DELIVERABLE REPORT

WP4 ICT infrastructure

D4.4

e-SAFE BEMS early version

Due date

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LEAD PARTNER

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CONTRIBUTING PARTNER(S)

ENG

LEAD AUTHOR(S)

M. Serdar Yümlü, Caner Tosunoğlu, Levent Misafir, Berk Yantaç, Cenk Güreken (SAMPAS)

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TYPE

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- ☒ DEM - Demonstrator
- ☐ DEC Websites, patents filling, videos, etc.
- ☐ OTHER
- ☐ ETHICS – Ethics requirement
- ☐ OPRP - Open Research Data Pilot
- ☐ DATA – Data sets, microdata, etc.

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1.1	Giuseppe MARGANI	Project Coordinator	UNICT	26.04.2022	GM

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CONTENTS

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EXECUTIVE SUMMARY

This Deliverable corresponds to the first and early version of the **e-**BEMS (Building Energy Management System). The present document contains the collection of all the developments carried out in Task 4.3. It contains the definition of the BEMS as an ICT solution for monitoring purposes and for managing the energy systems.

The objective of this deliverable is to provide the first version of the **e-**BEMS system that will monitor and partly control the building's mechanical and electrical equipment within Task 4.3.

In this way, the document first analyzes the BEMS scope and provides some examples of BEMS frameworks that are suitable for the project purposes. **e-**BEMS is then analyzed from the end-user's perspective through user stories, and functional and non-functional requirements within **e-**SAFE project are considered. Probes for indoor and outdoor comfort, energy production and consumption, and also thermal system probes, are presented in this first version.

Moreover, the first version of the **e-**BEMS is provided with its main features and components. Supported data communication and exchange protocols, the data model of the **e-**BEMS environment and user interfaces are provided as the base platforms.

The first version of **e-**BEMS relies on simulated data and for this reason the runtime environment is not being moved now to a dedicated hosting platform. **e-**BEMS will run in development environment at SAMPAS premises for this first version. The installation on the real pilot will start at M30 within WP5 (Task 5.5 and Task 5.6).

The final version of the **e-**BEMS, delivered at M30, will include real pilot installation details for hardware and sensing components. The integration approach will be addressed also in the final version at M30.

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GLOSSARY OF TERMS

ACRONYM	DESCRIPTION
BEMOSS	Building Energy Management Open Source Software
BEMS	Building Energy Management System
BMS	Building Management System
CSR	Corporate And Social Responsibility
DR	Demand Response
HVAC	Heating, Ventilation, And Air Conditioning
ICT	Information and Communication Technology
MS/TP	Multiple Spanning Tree Protocol
OSGi	Open Services Gateway initiative
PR	Periodic Report
RTU	Remote Telemetry Unit
SOA	Service Oriented Architecture
WP	Work Package

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1. INTRODUCTION

The deliverable aims at providing the first version of the Building Energy Management System called **e-**BEMS.

The document introduces building energy management systems, their general characteristics and the activities done for the specific **e-**SAFE **e-**BEMS platform during the first period of the project. Task 4.3 aims at designing and developing the system architecture and the overall representational model for the **e-**BEMS. For this purpose, this deliverable first describes the general requirements of the **e-**BEMS component. Several alternative open source and proprietary **e-**BEMS framework and platforms are evaluated. Within this period, the requirements in terms of data agnostics, scalability, compatibility, interoperability, governance, and standards are identified and these criteria drive the overall reference architecture selected for the **e-**BEMS platform.

This document also contains the end-user requirements analysis from two different user type perspectives. Functional requirements needed by residents and also by building managers and technicians are grouped into two categories. This document delivers **e-**BEMS probes and the corresponding parameters that should be measured for indoor and outdoor spaces, for energy production systems and also for thermal systems in **e-**SAFE pilot buildings.

e-BEMS design includes the first version of the logical entities, user interface definitions, application and data management, operating system and the framework, connectivity layers with hardware interfaces for the **e-**SAFE components (e.g. **e-**TANK, water temperature sensors, electrical PV production).

The output of this document is the description of the first and early version of the **e-**BEMS Building Energy Management System. This work is part of Task 4.3 by SAMPAS and D4.4 is a prototype with simulated data and environment since no real sensors are installed and integrated now. Further implementation of real probes, sensors and measured parameters of the **e-**SAFE pilot building will be integrated and reported in the second and final version of this deliverable. Final version of **e-**BEMS will not only cover the real implementation and integration in the pilot building, but also further integration with the **e-**DSS developed by ENG, through service-oriented architecture. Indeed, the final version of **e-**BEMS will be able to monitor data from Catania pilot coming from sensors, probes and so on and therefore its integration with the **e-**DSS tool will be more useful. As the real pilot implementation has not been started yet, and this first version of **e-**BEMS is only available with simulated data, **e-**DSS integration is postponed for the second period.

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 particular reference to the first and early version of **e-**BEMS tool.

1.2 Relation to other activities

D4.4 is one of the official reports of Task 4.3. Task 4.3 take advantages of the work done in WP3 with regards to the technological solutions proposed in the project for the energy probes and parameters (Task 3.3). The outcome of this deliverable will be the basis for the final version of the **e-**BEMS Building Energy Management System (Task 4.4 and D4.6 Integrated BEMS) [1, 2].

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1.3 Document overview

The report is structured as follows:

Chapter 2 describes the building energy management concepts and introduces several different possible alternative BEMS architectures and frameworks.

Chapter 3 provides **e-**BEMS high level functional specification providing 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 4 represents the core of the document: the first version of the **e-**BEMS tool is described. The general subcomponents of the **e-**BEMS frameworks, its communication protocols, ontology and semantic model, and user interface designs for the first version.

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2. BUILDING ENERGY MANAGEMENT SYSTEMS

This section describes the general concept of building energy management concept and systems.

2.1 Building Energy Management Systems (BEMS)

Managing the energy systems and other needs in buildings efficiently and intelligently can have considerable benefits. This requires IT-based monitoring and control systems. These systems deal with existing energy-related data streams of a building's infrastructure, such as its heating, ventilation, and air conditioning (HVAC) and lighting systems.

A building energy management system (BEMS) is a way to monitor and control the building's energy needs. It provides visualization and analysis of energy data to enable better energy-related decision-making. Next to energy management, these systems can control and monitor a large variety of other aspects of residential and/or commercial buildings. The BEMS technology allows end-users to control their living and/or working areas with suitable devices and sensors.

2.2 General characteristics of BEMS

A Building Management System (BMS) is generally defined as a cost-effective computer-based control system installed in buildings that monitors and controls the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems [3]. BEMS systems are mainly used for four main purposes [4]:

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

BEMS systems mainly control several different features of buildings or home including smart meters, heat pumps, renewable energy production systems (solar, wind, geothermal, etc.), lighting systems, storage, or heating and/or cooling systems. Figure 1 provides an example of the measurement points for a residential building.

There are many advantages of BEMS some of them are reported as follows:

- Sustainability: many business owners are under increasing pressure to reduce their energy consumption. A BEMS will detect regular usage patterns and compare them to your expected or intended levels, allowing you to reduce energy waste while maintaining occupant comfort. A BEMS can control building's energy consumption; fully automatically, day-in and day-out giving you complete peace of mind that your energy usage is fully optimized.
- Cost-saving: saving energy is also beneficial to residents' bills. Reducing waste will help users save money on building's operational costs. With a BEMS, users can rapidly see how they can save money while still providing a good user/tenant experience.
- Adaptation: a BEMS also helps a built environment adapt to changing occupant needs. New goods must be compatible with current installations as requirements change, reducing the cost of reinstalling systems and the waste of perfectly fine equipment.
- Social responsibility: with a BEMS, users have tangible proof of their building's contribution to wider corporate and social responsibility (CSR) goals. A BEMS will provide reports to demonstrate how a building's energy usage and carbon emissions are reducing, helping users meet legislative and CSR demands with external stakeholders, decision-makers and more.

