A web-based Building Automation and Control Service

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***Abstract*—The reduction of the environmental impact in the building sector is necessary in achieving global sustainability. In this context, Building Automation and Control systems provide the opportunity for efficient monitoring and control facilities' subsystems, such as the heating and cooling system, the ventilation system, the hot water system, the lighting appliances among others, with the goal of improving thermal comfort as well as energy efficiency. This paper presents a Building Automation and Control system aiming at facilitating data-driven monitoring of complex, multi-storey facilities, by disagreggating total consumption of the different floors and rooms of the building and offering advanced insights and benchmarking indicators. The service is showcased with a use case application on a real building, where the benefits of the service for the energy manager are highlighted.**

***Index Terms*—Building automation and control; Smart systems; Decision support; Energy efficiency**

I. INTRODUCTION

The limitation of the building sector's footprint in big cities and urban environments is a necessary step towards aligning to global sustainability goals [1]. More specifically, according to Economidou et al., the sectors of both residential and commercial buildings account for more than the 30% of the primary energy consumption globally at present [2], and even more importantly for approximately the 40% of total primary energy in the EU [3]. Moreover, the 2020 global status report for buildings and construction, indicates that even though energy consumption of the global buildings sector has been in the same levels as 2019, CO_2 emissions from the operation of buildings have increased to their highest level, at around 10 $GtCO_2$ [4]. Therefore, it is evident that is necessary to take measures immediately, through which the reduction of the environmental impact will be facilitated, both in national and global level.

In this context several cross-sectoral efforts have been made aiming to reduce the environmental impact of the building sector. One of the most important pillars is the fostering of energy efficiency (EE) investments through data-driven approaches, especially in buildings, as well as the citizens' willingness to engage in community-based renewable energy projects [5], [6]. Another aspect is the monitoring of energy savings of EE investments at an early stage with the aim to quantify the impacts of such renovation measures [7], [8], as well as the development of MCDA methodologies which address the problem of energy poverty by proposing home renovation actions [9]. Except for EE financing, real-time monitoring system also constitute a useful tool in the hands of energy managers and operators in order to control the performance of buildings.

Building Automation and Control (BAC) systems and Technical Building Management (TBM) offer the capability for effective monitoring and control functions of a building's subsystems [10], such as the heating and cooling system, the ventilation system, the usage of hot water, the lighting appliances etc., with the ultimate goal of improving comfort as well as energy efficiency [11]. BAC services usually allow the energy manager or operator of a building, gaining access and control to the systems of the facility, through a single platform in an easy, uniform and automated way [12]. Thus, BAC services enable the operator to have centralized control over the facility, exploiting smart-meters and Internet of Things (IoT) devices installed and networked into the subsystems of the building. This can result in modernizing old time-consuming approaches, requiring extensive manual effort and monitoring of each subsystem, via gaining centralized control from a single view based on the interconnection of all subsystems' smart metering devices to a single platform, enabling upgraded decision-making [13].

Another novelty provided by BAC systems and platforms is, the balancing between the inhabitants' comfort and the energy efficiency of the building [14]. This can be achieved by taking into consideration continuous streams of data, which enable the energy manager to detect and reduce, or even eradicate, not necessary energy waste, without interfering to the comfort of inhabitants. A typical example is to consider unoccupied areas where the HVAC system or the lights are left open, consuming energy unnecessarily. BAC systems provide the chance to tackle such issues, as the operator can detect unusual patterns, through data-driven monitoring platforms and smart services.

However, the design of an effective BAC service requires a systematic approach that should take into consideration three main components: (a) The topology and the architecture of the building, (b) the available smart metering devices and consequently the available datasets, and (c) the specific goals of the building operator or energy manager. Additionally, modern facilities incorporate complex data flows, including data from different smart metering devices, which are becoming available in different frequency and through different - sometimes conflicting - protocols. The bulk of generated data is continuously increasing [15], [16], as real time data is generated by Internet of things technologies, including smart meters for energy consumption and energy production, as well as sensor based data [17]. This emphasizes the need for a holistic architecture of the BAC system, which would include all technological and quantitative parameters, while also respecting human-related objectives. In this landscape, it must be ensured that the designed BAC system can handle all different big data components, mainly volume, variety and velocity of data, while also enabling real-time data processing of heterogeneous data streams.

