e-SAFE

DELIVERABLE REPORT

WP4 ICT infrastructure

D4.6

Final integrated e-BEMS

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☐ DEC Websites, patents filling, videos, etc.
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☐ ETHICS – Ethics requirement
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CONTENTS

Executive Summary 6

Glossary of Terms 7

1. Introduction 8

  1.1 Intended Audience 8

  1.2 Relation to other activities 8

  1.3 Document overview 8

2. e-BEMS, Requirements and User Stories 9

  2.1 e- BEMS & Building Energy Management System 9

  2.2 Final Version of e-BEMS: Probes & Parameters 9

  2.3 Revision of User Stories 12

    2.3.1 User stories for residential use 12

    2.3.2 User stories for building management 13

3. e-BEMS Final Integrated Version 14

  3.1 Configuration for the real pilot installation 14

  3.2 Technologies used to develop e-BEMS 16

4 User Interface & Design Guideline to use e-BEMS: Residents & Technicians 18

  4.1 Web Interface Module for Technician User 18

    4.1.1 User registration and sign-in 18

    4.1.2 e-BEMS web-interface for technician usage 19

  4.2 Mobile App Module for Resident User 32

    4.2.1 Settings & User registration and login 32

    4.2.2 e-BEMS Mobile application for resident user 37

    4.2.3 Notification Messages of **e-**BEMS Mobile App 40

5. Conclusion 42

Acknowledgements 43

References 44

  Internal references 44

  External references 44

e-SAFE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 893135.

EXECUTIVE SUMMARY

This Deliverable D4.6 corresponds to the final version of the **e**-BEMS (Building Energy Management System) that should be used for monitoring and management activities in the real pilot in Catania. It describes the progress of Task 4.4 and contains the building hierarchical modelling / system architecture, as well as the list of sensors and probes that has been identified in the early version (see Deliverable D4.4 [1]). Further activities implemented in this stage consist in testing the **e-**BEMS structure and MQTT Mosquito link by generating simulated data.

The objective of Deliverable D4.6 is to present the tool, providing a recap of its main functionalities, the difference with the previous version and a guideline for the **e-**BEMS configuration in the real pilot and the usage from end users.

The document first explains the BEMS framework. All probes for indoor and outdoor comfort, energy production and consumption, and the probes in the thermal system that were presented in the first version [1] were revised and are explained in this document. Then, the document summarizes the revised version of end-user's technical and non-technical requirements identified within **e-**SAFE project.

The second part explains the Final Integrated Version of **e-**BEMS, with the configuration needed to the real pilot installations by using the hierarchical structure as a digital replica of the real pilot building. The technologies used to develop the **e-**BEMS are also illustrated.

The last part is a user guide for **e-**BEMS modules: web interface module for technician, and mobile application module for residents. This section explains how to use their interfaces effectively and how the designed features correspond to user requirements.

The version of **e-**BEMS in this document relies on simulated data, but with a clear perspective that proves that the system is working. The finalized version of the **e-**BEMS, delivered at M48, will describe possible improvements or modifications based on the monitoring experience after the real pilot installation.

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GLOSSARY OF TERMS

ACRONYM	DESCRIPTION
BEMS	Building Energy Management System
BIM	Building Information Modelling
BMS	Building Management System
D	Deliverable
DWH	Domestic Hot Water
EC	European Commission
HC	Heating Cooling
HVAC	Heating Ventilation Air Conditioning
ICT	Information and Communication Technology
IT	Information Technologies
IoT	Internet of Things
PR	Periodic Report
RH	Relative Humidity
T	Temperature
TNO	Task No.
WP	Work Package

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1. INTRODUCTION

The deliverable aims at providing a systematic report on details of the final version of the Building Energy Management System called **e-**BEMS, before the real pilot building installation.

This document introduces the system architecture and the hardware and sensing components, to guide installation in the real pilot. Also, the document contains the revised end-user requirements analysis from two different user type perspectives: residents and technicians. **e-**BEMS design includes the logical entities, user interface examples, application and data management, operating system and the framework, connectivity layers with hardware interfaces for the e-SAFE components.

The output of this document is the description of the final version of the **e-**BEMS Building Energy Management System. This work is part of Task 4.4 led by SAMPAS, and Deliverable D4.6 is a properly working prototype tested on simulated data and environment, since no real sensors are installed in the Catania pilot yet.

1.1 Intended Audience

The intended audience of the report is primarily the members of the project's consortium and European Commission (EC) representatives tasked with reviewing the project and its progress towards meeting the specified milestones. Indeed, it reports relevant information for implementation activity with reference to the final version of **e-**BEMS tool.

1.2 Relation to other activities

D4.6 is one of the official reports of Task 4.4. Task 4.4 is the Task that works to an advanced version of the Deliverable D4.4 [1], an early **e-**BEMS version delivered as an outcome of Task T4.3. The work of this task has taken advantage of WP3 outcomes regarding the technological solutions proposed in the project for the energy probes and parameters, but also of WP5 regarding the detailed design of the pilot renovation in Catania.

1.3 Document overview

The report is structured as follows:

- Chapter 2 summarizes the building energy management concepts based on the previous report, final version of **e-**BEMS probes and parameters which have been improved since previous document, revised version of user stories. **e-**BEMS functional specification provides residents and building managers user requirements, as well as the probes and parameters identified for indoor and outdoor spaces, energy production systems and thermal systems.
- Chapter 3 provides the basic and critical information about the hierarchical system model of the probes as the real pilot replica on digital environment, and system architecture is explained respectively.
- Chapter 4 contains user guidelines for e-BEMS for both end-users. This chapter explains how to use web interface and mobile application. It also clarifies the graph control panel, downloading panel and server settings.
- Chapter 5 is the conclusion.

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2. e-BEMS, REQUIREMENTS AND USER STORIES

2.1 e- BEMS & Building Energy Management System

Energy management and IT integration to monitor and control building energy systems (heating, ventilation, air conditioning and lighting systems) has long-term benefits in terms of cost savings and improved thermal comfort. Indeed, The BEMS technology allows end-users to monitor and control their living and/or working spaces with suitable devices and sensors, thus also being able to take appropriate decisions for energy saving purposes.

BEMS systems are mainly used for four main purposes [2]:

- Monitoring: continuous monitoring of the sensor's measurements.
- Controlling: control algorithms for improving the facilities' behaviour in the building.
- Optimizing: working out the best performance of the system.
- Reporting: documentation of the intermediate and final results.

The detailed explanation of building energy management concept is already introduced in Deliverable D4.4 [1]. In the context of **e-**SAFE, the **e-**BEMS has been developed, which is a tool dedicated to Monitoring and Reporting purposes. Instead, Control and Optimization activities will be developed through the control system designed and installed in collaboration with the company that will renovate the pilot building, which will be adjusted after experimental monitoring on the pilot case.

The identified building energy management framework was also presented in the Deliverable D4.4 [1]. Based on preliminary evaluations, the OpenHAB open-source framework [3] is the most suitable component for **e-**BEMS development and implementation. This model collects and stores the data gathered from the sensors located in different places in the building/apartments and provides information to technicians via web-module as well as to residents via mobile application. **e-**BEMS architecture is explained in Section 3 in detail.

In the **e-**SAFE project, **e-**BEMS have a critical role to measure indoor comfort and outdoor environmental/climatic features that directly affect the energy efficiency, and also allows the end-users (residents and technician) to verify indoor comfort conditions and energy consumption. This will be a necessary step to collect information about the real performance of the pilot in Catania, and to make it possible to quantify the actual benefits of the proposed renovation technologies in terms of comfort, indoor air quality and energy savings.

In the specific case of the real pilot building in Catania, the **e-**BEMS aims to measure indoor temperature, CO_2 concentration, and indoor humidity in real time for indoor comfort; moreover, energy consumption from the thermal system and the energy production from the PV system will be monitored both at building scale and at single dwelling scale, in order to evaluate suitable energy efficiency factors and to allow energy metering and cost allocation.

2.2 Final Version of e-BEMS: Probes & Parameters

The probes and parameters to monitor indoor spaces, outdoor weather conditions, Domestic Hot Water temperature, energy production and consumption of thermal systems, which were already defined within the previous Deliverable D4.4, have been further developed and finalized in this report. Table 1 to Table 5 present the set of requirements for the parameters and probes identified for the **e-**BEMS. : the tables describe where and how many probes will be installed, the unit of

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measurement, their data collection frequency, explanations on possible needed post-processing, and the ranges for data accuracy.

In particular, Table 1 introduces the selected indoor environmental parameters for residential use, which are regarded as the most relevant ones: temperature, relative humidity and CO_2 concentration. These sensors will be installed in one living room and one bedroom per apartment.

Table 1. Probes for indoor spaces in the real pilot.

What	Unit	Where	When	How many	Accuracy	Range
Dry-bulb air temperature	°C	Living room and one bedroom	Every 5 minutes	2 x dwelling (20 overall)	± 0.1 °C	At least 0 – 50 °C
Relative humidity	%	Living room and one bedroom	Every 5 minutes	2 x dwelling (20 overall)	± 3%	At least 5 – 95 %
CO_2 concentration	ppm	Living room and one bedroom	Every 5 minutes	2 x dwelling (20 overall)	± 50 ppm	At least 0 – 5000 ppm

Table 2 presents the environmental parameters for outdoor space. Outdoor temperature and humidity will be collected as relevant outdoor parameters. Besides these data, wind speed and wind direction will be also collected to characterize the weather conditions. The table describes where and how many of these probes will be installed and their data collection frequency. These parameters are grouped under the "above roof" subcategory based on their location for installation; indeed, they will be collected by a weather station that will be installed on the rooftop.

Table 2. Probes for outdoor spaces in the real pilot.

What	Unit	Where	When	How many
Dry-bulb air temperature (Outdoor temperature)	°C	Above roof	Every 5 minutes	1
Relative humidity (Atmospheric humidity)	%	Above roof	Every 5 minutes	1
Wind speed	km/h	Above roof	Every 5 minutes	1
Wind direction	° *	Above roof	Every 5 minutes	1

*(*0°: North; 90°: East; 180°: South; 270°: West)*

Table 3 and Table 4 show the energy-related parameters that need to be monitored in the pilot building, addressing energy consumption in the residential units and the central thermal systems, plus the electric energy generation from PV panels. **e-**SAFE will collect information about the electric power from auxiliary systems at every 10 minutes on the consumption side through smart meters. **e-**BEMS will also monitor the energy production through PV systems analyzers, together with the self-consumption rate and the electricity taken from the grid (Table 3).

Table 3. Required parameters for electric energy consumption and production.

What	Unit	Where	When	How many
Total Electricity Production from PV (PV_{TOT})	kWh	PV System	Every 10 minutes	1
Self-consumption (electricity produced by PV and directly used - PV_{self})	kWh	PV System	Every 10 minutes	1

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Electricity taken from the grid (E_{GRID})	kWh	PV System	Every 10 minutes	1

Table 4 specifically addresses the parameters to be collected for thermal systems in the pilot building. Basically, heat flow meters and suitable probes for water temperature in the heat pumps, the centralized tanks and the decentralized **e-**TANKs will be the main sensing elements. Besides, electricity consumption will be measured for the two heat pumps and the four circulation pumps in the supply circuit.

Table 4. Required parameters for thermal systems – central units.

What	Unit	Where	When	How many
Water temperature	°C	Outlet from the central storage tanks	Every 10 min	2
Inside water temperature	°C	Inside of the large central storage tanks	Every 10 min	2
Inlet water temperature	°C	Heat Pumps	Every 10 min	2
Outlet water temperature	°C	Heat Pumps	Every 10 min	2
Mass flow rate	kg/s	Heat Pumps	Every 10 min	2
Electricity consumption	kWh	Heat Pumps	Every 10 min	2
Supply temperature (pump)	°C	Pumps in the supply circuit	Every 10 min	4
Return temperature (pump)	°C	Pumps in the supply circuit	Every 10 min	4
Mass flow rate (pump)	kg/s	Pumps in the supply circuit	Every 10 min	4
Electricity consumption (pump)	kWh	Pumps in the supply circuit	Every 10 min	4

In principles, all above parameters should be measured by appropriate probes. However, some of them can also be inferred from other measured quantities, such as:

- "Supply temperature": this roughly corresponds to the water temperature in the upper part of the large central storage tanks, called "inside water temperature" in Table 4. Each "inside water temperature" applies to two "supply temperature" values.
- "Mass flow rate (pump)": this corresponds to the sum of the mass flow rates measured by the heat flow meters installed in the e-TANK in each dwelling (see Table 5).
- "Electricity consumption (pump)": we can calculate it as an aggregated value for the four circulation pumps, as the difference between the total electricity consumption absorbed in the central unit (see Table 3) and the electricity consumption of the only Heat Pumps.

Finally, Table 5 summarizes the required measured parameters in the local **e-**TANKS placed in the apartments. These measurements will help analyze the energy consumption in the end-user perspective.

Table 5. Required parameters for local units and **e-**TANKS.

What	Unit	Where	When	How many
Supply temperature	°C	Heat flow meters	Every 10 min	20
Return temperature	°C	Heat flow meters	Every 10 min	20
Mass flow rate	kg/s	Local **e-**TANK	Every 10 min	20
Thermal energy	kWh	Local **e-**TANK	Every 10 min	20
Water temperature in the **e-**TANK	°C	Local **e-**TANK	Integration with time	10

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2.3 Revision of User Stories

Since the outputs of the **e-**BEMS this task must be useful for the end-users, functional and non-functional requirements were oriented to their fruition. The user stories and requirements were defined looking at two main roles: residents and technicians.

A first set of user requirements for the **e-**BEMS has been conceived with the support of UNIBO and UNICT and reported in the early version, Deliverable D4.4 [1]. The user requirements have been revised at the Project Meeting in Brussels in November 2022 and via e-mail among SAMPAS, ENG, UNIBO and UNICT.

Revised **e-**BEMS requirements are listed in the following sub-sections. Residents mainly look at monitoring parameters, while the technicians need more technical details and also loom at data processing, analytics, and control of the hardware components.

2.3.1 User stories for residential use

This section describes functional requirements for the residents. Residents will be mainly using the mobile interfaces of the **e-**BEMS platform and will require mainly to monitor parameters associated with thermal comfort and energy consumption. Table 6 summarizes the user stories revised after the early draft of this Deliverable.

Table 6. User stories referred to the residents.

Requirement
1. As a resident, I need to register to the **e-**BEMS application so that I can exploit it.
2. As a resident, I need to know the temperature in my home, in two rooms out of the three ones where fan coils are installed. I wish to check these data on an application in my Smart Phone, that will suggest me some behavioral changes (e.g. turning off the fan-coils, changing fan coil set-point; operating the shading devices) if the indoor conditions are not optimal.
3. As a resident, I need to know relative humidity in my home, in two rooms out of the three ones where fan coils are installed. I wish to check these data on an application in my Smart Phone, that will suggest me some behavioral changes if the indoor conditions are not optimal (e.g. open the windows when RH is too high).
4. As a resident, I need to know if the CO_2 concentration in the two above rooms is too high. The application in my Smart Phone can suggest me to open the window to change stale air, when necessary.
5. As a resident, I need to know the temperature of domestic hot water inside my **e-**TANK. The application in my Smart Phone has to suggest if the temperature inside is good enough for its use, so that I can eventually turn on the electric resistance if I need to get a shower, but the water temperature is not appropriate.
6. As a resident, I need to know (through the application in my Smart Phone) the thermal energy consumption for both domestic hot water and heating/cooling services in my apartment.
7. As a resident, I want to know (through the application in my Smart Phone) the daily electricity production from the PV system, so that I can understand how the PV system is working.
8. As a resident, I need to visualize (through the application in my Smart Phone) the current value of all main environmental parameters outdoors (dry-bulb air temperature, relative humidity, CO2 concentration, wind velocity).