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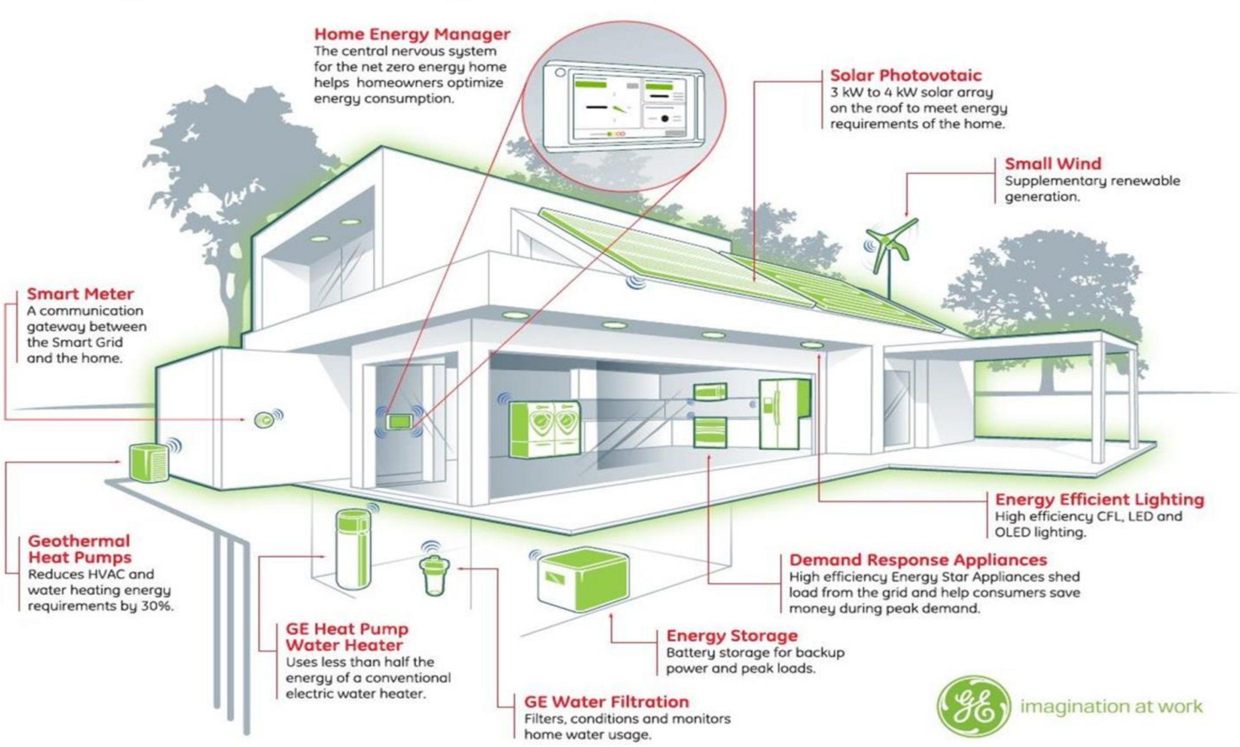

Figure 1: Example probes monitored by BEMS from GE

There are also some disadvantages of BEMS, such as

- Cost: the installation and design are expensive. In order to build these systems, there will be higher initial costs. Certain tasks would cost more to automate than to perform manually. Automation is typically best suited to processes that are repeatable, consistent, and high volume.
- Operation and Maintenance: a skilled maintenance department is often required to service and maintain the automation system in proper working order. Failure to maintain the automation system will ultimately result in lost production and/or service.

These advantages and disadvantages are categorized in Table 1 below.

Table 1: Advantages and Disadvantages for BEMS systems

ADVANTAGES	DISADVANTAGES
Increased energy efficiency	Higher initial costs for design and installation
Improved environmental conditions	Operation and maintenance costs might be higher compared to simpler management systems. However, the BEMS is also capable of reducing overall costs through improved energy efficiency and more efficient use of staff
More efficient use of staff	Need for a skilled operator
Improved security and other emergency procedures	Requires commitment at all levels throughout its operational life to maintain maximum effectiveness
Improved standards of plant/building functioning	
Improved management of the building	

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2.3 IoT-Based Analytics & BEMS Frameworks

The section describes the existing frameworks and technologies on building energy management systems. Each framework or system has its own advantages and disadvantages and brings an approach and a specific architecture with pre-defined modules. All these frameworks are evaluated accordingly to their features and **e-**BEMS requirements given in Section 3.

To have the right architecture for **e-**BEMS, SAMPAS as leader of Task 4.3, researched on different alternatives of standards and protocols, applications, open software solutions for **e-**BEMS. Under Task 4.3, requirements are identified for **e-**BEMS architecture such as data agnostics, scalability, compatibility, interoperability, governance, and standards. Information provided by technology providers about specific **e-**SAFE technologies and solutions regarding the data integration of these components with **e-**BEMS and **e-**DSS are collected and all the available frameworks are evaluated accordingly to the following criteria:

- Free and open-source software
- Integration and management of systems, devices, and services independently from vendors, technologies, and protocols
- Persistence and database support capabilities (MySQL [5], MongoDB [6], InfluxDB [7])
- Stability
- Modularity through the development of bindings
- Active community (users as well as developers)
- User interfaces, M2M interfaces (RestAPI [8], MQTT [9])
- Platform independent (beginner-friendly)

The identified building energy management frameworks are presented in the following sub-sections. Based on the evaluations, OpenHAB [10] based open-source framework is considered to be the most suitable component for **e-**BEMS development and implementation.

2.3.3 BEMOSS

Building Energy Management Open-Source Software (BEMOSS [11]) is an open-source, open-architecture platform that is engineered to improve sensing and control of equipment in small- and medium-sized commercial buildings that lack building automation systems. BEMOSS will be able to optimize electricity usage to reduce energy consumption and help implementing demand response (DR). It allows sensing and control of HVAC, lighting and plug load controllers in small- and medium-sized commercial buildings. The optimal level of efficiency is achieved by continuously maintaining the correct balance between end-users operating requirements and external/internal environmental conditions.

BEMOSS™ is designed to work with load control devices form different manufacturers that operate on different communication technologies and data exchange protocols. These include both new commercially available products that operate on Ethernet and Wi-Fi, as well as legacy devices that operate on serial communications using Modbus RTU and BACnet MS/TP protocols.

The entire BEMOSS software architecture is illustrated in Figure 2. As shown, it comprises four layers: (1) User Interface (UI); (2) Application; (3) Operating system and agent; and (4) API translator. In addition to these, all layers use databases to store metadata (e.g. device information) and time-series data (e.g. power measurement), and share important information.

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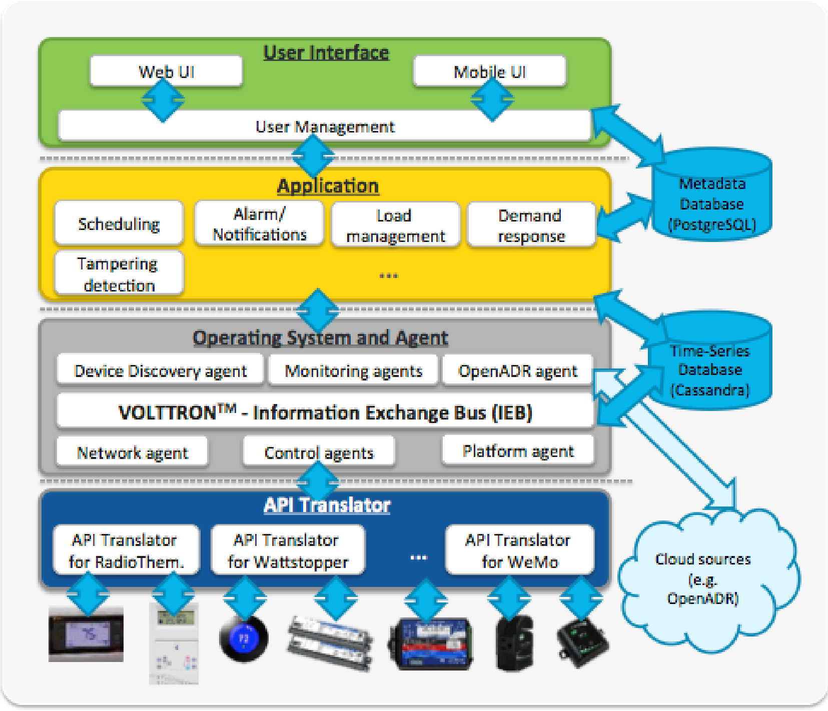

Figure 2: BEMOSS general architecture

2.3.4 BEMS Server

BEMServer [12] is an open-source solution to deploy a modular, scalable, and secure Building Energy Management System. With the increasing amount of data to monitor buildings, it becomes crucial to offer tools that help building managers in taking the best decisions to better control the energy of their buildings, and to involve all actors in reducing their environmental impact.

BEMServer was created to ease the deployment of these services, and to allow building managers to install applications that answer to their specific needs, instead of being confined to a monolithic, rigid solution.

The emergence of the smart building concept transforms the needs expressed by building owners, managers, and occupants. BEMServer is a solution to transform a monitored building into a platform of services.