In this paper we present a BAC system with the aim of addressing the above-mentioned challenges and facilitate data-driven monitoring of complex, usually multi-storey, facilities, disagreggating consumption to the different floors and building areas and providing advanced insights and benchmarks for the facility. This study also addresses the issue of handling energy-related data in an efficient way, and incorporating them in a user-friendly web-based application following a solid methodological approach. Additionally, several smart building benchmarks are utilised towards informed decision support.

Apart from this introductory section, the rest of the paper is organized as follows. Section II gives an overview of the architecture of the proposed methodology. Section III presents a real-life case-study of the proposed methodology in a multi-storey building. Finally, in Section IV the main conclusions of the paper are summarized and key points for further research are proposed.

II. SERVICE ARCHITECTURE

The BAC service offers a centralized and automated framework, based on real-time and historical data, in order to assess a building's heating, ventilation, air conditioning and lighting sub-systems, as well as the cumulative energy consumption. Performance monitoring functionalities are available, as the service provides information to the user, regarding the performance of the building by presenting several energy efficiency indicators. Then, control actions over the building's different areas, possible action plans and measures which improve energy efficiency are supported. It is evident that with each building having different subsystems and different available data, the BAC service needs to be tailor-made according to the three pillars described in I, despite the overall unified architectural methodology. Moreover, building characteristics are also considered, including total area, type of building, use patterns and occupancy among others. Weather data are also used, in order to assess the impact of the control actions to the performance indicators.

The BAC service follows an integrated architecture, covering all parts of the data flow, from data collection and data modelling to visualization and informed decision support. Data are retrieved from databases and they are used to create consumption patterns, profiling and monitoring performance. The service has been developed on the Django web framework, which is a high-level Python-based framework, enabling development of secure and maintainable web-applications [18], including several computational services such as multi-criteria decision support for energy efficiency investments [19] and portfolio optimization problems [20], [21]. This web framework was selected as it offers the opportunity to implement an out of the box, versatile, secure, scalable, maintainable and portable web application. Thus it can be an alternative approach for the design of BAC systems, substituting and complementing traditional building information modelling systems

[22], [23]. The architecture of the BAC service is presented in Fig. 1.

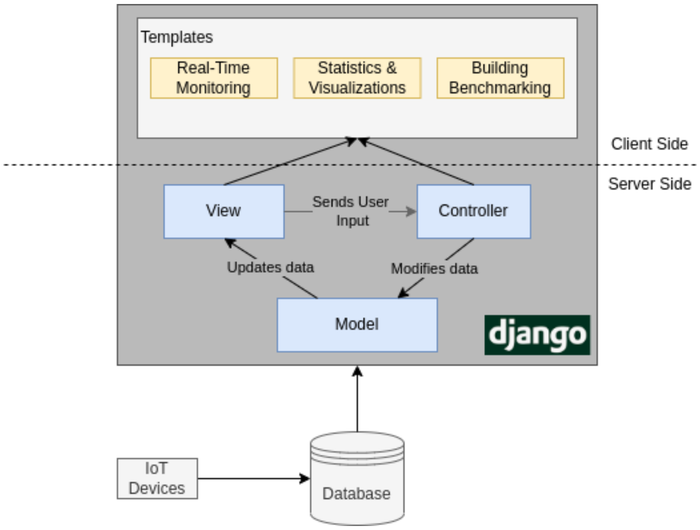

Fig. 1: The architectural scheme for Building Automation and Control service.

The service consists of five discrete steps; namely collecting data from IoT devices, pre-processing these data and finally ingesting them into the application's database. In a second stage, data are drawn from the database and they are processed, resulting in tabular presentations and visualizations that facilitate informed decision making.

