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Big data for buildings

Building Information aGGregation, harmonization and analytics platform

Project Nº 957047

WHITE PAPER

"Validation of the BIGG Data Analytics Toolbox over the BIGG Data Reference Architecture in 6 Business Cases in Spain and Greece"

Responsible: ECTP, ICAEN

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Executive Summary

The BIGG project (Building Information aGGregation, harmonization and analytics platform), launched in December 2020, demonstrates the application of big data technologies and data analytic techniques in the complete building's life cycle, in more than 4,000 buildings in 6 large-scale pilot testbeds, 3 in Spain (Catalonia) and 3 in Greece (Athens, Volos and Thessaloniki).

The six business cases considered in the project can be divided in 3 case study areas :

In Catalunya, Spain, BIGG has 3 business cases: BC1. Benchmarking and energy efficiency tracking in public buildings, BC2. Energy certification in residential and tertiary buildings and *BC3. Building life-cycle – From planning to renovation*. The site integrates key actors in the area disposing of large datasets of building energy performance data. The local consortium includes regional energy policy institution, public building management company and building research centre. The pilot site will demonstrate a number of analytic services that address several needs of the public administrations to enhance the data gathering and analysis for monitoring the performance and improving the energy efficiency of the building stock.

The business cases BC4. Energy Performance Contract-based savings and *BC5. Buildings for occupants: Comfort case* study 17 large commercial office buildings in Athens, Greece, managed through Energy Performance Contracting (EnPC) or Maintenance Contract. The pilot site will demonstrate the application of EnPC-based management for commercial buildings. Focus will be on continuously optimizing the building operation-consumption, to guarantee comfort of occupants, by controlling HVAC systems/lighting. All buildings have passed Energy Audits (ISO 50001 or ISO14001), offering extensive information about building physical characteristics (GREY), performance and consumption before and after the energy efficiency improvements.

The business case *BC6. Electricity and Gas demand-response* consist of 150.000 HERON electricity and natural gas clients (residential and commercial) spread across Volos and Thessaloniki, Greece. Residential consumers can tune the operation of their heating system through a smartphone application and let the controller optimally adapt the heating operation to their comfort limits, weather conditions and building characteristics. The pilot site will demonstrate the application of Demand Response management on top of electricity and gas consumers of HERON including the gathering and harmonization of data stored in different databases.

Throughout this White Paper, the six business cases will be introduced, including the main details about each use case. The technical solution proposed will be presented, together with some results and the analysis of each solution, with the aim of understand how BIGG has helped with the challenges found.

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Table of Acronyms and Definitions

ACRONYM	DEFINITION
AI	Artificial Intelligence
API	Application Programming Interface
BC	Business Case
BIM	Building Information Modelling
BMS	Building Monitoting System
BPC	Buildings Performance Contracting
CMMS	Computerized Maintenance Management System
DEEP	De-risking Energy Efficiency Platform
DL	Deep Learning
DR	Demand Response
DSO	Distribution System Operator
EEM	Energy Efficiency Measure
EnPC	Energy Performance Contract
EPC	Energy Performance Certificate
ESCO	Energy Service Company
EUBSO	European Building Stock Observatory
GDPR	General Data Protection Regulation
HVAC	Heating, Ventilation, and Air Conditioning
IFC	Industry Foundation Classes (file extention)
IoT	Internet of Things
IPMVP	International Performance Measurement & Verification Protocol
KPI	Key Performance Indicator
ML	Machine Learning
M&V	Measurement & Verification
RDF	Resource Description Framework
SRI	Smart Readiness Indicator
UC	Use Case
UPoD	Unique Point of Delivery

VPN	Virtual Private Network
WO	Work Order
XML	Extensible Markup Language

INTRODUCTION

The BIGG project (Building Information aGGregation, harmonization and analytics platform), launched in December 2020, demonstrates the application of big data technologies and data analytic techniques in the complete building's life cycle, in more than 4,000 buildings in 6 large-scale pilot testbeds, 3 in Spain (Catalonia) and 3 in Greece (Athens, Volos and Thessaloniki).

The main objectives of BIGG are:

1. To design and implement a flexible and open-source big data reference architecture to collect, analyse and exchange dynamic and static building data from heterogeneous external data sources and digital building technologies, while ensuring data protection and security

Based on the design of the BIGG Data Reference Architecture 4 Buildings, an instance is deployed, as a cloud platform, and can acquire:

- Dynamic data from different sources including smart meters, sensors and other IoT devices and external data services
- Building and its related ecosystem static data from existing databases, user submitted information about building characteristics, comfort and energy efficiency measures applied, contracts and investments done.

A modular and extensible data communication layer allows the data bi-directional exchange with existing data storages and the support of third-party applications and tools.

2. To standardise and internally harmonize the data collected from different sources as a basis for full interoperability between databases and tools

The architecture implements the BIGG Standard Data Model 4 Buildings in order to make data comparable, combinable and suitable for joint analysis. Standard ontologies and dictionaries, such as SAREF and BEDES, are used as an internal reference for data harmonization.

3. As part of the BIGG architecture, to develop an open, cloud-based building-related data analytics toolbox - supporting different data analysis techniques - extensible to support third party developments and wide range of services

The BIGG Data Analytics Toolbox provides analytic modules supported by open-source software libraries enabling advanced analytics dedicated to deliver specific services with state-of-the-art data science technologies, such as statistical analysis, BI, ML, DL, AI – accessible to external tools via API in order to provide services to third parties.

4. To validate the BIGG Data Analytics Toolbox over the BIGG Data Reference Architecture 4 Buildings in large-scale pilots supporting different multi-party business cases, in different countries

Support 6 business cases (BC), 15 use cases (UC), on multiple locations in a cost-effective way, creating value for the involved building actors and ensuring cybersecurity and data privacy.

This Toolbox will be validated in pilots under following objectives:

- The evaluation of the applicability of the designed BIGG platform to support diverse real-world business scenarios, in terms of defining the KPIs (from technical, business and/or legal perspectives), and collecting monitoring information to check KPIs are met;
- The performance of cross-pilot evaluations of the different business scenarios.

Figure 1 - High-level view of the 6 business cases considered in the BIGG pilots

5. **To promote and incentivise the widespread adoption of BIGG platform by providing 1) attractive services, considering their financial sustainability and improving the user experience; 2) standardized and open solutions**

As part of this objective, a catalogue of services based on the BIGG Data Analytics Toolbox is to be published together with the definition of the OpenAPIs for their public usage. The BIGG Standard Data Model 4 Buildings will be published and open for 3rd parties' adoption and future extension.

The six business cases considered in the project can be divided in 3 case study areas :

CASE STUDY AREA: SPAIN - Catalunya

In Catalunya, Spain, BIGG has 3 business cases: BC1. Benchmarking and energy efficiency tracking in public buildings, BC2. Energy certification in residential and tertiary buildings and *BC3. Building life-cycle – From planning to renovation*. The site integrates key actors in the area disposing of large datasets of building energy performance data. The local consortium includes regional energy policy institution, public building management company and building research centre.

The pilot site will demonstrate a number of analytic services that address several needs of the public administrations to enhance the data gathering and analysis for monitoring the performance and improving the energy efficiency of the building stock. Therefore, the main targets within this case study area are:

- Gather and harmonize data stored in different databases (regional, research databases, cadastre (land registry), meteorological data, building certification data, monitoring data, modelling data)
- Data driven support to energy policy design and implementation: Current state evaluation (Baseline), General Fault detection, Policy decision support and Evaluation of policies applied
- Improvement of Energy Performance Certification, Comparability with EnPC of other Spanish regions and EU countries
- Building renovation decision support: Selection of the most appropriate EEM to apply and De-risking of energy efficiency investments

Supporting services modules from the BIGG analytics toolbox:

- Gathering and harmonization of data from different sources (utilities, energy management systems, existing databases) over the internal standard data model of the BIGG architecture.
- Acquisition of data from cadastre (INSPIRE GML format) through API to complete the datasets
- Acquisition of meteorological data through APIs and their association with the buildings
- Quality check and data cleaning service
- Generation of baselines for calculation of energy savings (IPMVP methodology)

CASE STUDY AREA: GREECE - Athens

The business cases BC4. Energy Performance Contract-based savings and *BC5. Buildings for occupants: Comfort case* study 17 large commercial office buildings in Athens, Greece, managed through Energy Performance Contracting (EnPC) or Maintenance Contract. The pilot site will demonstrate the application of EnPC-based management for commercial buildings. Focus will be on continuously optimizing the building operation-consumption, to guarantee comfort of occupants, by controlling HVAC systems/lighting. All buildings have passed Energy Audits (ISO 50001 or ISO14001), offering extensive information about building physical characteristics (GREY), performance and consumption before and after the energy efficiency improvements.

Supporting services modules from the BIGG analytics toolbox:

- For Business Case #4
  - Monitoring service module collecting data from BMS, IoT sensors, utility invoices …, computing relevant KPIs which can be viewed in dashboards and reports. Identification of baseline models which are mathematical equations giving dependencies between consumption and influencing factors such as weather and occupancy. The model accuracy is assessed according to the IPMVP protocol.
  - Contract Management service module to manage EnPC and maintenance contracts. Involved stakeholders are notified when milestones are reached. Reports are generated for follow-up purposes.
- For Business Case #5
  - Optimisation service module addressing the different goals related to energy efficiency, renewable energy usage, comfort and cost of the building together and not in an isolated way. Weather conditions have a direct impact on the energy demand of buildings (e.g., necessity of heating/cooling). Forecasted weather conditions will allow to proactively match energy demand and supply (e.g., heat less if large solar gains are expected later in the day). Multi-objective function resolution to support building optimization.

CASE STUDY AREA: GREECE - Volos & Thessaloniki

The business case *BC6. Electricity and Gas demand-response* consist of 150.000 HERON electricity and natural gas clients (residential and commercial) spread across Volos and Thessaloniki, Greece.

Residential consumers can tune the operation of their heating system through a smartphone application and let the controller optimally adapt the heating operation to their comfort limits, weather conditions and building characteristics. The pilot site will demonstrate the application of Demand Response management on top of electricity and gas consumers of HERON including the gathering and harmonization of data stored in different databases:

- Real-time consumption data (electricity, gas) from meters and controllers

- Real-time data collected from home-IoT sensors (temp, hum, presence) and heating controllers
- Greek and EU energy market data (day-ahead, intra-day, balancing)
- Meteorological data
- Consumer past billing data

Services modules from the BIGG analytics toolbox:

- Gathering and harmonization of data from different sources (DSO meters, submeters, EPC registry data) over the internal standard data model of the BIGG architecture.
- Acquisition of market data from national and EU level sources through APIs to complete the datasets
- Acquisition of meteorological data through APIs and their association with the buildings
- Quality check and data cleaning service
- Monitoring service module collecting data from participating households IoT sensors, smart meters, status per connected device, user schedules and comfort limits.
- Visualization of calculated KPIs in dashboards and reports.
- Application of AI and cloud-based mechanisms (energy forecasting algorithms, flexibility potential evaluation) for optimal demand forecasting and management.
- The algorithms take as input historical and real-time collected building, user data, along with the prevailing energy market and meteorological data.

BC1. BENCHMARKING AND ENERGY EFFICIENCY TRACKING IN PUBLIC BUILDINGS

The road to building energy management, 4,000 buildings, 14 government departments (ministries), hundreds of energy efficiency measures and one platform.

This business case pursues to obtain the greatest value from the energy information, in order to improve the identification of energy efficiency measures in most of public buildings of the Catalan Government, by monitoring their consumptions. Its main features are:

1. Open big data infrastructure for storing all building data in one place and monitor performance.
2. Energy benchmarking using data analytics developed in the project.
3. Continuous gathering of data from different sources, energy consumption, investments in energy measures, information on users, building information, etc.

The data provided spans from the buildings data (building descriptions, energy efficiency measures applied to the buildings, and hourly electricity consumption), to data such as weather conditions and municipal data.

The goals of BC1 were divided into two different UC described below:

1. UC1. Benchmarking and monitoring of energy consumption

Which focuses on the comparison of buildings based on their energy consumption

2. UC2. Energy Efficiency Measures (EEM): registration & evaluation

Which builds a repository of EEM to evaluate their impacts on achieving energy savings.