In the essence, BEMServer is a building data aggregator and acts as a gateway between the hardware level of a building (sensors, BMS…) and the data-oriented services.

By design, BEMServer is modular and interoperable and includes:

- a connectivity module allowing agile data collection from the field level of a building (sensors infrastructure, Building Management System),
- a management middleware ensuring a coherent information platform by providing a semantic interoperability (through the use of formal ontologies) to unify and normalize the data between all the components of the platform,
- several advanced data processing modules based on data mining techniques and energy management approach to interpret data and identify issues or non-optimized functioning, and to deliver recommendations and decision support,
- information display modules targeting different typologies of end-users and needs and presenting key results in a user-friendly manner, tailored for these various audiences.

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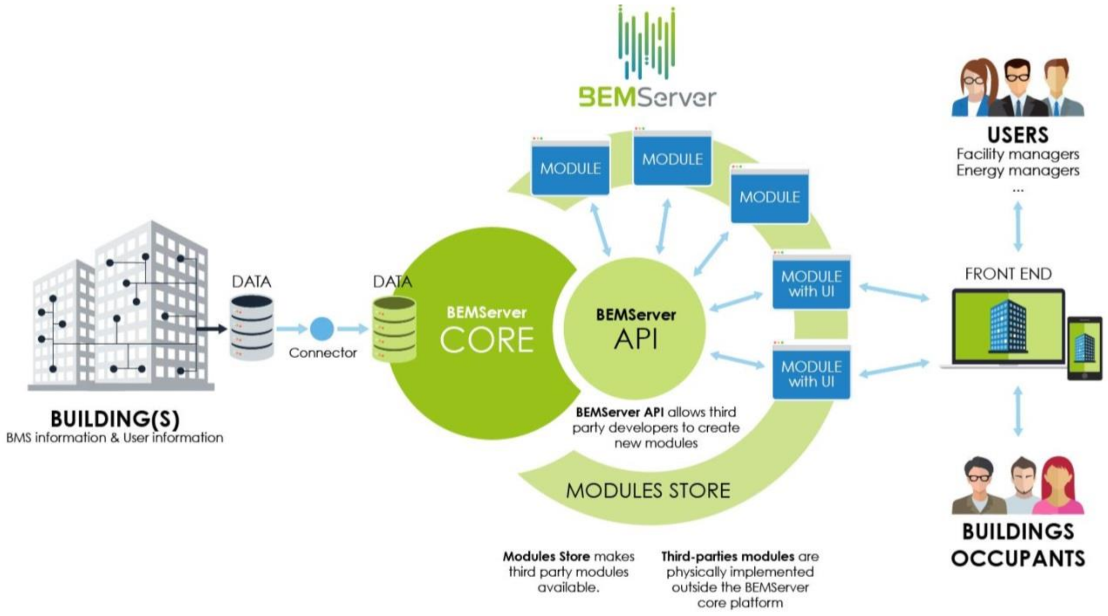

Figure 3: BEMServer data flow[1]

2.3.5 OpenHAB

OpenHAB (Open Home Automation Bus) [10] is an open-source platform that combines components used in building automation on a single platform, regardless of manufacturer and communication protocol. Figure 4 presents the general architecture and components of the OpenHAB solution suite. Main components are the protocol bindings that manage the communication layer with devices. The rule engine defines the rule sets and automation capabilities of the platform. REST services provide service interaction capabilities in a loosely manner within the service-oriented architecture (SOA). OpenHAB specifically uses an OSGi runtime as the message bus to integrate the core libraries, things and sensors management and the rest of the components. User interface is the web and mobile experience that is provided to end-users.

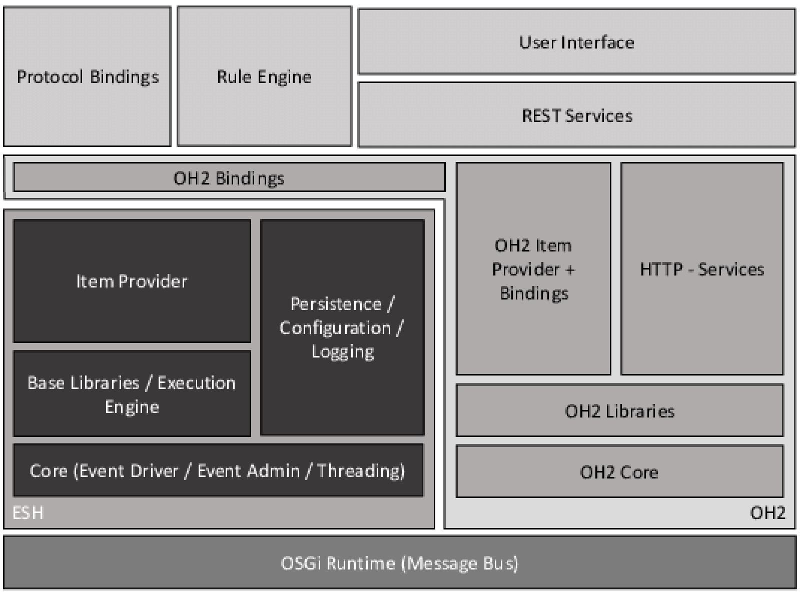

Figure 4: OpenHAB General Architecture

[1] https://www.bemserver.org

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OpenHAB has an extensible and scalable architecture that can be further enhanced and developed with new technologies and protocols with additional connections independent of any operating system. Current stable versions provide support for 200+ custom plugins, brands, devices, technologies, and communication protocols. OpenHAB is developed under the Eclipse public license (EPL) and open source (Open Source) and has specific user interfaces to support web browsers, Android and Apple iOS.

e-SAFE project focuses on residential units' energy interventions, monitoring, and control. After evaluating several different powerful **e-**SAFE framework and architecture, SAMPAS decided to use OpenHAB as the base framework and implement the **e-**BEMS solution on top of this framework. SAMPAS has evaluated several different technical and non-technical criteria while deciding the BEMS base framework. Among these being open source, supporting international standards and protocols, cost effectiveness, interoperability, user friendliness, scalability monitoring and integration capabilities are among the most important factors. Comparing all different alternatives, SAMPAS decided to proceed with the OpenHAB architecture and framework components.

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3. E-BEMS REQUIREMENTS

The **e-**SAFE ICT-based Building Energy Management System (e-BEMS) software tool aims to monitoring and managing the energy needs in the pilot buildings efficiently and intelligently, so that considerable benefits are provided. A building energy management system (BEMS) is a sophisticated method to monitor and control the building's energy needs. Next to energy management, the system can control and monitor a large variety of other aspects of the building regardless of whether it is residential or commercial. Examples of these functions are heating, ventilation, and air conditioning (HVAC), lighting or security measures. BEMS technology can be applied in both residential and commercial buildings.

In the specific case of the real pilot building in Catania, the **e-**BEMS aims to measure indoor temperature, CO_2 concentration, indoor humidity, and electricity consumption in real-time. Also other features of **e-**BEMS are the following ones:

- e-BEMS will send information to a software application available on occupants' smartphones;
- e-BEMS will actively interact with the technical systems and the storage devices. It will mainly let the heat pump operate in sunny hours, to maximize PV self-consumption rate while storing thermal energy in the **e-**TANKs;
- e-BEMS will help in detecting patterns in order to support forecasting optimum operational schemes, using data-driven models to predict energy consumption;
- e-BEMS will rely on hardware components already available on the market, but the software for its management will be developed within **e-**SAFE as part of **e-**BEMS;
- e-BEMS will be able to integrate Smart Appliances and Smart Meters, Building Automation System and IoT interfaces of **e-**SAFE building components (e-PANEL, **e-**CLT, **e-**TANK).

3.1 Requirements for Building Energy Management Systems

A first set of user requirements for BEMS has been conceived with the support of UNIBO and UNICT. Different scenarios and end-user requirements are drafted for building manager, technician, and residents.

While designing a solution, functional and non-functional requirements will act as the main criteria for the design phase and selection of the main framework components. This section also follows this approach and first analyzes the non-functional requirements that should appear in **e-**BEMS and also discusses the user stories and requirements from two main roles within the first version: residents and technicians.

e-BEMS requirements are identified through user stories in the following sub-section. Residents are one of the main end-users of **e-**BEMS systems. Residents mainly look for monitoring parameters from indoor air quality, air ventilation, energy, and thermal systems. Residents' requirements are listed below as user stories. Another active user group are the technicians. Technicians have more technical and detailed concerns on visualization, analytics, and control of the hardware components. For this purpose, their requirements are grouped for mainly web based usage of the **e-**BEMS solution. All these stories acted as the main requirements for the **e-**BEMS solution and main criteria while implementing the platform components.

