IoT and Cloud-Based Energy Monitoring and Simulation Platform

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***Abstract-* Nowadays, in order to optimize resource consumption and reduce costs, companies concern themselves with the adoption of innovative energy efficiency solutions. Substantiating the decision to implement energy efficiency measures is challenging, due to a high number of factors that influence the rentability of the project, such as weather conditions, energy pricing, laws and regulations, available resources and energy demand. Thus, each company faces a unique combination of factors that needs to be properly evaluated prior to the adoption of energy efficiency measures. The paper presents an IoT and Cloud-based energy monitoring and simulation platform that aims to help companies monitor energy production and consumption within various cost-centers, forecast the energy production potential and simulate the economic efficiency for multiple investment scenarios.**

***Keywords*: Smart Energy, Smart City, IoT, Business Intelligence**

I. INTRODUCTION

In the past decades, the compliance with laws and regulations became a priority for companies of all sizes and from all activity fields as their competitiveness on the market is determined by the optimization of resources and their impact on the environment [1]. Internet of Things (IoT) technologies became a key element in managing energy production and consumption, thus facilitating actuation towards optimization of resources within companies. Moreover, monitoring the energy consumption contributes to the long-term sustainability of businesses by generating awareness regarding inefficient equipment and processes, consumption patterns within various cost centers of the companies and potential investments in alternative power sources [2].

At a global level, Energy Service Companies (ESCO) provide a broad range of Business-to-Business (B2B) solutions for managing energy consumption and production, thus aiming to increase energy efficiency within customer's company [3]. Energy Performance Contracts (EPC) commonly start with an audit by which the ESCO identifies sources of inefficiency and proposes improvement measures. An analysis of the potential savings is performed and after the terms of the contract are agreed upon by involved parties, the project starts and the savings are periodically verified [4].

Prior to the implementation of energy efficiency measures, companies need to determine all relevant internal and external factors that may enhance or threaten the feasibility of the project. A wide range of simulation tools can be used in order to determine the impact of factors such as local weather conditions or energy prices on the energy production and consumption, but, in addition, business analytics plays a significant role in assessing the middle and long-term economic effects of investment decisions [5].

CitiSim [6] is a Smart City 3D simulation and monitoring platform that provides advanced services and tools in domains such as smart energy, smart mobility and smart emergencies.

In the context of the CitiSim project, the current paper presents an innovative IoT and Cloud-based platform that uses energy simulation data and energy production / consumption data collected by sensors for simulating the economic efficiency within various investment scenarios of projects based on Energy Performance Contracts (EPC).

The rest of the paper is organized as follows: Section II depicts various solutions for monitoring and simulating energy production and consumption, Section III presents an innovative IoT and Cloud-Based Energy Monitoring and Simulation Platform developed within the CitiSim project, while Section IV concludes the paper.

II. RELATED WORK

The Internet of Things technologies facilitate the design and development of innovative monitoring and actuation solutions, provide companies more control over the utility operations and even upgrade the security and quality of the existent equipment. Using sensors and actuators inside buildings can help businesses reduce the amount of energy consumption through real-time monitoring and management of lighting and temperature.

The advantages of IoT technologies are materialized in Zero-Net Buildings (ZNE) or zero-energy buildings, which are becoming more popular globally [7]. These are high-performance buildings, where the amount of on-site produced sustainable energy produced in the building is equal to the amount of energy consumed every year, with the help of Artificial Intelligence (AI), LED light systems or solar systems [8].

Companies, regardless of their size and activity field, keep searching for new approaches for energy consumption reduction. In this sense, a wide range of energy management software programs have been developed to contribute to the optimization of energy costs.

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Cisco Energy Management Suite [9] is a tool that facilitates the optimization of energy use by supplying data regarding emissions, energy use, savings and costs. The data is acquired using operational technology and IoT devices, and it is being displayed and categorized by timeframe and cost center (device, location, group). Therefore, its applicability in substantiating the decision-making process for enhancing energy efficiency is based on generating awareness regarding inefficient equipment and practices within the client company. Moreover, Cisco Energy Management Suite doesn't require the integration of smart meters for data collection.

DEXCell Energy Manager [10] [11] is a Cloud energy management platform focused on real time monitoring and energy analytics. The main features of this solution are the following: real time monitoring of energy consumption, utility bill tracking, widget-based dashboards, discovery of energy patterns, benchmarking, cost analysis, reporting and notification. Using the API provided by DEXCell, users can create customized dashboards, alarms and reports. The platform provides support for a wide variety of IoT devices available on the market.

Engage [12] [13] is an energy management software that facilitates the monitoring and management of energy in real-time. Its functionalities include energy consumption monitoring, budget planning, costs calculation, energy demand evaluation and visualization of consumption history. For data collection, the platform uses proprietary sensors from Engage.

To predict energy consumption given a wide variety of environmental factors, building energy simulation software uses inputs regarding climate conditions, individual equipment consumption and operation hours, occupation, building isolation, activity schedule, etc. Energy modeling software generates predictions for energy consumption and associated costs related to typical end-user scenarios [14].

EnergyPlus [15] is a solution for simulation of energy consumption and production within buildings. It facilitates the simulation of the consumption related to illumination, cooling, heating, ventilation, and also of the amount of energy used by other equipment. The program essentially focuses on the convective effects and thermal balance in the building.