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2.3.2 User stories for building management

This section describes the user stories and requirements for the technicians, revised after the early draft of this Deliverable. Table 7 summarizes the providing status of the requirements came from the technicians' user stories. Technicians require to get more detailed information through the web interfaces of the **e-**BEMS platform for indoor, outdoor, energy and thermal systems parameters. They are interested to download the data periodically and will use these data also for cost allocation.

Table 7. User stories referred to the technicians.

Requirement
1. As a technician, I need to register to the **e-**BEMS application so that I can exploit it.
2. As a technician, I want to know the temperature and the relative humidity in all apartments, in two rooms out of the three ones where fan coils are installed.
3. As a technician, I want to check the CO_2 concentration in the two above rooms for all apartments.
4. As a technician, I need to know the temperature of domestic hot water inside all **e-**TANKs.
5. As a technician, I need to login to the **e-**BEMS platform and visualize the trend of all measured parameters.
6. As a technician, I need to know the hourly electricity yield from the PV system, and to see aggregated statistics about Total Electricity Production from PV, Self-consumption (electricity produced by the PV system and directly used), and electricity taken from the grid.
7. As a technician, I need to register and visualize the time trend of the main environmental parameters (dry-bulb air temperature, relative humidity, wind velocity and direction,). These data are important to me, since I can correlate them to the performance of the building and the technical system, thus understanding if the system is working properly.
8. As a technician, I need to know the water temperature in the two large storage tanks coupled to the heat pumps. To this aim, one temperature probe has already been installed in the upper part of each storage tank, but a second probe in the bottom part would be very useful. The **e-**BEMS must read the data from these probes.
9. As a technician, I need to know the trend of the main parameters describing the operation of the two heat pumps (inlet water temperature, outlet water temperature, water flow rate, electricity absorption). From these data, I need that the **e-**BEMS calculates the COP of the heat pumps.
10. As a technician, I need to know the thermal energy consumption for both domestic hot water and heating/cooling services for each apartment, which are measured by the heat flow meters already installed inside the **e-**TANK hydraulic unit. This allows me to perform cost allocation.
11. As a technician, I need to know at which time (and for how long) the electric resistance inside each **e-**TANK has been activated.
12. As a technician, I need to download a weekly or monthly report from the **e-**BEMS, so that I can verify all measured parameters to assess the correct behaviour of the system and show it to the building manager.
13. As a technician, I want to download building monitoring data from **e-**BEMS GUI for allowing further processing.

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3. e-BEMS FINAL INTEGRATED VERSION

The **e-**BEMS system is designed according to the user requirements described in the previous Section. Once the user requirements are examined, two basic common actions emerge for the two types of end-users:

- monitoring the data in real time, at predefined time steps;
- visualizing the data as charts.

There are also two additional actions in the technician end-user: analyzing the data and downloading the data. Two interfaces have been designed to meet these needs in the **e-**BEMS: the web interface for the technician and the mobile application for the residents. In both interfaces, different pages and tools were designed to meet monitoring, visualization, downloading, and analyzing needs.

3.1 Configuration for the real pilot installation

The **e-**BEMS model conceived in the scope of the project is a system with a web and mobile interface. In order to be effectively managed by the end-users, the physical world has to be replicated in the virtual world to create the digital copy of the energy consuming and producing elements. A system model for the building was created from Deliverable D4.4 [1] until the preparation of this report. This model was created to include predetermined locations, equipment, and probes. Synthetic data created in the simulated environment were integrated into these probes according to predetermined time steps, thus ensuring that the **e-**BEMS works properly on the pilot building.

The building is divided into five floors and – for each floor – each apartment is modeled as an entity in the **e-**BEMS component. Each floor is divided into apartments and their rooms (living room and bedroom). Using this model, each sensing point is located and attached to one of these locations. **e-**BEMS will easily identify and allow residents to monitor relevant parameters according to their location and usage.

The PV-related sensors and environmental sensors are located above the roof, DHW and Heating/Cooling components and their sensors are located in the ground floor level, sensors for indoor environment and local **e-**TANK \are located in each apartment.

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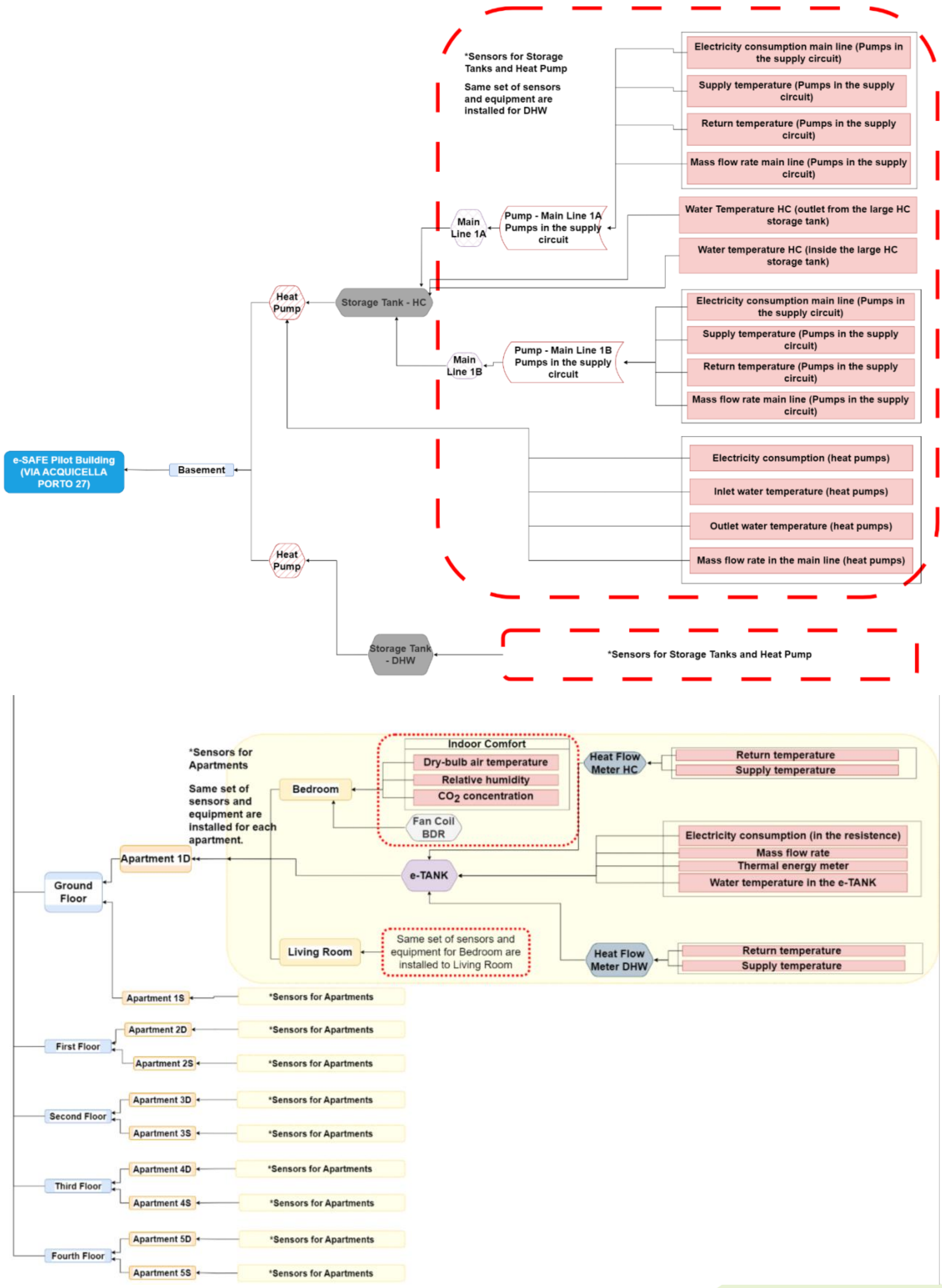

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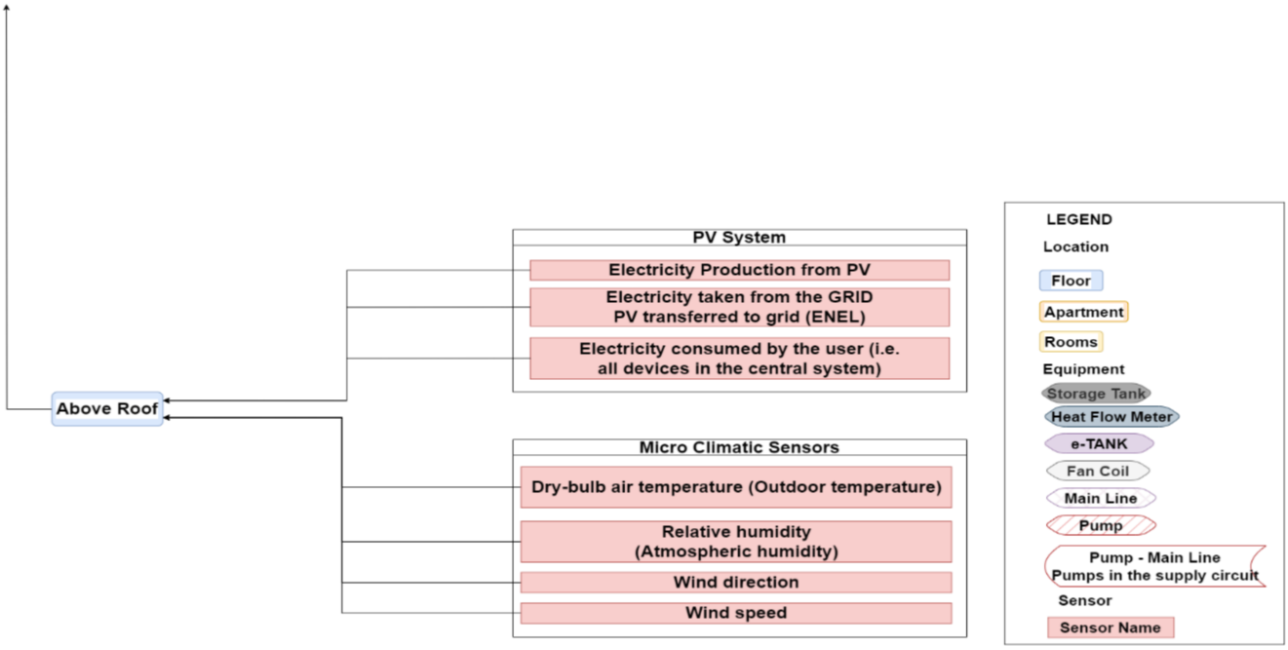

Figure 1. Hierarchical Model of the Probes for pilot building in Catania

As it is seen in Figure 1, there are basement, five floors and above-roof level in the model. In one living room and one bedroom of each apartment there are CO_2 Concentration, Temperature and Relative Humidity sensors. Each apartment has its own local **e-**TANK. There are two heat flow meters in each **e-**TANK, and return and supply water temperature, together with mass flow rate and thermal energy, are defined via these sensors.

Two main storage tanks are located in the courtyard in a dedicated technical room. Each storage tank is fed by one heat pump and has two main supply circuits to the apartments. There are water temperature sensors that measure outlet and inlet water temperature of the storage tank. There are also four sensors directly linked to the main heat pumps (electricity consumption, inlet water temperature, outlet water temperature, mass flow rate). Lastly on the roof, there are two categories of sensors; one of them is related to micro climatic sensors that inform the end-users about the weather, the second category of sensors is associated with the PV System that provides electricity to the thermal systems.

3.2 Technologies used to develop e-BEMS

The system implementation network for the **e-**BEMS is presented in Figure 2. There are basically more than a hundred sensors in the pilot building, that transfer the data via a SmartX server to **e-**BEMS Central Processing Unit, locates in the courtyard of the pilot building.

The **e-**BEMS will exploit several different hardware components to collect and transfer all data from the probes to the server. At the moment, we have identified the following items available on the market, sold by a leader company in the field:

SmartX Sensor: SmartX sensors are a family of living space sensors for use with RP SmartX IP controllers. These sensors use a sensor bus that provides communication and power from the SmartX IP controller [4].

SmartX RP-C Controller: It is a room-purpose, fully programmable, IP-based field controller that suits BEMS applications. The RP-C can either be used as a standalone BACnet/IP field controller or as part of an EcoStruxure BMS with a SmartX AS-P or AS-B server or an Enterprise Server as the

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parent server. The RP-C features a wireless chip that allows the mobile commissioning application to connect directly to the controller [5].

SmartX AS-B Server: The SmartX AS-B server holds the key functionality, such as control logic, trend logging, and alarm supervision, provides built-in I/O, and supports communication and connectivity to the field buses [6].

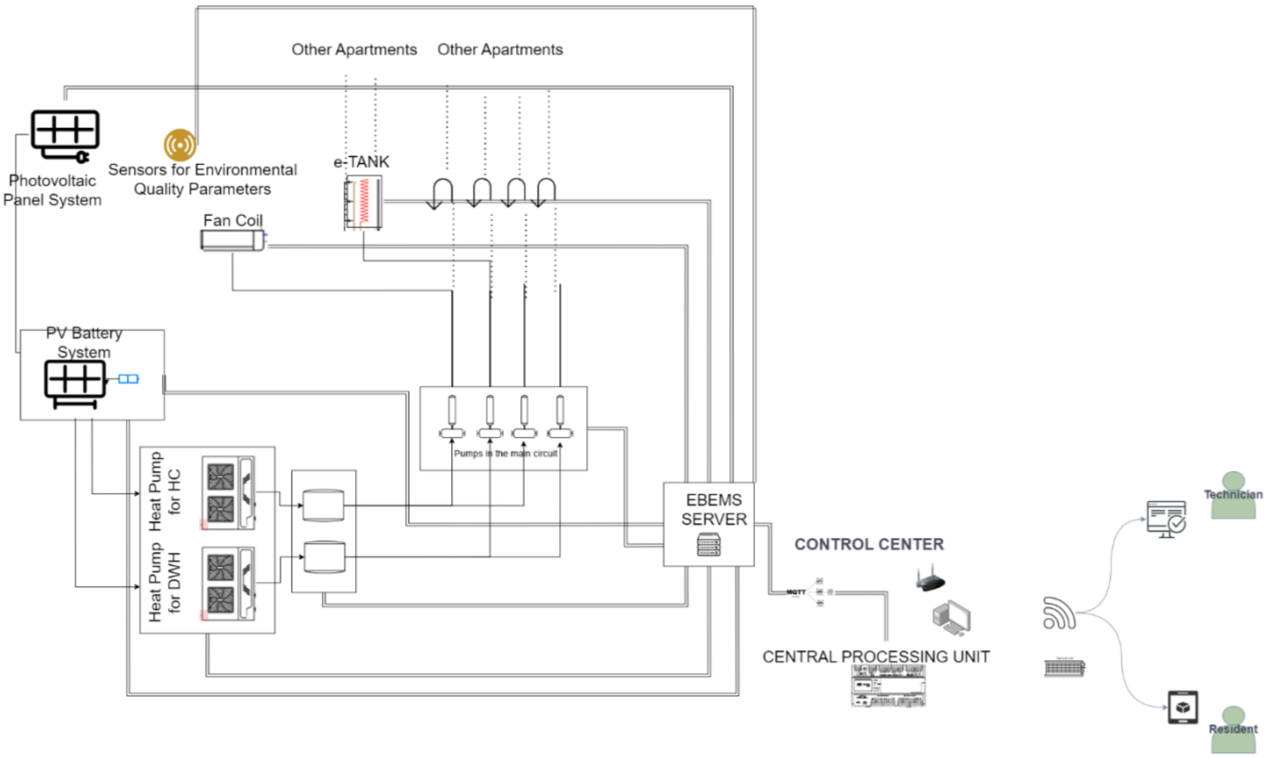

Figure 2. System Architecture of **e-**BEMS for pilot building in Catania

As it can be read from Figure 2, SmartX sensor communicates via sensor-bus with RP-C controller, which then transfers data directly over Bacnet IP network. SmartX server is a tool for functionality, supporting communication for Building Management Systems. It ensures the communication of data delivered from multiple sources. A MQTT License [7] is added to the AS-B Controller so that the data collected on SmartX server can be transferred to local servers of **e-**BEMS via the MQTT add-on. Thus, **e-**BEMS ensures that end users can follow the measured and calculated data related to indoor comfort, thermal and electric energy in the pilot building on their mobile devices and web-interface.