The instantiated platform ingests data through adapters developed on purpose for specified input data, which are modeled by a pre-specified schema. Specifically, the BAC service allows the facility manager to take control over the available data, apply (near) real-time data processing at facility/assets site, and expose flexibility to various service providers. The application of secure gateway aims at enhancing assets interoperability and enabling the coordination of sub-systems corresponding to different energy vectors. Overall, the aim is to increase site operational efficiency and aid maintenance and planning activities.

The design of the web application is based on the standard Model - View - Controller (MVC) framework, customized according to the needs of the provided services. More specifically, the Model defines the structure of the available data and it is responsible for any updates. The Controller includes the logic of the web application, using the information from the view in order to notify the model about potential changes. Finally, the View is responsible for the definition of the User Interface (UI). The communication among these server side components is vital for the functionality of the application. Bilateral communication of these components are optimally managed by the Django-based web-application. It should be noted that the BAC service follows the MVC pattern very closely, but it uses slightly different terminology. Django is essentially a MTV (Model-Template-View) framework, using the term template for view and view for controller. Hence, HTML scripts are set in templates while Python code in views and models.

Except from the server side components, the application also includes the client side rational, which is responsible for providing the required functionalities to the end user, provided through application's templates. The role of the templates is to embody text and visualization marked-up, using the Django template language, recognized and interpreted by the template engine. Thus, they represent the front-end functionalities of the application. On top of the Django templates, the structuring and content management has been performed using *HTML* scripts, the styling is based on *CSS* and the interaction between the app's functionalities is implemented with *Javascript*. Additionally, UI interface elements have been enriched with the *Bootstrap 4* framework, while the advanced visualizations are designed using *ChartJS*. As mentioned above, the UI of the BAC service is customized according to the specific needs of each instance. That said, there is a standard set of modules, easily generalized for every facility, that the BAC service should support. These modules are the following:

- *Real-Time Monitoring*
- *Statistics & Visualizations*
- *Building Benchmarking*

The *Real-Time Monitoring* module helps the energy manager of the facility identify the actual time that an incident occurs in the inspected facility. By identifying such incidents, energy managers can get more proactive with predictive monitoring and deal with recurring problems directly and effectively.

The *Statistics & Visualizations* module provides useful aggregations of the available datasets offering useful insights, regarding daily use patterns of different building subsystems. Except from daily patterns, the BAC service also supports disaggregation of energy usage per room, per floor or per functionality in complex multi-storey buildings.

Finally, the *Building Benchmarking* module is a sophisticated module, supporting visualization of different indicators that provide insights for different subsystems taking also into consideration topological characteristics.

The output of the service is the presentation of insights on the performance of the building as a whole, as well as of its sub-systems based on the benchmarking performance indicators. The service also enables the energy manager to visualise performance analysis through graphs, plots and charts, offering an overview of energy efficiency and recommending control actions on different areas. Alarms can be triggered by special events (such as, high consumption in a certain day) or in the case of a high value of inefficiency based on the performance indicators.

III. USE CASE ON A REAL BUILDING

The Building Automation and Control service can be tailor-made for the monitoring of specific buildings or even for groups of rooms and area in them. In these areas, the overall energy efficiency is calculated based on the type of the building, resulting in the detection of energy use anomalies and potentially to the proposition of action plans for performance improvement actions. In this section, a use case on a real building is showcased with the aim to present in detail the BAC service. The presented facility is a multi-purpose building where offices, commercial stores and leisure shops are all accommodated in one multi-storey building. Building characteristics, such as size, total and per floor area, and topology of the HVAC systems are also taken into account. The historical electricity and heating consumption per floor and room are provided.

As stated in Section II the BAC service is composed of three modules. The real time monitoring module is also used as the homepage of the web application of the tool. This module shows the last 24 hours of total consumption for both electricity and heating. This information intends to give the user a well-rounded first impression of the energy consumption for the inspected facility. An indicative instance of the real time monitoring module of the web application is presented in Figure 2.