Figure 2. BC1 Data providers logos

UC1. Benchmarking and monitoring of energy consumption

The overall objective is to provide public authorities and energy managers a platform with tools that will help them to manage the energy performance of their public buildings with automated methods. The target is to process large amounts of data from different databases and data sources, to provide with qualified and useful information and to improve decision making in building energy management. Information such as:

Figure 3. Administrative District building A, Zona Franca (Barcelona)

- Energy performance benchmarking. By normalizing building conditions to be effectively comparable and classified, so that energy managers and public authorities can monitor the energy performance of their buildings and understand why they are consuming more or less in similar conditions.
- Trends of building energy performance. Will show the evolution in building performance indicators to trace the energy performance improvement or deterioration over time. This will help to evaluate the real impact of energy efficiency measures and to identify and correct deterioration situations on a building.

- **The technical solution proposed**

The technical solution to improve public buildings energy management is the creation of a centralised data repository (including energy consumption data, building properties, energy performance certificates, etc.) that feeds AI tools developed during the BIGG project. These tools automate the data analysis and allow advanced building benchmarking to facilitate decision making for the building and energy managers. The automated analysis aims to free the energy managers' time carrying out the data collection and processing steps, delivering energy mangers the essential information, from baseline to savings calculations, and tracking building energy performance, both for the improvements and the detection of degradation.

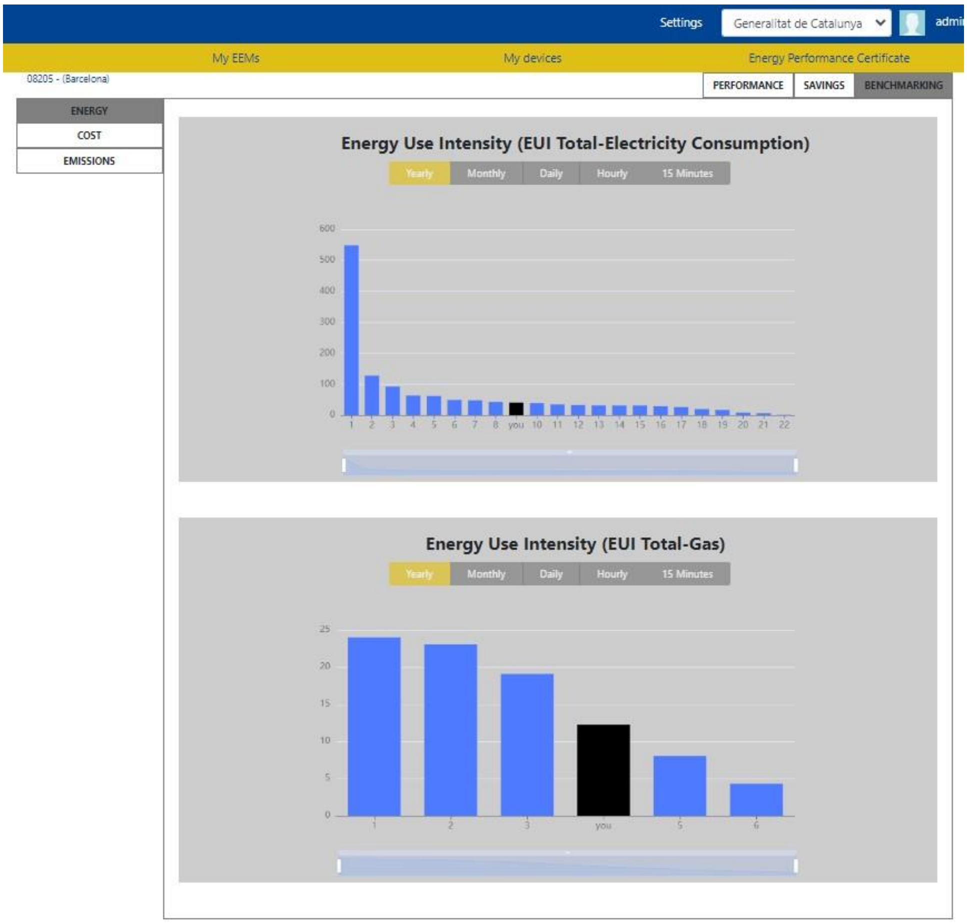

Figure 4. UC1 building benchmarking functionality for Electricity (top) and Gas consumption (bottom)

- **Some results**

The project progress, has already led to major improvements in how the information is gathered, stored and processed. In the case of energy consumption data an API to collect all buildings' consumption has been created. The energy consumption is being collected hourly with access to a back catalogue of energy consumption spanning two years from the moment of first connection for each buildings key point of consumption. The benchmarking graph shown above easily display the current situation of any building you want to its peers, normalised and corrected by climate. This kind of benchmarking frees time of energy managers to focus on the buildings with higher potential savings allowing for more in depth studies of them and to detect where the investments will be more impactful.

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The result of UC1 of the BIGG project provided a platform with the capability to store and display the building information and energy consumption, which then are used to provide advanced metrics such as normalised consumption. The methodology applied to data gathering has freed energy and building managers from having to gather and process the data and offered them results, allowing them to tackle the most consuming buildings. ICAEN is in charge of the energy efficiency plan of the Catalan government, promoting actions, accompanying energy managers and guiding policy on the topic. The UC1 results have started providing ICAEN with data and analysis that facilitate the performance tracking of the buildings, both improvements and degradation, which are essential to reach the targets set by the EU and the Catalan government for the upcoming years up to 2050.

UC2. Energy Efficiency Measures (EEM): registration & evaluation

The objective is to build a structured database to store energy efficiency measures (EEM) and evaluate their impact on achieved energy savings from energy consumption data processing. As well as, to provide an easy to use interface for energy managers to upload and browse the information (see **Erreur ! Source du renvoi introuvable.**).

The expected improvements: to obtain more detailed information on the EEMs involving energy managers by registering the information in a more structured way. It will facilitate:

- Historical information of applied EEMs, reformulating them and mapping the historical data;
- Improve statistical analysis over the registered EEMs to extract more valuable information, that will help to improve the decision-making process within the organization;
- Improve the algorithms of EEM savings evaluation.

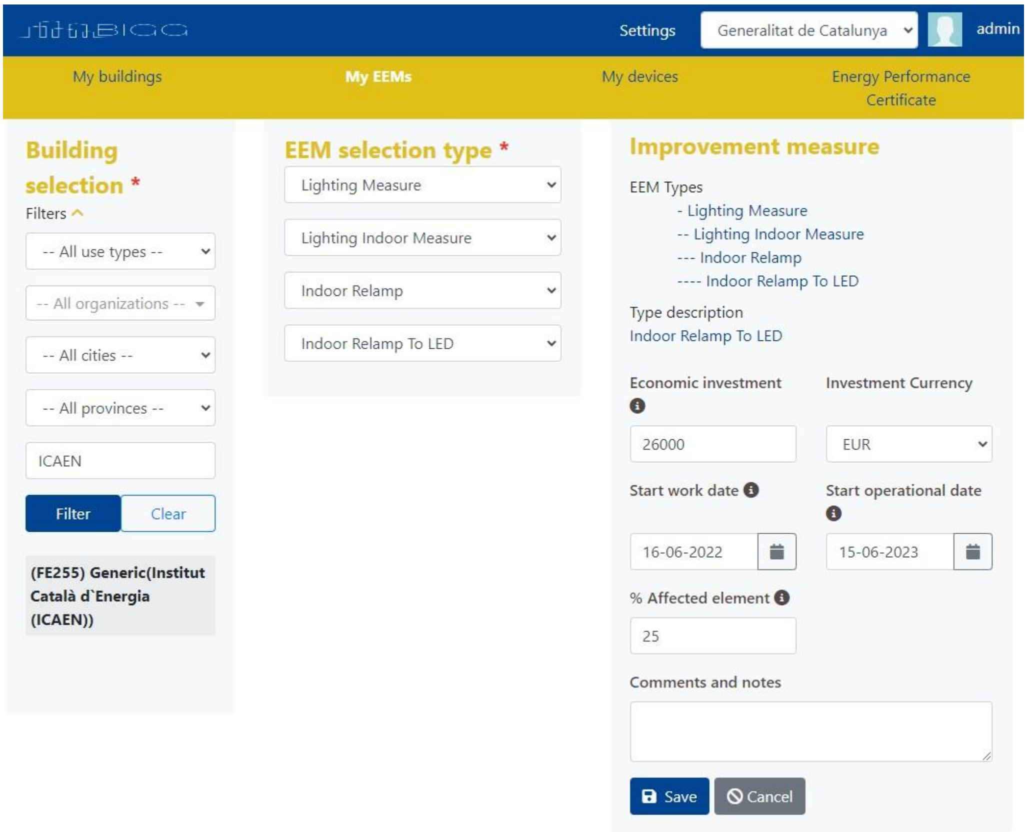

Figure 5. UC2 solution: new EEM registration form

- **The technical solution proposed**

The technical solution to improve public buildings energy management is the creation of a centralised data repository (including energy consumption data, building properties, energy performance certificates, etc.) that feeds AI tools developed during the BIGG project. These tools automate data analysis and allow advanced building benchmarking which facilitate decision making for building and energy managers.

- **Some results**

The project progress, and the accompanying platform, have already led to major improvements in how the information is gathered, stored and processed. These improvements are greatly exemplified with the case of energy efficiency measures data collection.

ICAEN is tasked with promoting and tracking the energy savings of the Catalan government, its public entities and dependant companies' buildings. The improvements achieved with BC1 have already facilitated data gathering (see **Figure 5Erreur ! Source du renvoi introuvable.**) that before the project was doable but highly challenging and became a time-consuming act of handling hundreds of energy managers, encouraging them to gather the EEM data and providing them a method to record this data. The latest and best iteration of the process was a large excel file (see **Figure 6**) in which the essential information was requested (investment cost, typology of actions, operation date, etc.). The main issue of the excel file was that allowed users to fill several columns at the best of their capabilities and time, without mandatory columns or data types. This process has a large margin of error since most of the information was open for managers to introduce (only the typology was selected from top-down lists). These files then had to be processed by ICAEN to filter errors, remove writing typos and combine them to get the full picture of the actions implemented by the full Catalan government.

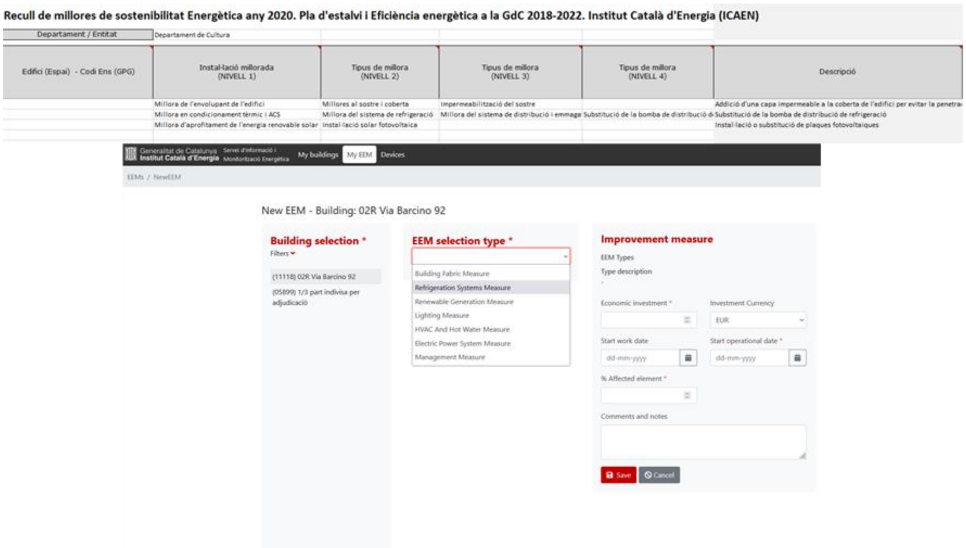

Figure 6. Example of old EEM gathering method using excel files (Catalan version)

The process required a lot of cleaning up and merging of the data, while losing vast amounts of it due to the process itself being not appealing to energy managers and hard for ICAEN to track which entities have and have not provided the data.

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The BIGG project results of UC2 consist of a platform to register buildings information, energy efficiency measures (EEM) (implemented to the buildings) which users can browse it all and register new measures. The platform has provided ICAEN with a tool which facilitates energy managers the task of recording their EEM. Which are associated to their respective buildings and therefore assigned to the right entities of the Catalan government without any need of cleaning and post processing of the data by ICAEN, saving hours of work to reach the results. The platform also minimises the data loses since it is an easy system to use that is always active (continuously allowing managers to log data) and that ensures a common format of collection by requesting minimal information to be logged when recording new EEM.