Non-functional requirements are very important for the scalability, interoperability with other systems, security, replicability, and adaptability of software solutions. Besides functional requirements given in the following sub-section, **e-**BEMS component is expected to have the following non-functional requirements:

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- based on an open source architecture;
- supporting international standards and device communication protocols;
- cost effective;
- interoperable;
- scalable;
- user friendly end-user interfaces;
- easy to customize and deploy;
- supporting plug and play;
- cloud and or on premise deployment options;
- with proven security features;
- integration services and Application Programming Interface (API);
- real-time monitoring of building energy consumption and device status through web and mobile interfaces.

Based on several evaluations, OpenHAB framework is considered as the best base framework to fulfill the functional and non-functional requirements according to different uses for residential and building management purposes. The following section describes the functional requirements driven from the research and end-user partners of the **e-**SAFE ecosystem.

3.1.1 Functional Requirements of BEMS

This section describes functional requirements of residents and technicians regarding the **e-**BEMS solution.

3.1.1.1 User stories for residential use

This section presents user stories regarding residents. Residents will be mainly using the mobile interfaces of the **e-**BEMS platform and will require mainly to monitor parameters of indoor, energy and thermal systems. Identified stories are given below:

- As a resident, I want to know the temperature and the relative humidity of the main rooms in my home
- As a resident, I want to control the velocity of the fans in each fan-coil unit
- As a resident, I want to set an indoor temperature value for each room in my home
- As a resident, I want to know the temperature of the domestic hot water inside my e-TANK
- As a resident, I need to know if the CO_2 concentration in the room is too high, so that I can open the window to change stale air
- As a resident, I need to visualize in my app the current value of the main environmental parameters (dry-bulb air temperature, relative humidity, CO_2 concentration, wind velocity).
- As a resident, I need to know the daily electric energy consumption in my home, so that I can understand if any actions are needed to improve my habits and reduce the energy bills
- As a resident, I need to see on my app a report about what has happened in my dwelling during the day, i.e. how the temperature, the relative humidity and the CO_2 has evolved. An app might suggest me some behavioral changes if something has gone wrong.

3.1.1.2 User stories for building management

This section describes the user stories and requirements regarding the technicians. Technicians require to get more detailed information through the web interfaces of the **e-**BEMS platform for indoor, outdoor, energy and thermal systems parameters. User stories are given below:

- As a technician, I want to register to the **e-**BEMS application so that I can exploit it
- As a technician, I want to login to the **e-**BEMS platform so that I can create a new option
- As a technician, I need to know the battery life and maintenance time of the devices
- As a technician, I need to know status information for PV modules

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- As a technician, I want to know how much electric energy they produce per day
- As a technician, I want to register and visualize the time trend of the main environmental parameters (dry-bulb air temperature, relative humidity, CO_2 concentration, wind velocity and direction, global horizontal radiation). 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 properly working.
- As a technician, I need to know the water temperature in the large storage tank coupled to the heat pumps
- As a technician, I need to know the main parameters related to the operation of the heat pumps (inlet water temperature, outlet water temperature, water flow rate)
- As a technician, I want to download a weekly or monthly report from the **e-**BEMS, so that I can verify all measured parameters and the consequent electricity consumption, in order to assess the correct behavior of the system and show it to the building manager.

Some information collected by the technician is also useful to the Building Manager:

- As a building manager, I need to visualize the building and its separate sensing items on the **e-**BEMS platform
- As a building manager, I need to receive from the technician a monthly report about the correct performance of the systems, the electricity production of the PV modules and overall energy consumption.

3.2 e-BEMS Probes & Parameters

e-BEMS requirements are also analyzed from the perspective of the required parameters and probes for different uses including indoor spaces, outdoor spaces, energy production and thermal systems. Table 2, Table 3, Table 4 and Table 5 present the first set of requirements for the parameters and probes identified for the **e-**BEMS. Table 2 introduces the indoor environmental control parameters for residential use. Among several indoor parameters, most effectives ones including the temperature, humidity and CO_2 concentration are selected for **e-**SAFE pilots for their direct impact on indoor spaces. The table describes where and how many of these data probes will be installed, their data collection frequency, explanations on their calculation methods and also ranges for data accuracy and data quality measures.

Table 2: Probes for indoor spaces in the real pilot

What	Where	When	How many	Notes	Accuracy	Range
Dry-bulb air temperature	Living room and one	Every 5 minutes	2 x dwelling (20 overall)	Calculation of average values over	± 0.2 °C	At least 0 – 50 °C
Relative humidity	Living room and one	Every 5 minutes	2 x dwelling (20 overall)	Calculation of average values over	± 3%	At least 20 – 80 %
CO_2 concentration	Living room and one	Every 5 minutes	2 x dwelling (20 overall)	Calculation of average values over	± 50 ppm	At least 0 – 4000 ppm

Table 3 presents air quality and microclimate parameters for outdoor spaces. Outdoor temperature, humidity, CO_2 concentration will be collected as relevant outdoor parameters. Besides these data sets, wind velocity and wind direction and global horizontal radiation will be additional important parameters for outdoor environment of the pilot buildings. The table describes where and how many of these data probes will be installed and their data collection frequency.

Table 3: Probes for outdoor spaces in the real pilot

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What	Where	When	How many
Dry-bulb air temperature	Above roof	Every 5 minutes	1
Relative humidity	Above roof	Every 5 minutes	1
CO_2 concentration	Above roof	Every 5 minutes	1
Wind velocity	Above roof	Every 5 minutes	1
Wind direction	Above roof	Every 5 minutes	1
Global horizontal radiation	Above roof	Every 5 minutes	1

Table 4 shows the energy related parameters that need to be monitored in the pilot building, both addressing consumption in residential units and energy generation using solar panels. **e-**SAFE will collect electric power from fan coils and auxiliary systems at every 5/10 minutes on the consumption side through smart meters. **e-**BEMS will also control the energy production side through PV systems analyzers and also energy transferred to the ENEL grid via smart meters.

Table 4: Probes for energy consumption and production

What	Where	When	How many
Electric power	Fan coil (same rooms where we get T and RH)	Every 5/10 minutes	2 x dwelling (20 overall)
Electric power	EHP with its auxiliary systems	Every 5 /10 minutes	1 + 1
Electric power	PV production	Every 5 /10 minutes	1
Electric power	PV transferred to grid (ENEL)	Every 5 /10 minutes	1

Table 5 specifically addresses the probes and parameters to be collected for thermal systems in **e-**SAFE pilot buildings. Heat meters, heat pumps and **e-**TANK system probes for water temperature will be the main sensing elements. **e-**BEMS will get required water temperature and flow data through **e-**TANK and heat pump interfaces periodically.

Table 5: Probes for thermal systems

What	Where	When	How many	Notes
Heat meters	One per apartment	Integration with time	10	This is compulsory by law in Italy for centralized systems.
Water temperature	Inlet/outlet from heat pumps	Every 2 min	2 + 2	The shorter time of acquisition (2 min) allows identifying transient HP performance.
Water temperature	Outlet from the storage tanks	Every 2 min	2	This also identifies the temperature inside the tank. Inlet temperature can be reasonably assumed equal to HP outlet.
Water flow rate	Heat pumps/main line	Every 2 min	2 + 1	Water flow rate (main line + heat pumps)
Water temperature	Inside **e-**TANK	Hourly	1	Temperature of the water tank (inside).
Water flow rate	From **e-**TANK	Hourly	1	Water flow rate extracted from the **e-**TANK

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4. E-BEMS

e-SAFE ICT-based Building Energy Management System (e-BEMS) is based on open source OpenHab framework. This section presents the general concepts and features of the **e-**BEMS in its early version.

e-BEMS will have a role to measure indoor temperature, CO_2 concentration, indoor humidity, and electricity consumption in real-time. This will be a necessary step to collect information about the real performance of the **e-**SAFE pilot in Catania, and to make it possible to quantify the actual benefits in terms of comfort, indoor air quality and energy savings.

e-BEMS will also have integration end-point for the residents' mobile application to engage occupants and make them aware of and confident with **e-**SAFE benefits and operational aspects. This includes notifications to users of the possibility/opportunity to carry out specific energy-related actions (e. g. open windows to get suitable air change or operate the external blinds to improve visual comfort and reduce overheating).