Summarizing, sensors measuring different parameters for different components in **e-**BEMS are connected. Some parameters are calculated using software codes through the data obtained from these sensors. All this data set is stored and processed on the server installed in the pilot building. It is transmitted from the sensors to the end-user via wired and Wi-Fi systems. Of course, other similar hardware components can be installed in place of those reported above, provided that they have the same functionalities and support the same protocols. Some configuration details might be adjusted while the data monitoring in pilot building is running.

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4 USER INTERFACE & DESIGN GUIDELINE TO USE e-BEMS: RESIDENTS & TECHNICIANS

e-BEMS offers two different interfaces that were designed for two types of end-users: technical and non-technical ones. With these interfaces, "technician" and "resident" user requirements were fulfilled. Especially the **e-**BEMS mobile application has been designed with a basic interface as it will be used by the residents of the apartments. On the other hand, the web interface developed for the technician is a user-friendly structure that offers more complex functions, to meet the requirements such as data analysis and data downloading.

This section shows the structure of the **e-**BEMS as seen by the user, and provides a brief guideline to explain how the user can interact with it. One technician account, as well as ten resident accounts for the various apartments, were created by the administrator. The account names and passwords will be provided to the end users by admin (**e-**BEMS developer).

4.1 Web Interface Module for Technician User

4.1.1 User registration and sign-in

The web-link of the technician user **e-**BEMS is: https://esafe.sampas.com.tr

The first step in the use of the **e-**BEMS is the user sign-in via the account ID and password that is provided by the **e-**BEMS manager. The main landing page seen in Figure 3 includes a lock button in the bottom left-hand side of the page for sign-in function.

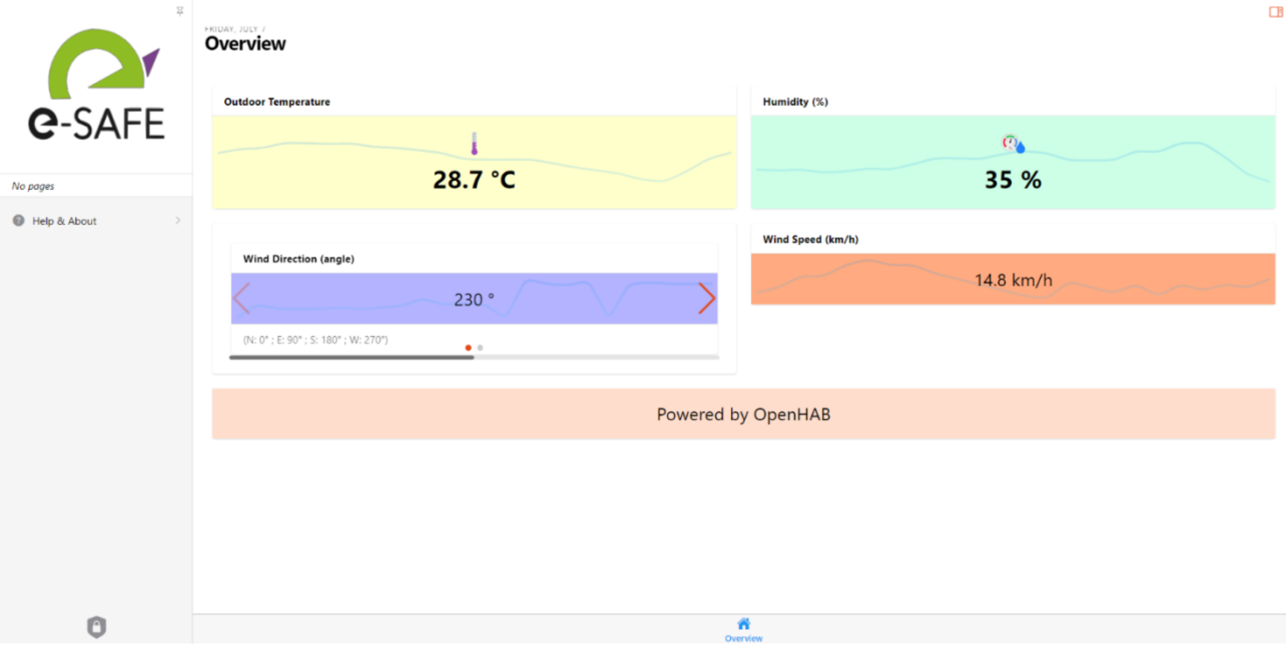

Figure 3. Landing page of **e-**BEMS (web-based tool for technicians)

After clicking the lock button, the technician can proceed with the account name and the password that was provided for them by the right-holder. After the login the user is redirected to the **e-**BEMS home page.

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Figure 4. Web interface sign-in page.

Next subsection explains the specific features and content of **e-**BEMS web module for technician.

4.1.2 e-BEMS web-interface for technician usage

It is important to highlight the features of **e-**BEMS that are meeting the technician user requirements, before explaining the contents of every page.

Chart Control for Visualization

After opening a data page on the side menu, technician can click and open a graph for that data. As an example (Figure 5), the technician can click on electricity consumption HC (heat pumps).

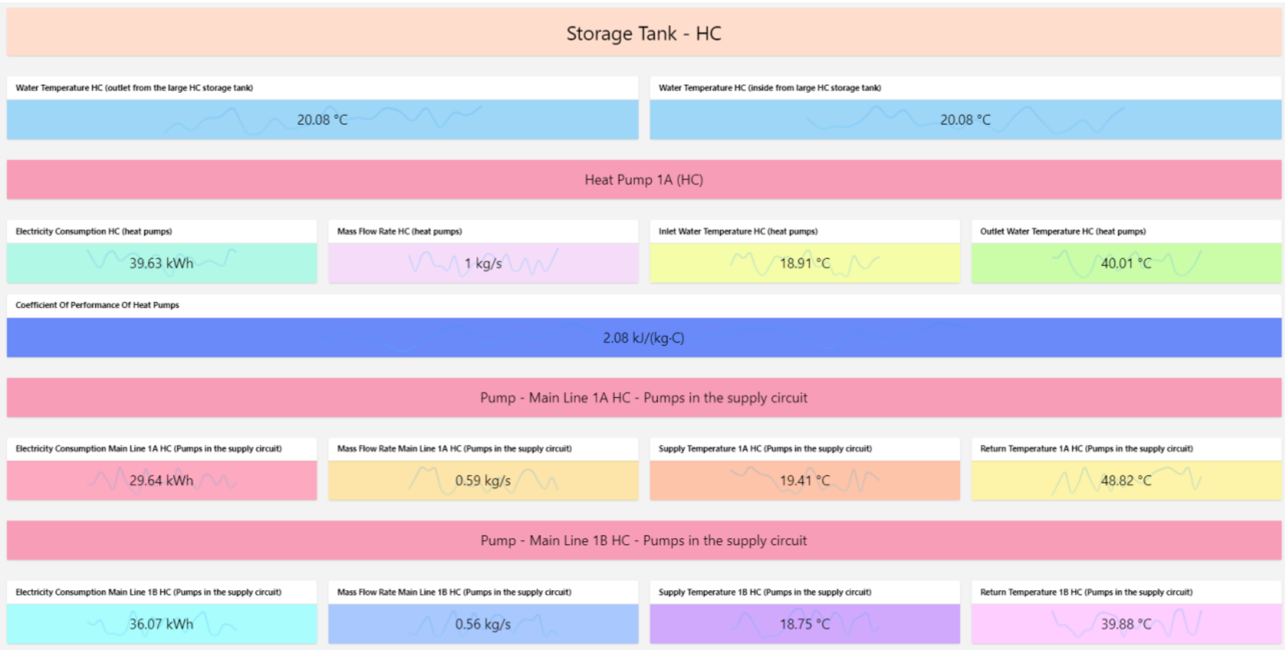

Figure 5. Data page as an example

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Then directly access to the graph of this specific data. On this page, technician can change the extension of the x-axis from one hour to one year, change the chart type (Figure 6), and add markers with the average, maximum and minimum values on the chart (Figure 7).

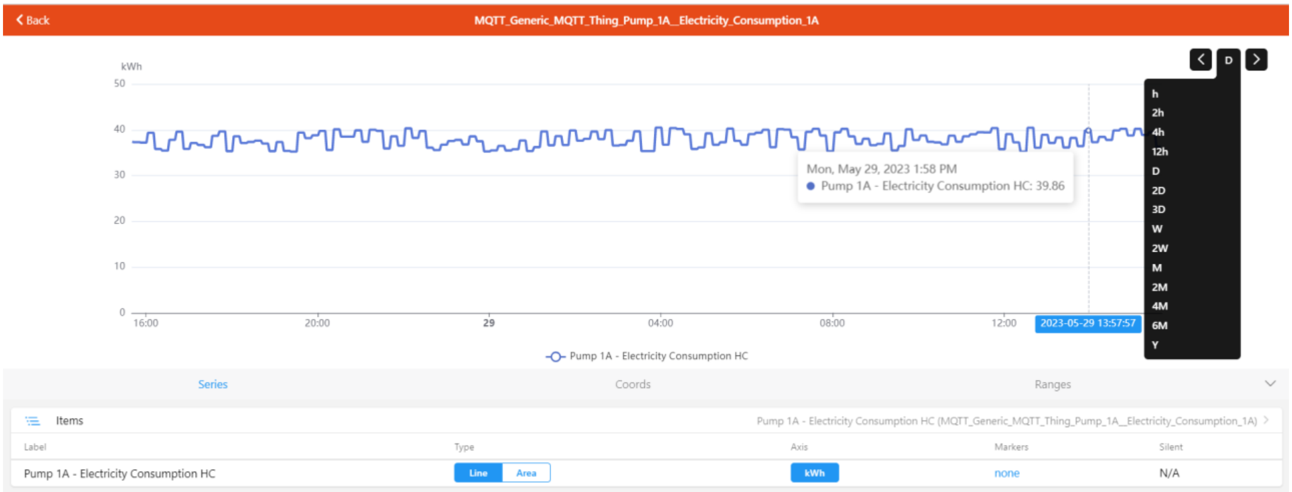

Figure 6. Chart visualization page and chart control feature

Figure 7. Markers menu of the chart control

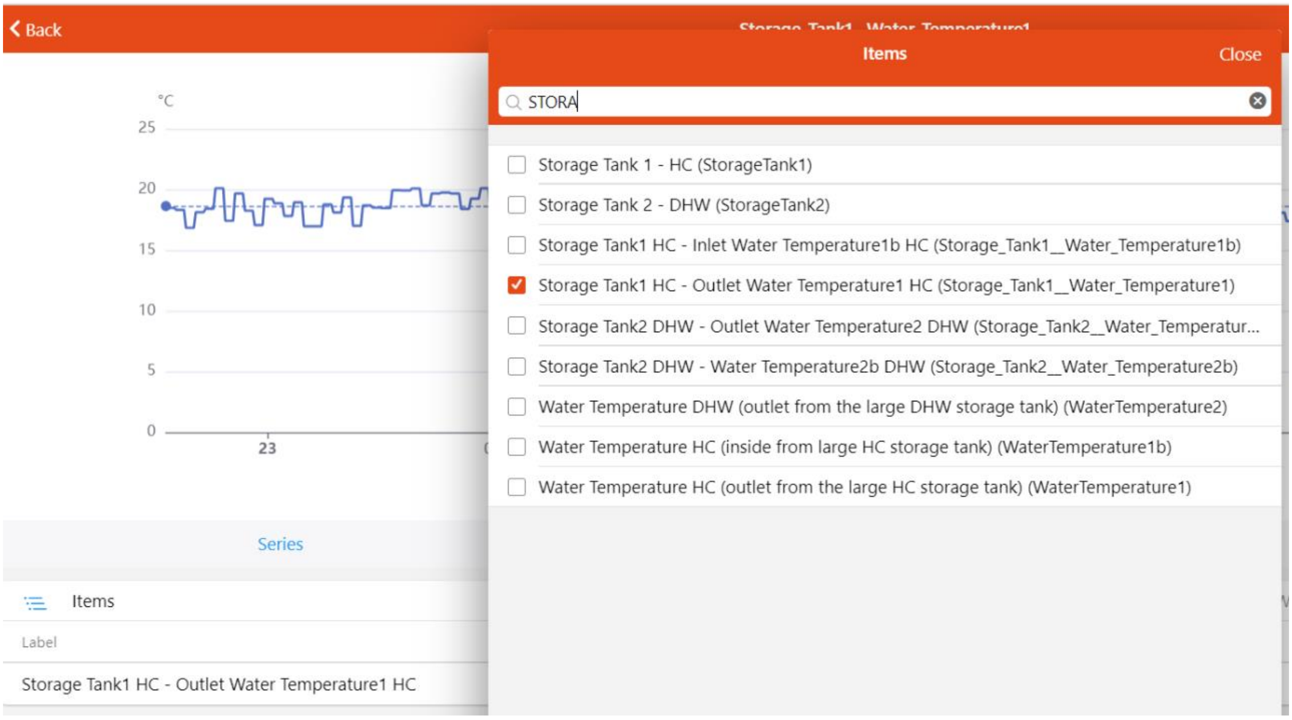

Figure 8. Items page

Figure 8 shows the "items" page, accessible from the bottom-left button, which opens as a pop-up and answers the purpose of analysing different data together in one chart.

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Downloading for Data Reporting

After the visualization, downloading data sets is another critical point in technician user-requirements.