The graph below shows the results already collected by the platform for the year 2021 (collected between October and December) and the on going collection for the year 2022 showing the results aggregated by departments (ministries) of the Catalan government.

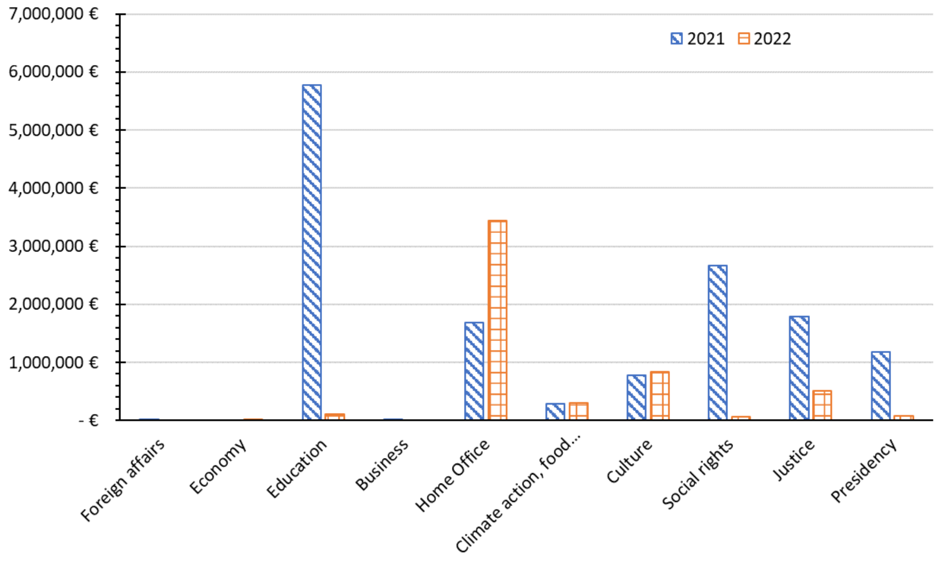

Figure 7. Overall EEM investments data collected using BIGG solution, divided by the Catalan Government's departments (ministries)

BC2. ENERGY CERTIFICATION IN RESIDENTIAL AND TERTIARY BUILDINGS

The purpose of this business case is to demonstrate the benefits that the BIGG platform brings to aggregating, harmonizing, and analyzing data from energy efficiency certificates of buildings, whether they are residential or commercial:

The main actors to be involved in this pilot are policymakers and politicians, who are key in the decision-making process. Other potentially interested actors are citizens, insurance companies, financial entities, public entities, administrations, constructors, and energy refurbishment companies.

ICAEN is commissioned by the government of Catalonia to manage and process all energy efficiency certificates for buildings in the territory. So far, 1.4 million certificates have been registered. For some time now, attempts have been made to process this large volume of data, trying to cross-reference it with other information to extract interesting information for the management of the territory, but so far it has been a complicated task because the data are not harmonised, and a large volume of data must be processed.

The main data involved in this Business Case are tertiary and residential building certification data. These have been obtained from two main sources.

The first is the Open data system of the Generalitat de Catalunya, which can be accessed through this link. This source has summary data (69 fields) of all building energy certificates registered in Catalonia (1.4 M). A client API has been developed in the BIGG to systematically retrieve this data.

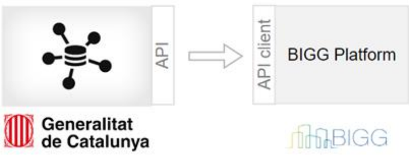

Figure 8. BC2 Import data from API

The second is the XML files that come out of the energy certification programs. To retrieve these data, a web form has been enabled in the BIGG user interface where these files can be uploaded. In the backend of the application, an ingestor of these files has been developed to collect them.

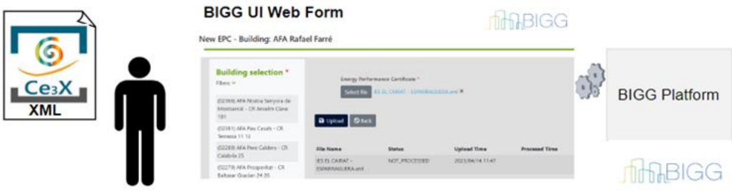

Figure 9. C2 Import data from web form

In the BIGG project, the necessary components have been created in the ontology of the BIGG4BUILDINGS data model so that it can host the energy efficiency certificate data from these two sources.

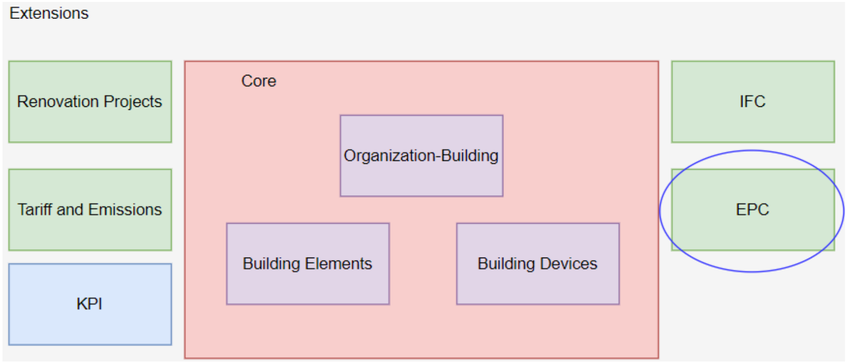

Figure 10. BIGG ontology schema with Energy Performance Certificates

To transform the initial data into the BIGG ontology format, mappers (equivalence of raw data to the harmonized data) have been created for each of the above sources to obtain the EnPCs data. The harmonizer developed in BIGG is used to effectively transform the data into the BIGG ontology format.

This business case is composed of two use cases that use building energy certificate data combined with other data to obtain different results. Both are described in the following sections.

UC3. Integration of INSPIRE Spatial data to Certification

This use case aims to demonstrate how we can take advantage of the integration of energy performance certificate data with georeferenced data in INSPIRE format, specifically cadastral data.

The cadastral data of buildings in Spain can be found in INSPIRE format on the cadastre's website at the following link. The main advantage of having the cadastral data georeferenced in INSPIRE format is that they follow a standard ontology used as a reference throughout Europe.

The data of the energy performance certificates already contain the cadastral reference of the building, so the link between both databases is direct.

To obtain this data, an ingestor has been created to retrieve these data and mappers have been created to harmonize them in the format of the BIGG data model, in all cases using the components developed in the project.

- **The technical solution**

The technical solution to improve the management of building energy certificates is the creation of a centralized data repository with harmonized data linked to cadastral data in INSPIRE format to facilitate the geo-spatial processing of the certificates.

- **Some results**

The BIGG project has introduced significant improvements in the way building energy certificates are collected, stored and processed. The major advance is the efficient geolocation of the certificates, which allows, among others, the following functionalities:

– Performs visualizations, searches, and geo-referenced processing of energy efficiency certificates in an agile and robust way. In this sense, a geo-specialized viewer is used to present the data graphically. This facilitates, both for technicians and general users, the exploration of building energy certificate data throughout the territory. So, you can easily answer questions with the spatial location of the certificates such as:
    - Where are the certificates located?
    - How is the building energy demand evolving across the region?
    - In which areas do the buildings have a better or worse energy rating?
    - Where is it most important to apply policies to incentivize building improvement?
    - The following figures show some visualizations extracted from this application.

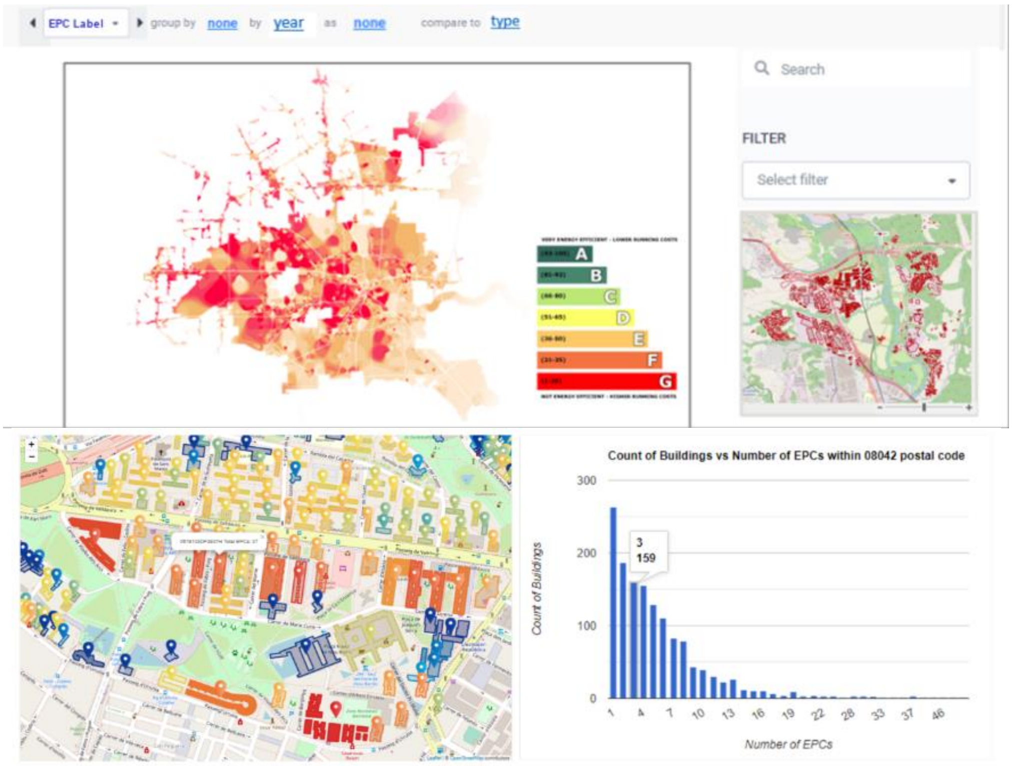

Figure 11. UC3 EPC view with geospatial data

– Having linked data thanks to the BIGG data model allows us to quickly make queries using Sparkql or Geo Spark on large amounts of available data and even link the current data with other harmonized geo-referenced databases such as can be: Geo-names, Wiki data, Schema.org, OpenStreetMap, Linked Open Data of Barcelona city council. This allows the extraction of interesting information from the energy efficiency certificates.

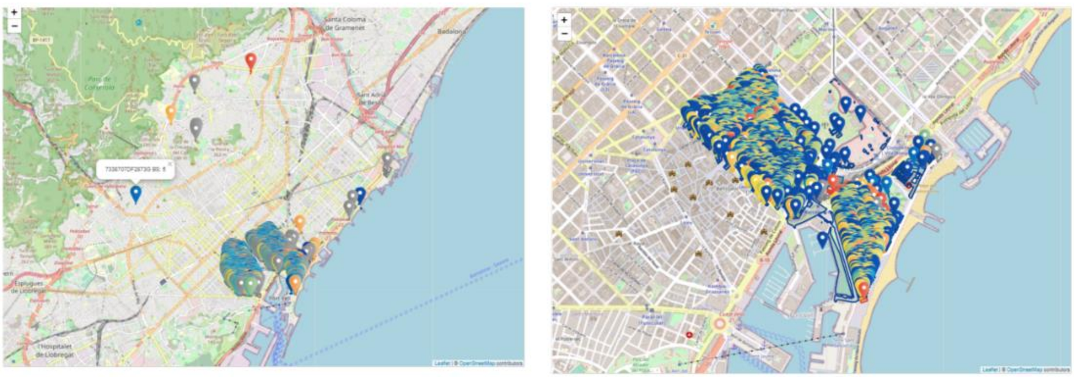

Figure 12. UC3 Visual analysis of EPC

- Evaluation of the number of building roofs and their surface area on which self-consumption photovoltaic installations can be installed. Another more specific application that has been tested, taking advantage of the linking of the EnPC with the cadastre in INSPIRE format, has been a study of the roofs of the buildings of the Generalitat de Catalunya on which photovoltaic systems for self-consumption can be installed.

Figure 13. UC3 Evaluation of building roofs with geospatial data

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The UC3 results of the BIGG project consist mainly in the creation of a harmonised repository linked to INSPIRE, which favours the geo-referenced exploration of these. Having the data harmonised and stored in Graph format (RDF) allows the link with other graph databases, enriching in an agile way the studies that can be made of the energy certificates of buildings.

