Added value services suite v2

The D^2EPC project has received funding from the EU's Horizon 2020 research and innovation programme under gr

Project Acronym: D^2EPC

Project Full Title: Next-generation Dynamic Digital EPCs for Enhanced Quality and User Awareness

Grant Agreement: 892984

Project Duration: 36 months (01/09/2020 – 31/08/2023)

DELIVERABLE D4.6
Added value services suite v2

Work Package: WP4 Digital Platform for Dynamic EPCs Issuance and Enabled Applications

Task: T4.2 Added value services suite

Document Status: Final

File Name: D^2EPC_D4.6_Added_value_services_suite_v2_CERTH

Due Date: 31.08.2023

Submission Date: 31.08.2023

Lead Beneficiary: CERTH

Dissemination Level

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

Authors List

Leading Author				
First Name		Last Name	Beneficiary	Contact e-mail
Nikolaos		Mpouzianas	CERTH	nickbouzi@iti.gr
Ioannis		Pastaltzidis	CERTH	gpastal@iti.gr
Nikolaos		Katsaros	CERTH	nkatsaros@iti.gr
Co-Author(s)				
#	First Name	Last Name	Beneficiary	Contact e-mail
1	Stavros	Koltsios	CERTH	skoltsios@iti.gr
2	Mija	Susnik	DMO	Mija@demobv.nl
3	Stelios	Choumas	HYP	s.choumas@hypertech.gr
4	Stefanos	Makris	HYP	s.makris@hypertech.gr

Reviewers List

Reviewers			
First Name	Last Name	Beneficiary	Contact e-mail
Egle	Klumbyte	KTU	egle.klumbyte@ktu.lt
Paulius	Spudys	KTU	paulius.spudys@ktu.lt
Adrian	Cano	SGS	adrian.canocabanero@sgs.com

Version History

v	Author	Date	Brief Description
1.1	**N. Mpouzianas, N. Katsaros**	**16.05.2023**	**Initial draft based on the previous version**
1.2	**N. Mpouzianas, N. Katsaros, I.Pastaltzidis**	**30.07.2023**	**Draft Version with initial content for all section**
1.4	**N. Mpouzianas, N. Katsaros, I.Pastaltzidis, S. Koltsios**	**18.08.2023**	**Document ready for peer review**
1.6	**N. Mpouzianas, N. Katsaros, I.Pastaltzidis**	**30.08.2023**	**Document updated based on peer review comments**
2.0	**N. Mpouzianas, I.Pastaltzidis**	**31.08.2023**	**Final version ready for submission**

Legal Disclaimer

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

Copyright

Executive Summary

This document is the second version of the D^2EPC Added Value Services Suite. D4.6 provides a description of the updates of D4.2 of the main components that comprise the Added Value Services Suite, namely, the roadmapping tool, the AI-driven performance forecasts, and the Performance alerts and notifications. Furthermore, it provides information about the updated development status, describing the finalised work of the project. The interconnection between the examined sub-modules and other core components of the D^2EPC architecture is also analysed.

In the first part of this deliverable, a literature review is presented, analysing state-of-the-art methods and best practices with regard to the three sub-modules. Some of these methods are selected and experimented towards investigating whether they present a good fit for the D^2EPC ecosystem.

The second part provides the reader with more specific information about the applied methodologies along with software-specific implementation details. The document provides information about aspects such as the required inputs and the necessary pre-processing that is used to the collected data, as well as, the general workflow of these tools in order to achieve the desired results.

In the case of the roadmapping tool, the already existing building documentation from the Building Digital Twin module is leveraged to diagnose the building's current state and strategically recommend the right renovation actions to increase the asset's energy efficiency. The analysis is performed both in terms of the building's envelope as well as of the installed technical systems that serve the asset's requirements. Finally, the tool examines the use of Renewable Energy Sources (RES) to reach the nZEB goal.

The operational characteristics and behaviour profiles in terms of the asset's energy consumption and indoor conditions are examined by the AI-driven performance forecasts. The module relies on temporal data, namely the day of the week and the month of the year, weather data such as the daily average, maximum and minimum temperature, and historical consumption data. It becomes evident that the successful integration of these modules will be aligned with the data quality that they receive, and the techniques that will be deployed to tackle the issue of missing or corrupted data.

The Performance alerts and notification tool further facilitates the end-user's interaction with D^2EPC's certification and monitoring platform. The document reports the tool's articulation and its basic functionalities. Furthermore, there is an analysis of the tool's interoperability with the rest of the platform's submodules according to the D^2EPC Framework Architecture.

The third and final part of this report illustrates the results of the first two developed sub-modules. The results derive from the application to various case studies. The results are presented both in a qualitative and quantitative manner. The main conclusions drawn from the tools' development and application indicate the best practices and future improvements that need to be implemented in order to extend the functionality and the accuracy of the tools.

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

Term	Description
AI	Artificial Intelligence
AR	Asset Rating
BIM	Building Information Model
BRP	Building Renovation Passport
CNN	Convolutional neural network
DNN	Deep Neural Network
EC	European Commission
ELM	Extreme Learning Machine
EMD	Empirical Mode Decomposition
EPC	Energy Performance Certificate
EPBD	Energy Performance of Buildings Directive
DHW	Domestic How Water
DNN	Deep Neural Network
GRU	Gated recurrent units
LSTM	Long-short term memory
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MS	Member States
MTLF	Mid-term load forecast
NCPE	National Integrated Energy and Climate Plan
nZEB	Nearly zero-emission building
PV systems	Photovoltaic systems
RBF	Radial Basis Function
RES	Renewable Energy Systems
ResNet	Residual Network
RMSE	Root mean square error
RNN	Recurrent Neural Networks
STC	Solar Thermal Collector Systems

STLF	Short term load forecasting
U-value	Thermal Transmittance value
XGBoost	extreme gradient boosting
Web	World Wide Web

1 Introduction

1.1 Scope and objectives of the deliverable

This deliverable aims to provide an overview of the D^2EPC Added Value Services Suite. The purpose of the document is to report and expand the building's current state by integrating three unique tools for an energy performance upgrade (Roadmapping tool), prediction of the month ahead energy consumption (AI-driven performance forecasts) for optimal operational behaviour combined with alerts and notifications for excess energy consumption warnings.

This report provides a theoretical rationale for the three tools that are part of this module and an analytical description of the implemented methodologies. Moreover, the connection between the theoretical background and the actual implementation is emphasized along with the technical challenges that have come up during the initial phase of this task T4.2.

1.2 Structure of the deliverable

The Added Value Services Module's main goal is to provide recommendations for energy performance upgrades, and energy consumption forecasting for the operational functionality of the building with early notifications to the end user. In order to achieve the aforementioned targets, the report is organised into the following chapters:

- **Chapter 2** includes methodology and theoretical background, which contains a literature review to identify the current approaches to every submodule and the presentation of the D2EPC approach.
- **Chapter 3** refers to the implementation of every submodule. A technical report is created for every submodule, which describes the implemented technologies and challenges during the development of the Added Value Services Suite.
- **Chapter 4** refers to the presentation of results for each submodule and their application to the pilot cases.
- **Chapter 5** is the summary of this deliverable. It describes the overall work that has been reported in this deliverable and potential next steps for functionality improvement of the modules.

1.3 Relation to other tasks and deliverables

Task 4.2 whole rationale and methodology are based on the developed architecture of deliverable 1.4 and its updated version of D1.9, named "D^2EPC Framework Architecture and specifications." As a technical development task, T4.2 cooperates with T4.1 "Building Performance Module" to acquire calculation results. More specifically, the Roadmapping tool is based on the Asset Rating Module and the AI-driven performance forecasts rely on the outputs of the Operational Rating Module. It is worth mentioning that the needed input for T4.2 results from the work performed in T3.3, where a BIM-file is translated into accessible data that will be used by tools for processing. Finally, T4.2 results are used as input to T4.3, and T4.4 to increase the functionality of the D^2EPC Web Platform. The Roadmapping tool output is related to T6.3 "Linking EPCs with building passports and renovation roadmaps".

2 Methodology and theoretical background

2.1 Roadmapping tool

As climatic change sharpens, different approaches and strategies have been developed to minimize the environmental impact across Europe. Europe's building stock tends to be old and energy inefficient. Europe's building stock is responsible for 40% of energy consumption and 36% of energy-related carbon dioxide emissions [1]. The implementation of holistic building renovation roadmaps is mandatory for the achievement of Europe's decarbonization targets.

A step towards decarbonization is the Renovation Wave Strategy [2], published by the European Commission (EC) in October 2020. The aim of the Strategy is to improve the energy performance of buildings and at least double the renovation rates in the next ten years. An essential part of the Strategy is also the revision of the Energy Performance of Buildings Directive (EPBD) [3], published in December 2021, where ambitions are set out on how to achieve a zero-emission and fully decarbonised building stock by 2050. The proposed measures focus on the increased renovation rates of low-performance buildings. In the EPBD, the term Building Renovation Passport is introduced, as a clear and tailored roadmap with timing and scope of interventions for the building owners and investors who are planning a staged renovation for significant improvement of the building's energy performance. According to the revised EPBD's Article 10, the EC shall establish a common European framework for the renovation passports by December 2023 and each member state shall introduce a scheme of renovation passports by 2024. The requirements for the renovation passports include a renovation roadmap indicating a sequence of renovation steps toward zero-emission building by 2025 while indicating the expected benefits in terms of energy savings, emissions, and benefits related to health and comfort, etc.

Regarding the renovation roadmap, different approaches are suggested by national energy policies or research papers based on each country's unique conditions. The common approach is the envelope renovation of roofs, floors, walls, windows, and doors [4] as it is the most effective way to reduce thermal losses and operational carbon dioxide emissions [5]. Moreover, each country has developed its own renovation approach based on its needs. For example, in Germany is highlighted the need for an upgrade of heating systems and integration with a boiler for Domestic Hot Water (DHW) needs [6]. In Greece and Cyprus, the governments have published a technical guide, which includes renovation measures for heating, cooling, lighting, DHW, and Renewable Energy Systems (RES) [7], [8]. Lithuania's national renovation guideline includes measures for heating, DHW, ventilation, and solar collectors (photovoltaic for electricity loads and solar thermal collectors for DHW needs) systems with indicative costs and the economic lifecycle of each renovation action [9]. Regarding the Netherlands' housing stock, a study suggests a classification of thermal energy renovation measures. The classification is based on the renovation action type (envelope or building technical systems) and quantity (e.g., upgrade of one heating system or simultaneous upgrade of heating, DHW, and ventilation system) [10]. Also, it is recommended that the transition of fossil gas to a sustainable heating alternative [11]. Another study showed that in the National Integrated Energy and Climate Plan (NCEP) for decarbonization of Spain's existing residential building stock, priority is given to the building's envelope to reduce the demanded thermal load and to avoid the oversizing of heating systems [12].

There are several ongoing EU-funded projects, which are in some parts working on the development of renovation roadmaps. One of such is also the BIM-SPEED project[13], a "Harmonised Building Information Speedway for Energy-Efficient Renovation". One of the tasks within the project is focusing on the definition of semantic design rules and tools for deep renovation design, presented in deliverable 7.3[14]. A specific BIM-based model checker was developed, which allows the design team to automatically compare the model against the design rules of a country regarding thermal and acoustic standards, fire safety, and accessibility requirements in residential renovation projects. The tool assesses the elements and points out the ones that do not comply with the design rules, which allows the design team to plan the renovation of the building easily.

One of the added value services within the D^2EPC platform is a Roadmapping tool for performance upgrades. The purpose of the 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 toward improved energy efficiency and can further feed the relevant building renovation passport, as seen in Figure 1.

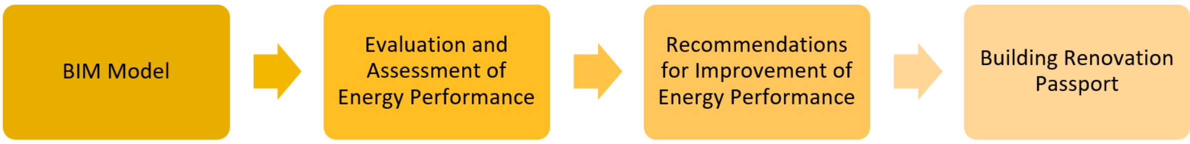


Figure 1: Roadmapping Tool description

In the case of the Roadmapping tool within the D^2EPC project, the process of evaluation and assessment of the building's energy performance based on the BIM model can be divided into three main steps or categories.

1. Firstly, the **envelope** state is considered based on the thermal transmittance (U-values) of the individual elements, such as walls, roof, windows, doors, and floor. Based on that, the recommendations are formed indicating which elements and in which order should be improved in order to increase the EPC classification.
2. In the next step, the **building systems** can be improved, by replacing the heating or cooling system
3. As the third step, the Roadmapping tool considers the **renewable energy sources** and whether they can be installed or improved in order to increase the EPC of the building.

The important criteria of the Roadmapping tool are that this 3-step evaluation can be universally applied within all Member States (MS), however, there are different national legislations, defining minimum requirements for the U-values per element per country. In order to maintain the relevance of the tool, national regulations had to be investigated. This way the actual U-values of elements or systems efficiency could be evaluated by comparing them to the defined minimums. For example, if the U-value of walls is lower than what is indicated in the national legislation, then the improvement of wall insulation is considered mandatory.

The overall workflow can be described in Figure 2, 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 2.

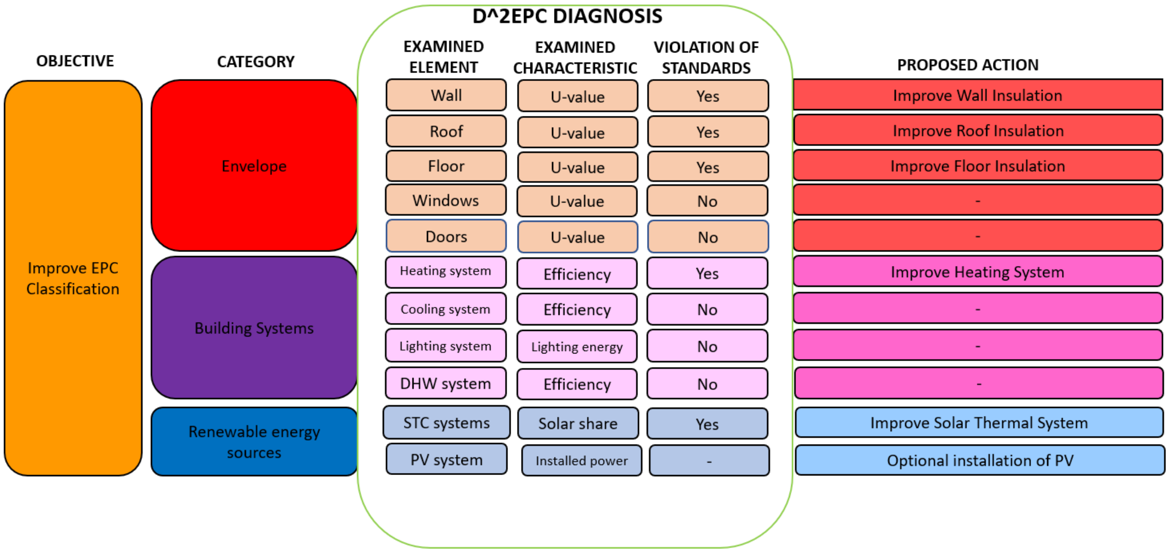


Figure 2: Workflow of the Roadmapping tool

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.