Furthermore, the **e-**BEMS will actively interact with the technical systems and the storage devices. It will mainly let the heat pump operate in sunny hours, to maximize PV self-consumption rate while storing thermal energy in the **e-**TANKs. **e-**BEMS will also detect patterns to allow defining optimum operational schemes

e-BEMS is an integrated system of hardware components already available on the market (smart meters, temperature and humidity sensors, home control gateways, HVAC systems, , thermostats, heat pumps, etc.) plus the software toll for its management, which is being within **e-**SAFE. **e-**BEMS will be able to integrate Smart Appliances and Smart Meters, Building Automation System and IoT interfaces of **e-**SAFE building components (e-PANEL, **e-**CLT, **e-**TANK).

With its multi-layer architecture, it will be easily expanded to the entire building, and it will allow remote and local monitoring by supporting enhanced security features.

4.1 e-BEMS First and Early Version

e-BEMS consists of several different modules including the persistence layer, communication and data exchange with devices, bindings, rule engine, core data management modules, REST services and user interfaces.

To effectively manage the building energy requirements, the physical world has to be replicated in the virtual world to create the digital copy, the digital twin of the energy consuming and producing elements.

For this purpose, devices and sensors have to be modeled as one of the Internet of Things components. These are named as "Things". Fundamental concepts and model elements are explained below and also described in Figure 5.

In particular, Figure 5 presents the relationship between the physical and the virtual layers of the **e-**BEMS. The physical layer represents the hardware interfaces as Things. A Thing is the representation of a sensing probe, namely sensors. For instance, a thing can be a light bulb or a humidity sensor. Thing can either be a device or represent a service in front of a data source. Each thing or sensing probe has to be connected to the virtual layer of the **e-**BEMS component via channels. Each sensing device or sensor, each thing may measure more than one value such as a single indoor sensor measuring humidity and temperature at the same time. Channels are used to connect each different measurement to the platform. For this example, the indoor sensor is the Thing and humidity, and

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temperature measurements are two different channels. Each channel is connected to the Virtual layer to separate items. An Item is the virtual representation of each measurement probe that has specific data structures such as Switch, Number or String. Each measurement channel is linked to Items via links.

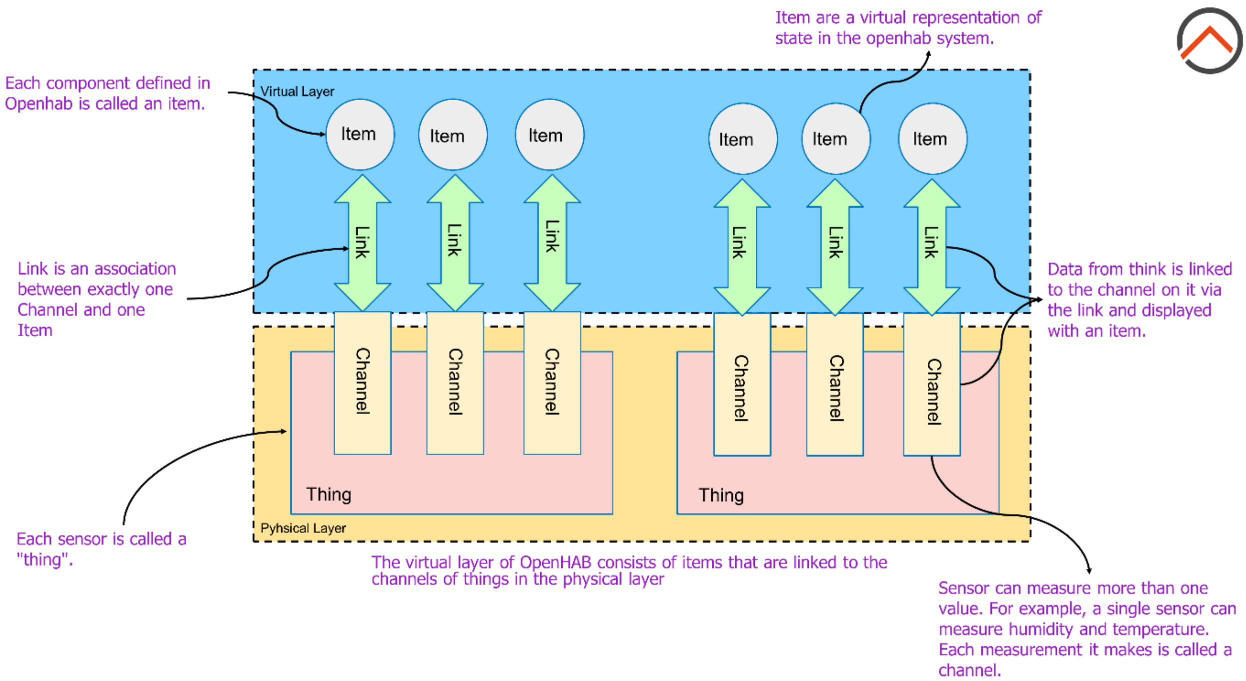

Figure 5: Virtual and Physical layer communication in the OpenHab framework

e-BEMS provides persistence services to store the measurements into relational databases. These measurements can be a time series and allows **e-**BEMS end-users to visualize and monitor current and historical measurements. To manage and visualize specific devices, sensors (Things) and measurement points (Items), **e-**BEMS has a specific hierarchical model to represent the items, equipment and locations. For example, **e-**SAFE pilot building, has a hierarchical model that represents the building itself, floors, apartments, specific rooms, equipment, and their points. If we have two equipment "Light" and "Heating" in the Living Room, then Living Room is the location, the "Heating" is the equipment, and it may have multiple points such as "Actual Temperature" and "Set Temperature". **e-**BEMS also provides rule definition for creating actions when an event occurs such as turn on the air conditioning if the temperature goes beyond a certain value.

4.2 e-BEMS Ontology & Semantic Model

e-BEMS has complex system structures including sensors, energy smart meters, actuators, analyzers, communication devices and web service interfaces. To have specified definitions and to define the relationship between items, equipment and locations, the data model of **e-**BEMS is defined across four different models. Figure 6 represents a generic approach of the data model behind **e-**BEMS. Each sensing device or sensor is located in a physical location in the physical world. **e-**BEMS models these locations as Location entity (object) that represents different layers of building structures. A location allows technicians to define buildings, floors or rooms and arrange many layers according to end-user requirements. For the pilot **e-**SAFE building we have building level, floor level, residential unit level and room level hierarchical modeling to model indoor and outdoor spaces.

The dynamic structure becomes a hierarchical tree given as an example in Figure 6. Each sensor is defined as an Equipment. A piece of equipment can be a battery, a light bulb, a radiator, a speaker,

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or a smoke detector. These pieces of equipment are located in specified locations such as living room, kitchen or basement of the building. Each piece of equipment has a specific point that identifies its link to the virtual representation of the measurement items through channels. Each point in **e-**BEMS relates to measurements called "Property" which are specific measurements such as the temperature, CO_2, current, noise or power from different sensing points.

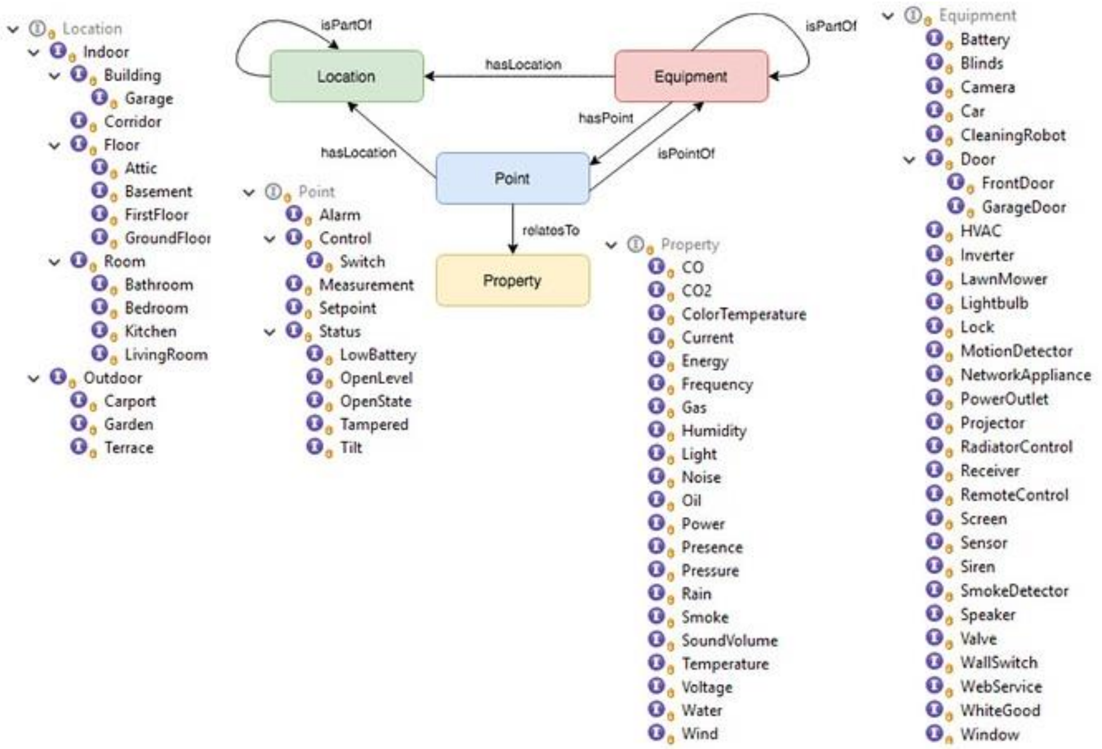

Figure 6: BEMS Ontology and Semantic model [13]