UC4. Sustainable indicators for building certification

This use case seeks to expand the current indicators of the building's certification, according to the European Level(s) framework[1]. The main objective is to improve the exploration and indicators that can be extracted from the Buildings Performance Certification (BPC) registry by exploring indicators of current BPCs and aligning them with those marked by Level(s).

Level(s) is a common EU framework to measure the environmental performance of buildings with a life cycle approach. Beyond environmental aspects Level(s) also offers methods to take into account aspects such as occupants' comfort and health, cost over the life cycle of the buildings and even risks associated to the changing climate.

Level(s) consists of 16 core indicators that can be aggregated within 6 macro-objectives:

1 https://ec.europa.eu/environment/topics/circular-economy/levels_en

Macro-objective	Indicator
1: Greenhouse gas and air pollutant emissions along a building's life cycle	1.1 Use stage energy performance
	1.2 Life cycle Global Warming Potential
2. Resource efficient and circular material life cycles	2.1 Bill of quantities, materials and lifespans
	2.2 Construction & demolition waste and materials
	2.3 Design for adaptability and renovation
	2.4 Design for deconstruction, reuse and recycling
3. Efficient use of water resources	3.1 Use stage water consumption
4. Healthy and comfortable spaces	4.1 Indoor air quality
	4.2 Time outside of thermal comfort range
	4.3 Lighting and visual comfort
	4.4 Acoustics and protection against noise
5. Adaptation and resilience to climate change	5.1 Protection of occupier health and thermal comfort
	5.2 Increased risk of extreme weather events
	5.3 Increased risk of flood events
6. Optimised life cycle cost and value	6.1 Life cycle costs
	6.2 Value creation and risk exposure

Figure 14. Macro-objectives and indicators of the European Level(s) framework

- **The technical solution proposed**

The data model has been prepared to have all the information required to calculate the Level(s) indicators and expand it, if necessary, in preparation to process all the available certificates within the ICAEN database (more than 1,000,000) and integrate the results with the currently available visualisation tools.

- **Some results**

The work analysed the available information in open data combined with all the mandatory documents for buildings such as the energy performance certificates (EnPC), to define a path towards Level(s) starting from the energy performance certificates.

Firstly, it focused on defining which of the Level(s) indicators required information that was available to the current energy performance certificates. After defining the limitations of information any necessary extra information was defined, and possible other sources pointed at.

This process highlighted which indicators could be calculated with the current and external sources of information and which could not. The current EnPC holds information for the first 3 macro-objectives, which focus on the Energy use and Life cycle; Buildings materials used and end of life; and Water use (very limited). The information of the EnPC had to be complemented with external sources of information, due to the limitations of the EnPC design itself. For example, the quantity of materials used on a building (macro-objective 2) requested by Level(s) requires an in-depth analysis of materials, cost and deconstruction procedures that exceeds the normal certification needs, which requires a specialised database for materials. The macro-objective 3 analyses water use on the building, which the EnPC contains in a limited format, and requires fieldwork to complete since it is an ad-hoc calculation based on the building use.

On the other hand, the indicators that hold no information within the current EnPC are the 4, 5 and 6, which focus on the Health and comfort of the buildings; the Adaptation and resilience to climate change; and the Optimised life cycle cost and value.

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The results helped to prepare our database for the future changes coming to energy certificates, some of the changes in the form of the draft proposal of EPBD directive, and others linked to the evolution that energy certification is experimenting with SRI and integration with building passport, necessary steps to take full advantage of the Level(s) framework.

BC3. BUILDING LIFE-CYCLE – FROM PLANNING TO RENOVATION

The main objective of this business case is to facilitate the interoperability between the different tools and their datasets that can be used during the whole building cycle life.

The interoperability must ensure the data exchange between systems and applications, facilitating the reuse of data between them, reducing the cost of setting and giving more value and new advanced services of data processing for the buildings.

Figure 15. Infraestructures de la Generalitat de Catalunya headquerters building

This business case is divided into three different use cases, which are described in the sections below.

UC5. Interoperability between BIM, BMS, CMMS and building simulation engines

The objective is to guarantee the interoperability between the different data acquisition/generation systems that we can find during the life cycle of the buildings. This interoperability must enable the creation of an integrated value chain across building design, operation, maintenance, commissioning and refurbishment decision-making.

The main actors are building operators, maintenance staff and building managers.

The set of buildings used in this use case has been provided by Infraestructuras.cat and all of them are public buildings of Generalitat de Catalunya.
The datasets for the development of this pilot are:

- Monitoring data and HVAC Control systems data extracted from existing Building Management Systems (BMS) of public buildings
- Equipment inventory, preventive and corrective maintenance actions of public buildings from computerized maintenance management system (CMMS).
- Building Information Modeling (BIM) models of public buildings

- **The technical solution**

The processes followed to ingest each of the datasets into the BIGG platform are described below.

Monitoring and control systems data (BMS)
The BMS of these buildings are from different suppliers (Schneider, Siemens, Danfoss, Mitsubishi, etc.), which a priori implies having to develop an API client for each supplier.
To avoid this situation and to develop a more scalable methodology, the following actions has been done:

- install a common VPN gateway in all the buildings that allow direct communication with the local systems of each of them. The gateway installed in the case study buildings was the IXON gateway (https://www.ixon.cloud/iiot-platform/connectivity-products/ixrouter-edge-gateway).
- reconfigure all systems to provide a common communication format output. In this case, the BACnet protocol has been chosen.
- a standardized naming convention has been established to ensure the clear identification of signals for each system and location. This convention has been implemented in all buildings by reprogramming the local systems.

Table 1. Standardisation of BMS fields

Field	Description	Examples
CmmsId	Id used in the CMMS	--
buildingFloorId	Building floor identifier where the equipment or device is located.	P0, P1, P2, etc.
system	Identify the system that the device belongs to.	HV, HVAC system; LS, Lighting system.; GenSev, General services
Subsystem	Identify the sub-system that device belongs to.	Co, cooling part of HVAC.; He, Heating part of HVAC.; AC, Air conditioning.; TU, Terminal units.
Equipment	Identification of the device or equipment.	MQ1, chiller 1.; B01, Boiler 1.; AC01, Air conditioning unit 1.; FNC01, fan coil 1.; PU01, pump 1.; Fsup, supply fan.
flowDirection	identification of the flow direction in which the device is located.	Sup, supply; Ret, return
Type	identify the type of device	Temp, temperature.; Pres, pressure.; Hr, humidity.

Once the above modifications have been made to the local IoT systems. A data ingestor has been developed on the BIGG platform that collects data from all building BMSs via VPN remote access.

<u>The buildings maintenance data. (CMMS)</u>
In the case of the maintenance data, all buildings involved in this use case use the same provider of computerized maintenance management system (MantTEST - TEST JG). This makes the initial collection of data easier compared to the Building Management System (BMS) case.
To collect the data an API client for MANTEST has been developed in the BIGG project, which retrieves maintenance data from all buildings. These data include:

- Zones of each building (roof, floors, offices, restrooms, machine rooms, etc...)
- Inventory of assets of each building (equipment, elements, sensors, etc...)
- Corrective, preventive, and regulatory work orders (fixing door 0231, performing monthly maintenance on the boiler, etc...)

<u>BIM Models</u>
Building Information Modelling (BIM) models are digital representations that contain detailed information about the geometry, materials, components, and systems of a building.
To process data from BIM models, the results have been exported in XML format.

BIGG's user interface includes a form where users can upload BIM files in XML format for each building. This ensures that there is a connection between the BIM model and the specific building it represents.

An ingestor tool has been developed to extract the desired information from each file. The information that is currently being processed includes various aspects of the building, such as building spaces, zones, systems, and elements.

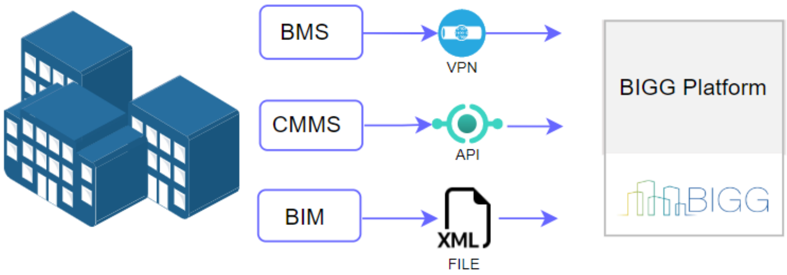

Figure 16. BC3 Ingestions

Data harmonisation

The ontology developed by BIGG contains the necessary classes and properties to accommodate the input data required to cover this use case. Most of the data is stored in the core of the ontology in bigg:Buildings and their extension bigg:IFC.
To make the transformation of the data to the BIGG ontology effective, a mapper has been created for each data source. This mapper feeds the BIGG harmonizer to effectively transform the data into the BIGG ontology.

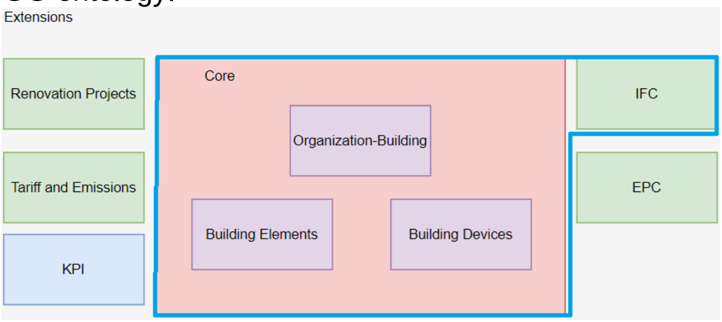

Figure 17. Blocks of the Bigg ontology used in BC3

- **Some results**

Users of this use case have access to the BIGG user interfaces to view the aggregated data from the BMS, CMMS and BIM.

The data is presented in the building form, as shown in the graphic below. The users can explore for each building zone the data aggregated from all the sources. The different information is placed in the following tabs of the application:

- Area: Area of the selected zone.
- UPod: Supply points associated to the area
- EEM: Energy efficiency measures applied in the area.
- Elements: Elements or assets linked to the zone (from CMMS or BIM)
  - WO: Work Orders associated to elements (from CMMS).
- Devices: Reading devices associated to the zone (from BMS)

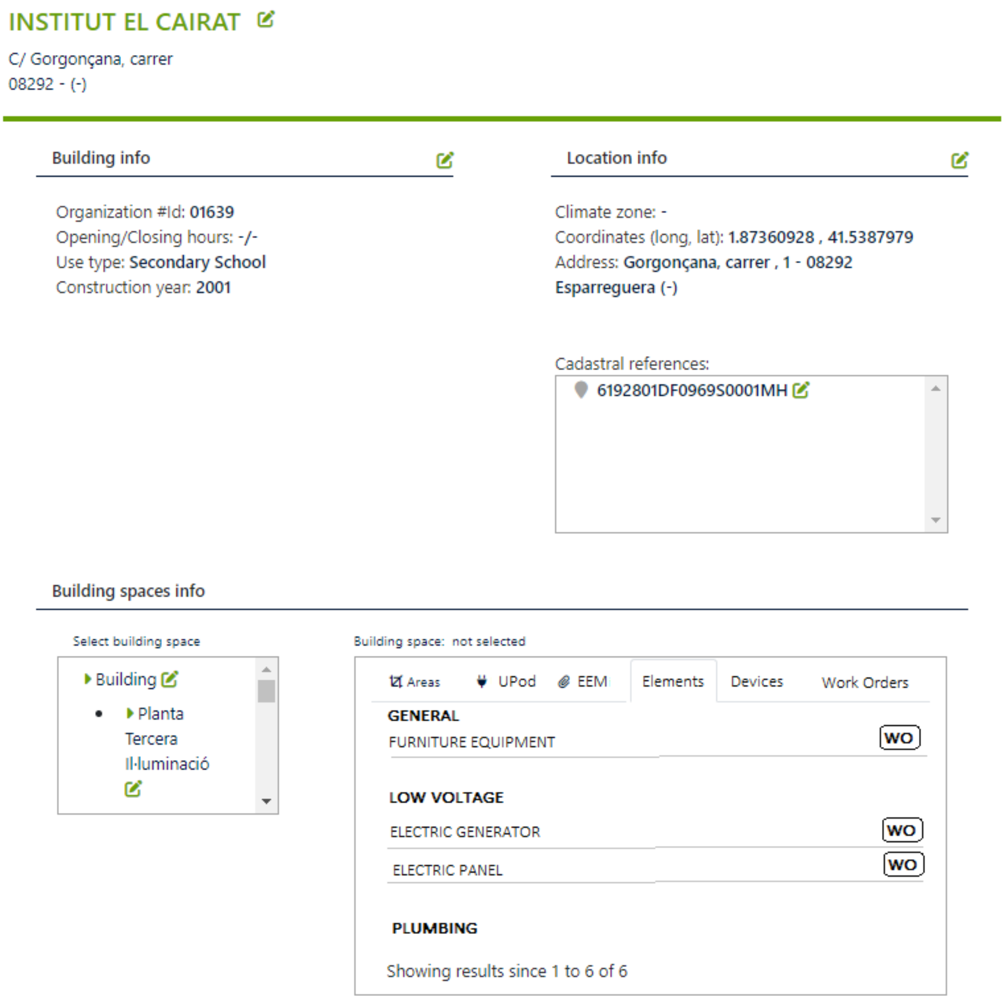

Figure 18. UC5 User interface: building space, elements, devices and work orders

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The results obtained from UC5 allow the integration of building data throughout the lifetime of the building. This favours the reuse and linking of data from the different systems involved in the building.
This provides a great improvement when managing multiple buildings with multiple suppliers as is the case for ICAT buildings. This opens new business opportunities around building data processing.

