: Governmental organizations and public policy makers play a key role in establishing energy efficiency laws, guidelines, and rewards. D^2EPC can offer these stakeholders, solid data, insights, and tools for evidence-based policy choices, energy planning, and promoting sustainable building practices by focusing on these stakeholders.
- Global Partnerships and Collaborations: To expand the scope of the D^2EPC platform beyond Europe and facilitate access for customers in various regions, establishing global partnerships and collaborations is essential. Partnering with international organizations, energy efficiency initiatives, and sustainability programs can help disseminate the platform's capabilities, share best practices, and drive the adoption of energy-efficient practices worldwide. By leveraging

global networks, the D^2EPC platform can aim for a wider audience and contribute to the global transition towards sustainable buildings.

#### 1.3.4.5 Conclusions

In conclusion, the D^2EPC market analysis reveals both opportunities and challenges. Due to growing environmental concerns, the market for energy-efficient solutions offers a promising path for the project's expansion and it appears that the concepts and objectives of the D^2EPC project are even more crucial. The market stakeholders as well as the socio-political opinion, prepare and demand the next steps that will enable buildings' decarbonization and effective energy savings. By establishing a strong brand identity and strong customer relationships in addition to concentrating on its technological edge, D^2EPC sets the foundations for wide and impactful exploitation and market outreach. Keeping a competitive edge will require adapting to changing customer preferences and regulatory changes.

## 1.4 Contact Details

Further information about the D^2EPC project can be acquired either from its website or via establishing direct contact with the D^EPC partners.

### 1.4.1 Project Website

A publicly available website was launched early in the first year of the project (October 2020) with the aim to act as a communication and dissemination channel for the project's results and for involving and enlarging the stakeholders' community. Thus, public documents deriving from the project work (e.g., deliverables, newsletters, publications etc.) are included, and are being regularly updated under the section Project results. Next, there is a section dedicated to consortium partners with links to partners' websites. In the section Demonstration cases all 6 sites are presented with a photo and text. Section Network lists all the sister projects and other projects that have synergies with the D^2EPC. Finally, the section News & Events reflects the dynamics of the projects by listing all the participations to major events, published papers and newsletters, organisations of workshops etc., in order to address both the general public and the potential stakeholders for the results of the project.

The website is hosted and managed by DMO and is available at the following address: https://www.d2epc.eu/en. It is planned that the D^2EPC website will be maintained for two years after the end of the project.


**Figure 69. Snapshot from the D^EPC official web site**

## 1.4.2 List of Beneficiaries/ Consortium Composition

The D^2EPC consortium is made of 13 high-profile European partners carefully selected for their acknowledged excellence as well as both their complementarity and trans-nationality in order to provide the necessary knowledge, expertise, and state-of-the-art background required to ensure the success of the D^2EPC project as well as the sustainability of the proposed research and expected results.

Industrial entities and SMEs range from software tools developers (SEC, HYP, GSH, DMO) to energy services companies (CLEO, IsZEB) and certification and dissemination experts (SGS) that collectively worked towards fulfilling the project objectives. Three world-class research centres (CERTH, KTU, FRC) participated in the consortium, offering cutting-edge scientific background, as well as low TRL foundational research capabilities and ability to disseminate through top-notch scientific journals and conferences as well as one scientific association focusing on sustainable energy (AEA) that is involved in the Concerted Action EPBD and provided scientifically founded advice for decision-makers in politics, business and administration. In addition, two competent standardization bodies (UNE, ASI) provided their field experience, their knowledge of regulations and standards to ensure that the project activities and results will contribute to updating standards and promoting new ones.

In that sense, D^2EPC has been actively encouraging the business innovation trend whereby commercial companies were supported by and collaborated with high-end academic and research organizations. This collaboration approach provides academic and research organizations with a strong market orientation in their R&D efforts while commercial companies take advantage of focused task forces.

The following table demonstrates D^2EPC partners and their corresponding contact names.

**Table 17. D^2EPC partners and contact details**

| No | Partner Short Name | Partner Organization and Contact Details |
|---|---|---|
| 1 | CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS<br>iti CENTRE FOR RESEARCH & TECHNOLOGY - HELLAS Information Technologies Institute | **Centre for Research and Technology Hellas**<br>**Information Technologies Institute**<br>**Website:** www.iti.gr<br>**Project Coordinator & Contact Person**:, Dr. Dimosthenis Ioannidis<br>**Email**: djoannid@iti.gr<br>**Contact Person & Project Manager:** Panagiota Chatzipanagiotidou<br>**Email**: phatzip@iti.gr |
| 2 | ktu 1922 kaunas university of technology | Kaunas University of Technology- Centre for Smart Cities and Infrastructure<br>**Website:** https://ktu.edu/<br>**Contact Person**: Andrius Jurelionis<br>**Email**:andrius.jurelionis@ktu.lt<br>**Contact Person**: Egle Klumbyte<br>**Email**: egle.klumbyte@ktu.lt |

| | | |
|---|---|---|
| 3 | GEOSYSTEMS HELLAS | **GEOSYSTEMS HELLAS IT KAI EFARMOGES GEOPLIROFORIAKON SYSTIMATON ANONIMI ETAIREIA**<br>**Website:** www.geoysystems-hellas.gr<br>**Contact Person**: Mrs. Vasiliki (Betty) Charalampopoulou<br>**Email**: b.charalampopoulou@geosystems-hellas.gr<br>**Contact Person:** Christos Kontopoulos<br>**Email**: c.kontopoulos@geosystems-hellas.gr |
| 4 | innovation www.cleopa.de | **Cleopa GmbH**<br>**Website:** https://cleopa.de/<br>**Contact Person:** Mr. Detlef Olschewski<br>**Email**: dolschewski@cleopa.de<br>**Contact Person:**Ms. Christiana Panteli<br>**Email**: cpanteli@cleopa.de |
| 5 | senercon | **SEnerCon GmbH**<br>**Website:** www.senercon.de<br>**Contact Person**: Mr. Immanuel Hengstenberg<br>**Email:** Immanuel.Hengstenberg@senercon.de |
| 6 | UNE | **Asociación Española de Normalización**<br>**Website:** www.une.org<br>**Contact Person**: Mr. Aitor Aragon<br>**Email**: aaragonb@une.org |
| 7 | DEMO CONSULTANTS | **DEMO Consultants bv**<br>**Website:** www.demobv.nl<br>**Contact Person**: Mr. André van Delft<br>**Email**: Andre@demobv.nl<br>**Contact Person**: Mija Susnik<br>**Email**: Mija@demobv.nl<br>**Contact Person**: Samaneh Rezvani<br>**Email**: samaneh@demobv.nl |
| 8 | SGS | **SGS TECNOS S.A.**<br>**Website:** www.sgs.com<br>**Contact Person**: Mercedes Rodríguez-Caro<br>**Email**: Mercedes.Rodriguez@sgs.com |

| | | |
|---|---|---|
| | | **Contact Person**: Adrian Canocabanero<br>**Email**: adrian.canocabanero@sgs.com<br>**Contact Person**: Estefania Lopez<br>**Email**: estefania.lopezmontesinos@sgs.com |
| 9 | | **HYPERTECH Energy Labs**<br>**Website:** http://ht-energylabs.com<br>**Contact Person**: Thanos Kalamaris<br>**Email**: t.kalamaris@hypertech.gr |
| 10 | | Austrian Standards International<br>**Website:** https://www.austrian-standards.at/<br>**Contact Person**: Karl Grün<br>**Email**: k.gruen@austrian-standards.at<br>**Contact Person**: Anita Reiter<br>**Email**: a.reiter@austrian-standards.at<br>**Contact Person**: Alena Rabitz<br>**Email**: a.rabitz@austrian-standards.at |
| 11 | | Frederick Research Center<br>**Website:** http://frc.frederick.ac.cy<br>**Contact Person**: Dr. Paris A. Fokaides<br>**Email**: eng.fp@frederick.ac.cy<br>**Contact Person**: Phoebe Zoe Georgali<br>**Email**: res.gp@frederick.ac.cy |
| 12 | | Austrian Energy Agency<br>**Website:** www.energyagency.at<br>**Contact Person**: Naghmeh Altmann-Mavaddat<br>**Email**: Naghmeh.Altmann@energyagency.at |
| 13 | | **Intelligent Solutions for Zero and Positive Energy Buildings**<br>**Website:** https://iszeb.gr<br>**Contact Person:** Afroditi Zamanidou<br>**Email**: a.zamanidou@iszeb.gr |

**The individual role of each partner is briefly described below:**

1. **Centre for Research and Technology Hellas (CERTH)**

CERTH (Information Technologies Institute) has long experience in project management and quality assessment of project-related activities, undertook the coordination of the project. The Information Technology Institute exhibits substantial research activity as well as technology transfer actions, and employs a high-quality scientific group in the area of energy, environmental performance of buildings and their associated infrastructure, multi-sensorial systems, the development of simulation platforms, visual analytics for highly complex systems, and extended knowledge over Decision Support Systems.