4.3 Supported Data Exchange Protocols

e-BEMS supports wireless and wired protocols for integrating commercial and off-the-shelf gateways, devices, and sensors from different vendors. Among these: Ethernet - IEEE 802.3, Serial (RS- 485), ZigBee (IEEE 802.15.4) and Wi-Fi (IEEE 802.11)) and protocols such as BACnet, Modbus, Web, ZigBee API, OpenADR and Smart Energy Profile are supported by **e-**BEMS platform.

Wired protocols provide reliable connectivity but with a limited scope. Some of the most used wired protocols for the **e-**BEMS platform are:

- X-10
- Insteon (hybrid)
- Ethernet
- Universal Powerline Bus (UPB)

e-BEMS also provides wireless communication. Supported wireless communication protocols are:

- Wi-fi
- ZigBee
- Zwave
- Bluetooth

Also for data exchange the **e-**BEMS supports mostly used protocols such as MQTT, REST API and XMPP protocols. All supported protocols are given in Figure 7.

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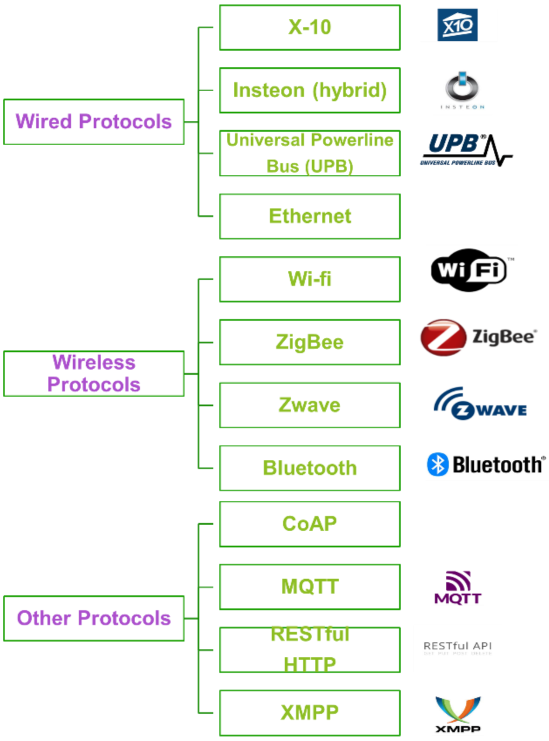

Figure 7: **e-**BEMS data communication and exchange available protocols

Among these protocols, **e-**BEMS can integrate any system that can generate data to MQTT based publish/subscribe mechanism (Figure 8). MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT)[2].

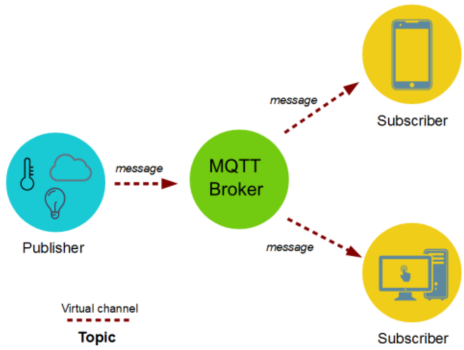

Figure 8: MQTT broker for **e-**BEMS

Figure 9 provides the general communication architecture of the **e-**BEMS component. Considering different level communication protocols and bindings (KNX, RS-232, etc.), **e-**BEMS isolates the repository, object model and user interfaces via an event bus where all messaging and events happens between different sub modules.

[2] https://mqtt.org

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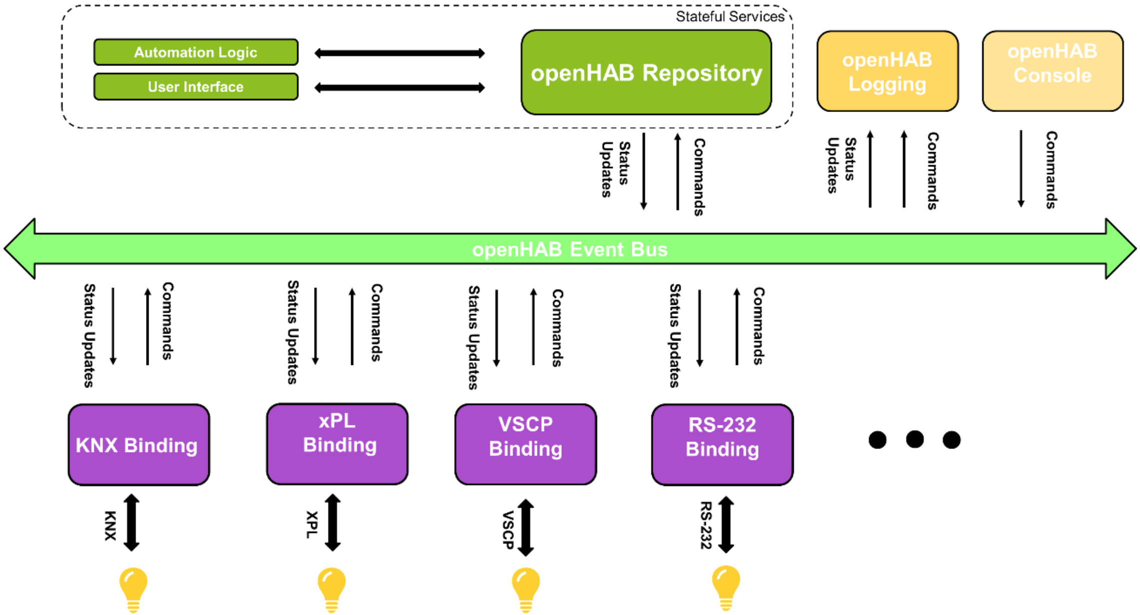

Figure 9: **e-**BEMS Communication Architecture

4.4 User Interface & Design

e-BEMS offers several different user interfaces for different end-user requirements such as web-based analytics or tablet mode usage in residential areas. This is required both to define end-user interfaces (either web based or mobile ones), and also for administrative requirements for the design and implementation of building energy management elements.

Basic user interfaces allow the user to define layout pages as the most common and flexible way of displaying information. Users have extensive options to customize layout pages, and they also support both built-in widgets and user-designer widgets.

e-BEMS provides four different user interfaces (UI) for end-users, who can select them according to their requirements. The first version includes basic UI elements:

- **Basic UI**: it is the simplest user interface for the general management and use of the **e-**BEMS for less complex operations. Technicians and building managers may use this Basic UI for the management of **e-**BEMS elements.

Figure 10 shows the landing page that gives the overview about the pilot building in real-time using weather APIs and services integrated in the first version and focuses on the outdoor and environmental probes and parameters including the outdoor temperature, humidity, wind speed and the direction of the wind and also UV index for radiation purposes (see Section 3.2).

Figure 11 provides the hierarchical data model defined for the **e-**SAFE pilot building in Catania. The building is divided into 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, bedroom, kitchen, etc.). Using this model, each sensing point is located and attached to one of these locations either it's a floor, apartment, or a room. BEMS will be easily identify and allow residents to monitor relevant parameters according to their location and usage. Figure 11 provides both building level and room level sensors and connected probes.