UC6. Interoperability of BIGG with EFFIG-DEEP

The objective is to ensure the interoperability between BIGG platform and De-risking Energy Efficiency Platform[2] (DEEP), by achieving the harmonization of the EEM collected with registers and models existing in DEEP platform, and by establishing the procedures for BIGG and DEEP platforms data exchange.

[2] https://deep.eefig.eu/

The actors identified within this pilot are: financial institutions, policy makers and public authorities.

The datasets used in this Use Case are identical to that used in BIGG Use Case 2. Consequently, the process of acquiring, ingesting and harmonising the data with the BIGG ontology is the same as explained in section UC2.

- **The technical solution**

One of the contributions of this use case to the BIGG platform is related to the contribution to the creation of the BIGG data model ontology, especially in the biggProjects extension.

The biggProjects extension defines the data model to host the characteristics of the energy renovation projects of the buildings and the specific measures that are applied.

In this sense, a wide taxonomy has been defined for the definition of the energy efficiency measures to be applied in the buildings. The use of this taxonomy greatly facilitates the subsequent analysis of these measures, being able to perform comparative analysis, draw average values, etc...

The EMM taxonomy of the DEEP platform, being the European reference platform for EEMs, has been the starting point for the definition of the EEM taxonomy for the BIGG project. This favors the alignment between the two platforms and greatly facilitates the exchange of data.

As mentioned above, the main objective of this use case is the data exchange with the DEEP platform.

The data exchange functionalities of the DEEP platform are performed through the exchange of an Excell file with the following fields:

FIELD
Project ID
Project Title
Country
City/locality
Is the investment in a building, in industry, or in infrastructure?
Industry Sector/Organisation type
Organisation size
Building type
Ownership
Floor area of building m2
Which Measures are included in the investment Copy paste Measures from Measures tab. You can add more than one, separated by semicolon

FIELD
Date investment became operational (month/year)
Energy Consumption BEFORE intervention kWh/a
Predicted Energy Consumption AFTER intervention kWh/year
ACTUAL Energy Consumption AFTER intervention kWh/year
Have the project energy savings been independently verified?
Value of EE investment €
Net annual saving €
Value of grant/subsidy (if any) €
Please state all the additional benefits triggered by the project (Copy paste Benefits from Benefits tab. You can add more than one, separated by semicolont)
Please rate actual financial performance compared with expectation
Energy savings, kWh/y , total

FIELD
EEM Type
System affected
System2 affected
EEM Reference
EEM Description
Scope of action [m2]

Figure 19. UC6 Fields exchanged with the DEEP platform

This is the format that has been prepared to extract EEMS data from the BIGG platform.

- **Some results**

To facilitate the exchange of data with DEEP through the BIGG platform by its users, a data export function has been enabled in Excell with the format mentioned in the previous section. The user from the EEMS list can click a button to export data. In this action the user can choose whether to export the table as presented in the UI or choose the DEEP format.

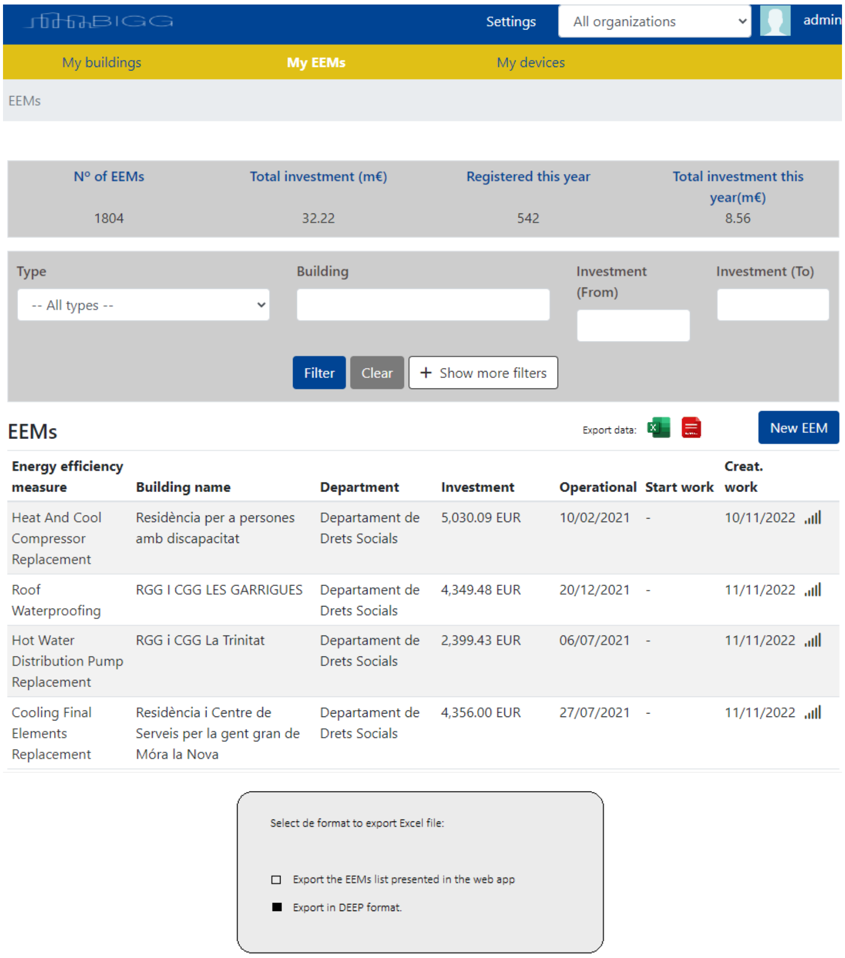

Figure 20. UC6 BIGG UI to export data to DEEP

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The results obtained from UC5 allow data exchange with the DEEP platform. Data exchange with DEEP is currently unilateral, from external applications to DEEP.

This will allow the DEEP platform to significantly increase the number of samples allowing to obtain much more reliable indicators that will be of great help to building owners and financial institutions to have real references in the field of application of energy efficiency measures.

UC7. Interoperability between EUBSO and energy Certification hubs through BIGG

The objective of this use case is to ensure the interoperability between the EU Building Stock Observatory[3] (EUBSO) and national/regional EPC hubs through the BIGG platform.

The actors involved in this pilot are managers of the different National Certification Hub's, politicians and policy makers to improve the decision-making processes provided by the increased value of the data.

[3] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/eu-bso_en

The Datasets needed for this use case are the energy certifications of 1,000,000 Catalan buildings comprising residential and tertiary buildings, and the Spanish Municipal data.

- **The technical solution**

The main contribution of this use case has been in the creation of the BIGG data model, and more specifically in the part of energy certificates for buildings.

For the creation of this part of the data model, the structure and taxonomies described in EuBSO have been taken as a reference. More than 1Milion certificates have been harmonised to the BIGG data model. So, the data exchange with EUBSO is guaranteed.

Unfortunately, the EUBSO web application is currently disabled, so that we cannot make the data exchange effective.

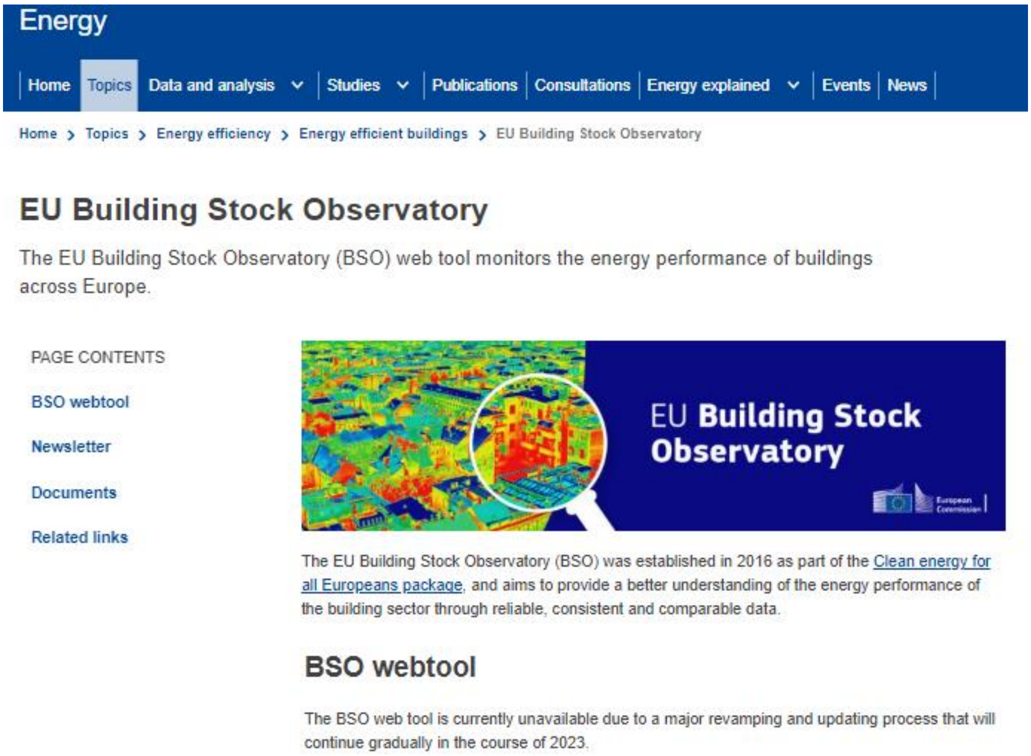

Figure 21. UC7 Image from EUBSO indicating that the platform is currently not operational

BC4. ENERGY PERFORMANCE CONTRACT-BASED SAVINGS

The Business Case 4 (BC4) aims to streamline the Measurement and Verification (M&V) process of Energy Performance Contract (EnPC), which is a crucial step for Energy Service Companies (ESCOs) in managing EnPCs. The M&V process involves collecting all the key asset and contract related data, identifying a baseline consumption model against which the actual consumption post-retrofit/renovation can be compared to estimate savings accurately as well as the financial follow up of savings, both for the ESCO and for the end customer. However, this process is typically managed manually with Excel sheets, which is time-consuming and prone to errors.

The solution developed in the BC4 of the BIGG project offers game-changer solutions for EnPC management. The solutions were applied and validated on multiple buildings managed by CORDIA Hellas.

Challenges and technical solutions

Standardizing the M&V process is challenging for mainly 3 reasons, each analysed through a specific use case: building data and assets management, savings tracking and contract management.

As a global constraint, the integration process of new or pre-existing EnPC contracts must be as seamless as possible, thereby allowing ESCOs to scale up their contract base. The M&V process can thereby be managed from start to end, including the follow up of the savings, the financial benefits, both for the ESCO and the building owner, the reporting, etc.

UC8. Buildings assets management

- **The challenge**

EnPC contract management and follow up requires collecting and monitoring static (e.g., building, operation and contract details) and dynamic (e.g., ambient & external conditions, consumptions) data relevant to the management of an EnPC contract. The required data varies with each project and can be collected with multiple formats and structures. The main challenge of this use case is thus to structure and standardize the data collection process to enable the storage of all relevant information for the management of EnPC contracts.

- **The technical solution proposed**

A generic set of relevant EnPC related data was identified. Building on the harmonized BIGG data model, this data was structured and organized in a logical way, separating and linking together the different elements such as buildings, assets, contracts, M&V scopes, etc.