Under D^2EPC, CERTH acted as project Coordinator and Ethics and Data manager. In particular, CERTH undertook the main role in the design and development of the buildings digital twin and was responsible for defining system's architecture, contributing significantly to the system's information model. CERTH was also responsible for the Added Value Services Suite and contributed to the development of the Extended dEPCs Applications Toolkit, leveraging its expertise on analytics techniques and user profiling. CERTH was mainly involved in the integration of the D^2EPC modules into one holistic functional packaged solution and led the development of the D^2EPC Digital Platform. Finally, CERTH was responsible for the activities for pilot planning and preparation and was involved in the demonstration activities leading the Greek pilot with the Smart House located at its premises. Overall, CERTH contributed to various tasks and activities: definition of dynamic EPC scheme, gathering energy-related data from IoT and BMS interfaces and also transferred its knowledge on pilot evaluation and assessment, especially for the Greek use case.

2. **Kaunas University of Technology (KTU)**

Kaunas University of Technology (KTU) is one of the largest technical universities in the Baltic region. In 2022, it achieved successful participation in 251 RD&I projects, which were financed by the EU and national research programs. The university maintains strong collaborations with over 350 research and academic institutions spanning 51 countries, in addition to engaging with representatives from international business enterprises.

KTU is known for its contribution towards the building energy performance field, as well as in the development of Building Information Modeling (BIM) and Digital Twin technologies. The collaborative efforts of the Sustainable Energy in the Built Environment research group, in conjunction with the Centre of Smart Cities and Infrastructure, have propelled their involvement in the D^2EPC project. KTU also plays an active role in the BIM LT project, contributing to the development of national BIM standards and BIM classification. The university also dedicates efforts to the training of building certification experts and the formulation of national building codes pertaining to energy performance.

Within the project's scope, KTU led the coordination of defining foundations for the next generation dynamic EPC scheme and development of the information model. This included the analysis and establishment of a novel set of indicators outlined in D^2EPC, encompassing aspects of Smart Readiness Indicators (SRI), Life Cycle Assessment (LCA), Life Cycle Costing (LCC), human comfort, and overall well-being. KTU further facilitated the integration of BIM models into the D^2EPC framework, along with systems integration. In addition, the university participated in technical and innovation management, playing a role in disseminating and capitalizing upon the project's outcomes.

KTU's contributions extended across all Work Packages, and it has led WP1 - "Foundations for Next Generation Dynamic EPCs (dEPCs): Identifying Challenges, Needs, and Opportunities," as well as WP2 - "Development of the Operational Framework for dEPC Schemes." KTU efficiently coordinated tasks related to the D^2EPC Information Model, as well as the evaluation and comparative assessment of next generation EPCs.

3. **Geosystems Hellas A.E. (GSH)**

Geosystems Hellas (GSH) is a leading geoinformatics SME company operating since 2009 in the fields of Downstream Space and Earth Observation, software development and computer vision, GIS and platform integration solutions. GSH is actively involved in a broad range of European-funded R&D and commercial projects associated with land management, crisis management and Spatial Data Infrastructure implementations. Furthermore, the company possesses extensive experience in mapping, geospatial data collection and processing as well as application development, all related to Big Data and Data Fusion. Utilizing machine learning and deep learning techniques, GSH contributes to the areas of Environment & Climate Change Adaptation, Urban Resilience & Well-being, Culture Heritage Preservation, and Forestry & Agriculture

Under D^2EPC, GSH acted as a technology provider partner participated in all respective task activities (T3.2 Development of a GIS scheme for EPC documentation) and also led the exploitation activities of the project under Task T7.4. The main technical contribution in the project was the design and development of the D^2EPC WebGIS application tool. The WebGIS application is part of the representation layer of the D^2EPC platform and provides a wide set of functionalities for the visualisation and provision of EPC statistics at the regional level as well as documenting BIM models in a 3D environment. The tool is fully operational and accessible through the D^2EPC platform.

GSH led the exploitation activities of the D^2EPC under Task 7.4 Exploitation activities, IPR management and post-project sustainability. More specifically, GSH created the D^2EPC Exploitation strategy that is needed in order to capitalize on knowledge and technologies developed through the implementation of the project and to bring value generated to market, as well as to society. The exploitation strategy comprises an extensive market analysis coupled with a highly cohesive business plan rooted in the utilization of D^2EPC assets. Moreover, Exploitation workshops were held during the D^2EPC project that GSH organised, utilizing the Horizon Results Booster (HRB) service and the Horizon Results Platform (HRP). These workshops sought to optimize the project's exploitation efforts by leveraging HRB's experience and resources and exploiting HRP's collaborative environment. The project team used these workshops to maximize the effect and utilization of the project's outputs, resulting in the successful exploitation and dissemination of the D^2EPC outcomes. Last but not least, an IPR plan was created in order to ensure that all project outcomes are well-protected and prepared for exploitation.

4. **Cleopa Gmbh (CLEO)**

Cleopa GmbH is a provider of innovations in the energy sector since 1998 and offers a wide range of consulting and service offers. Dealing as efficiently as possible with energy topics of our time, Cleopa offers solutions to improve energy efficiency and reduce energy consumption of buildings (Residential, industrial etc) using state-of-the-art methods and software. Cleopa is trusted very well with the chances and challenges of energy efficiency projects, which is based on its long-standing activity in the energy consulting. Cleopa GmbH is an active partner in research and innovation projects on a national and international level with a focus on energy, smart services, security and data protection. Cleopa develops and executes innovation projects for and with partners in the field of energy. This includes management consulting for energy efficiency, financing, commercialization, participation in the submission, involvement of the companies in associations as well as participation in the project implementation and documentation. As a project partner, we will be responsible for the demonstration and Validation of the next generation EPC and compare it with the existing schemes.

Within this project, CLEO acted as an Energy Service Company, providing access to the consortium members to buildings located in Germany for real-time monitoring of their energy performance and was responsible for defining user and stakeholder needs so as to be expressed within the next generation EPC scheme. CLEO was also responsible for delivering the aspired smart readiness aspects of the buildings’ assessment framework and the integration of energy-related data from sensors and connected devices into next generation EPCs. CLEO also led the demonstration and validation activities of the project, having contributed to two case study buildings in Germany, one residential and one industrial. Finally, CLEO was responsible for the quality and risk management of the project.

5. **SEnerCon Gmbh (SEC)**

SEnerCon is an energy service provider, focusing on Energy Performance Certificates for Buildings, Energy Consulting for the building sector and Energy Monitoring also including non residential buildings. Through partnerships with IoT/data acquisition specialists SEnerCon is able to implement significant reductions of energy demand and energy cost.

SEnerCon is also strong in developing innovative energy consulting approaches in research projects, making productive use of artificial intelligence and data science. SEnerCon is located in Berlin, having also a branch in Munich. Through its integrative multi cultural setting, SEnerCon integrates perfectly in European projects but also features competencies to implement national projects with high maturity.

