Using FusiX platform for Intelligent Energy Management Systems' development

V. Georgoutsos, G. Soulioti
EMTech GmbH, Darmstadt, Germany
V. Alifragkis, N. Livanos
EMTech Space P.C., Athens, Greece

ABSTRACT: A novel Decision Support System (DSS) development framework, named FusiX, with integrated simulation support, Graphical User Interface (GUI) support and data fusion engine, is developed to meet the needs of the modern building energy management sector. Its main objective is to facilitate and streamline the development and the expansion of a complete DSS. FusiX constitutes a versatile base on which Intelligent Energy Management Systems (IEMS) can be built, allowing a system engineer to incorporate different data resources into a single intelligent system. Its data fusion engine can process heterogeneous data from historic, real time sensed data, simulated and predicted data independently from their location (local or remote). The software system is extended with a web-based GUI for efficient administration, exposing all real-time measurements and available commands to authorized users, supporting user alerting, as well as providing means to produce and export business and technical reports.

Keywords: Decision Support Systems, Intelligent Energy Management Systems, energy saving, interoperability, SCADA, distributed nodes, virtual assistance

1. INTRODUCTION

1.1 REAL CHALLENGES OF MODERN ENERGY MANAGEMENT SYSTEMS

Saving energy in business, public sector and buildings is a common concern for modern communities and gives ground to the term "energy management" to flourish rapidly.

Today we have to deal with a multifaceted problem in order to bring a positive impact not only for the environment, but also for the beneficiary user. In the complex situation of building energy management one should take into account multiple parameters to efficiently optimize the problem; from current weather conditions and predictions, to system elements (renewable sources, thermal storages, Heating Ventilation and Air Conditioning - HVAC, batteries, etc.), thermal comfort, energy prices, and net metering. To address all these parameters efficiently, an automated intelligent system is required to process them rapidly and dynamically.

Crucial factor in this point are the user's demands, which differ from time to time, day by day and always imply a new undetermined variable at the problem's solution. The user must always be in focus of this optimization attempt and in order to keep him motivated, we need a win-win formula that impacts positively not only the environment, but also brings them greater living comfort with decreased costs. In other words, having to optimize the operation of household equipment, energy costs, living conditions, domestic energy production/consumption, etc. is a great challenge by itself. On top of this, we also need to consider the always changing weather conditions, building's behavior and of course user's interventions. This concludes to the necessity of modern energy management systems, which stand out for the intelligence they provide to user's decision making capabilities, and the way they handle complex problems, adapting seamlessly to the constantly changing needs and variable conditions.

1.2 IEMS DRIVING FACTORS

To tackle the challenges listed above, we need an out of the box solution, which accommodates the key factors that characterize a modern IEMS. These can be listed as:

- Heterogeneous data aggregation
- Interoperability
- Weather/Energy Load Prediction algorithms
- User behavior patterns
- Criteria-based Optimization (energy/cost efficiency, user comfort)
- User engagement/interaction
- Building simulations

Every feature of the above can be thought as a single unit, which demands great effort and time to be developed. But what if these features could be consolidated under a common platform which is able to orchestrate them for a common goal? This is where FusiX platform offers its versatile approach, abstracting information of the connected sources, optimizing and finally presenting the relative results to the end user.

Even though, fully automated systems with full control over a building exist, these systems impose investments in expensive equipment for accurate measurement and control (smart sensors, temperature, air quality, etc.) or even renovation of some very old buildings. The real game changer in this area, is the final user engagement in a way they form an integral part of the solution. It is believed that an automated user-driven IEMS which provides the user the knowledge required to solve the problem and optimize specific criteria (e.g. economy versus thermal comfort) will highlight the user as an efficient contributor in terms of expenses. So raising their energy awareness can prove extremely vital for the sustainability of the energy saving attempt.

To address the aforementioned challenges, a FusiX-based IEMS was built during the PVadapt H2020 project. In section 2 the market leading products in this area are discussed. In section 3 the features that distinguish FusiX DSS platform as a great candidate for IEMS deployment are presented in detail, while in section 4 iReact-NG and PVadapt use cases are presented.