2.2 AI-driven performance forecasts

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 [15] the authors propose a Deep Neural Network (DNN) using a Long Short-Term Memory (LSTM) architecture. They tried to predict the short-term load for residential buildings in a publicly available dataset having two hidden layers with 20 LSTM nodes each. They observed that the mean absolute percentage error was high for individual customers (44%) while when they aggregated the load for all the customers, or when aggregating the forecasts, this error decreased significantly to 8-9%.

In [16] they proposed a method using Gated Recurrent Units (GRU) with the attention of an attention layer. They too had 2 hidden layers with 20 nodes each and they aimed to tackle the problem of short-term load forecasting in industrial buildings, mainly offices. Their method showed promising results as they had better metrics when tested with similar methods across the board ranging from 5-15% MAPE based on the day they forecasted and 7-29% depending on the months the forecasts took place.

The aforementioned methods use Recurrent Neural Networks (RNN) for the forecasting problem. In [17] the authors used a popular architecture called Residual Networks (ResNet) for short-term load forecasting, at a power system level, instead of per building level. ResNets are stacked architectures using the ResNet block, which in turn has as a core component convolutional layers. Although these models are mainly aimed at Computer Vision tasks, their experiments showed promising results in a large dataset, beating the previous state-of-the-art method on that dataset.

In [18], there was an attempt at fusing the features from convolutional neural networks (CNNs) and LSTMs. They tested their model on very short-term forecasting (hourly), short-term (day ahead), mid-term (weekly), and long-term forecasting (month ahead). By comparing their method with other state-of-the-art models, they showed that their methodology was superior to the other methods across all the datasets they used, and it was better in almost every metric (MAPE, MAE, RMSE) for each one of the forecasting problems they tried to solve (STLF, MTLF, etc.).

[19] is another attempt to tackle the forecasting problem with the use of feature fusion, in a fully convolutional architecture, where they had two branches, one for the external factors (e.g. weather conditions) and another one called the forecasting branch, which had the historical load as the input. The features from the two branches were merged in order to produce a more robust model output.

Apart from Deep Learning methodologies, there are tree-based methods that have shown extremely good results and generalisation ability. For example, in [20] and [21], the authors used a robust method called eXtreme Gradient Boosting (XGBoost) for the forecasts. Tree-based ensembled methods are based on decision trees, each tree making a prediction, and the final prediction is the aggregation of those predictions based on a rule. The XGBoost algorithm creates a new tree at a time and fixes errors in the previous trees by fitting their residuals. The outputs of the trees are then aggregated as in (1), where $\hat{y}$ is the final prediction, N is the total number of trees, and f_n is the function of the n-th tree, containing its tree's structure and weight.

$$\hat{y} = \sum_{n=1}^{N} f_n(x) \quad (1)$$

Similarly, in [22] and [23] they used the XGBoost algorithm in conjunction with RNNs to retain a part of the temporal information. More specifically, in [22] they used LSTMs and XGBoost for the prediction of energy consumption, having two streams, one for the LSTM method and one for the XGBoost. The predictions were combined based on a weighted formula, depending on the MAPE of each stream. In [23] it was proposed to use GRUs with the XGBoost algorithm, the information flow was similar to the one that was mentioned in [22].

In [24] the authors proposed an Empirical Mode Decomposition (EMD) strategy to remove randomness and noise from the load data. They then used an Extreme Learning Machine (ELM) using a Radial Basis Function (RBF) kernel to predict the load in households, for the next day, week, and month.

2.3 Performance alerts and notifications

Because of climate change, a global focus on reducing residential energy demand has become critical. Continuous feedback to end users is required to inform better and raise their awareness of energy issues in order to reduce energy demand. Feedback referred to the structural investments, which include a more energy-efficient system and renovations, or the curtailment of daily energy behaviour [25]. To increase energy efficiency, feedback is suggested to be combined with either commitment or goal-setting targets of the end-users [26]. Studies have shown that a change in a daily energy habit can lead to a reduction of 20 % of home energy demand based on the returned feedback without the loss of thermal comfort [27]. Furthermore, it is mentioned that a lack of user awareness can increase energy consumption by one-third [28].

The most effective way to raise user awareness is by providing real-time feedback with the usage of metering and sub-metering systems to depict the impact (economic and environmental) of electrical consumption on the end-users [29][30].

In this direction, IoT systems have been deployed to depict an occupant's energy behaviour for optimal energy control [31]. Although IoT systems depict the energy consumption of an electrical device, due to the random behaviour of each end-user, the development of AI algorithms to personalise the returned feedback is crucial for efficient interaction. AI algorithms distinguish the depiction of behavioural patterns through IoT devices for optimal interaction between the data of a smart home and the end-user [31],[32]. However, the integration of AI is facing some challenges, like the definition of anomalous power consumption and annotated datasets [33].

Different applications have been implanted in order to inform the end-user about potential energy savings. A study has developed a smartphone application with real-time feedback from IoT systems, which informs the end-user of unnecessary energy consumption in a university office building [34].

In the D^2EPC project, the Alerts and Notifications sub-component seeks to provide notifications or alerts to the end-user. Notifications provide a simplified and personalized message to the end-user through the Web-Platform. The Notification context depends on the interaction with the Roadmapping tool or AI-driven Performance and alerts. 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.

3 Added value services suite implementation

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.

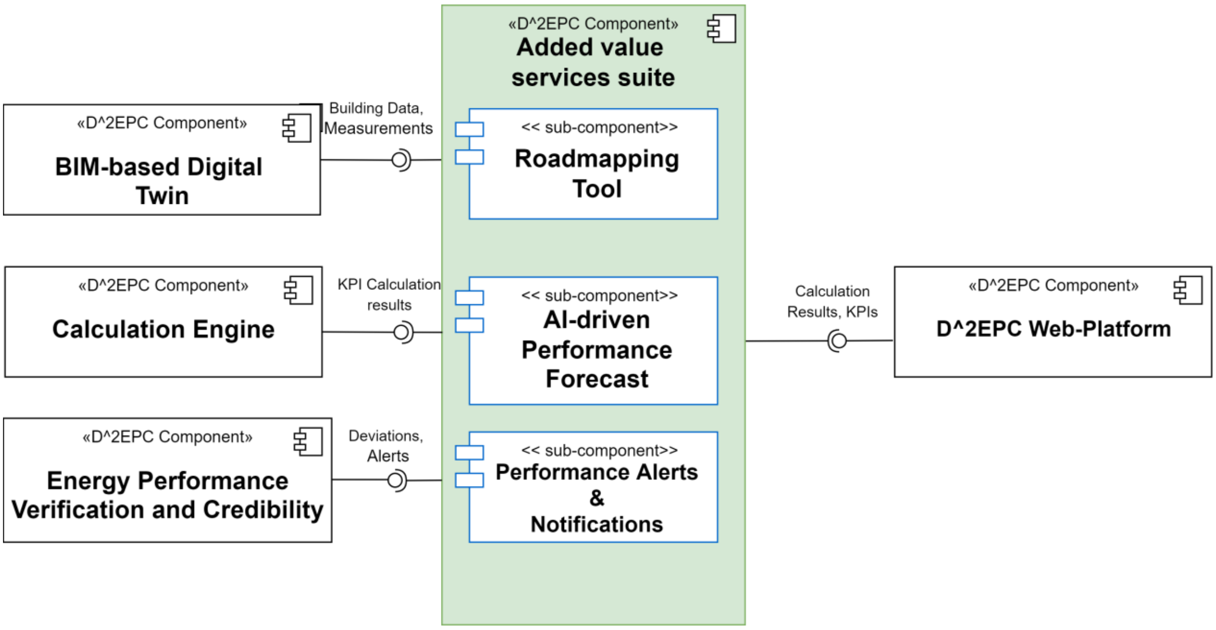


Figure 3: Added value services suite - Architectural view

3.1 Roadmapping tool Module

The Roadmapping tool's main purpose in the D^2EPC project is to provide renovation action for energy performance upgrade with integrating environmental and economic indicators for optimal strategy-making of the Web Platform end-user. Regarding the building's lifecycle Roadmapping tool can be mainly used during the operation and maintenance phase but it can also assist in the pre-design phase by providing different scenarios for optimal material and technical system selection.

Roadmapping tool's operation is enriched with Asset Rating (AR) Module calculations, which are described in D4.1 and D4.5. Asset Rating provides a Roadmapping tool with crucial feedback for energy performance indicators. Therefore, Roadmapping tool's strategy making is based on asset-based data retrieved from the BIM-based Digital Twin.

The main purpose of this section is to present the tool's required input, operational workflow, and technical requirements for the development of the tool.

3.1.1 Roadmapping tool input

The tool must acquire the national minimum requirements for the relevant EU country to provide the recommendation for an energy performance upgrade. The violation of the minimum requirement indicates the necessity of the renovation action. In the D^2EPC, the examined countries are Cyprus, Germany, and Greece. The boundaries are referred to as the minimum thermal transmittance value for each country's climatic zone, minimum efficiency standards for heating and cooling systems, and minimum solar share of Solar Thermal

Collector (STC) systems. Roadmapping requires minimum RES share requirements and maximum primary energy consumption for RES recommendations.

Indicatively, Table 1 documents the minimum thermal transmittance requirements (U-value) for the climatic zones of D^2EPC case studies. Annex A contains all the minimum requirements for Greece [35], Cyprus [36], and Germany [37] derived from national standards.

Table 1: Minimum U values per country

Country	External wall	Window	Floor	Roof	Door
Cyprus	0.4	2.25	0.4	0.4	2.25
Germany	0.28	1.3	0.28	0.2	1.8
Greece	0.45	2.8	0.4	0.4	2.8

Table 2 presents the minimum efficiency requirements for the various heating production units for D^2EPC case studies.

Table 2: Minimum efficiency of heating production unit

Heating System/ Country	Oil Boiler	Gas Boiler	Biomass Boiler	Heat Pump
Cyprus	0.9	0.9	0.9	2.5
Germany	0.85	0.95	0.95	3.5
Greece	0.85	0.95	0.95	3.5

The minimum efficiency requirement for cooling systems has a value of 3.1 for Greece and 3.6 for Cyprus. In the case study of Germany, there is no cooling demand. Finally, regarding the STC systems, the threshold of solar share is set for all countries to 0.6.

For lighting systems, Roadmapping examines the lux requirements per thermal zone for Greece [38], Cyprus [39] and Germany [40] for a variety of thermal zone types. Lux requirements are presented in Annex A.

For RES systems suggestions, Roadmapping requires two essential inputs per country. The first input refers to the minimum RES share of the total primary energy consumption. Minimum RES share expresses the minimum RES load coverage to characterize a building as nZEB. RES share percentages derive from national values [41] and are cited for all building types. Apart from minimum RES share percentages, the Roadmapping tool considers maximum primary energy consumption per area to satisfy the nZEB requirement. Primary consumption values provide an estimation of the maximum primary energy consumption of the nZEB building. The European Commission (EC) published the normalized primary energy values for residential and tertiary buildings [42]. Table 3, and Table 4 present the minimum RES share and maximum primary energy consumption values.

Table 3: Minimum RES share percentages per country

Country	Minimum RES share [%]
Greece	25
Germany	15
Cyprus	25

Table 4: Minimum primary energy values per area for every country

Country/Building type	Residential [kWh/m2]	Tertiary [kWh/m2]
Cyprus	100	125
Germany	40	75
Greece	80	85

It is worth mentioning that the Roadmapping tool has integrated BIM-based Digital Twin provides a validation procedure that assists the smooth Roadmapping tool operation. If the validation procedure fails, a notification alerts the end-user to fill in the missing required fields of the BIM file. The Validation procedure refers to:

- General building characteristics (building's location and coordinates)
- Envelope thermal characteristics (element U-values),
- Technical systems characteristics (efficiency, capacity, and energy source)
- RES systems (panel area and orientation)
- Existence of technical system (e.g., photovoltaic system)

3.1.2 Roadmapping tool Operation Workflow

This section constitutes 2 sub-sections to describe holistically the operation workflow of the Roadmapping tool. The first sub-section describes the general workflow of the tool for all renovation measures, and the second part explains the rationale for each specific renovation measure.

3.1.2.1 General Workflow of Roadmapping tool

This sub-section presents the general operational workflow of Roadmapping, which applies to all renovation measures. Roadmapping general workflow can be summarised in the following steps:

A. The first stage before scenario generation starts is the creation of a building instance with current characteristics and no applied renovation actions. The building's instance is used as an input to the AR Module. AR provides different calculations that will be used for comparison with the calculation of renovated building instances. AR provides the following calculations of the current building's state:
    a. Energy class
    b. Total primary energy, in absolute values and normalized per area
    c. Total carbon dioxide emissions
    d. The total operational cost of all energy carriers
    e. Total energy for lighting use
    f. Solar share of Solar Thermal Collector (STC) Systems for DHW need, if STC system exists
    g. Electrical energy from photovoltaic systems and RES share (PV), If a PV system exists
B. A digital copy of the building is created for each renovation measure.
C. Identification of the examined attribute per renovation category. For example, the examined attribute for a building's envelope is the thermal transmittance value.
D. The examined attribute is used as input to a diagnosis procedure to identify the need for a renovation action. The need for a renovation action is defined as mandatory if any of the examined attributes violate national guidelines. If renovation action is mandatory, the scenario generation starts, and the building's digital copy is modified according to suggested recommendations. If a building's digital copy does not violate national guidelines, its context remains immutable.
E. The modified copy of the building is used as an input to the AR Module for energy calculations. It is worth mentioning that for every iteration, the Roadmapping tool module validates the quality of AR results by comparing renovated results with the building's current state results. In case of inaccurate results, the Roadmapping tool stops operating and provides a notification to the end user. Also, the modified building copy can refer to the individual (only envelope modifications) or combined renovation action (envelope, heating, and lighting modification).
F. All energy calculation results are integrated with an indicative renovation cost in a final table.
G. The final table is sorted by payback years.

H. Non-modified building instances are integrated into the final table to depict the final Renovation Roadmap to the end user.
I. The final table is used to form the final output of the tool, which is described analytically in section 4.1

Figure 4 shows the general operational workflow of the Roadmapping tool.