SEC participated in the research of existing EPC schemes in Europe providing also translations. SEC organised several internal meetings for WP4 to discuss progress and decide on actions. SEC developed a dynamic server-based EPC front-end showing additional functionality. In Task 4.4 SEC developed a dashboard with operational data. SEC was responsible for two pilots in Germany:

- Organizing building data
- Sketching BIM representation
- Conducting additional EPC
- Progressing with building owners to invite tenants to allow installation of sensors
- Deploying the sensors
- Collecting sensor data and providing to the consortium via API
- Collecting meter data and providing to the consortium via API

Finally, SEC tested the SaaS functionality and its EPC dashboard using on line building data and allowing user feed back.

6. **Asociacion Espanola de Normalizacion (UNE)**

UNE is the organization designated by the Spanish Public Administration as the National Standardization Body (NSB). UNE is the national representative and member of the European (CEN/CENELEC), International (ISO/IEC) and Pan-American (COPANT) standards organizations, and member of the European Telecommunications Standards Institute (ETSI). UNE is a non-profit-making, private, independent and multisector organisation, recognised at National, European and

UNE has more than 32000 standards in catalogue, 200 national technical committees and 150 responsibilities (chairpersons, secretariats, convenors) in international standardization committees are a sample of the experience developed as national standards body during more than 30 years. UNE is participating in many Research and Innovation projects (Horizon 2020, FP7, Life+, CIP etc., see examples here).

In D^2EPC, UNE has developed several standardisation activities, in particular:

1. Description of the state of the art within the standardisation system, as a source of information for technical partners, including in-force standards applicable to D^2EPC and technical commitees or working groups.
2. Regular contact with standardisation working groups, including assessment of the relevant documents, attendance to meetings and, when relevant, providing information and data about the results of D^2EPC, in order to get feedback and peer-review.
3. Dissemination of the project results of D^2EPC, in particular the **creation of a new standardisation working group** and a **new European standard** on operational rating of the energy efficiency of buildings.

In addition, UNE proposed the transfer of the standardisation activities to other EU-funded reseach projects (**SmartLivingEPC** and **Chronicle**) and made presentations to other organizations interested in digital data for building assessment, like the InData platform. More information about these activitites is available in D7.4 and D7.12.

These activities have been recognized by CEN/CENELEC, as D^2EPC has been **nominated for the Standards+Innovation Awards 2023**, in the category **Project award**. The responsible for D^2EPC in UNE, Aitor Aragón, has also been nominated for these awards, in the category of **Technical Body Officer**, due to the work made on this project.

### 7. DEMO Consultants BV (DMO)

DMO Consultants is an SME located in The Netherlands, working on finding optimal solutions for real estate management. The company is divided into three sectors, namely the consultancy, the software, and the research. The later has more than 25 years of experience working on project related to sustainability, energy efficiency, smartnes, renovation and other.

In the D^2EPC project DMO was responsible for leading three tasks. Based on the experience and expertise DMO was given the role to lead the task about the development of financial indicators as one of the added values to the new generation EPCs. Next, DMO was responsible for the task of building renovation passports where DMO's research expertise were needed to perform thorough desk research on finding synergies between building renovation passport and project's outcomes. Finally, DMO was leading the task on communication and dissemination activities & materials and was responsible for maintaining project's website and social media channels, representing to the broaded audience the outcomes, activities and progress of the project. Besides, DMO participated as a contributing partner in eight tasks within WP1, WP2, WP3, WP4, WP6, WP7 and WP8.

### 8. SGS Tecnos SA (SGS)

SGS is the world's leader in certification, inspections, verification and testing. It´s also a renowned multinational company with long experience in certifications for the energy sector. They work to achieve an improvement in the energy performance of their clients and partners.

They have provided their expertise in the energy efficiency sector, having developed plans for energy savings for companies and municipalities. As a certification company, they can certify energy savings and help to develop energy efficiency plans to reduce consumption.

Because of his profile and experience in this field, SGS has been responsible for providing guidance for auditing and implementing the certification process proposed within the project. It was intended that the new EPCs reflect the real performance of the building and will be renewed regularly, so that a methodology for implementing D^2EPC scheme has been defined to ensure that the results remain reliable and objective. Furthermore, SGS has been involved in the definition of SRI and LCC indicators and in the evaluation and comparative assessment of the new dynamic EPC scheme, exploiting its expertise as a certification company already implementing the current EPC scheme.

In the same context, SGS has led the actions for the dissemination policy and subsequently has participated in the dissemination and exploitation of project's results to the identified interested parties, by leading the dissemination and communication work package of the project. Finally, it has also contributed to linking EPCs with building passports and to the development of motivational schemes for conscious users.

### 9. HYPERTECH Energy Labs (HYP)

Hypertech is a well-established company delivering digital solutions in different industries (i.e., Energy, Environment & Climate Change, Fintech, AI, IoT, AR-VR) since 1997. For over two decades now, Hypertech has supported EU public organisations, cultural institutions, and private businesses with their needs, achieving 400+ successful collaborations and delivering 500+ impactful projects revolving around Digital Transformation, Communication as well as Research & innovation.

Within D^2EPC, Hypertech participated in both technical and non-technical tasks. More specifically, HYP undertook the delivery of the D^2EPC IoT Framework the role of which was to satisfy the dynamic data requirements of the project. As a leader of the task, also participated in and orchestrated the works (along with the contributing partners CERTH/SEC) that delivered the Extended dEPCs Applications Toolkit. For this reason, Hypertech was in close collaboration with pilot and technical partners of the project towards materialising interfaces between data sources and integrations of components in the main system architecture of the project.

Regarding non-technical tasks, Hypertech was the main responsible for the definition of the Human-centric KPIs -addressing comfort and well-being aspects of the occupants, to be part of the novel set of indicators introduced in the new-age EPC.

Overall, Hypertec participated in various tasks and activities as a contributing partner, such as the design of the project's architecture and information model, the definition of the dynamic EPC scheme, various dissemination activities and more.

### 10. Austrian Standards International (ASI)

"Austrian Standards International – Standardization and Innovation" (ASI) is the recognized standardization body in Austria, a non-profit service organization founded in 1920. It is part of a national, European and international standardization network: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), the European Telecommunications Standards Institute (ETSI), the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU). Austrian Standards International cooperates with the Austrian Electrotechnical Association (OVE), which is responsible for standardization in the electrotechnical field, being a member of CENELEC and IEC. At the end of 2022 there are 4.562 experts representing 2.768 organizations from different stakeholder-categories (industry, SMEs, architects, civil engineers, consumer organization, public authorities, research organizations, conformity assessment bodies, trade unions, NGOs, etc.) participating in the development of Austrian, European and International standards coordinated by ASI. ASI is participating in many Research and Innovation projects (Horizon 2020, Horizon Europe).

In D^2EPC, ASI has contributed to T1.1, Comparative assessment of current EPC schemes and relevant emerging building performance paradigms, T7.2, Communication & Dissemination Activities & Material, and to T8.1, Project coordination and administrative management. As contributing partner of T7.2 ASI has disseminated the information about D^2EPC, such as newsletters, press release about the Joint Final Conference or the D^2EPC Training Session, to relevant national standardization committees mirroring the European and International technical committees of interest for D^2EPC as well as to stakeholder fora on construction hosted by ASI ("Dialogforum Bau Österreich" and "Baustammtisch"). Another dissemination activity was the presentation of the project to students at the University Applied Sciences FH St. Pölten, Austria, Bachelor Course Smart Engineering of Production Technologies and Processes. As leader of T6.1, Updating current standards towards dynamic EPCs, ASI developed version 1 of the Strategic Standardization Plan (D6.1) and version 2 (D6.5). These deliverables present the standardization landscape for D^2EPC, a survey to identify gaps in the standardization landscape, an assessment of the identified gaps and recommendations derived from the assessment used as input for other standardization activities, namely T7.3, Contribution to standardisation activities (lead by UNE).