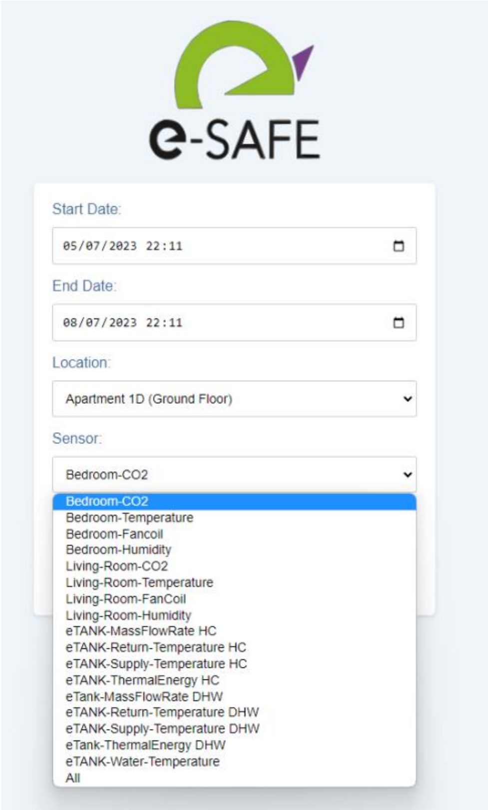

Figure 9. Dataset downloading feature.

To meet this, a feature was created and designed in analysis page on the side menu. On the analysis page, there is an excel button. This button directs the technician to a webpage:

https://esafe.sampas.com.tr/excel

As seen in the Figure 9, technician can select a time interval and data type to download. For each apartment, there is an "all" option in sensor tab. When the user clicks this "all" option, they can download all measured/calculated data for an apartment.

*Pages of **e**-BEMS Web Interface*

Following the specific features of **e-**BEMS for technician use, the pages of the web module are is explained hereafter.

After signing in with the technician account, the page (Figure 4) redirects the user to the main landing page with a side menu (Figure 10). The side menu includes pages that were created to meet technician user requirements. Through these pages, the technician can monitor the environmental data, analyse the indoor data for each apartment, download the datasets, visualize the data charts, analyse the PV system, Storage tank and circuit data, view the probes on a scheme of storage tanks and analyse water temperature and energy consumption for DHW and HC.

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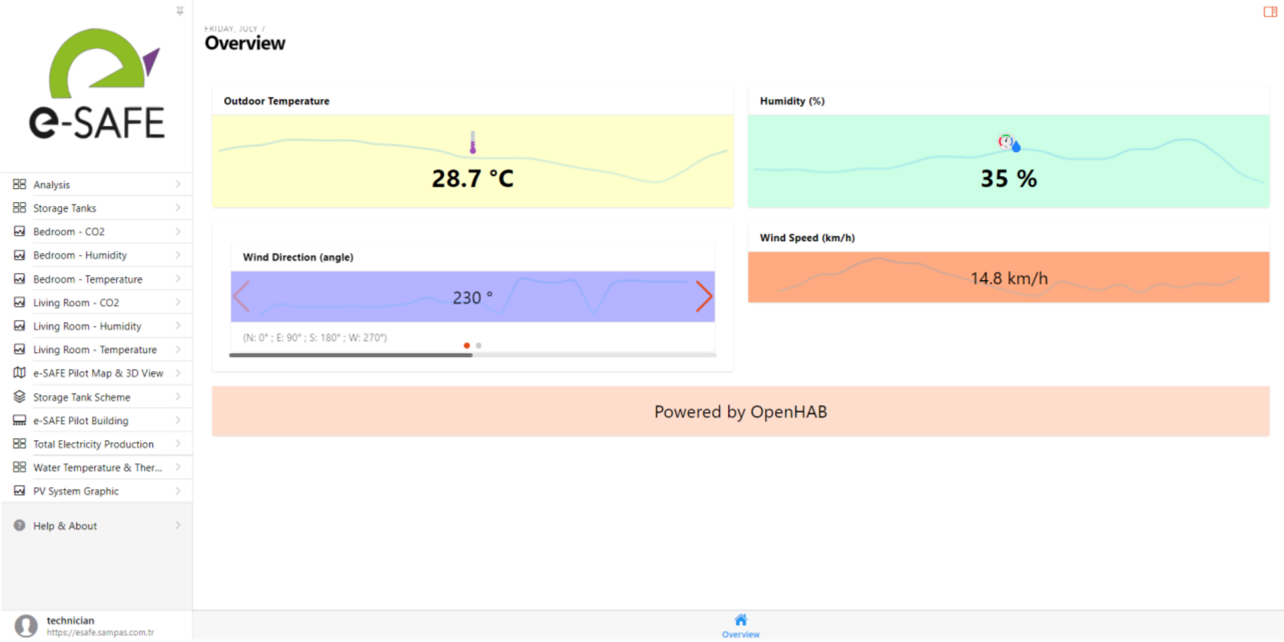

Figure 10. Landing page after sign-in.

Figure 10 shows the landing page that gives the overview about the pilot building in real-time using weather forecasting station, and focuses on the outdoor and environmental probes and parameters including the outdoor temperature, humidity, wind speed and the direction of the wind. It presents the building level interface to see a brief picture of the monitored outdoor parameters and delve into their details and visualization by clicking the specific parameter (e.g. Wind Direction). When the technician clicks on Wind Direction widget, the page directs the user to a new tab which presents a chart designed for **e-**BEMS by the developers. The chart includes dynamic values of wind speed and wind direction (Figure 11). When the user clicks on the little arrows on Wind Direction widget; they can see a tool to reach a data table of wind direction and wind speed (Figure 12).

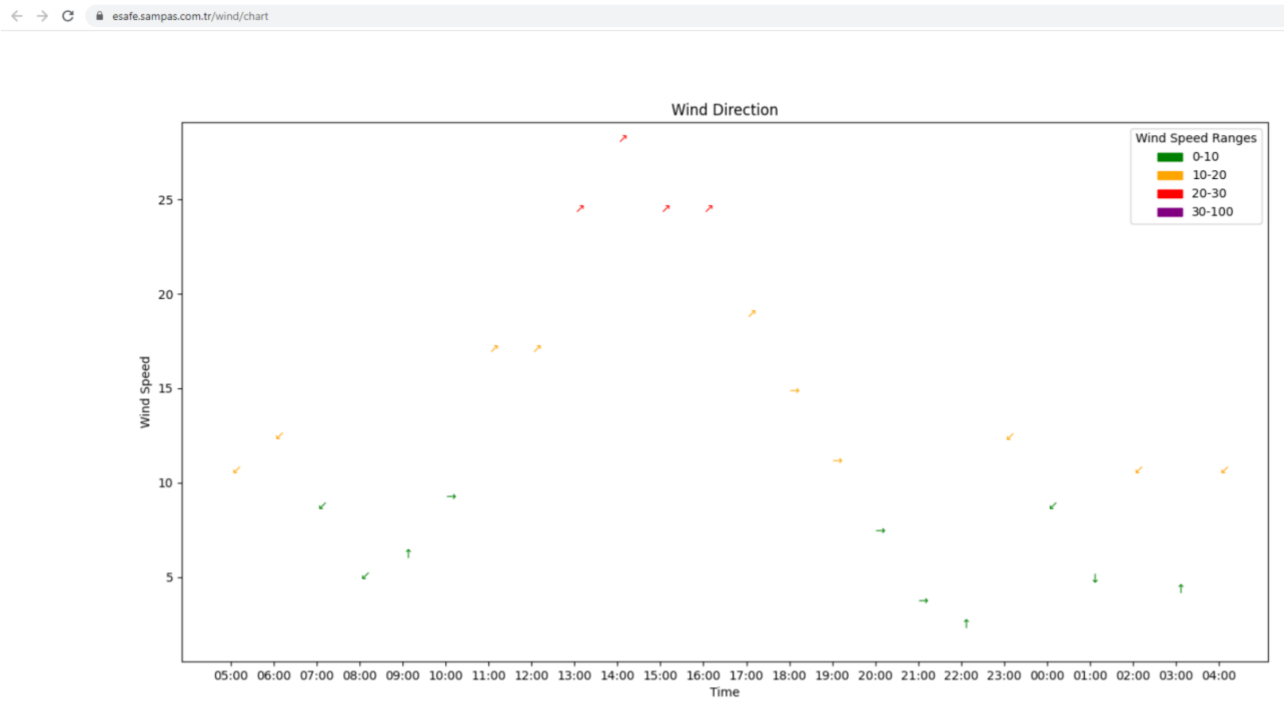

Figure 11. Wind direction and wind speed chart

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url: esafe.sampas.com.tr/wind/table

Wind Data Table

Time	Wind Speed (km/h)	Wind Direction (angle)
06 July 2023 05:00	11.12	230
06 July 2023 06:00	12.96	250
06 July 2023 07:00	9.25	230
06 July 2023 08:00	5.54	240
06 July 2023 09:00	5.54	0
06 July 2023 10:00	9.25	90
06 July 2023 11:00	16.67	60
06 July 2023 12:00	16.67	60
06 July 2023 13:00	24.08	60
06 July 2023 14:00	27.79	70
06 July 2023 15:00	24.08	60
06 July 2023 16:00	24.08	70

Figure 12. Wind data table

For Outdoor Temperature, Humidity and Wind Speed widgets, there are dynamic table embedded in the widgets. As seen in Figure 13, the graph of environmental sensors allows to examine the data at different time intervals.

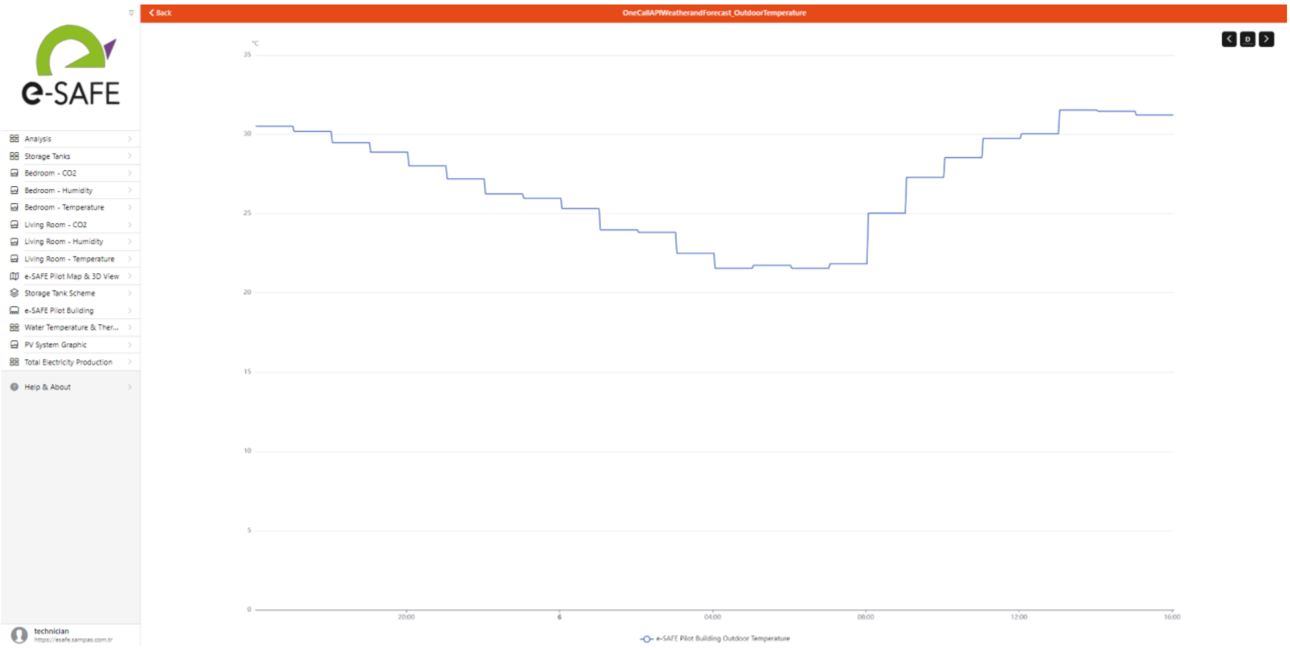

Figure 13. Outdoor temperature graph

Figure 14 shows the analysis page that was created to see indoor data on a scheme. For example, when technician click on the temperature icon, temperature icons pop-up and shows the room-based temperature data.

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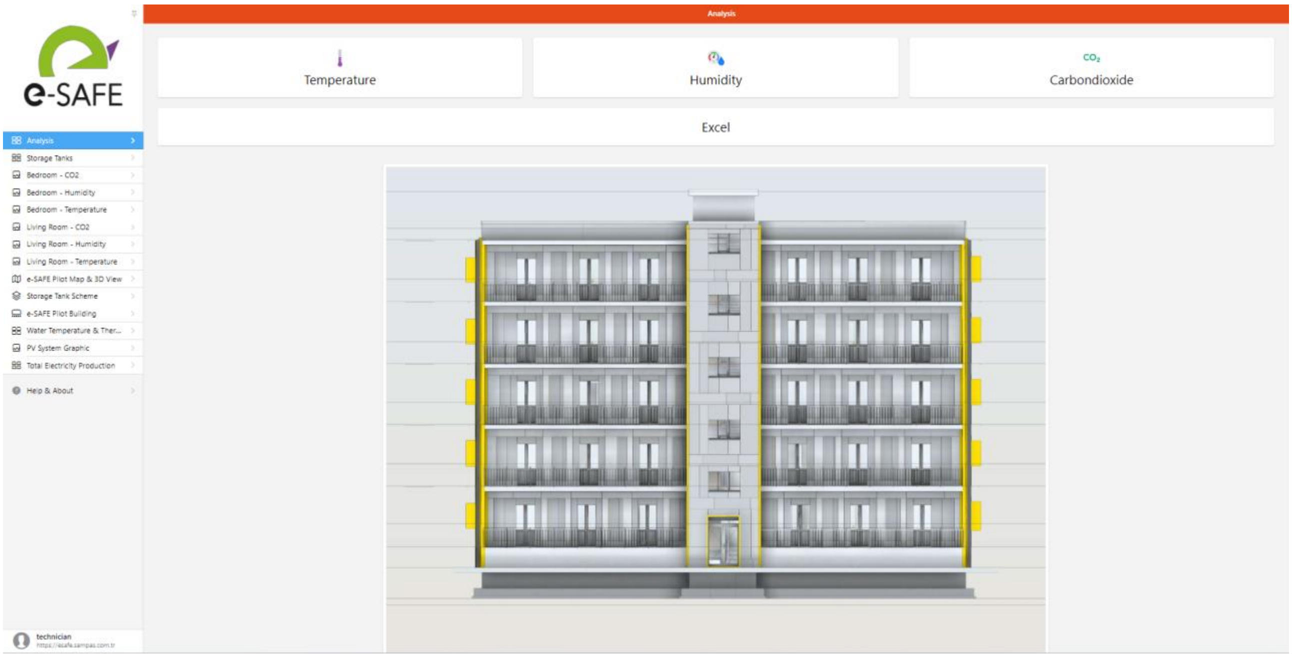

Figure 14. Analysis page

For instance, Figure 15 shows the real-time data of the bedroom temperature of the 5S apartment. The technician can download the room-based temperature, relative humidity and CO_2 data of the apartments through these pages.