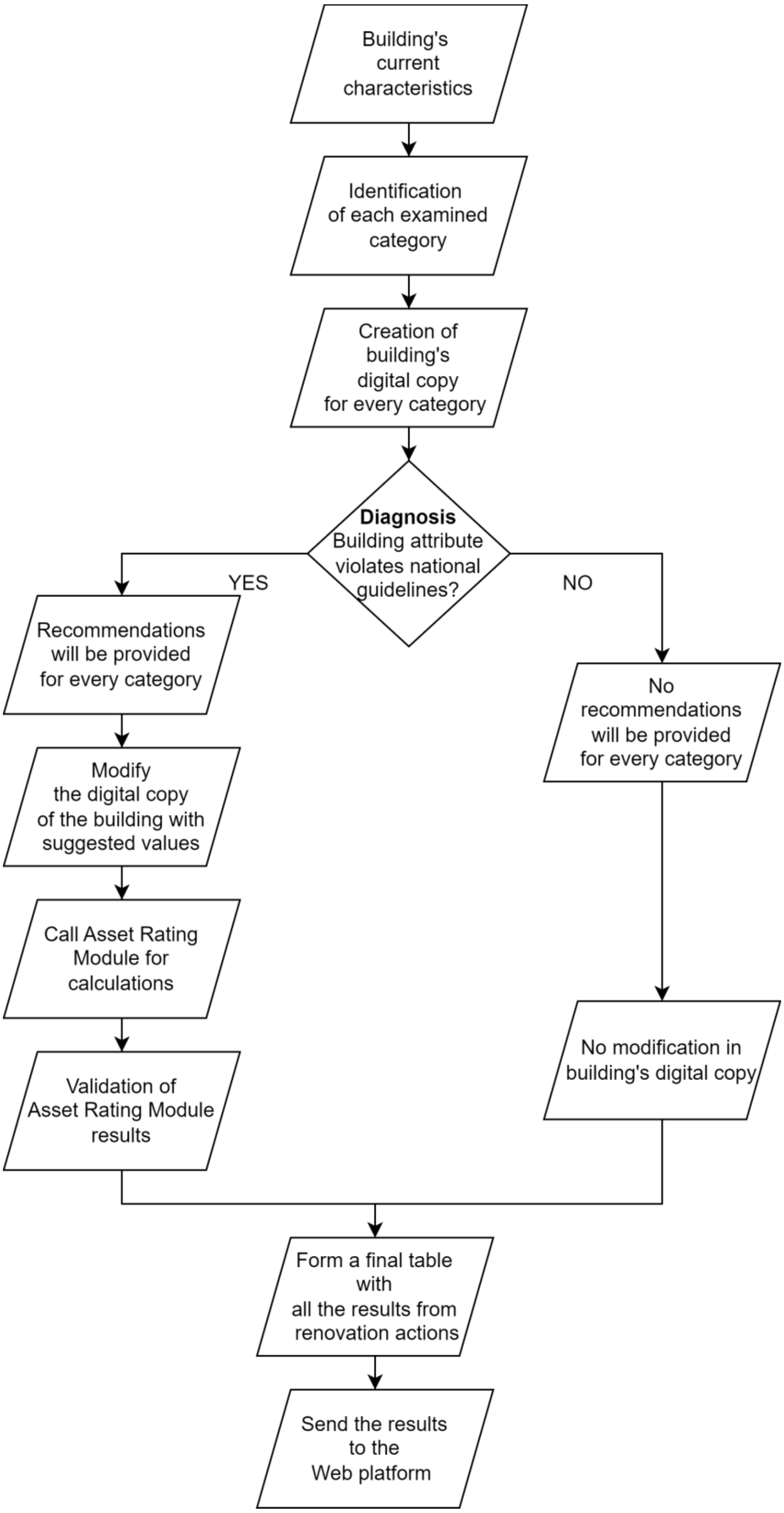


Figure 4: Roadmapping tool General Workflow

3.1.2.2 Renovation measures for energy performance upgrade

Apart from the general operational description, a brief technical description is made for each renovation measure. For the development of the tool, three main renovation categories were studied. For each renovation category, different renovation measures are applied. More specifically, the external insulation of elements in contact with the external air was examined regarding the building's envelope. The heating, cooling, lighting, and Domestic Hot Water (DHW) systems were considered in the category of technical systems. The Renewable Energy Sources (RES), Solar Thermal Collectors (STC) and Photovoltaic systems finalize the renovation roadmap of the end-user. It is worth mentioning for hot water services that the Roadmapping tool examines firstly STC system suggestions and then a DHW boiler suggestion. The order of the renovations is developed based on the renovations' measure efficiency and the fulfilment of the needs, increasing the end-user's standard of living.

The following paragraphs provide the rationale for each renovation measure. Specifically:

I. The building's external insulation is referred to as the external insulation measure, implemented in elements in contact with the external air. The examined elements are external walls, roofs, floors, doors, and windows. For each element, the envelope_diagnosis function calculates the average thermal transmittance value (U-value) and total area. Also, envelope_diagnosis compares calculated average U-value and national minimum thermal transmittance values. If the average value is greater than the national minimum value, then the change_u_value function is executed, and each building element is assigned the minimum value. With the knowledge of the total element's area, the renovation cost of the external insulation is measured in $€/m^2$.

II. Heating systems are defined as the systems that are used during the predefined heating period. The examination starts with activating the heating_diagnosis function, which is used for the identification and validation procedures. Identification refers to the system type (boiler or heat pump) and current heating fuel (oil, biomass, natural gas, electricity). After identification, validation procedures will be conducted to examine if the heating system's efficiency per heating zone meets minimum national guidelines. In case of national guidelines violation, the change_heating_technical_system function is triggered. Function proposes a new heating system based on parameters of the heating zone. More specifically, the Roadmapping tool provides functionality that calculates the demanded thermal power of the proposed heating system. System dimensioning considers parameters like average U-value, minimum and maximum temperature values per climatic zone, fresh air requirements, and total conditioned area of thermal zones. After dimensioning the heating system, the Roadmapping tool calls the heating_production_unit_cost function to calculate the total cost of the proposed system. Total cost derives from the nominal thermal power of the system.

III. Cooling systems are defined as the systems which are used during the cooling period. It is examined whether the cooling system efficiency per cooling zone meets the national standards with the assistance of the cooling_diagnosis function. In renovation, a system is proposed based on the cooling zone area and the system's efficiency. Roadmapping tool designs cooling system based on envelope characteristics (average U-values, opaque element area, and orientation), fresh air requirements of every thermal zone, temperature measurements of the climatic zone, and typical values of the zone's internal heat gains. The cooling zone area defines the required system's cooling power, and consequently, the cooling power defines the renovation cost. The renovation cost is calculated from the cooling_production_unit_cost function.

IV. Solar Thermal Collector (STC) systems include the system that partly covers DHW load with the harnessing of solar energy. The tool identifies the need for STC system installation, the non-existence of the system, or an upgrade of the current system for the specific thermal zone. The renovation action is characterized as critical in case the solar share of the STC system does surpass a solar share threshold. The following equation describes solar share:

$$solar\ share = \frac{Delived\ energy\ by\ the\ STC\ system}{Total\ demanded\ energy\ for\ DHW} \tag{2}$$

STC system proposal is based on add_solar_thermal_collector function. The function considers a variety of parameters to satisfy the solar share threshold. Parameters refer to orientation (W, S, E, SW, etc.), STC area and category (selective), installation tilt, and tank volume. The cost of the new STC system is calculated from solar_thermal_production_unit_cost and is related to the tank volume and the STC area.

V. DHW systems consist of units that will cover the remaining portion of the STC DHW load for every DHW zone. If the DHW system does not exist, the Roadmapping tool initializes a DHW system in the suitable thermal zone with the add_theoritical_dhw_production_unit function. Furthermore, Roadmapping considers if DHW demand is a positive value from AR calculation to proceed with suggestion scenarios. DHW production is based on the heating system, and the examination of the system follows the minimum efficiency standards for heating according to national guidelines. The examined attributes are production unit type (boiler or heat pump), fuel type (electricity, gas, or biomass), and efficiency percentage. The change_dhw_production_unit function proposes a new DHW production unit, which can also be incorporated as a building heating system. The cost of the DHW production unit is calculated from dhw_production_unit_cost and depends on the unit's capacity.

VI. An examination of lighting systems is being conducted for non-residential and conditioned thermal zones. Based on the usage of the lighting zone, the demanded lux is defined from national tables. National lux requirements are presented in Annex A. With knowledge of the total lighting zone area and the demanded lux, the total lumen per lighting zone is calculated. The function calculate_total_watts_per_type_lamp is activated to calculate the total number of lamps and installed lighting power. More specifically, the proposed lamps have specific high-efficient bright performance, measured in Lumen/Watt, and in combination with the total lumen, the total lighting installed power is calculated. In addition, the proposed lamp corresponds to specific power, resulting in the total number of lamps being calculated. The lighting examination finishes by comparing lighting energies between the current and lighting-renovated buildings. In the case of renovation, the cost is calculated on the number of lamps through the calculate_lighting_systems_cost function.

VII. A photovoltaic (PV) system examination suggests a PV system to minimize electrical demand and achieve the nZEB goal. The proposed system is sized considering parameters like the building's location, total primary energy normalized per area, and RES share. The following equation defines RES share:

$$RES\ share = \frac{present\ primary\ photovoltaic\ energy}{present\ primary\ energy\ without\ photovoltaics} \quad (3)$$

It is worth mentioning that the nZEB definition, apart from low energy consumption, includes that renewable energy sources must cover a major part of energy services. The Roadmapping tool utilizes the calculate_res_share_and_primary energy function to calculate the mandatory and check if the nZeb goal is satisfied. In case the nZEB goal is not achieved, the Roadmapping tool calls the increase_PV function to add photovoltaic systems until the achievement of the nZEB goal. Finally, the installation cost is calculated based on the total power of the proposed PV system. To sum up, the Roadmapping tool calculated the total area of the proposed PV system with the aim to provide some feedback to the end user regarding the feasibility of the proposed system installation.

3.1.3 Development of Roadmapping tool

The current version of the Roadmapping tool sub-module is developed in Python programming language, version 3.9. Roadmapping tool is based on structured programming, and the tool's flow is divided into numerous sub-functions, which were partially mentioned in Section 3.1.2.2. The whole tool is structured as a Python package to achieve interoperability among other services or third-party users. The following libraries were used for the development of the tool:

- Pandas version 1.4.2[1]
- Collection version 3.3[2]

[1] https://pandas.pydata.org/docs/index.html
[2] https://docs.python.org/3/library/collections.html

3.2 AI-driven performance forecasts

In the context of D^2EPC, the main idea 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. A dataset taken from CERTH's smart home metering data was used for the experiments, covering the period between January 2022 to December 2022. The data had a 15-minute granularity for the consumed energy, so it had to be preprocessed to extract the daily energy that was consumed.

Apart from energy consumption, we used weather and temporal data. The weather data were obtained from the meteostat[3] API. For the initial experiments, the data that we used were:

- 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

For the experiments with DNNs, the weather and energy information had to be normalized using equation (4). At the same time, for the temporal info apart from the binary mask for weekends, they were transformed into sine and cosine form, with equations (5) – (8). The XGBoost algorithm does not necessarily need the weather and energy data to be normalized, but we still used equations (4) – (7) for the temporal information transforms. The day parameter ranges between 0 and 6, Monday being 0 and Sunday 6, and the $month$ parameter ranged from 1 through 12, January being 1 and December 12.

$$x_i' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{4}$$

$$day_{sin}' = \sin(day * 2 * \frac{pi}{7}) \tag{5}$$

$$day_{cos}' = \cos\left(day * 2 * \frac{pi}{7}\right) \tag{6}$$

$$month_{sin}' = \sin(month * 2 * \frac{pi}{12}) \tag{7}$$

$$month_{cos}' = \cos\left(month * 2 * \frac{pi}{12}\right) \tag{8}$$

The experiments with DNNs were conducted using TensorFlow[4] with Keras's[5] backend in the first version of the deliverable D4.2. In this version, the DDN architectures were developed and deployed using Pytorch[6]. We used the regression eXtreme Gradient Boosting implementation provided by scikit-learn[7] and the implementation in [8].

Regarding the pre-processing, the sliding window technique was deployed. Temporal windows were generated, with their length being twice the days we were forecasting. The first half of the energy consumption window was the models' historical consumption input. In the second half, the energy consumption was used as the target variable. The temporal and weather data were added to the energy consumption from the first half of the window as input. In total, there were around 360 data points. The last month was used for validation and testing.

[3] https://meteostat.net/en/
[4] https://www.tensorflow.org/
[5] https://keras.io/
[6] https://pytorch.org/
[7] https://scikit-learn.org/stable/
[8] https://xgboost.ai/

Experiments were conducted with convolutional neural network (CNN) architectures and a CNN-LSTM hybrid architecture, where the CNN part was used to extract features from the data and to reduce the dimensionality of the features, while the LSTM followed after the CNNs and it serve as “memory” layers. A light self-attention module was also added, reinforcing the model’s accuracy. In Figure 5, the architecture of the model described above is presented.

In D^2EPC, the goal of this module is to forecast the energy consumption of the following month, its output will be forwarded to the Operational Rating module, defined in D4.1, 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. As the Operational Rating is under development this connection has not been established yet. 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.

A limitation that we have currently observed is the lack of publicly available APIs for month-ahead weather forecasting. This is not a limitation during the training phase, but it will cause issues when used in production since the weather data for the coming month are needed for the predictions. Since weather forecasts are unreliable for a period greater than 2 weeks, we utilize the past 10 years of weather data, taking the median of the features we need and using them as the weather “forecast”.