### 11. Frederick Research Center (FRC)

Frederick Research Center (FRC) is a research non-profit organization in Cyprus. It was established in 1995 in order to create a solid foundation for the development of scientific research activities of Cypriot and foreign scientists. Members of the FRC are the faculty of Frederick University and independent scientists that promote their research through their collaboration with the FRC. Since its establishment, the Center has been involved in more than 120 externally funded research projects. The research initiatives and activities that are being carried out at the Center, have been funded predominantly from external sources through competitive national and European programs, including Horizon2020, LIFE, ERASMUS+, LLP, FP7 and from Regional Funds (INTERREG). Besides the self-funded creative and other projects, the staff has implemented or currently running more than a hundred R&D and consulting projects, the majority of which are coordinated by FRC researchers.

**12. Austrian Energy Agency (AEA)**

The Austrian Energy Agency develops strategies for sustainable and secure energy supply, provides advice and training, and is the networking platform for the energy industry. klimaaktiv, the climate protection initiative launched by the Austrian Federal Environment Ministry (BMK) is managed by the Austrian Energy Agency and coordinates the various measures in the areas of mobility, energy saving, construction and renovation and renewable energy. AEA provides scientifically founded advice for decision-makers in politics, business and administration – both nationally and internationally. As a competence centre for energy, AEA concentrates on three strategic areas: "mission zero", transformation and smart energy. Focusing on mission zero the Austrian Energy Agency pursues the long-term objective of building a fossil-fuel-free future through strategy development and the implementation of concrete measures.

The Austrian Energy Agency has members from different political, administrative and business sections such as all nine Austrian provinces, two federal ministries and more than 40 energy agencies and social institutions. The result of the project will be discussed and disseminated to the members and to the relevant stakeholders. The Austrian Energy Agency has disseminated the project and its outcomes through stakeholder meetings and workshops as well as its website and newsletters to its members and relevant stakeholders. Furthermore, AEA is involved in the projects Concerted Actions EPBD, EED and RES and has introduced the project outcomes. The project was also presented by direct contacts with responsible bodies (like the federal Ministry of Environment (BMK), Austrian Energy Consultants (ARGE-Eba), Austrian provinces, EPC software companies). AEA attended many European conferences and workshops (e.g., Sister Projects, BUILD UP Skills) in order to exchange with international stakeholders. The project was actively disseminated via social media (LinkedIn) by AEA.

**13. IsZEB- Intelligent Solutions For Zero And Positive Energy Buildings (IsZEB)**

The IsZEB Cluster was founded in 2020 with a special focus on the Construction domain aiming to provide tools and guidelines for the entire lifecycle of a smart zero or positive energy building. Established in the region of Central Macedonia, it offers multiple services, covering the phases of planning, commissioning, construction, renovation, demolition and recycling of buildings and building components.

IsZEB and its partners actively contribute to the research and development needs of the sector and exploit cutting-edge technologies and ideas, through the deployment of National and European research projects. The specialized professionals, the state-of-the-art technical infrastructure, as well as the collaborations with universities, institutes and research centers both nationally and abroad lay the foundations for high-technology production and the evolution of the construction sector.

The offered services empower every organization to respond to external and internal opportunities and use creativity combined with technology to introduce new ideas, processes or products. In that way, IsZEB supports the identification of new market/business opportunities through strategic analysis of the ecosystem and trend watching, facilitates access to the various funding sources (EU, National, or private) and provides access to its infrastructure such as the nZEB Smart Home. By leveraging the R&D results and the vast experience in ICT solutions, the IsZEB cluster can aid companies in a new digital era with the provided solutions.

# 2 Dissemination and Exploitation of Foreground

## 2.1 Dissemination Methodology & Objectives

The main objective of the dissemination strategy has been to identify and organize the activities to be performed to maximize the influence/impact of the project and to promote commercial, and secondary exploitation routes of the project results. To ensure the widest possible dissemination of the project and to increase its impact and outreach, D^2EPC dissemination objectives were set around six pillars:

1. Demonstrate the improvement of the user-friendliness of EPCs in terms of clarity and accuracy of the information provided.
2. Achieve greater user awareness of the energy efficiency of buildings.
3. Demonstrate the primary energy savings triggered by the project (in GWh/year).
4. Promote Sustainable Energy Investments driven by the project (in millions of euros).
5. Reduction of greenhouse gas emissions (in tCO2-eq/year) and/or atmospheric pollutants (in kg/year) caused by the project.
6. To disseminate the respective project outcomes to the widest possible community of potential beneficiaries.

To achieve all these objectives, a dissemination strategy was planned in the Dissemination and Communication Plan in D7.1. to be followed by all the consortium members.

The dissemination strategy and activities have followed principles and best practices planned by the partners and in line with the EC Guidelines for successful dissemination. The focus of D^2EC's overall dissemination strategy was the identification and mapping of target stakeholders (who to disseminate) and an understanding of their needs and characteristics in order to tailor clear and concise messages (what to disseminate) to different target audiences. This also has ensured the use of the most appropriate and efficient dissemination channels and communication tools and has driven the development of appropriate material by the target stakeholders (how to disseminate it). Furthermore, a time plan was defined at the beginning of the project (when to disseminate), helping all the project partners to implement the communication and achieve the dissemination and exploitation objectives throughout the project implementation.

In order to reach a wider audience, beyond the main stakeholders of the project, links have been created with other EC projects. Especially with those within the H2020 programme that have similar goals to those of D2EPC. A network of sister projects has been created which has strengthened the image of these projects and has favoured the collaboration and the flow of information between all of them, thus improving the impact they all have.

The project's Dissemination Strategy has been based on a 4-step methodology detailed below, which describes why, what, to whom and how to communicate and disseminate:

| 1. Why to disseminate? |
| --- |
| A high visibility of the project and promotion of an active interaction with key stakeholders were necessary elements to build project familiarity and raise awareness among stakeholders. Providing the wider public with advance notice of possible future plans and actions, it also has strengthened collaboration links with partners and has helped to establish and reinforce a wider networking activity. In It has been very crucial to promote the project's results to stakeholders outside the project partnership to ensure that:<br>1. the project outputs are fully exploited in the most effective manner; |

2. the knowledge gained through the project, and more generally the information generated by the project, have been and will be available to all interested organisations (all the results of the projects can be found in the D^2EPC website);
3. elements of excellence of the project can be reused and replicated in other projects, becoming a reference point triggering further development in the field and beyond;
4. the project reaches out to decision-makers to contribute to improve future policies, through a policy recommendation that has been created by the consortium. A first version was created at M24, and a final version has been delivered at M36. In addition to this, a joint document has been created with all the sister projects where common policy recommendations have been made, with the support of renowned universities, technology institutes, research centres, and large companies among others.
5. the benefits that the project's outcomes will bring to society (services, employment, economy) are well pointed out in all the results.

**2. What to disseminate?**

This step concerns the selection of the project information provided for dissemination on a clear and obvious presentation and on the protection of specific know-how of the project partners so as not to endanger the exploitation of results.
Towards this direction, the following project information has been disseminated to the relevant audience:

1. The objectives, results and key facts of the project.
2. News (achievements and advancements). Partners have recaptured the main research results, focusing on their application on the demonstration cases. In this way, it is possible to attract the attention of investors and potential customers for the exploitation of project's results;
3. Events promotion and events results. The project's results has been presented at national and international events and conferences and workshops.

In addition, the following project outputs have been disseminated as widely as possible:

- D^2EPC solutions and application, along with lessons-learned and recommendations;
- Participation in standardization activities and training and educational sessions on the new tools delivered.

**3. To whom to disseminate?**

The dissemination strategy of the project focused on the following target groups:

**Policy enablers**

Key target groups: Regional, National and International policy makers and public authorities (i.e., industrial committees, ministry and regional councils), Regulators, Standardization bodies. This group can boost the exploitation of project's results and the realization of the long-term impact of the project, can affect EPC applications on the market, can help overcome barriers and promote sustainable development.