2. CURRENT TOOLS AND METHODS

Several tools are oriented to the monitoring, managing and optimizing energy consumption and provide a stable base for the next steps of Energy Management Systems evolution. The leading companies in the market are present with the following products:

- Schneider Electric EcoStruxure™ Building is a platform of interoperable and scalable applications, designed to provide management on building assets and prognoses maintenance needs. (Schneider 2020)
- Honeywell EBI-600 provides its user the tools to run smarter buildings focused on comfort, enhanced security and decreased expenses. EBI is an open, scalable solution that works with a wide range of third-party equipment and software. (Honeywell 2020)
- Trend IQVISION SUPERVISOR is a building monitoring and management solution capable of integrating Trend controllers, third party devices and internet protocols into a centralized software platform that is designed to manage buildings at an enterprise level. IQVISION serves real-time graphical information to standard web-browser clients and also provides server-level functions such as: centralized data logging, archiving, alarming, trending, master scheduling, system-wide database management, and integration with enterprise software applications. (Trend 2020)
- Siemens Synco™ is a building automation and control system for small and medium-size buildings offering monitoring and control for HVAC systems, supporting this way the entire lifecycle of the building. (Siemens 2020)
- Cylon Controls offer a variety of connected Building Energy Management Solutions scalable for automation and energy control of any size commercial or industrial building. With an interoperable open

protocol solution aims to decrease buildings efficiency by monitoring and regulating consumption every 15 minutes. (Cylon 2020)

Some of the tools mentioned above are mainly management systems at the building's level, regulating assets like lights, HVAC, elevators, security systems etc. and others are mainly modelling tools, which try to identify a building's behavior and optimize through the operation of the next 24 hours. However, the main focus of all of them is the centralized collection and visualization of the energy data and then the presentation of user friendly notifications in case of unexpected behavior or in case of users misbehave in relation to the energy consumption.

In order to improve the capabilities and deal with the inefficiencies of the above solutions, FusiX provides the base to consolidate heterogeneous sources in a decentralized way, building powerful decision support systems for energy management, which can cover a very wide range of needs.

3. FUSIX DSS DEVELOPMENT FRAMEWORK

FusiX is a customizable platform used in the development of DSSs. Its main goal is to abstract and virtualize data sources as well as every application-related piece of data generated or consumed by the system. This is achieved by abstracting the data using an expandable meta-model which can be tailored for the needs of the corresponding application. This corresponds to the application's information model which is, in fact, a conceptual and formal description of the nature of the data managed by the system. Format- or protocol-specific data are converted to information model data and can be then handled in a format- or protocol-independent manner.

FusiX follows a decentralized architecture where the FusiX system is comprised by interconnected FusiX Nodes (Fig. 1). These nodes are generally deployed on servers, smart devices or embedded hardware in order to interface with the services, sensors, or actuators of each system. The nodes are connected in a macro-network so that each node can communicate with the other connected nodes and seamlessly use the operations it provides. The operations of each node are defined in high-level scripts which are launched as independent agents. Agents either connect FusiX with external devices/sensors/services or perform some kind of processing on the data.

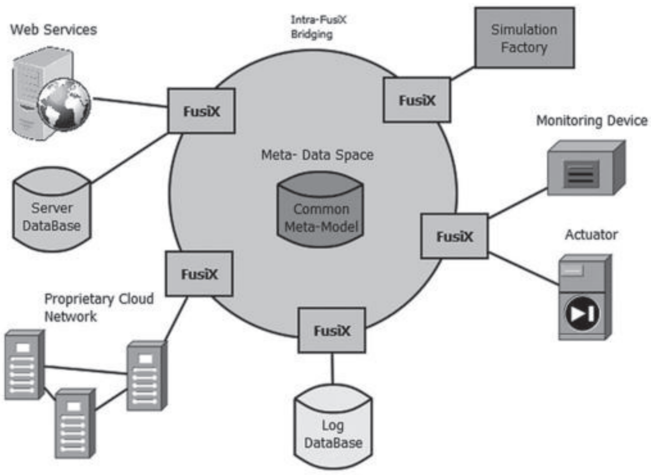

Fig. 1: FusiX High Level Architecture

Moreover, FusiX provides natively some of the most common services that the DSS usually needs. These services include scheduling and synchronization mechanisms, data storage, a web-based GUI interface and a cetralized logger service. It also provides a fully functional simulation environment to be used for predictions or system optimizations and allows a system engineer to incorporate different resources into a single intelligent system quickly and efficiently. In this way, it enables the rapid development and deployment of applications that access, process and integrate data from various local or remote resources. It performs these operations by providing three conceptual components:

- Fully customizable computational nodes, called Agents, which perform any kind of operation such as connecting to external resources or implementing user functionalities, timekeeping, etc.
- The Information Model, is a meta-model structure that allows for high-level seamless and complex querying for system resources regardless of their actual location.
- A scalable and robust virtual environment for the agents to execute on and communicate efficiently.

To support the building of DSS applications, FusiX provides a variety of external components that are bundled together within the framework:

- A Graphical User Interface (GUI) builder and a web interface for this GUI
- Database Storage facilities and appropriate virtual interfaces
- A Parallel Discrete Event Scheduler
- A complete real-time Simulation Framework
- An Information Model layer to abstract data points and functionality, it order to allow reuse

It can be seen that, the objective of FusiX is to enable a system engineer of any discipline, given the descriptive information model and some basic infrastructure and data handling mechanisms, to build an arbitrarily complex data-processing system and rapidly prototype any functionality using high-level scripts in an implementation-independent manner and all this into a virtualized environment. FusiX is tailorable to serve any application that requires real-time control and monitoring, data aggregation and prediction functionalities.

Last but not least, FusiX is extensible and scalable. Extensible by incorporating additional data sources and providing the required adapter agents along with their information model. And scalable by distributing the system to several computational nodes, each communicating in a peer-2-peer manner inside the cloud.

FusiX is already used in a market-ready product (iReact-NG) and three ongoing H2020 project (PV-adapt, E-DYCE and PRELUDE).

4. FUSIX-BASED INTELLIGENT ENERGY MANAGEMENT SYSTEMS

The profound usability of FusiX platform, gave birth to several real applications that are already deployed or under construction. It is worth to mention that already 150 power distribution substations of the Greek Transmission System Operator are under supervision of a decision support system, named iReact-NG, built on FusiX.

4.1 IREACT-NG USE CASE

Using the FusiX technology, an integrated software for reactive-load management in power distribution substations, called iReact-NG, has been developed. It is a complete information fusion environment, able to acquire and aggregate real-time information coming from all distributed automation units and sensors (SCADA), analyze and use historical data and service data analytics (Historian), as well as perform real-time simulations (Fig. 2). This complicated simulation framework is called "Smart-Grid Parallel Universe" which consists of a realization of a simultaneous simulation execution of "identical" smart-grid topologies under investigation, fused with data-bases maintaining historical knowledge, real-time measurements, and introduction of contingency events. FusiX's intelligent processes gather information and perform iterative calculations, in order to spawn smart-grids' "Big-Bangs", creating new simulations of parallel universe instances, or even terminate other parallel universe instances that seem improbable to occur in the future. With iReact-NG the feasibility of controlling large data, supervising locations over cloud and managing different topologies from a single computer, is proven.