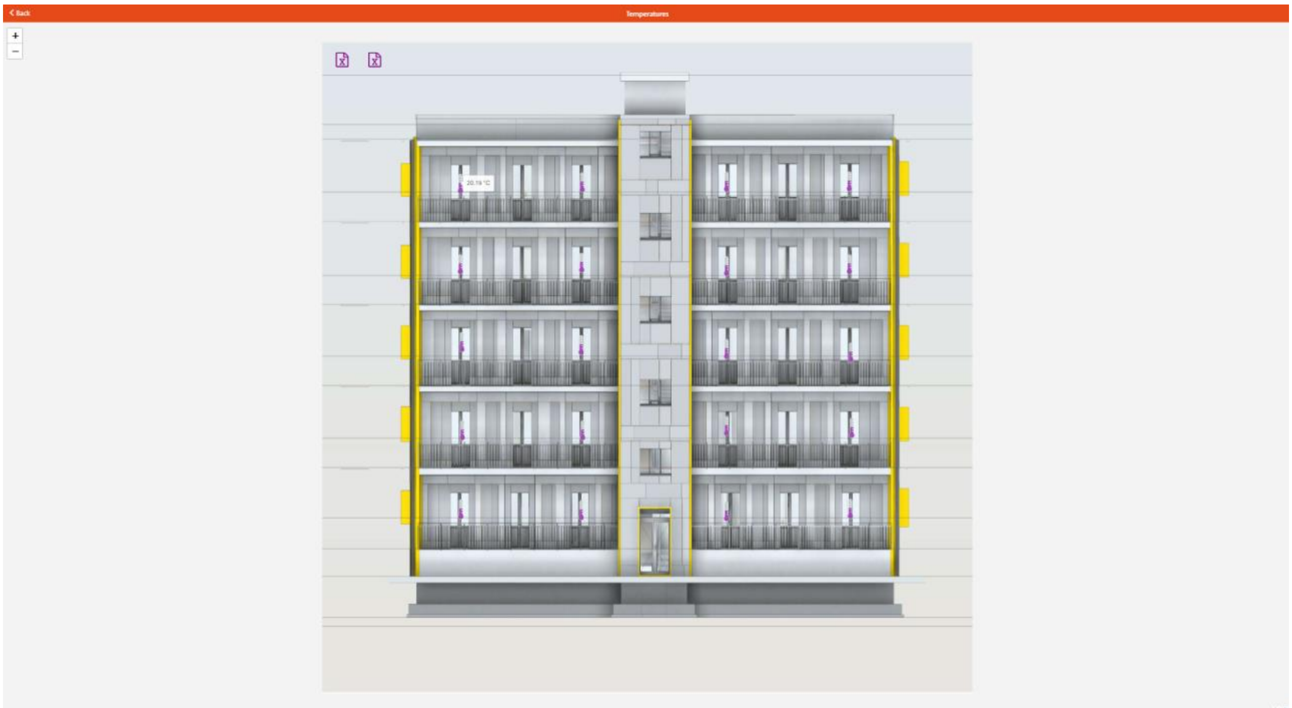

Figure 15. 5S bedroom temperature data shown on temperature page.

When technician click on the temperature icon on a room, the chart of the dataset is opened. This page works as described in the chart control panel (Figure 16).

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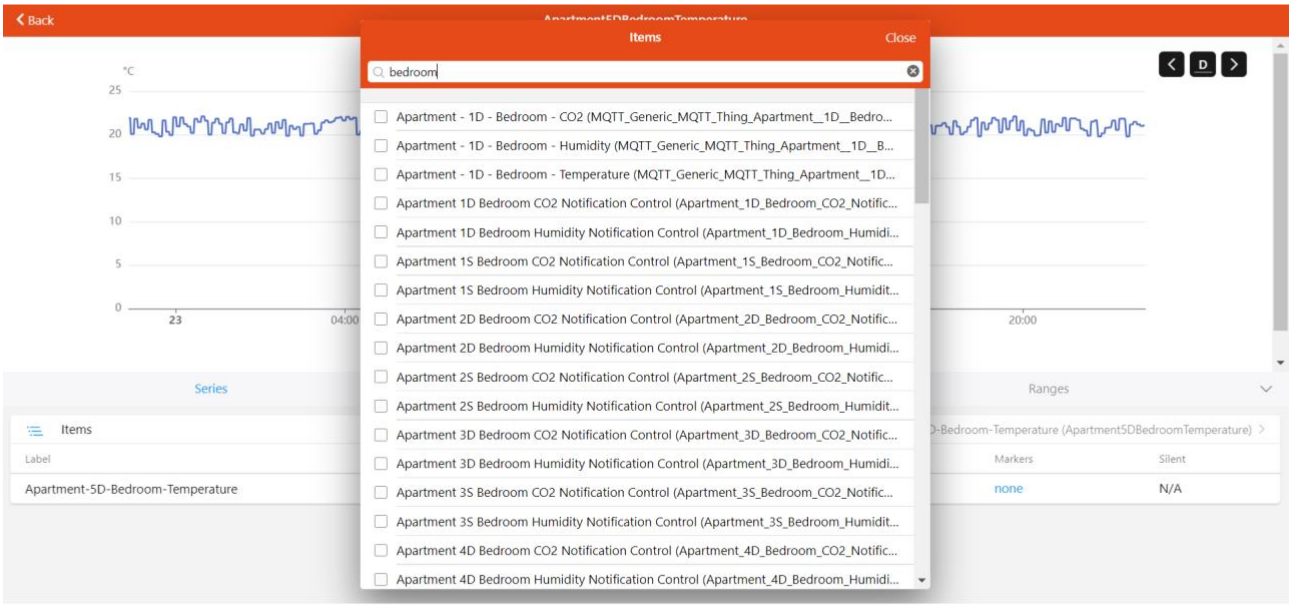

Figure 16. Chart control panel example on bedroom temperature

Figure 17 shows the dataset-specific graphic pages that were created to analyse the indoor environment data of all apartments together.

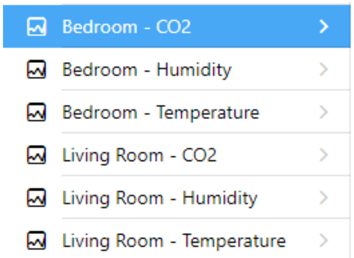

Figure 17. Dataset-specific graphic pages

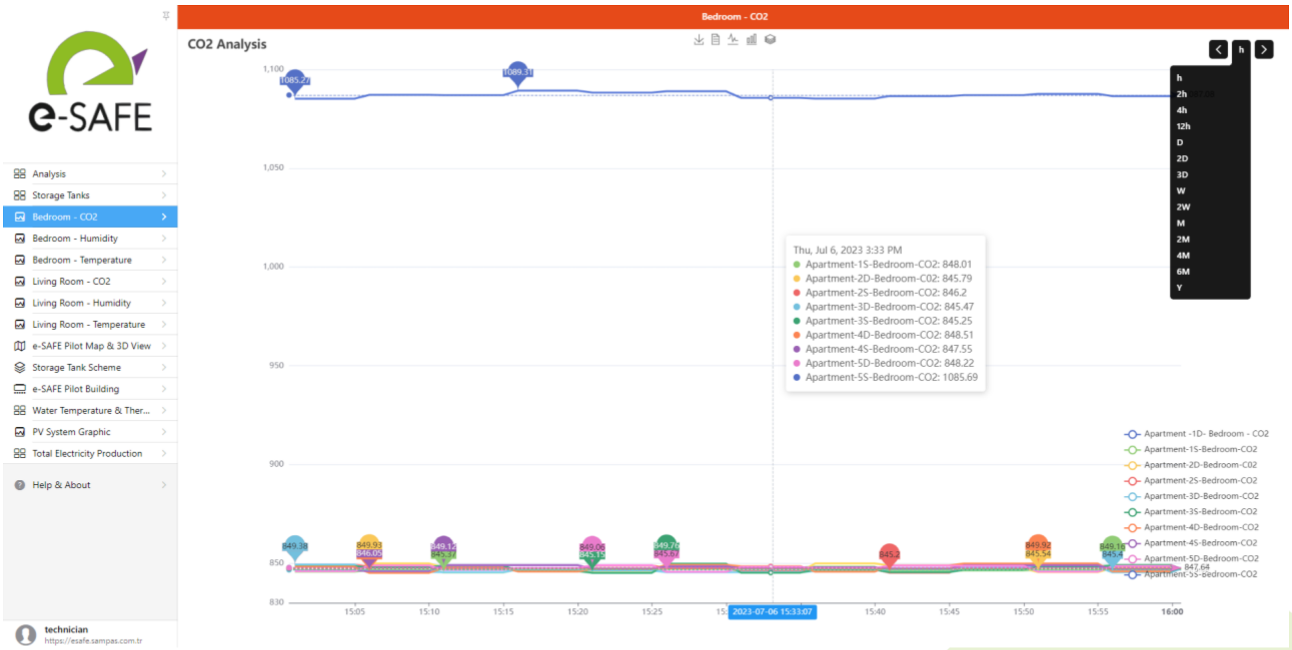

Figure 18. Dataset-specific graphic page example: CO2 analysis of bedrooms

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As seen in Figure 18, all bedroom CO_2 values can be seen in a single graph. With the time range defining feature, time axis of the graph can be changed. With the icons at the top of the page, technician can download the table, change the chart type and view the dataset. There are pages with the same features for three parameters for bedrooms and living rooms.

There is HC (Heating-Cooling) and DHW (Domestic Hot Water) system in the pilot building in Catania. Figure 19 and Figure 20 show the real-time data of the sensors on these HC and DHW heat pumps, storage tanks, and the circuit that connects them. In those pictures, it is also seen that calculated COP values were presented as in real-time data. As a technician requirement, COP value is needed to be calculated by **e-**BEMS. The calculation formula for COP was developed based on the parameters that is directly measured via sensors. That mathematical formula of COP was coded and embedded in **e-**BEMS to show the calculated COP data to technician user for analysing purposes.

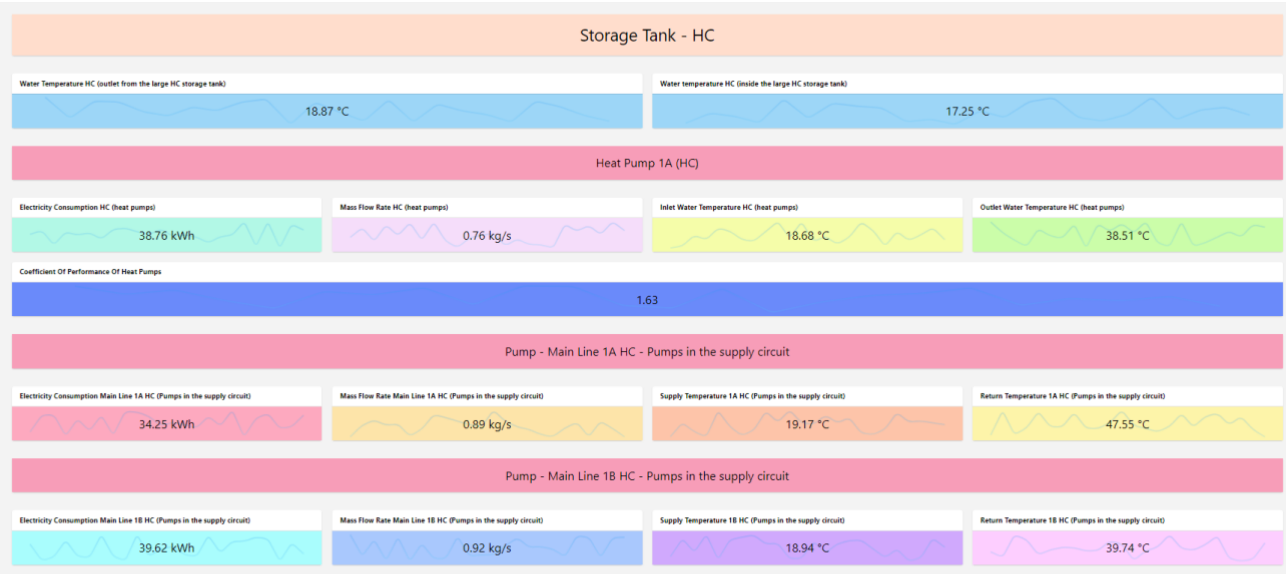

Figure 19. HC Heat Pump and Storage Tank

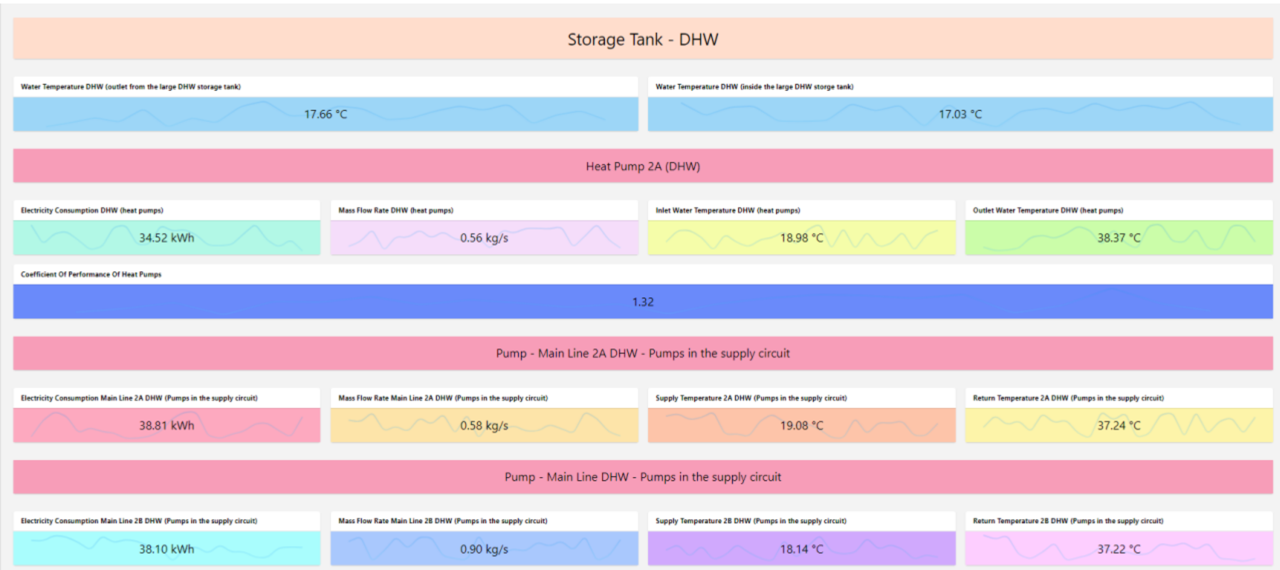

Figure 20. DHW Heat Pump and Storage Tank

Figure 21 shows the summary of the mass flow rates to the apartments in terms of HC and DHW.

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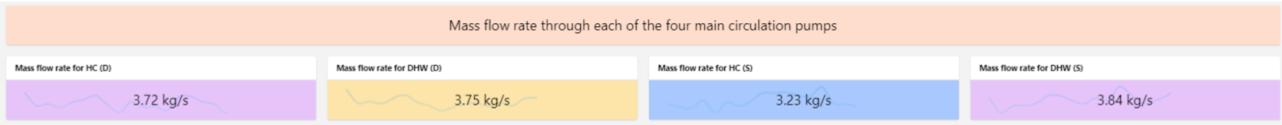

Figure 21. Mass flow rate through each of the four main circulation pumps

On the left side menu bar, there is a page with a scheme of the central thermal system architecture. All measured and calculated parameters are located on this scheme (Figure 22): blue points represent the Heating Cooling related parameters, red points show the Domestic Hot Water values, yellow points indicate the PV related values, black points represent water temperature and electricity consumption of the local **e-**TANKs respectively.