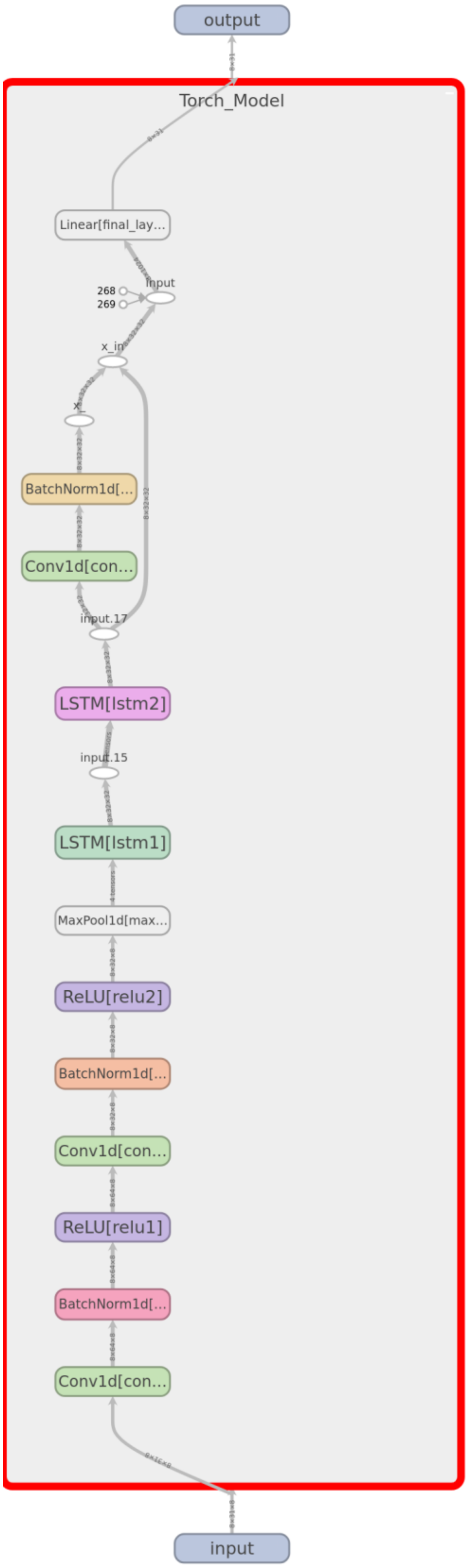


Figure 5: Hybrid CNN-LSTM architecture

3.3 Performance alerts and notifications Module

The functional diagram of the Performance alerts and notification tool, as documented in D1.9, is shown in Figure 6. It includes two main sub-components, namely the notification engine and the communication client and has been designed as a Python package, allowing it to be integrated into all D^2EPC tools. To this end, the latter can record important information related to internal pre-processing, execution and evaluation of results and provide it to the user.

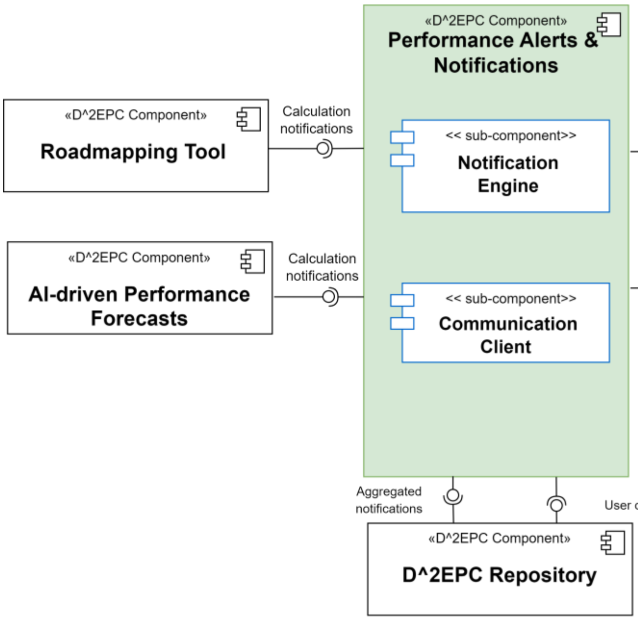


Figure 6: Performance alerts and notifications - Architectural view

The class diagram of the Performance alerts & notifications tools is shown in Figure 7 below. Objects of the main *Alerts* class are instantiated within each tool to collect the generated measurements. They feature all the variables and methods necessary to store enriched notification content with a predefined format properly. Four alert levels are defined, namely:

- *SUGGESTION*, which is utilized for recommendation messages, e.g., to adjust the heating system's temperature towards to improve conditions in terms of thermal comfort
- *INFO,* which characterizes informative messages, e.g., that the EPC assessment results have been successfully calculated
- *WARNING,* to highlight notification messages that require the user's attention, e.g., that missing information regarding specific building materials may have impacted the LCA calculation results
- *ERROR,* to provide context on important malfunction issues, e.g., malformed BIM file input information that impedes asset-based EPC calculation to be executed.

Additionally, a custom exception class, *ToolAlertException* has been modelled, which enables the implementation of controlled execution interruptions by the *Alerts* object that corresponds to each tool. This allows each D^2EPC tool to properly handle complex execution flow errors and provide semantically enriched context to the user.

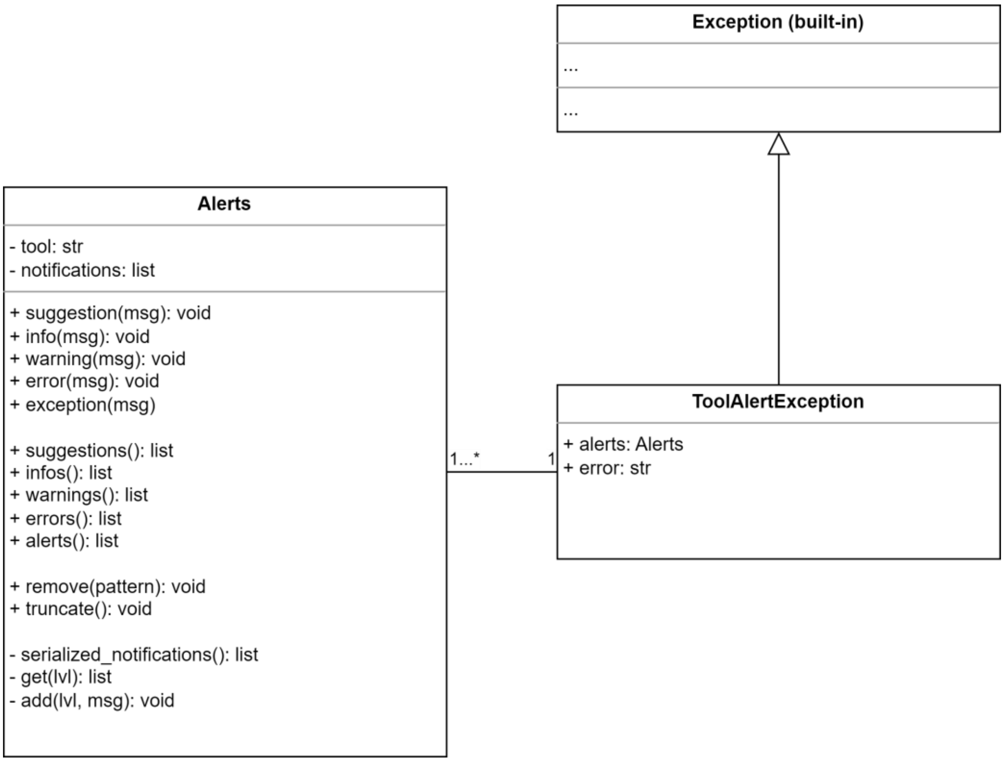


Figure 7 Performance alerts & notifications tool class diagram

Upon successful yield of a tool's results or interruption due to an exception, the collected alerts are aggregated and stored in the D^2EPC Repository, where they are accessed by the D^2EPC platform for visualization to the user. They include the defined level and the notification message.

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 • 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 • 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 • Issuance of an updated set of calculated static or dynamic indicators • Warnings/errors regarding the input information and the calculation processes • 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 8.

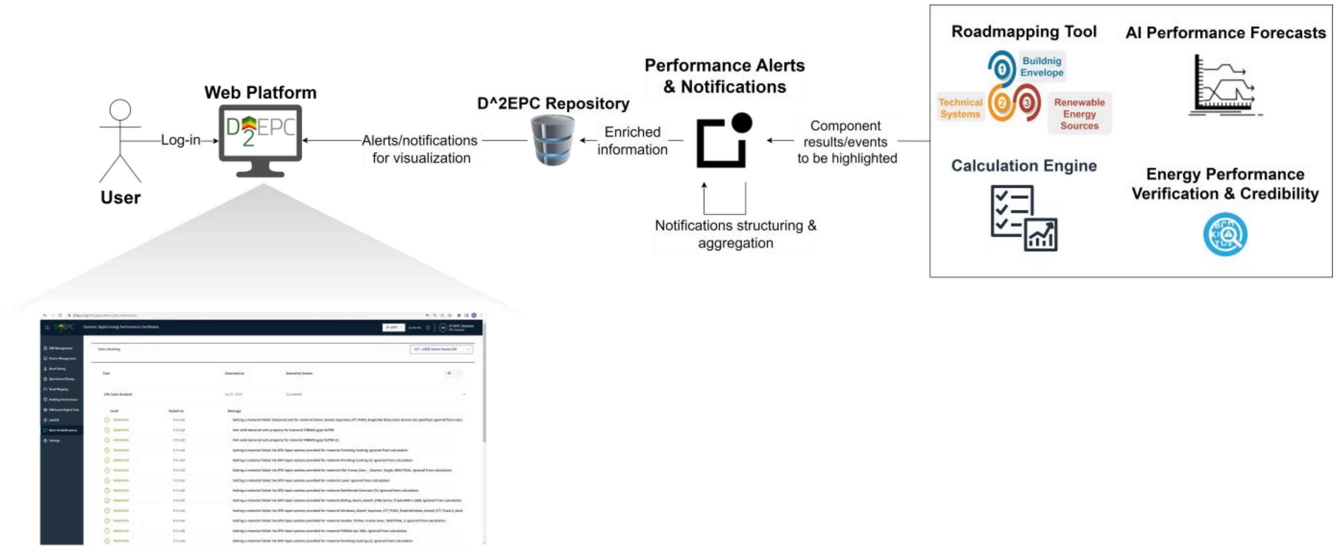


Figure 8: Performance alerts & notifications component interactions

4 Added value services suite results

4.1 Roadmapping tool

The purpose of the Roadmapping tool is to provide optimal renovation recommendations for a building's energy performance upgrade. The tool produces results from BIM-based Digital Twin in a JavaScript Object Notation (JSON) format. The produced results are stored in the D^2EPC repository to be given as input to the D^2EPC Web Platform for visualization purposes. The following sub-section describes the Roadmapping tool's results for the FRC pilot site.

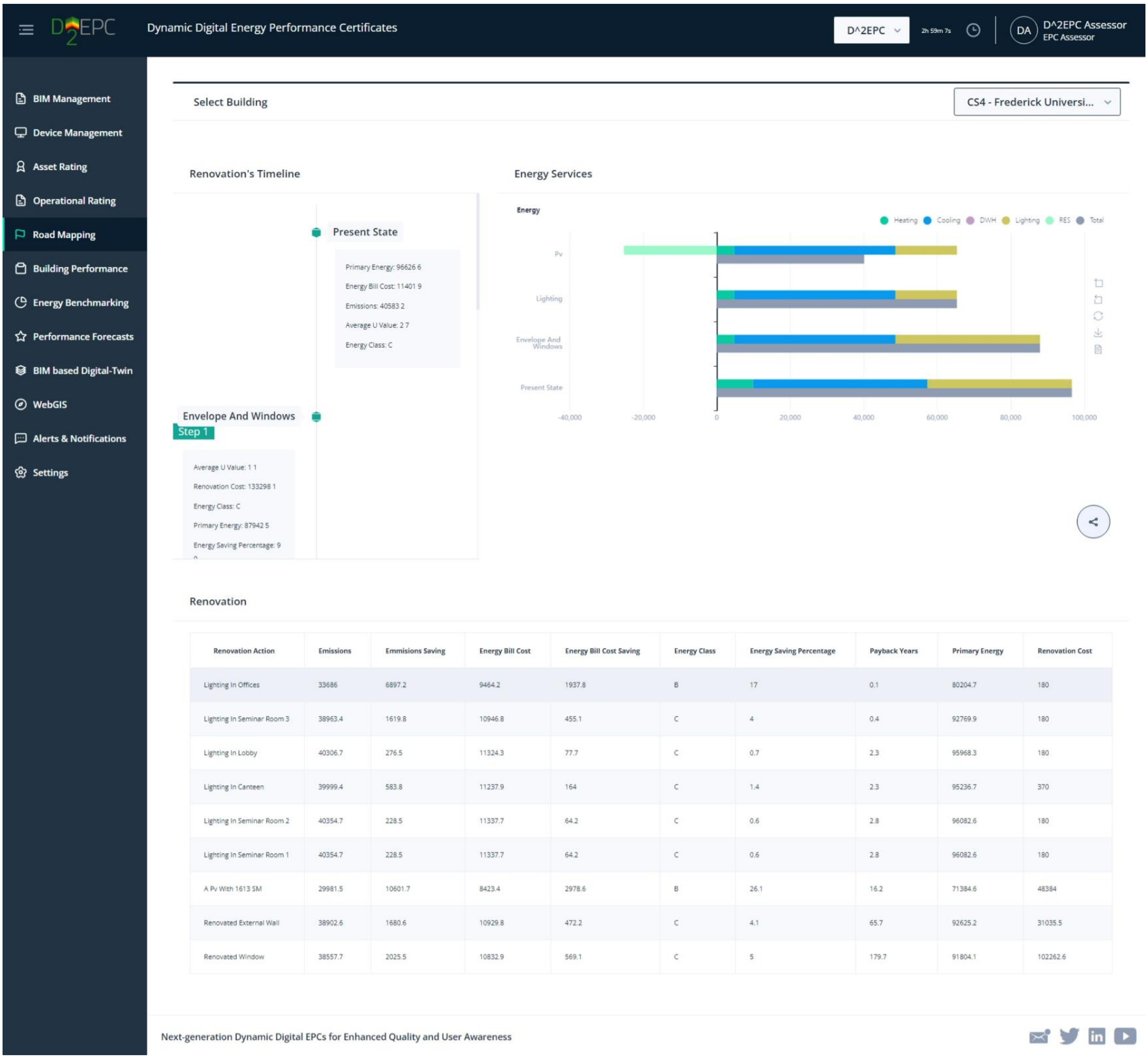
4.1.1 Web Platform

Figure 9 shows the produced results of the Roadmapping tool in a JSON format.


```
[
 {
    "Table": {
      "Energy_Class": {...},
      "Primary_Energy": {...},
      "Energy_saving_percentage": {...},
      "Energy_Bill_Cost": {...},
      "Energy_Bill_Cost_saving": {...},
      "Emissions": {...},
      "Emmisions_saving": {...},
      "Renovation_Cost": {...},
      "Payback_years": {...},
},
    "Timeline": [
      {
        "Present_State": {...},
      {
        "Envelope_and_Windows": {...},
      {
        "Lighting": {...},
      {
        "PV": {...}
    ],
    "Barcharts": [
      {
        "Present_State": {...},
      {
        "Envelope_and_Windows": {...},
      {
        "Lighting": {...},
      {
        "PV": {...}
    ]
 }
 ]
```


Figure 9: General overview of Roadmapping tool results

Then, the results are forwarded in the Web Platform to depict meaningful indicators to the end user in a user-friendly way. Figure 10 illustrates the general overview of Roadmapping's tool results.