UC9. Actual savings tracking realised by the Energy Efficiency Measures (EEMs)

- **The challenge**

The central element of M&V is the baseline model against which the actual consumption post retro-fit is compared to calculate the savings made. Identifying such models with a good accuracy is a key aspect to reach accurate savings calculations but also to be able to detect deviations from the expected savings behavior of the building, possibly resulting from a misuse of the building (in which case a revision of the EnPC contract conditions may be requested by the ESCO). This is why the ability to identify good and human interpretable baseline models is one of the objectives of the project.

The previous point only holds for new contracts for which a baseline model remains to be identified. However, to kickstart the adoption of a standardized M&V process, integrating already existing contracts with their pre-existing baseline models must also be guaranteed. Such models come with various structures and formats and one of the challenges of the project is to propose a simple process allowing to integrate them seamlessly.

- **The technical solution proposed**

We addressed the above challenges independently, building up on the AI toolbox developed by the BIGG project.

The project developed a solution using the AI toolbox to identify baselines accurately and flexibly. The toolbox's core modules were used to build a pipeline that could adapt to any EnPC contract's requirement and identify a consumption baseline regression model from historical data, using weather, occupation, and calendar data as input. The developed pipeline allows for a high degree of flexibility in the types of models used to identify the baseline, enabling users to adapt the resulting models to their needs while ensuring interpretability by non-expert users.

Integrating baseline models from pre-existing contracts was done in the Energis.Cloud energy management software (EMS) by carefully separating the logical elements of the contract. To this end, we decomposed the overall contract into sub-scopes that all have their own baseline models. For instance, an EnPC contract can cover both Electricity and Gas consumption, i.e. the sub-scopes, with a distinct baseline model for both because gas consumption has a strong dependency with the weather conditions whereas electricity is generally more occupancy related. Energis.Cloud allows us to manage all the required input data (consumption, weather, occupation, etc.) Then, filling in a simple formula, providing the savings target per sub-scope and the contract period start and end dates are the only elements required by the system to start following up the savings.

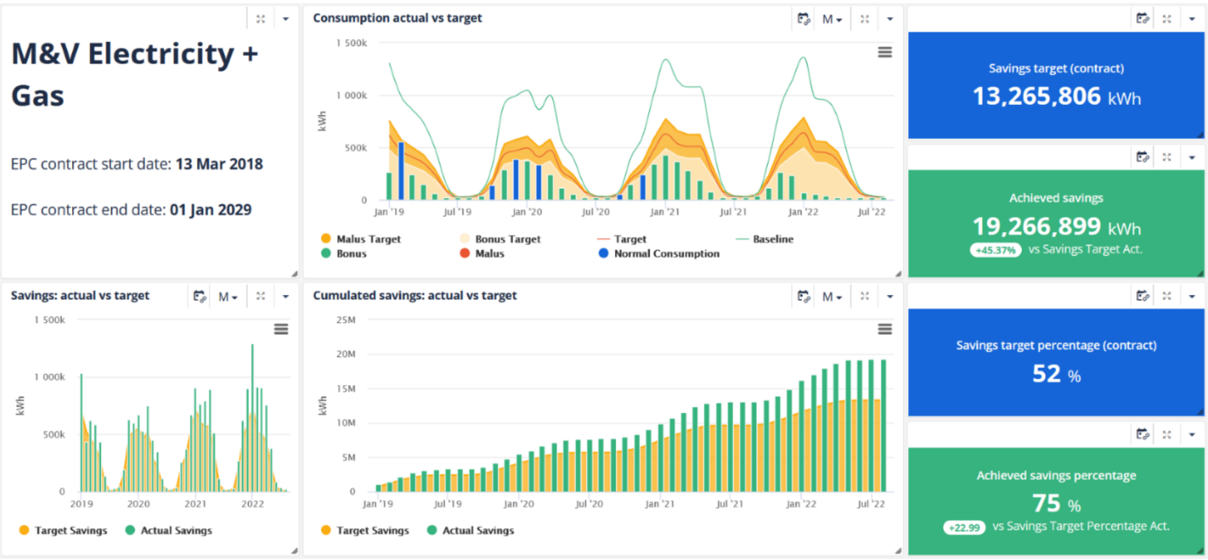

Figure 22. The typical and generic savings follow up dashboard

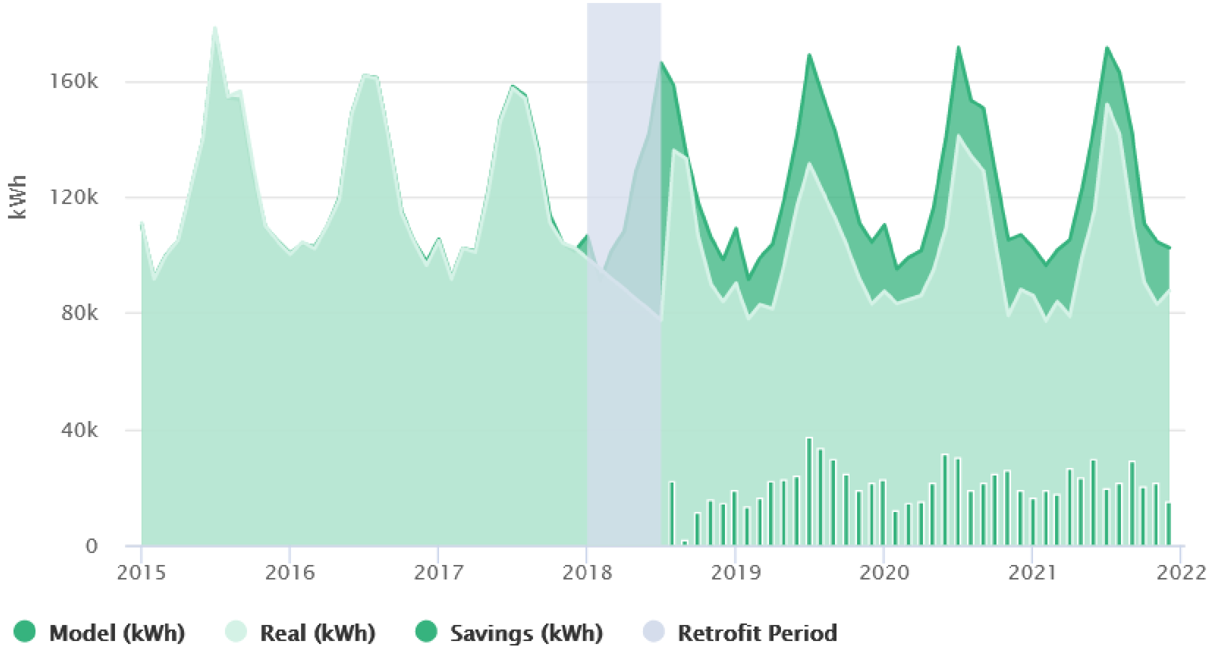

Figure 23. Before the retrofit period: the baseline model fits well with the observed real consumption. After the retrofit: the baseline model is used to calculate the savings made

UC10. EnPC Contract Management

- **The challenge**

The project aims to integrate the financial structure of the contract, that is, the mechanism agreed between the parties allowing the ESCO to receive remuneration for their services and the end customer to benefit from the energy savings. Such financial elements come in a variety of flavours (every ESCO has their own logic and variations can come even within the same ESCO for different projects, teams or with time evolutions) but the ultimate goal always remains the same: to calculate the share of the savings that each party can claim (through mensuality and/or through a bonus/malus mechanism based on the savings made). It is also the goal of the project to propose a unified approach to incorporate such financial contracts.

- **The technical solution proposed**

We addressed this challenges building up on the Energis.Cloud software solution developed by Energis, partner of the project.

To integrate the financial aspects, a generic financial model was built, determining the key parameters required. Such parameters include aspects such as "from which amount of savings do you consider a bonus is owed" or "what is the share key between the ESCO and the end customer". With this approach, 12 key parameters were identified which allow to capture the financial logic of all the EnPC contracts encountered so far with the partners of the project like CORDIA Hellas and beyond.

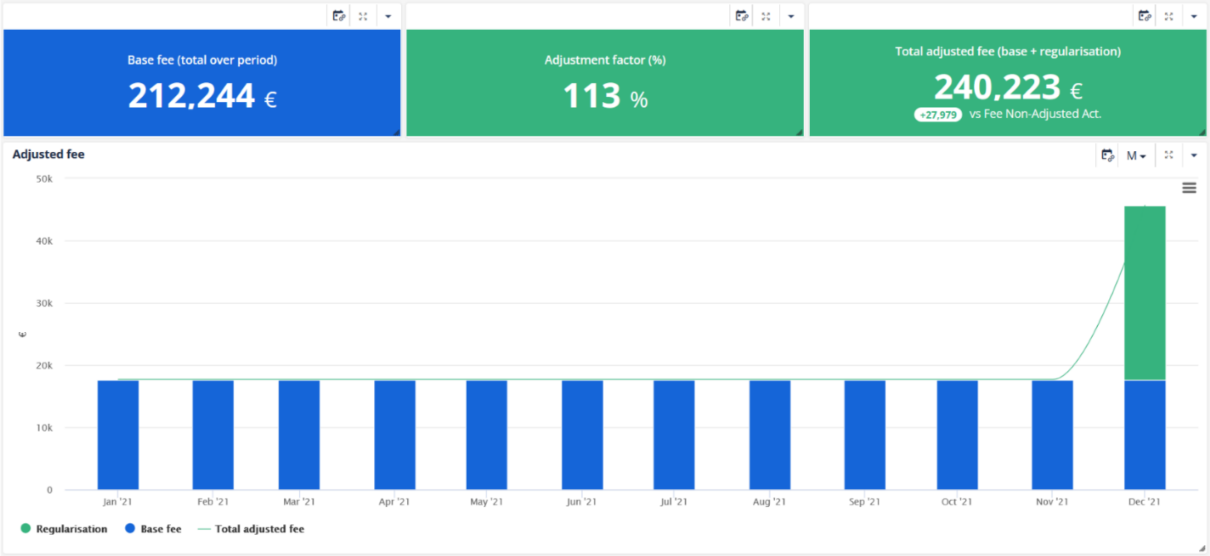

Figure 24. Savings from the perspective of the ESCO

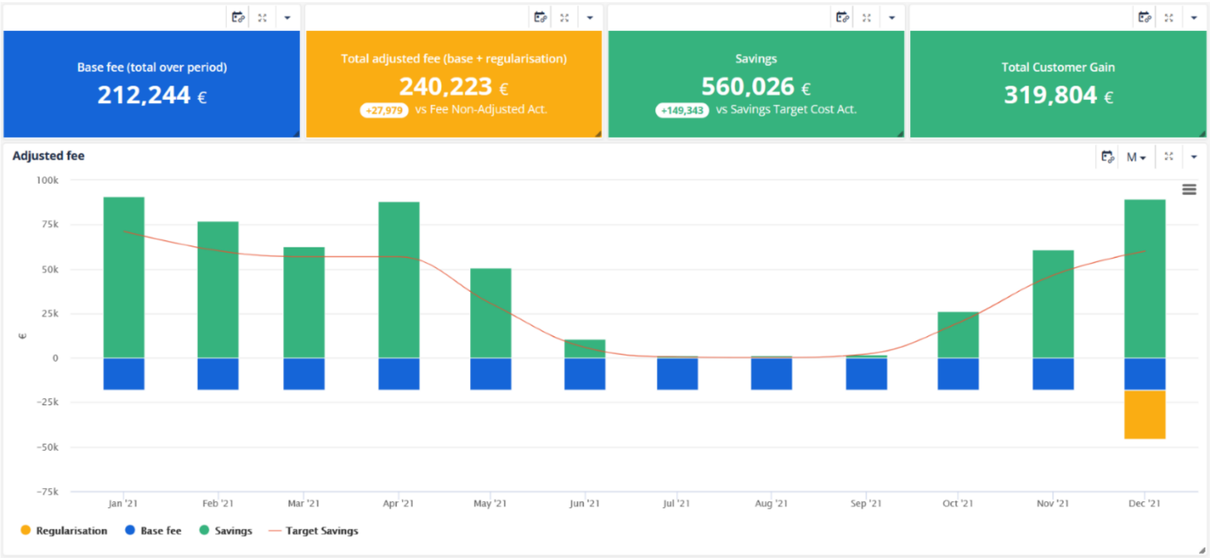

Figure 25. Savings from the perspective of the customer

New perspectives opened for EnPC Management

The BIGG project solution improves the market prospects, reduces internal costs and opens up new ways of working in the following ways:

- It centralizes and standardizes the assets and consumption data collection process
- It uniformizes practices to follow up EnPC Savings and provides a professional framework
- It reduces the amount of manual work to start and maintain the contract follow up and makes it more pleasant (working with Excel sheets is almost universally recognized as a pain)
- It reduces the risk of human mistakes which can sometimes generate significant losses

- It automates a large fraction of the implementation of the required calculations and enables scaling up the number of EnPCs
- It automates the reporting
- It provides a friendly interface for end users to follow up and understand their savings and can be used as a marketing and upselling tool

BC5. Buildings for occupants: Comfort case

When it comes to building management, one of the main challenges faced by energy experts is to optimize the energy usage of buildings while maintaining a comfortable environment for the occupants. Indeed, traditional Building Management Systems (BMS) are only focusing on the comfort conditions which are not compatible with the ever growing need of building owners to reduce their energy bills. Moreover, most of the BMS algorithms do not take into account the current conditions of the building spaces, e.g. occupied/unoccupied, forecasted weather conditions and exceptional scenarios, e.g. holidays, exceptionally unoccupied.