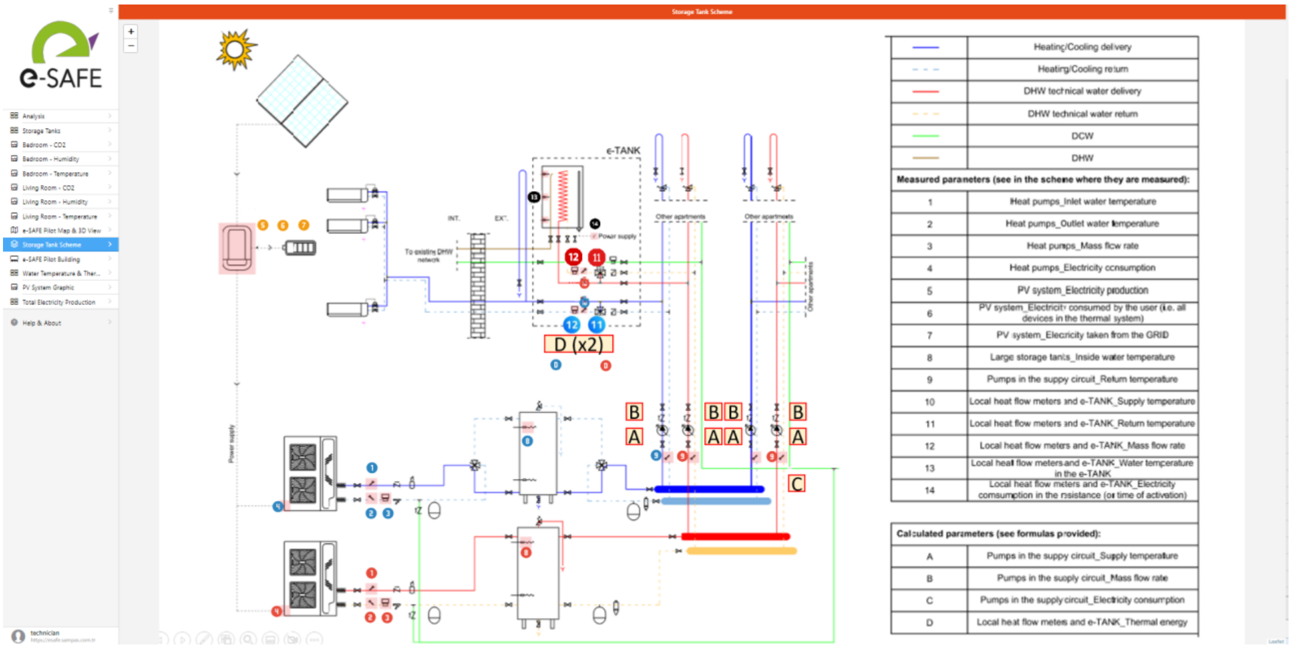

Figure 22. Scheme of the thermal system architecture .

When the technician holds the cursor on the points, real-time data will be displayed (Figure 23).

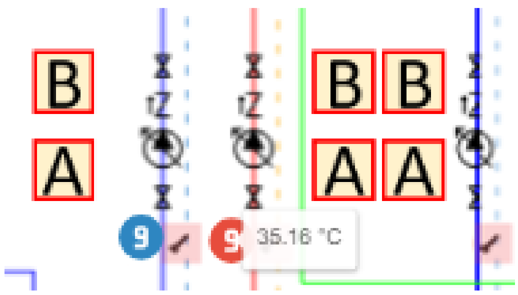

Figure 23. Real-time data coded in the points

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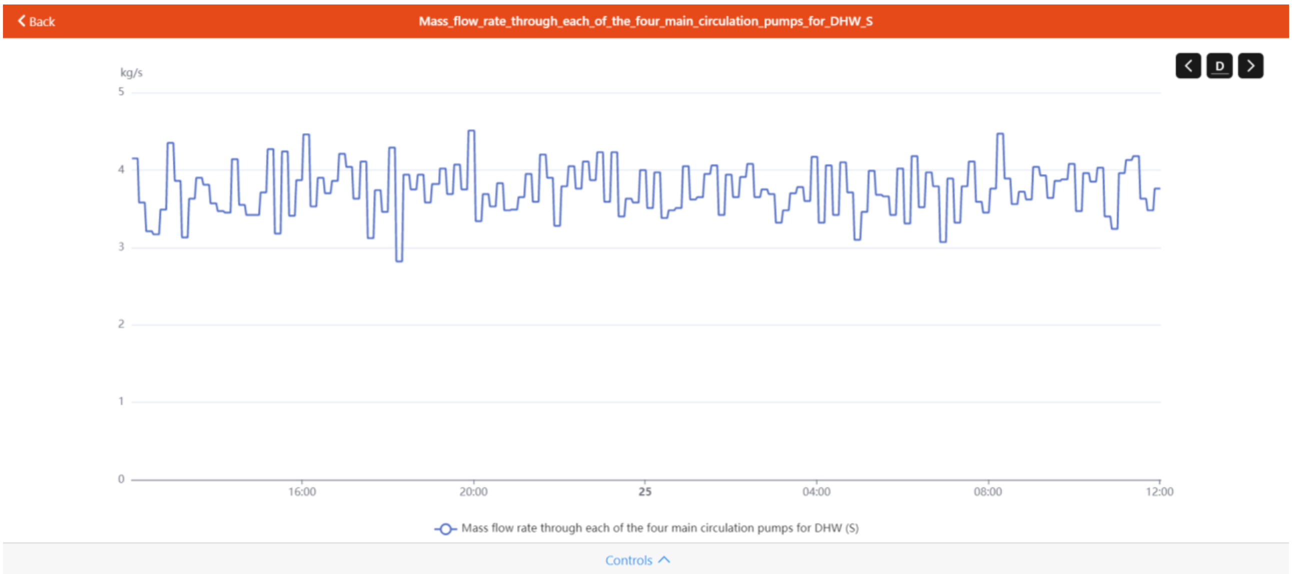

Figure 24. Mass flow rate graph

For example, when one clicks B, the graph of the total mass flow rate in the supply circuit value for HC and DHW can be accessed. Graphics can be edited from the control panel (Figure 24).

To meet the technician user requirement, this mass flow rate value was calculated by writing the system code and added to the web-page as an **e-**BEMS feature. On this page, the measured and calculated parameters can be accessed as real-time data on the scheme, and as data graphs when the points are clicked.

Figure 25 shows the thermal energy related values of each apartment.

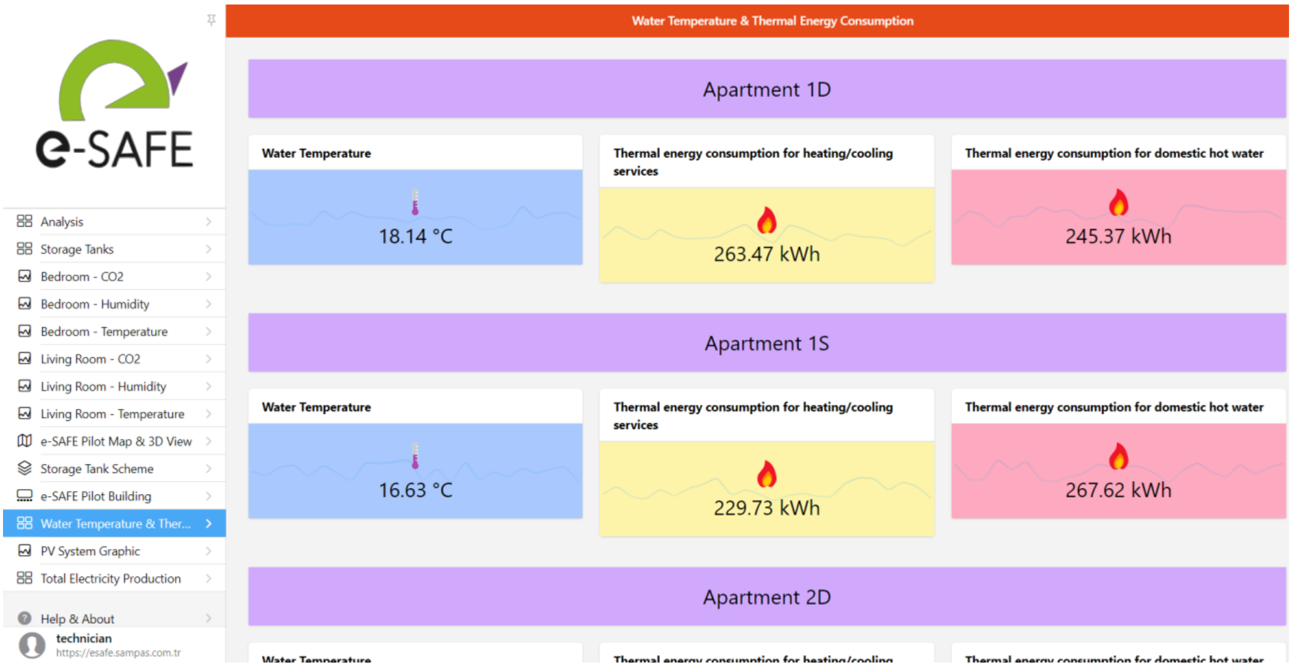

Figure 25. Water temperature and thermal energy

Technician can control and monitor apartments' local **e-**TANK data. When the technician clicks on the box of the data, it redirects to the data graph (Figure 26).

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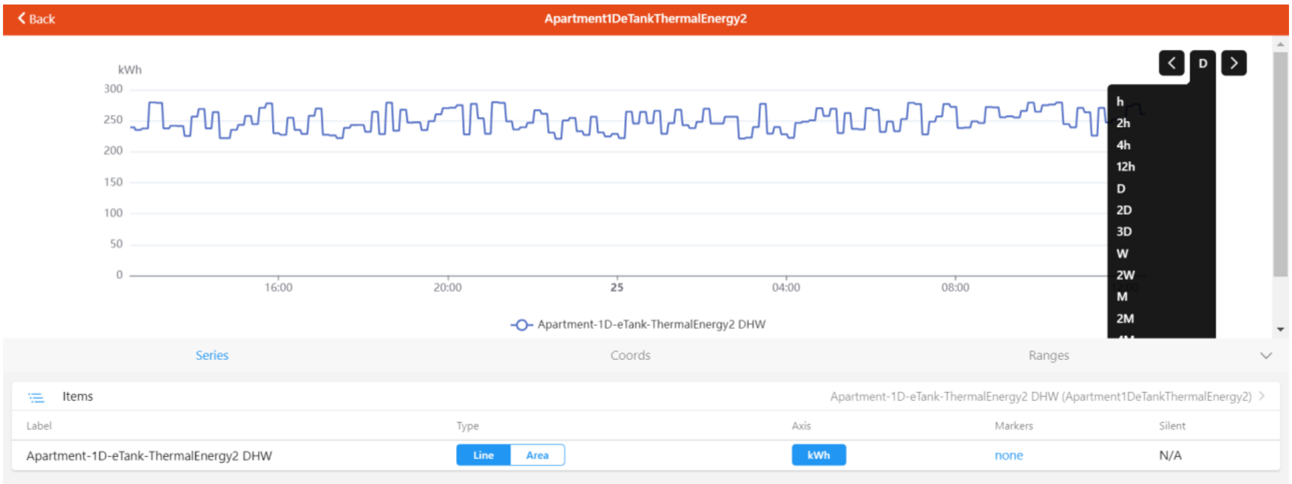

Figure 26. Thermal energy graph and graph control panel

The last page on web module regarding the data monitoring is PV System. Figure 27 presents the PV System sensors located above the roof of the pilot building. As it is a graph page, technician can use the features on top of the page and download the graph, change the graph type and see as a dataset.

Figure 27. PV System graphic page

There is one page named as "Total Electricity Production", to show calculated values of daily and monthly total electricity production. The technician can either click on PV System widget on top or "Click for Electricity Production Rates" button on the bottom to reach the calculated total values. After clicking, the user will be redirected to a new page https://esafe.sampas.com.tr/total/electricity. Figure 28 shows daily and monthly total electricity production values, and two graphs with the rate of daily/monthly total electricity taken from the GRID and taken directly from the PV system.

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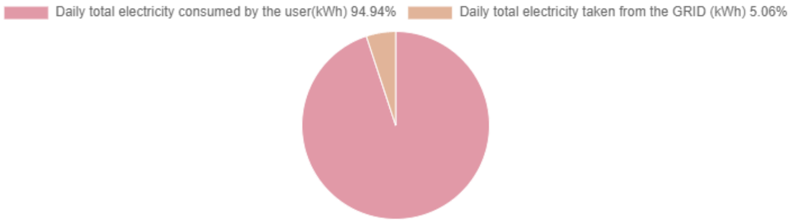
PV_TOT	Value (kWh)	EGRID
Daily total electricity production (PV)	12266.51	Daily total electricity taken from the GRID
Monthly total electricity production (PV)	226617.84	Monthly total electricity taken from the GRID



Value (kWh)	Total electricity taken from PV	Value (kWh)
268	Daily total electricity taken from PV	5027.29
7104.21	Monthly total electricity taken from PV	206636.01

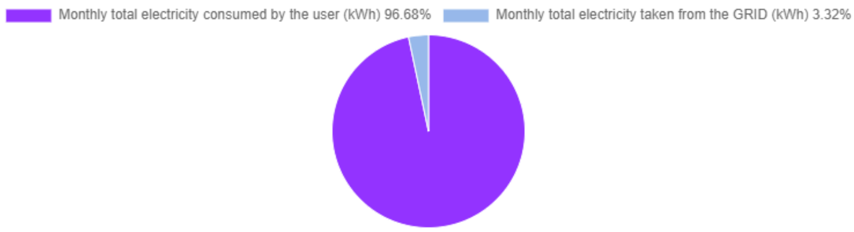


Figure 28. Daily and monthly total electricity production values

There is also a page (**e-**SAFE Pilot Map & 3D View) that uses Open Street Map API [8], and shows the building location (Figure 29). This page includes the visuals of the building. When the users click on the building icon, they can view the images on the tabs of the pop-up page (Figure 30).