Renovation Action	Emissions	Emmisions Saving	Energy Bill Cost	Energy Bill Cost Saving	Energy Class	Energy Saving Percentage	Payback Years	Primary Energy	Renovation Cost
Lighting In Offices	33686	6897.2	9464.2	1937.8	B	17	0.1	80204.7	180
Lighting In Seminar Room 3	38963.4	1619.8	10946.8	455.1	C	4	0.4	92769.9	180
Lighting In Lobby	40306.7	276.5	11324.3	77.7	C	0.7	2.3	95968.3	180
Lighting In Canteen	39999.4	583.8	11237.9	164	C	1.4	2.3	95236.7	370
Lighting In Seminar Room 2	40354.7	228.5	11337.7	64.2	C	0.6	2.8	96082.6	180
Lighting In Seminar Room 1	40354.7	228.5	11337.7	64.2	C	0.6	2.8	96082.6	180
A Pv With 1613 SM	29981.5	10601.7	8423.4	2978.6	B	26.1	16.2	71384.6	48384
Renovated External Wall	38902.6	1680.6	10929.8	472.2	C	4.1	65.7	92625.2	31035.5
Renovated Window	38557.7	2025.5	10832.9	569.1	C	5	179.7	91804.1	102262.6

Figure 10: General overview of Roadmapping tool result in the Web Platform

The general overview of the results is categorized into three main sections: Tables, Timeline, and Barcharts. Every section delivers different information to the building owner to provide a holistic view of the effect of each renovation suggestion.

Starting from the Table section, the results depict the influence of each retrofit action with meaningful indicators. Indicators refer to EPC class, primary energy, energy saving percentage, CO_2 emissions, operational cost, operational cost savings, renovation cost, and payback years. The basic characteristic of this section is that the recommended actions are examined individually. More specifically, it is presumed that the building is renovated only with the proposed suggestion focusing on the impact of the specific renovation action without further renovations. Also, the results in the Table are sorted by payback years. All saving indicators derive from comparing the renovated building's instance with the building's current state. Figure 11 depicts the Table section.

Renovation

Renovation Action	Emissions	Emmisions Saving	Energy Bill Cost	Energy Bill Cost Saving	Energy Class	Energy Saving Percentage	Payback Years	Primary Energy	Renovation Cost
Lighting In Offices	33686	6897.2	9464.2	1937.8	B	17	0.1	80204.7	180
Lighting In Seminar Room 3	38963.4	1619.8	10946.8	455.1	C	4	0.4	92769.9	180
Lighting In Lobby	40306.7	276.5	11324.3	77.7	C	0.7	2.3	95968.3	180
Lighting In Canteen	39999.4	583.8	11237.9	164	C	1.4	2.3	95236.7	370
Lighting In Seminar Room 2	40354.7	228.5	11337.7	64.2	C	0.6	2.8	96082.6	180
Lighting In Seminar Room 1	40354.7	228.5	11337.7	64.2	C	0.6	2.8	96082.6	180
A Pv With 1613 SM	29981.5	10601.7	8423.4	2978.6	B	26.1	16.2	71384.6	48384
Renovated External Wall	38902.6	1680.6	10929.8	472.2	C	4.1	65.7	92625.2	31035.5
Renovated Window	38557.7	2025.5	10832.9	569.1	C	5	179.7	91804.1	102262.6

Figure 11: Table section of Roadmapping tool

Following the Timeline sections provides a renovation roadmap towards the nZeb goal or the desirable energy performance of the building owner. In contrast with the Table section, the timeline consists of a combined renovation actions that follow the Roadmapping strategy rationale described in Figure 2: Workflow of the Roadmapping toolFigure 2. Timeline applies renovation steps starting from the building's current state, continuing with envelope and technical systems, and concluding with RES systems. More specifically, the newly generated building instance contains all the proposed values from the previously renovated building instance, resulting in a step-wise renovation roadmap. Moreover, the timeline results express the renovation impact of combined scenarios by introducing two extra essential indicators. Indicators refer to average U-values of envelope elements and panel area of PV systems. The timeline steps for the Case Study 4 are depicted from Figure 12 to Figure 15.

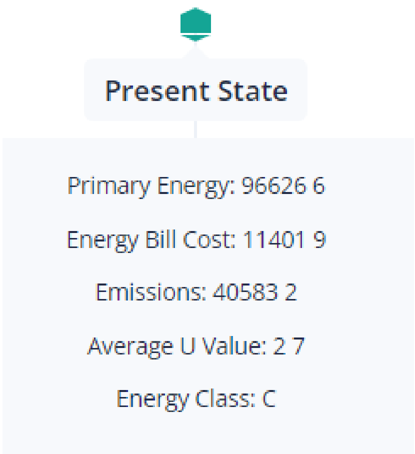


Figure 12: Timeline presentation of the building's current state

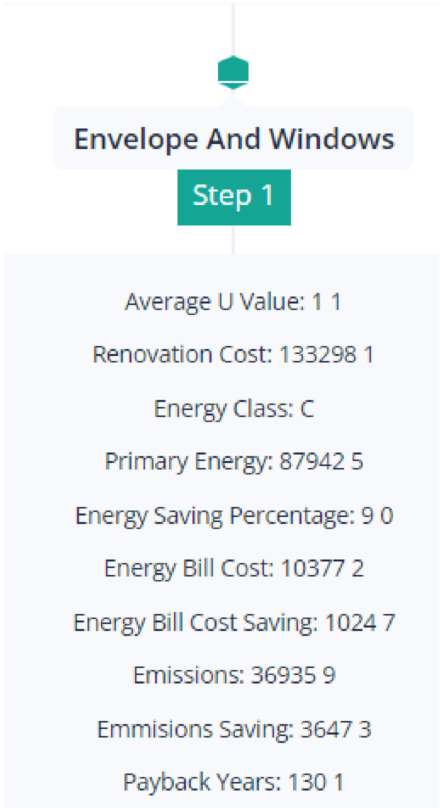


Figure 13: Envelope renovation in a timeline graph

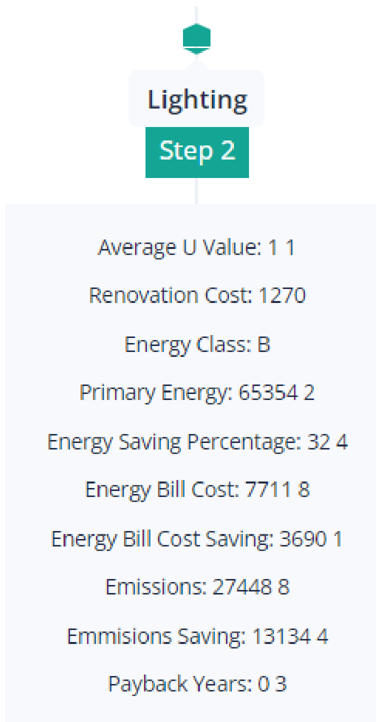


Figure 14: Lighting renovation in a timeline graph

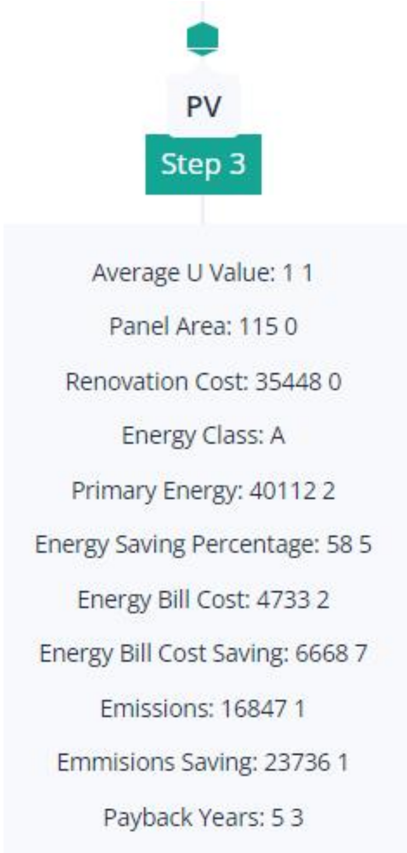


Figure 15: Photovoltaic suggestion in timeline graph

Following, the Barchart section seeks to inform the building's owner about the influence of the renovation action in relation to the energy services. Barchart expresses the effect of the renovation impact for a combination of scenarios, similar to the timeline graph. The bar charts are shown in Figure 16.

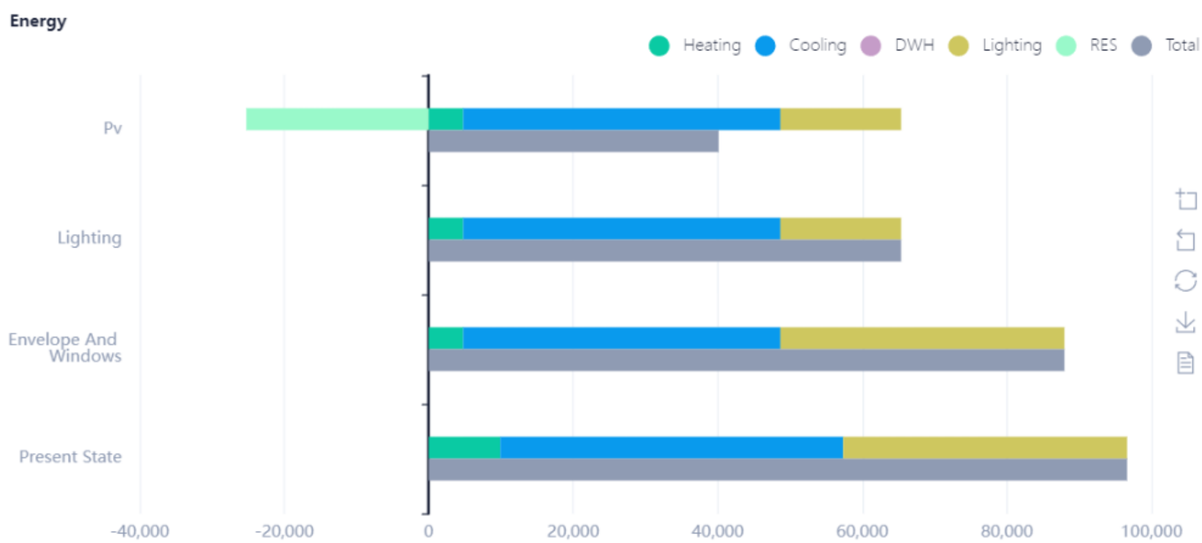


Figure 16: Barchart section of Roadmapping tool

This section presented the calculated results of the Roadmapping tool for the FRC pilot site. According to estimated results, FRC requires an envelope renovation to external walls and windows to achieve 9 per cent annual savings and decrease the average U-value from 2.6 to 1.1. Following, the tool recommends the replacement of current light lamps with more efficient lamps in different thermal zones (offices, seminar rooms, and lobby), with 32 per cent annual saving and 4-month payback time. To satisfy the optional nZEB goal, the tool suggests installing a photovoltaic system, whose total area is 115 square meters.

To sum up, the Roadmapping tool provides renovation suggestions to the building owner by implementing a step-wise renovation roadmap starting from envelope to RES systems. It is worth mentioning that the role of the EPC assessor remains critical during the renovation process. EPC assessor must re-evaluate the results of the Roadmapping tool and interact with the building owner for the format of the final renovation roadmap strategy.

4.2 AI-driven performance forecasts

Similarly to D4.2, we have experimented with the XGBoost algorithm with data from the other pilot sites. In addition, we have added a new implementation of a CNN-LSTM architecture, and in this case, the convolutional layers are serially connected to the LSTM nodes instead of parallel. A core difference between this and the previous implementation of this tool is that in the newer version, a model is trained for each individual energy metering device in the Digital Twin (D3.5).

Without bells and whistles, the different pilot sites and meters results are provided in Figure 17 through Figure 27. From Figure 17 through Figure 19, we offer qualitative results to the Case Study 1 energy consumption metering devices. More specifically Figure 17 refers to the heating consumption, Figure 18 to the cooling and Figure 19 to the electrical appliances. The data range is from 01/01/2022 through 31/12/2022.

In Figure 20 and Figure 21, the presented results are for the gas meters for two apartments from Case Study 2, Figure 22 and Figure 23 refer to Case Study 3. In contrast, Figure 24, Figure 25, Figure 26, Figure 27 refer to energy consumption from Case Study 4, in the Basement, first floor, second floor and rooftop respectively.

In Table 5, quantitative results for Case Study 1 are provided, comparing XGB and CNN-LSTM architectures in terms of mean absolute percentage error (MAPE) (monthly), Root Mean Square Error (RMSE) and the Coefficient of the Variation of the Room Mean Square Error (CVRMSE). It becomes evident that in this Case Study, the XGBoost algorithm outperforms the CNN-LSTM architecture. Similar results were observed in D4.2 as well. In Table 6, again, the two algorithms are compared, this time in Case Study 2. Note that in this case, the CNN-LSTM outperforms XGBoost, but it should be noted that the results are not that great for any of the algorithms. Table 7 refers to the results of Case Study 3, and, lastly, in Table 8, the methods are tested on Case Study 4. In 1 meter, the CNN-LSTM architecture vastly outperforms the XGBoost algorithm while performing similarly in the other 3 meters for this Case Study.