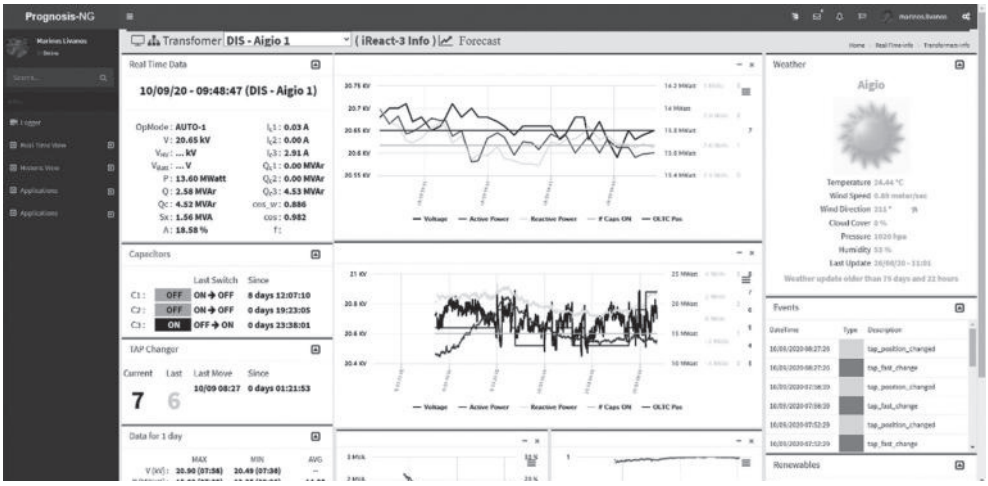

Fig. 2: i-React-NG SCADA main dashboard

4.2 PVADAPT USE CASE

PVadapt is an ongoing H2020 project, aiming to create an adaptable and multifunctional Building Integrated Photovoltaic (BIPV) system, as well as an Intelligent Energy Management System (IEMS) for optimized building energy production/consumption, and minimized dependency on the electricity grid, while satisfying the users' comfort constraints. For the deployment of these BIPVs, several demo sites are selected to accommodate those installations, which will also be equipped with a Smart Envelope System that manages the buildings assets.

4.2.1 Smart Envelope System

Under the Smart Envelope System, a DSS for intelligent energy management featuring grid connectivity, load prediction and shifting, and predictive algorithms is being developed, based on FusiX. This IEMS will integrate heterogeneous send parameters, spanning from weather conditions and solar radiation to electrical power and water/air quality. It is also required to control the flow of energy between the energy consumption components and storage components and/or the power grid. The system is also capable to monitor the real-time power pricing and manage the storage and production components accordingly, in order to maximize profit or minimize the operational daily costs. A model predictive control algorithm is also integrated to describe building's behavior in order to identify future heating or cooling needs. (Veynandt et al. 2020) Additionally, the system analyses values of energy production, predicted production, equipment characteristics and past observations, and based on machine learning regression algorithms it allows the early detection of downward trends and malfunctions in support of the system's predictive maintenance (Meintanis et al., 2020).

4.2.2 Tailoring per demo-site

This multi-module system uses FusiX as an integration service to bring together the various tools and services, provided from the PVadapt partners, in a unified application and also to provide the corresponding GUI. In the context of the project a specific application per demo site is deployed, including all the control algorithms and modules related to the specific site.

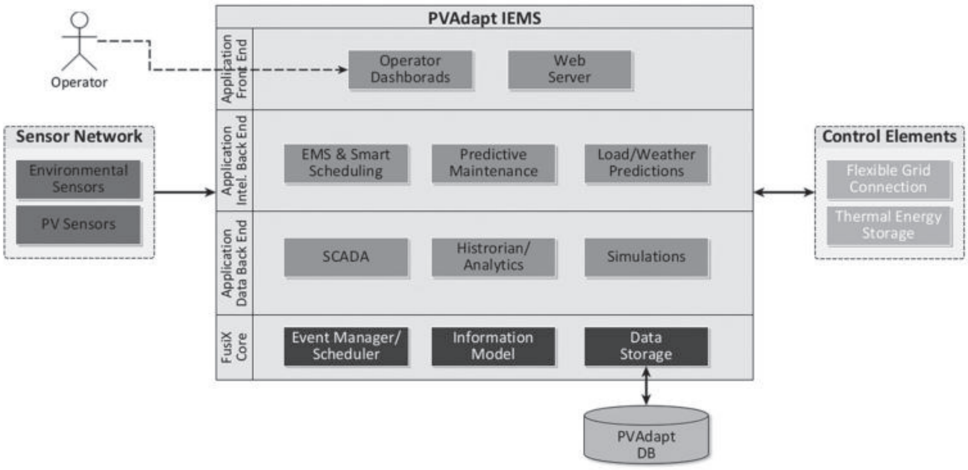

Fig. 3: PVadapt application main architecture

As Fig. 3 above depicts, the software provides:

- All the necessary bridges with the external services and sensor networks
- Appropriate storage mechanism to store data moving through the application
- Detailed Information Model holding all data specific information for each application
- Appropriate mechanisms to allow alert definition and execution depending on threshold violations and other constraints of the system's input and output data
- Customizable front end with appropriate user friendly interface for user interaction

New services and external tools can be easily integrated in this platform, enhancing adaptability to new technological challenges or alternating customer needs.