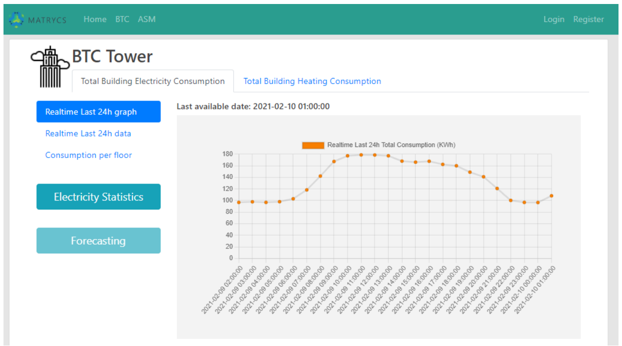

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Fig. 2: An instance of the *Real-Time Monitoring* module used as homepage of the Building Automation and Control service.

The BAC Service offers visualization and data tables of the past 24 hours enabling the user to easily distinguish patterns and draw conclusions for the energy consumption. In addition, per floor and room insights are provided, which can be selected through a map visualization of the building's rooms, areas and floors.

One of the most important functionalities of the BAC service is provided by the *Statistics & Visualizations* module that aspires to interpret data through various statistical mechanisms, providing different aspects of the data and offering useful insights to the energy manager. The presented statistics and visualizations can be viewed either for the building as a whole, or for specific floors and rooms. For instance by showing the average consumption per hour 3a, the user can easily distinguish the different energy profiles among hourly intervals. Additionally, the consumption distribution tab 3b offers specific insights that there is high energy consumption at night hours, necessitating actions to be taken and further investigation to be made. Another useful insight offered by the tool is the daily profiles tab shown in Figure 3c, that presents average daily energy profiles (as expected consumption is higher during workdays compared to weekends). Moreover, the per floor distribution tab shown in Figure 3d, assists in comparing floors and types of rooms, presenting more advanced statistics and helping to figure out energy consumption disaggregation patterns.

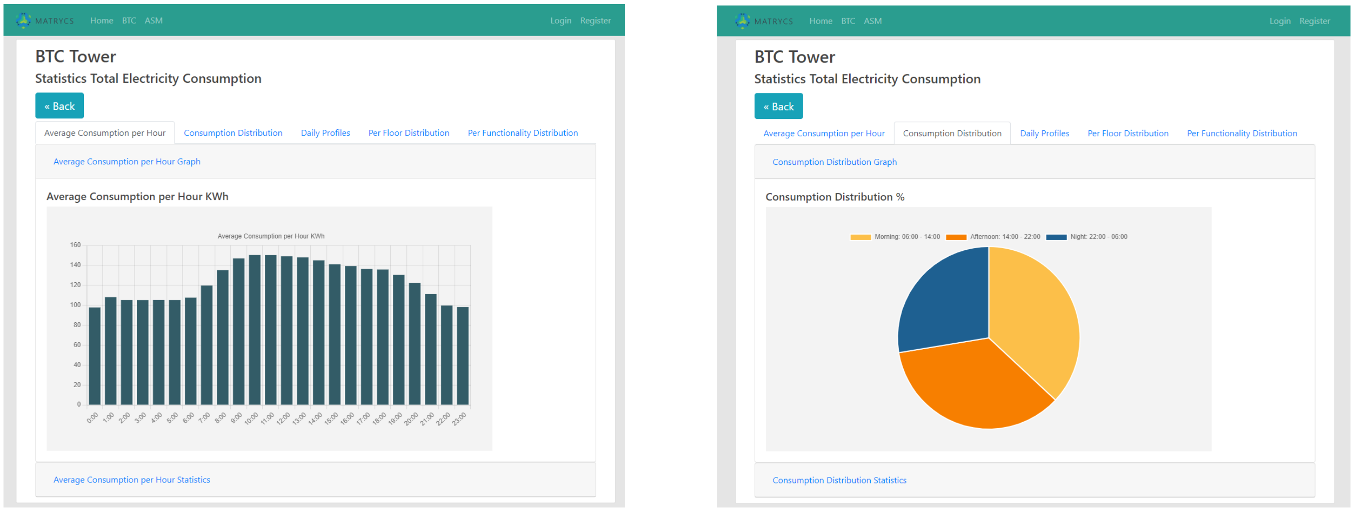
Finally, the presented use case includes monitoring the facility's conditions in real time providing the relevant energy performance indicators for selected areas. This is achieved through the *Building Benchmarking* module. The identified indicators for this use case are the following: (a) *Total Energy Use*, (b) *Energy Use Intensity*, (c) *Electrical Load Factor*, (d) *Lighting Power Density*, (e) *Daylight Effectiveness*. Additionally, future electricity and heating demand is also predicted using an energy prediction module as a sub-service, in order to assess the impact of action plans for performance improvements by using the benchmark values of the performance indicators. The definition of the benchmarking indicators is presented in Table I.