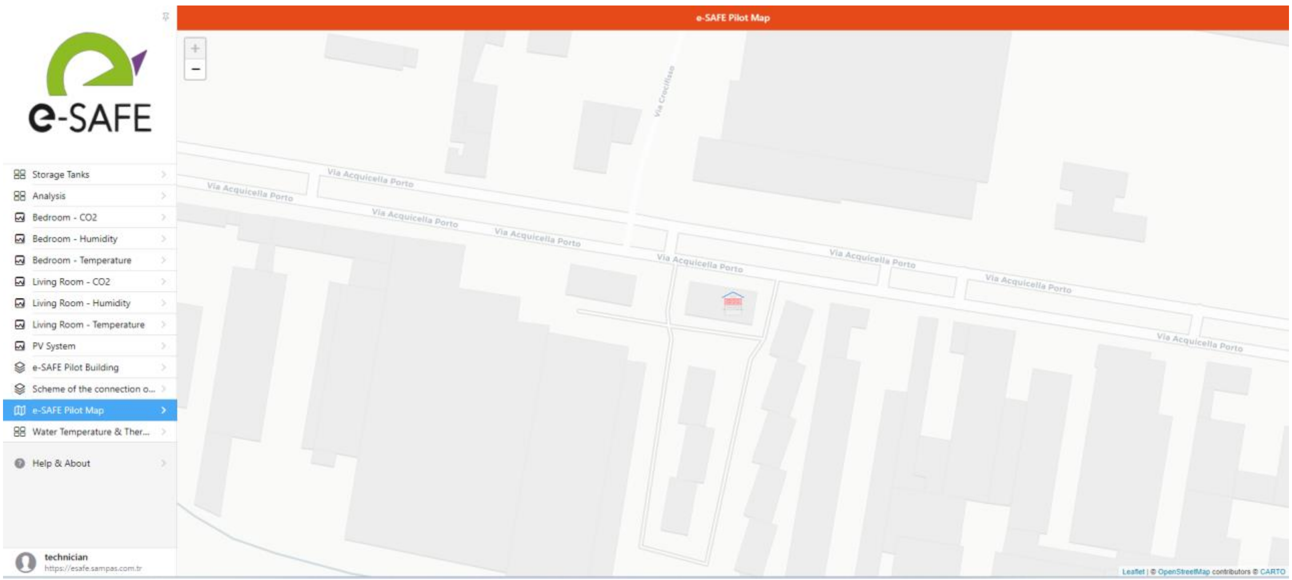


Figure 29. Location of the Catania pilot building

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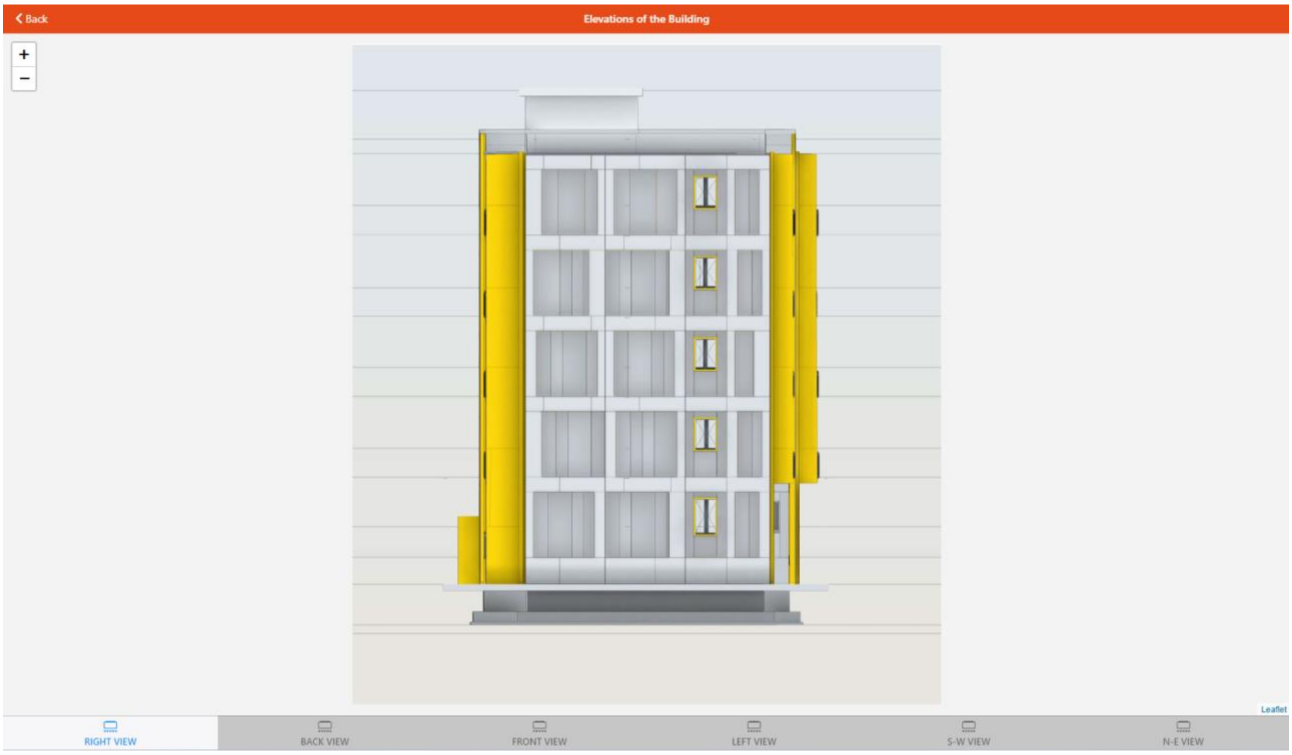

Figure 30. e-SAFE Pilot Map & 3D View Page

Also, there is one page for building photographs (Figure 31). The user can see various pictures of the building on different tabs on this page.

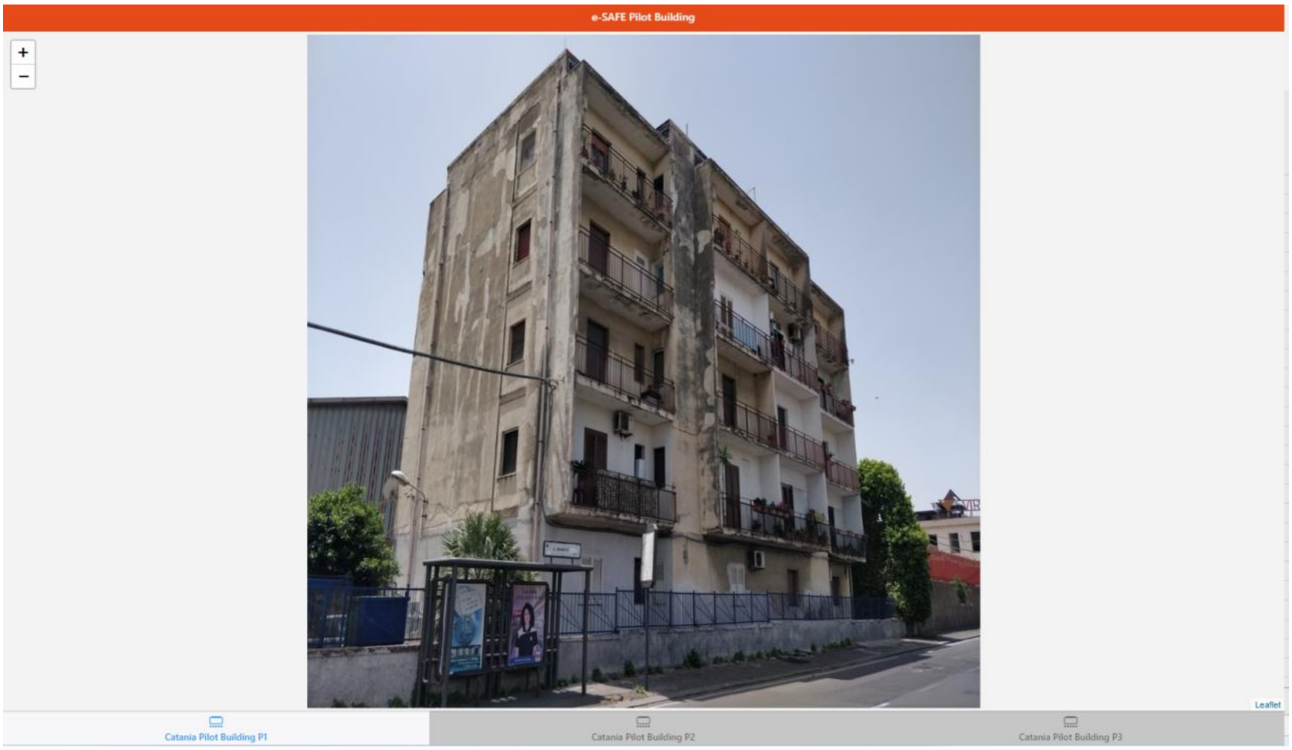

Figure 31. Photographs of the Catania pilot building

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4.2 Mobile App Module for Resident User

The mobile module is for residents to verify and monitor the parameters in their apartment. Residents can see the floor plans of the apartments, check the room temperature, relative humidity and CO_2 etc. where the sensors are installed.. The mobile application of **e-**BEMS was developed for Android devices. The .apk file is provided by SAMPAS to the residents as end-users. Mobile application can work both Wi-Fi and mobile data.

4.2.1 Settings & User registration and login

Residents are required to do server settings to use the app after installing the .apk file that is provided by SAMPAS. Figure 32 shows the mobile application's logo.

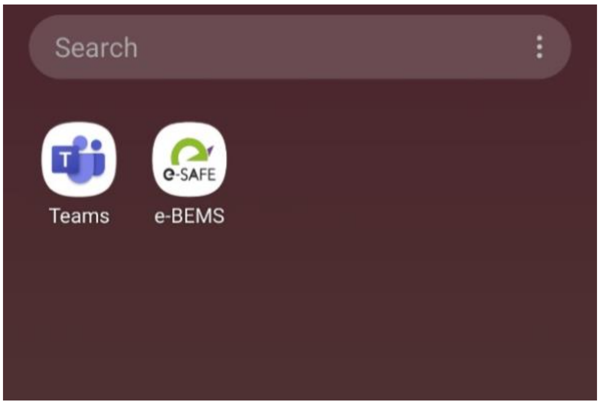

Figure 32. Mobile application logo

When the user first opens the mobile application, it starts to search local servers in the network. Then immediately the screen seen in Figure 33 occurs because the server cannot be found in the local network.

The user needs to do server setting, that is why they need to click on "go to settings". On the settings page seen in Figure 34, residents need to click on add server and set the local and remote servers (Figure 35) by using the information that will be provided to them.

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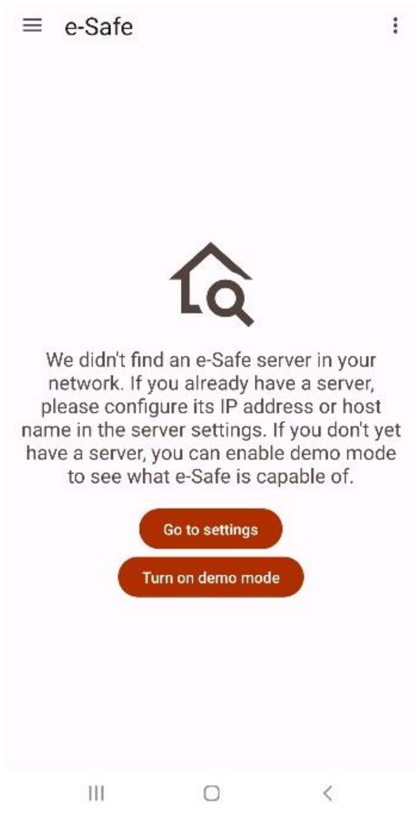

Figure 33. Server page

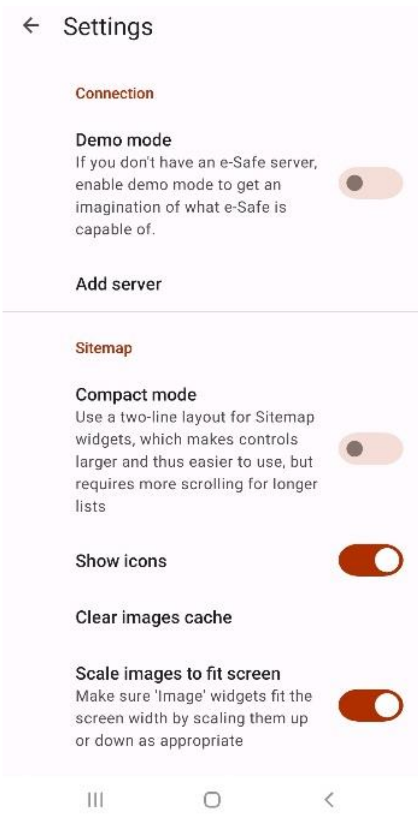

Figure 34. Settings page

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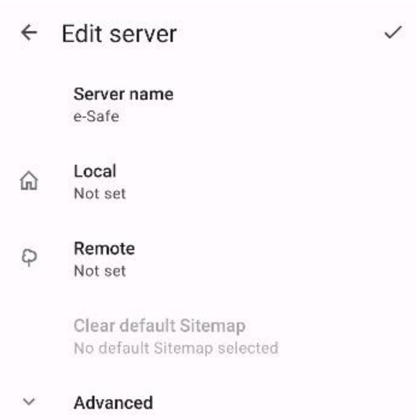

Figure 35. Edit server page

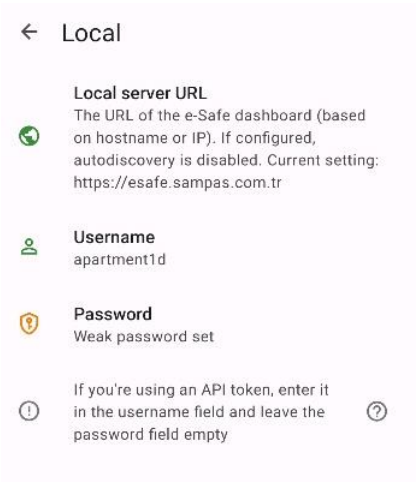

Figure 36. Local server settings for apartment 1d as an example

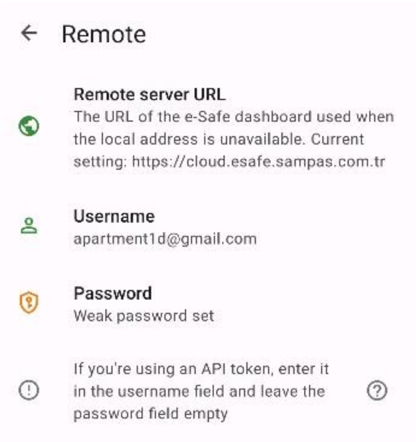

Figure 37. Remote server settings for apartment 1d as an example

Then after clicking the back arrow, they need to approve the settings. Finally, the **e-**SAFE server will be set on their phone. After setting the server, the certificate needs to be accepted. A pop-up screen will open and ask if the user wants to continue or not.

Figure 38 shows the main landing page. The user clicks on the **e-**BEMS button, and will be redirect to the overview page that presents the environmental data (Figure 39). When the user clicks on the three lines on top of this page, the side menu will open (Figure 40).

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Figure 38. **e-**BEMS Mobile Application main landing page

Figure 39. Overview page

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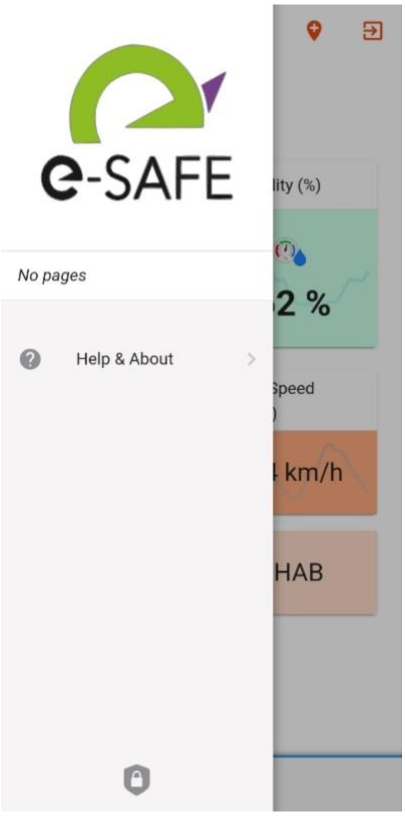

Figure 40. Side menu

On the bottom of that side menu (Figure 40), there is a lock button for sign-in to the resident account. Figure 41 shows the sign-in page for the residents.