UC11/12/13. Optimisation using weather / occupancy /price forecasts

- **The challenges**

To achieve this combination of minimizing energy consumption while maintaining comfort conditions, controllers for HVAC systems must be adapted to exploit newly available information such as weather data, forecasts, and other factors like on-site production, and thereby enabling reduction of the energy consumption without compromising on comfort. This objective is the object of Use Case 11 (UC11).

Moreover, an essential component is to be able to accurately detect occupancy patterns in the building because it determines when maintaining comfort conditions is critical and conversely when more flexibility exists for energy savings. Identifying such patterns can be a complex task when done manually and is the object of Use Case 12 (UC12).

Finally, varying prices may have a significant and sometimes counter-intuitive impact on the consumption costs and may therefore justify consuming more at strategic moments in order to consume less when prices are high such as within peak hours. This optimisation is the object of Use Case 13 (UC13)

- **The technical solution proposed**

The AI toolbox developed in the BIGG project is used to automatically detect occupancy patterns in a building, thus reducing the workload for energy experts and improving the accuracy of the data collected. This detection relies on movement sensor data as well as official holidays and calendar features.

Then, a rule based approach is developed to control HVAC devices such as air handling units, chillers, boilers, pumps, etc. The control scheme takes all the above mentioned factors into account, including the occupancy forecast, which allows for significant energy savings while maintaining the comfort within an acceptable range. Specific rules can also be formulated to take benefit from cheaper energy prices.

With this capability coupled with a grafana dashboard allowing to track the control actions and their effect, the solution developed is a valuable asset for energy experts looking to optimize energy usage and improve occupant comfort in buildings.

New perspectives opened for building optimisation

The BIGG project solution improves the market prospects, reduces internal costs, and opens up new ways of working in the following ways:

- It allows significant energy savings without sacrificing comfort using only simple data, making it an affordable and quick to deploy solution compared to a BMS system
- It improves the quality of the work thanks to the interactive dashboards which allow to easily follow up the control actions and how they affect the building.

BC6. ELECTRICITY AND GAS DEMAND-RESPONSE

This BC will demonstrate and exploit the flexibility potential of residential and commercial buildings in electricity and natural gas.

The focus will be on characterizing the availability and distribution of flexible loads in the buildings by analyzing a plurality of data captured from heterogeneous sources: devices deployed at consumer premises (smart meters, heating controllers, IoT, sensors, etc.), user preferences (comfort limits, schedules, etc.) collected through smartphone applications, external services (weather forecast, balancing market prices, consumption & billing) and static information, such as the building and heating system characteristics.

UC14. Electricity demand response (DR)

- **The challenge**

Energy consumption forecasting is essential for efficient energy management and planning. Accurate energy consumption predictions can help in better decision-making for both energy providers and consumers. Developing an AI algorithm to predict energy consumption can greatly improve the accuracy of these forecasts and help in creating more sustainable and cost-effective energy systems. Additionally, this can also aid in reducing greenhouse gas emissions and mitigating climate change.

The primary objective of UC-14 is to develop an AI algorithm for energy consumption forecasting to accurately predict the future energy demand. This can help energy providers to plan their energy production and distribution, avoid blackouts, and optimize energy usage. For energy consumers, accurate predictions can assist them in managing their energy usage and to reduce costs by taking advantage of off-peak hours. Furthermore, the algorithm can also help in identifying trends and patterns in energy consumption, which can be used to develop more efficient energy systems and policies. Ultimately, the goal is to create a more sustainable and reliable energy future for everyone.

- **The technical solution proposed**

A high-level data diagram of the overall architecture is shown in **Figure 26**. In terms of technology, cloud computing and cloud storage isused with all GDPR compliant measures. In our solution, we are leveraging Azure's cloud computing capabilities to store and process large amounts of data from smart meters, temperature sensors, and other sources. By using Azure's scalable and flexible computing infrastructure, we are able to quickly process and analyze large data sets to make accurate predictions about power consumption and energy demand. Additionally, Azure's machine learning tools enable us to train and deploy advanced models that can accurately forecast energy usage, helping energy providers optimize their operations and reduce costs.

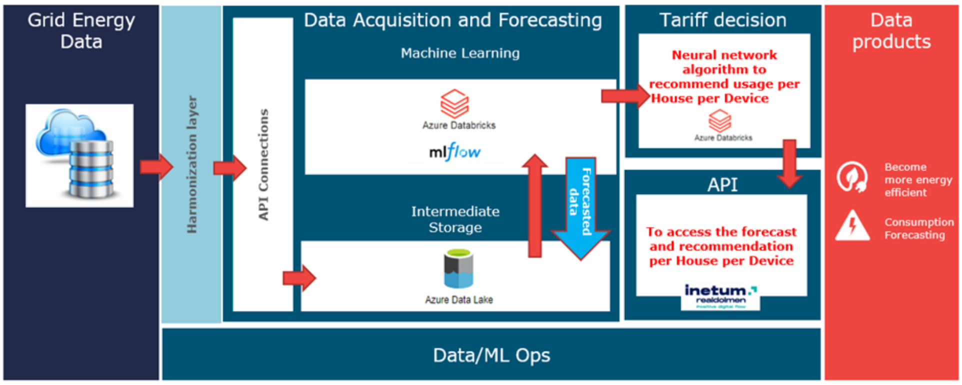

Figure 26. High level data architecture diagram of the solution with the corresponding tools/resources that is used.

In the proposed AI solution, our principal provider/partner is Heron. To develop an accurate model for predicting residential power consumption, we gather historical data from Heron's API, which is derived from smart meters installed in homes. This data is then processed and cleaned in order to train various machine learning models.

To further enhance the accuracy of our models, we extract calendar components from the datetime index of the time series and incorporate them as a feature. This allows us to analyze whether there is a correlation between the power consumption of a household and the day of the week. By examining these correlations, we can determine the most significant factors that contribute to power consumption and use them to refine our models. Once all of the relevant data has been collected and cleaned, we train several models to predict the power consumption of households for the next 24 hours. The models are trained using a combination of the data collected, including power consumption, device data, and calendar components.

Finally, after training the models, they are evaluated to determine the most accurate one for forecasting residential power consumption. This evaluation process involves comparing the predicted power consumption values with actual power consumption values, and choosing the model that provides the most precise and reliable forecasts. The resulting model can then be used to forecast residential power consumption with a high degree of accuracy, allowing energy providers to optimize their operations and consumers to manage their energy usage effectively.

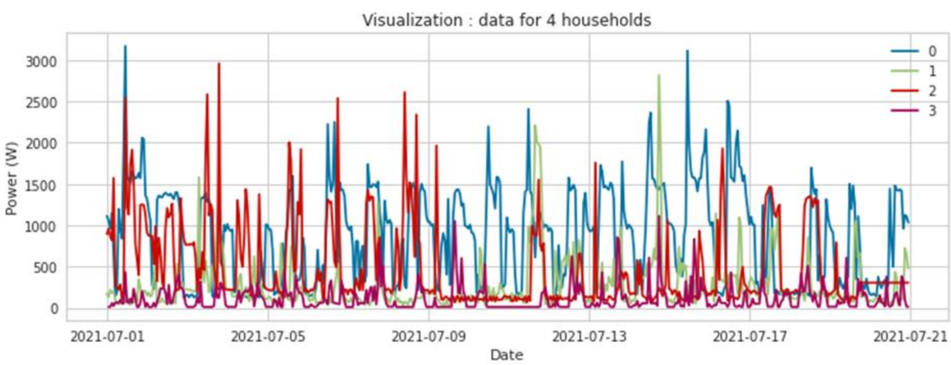

Figure 27. Power consumption for 4 households of a historical data in 2021. Power (W) is shown on the Y-axis and dates are shown on the X-axis.

Following the forecasting, the tariff for the upcoming hours is brought into our system to calculate the overall cost of consumption. This includes taking into account the customer's energy usage and the corresponding rates for the given time period.

- **Some results**

This calculation provides each customer with an estimate of their total expenditure on energy consumption.

Figure 27 shows an example of data for four households. It can be seen that the consumption behavior of each household are different. However, we are able to model each of them separately and forecast their consumption. **Figure 28** and **Figure 29** shows the historical consumption pattern and the forecasted consumption pattern. The model has demonstrated a high degree of accuracy in predicting energy consumption patterns across a wide range of households. As seen from **Figure 28** and **Figure 29**, it effectively identifies and forecasts both peak and low energy consumption periods, facilitating optimized resource allocation and efficient energy management. Additionally, the model exhibits robust performance in capturing the inherent variability within individual households, accurately predicting fluctuations in energy demand.

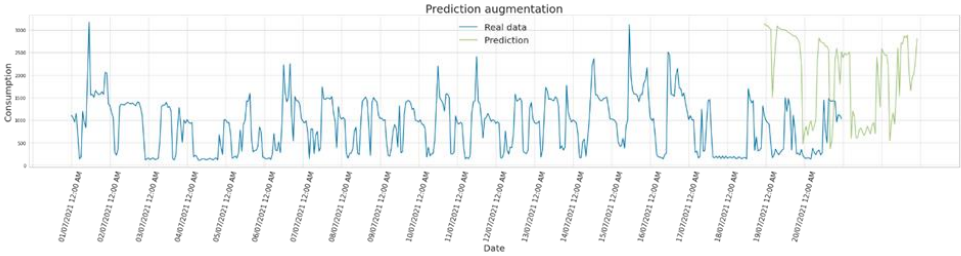

Figure 28. Forecasted output for one house. The predicted data is shown in green line.

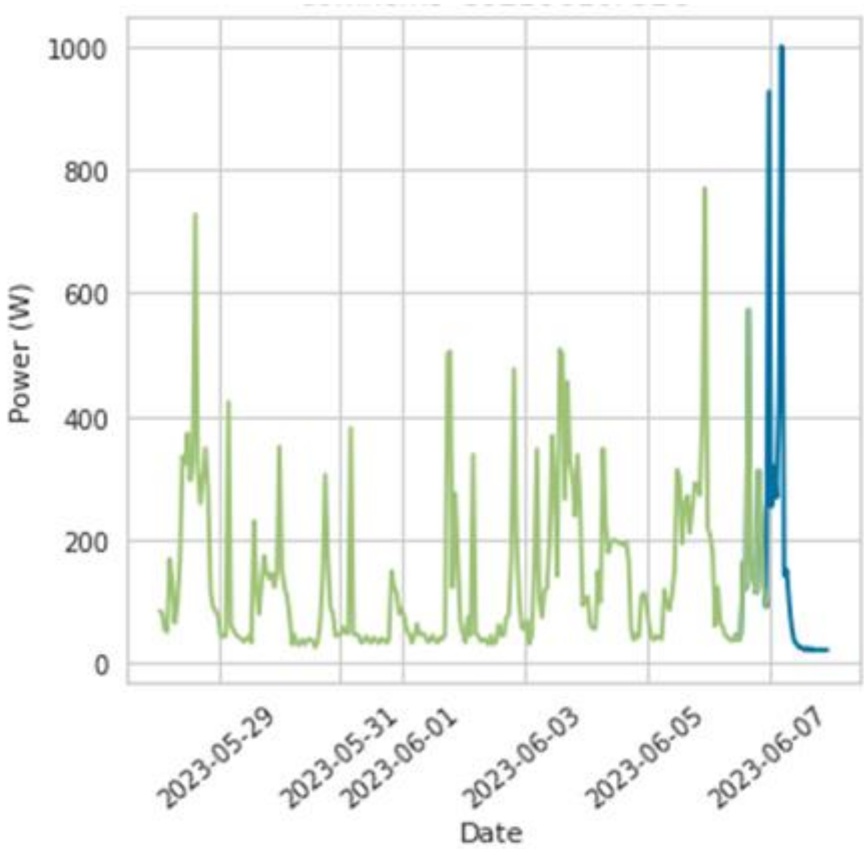

Figure 29. Forecasted output of another household. The forecasting of the twin peaks is noticeable. The model is able to predict one or multiple peaks with 95% accuracy.