4.2.3 User Interface

Particular weight has been also given to the construction of a user interface that promotes the consistent participation of the user. Energy awareness is a key point in the effort of energy saving, so it has to be dealt exceptionally in order to be engaged and active. To facilitate the different user needs and expectations, several user groups have been defined:

- **System Administrators**. Users responsible for handling the IEMS application itself. They require a way to measure the performance and generally control the application itself in terms of scaling, security management and user management.
- **Professionals**. Users with the technical know-how to control the IEMS application and understand advanced metrics. As such technical oriented data is provided to them along with appropriate Key Performance Indicators (KPIs).
- **End-Users**. Final consumers not concerned with system's operation. As such, simpler metrics and KPIs are presented to them with no or very limited control functionality.
- **Business Analysts**. Personnel of organizations with main interest on economical and higher level analytics. Example users: Energy Providers, Large/Office building administrators.

The application is conceptually segmented to certain groups of pages so that the groups of users can interact with more than one group of pages (Fig. 4).

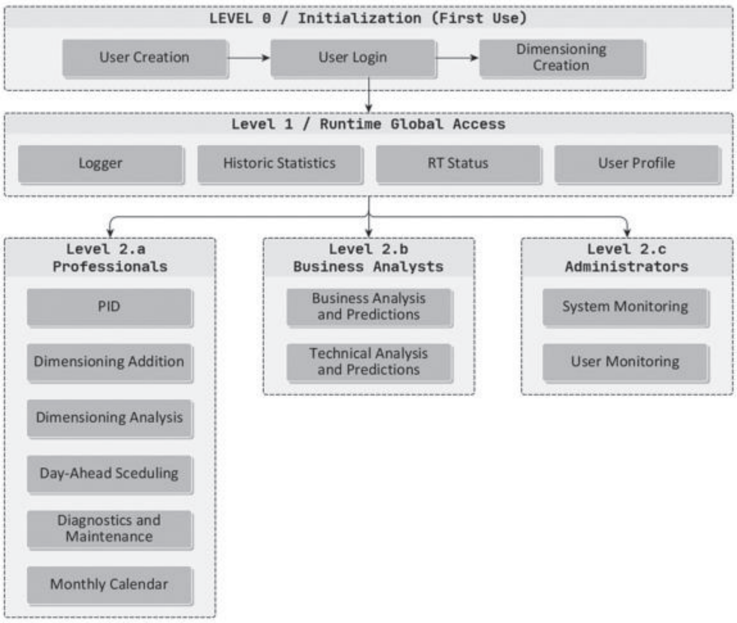

Fig. 4: Schematic representation of the GUI segmentation

Every single page of the above is further tailored according to the user accessing them. For example, while a main dashboard may be available to all users as a landing page, different users will see and access different features of this page. This clustering is oriented towards the desired awareness we want to achieve at the user end. The main groups of PVadapt pages are:

- **Dimensioning**. Page(s) that concern the configuration of a building in terms of main properties (ex. Location, Surface Area, Orientation, etc.)
- **SCADA**. Page(s) that concern the visualization of real time information to the users and the facilitation of control facilities.
- **Analytics**. Page(s) that concern higher level and historic visualization of gathered information. This includes simulations and predictions.
- **Administrative**. Page(s) that concern the control of the application itself.

Last but not least, like every modern software application, a consolidated mobile application is developed in order to provide the user with quick view, statistics and critical alerts.

4.2.4 Dimensioning Tool

In the context of PVadapt a Sizing Tool (Fig. 5) for PVs or photovoltaic thermal collectors (PVTs) and Green Walls (GWs) is also being developed.

Fig. 5: Investment proposition based on area selection on a virtual map

Users such as individuals or professionals will be able to conduct in depth calculations and derive scalable propositions for green energy production, in terms of electricity or a combination of electricity and thermal energy. Should the filtering of grey water be the case, the alternative of GW installations is also examined. An overview of the amount of grey water, that can be filtered per square meter of GW, can be easily calculated, as well as the derived liters of low quality water for laundry, flushing or irrigation activities.