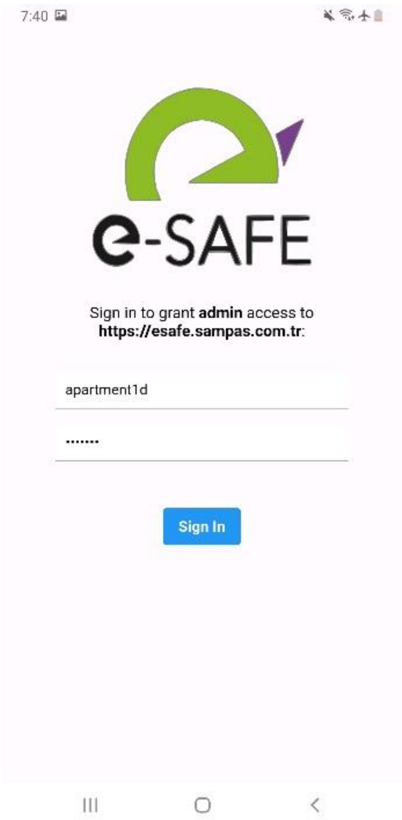

Figure 41. Sign-in page

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4.2.2 e-BEMS Mobile application for resident user

Figure 42 shows the overview page for "resident user" that presents the outdoor environmental data. This page is also the first page after signing-in the account. Users can click on the real-time data and access the data graph as it is seen on the Figure 43.

Figure 42. Overview page for resident user

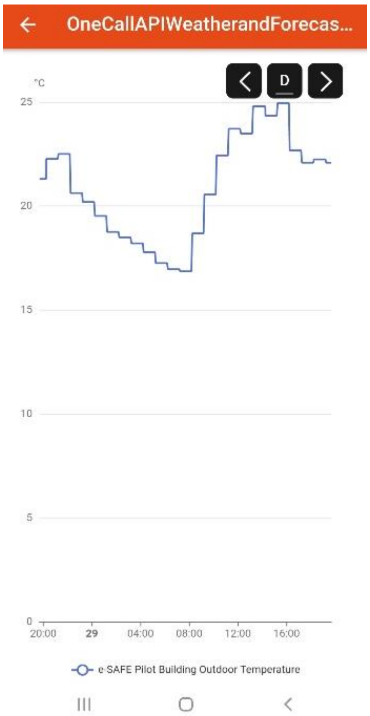

Figure 43. Data graph example for environmental quality sensors on above roof

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Figure 44 shows the side menu where the user can select pages that were designed to reach **e-**BEMS data. At first, the user can see indoor sensors' real time data on floor plan (Figure 45).

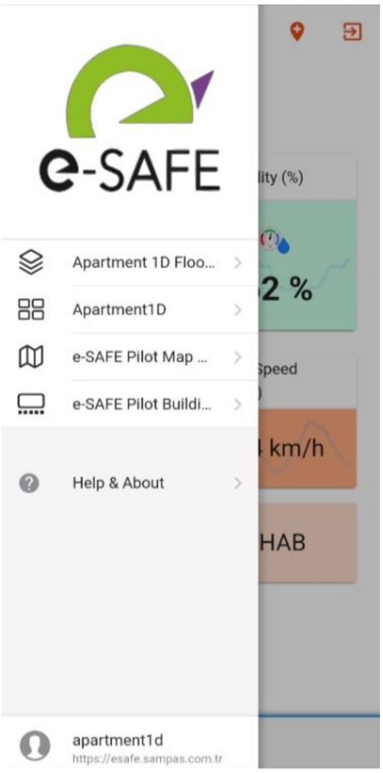

Figure 44. Side menu

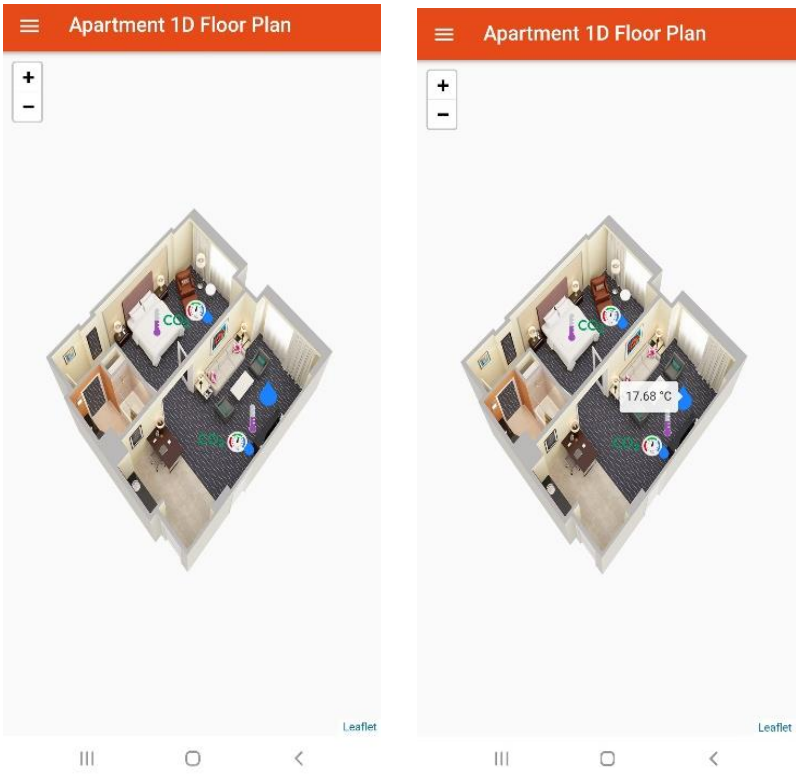

Figure 45. Floor plan as an example

Figure 46 shows the apartment specific main page of the mobile application where the residents can see their own features in real-time. Temperature, humidity and CO_2 data is shown on this page.

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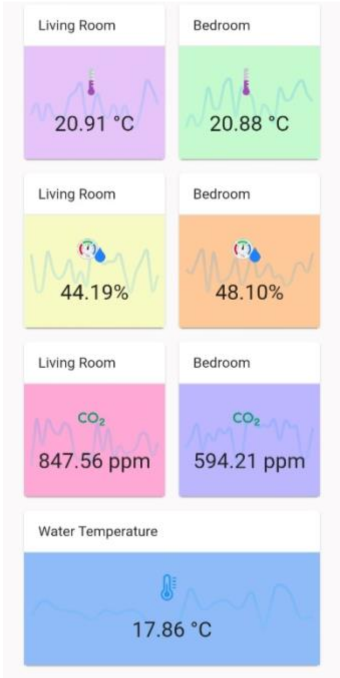

Figure 46. Apartment specific sensors' real time data

Water temperature of the local e-TANK is also shown in this main page (Figure 46) and the color is changing based on the temperature changes (See Section 4.2.3).

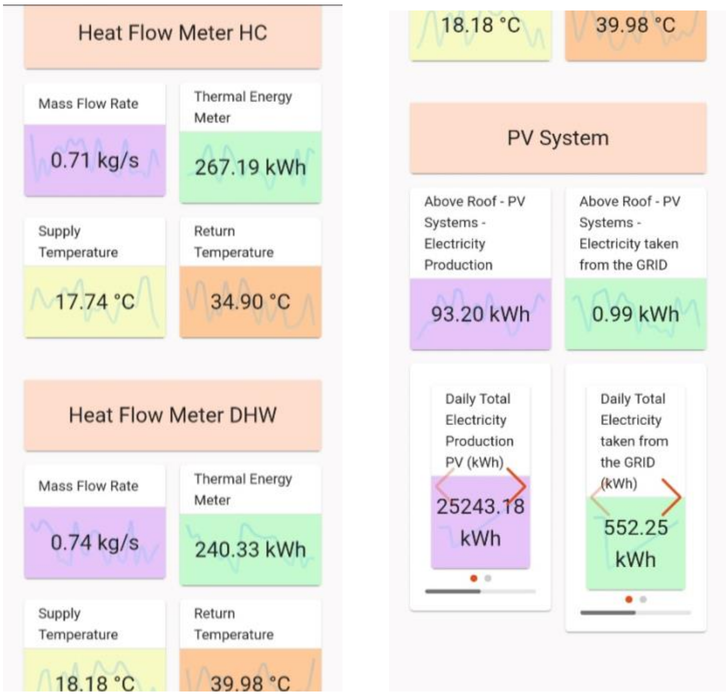

Figure 47. Local e-TANK specific real-time data and PV System data

When the user scrolls down in this page, they will see HC and DHW specific sensors' real time data (mass flow rate, supply temperature, return temperature, thermal energy), and at the end the PV System data in real-time. The resident can see PV_{TOT} (in kWh), E_{GRID} (in kWh) in an integrated time step, daily and monthly total to monitor their total energy consume and production on PV (Figure 47).

e-SAFE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 893135.

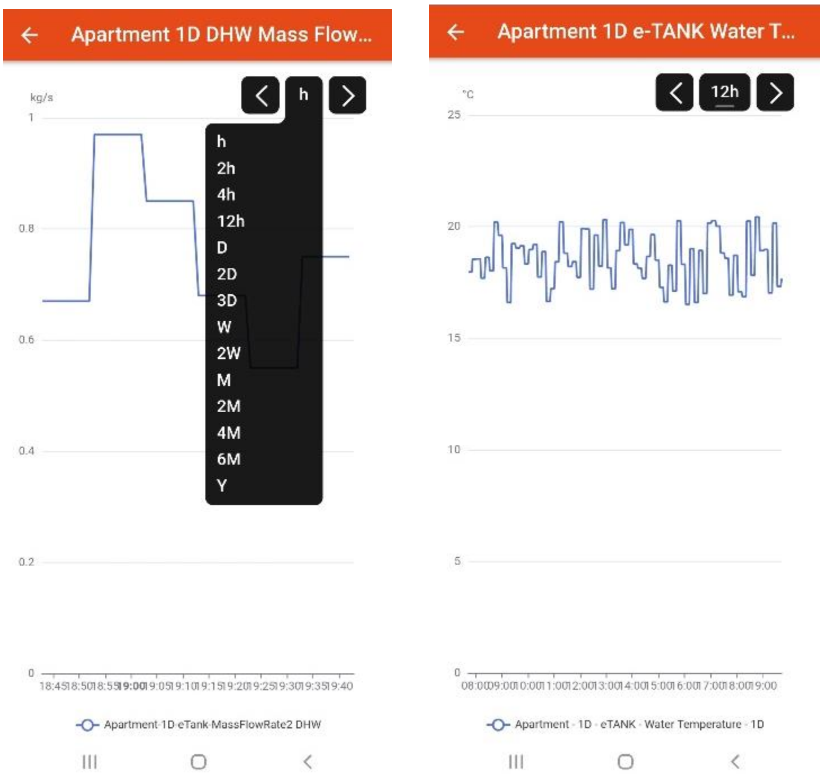

Figure 48. Graph examples on mobile application

The mobile application also offers its users the feature to visualize data and see it in the form of daily, weekly, monthly graphs. Figure 48 presents two different version of visualizing the data. The left graph is a representation of hourly graph, and the right graph shows the data graph over twelve hours.

4.2.3 Notification Messages of **e-**BEMS Mobile App

For **e-**BEMS mobile application configuration, user-friendly notifications were designed by ICT partners of **e-**SAFE. Figure 49 shows some examples on the notification page. The mobile application can send notification to the resident based on their usage preference of the mobile application. However, in order not to bore the user, messages are triggered once a day if it is a recurring situation.

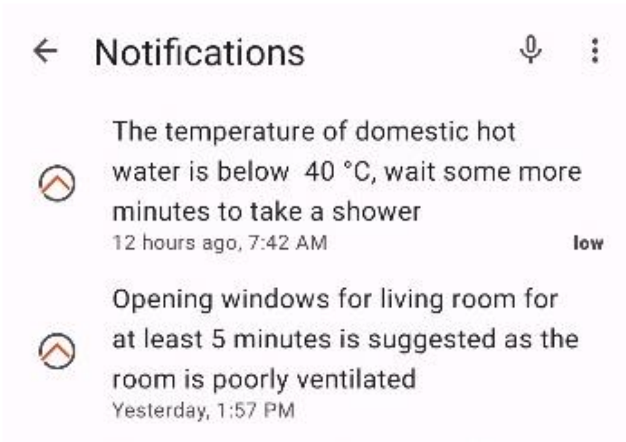

Figure 49. Notification examples

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Message List of e-BEMS

Indoor Quality

• when CO_2 > 1000 ppm in the living room

"Opening windows for living room for at least five minutes is suggested as the room is poorly ventilated"

• when CO_2 > 800 ppm in the bedroom

"Opening windows for bedroom for at least five minutes is suggested as the room is poorly ventilated"

• when RH > 75% in a bedroom

"There is too much humidity in the bedroom, I suggest that you open the windows for at least five minutes"

• when RH > 75% in a living room

"There is too much humidity in the living room, I suggest that you open the windows for at least five minutes"

• In the SUMMER, when $T_{OUT} > (T_{IN} + 3\ °C)$ and the fan-coil is ON

"We suggest that you keep the windows and doors closed, in order not to waste energy"

• In the WINTER, when $T_{OUT} < (T_{IN} - 3°C)$ and the fan-coil is ON

"We suggest that you keep the windows and doors closed, in order not to waste energy"

• Colors associated with **e-**TANK Water Temperature (Figure 46):

- If T ≤ 40 °C: light blue
- If T > 40 °C: green
- If T > 45 °C and the electric resistance is ON: orange

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5. CONCLUSION

This deliverable presented the **e-**BEMS platform components that should be installed in the real pilot in Catania. They will have an important role in monitoring the energy performance of the pilot, while also transferring the **e-**SAFE project's practices and outcomes to the end-users. Although the system has been working so far with simulated data, it has been determined and modelled in detail. The model structure is ready to work with real data when real installations in the pilot building in Catania will be completed. The pre-established probes and MQTT network will be connected to the local server in Catania and will directly work with real data.

To implement the **e-**BEMS in the pilot building during the renovation works, SAMPAS will coordinate the provision of the IT components (gateways, sensors, smart meters) and will supervise the installation and the configuration of **e-**BEMS. UNICT and UNIBO will assist SAMPAS in the provision of the probes. This will allow the real-time integration of all sensing probes with **e-**BEMS and to develop the required interfaces for building managers, technicians, and residents.

The following features have already been developed and added to the final version of the **e-**BEMS platform:

- Revision and finalization of the data model according to the real pilot implementation in Catania.
- Configuration for the integration with the "to be installed hardware" components on the pilot site (smart appliances, smart meters, building automation system and IoT interfaces of e-SAFE building components.
- Mobile application for the residents.
- Development and integration of the advanced user interfaces and analytics for technicians.
- Post-processing of monitored data and comparison with historical data.

The next and final version of **e-**BEMS will be reported in M48 at the end of the project, and it will present the required upgrades to the interfaces (if any). So far, all the probes were connected, and the model was able to operate with stimuli data via MQTT. In the last version that will be submitted at M48 of the project, the probes will be integrated into the real-world installation system in the building and will work with real data. Data transfer via MQTT and the system can operate automatically as planned.

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