**Building Industry**

Key target groups: Building professionals (i.e. Engineers, Architects, Designers), ESCOs, SME contractors, Construction companies, Consultancy firms. This group can act as collaborators and catalysts for delivering dynamic EPCs and can help improve the proposed framework and services.

**Building End-users**

Key target groups: Building users/owners/managers, Energy auditors, Relevant stakeholders at the Pilot Sites. This group is very important as it can define the success or failure of the project and will provide feedback on the envisioned dynamic EPC framework and are one of the main beneficiaries of the project.

**Scientific Community**

This target group corresponds to research and academic organisations, scientific journals, committees, internet fora, and other working groups in research fields related to the D^2EPC work.

| |
|---|
| This group can support novel technologies, can pass on knowledge and boost and distribute innovation, while at the same time it can develop potential synergies to maximize impact. |
| **4. How to disseminate?** |
| Given that the target groups identified cover a wide variety of sectors, from high-level to low-level stakeholders, a different approach-dissemination plan were needed per target group. At the same time, experience has shown that the usage of the new social media (youtube, Linkedin, Twitter, etc.) and the web (D^2EPC website) can also play an important role, apart from the dissemination of the project, promoting possible future cooperation but even more providing real feedback over the circulation of project and a valuable participants' data bank for future projects. All these channels have been created and updated throughout the project.<br>D^2EPC has used a variety of materials for this purpose: leaflets, brochures, posters, position (white) papers, publications, presentations, newsletter, etc. |

## 2.2 Exploitation of Results

Exploitation is defined by the European Commission as the utilization of results in developing, creating and marketing a product or/and process, or/and in creating and providing a service, or/and in standardization activities. The exploitation of the results of a research project has a double value: on the one hand it offers to society ways to progress by utilizing novel methodologies, tools, etc. and on the other hand, it can promote research and development of the involved bodies through the dissemination of their research work as well as the financial resources that can be gained. From any perspective, society is the final recipient of the results of the research and its exploitation.

The Exploitation Methodology is recognized by the D^2EPC consortium as the key driver for any future commercial success. The commercial exploitation plan is based on a study that deals with the Background and Foreground Rights, the Patents, trademarks and IPR issues. This will be the baseline for future D^2EPC products, by taking into account the EU policies and security framework, including those to foster the transfer of technology to SMEs, and promoting the use of generic, non-proprietary technologies. In order to design a successful strategy, the exploitation plan has been developed on the basis of the Business Model Generation, that was proposed by Osterwalder and Pigneur (2010)[38].

The objectives of the exploitation strategy and the IPR protection plan are:

- Identification of the Key Exploitable Results (KERs) /assets of the project
- Conduct a Market Analysis
- Definition of Business Models
- Protection of the Intellectual Property Rights (IPRs) of the Consortium's members

The Exploitation Strategy uses a participatory methodology: all members of the Consortium have worked closely together to identify and outline the project's main exploitable results and according to these, the target groups have been defined. This has been achieved during the meetings of the WP7 partners and through dedicated questionnaires. Additionally, this provides a concrete business plan and a comprehensive market study, offering an in-depth analysis of the project's market positioning and growth strategies upon completion.

### 2.2.1 Key Exploitable Results & Exploitation Foreground

In more detail, D^2EPC introduces **a series of innovative services and modules** regarding the procedure of generating EPCs, but also to the energy management of buildings in general, with

[38] Osterwalder, Alexander, and Yves Pigneur. *Business model generation: a handbook for visionaries, game changers, and challengers*. Vol. 1. John Wiley & Sons, 2010.

emphasis given to the following axes:

**a**. Utilization of advanced information in the **calculation of EPCs** in order to increase the accuracy of the calculation, e.g., novel set of environmental, financial, human comfort and smart aspects indicators, BIM-based Digital Twins;
**b.** Integration of **advanced algorithms** for providing recommendations for energy upgrade of buildings and forecasting;
**c.** Implementation of an intelligent **operational digital platform** for EPCs.

According to the aforementioned, the exploitable assets of the D^2EPC project can be categorized into two (2) groups as described below and shown in the following figure:

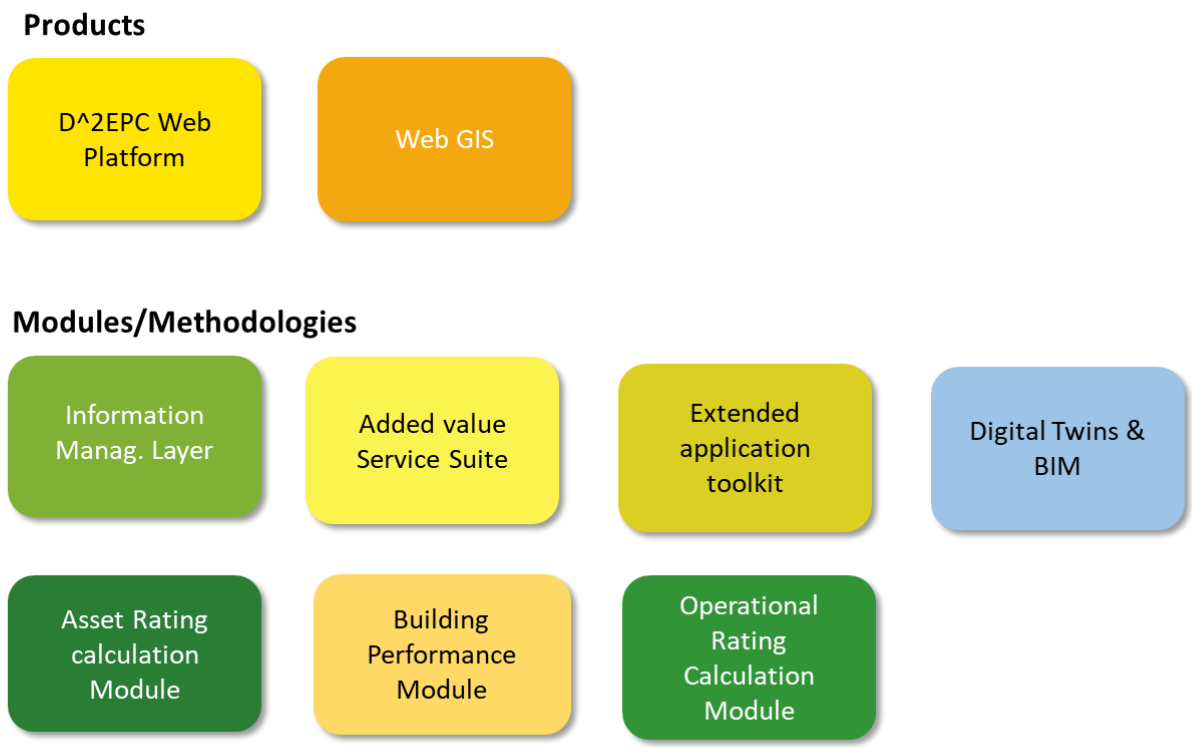


**Figure 70. D^2EPC's exploitable assets.**

• **Web Platform**: The project's web platform should offer a user-friendly interactive environment in which the user can adjust preferences and request the execution of processes ad-hoc for updating EPC results. Within this environment all subcomponents and project services will be accessible such as a) the asset rating, b) the operational rating, c) the Roadmapping tool, d) WebGIS etc.

• **WebGIS**: a handy tool for visualizing statistics and perform queries over issued EPCs in different **scales** by providing aggregated EPC data per region, thus offering valuable information for a multitude of stakeholders (e.g., real estate owners, policymakers etc.). This tool is also offering the capability of 3D BIM visualization of the pilots.

• **Information Management Layer:** Several important measurable parameters and indicators captured from installed sensors inside a building that provide an informative real-time representation of the indoor conditions of the dwelling. The Information Management Layer component is responsible for storing, processing and management of real-time information related to the pilot buildings and guarantees a secure environment for processing the vast amount of data collected from the locally installed IoT devices and streamed through the IoT gateways at the pilot buildings.