The suggestions are able to consolidate the needs of the customer/investor, based on several parameters, having as a goal to return a plan expressed on financial indicators for better understanding of the user. Such indicators are the payback period of the initial investment as well as the expected revenue in the lifetime of the PVs, PVTs or GWs accordingly.

4.2.5 SCADA

The SCADA system of the PVadapt application concerns the real-time monitoring and control of the building site under observation. The SCADA is tailored for each building to support the available sensors and control options. The agent-based approach provided by the underlying FusiX platform allows for this tailoring to take place mostly based on text-based configuration with no change of source code elements. Apart from configurable sensors and control elements, it is also possible to tailor more generic settings such as refresh rate and caching window.

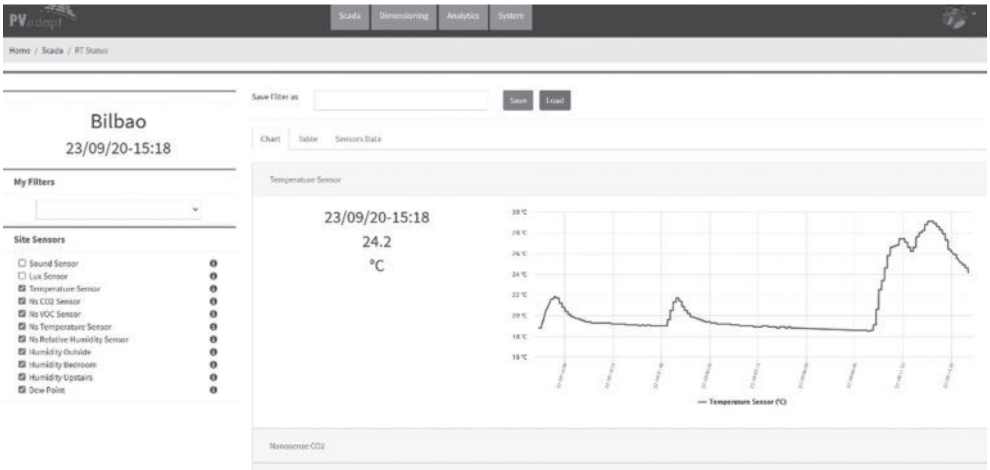

Fig. 6: SCADA view (simple user)

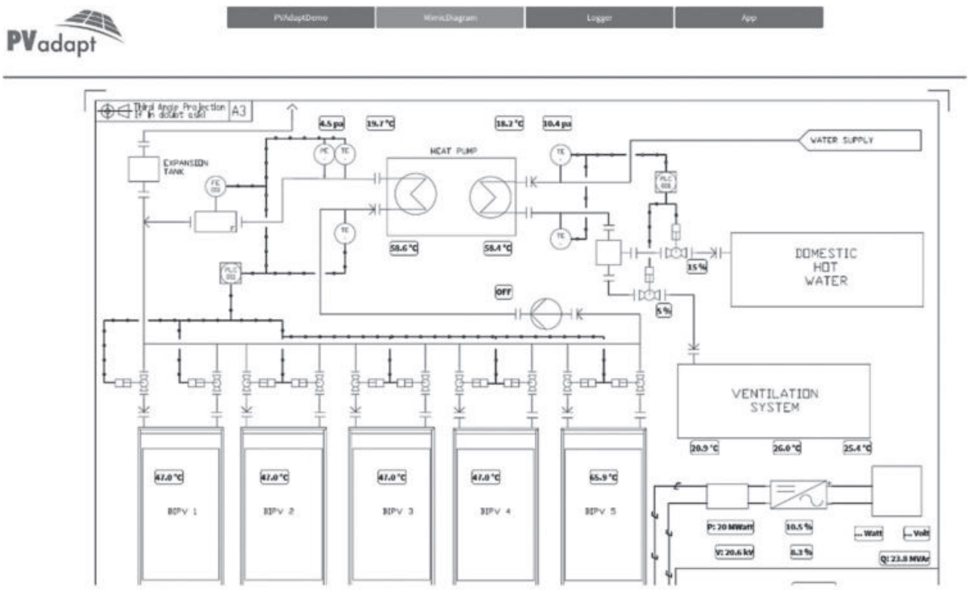

Fig. 7: SCADA views (building administrator)

In terms of user-interface, and based on the principles previously defined in section 4.2.3, users are provided information relevant to them based on their classification. For example a simple end-user will view a high-level representation of the building's status (Fig. 6) without the ability to perform control actions. An expert user on the other hand will be able to interact with the building's P&ID diagram in order to both view and control the building operations from a schematic representation (Fig. 7).