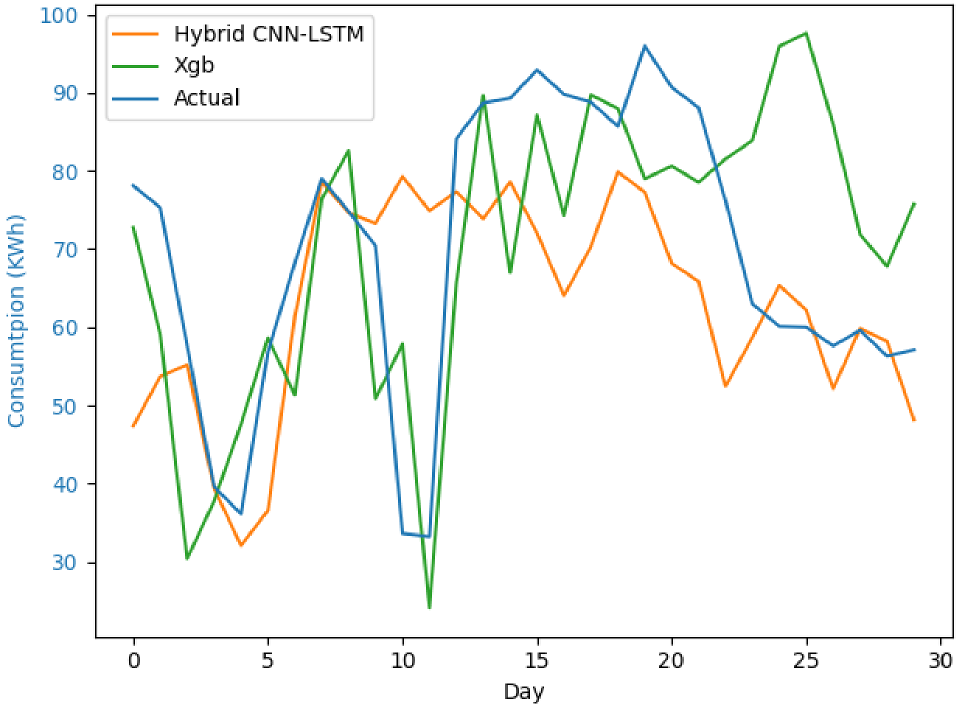


Figure 17: Smarthome Heating meter

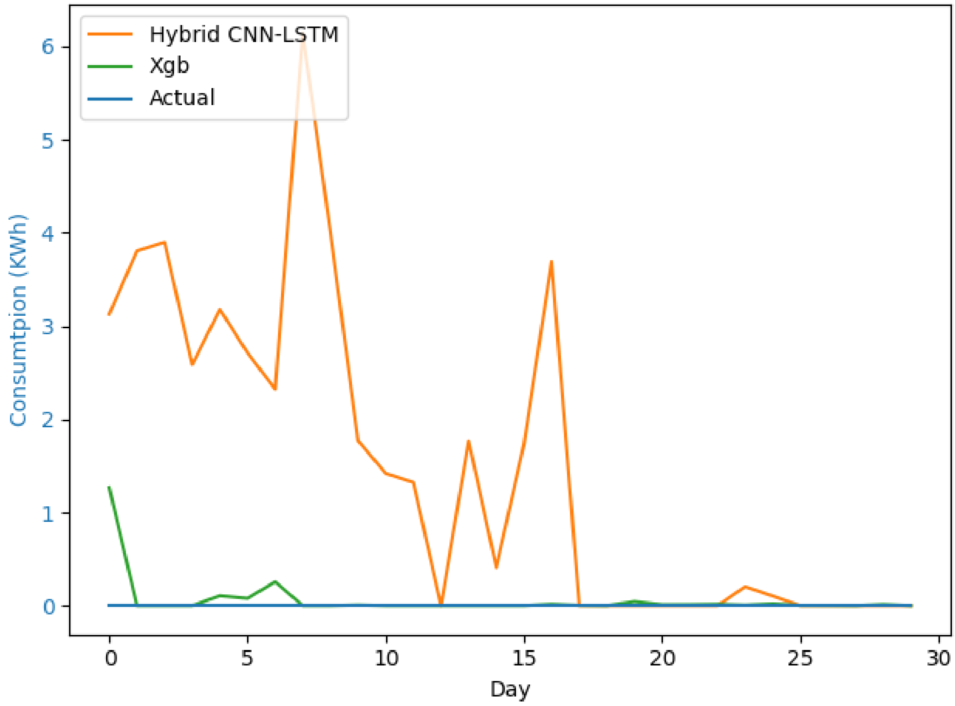


Figure 18: Smarthome Cooling meter

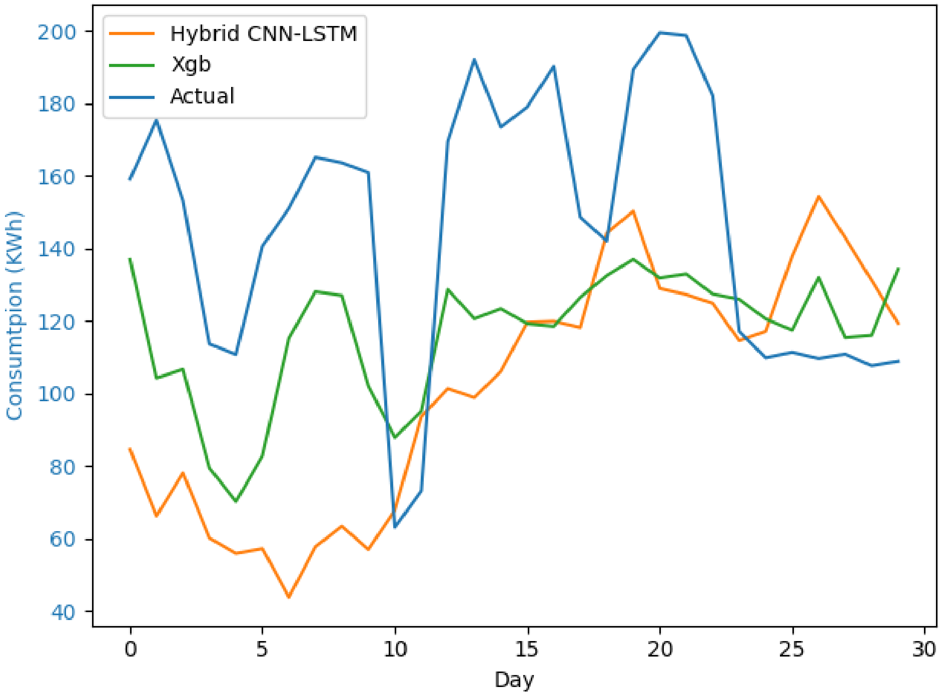


Figure 19: Smarthome Electrical Appliances meter

Table 5: Case Study 1 Quantitative Results

Method	Metering	MAPE (%)	RMSE	CVRMSE (%)
XGBoost	**Electrical Appliances**	**1**	**43.65**	**29.97**
CNN-LSTM	Electrical Appliances	9.4	65.06	44.68
XGBoost	***Heating***	***20***	***17.11***	***24.6***
CNN-LSTM	*Heating*	*30.3*	*17.94*	*25.8*

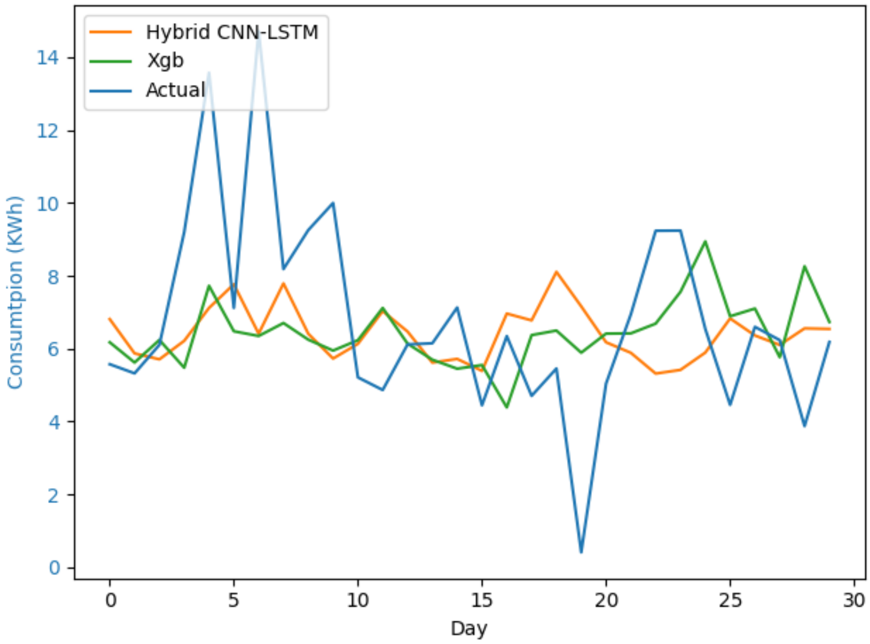


Figure 20: Cleopa Apartment 1 meter

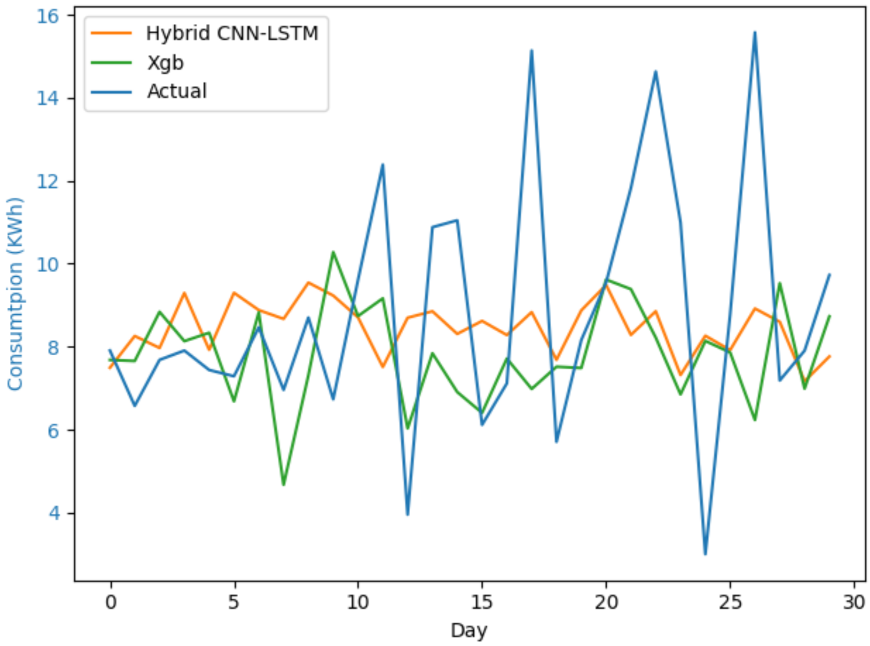


Figure 21: Cleopa Apartment 2 meter

Table 6: Case Study 2 Quantitative Results

Method	Metering	MAPE Monthly (%)	RMSE	CVRMSE (%)
XGBoost	Apartment 1	5.4	3.27	37.10
CNN-LSTM	**Apartment 1**	**5.5**	**2.92**	**33.11**
XGBoost	Apartment 2	11.3	2.81	41.33
CNN-LSTM	**Apartment 2**	**4.31**	**2.99**	**33.86**

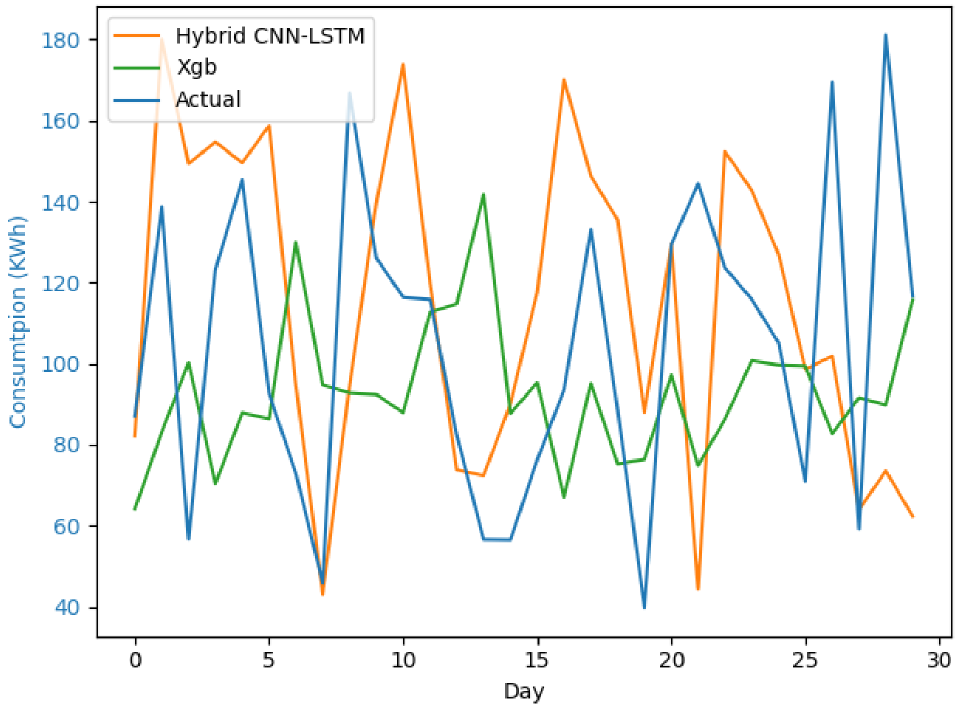


Figure 22: Cleopa Electrical Appliances meter

Table 7: Case Study 3 Quantitative Results

Method	Metering	MAPE Monthly (%)	RMSE	CVRMSE (%)
XGBoost	Electrical Appliances	10.7	45.96	44
CNN-LSTM	**Electrical Appliances**	**2.33**	**48.52**	**38.57**
XGBoost	**Heating Oil**	**4.12**	**263**	**40.44**
CNN-LSTM	Heating Oil	1.2	290	44.6