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• **Asset rating calculation module** A novel state-of-the-art semi-automated procedure of EPC issuance by exploiting the BIM model of a building. It offers easy and fast issuance and updating, while also minimizing, the overall EPC issuance cost. D^2EPC has adopted the EN ISO 52000 series of standards as the foundation for the development of the Asset Rating calculation module. The development of this module is based on two main pillars; the automation of the EPC issuance procedure and the development of a rating tool for the energy performance assessment of any building type throughout the EU MS included in the D^2EPC project. Additionally, it can provide a unified approach for all EU Member States and thus overcoming various limitations from national/regional bureaucracy.

• **Operational rating calculation module**: new calculation methodology developed in the project and tested on D^2EPC pilots. D^2EPC project develops and delivers a methodology for the operational energy performance ratings of buildings, which will be used in the framework of the next-generation D^2EPC tool through a set of cutting-edge digital design and monitoring tools and services. The Operational Rating Module will allow calculating the operational EPC, based on the methodology defined. The introduction and establishment of the operational EPC (dEPC) concept, a calculating interface, empowers the regular energy classification of buildings based on their operational performance.

• **Digital Twins & BIM**: D^2EPC introduces BIM-based Digital Twins coupled with a state-of-the-art IoT ecosystem for the near real-time asset and operational energy assessment of the building. The calculation of the EPC of the building with real data from the installed equipment makes issuing certificates more valid and easy. This is a major comparative advantage of the project's methodology over the existing ones as it enables the unification of various forms of user-provided data with dynamic information collected from the building’s field devices, under a common, digital building model.

• **Added value services suite**: advanced AI tool that will provide recommendations towards energy performance enhancement, and optimal comfort and will contribute to fostering energy-saving consciousness. These recommendations take into account the characteristics of the building as well as the needs of user/owner for exploring from a large pool of potential solutions and identifying the optimal scenarios for upgrades and forecast building operating conditions and their impact on the building’s energy efficiency/performance. As a result, a solid and efficient renovation roadmap can be generated to guide both the EPC assessor and inform the building owner about the impact of a potential renovation. In addition, this tool provides customized alerts to property’s users/owners, thereby promoting a sophisticated notification system towards energy management. Some of the identified gaps in current energy management methodologies can be covered by this module.

•**Extended dEPCs applications toolkit:** This tool can provide a ranking of the buildings in terms of EPC criteria concerning several indicators. It presents the comparative results in various forms and in a user-friendly way. In addition, this tool can also validate and verify the quality and reliability of the data collected.

•**Building performance module:** This tool is responsible for calculating the enriched set of D^2EPC KPIs, including the ones that already exist in current EPC practices and present the comparative results in various forms and in an understandable way for the user. In addition, this tool can enhance the interoperability of the produced information and paves the way for further enrichment of the performance indicator’s set though the combinations that can be generated.

### 2.2.2 Business Innovation and Exploitation Plans

D^2EPC's objective is to provide an innovative, cost-effective, user-friendly, and efficiently multipurpose tool, catering not only to the private sector, but also to public bodies and policymakers. The commercialization and market positioning of the final product of D^2EPC will be driven by its originality, aiming to address the market gap for innovative services related to EPCs. The target audience for D^2EPC, as mentioned above, includes private sector organizations, public bodies, policymakers, real estate owners, energy consultants, and European academic institutions. The distribution strategies are tailored to address the needs and interests of each target group.

The tables below present an exploitation analysis for the three main D^2EPC exploitable results, considering that the D^2EPC Web platform integrates all the different sub-components described above into one holistic digital solution and this analysis incorporates the findings for the different standalone modules. It is worth mentioning that the Horizon Results Platform has been used for the selected three KERs to further foster collaboration and facilitate exploitation beyond the project.

| KER#1 | |
|---|---|
| **Type of exploitable result** | D^2EPC Web Platform |
| **Target Users** | Building professionals (e.g., EPC assessors, architects, engineering companies, retrofitting/construction companies, ESCOs, software developers), building end–users (e.g., occupants/owners and facility managers), policy actors (e.g., regional, National and International policy makers and public authorities, standardization bodies) |
| **Target sectors** | Construction and Architecture Sector, Real Estate and Property Management Sector, Hospitality, Manufacturing sector, Energy Services and Engineering sector, Education and Research sector, public sectors. |
| **Possible competitors** | **SBEM (Standard Assessment Procedure for Energy Rating of Buildings) method**, developed by BRE, is used in the UK, Ireland, Malta, Cyprus, and Gibraltar as the default calculation tool for non-domestic buildings. It is used as the standard computation tool, demonstrating its wide market acceptance. However, SBEM might not fully include additional elements like LCA indicators, GIS building information, indoor air quality, thermal comfort, and occupancy, nor may it integrate real-time energy-related data.<br><br>The **IES Virtual Environment (IESVE)** generates Energy Performance Certificates and provides comprehensive dynamic thermal calculations. Additionally, it has BIM platform compatibility, which is useful for smooth interaction with architectural and engineering design processes. While IESVE covers certain sophisticated capabilities, a complete solution that takes into account current energy-related statistics, LCA indications, and other important elements might not be offered.<br><br>**4M-KENAK** Energy Software - This program combines BIM using IFC files and addresses criteria for building certification. It applies an in-depth methodology for evaluating and certifying energy performance. However, it is crucial to assess its capacity with regard to the integration of real-time energy data, sophisticated indicators, and the all-encompassing coverage offered by the DEPC platform.<br><br>The RdSAP Online software - The program from Elmhurst is concentrated on household energy evaluations and EPC ratings. It makes it simple to submit EPCs to central registries and fulfills UK market regulations. The D^2EPC platform seeks to handle the greater spectrum of building complexes and public buildings. |

| | |
|---|---|
| | DesignBuilder promises to be the quickest and simplest technique in the UK for producing EPCs from BIM models. While the platform excels at producing EPCs, it's critical to evaluate its capabilities in terms of the integration of real-time energy data, coverage of additional elements, and potential to serve a larger worldwide market.<br><br>By incorporating pertinent reference sources, the Greek web-based easykenak automates the majority of EPC data entry. The wide range of dynamic energy-related data and the list of additional parameters that are taken into account by the D^2EPC platform should be assessed. |
| **Expected added value** | • BIM-based Digital Twins coupled with a state-of-the-art IoT ecosystem for the asset and operational energy assessment of the building;<br><br>• Recalculation of the operational EPC on a regular basis and the potential of regular definition of the reference building (dynamic concept);<br><br>• Enhanced multi-parameter assessment by the inclusion of new indicators (energy, smart readiness-SRI, sustainability, human comfort, financial) to facilitate the understanding of buildings energy performance;<br><br>• Improved AI-driven assessment recommendations towards energy efficiency and optimal comfort, fostering energy-saving consciousness;<br><br>• Establishing a monitoring tool of the building's energy behaviour to be aware of energy consumption, ensure information transparency and facilitate energy-related policy planning (AI driven notifications and alerts, performance forecasts);<br><br>• Visualizing the actual performance of the building and providing comparative assessments to show the potential of improvements and promote energy efficient occupant models (energy performance benchmarking);<br><br>• Developing a trustworthy and reliable mechanism for verifying the calculation process and ensure data quality (energy performance verification and credibility);<br><br>• Integration with geolocation practices, enhancing information transparency and accessibility;<br><br>• Introducing "polluter pays" concept and reward policies. |
| **Potential market barriers** | Partnership Risk Factors<br><br>-Disagreement on ownership rules<br><br>-Limited or inadequate resources to manage the product complexity<br><br>Technological Risk Factors<br><br>-Significant dependency on other technologies |