4.2.6 Analytics

The analytics components of the PVadapt application concerns aggregation of data and predictions. Specifically, data gathered from external sources (sensor networks, weather service, etc.) can be aggregated in a number of ways to provide valuable insights in terms of the site's operation and performance. For example, useful aggregate events can be produced for a building's maintenance needs based on tracking and comparing the nominal and actual curves of PV elements or batteries and cross-referencing them against weather information.

Predictions are produced by specialized algorithms and estimate key values of the system. In the current context, predictions can also be based on dimensioning profiles, discussed earlier, to provide appropriate user groups sufficient information on extending a building's configuration. Fig. 8 demonstrates a simple mockup of a 24 h window prediction for insolation and temperatures.

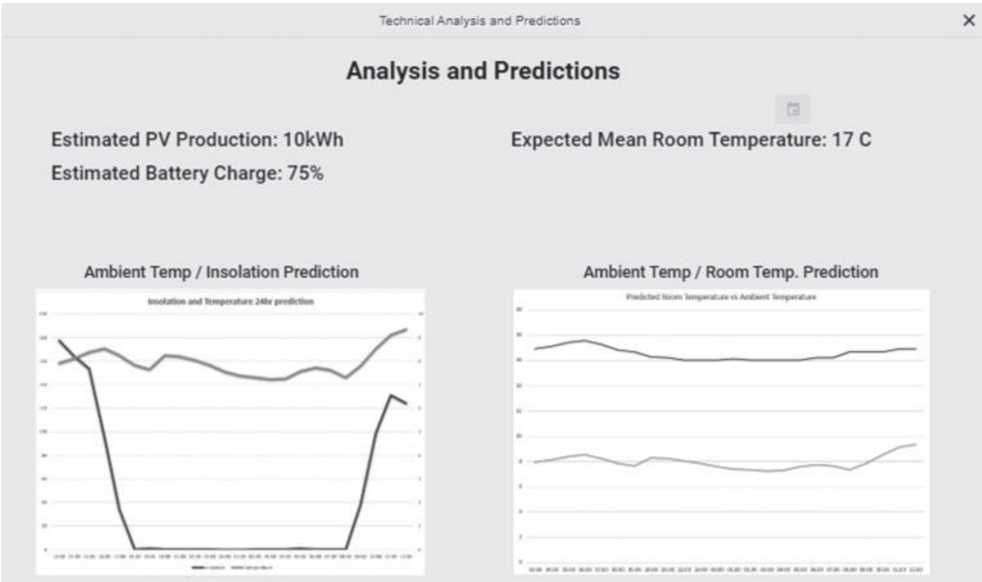

Fig. 8: Current status analysis and prediction

5. CONCLUSIONS

To sum up, modern Energy Management Systems have to deal with numerous challenges to efficiently optimize both economic and environmental criteria, as well as to satisfy the user comfort. These challenges span from handling different technological systems, such as renewable resources and legacy systems, to predicting weather conditions and load energy production/consumption. The end user behavior patterns, their motivation and long-term engagement to contribute in this optimization effort has been also discussed. In order to support the users in their decision making process, an Intelligent DSS has to be provided. In this paper, the FusiX-based DSS platform for IEMS was presented, along with two real cases of its usage (iReact-NG and PVadapt). The FusiX-based DSSs feature many characteristics that are vital for the development of such systems such as: application abstracted information model, agent-based decentralized architecture, data sources infusion and storage, data and simulation analytics, alerting system and a web-based user interface.

Finally, the inclusion of new technologies, such as vehicles connected to grid or dynamic energy certifications for buildings, as well as the application's gamification for longer-term engagement of the user are some of the future steps for FusiX-based applications. Last but not least, the system will be able to communicate with multiple smart buildings, thus further optimizing their energy usage/production and/or storage capabilities, forming this way large communities of smart buildings, which have common management point.

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