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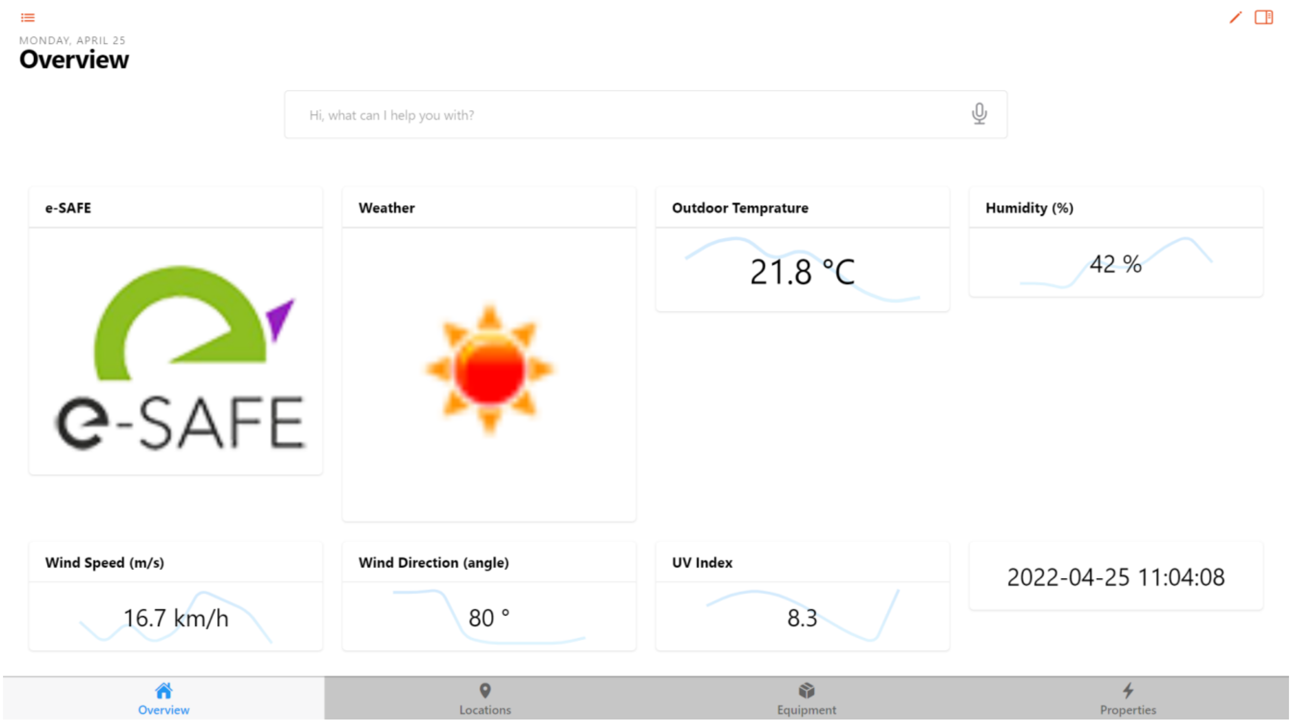

Figure 10: **e-**BEMS Landing page

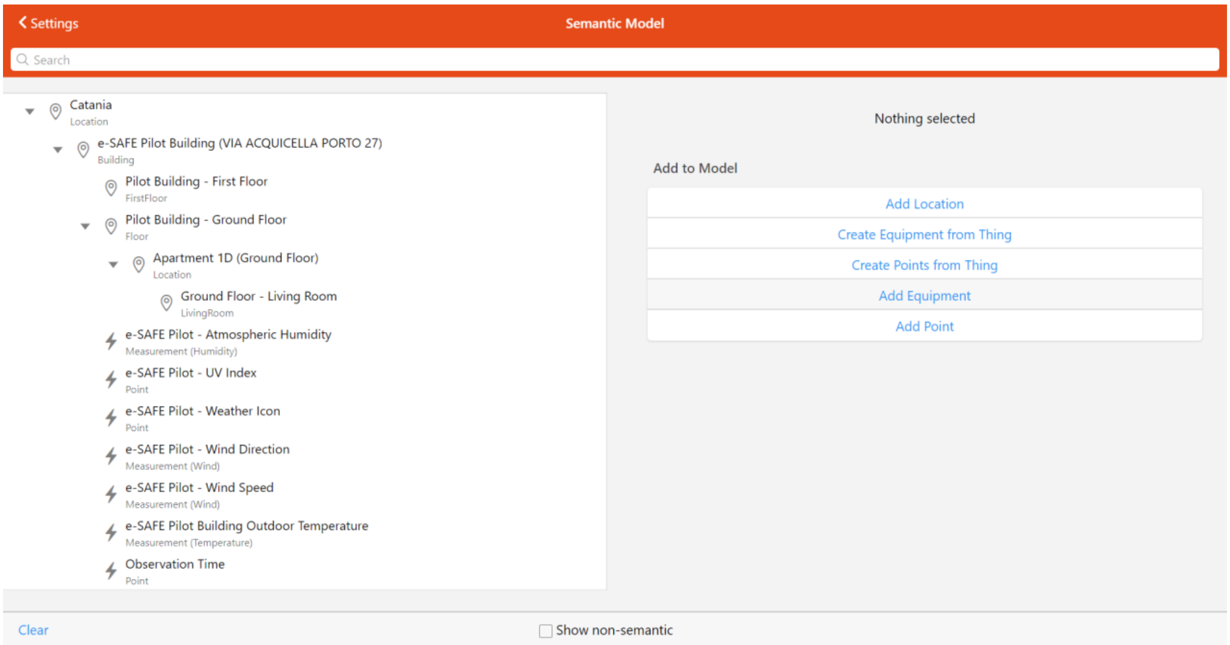

Figure 11: **e-**SAFE pilot building hierarchical model (Building to sensor level)

Figure 12 is the graphical visualization for specific parameters monitored. Graphical charts allow to visualize the data sets (e.g. Wind direction in pilot location) as a time series and allows the technicians to use them for analysis purposes.

Figure 13 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). Figure 14 shows the geospatial visualization feature that allows end users to easily locate their buildings and reach their parameters in real-time.

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Figure 12: Time series analysis & visualization for Wind Direction

Figure 13: Building level probes and outdoor parameters

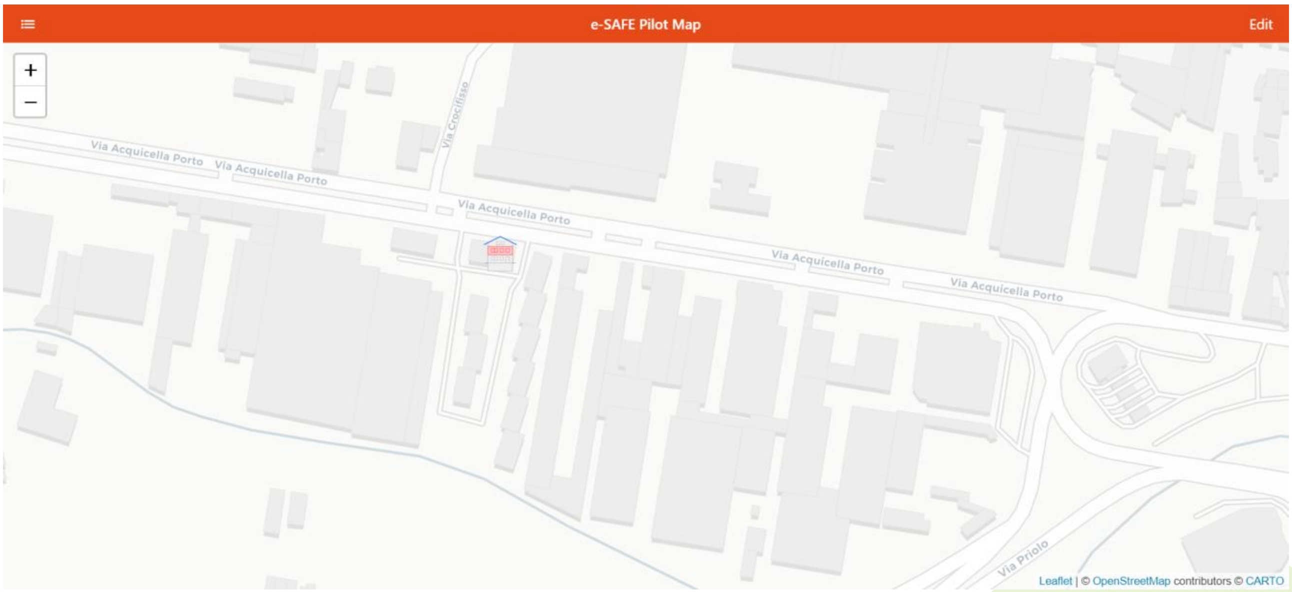

Figure 14: Building location

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Figure 15 is the listing interface for each subcomponent identified in the pilot building. Within this listing interface building, floor, apartment, room and sensing probe level items are listed in the same order allows the web-based users (e.g. technicians) to select and analyze the specific element accordingly.