| | |
|---|---|
| | -Difficulty in collecting and fusing data from different end-devices, IoT<br>-Complex solution/ Cooperation problems between the different components<br>Market Risk Factors<br>-Integration of BIM with BEPS and additional indicators (smart readiness, LCA etc.) in the certificate might be seen as too complex<br>-May not be easily adopted by users not familiar with technology<br>Similar integrated solutions introduced by global players at the same time<br>IPR/Legal Risk Factors<br>-Disputes over IPR or investment<br>Financial/Management Risk Factors<br>-No additional resources secured for exploitation<br>Environmental/Regulation/Safety risks:<br>-SRI assessment not established yet and it can be a barrier for adoption |
| **Timetable** | 3-12 months ahead:<br>Evaluate the smooth operation of the Web platform on the demonstration cases already streaming data to KER in the context of D^2EPC.<br>1-2 years ahead:<br>Submit proposals to secure personnel funding for the next steps of testing and development of the platform.<br>2-5 years ahead:<br>Apply the solution in more buildings to address more use-cases (beyond EPC issuance) |

| **KER#2** | |
|---|---|
| **Type of exploitable result** | Web GIS |
| **Target Users** | Building Professionals/ Construction companies, Real Estate agents / Various industries (hotels, factories, commercial buildings etc.), Integration with the 3D/BIM model of the building, Governmental agencies / Public policymakers, Academic institutions |
| **Target sectors** | Construction and Architecture Sector, Real Estate and Property Management Sector, Hospitality, Manufacturing sector, Energy Services and Engineering sector, Education and Research sector, public sectors. |

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| **Possible competitors** | The main competitors in this market are the companies providing IT solutions and commercial software for GIS and WebGIS applications. Enterprises such as ESRI with the well-established WebGIS portfolio around ArcGIS could offer similar solutions assuming an already established interconnection with official EPC registries.<br><br>However, to our knowledge a similar application (providing each of our WebGIS functionalities) has not yet been implemented - let alone commercialized. |
| **Expected added value** | The D^2EPC WebGIS offers a generalised, across all EU member states (MSs) EPC documentation and visualisation tool. The WebGIS offers the functionality of visualising this information in a uniform manner and on a map, while enabling the extraction of meaningful statistics (EPC, type, location, materials). The benefits of having a central EPC register are obvious: central and regional authorities receive substantiated policy impact assessments based on the gathered data, and thus, future policies, such as the planning for energy efficiency grant schemes can be better informed and more effective. The use of a WebGIS scheme for the visualization and provision of EPC statistics and their respective geographic distribution can be crucial insight information for policy makers for: a) proper energy-related funding in targeted regions, b) the promotion of specific construction materials and building energy efficiency policies, c) promotion of responsible energy consumption guidelines d) comparison of energy over-performing and under-performing European regions in different geographical scales and NUTS etc. |
| **Potential market barriers** | Technological Risk Factors<br><br>-The solution would become increasingly reliant on certain software and IoT hardware<br><br>-Platform maintenance on potential bigger loads of data<br><br>Market Risk Factors<br><br>-Engineers, EPC inspectors, and other professionals might not accept or adopt the tool<br><br>-To be accepted as a complex/expensive overall approach<br><br>IPR/Legal Risk Factors<br><br>-Data Privacy, vulnerabilities, hackers<br><br>Financial/Management Risk Factors<br><br>-Information management could be difficult, due to each member state's varied EPC classification |
| **Timetable** | 3-12 months ahead:<br><br>Evaluate the smooth operation of the component on the demonstration cases already streaming data to KER in the context of D^2EPC. |

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| | 1-2 years ahead:<br>Submit proposals to secure personnel funding for the next steps of testing and development of the component.<br>2-5 years ahead:<br>Apply the solution in more buildings to address more use-cases (beyond EPC issuance) |

| **KER#3** | |
|---|---|
| **Type of exploitable result** | Information Management Layer |
| **Target Users** | Facility managers, ESCOs, owners- tenants |
| **Target sectors** | Construction and Architecture Sector, Real Estate and Property Management Sector, Hospitality, Manufacturing sector, Energy Services and Engineering sector, Education and Research sector, public sectors. |
| **Possible competitors** | There are alternative solutions (e.g., Confluent or Google Data Flow) of significant cost for specific, large-scale commercial uses equipped with a multitude of functionalities. Other solutions (e.g., IBM Watson IoT, Google Cloud Platform, Samsung's SmartThings and Google Assistant) are suitable for smaller-scale use-cases (i.e., IoT platforms for residences) but come either with limited functionalities or high cost. However, IML is equipped with state-of-the-art data processing algorithms which focus exclusively on energy consumption and ambient condition metrics. It guarantees that the streaming data are free from outliers or other misleading values and eventually become trustworthy. IML is best utilised in cases where operational energy performance certificates should be issued when mutual trust is of high importance between contracting parties. |
| **Expected added value** | Filter data from numerous IoT devices deployed in the building in a fast, secure and interoperable manner through a flexible and low-cost tool with a multitude of integrated functionalities (e.g., data management, processing, visualisation). Constantly monitor the operation status of the building's IoT equipment and guarantee the adequacy and validity of the filtered data. Utilise the validated information to enable the issuance of a new-age energy performance certificate maintaining the mutual trust between contracting parties |
| **Potential market barriers** | Partnership Risk Factors<br>-Other partners are not involved in the development of the component<br>Technological Risk Factors<br>-Supported devices by the IML to become obsolete<br>Market Risk Factors |

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| | |
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| | -Large and well-established IoT vendors or other tech companies might commercialize a data filtering solution tailored for building energy consumption and indoor condition data for EPC issuance.<br>Financial/Management Risk Factors<br>-Lack of funding from R&D-funded projects |
| **Timetable** | 3-12 months ahead:<br>Evaluate the smooth operation of the component on the demonstration cases already streaming data to KER in the context of D^2EPC.<br>1-2 years ahead:<br>Submit proposals to secure personnel funding for the next steps of testing and development of the component.<br>2-5 years ahead:<br>Apply the solution in more buildings address more use-cases (beyond EPC issuance) |

## 2.2.3 Beyond D^2EPC

The D^2EPC project has undergone a detailed **SWOT analysis** to assess its strengths, weaknesses, opportunities, and threats. This analysis provides valuable insights into the project's potential and challenges in transforming building energy performance**.** Table 1 offers an extensive list of D^2EPC SWOT analysis.

**Table 18. SWOT Analyses.**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ **Building/dwelling-oriented digital and visualization tools**<br>▪ **Provision of recommendations regarding energy upgrading of buildings**<br>▪ **Solutions for lowering energy consumption and saving money**<br>▪ **Real-time performance for operational rating**<br>▪ **EPCs can be calculated using a smart, simple, and dynamic process**<br>▪ **First digitized integration of building energy classification and analytics**<br>▪ **The EPC is always up to date based on real-time data available**<br>▪ **Possibility of better comparability of the actual data of different buildings** | ▪ **Potential problematic integration of a full-scale platform deployment, due to different tools and technologies**<br>▪ **Lack of real data for some tools/services to be tested upon (e.g., WebGIS)**<br>▪ **Information management could be difficult, due to each member state's varied EPC classification**<br>▪ **Possibility of costly IoT setups, necessary for operational rating**<br>▪ **Data quality determines result - uncertainties, errors** |
| **Opportunities** | **Threats** |
| ▪ **Monitoring building status on a shared platform, thus offering policymakers a strong mechanism to enable action at a European or national level**<br>▪ **Utilizing the advantages of the digitalization era**<br>▪ **Higher motivation to renovate the building via actual representation**<br>▪ **Given the world's energy problem, the EU is** | ▪ **Engineers, EPC inspectors, and other professionals might not accept or adopt the tool**<br>▪ **The solution would become increasingly reliant on certain software and IoT hardware**<br>▪ **To be accepted as a complex/expensive overall approach**<br>▪ **Platform maintenance on potentially bigger** |

| | |
|---|---|
| always looking for methods and tools to handle energy consumption in the most effective way<br>▪ Optimization of entire settlement areas, with sufficient density of mapped buildings<br>▪ EPC is always "valid" - no expiration date<br>▪ One unified solution for many agendas around the building | loads of data<br>▪ Data Privacy, vulnerabilities, hackers<br>▪ Possibly too confusing for end customers<br>▪ IPRs possible dispute<br>▪ Introduction of the new legislature regarding EPCs |

The SWOT analysis of the D^2EPC project provides a comprehensive overview of its current standing and future prospects. The project's strengths rely upon its innovative digital tools, energy upgrading recommendations, energy-saving solutions, real-time performance monitoring, streamlined EPC calculation process, and integration of building energy classification and analytics. These strengths position the project as a game-changer in the field of building energy performance. By leveraging its strengths, addressing weaknesses, capitalizing on opportunities, and mitigating threats, the D^2EPC project can maximize its potential and contribute significantly to sustainable building practices, energy efficiency, and policy formulation. With careful planning, collaboration, and adaptability, the D^2EPC project can achieve its goals and pave the way for a more energy-efficient future in the European building sector.