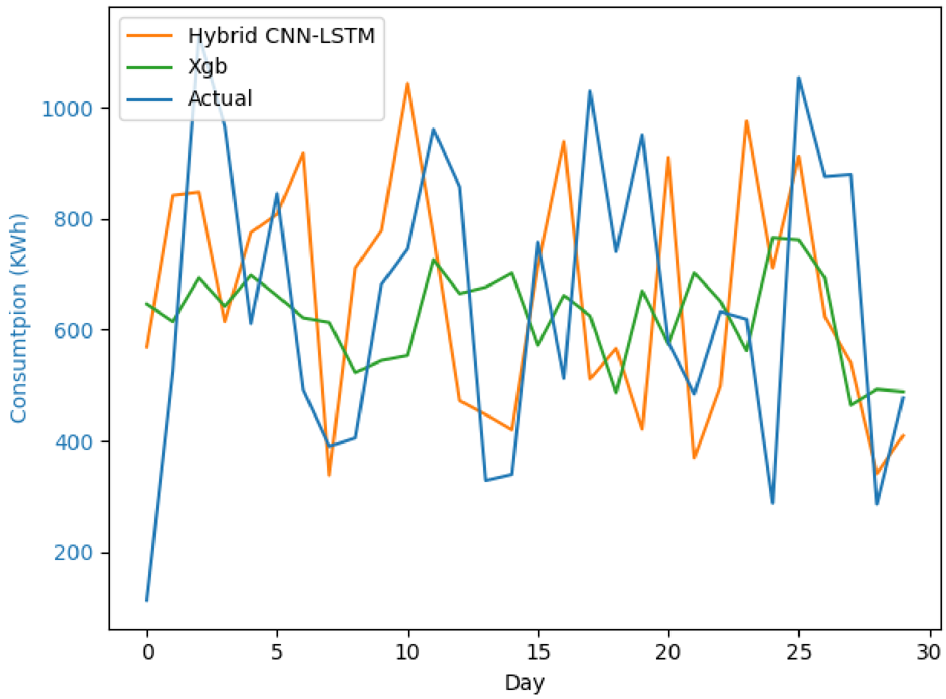


Figure 23: Cleopa Heating Oil meter

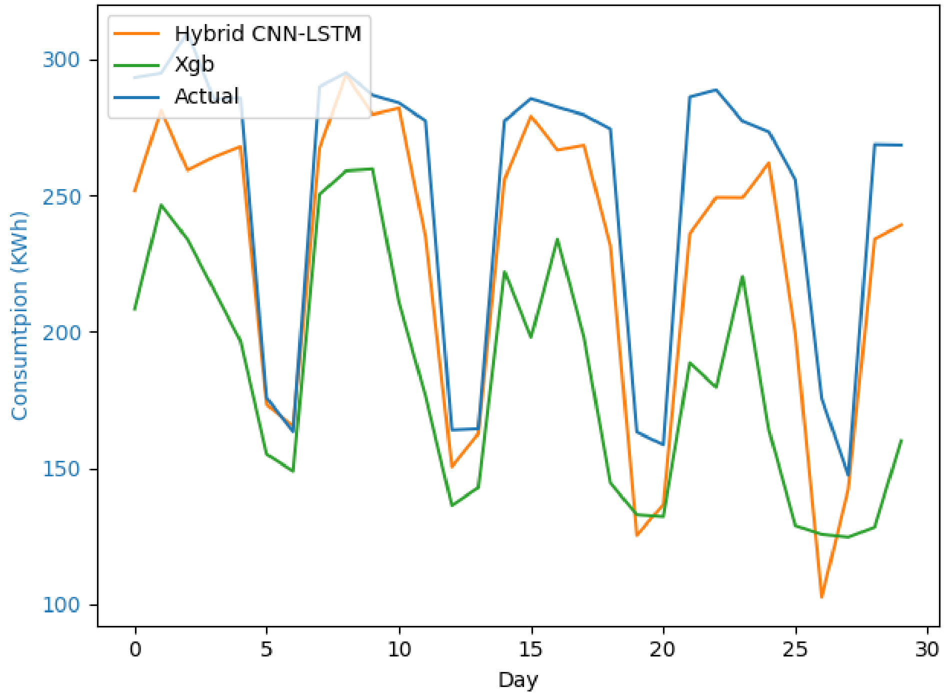


Figure 24: FRC Basement meter

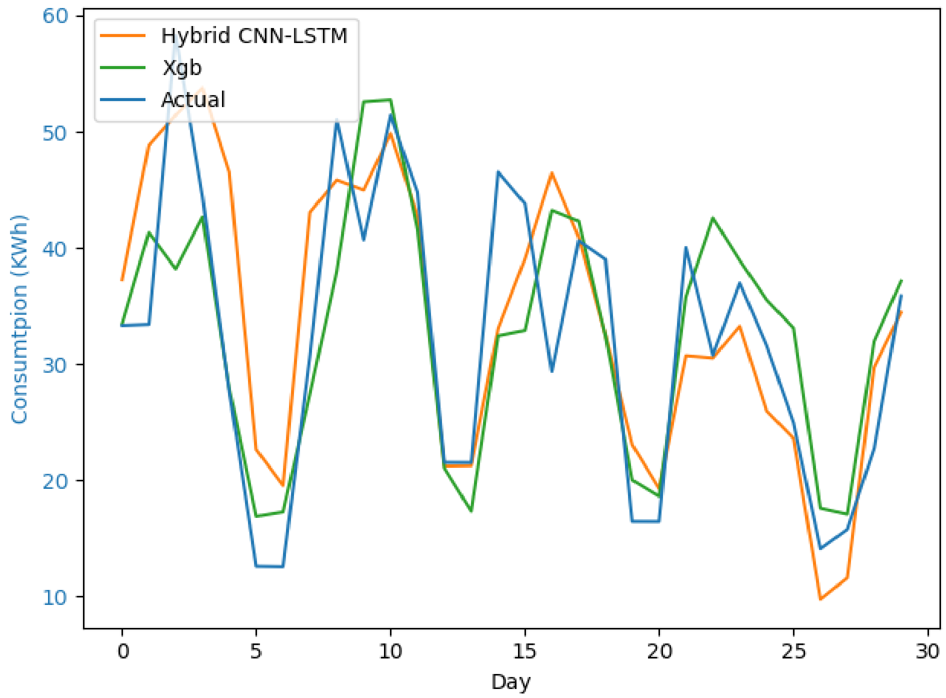


Figure 25: FRC First Floor meter

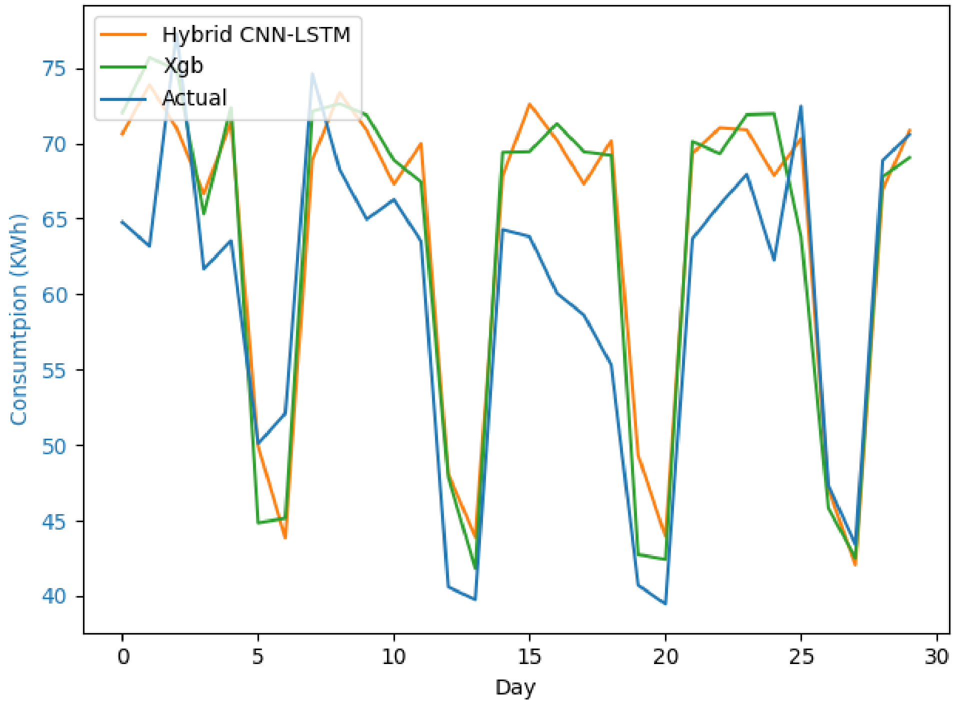


Figure 26: FRC second-floor meter

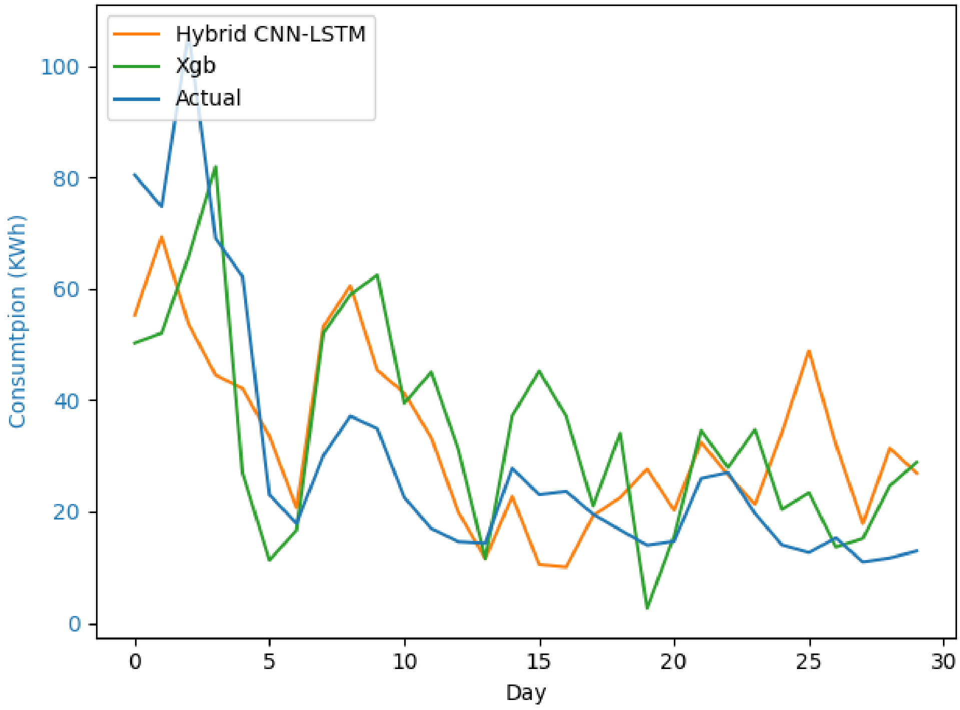


Figure 27: FRC Roof meter

Table 8: FRC Case Study 4 Quantitative Results

Method	Metering	MAPE Monthly(%)	RMSE	CVRMSE (%)
XGBoost	Basement	26.6	76.30	30.39
CNN-LSTM	***Basement***	***9.5***	***30.57***	***12.17***
XGBoost	***First Floor***	***1.1***	***7.70***	***23.83***
CNN-LSTM	*First Floor*	*4.5*	*7.97*	*24.68*
XGBoost	*Second Floor*	*5.7*	*6.54*	*10.94*
CNN-LSTM	***Second Floor***	***6.2***	***6.43***	***10.75***
XGBoost	Roof	14.3	18.02	60.53
CNN-LSTM	**Roof**	**10.7**	**17.94**	**60.25**

4.3 Performance alerts & notifications

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 28 displays the designed web interface. The produced notifications are organized per tool, annotating the corresponding execution time. Within each expanded list (Figure 29), 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.

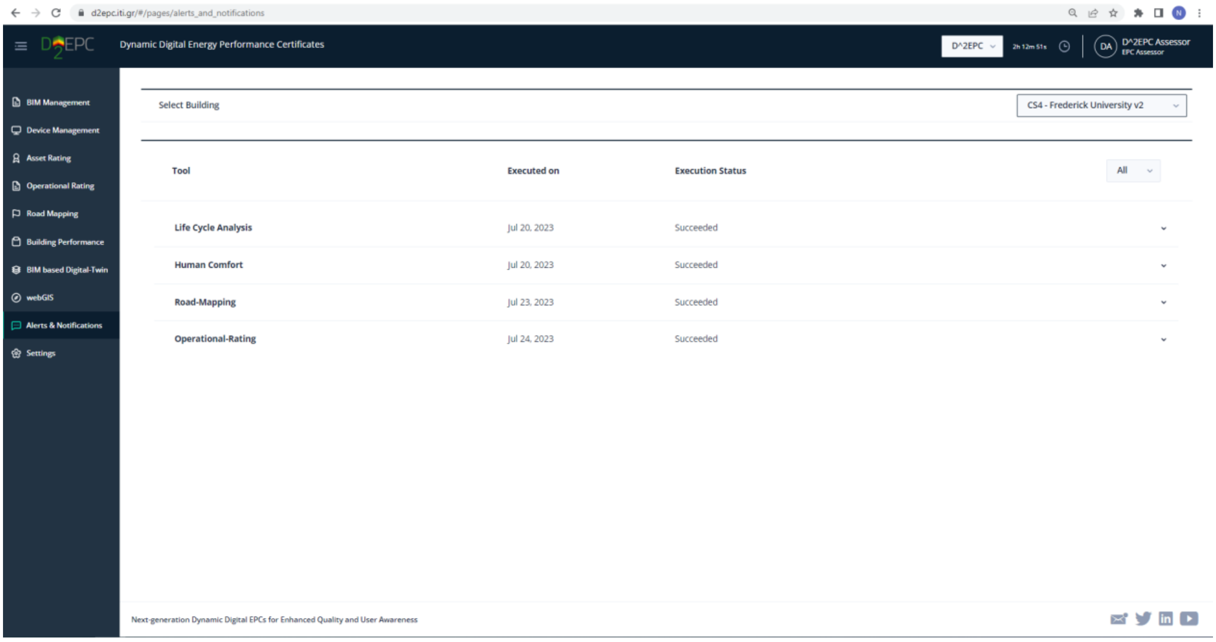


Figure 28: Performance alerts & notifications tool interface

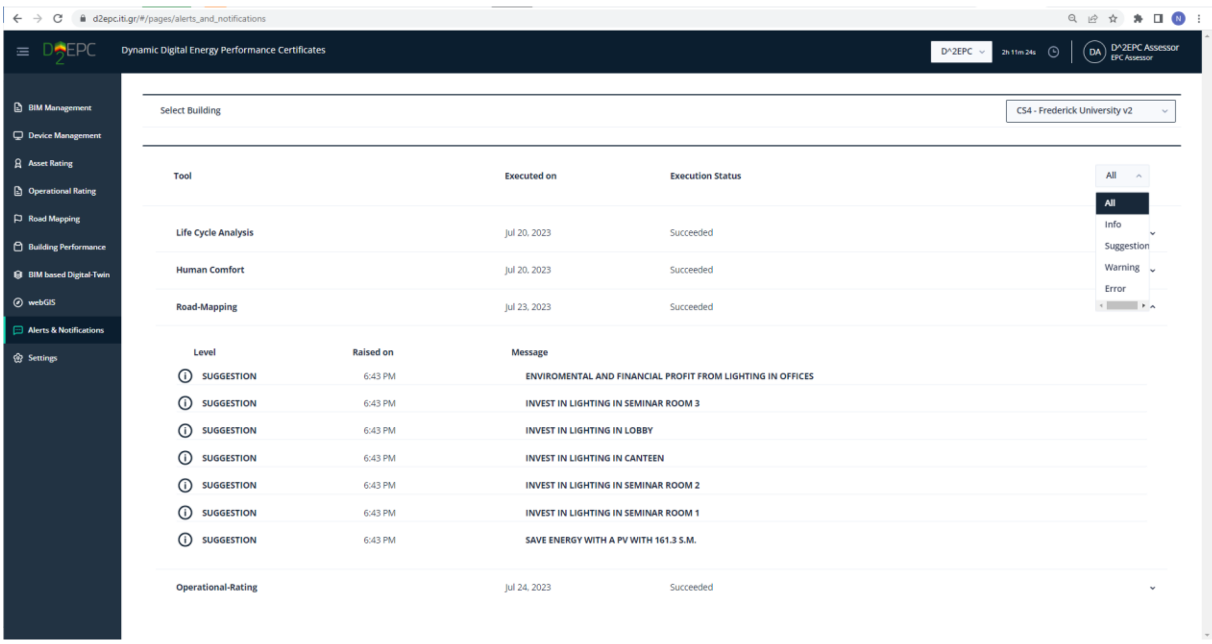


Figure 29: Expanded lists of notifications and alert level-based filtering

Additionally, alerts that correspond to an execution interruption are provided to the user as a popup message within each tool's interface, indicating the necessary corrective actions. An example is shown in Figure 30, where wrong input information is provided to the SRI calculation subcomponent of the Building Performance Module (i.e. not supported country name), leading to the inability to perform the relevant calculations.