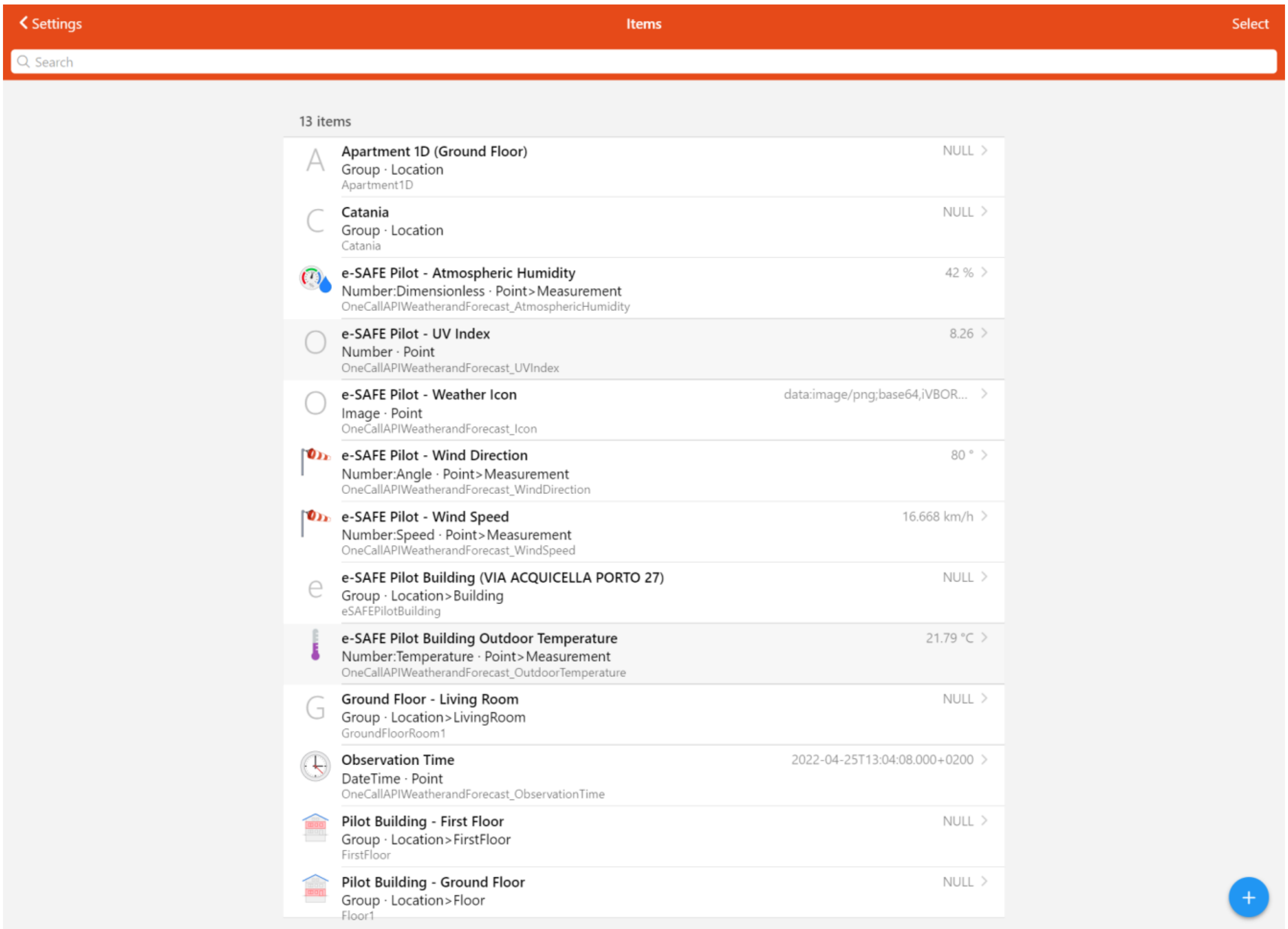

Figure 15: **e**-SAFE pilot probes

Final and integrated version of the **e-**BEMS will include other user interfaces including tablet model, mobile interfaces and advanced interfaces (CometVisu).

- **Tablet Mode**: Tablet mode is the user interface mainly for indoor residential use that is designed for fixed wall-mounted tablets and touchscreens. This is based on Windows 10 type menu with lots of customization options for end-users. Residents who would like to invest for wall-mounted tablets prefer Tablet Mode. An example as a reference is provided Figure 16. Tablet Mode interface for **e-**BEMS will be implemented in the final version.
- **Mobile interface**: it is another option for residential use that allows end-users to manage and monitor energy elements of their residential apartments via mobile interfaces.
- **CometVisu**: is the most complex and advanced interface where end-users (mainly technicians and **e-**BEMS solution providers) see and adjust all details of elements such as maps, charts and all available visualization and control features.

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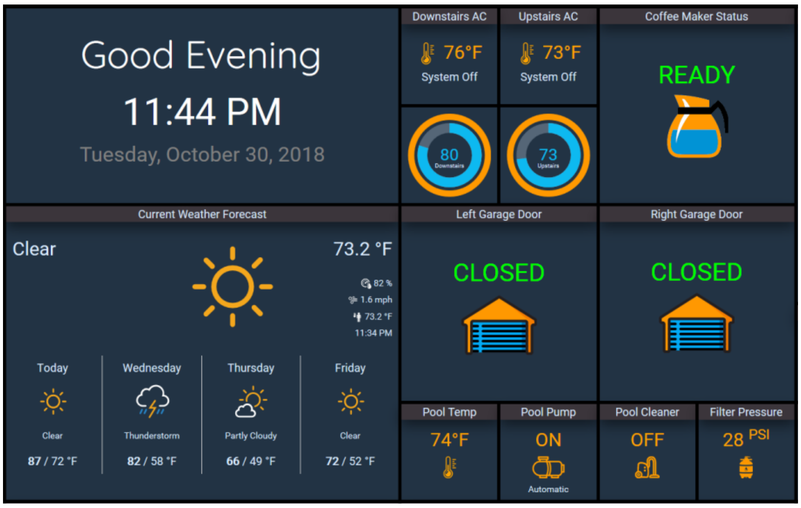

Figure 16: **e-**BEMS generic panel for Tablet usage

Within this way, **e-**BEMS will be able to provide uniform user interface and a common approach to automation rules across the entire system, regardless of the number of building energy elements and devices. Alternative user interfaces (Basic UI, Tablet mode, Mobile interface, CometVisu), **e-**BEMS targets to cover expectations of different user groups including residents, technicians and building managers.

Figure 17 and Figure 18 present the BIM models of the pilot building. SAMPAS will use the hierarchical model and integrate all probes and parameters for indoor spaces, outdoor spaces, energy production and consumption and thermal systems according to their levels starting from the building level, to floors, to units (apartments) and even different rooms. This deliverable does not provide details of the pilot building since a detailed survey for the pilot building and its technical aspects is given in D5.1 "Detailed Survey of the Real Pilot".

Figure 17: **e-**SAFE pilot building Revit Model

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Figure 18: Pilot Building perspectives from the BIM model

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5. CONCLUSION

This deliverable presented the first and early version of the **e-**BEMS platform components. **e-**BEMS will have a role to measure indoor temperature, CO_2 concentration, indoor humidity, and electricity consumption in real-time. This first version is currently implemented using simulated data sets.

First, the general concepts of "Building Energy Management System" are provided. Existing BEMS platforms and frameworks are analyzed and evaluated based on the criteria and project requirements. Then, the expected functional requirements are presented according to residents' and building managers' perspective, while also identifying the parameters that need to be measured to monitor indoor and outdoor spaces, energy production and thermal systems performance, as well as the necessary probes.

For the real-pilots' integration, whose design will be completed by M30 in order 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, while ENG will contribute to the establishment of the software framework with regards to the **e-**DSS integration. 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 will be developed and added to the final version of the **e-**BEMS platform:

- finalization of the data model according to the real pilot implementation in Catania;
- implementation of the integration with the installed hardware components on the pilot site (Smart Appliances, Smart Meters, Building Automation System and IoT interfaces of **e-**SAFE building components (**e-**PANEL, **e-**CLT, **e-**TANK);
- development of the mobile application for the residential use;
- development of the tablet mode for residential use;
- development and integration of the advanced user interfaces and analytics for technicians and building managers;
- integration with **e-**DSS tool
- post-processing of monitored data and comparison with historical data.

The next and final integrated version of **e-**BEMS will be reported in D4.6 "Final integrated **e-**BEMS". This will present the integrated and final version of the **e-**BEMS, which will be used for monitoring and management activities in the real pilot. The final version of **e-**BEMS will also be integrated with the **e-**DSS solution for the energy-oriented parameters.

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