Furthermore, the success or failure of a project can be influenced by major external factors and trends, which can be identified and understood. Political factors encompass government regulations, policies, and political stability. Analyzing the legislation helps to identify support or obstacles from authorities and understand the alignment of the project with existing policies. Economic factors examine economic conditions, market dynamics, and financial considerations. Assessing these factors helps determine the economic feasibility, market demand, and potential barriers related to affordability and market acceptance. Social factors explore societal attitudes, preferences, and behaviours. By understanding social factors, the project team can gauge the level of awareness, market demand, and user needs and preferences regarding energy efficiency and sustainability. Technological factors focus on technological advancements, compatibility, and data security. Evaluating these factors ensures that the project leverages the right technologies, addresses compatibility issues, and safeguards data privacy and security.

**Table 19. PEST analysis**

| Political Aspects | Economic Aspects |
|---|---|
| ❑ The adoption and use of D^2EPC may be impacted by governmental legislation and policies surrounding energy efficiency and sustainability in buildings.<br>❑ A supportive environment for the acceptance of D^2EPC may be created via political backing, incentives for energy-efficient construction, and green certifications.<br>❑ The demand for and market for D^2EPC may be impacted by changes in governmental goals and policies linked to energy and the environment. | ❑ The investment and uptake of D^2EPC will be impacted by market economic conditions.<br>❑ Some stakeholders may find the expense of deploying D^2EPC and related technologies to be a deterrent, particularly in areas where resources are few.<br>❑ Adoption may be encouraged by the potential cost savings and return on investment from energy efficiency improvements made possible by D^2EPC .<br>❑ The market's desire and readiness to pay for sophisticated energy performance evaluations and individualized guidance will have an impact on D^2EPC 's economic sustainability. |
| **Social Factors** | **Technological Factors** |
| ❑ Demand for D^2EPC may rise as people's understanding of and concern for environmental sustainability and energy efficiency rises.<br>❑ The popularity of D^2EPC may be influenced by consumer desires for energy-efficient buildings and the need for healthier interior spaces.<br>❑ Important sociological criteria for D^2EPC 's success are its user-friendliness and its capacity to meet the particular demands and expectations of homeowners, investors, and construction professionals.<br>❑ Adoption of D^2EPC may be impacted by public perception and acceptance of digital solutions, such as the application of AI and data analytics in the evaluation and certification of building energy performance. | ❑ A crucial enabler for D^2EPC is the availability and development of technologies like sensors, data analytics, AI, GIS, and BIM models.<br>❑ For easy deployment and interoperability, compatibility with current systems and platforms as well as support for various data formats and protocols will be essential.<br>❑ The competitiveness and long-term profitability of D^2EPC can be influenced by the rate of technological advancement and the appearance of new tools and techniques in energy performance evaluation and visualization.<br>❑ To build trust and confidence in D^2EPC , data security and privacy issues related to the gathering, processing, and storing of multi-modal data must be addressed. |

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Finally, the D^2EPC project's Intellectual Property Rights (IPR) plan seeks to efficiently manage and protect the primary exploitable outcomes owned by the project partners beyond the D^2EPC project. The strategy is tailored for each specific component as follows:

***D^2EPC Web platform:***

Ownership: CERTH. CERTH has developed the final D^2EPC Web platform and SEC has developed an initial testing environment for its use cases and has tested the access to the main D^2EPC Web platform by a third party through API.

Copyright protection will be sought for the web platform.

Licensing: The web platform may be licensed to relevant stakeholders and industry players, allowing them to utilize and benefit from its features.

Spin-off Opportunities: The potential for a spin-off company dedicated to the continued development and commercialization of the web platform will be explored.

***Asset Rating Calculation Module:***

Ownership: CERTH

Copyright protection will be sought for the calculation module.

Licensing: The calculation module can be licensed to stakeholders in the industry, enabling them to perform accurate asset ratings and assessments.

***Operational Rating Calculation Module:***

Ownership: CERTH/FRC. CERTH has developed the software component for the calculation of operational rating and FRC has developed the methodology for operational rating indicators.

Copyright protection will be sought for the calculation module.

Licensing: The operational rating calculation module can be licensed to stakeholders interested in evaluating and optimizing the operational performance of buildings.

***WebGIS tool:***

Ownership: GSH

Copyright protection will be sought for the WebGIS tool.

Licensing: The WebGIS tool can be licensed to stakeholders, providing them with geospatial analysis capabilities for building performance assessment and decision-making.

***Information Management Layer:***

Ownership: Hypertech

Copyright protection will be sought for the information management layer.

Licensing: The information management layer can be licensed to stakeholders, enabling effective data management and integration within the D^2EPC ecosystem.

***BIM-Based Digital Twin:***

Ownership: CERTH

Copyright protection will be sought for the BIM-Based Digital Twin.

Licensing: The BIM-Based Digital Twin can be licensed to stakeholders, offering them a powerful tool for building simulation, visualization, and analysis.

***Added Value Service Suite:***

Ownership: CERTH

Copyright protection will be sought for the suite of added-value services, including the road mapping tool, AI-driven performance forecasts, performance alerts, and notifications.

Licensing: The added value service suite can be licensed to stakeholders, providing them with advanced capabilities to optimize building performance and energy efficiency.

***Extended dEPCs Applications Toolkit:***

Ownership: CERTH/ Hypertech. CERTH has developed the Building Energy Performance Benchmarking and HYP has developed the Energy Performance and Credibility Verification tool.

Copyright protection will be sought for the extended application toolkit, which includes building energy performance benchmarking, energy performance verification, and credibility assessment.

Licensing: The extended application toolkit can be licensed to stakeholders, supporting them in evaluating and improving the energy performance of buildings.

***Building Performance Module:***

Ownership: CERTH. CERTH has developed the Building Performance Module that implements the calculation of the additional indicators based on the procedures elaborated within WP2 by leading partners CLEO, FRC, HYP and DMO.

Copyright protection will be sought for the building performance module.

Licensing: The building performance module can be licensed to stakeholders, offering them comprehensive tools for analyzing and optimizing building performance.

Table 20 highlights the primary exploitable outcomes and the partner in charge of each module.

**Table 20. The Primary Exploitable outcomes and the partner in charge of each module**

| Key Exploitable Results | Developer/Responsible partner | Contributors |
|---|---|---|
| **D^2EPC web platform** | CERTH | KTU, CLEO, SEC, DMO, SGS, HYP, FRC and GSH |
| **Asset Rating Calculation Module** | CERTH | CERTH, KTU, and HYP |
| **Operational Rating Calculation Module** | CERTH/ FRC | SEC |
| **WebGIS tool** | GSH | |
| **Information Management Layer** | Hypertech | |
| **BIM-Based Digital Twin** | CERTH | |
| **Added Value Service Suite (Road mapping tool, AI-driven Performance Forecasts, Performance Alerts and Notifications)** | CERTH | CLEO, SEC, DMO, SGS, HYP, and FRC |
| **Extended Application Toolkit (Building Energy Performance Benchmarking, Energy Performance Verification and Credibility)** | CERTH/ HYP | KTU, CLEO, SEC, DMO, SGS, and FRC |
| **Building Performance Module** | CERTH | |

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