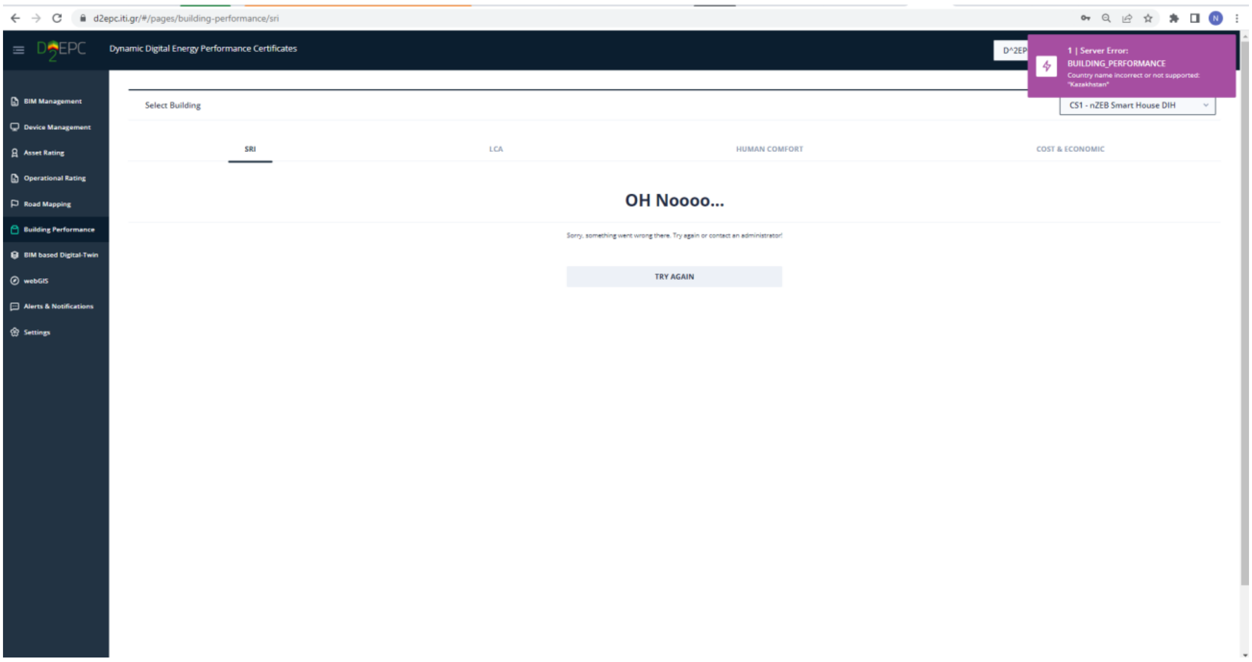


Figure 30: Alert error message due to malformed input

5 Conclusions

This report describes the updates of the development procedure of the Added Value Services Suite. The module consists of three basic sub-components: the Roadmapping tool, the AI-driven performance forecasts, and the Performance alerts and notifications. Each sub-component enriches the D^2EPC framework's functionalities by providing recommendations for building energy performance upgrades, forecasted energy consumption behaviour of the end-user, and creation of notifications.

Regarding the Roadmapping tool, a complete renovation roadmap is provided with all possible renovation actions that refer to the envelope, technical, and RES systems. Roadmapping has enriched the functionality regarding the RES systems and extended functionality for Cypriot and German pilot case studies. Moreover, the Roadmapping tool has been integrated with the Alert and Notification Module to produce meaningful alerts for the building's owner and within the D^2EPC Web platform for renovation roadmap depiction. Potential next steps of the Roadmapping Tool can be a renovation roadmap based on Operational Rating, evaluate the impact of the renovation action through the smart readiness, life cycle cost, and human comfort and well-being indicators, and alignment with the Building Renovation Passport concept.

From the work carried out in T4.2.2, the two dominant architectures that have emerged are the XGBoost algorithm and the hybrid CNN-LSTM, since they were the two with the lowest monthly error. With the additional experiments that we conducted, we have chosen the CNN-LSTM architecture to be the method that will be used in the D^2EPC ecosystem, as it appears to perform better or at a similar level to the XGBoost algorithm depending on the pilot site and metering device that is trained and tested on.

The main structure of the Performance alerts and notifications tool has been laid out, with a main focus on its interaction with the rest of the Added Value Services Suite components, as well as with other components of the D^2EPC architecture. This tool has been developed and finalized in parallel with the other two tools analysed in this document.

6 References

[1]. ECSO, 'Digitalisation in the construction sector. Analytical report'. 2021. [Online]. Available: https://ec.europa.eu/growth/document/download/3ae8a41e- 4b82-4150-968c-1fc73d1e2f61_en

[2]. EUROPEAN and COMMISSION, 'COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS'. Oct. 14, 2020. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf

[3]. EUROPEAN and COMMISSION, 'DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast)'. Dec. 15, 2021.

[4]. European Commission, European Construction Sector Observatory, 'Renovating the building envelope - Quo vadis?' Dec. 2021.

[5]. Yongqiang Luoa, Ling Zhang, Michael Bozlar, Zhongbing Liu, Hongshan Guo, Forrest Meggers, 'Active building envelope systems towards renewable and sustainable energy', in *Renewable and Sustainable Energy Reviews*, vol. 104, 2019, pp. 470–491. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S1364032119300061

[6]. dena, German Energy Agency, 'Energy transition for buildings'. https://www.dena.de/en/topics-projects/energy-efficiency/buildings/building-and-refurbishment/

[7]. HELLENIC MINISTER OF ENVIRONMENT AND ENERGY, 'Implementation Guide of Program <<SAVING 2021>>

[8]. N. Chatzinikolaou, CYPRUS MINISTRY OF ENERGY TRADE AND INDUSTRY, 'Long term renovation strategy for building's stock', p. 123, Apr. 2020.

[9]. MINISTRY OF THE ENVIRONMENT OF THE REPUBLIC OF LITHUANIA, 'REPORT ON THE RESULTS OF THE CALCULATIONS OF, THE INPUT DATA FOR AND ASSUMPTIONS RELATING TO COST-OPTIMAL LEVELS OF MINIMUM ENERGY PERFORMANCE REQUIREMENTS UNDER THE COMPARATIVE METHODOLOGY FRAMEWORK ESTABLISHED IN COMMISSION DELEGATED REGULATION (EU),NO 244/2012 OF 16 JANUARY 2012', Jan. 2012.

[10]. P. Brom, *Energy in dwellings: a comparison between theory and practice*. Delft: BK Books, 2020.

[11]. Netherlands Enterprise Agency, 'Long-Term Renovation Strategy En Route to a low-CO2 Built Environment', Mar. 2020.

[12]. M. Rousselot and S. Morgan-Price, 'Energy renovation of buildings in Spain and the EU', p. 6, 2021.

[13]. BIM SPEED'. https://www.bim-speed.eu/en

[14]. BIM SPEED DELIVERABLE 7.3'. https://www.bim-speed.eu/en/Project%20Results%20%20Documents/Deliverables/D7.3.pdf

[15]. Kong, Weicong & Dong, Z.Y. & Jia, Youwei & Hill, David & Xu, Yan & Zhang, Yuan. (2017). Short-Term Residential Load Forecasting based on LSTM Recurrent Neural Network. IEEE Transactions on Smart Grid. PP. 1-1. 10.1109/TSG.2017.2753802.

[16]. Jung, Seungmin, Jihoon Moon, Sungwoo Park, and Eenjun Hwang. 2021. "An Attention-Based Multilayer GRU Model for Multistep-Ahead Short-Term Load Forecasting" *Sensors* 21, no. 5: 1639. https://doi.org/10.3390/s21051639

[17]. Chen, Kunjin & Chen, Kunlong & Wang, Qin & He, Ziyu & Hu, Jun & Jinliang, He. (2018). Short-Term Load Forecasting With Deep Residual Networks. IEEE Transactions on Smart Grid. PP. 10.1109/TSG.2018.2844307.

[18]. Shao X, Kim C-S, Sontakke P. Accurate Deep Model for Electricity Consumption Forecasting Using Multi-Channel and Multi-Scale Feature Fusion CNN–LSTM. *Energies*. 2020; 13(8):1881. https://doi.org/10.3390/en13081881

[19]. Wang, Jinsong & Chen, Xuhui & Zhang, Fan & Chen, Fangxi & Xin, Yi. (2021). Building Load Forecasting Using Deep Neural Network with Efficient Feature Fusion. Journal of Modern Power Systems and Clean Energy. 9. 160-169. 10.35833/MPCE.2020.000321.

[20]. Abbasi, R.A., Javaid, N., Ghuman, M.N.J., Khan, Z.A., Ur Rehman, S., Amanullah (2019). Short Term Load Forecasting Using XGBoost. In: Barolli, L., Takizawa, M., Xhafa, F., Enokido, T. (eds) Web, Artificial Intelligence and Network Applications. WAINA 2019. Advances in Intelligent Systems and Computing, vol 927. Springer, Cham. https://doi.org/10.1007/978-3-030-15035-8_108

[21]. Liao, Xiaoqun et al. “Research on Short-Term Load Forecasting Using XGBoost Based on Similar Days.” *2019 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)* (2019): 675-678.

[22]. Chen Li, Zhenyu Chen, Jinbo Liu, Dapeng Li, Xingyu Gao, Fangchun Di, Lixin Li, and Xiaohui Ji. 2019. Power Load Forecasting Based on the Combined Model of LSTM and XGBoost. In Proceedings of the 2019 the International Conference on Pattern Recognition and Artificial Intelligence (PRAI '19). Association for Computing Machinery, New York, NY, USA, 46–51. https://doi.org/10.1145/3357777.3357792

[23]. Xiaojin Li *et al* 2021 *J. Phys.: Conf. Ser.* **2026** 012022

[24]. Khan, Sajjad & Javaid, Nadeem & Chand, Annas & Abbasi, Raza & Faisal, Muhammad. (2019). Forecasting day, week and month ahead electricity load consumption of a building using empirical mode decomposition and extreme learning machine. 10.1109/IWCMC.2019.8766675.

[25]. P. Gardner, G. Stern, Environmental Problems and Human Behavior, 2nd ed.,Pearson, Boston, 2002

[26]. Obiajulu Iweka, Shuli Liu, Ashish Shukla, Da Yan, Energy and behaviour at home: A review of intervention methods and practices, Energy Research & Social Science, Volume 57,2019,101238, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2019.101238.

[27]. https://www.iea.org/commentaries/empowering-people-to-act-how-awareness-and-behaviour-campaigns-can-enable-citizens-to-save-energy-during-and-beyond-today-s-energy-crisis

[28]. Nguyen, T.A. and Aiello, M. (2013) Energy Intelligent Buildings Based on User Activity: A Survey. Energy and Buildings, 56, 244-257, https://doi.org/10.1016/j.enbuild.2012.09.005

[29]. Sium, F.S., Ghosh, A.K., & Junaed-Al-Hossain, M. (2020). IoT Based Smart Energy Monitoring and Warning System. 2020 11th International Conference on Electrical and Computer Engineering (ICECE), 93-96.

[30]. IEA, Energy savings across behavioural interventions implemented in the United States, IEA, Paris https://www.iea.org/data-and-statistics/charts/energy-savings-across-behavioural-interventions-implemented-in-the-united-states

[31]. Abhishek Bhati, Michael Hansen, Ching Man Chan, Energy conservation through smart homes in a smart city: A lesson for Singapore households, Energy Policy, Volume 104, 2017, Pages 230-239, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2017.01.032.

[32]. Ubaldo Ayr et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 609 062008

[33]. Yassine Himeur, Khalida Ghanem, Abdullah Alsalemi, Faycal Bensaali, Abbes Amira, Artificial intelligence based anomaly detection of energy consumption in buildings: A review, current trends and new perspectives, Applied Energy, Volume 287, 2021, 116601, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.116601.

[34]. Jui-Sheng Chou, Abdi S. Telaga, Wai K. Chong, G. Edward Gibson, Early-warning application for real-time detection of energy consumption anomalies in buildings, Journal of Cleaner Production (2017), doi: 10.1016/j.jclepro.2017.02.028

[35]. GREEK GOVERMENT, JOURNAL OF THE GOVERNMENT OF THE GREEK REPUBLIC, 2017, https://ypen.gov.gr/wp-content/uploads/2020/11/KENAK_FEK_B2367_2017.pdf [GR], [Accessed in 25/08/2023]

[36]. CYPRUS MINISTRY OF ENERGY, TRADE, INDUSTRY AND TOURISM,'2 NATIONAL PLAN FOR THE INCREASE OF NZEB BUILDINGS', 2017 ,https://www.cea.org.cy/wp-content/uploads/2021/01/2o-ethniko-schedio-ksmke.pdf [GR], [Accessed in 25/08/2023]

[37]. Horst-P. Schettler- Kohler et al, 'EPBD implementation in Germany', 2016, https://epbd-ca.eu/wp-content/uploads/2022/10/Implementation-of-the-EPBD-in-Germany-2020.pdf, [Accessed in 25/08/2023]

[38]. MINISTRY OF ENERGY AND ENVIROMENT OF GREECE,TECHNICAL CHAMBER OF GREECE, 'DETAILED NATIONAL SPECIFICATION OF PARAMETERS FOR THE CALCULATION OF THE ENERGY PERFORMANCE OF THE BUILDINGS AND THE ISSUING OF THE ENERGY PERFORMANCE CERTIFICATE', 2017, http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf [GR],], [Accessed in 25/08/2023]

[39]. FREDERICK UNIVERSITY, '' Calculation of cost-optimal levels of minimum energy performance requirements for buildings in accordance with Article 5 of Directive 2010/31/EU on the energy performance of buildings ",
2018,https://www.energy.gov.cy/assets/modules/wnp/articles/202303/112/docs/ipologismos_veltiston_apaitiseon.pdf [GR], [Accessed in 25/08/2023]

[40]. DIN STANDARD 18599-10:2007-02

[41]. "POLICY BRIEFING NEARLY ZERO: A REVIEW OF EU MEMBER STATE IMPLEMENTATION OF NEW BUILD REQUIREMENTS.", https://ec.europa.eu/clima/policies/strategies/2050_en, [Accessed in 25/08/2023]

[42]. "Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU Final report.", https://op.europa.eu/en/publication-detail/-/publication/97d6a4ca-5847-11ea-8b81-01aa75ed71a1/language-en/format-PDF/source-119528141 , [Accessed in 25/08/2023]

Annex A: Roadmapping inputs

Minimum U-values requirements

Cyprus

Climatic zone	External wall	Window	Floor	Roof	Door
A-D	0.4	2.25	0.4	0.4	2.25

Germany

Climatic zone	External wall	Window	Floor	Roof	Door
1-15	0.28	1.3	0.28	0.2	1.8

Greece

Climatic zone	External wall	Window	Floor	Roof	Door
A	0.6	3.2	0.5	0.5	3.2
B	0.5	3	0.45	0.45	3
C	0.45	2.8	0.4	0.4	2.8
D	0.4	2.6	0.35	0.35	2.6

LUX requirements

Country /Thermal Zones	Cyprus	Germany	Greece
Office	500	500	500
Hotel	200	200	300
Restaurant	300	200	200
Theatre	100	200	100

Seminar room	300	500	300
Pharmacy	500	200	500
Library	300	500	500
Mall	300	300	300
Corridor	100	100	100
Lobby	100	100	100
Gym	300	300	300
Hospital	300	300	300
University	500	300	500
Candy store	250	300	250