These benchmark indicators offer advanced insights produced by the available data. An indicative example is the daily Total Energy Use indicator 4a that offers daily information from the last 30 days in comparison with last 24 hours. Another important indicator is the Electrical Load Factor 4b, which shows the last 72 hours of the average electrical load divided by the peak load in a specified time period. This information is useful for the inspection of how present consumption differs from its peak value. Furthermore, the Daylight Effectiveness indicator shows the lightning energy use density considering the time of the day. This indicator is used to recognise how much lightning energy is used when this is not necessary 4c.

IV. CONCLUSIONS

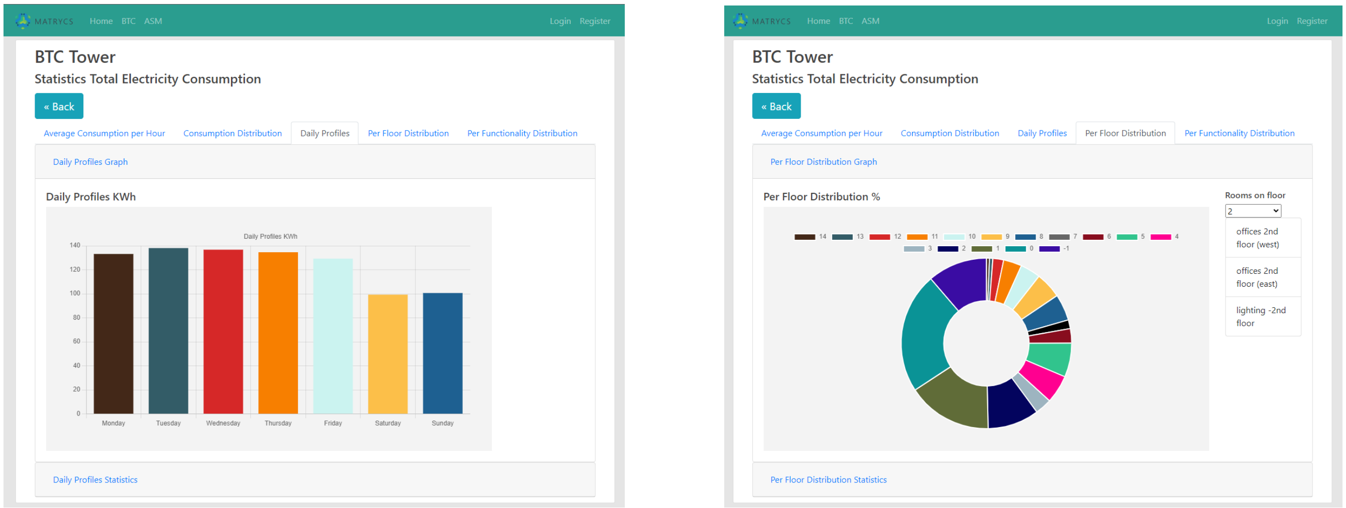
In this paper an integrated BAC service is presented aspiring to facilitate data-driven monitoring of complex facilities with different sub-systems, able to disaggregate consumption to different building areas. Moreover, a group of benchmarks have been integrated aiming to enhance informed decision making for the facility. For this purpose, a web-based application has been developed and demonstrated in a real building. The architecture of the application successfully addresses the challenge of managing energy-related data in an efficient way while also providing insightful graphs and statistics to the end-user.