- **The analysis of the solution: does it help with the challenge? Does it open new opportunities?**

The solution assists customers in greatly reducing their energy costs. To aid the customers a dynamic threshold is set by the energy provider. This threshold aims to determine the maximum amount of energy that can be used without exceeding a customer's pre-determined budget. Using this threshold as a guide, a decision algorithm is then applied to recommend specific actions that can be taken to minimize the customer's expenditure.This algorithm will then suggest that certain appliances be avoided during periods of high energy usage, or that they be used at specific times when energy rates are lower. By following these recommendations, customers can optimize their energy usage and reduce their overall expenditure on energy consumption.

Overall, this process not only benefits customers by reducing their energy costs, but it also benefits energy providers by helping to balance energy demand and reduce the strain on the energy grid during peak periods. This, in turn, can contribute to a more sustainable and efficient energy system in the future when done in larger grid scale.

UC15. Natural Gas demand response (DR)

- **The challenge**

The application of demand monitoring and management approaches for natural gas primarily lags behind from corresponding applications to electricity, mainly due to the following challenges: a) gas demand cannot be directly measured, as smart gas meters are rarely installed by grid operators (±5% in GR), while market available sub-meters have high equipment cost, b) gas demand cannot be widely managed, as most market available solutions (smart thermostats) are designed to address the need of end-users and not energy market actors.

- **The technical solution proposed**

DOMX offers a cost-effective and universal retrofit IoT solution that integrates seamlessly with legacy natural gas boilers, providing for optimized space heating and circumventing the need to install dedicated metering equipment for consumption monitoring. Through this UC, 100 households equipped with legacy space and hot water heating boilers operating on natural gas have been upgraded with the cost-effective smart heating solution of domx. The smart heating controller of domx has been installed in all pilot households, while their consumers have been granted access to the domx smartphone enabling the smart and remote management of their residential heating system. Various parameters are considered as input for the underlying energy management algorithm, including the user specified comfort limits (set through the app), the specific building and boiler characteristics (configured by the installers) and the prevailing weather conditions and their forecasts (fetched through local sensors and weather APIs). The overall system enables the optimal management of natural gas consumption, by actively controlling and optimizing the boiler operation in real-time, towards (a) improving the attained energy efficiency up to 35% and (b) contributing to energy system flexibility providing real-time gas balancing services, while constantly guaranteeing the user specified comfort requirements.

- **Demonstrated services and results**

Energy efficiency service

Portfolio level demand monitoring and management is enabled for the natural gas supplier, through a custom dashboard that visualizes a plurality of energy (boiler consumption, savings, etc.) and non-energy (temperature variations, user preferences, etc.) data sources. The heterogeneous data types are collected in real-time and enable the analysis of heating demand and visualization of historical data through a common user interface. End users get informed about the attained energy savings through the smartphone application.

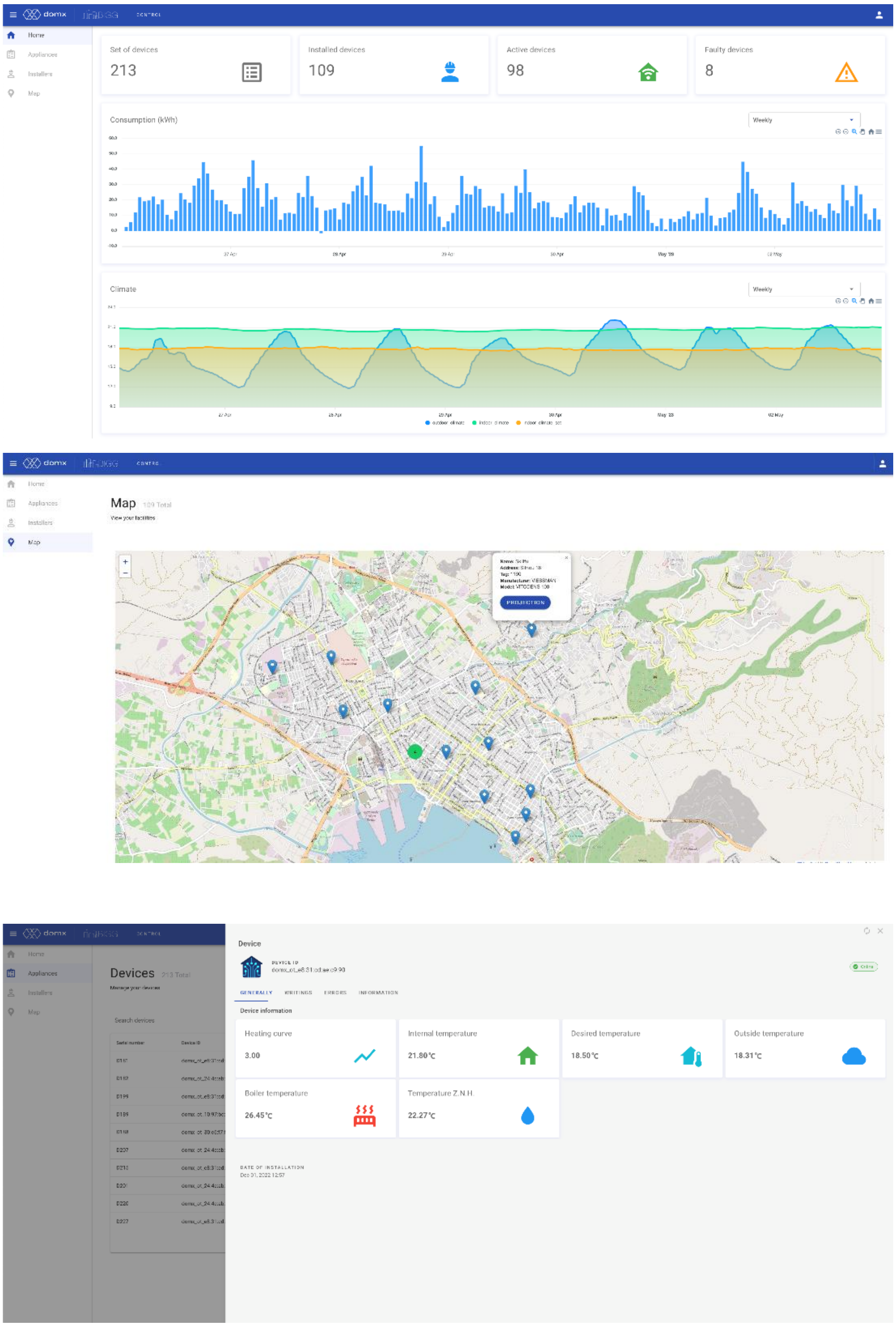

Figure 30. Portfolio level demand monitoring dashboard for the Natural Gas supplier

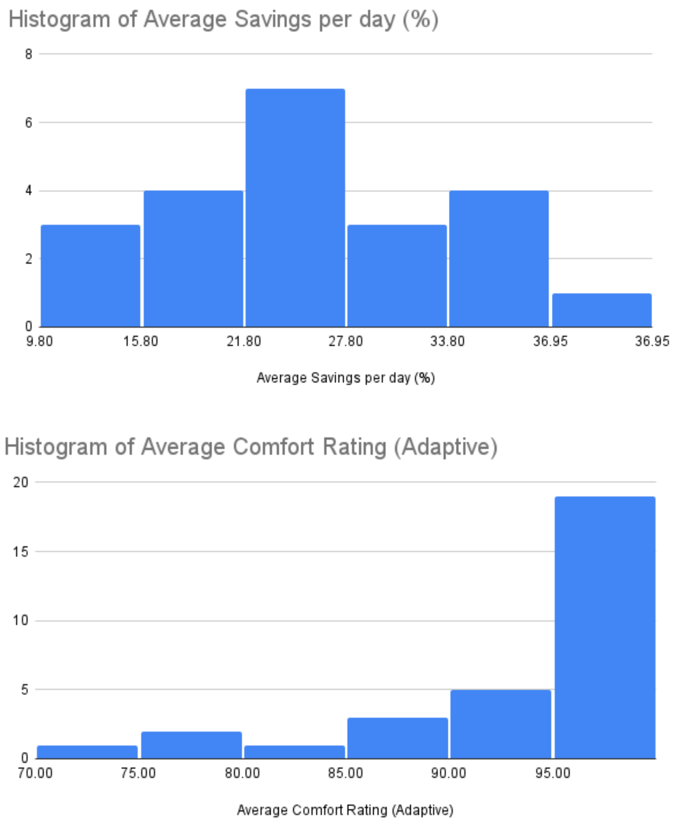

Figure 31. Portfolio level performance of the energy efficiency service

Flexibility management service

In February 2023, a real-life pilot for natural gas demand management was executed over 8 pilot households, resulting in 25 natural gas DR events. A reinforcement learning control mechanism and a dashboard to be used by system operators have been developed for this purpose.

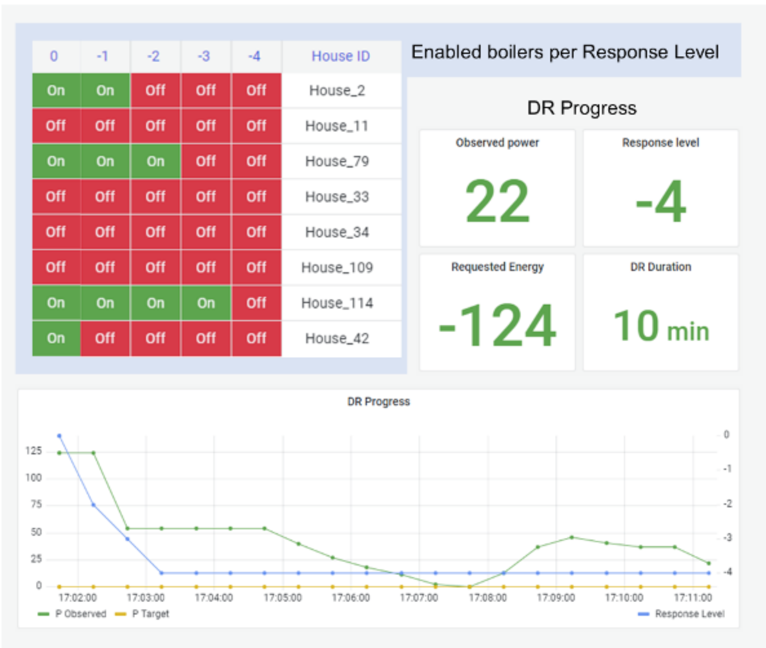

Figure 32. DR management dashboard for system operators

The dashboard, as illustrated in

Figure 32, is a single place for monitoring room temperatures, boiler mechanics, and demand response progression. System operators can use this platform to see in real-time which boilers are actively participating in a DR-event. New DR events can also be instantiated through the dashboard.

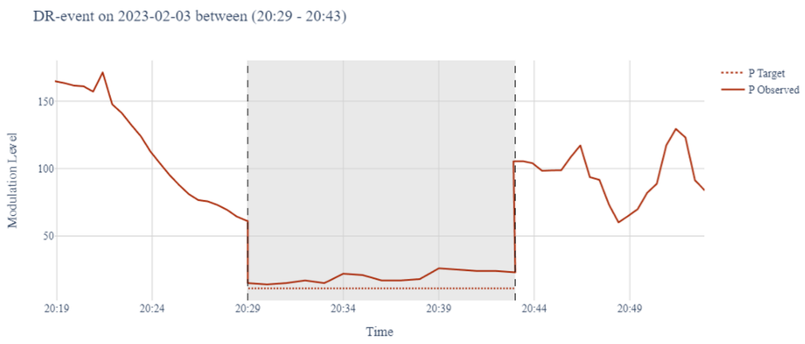

Figure 33. Example of a DR event and its impact on the boiler's operation

Figure 33 illustrates a real-world example of a downwards DR event. The overall gas usage reduces greatly for a period of 10 minutes, after which the original consumption is quickly recovered after the DR event finishes.