Future work should further enrich the architecture of the BAC service, providing a complete documentation that describes in detail how to deal with data of each specific subsystem. This documentation would enable the service to be not only generalizable, but also well-documented and easier to fit to the unique requirements of each facility in a solid, methodological way. Towards this direction, the development of a common data model is necessary, as it would simplify data management, and consequently the service development, by unifying data into a common form and by applying structural uniformity and semantic consistency across all instances and deployments of the application.



(a) Average Consumption per Hour for the Building Automation and Control service.

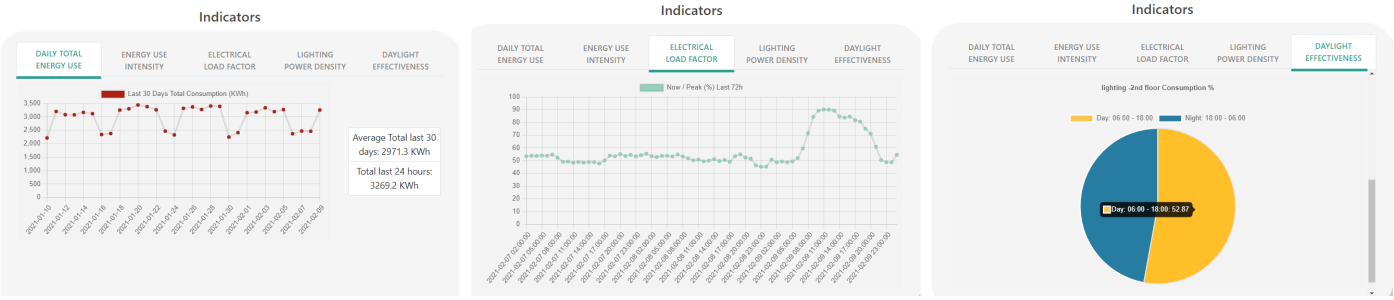
(b) Consumption Distribution for the Building Automation and Control service.



(c) The daily Profiles for the Building Automation and Control service.

(d) Per Floor Distribution for the Building Automation and Control service.

Fig. 3: The *Statistics & Visualization* module of the Building Automation and Control service.



Average Total last 30 days: 2971.3 KWh

Total last 24 hours: 3269.2 KWh

(a) Daily Total Energy Use Indicator for the Building Automation and Control service.

(b) Electrical Load Factor Indicator for the Building Automation and Control service.

(c) Daylight Effectiveness Indicator for the Building Automation and Control service.

Fig. 4: An instance of the *Building Benchmarking* module of the Building Automation and Control service, depicting three benchmarking indicators for the inspected building.

TABLE I: Benchmarking indicators for Building Automation and Control Service.

Indicator	**Definition**
Total Energy Use	Total site energy use of a building
Energy Use Intensity	A building's energy use normalized by its size (usually the total floor area).
Electrical Load Factor	The average electrical load divided by the peak load in a specified time period.
Lighting Power Density	Lighting power per unit building floor area
Daylight Effectiveness	Reflection of monthly lighting energy use density considering daylight hours

Finally, as the volume, variety and velocity of data increase, future perspective should definitely consider the integration of data spaces concepts into the BAC service. Data spaces offer a methodological framework for innovative cooperation through sovereign and entrusted data sharing principles, lowering the barriers towards the next generation data economy. Thus, the BAC service should incorporate these principles, being IDSA compliant and enabling data sharing without security concerns and enabling data providers to determine the processes and pipelines of the management of their data.

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