DesignBuilder [16] is a user-friendly solution that consists of a modeling environment where virtual building models can be created. It is based on EnergyPlus for simulating the energy consumption inside buildings and for forecasting the energy production potential using alternative energy sources, such as solar systems. Moreover, the solution facilitates the modeling of lighting control systems, solar shading, environmental conditions, thermal conditions inside buildings, carbon emissions, energy consumption, daylight illuminance, comfort conditions, and maximum summertime temperatures etc.

IDA Indoor Climate and Energy (IDA ICE) [17] is a simulation tool used in modeling buildings and their systems, being essential in studying energy consumption and indoor thermal climate since it focuses on a minimum energy consumption. This software provides techniques for computing and reporting energy, air, heating or cooling requirements. IDA ICE is adjusted to local requirements such as standards, climate data, special reports, specialized systems, product and material data, and languages since it serves the global market.

III. CitiSim Smart Energy Business Intelligence

In the past decade, the energy efficiency has grown substantially due to its benefits in addressing many of the businesses' most pressing concerns: system reliability, regulations and rising costs. The platform relies on creating and evaluating economic performance perspectives of energy efficiency for various user-defined scenarios.

The CitiSim Smart Energy Business Intelligence platform relies on three functionalities (Fig. 1):

- energy production and consumption monitoring, based on IoT devices, MQTT (Message Queuing Telemetry Transport) [18] and Grafana [19];
- energy production potential simulation, based on EnergyPlus and weather data;
- simulation of economic performance of energy efficiency projects for various investment scenarios.

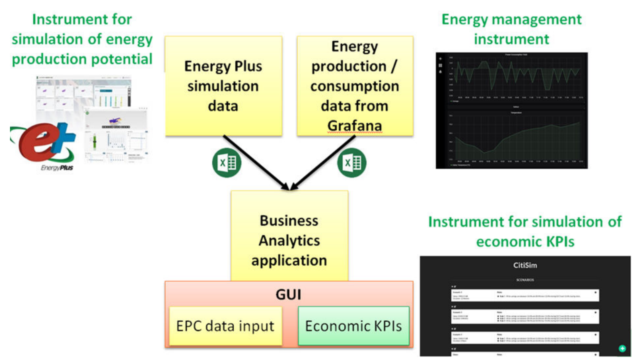


Fig. 1. CitiSim Smart Energy Business Intelligence tools

A. *Energy production and consumption monitoring*

As depicted in Fig. 2, the IoT devices used for data collection are Verbund energy sensors and Libelium environmental sensors.

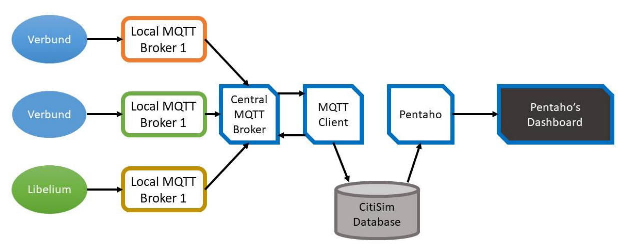


Fig. 2. CitiSim energy monitoring tool architecture

The goal of the energy monitoring tool is to extract the output parameters of an energy sensor, in the current case an inverter, and sent this information to a data visualization platform. The Verbund IoT device [20] represents a key element to energy efficiency. This equipment records the desired parameters and transmits them further by accessing the JSON link address REST/JSON. However, this request can only be made if it is in the same wireless network. With the help of the Siemens IoT2020 [21], the information received from Verbund can be transferred via MQTT to the mqtt.beia-telemetrie.ro server with a precise sampling period. Then, the Grafana platform takes the necessary parameters from the server and displays it as a graph to facilitate understanding the events that take place at the inverter level.

Libelium IoT sensors are used for monitoring the temperature, solar radiation and luminosity. After being collected, the data is sent by the sensor nodes to the Meshlium gateway using XBee, LoRa, GPRS, 3G or WiFi, where it is stored. The Meshlium gateway sends data to the Local MQTT Broker using the MQTT protocol for M2M communication, and then to the Central MQTT Broker.

Through the MQTT Client, the information is being sent to the POSTGRESQL CitiSim Database. Pentaho retrieves data stored in the CitiSim Database and displays it using Grafana as a GUI (Graphical User Interface), as presented in Fig. 3.

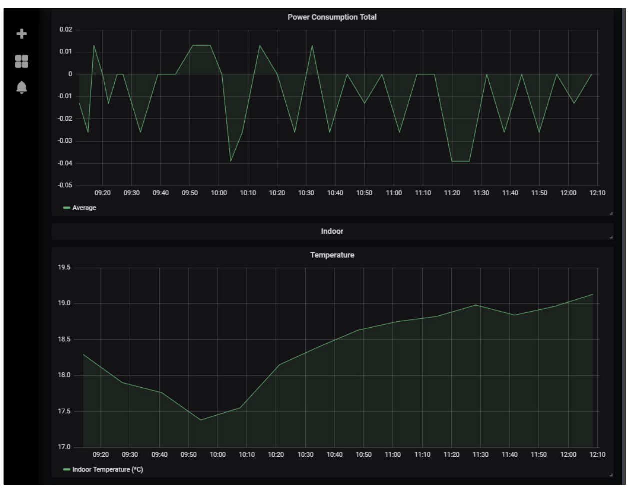


Fig. 3. Grafana data visualization

B. *Energy production potential simulation*

Building simulation programs demonstrated a method of combining design and energy simulation for data visualization technique. One of these modeling tools is DesignBuilder, a solution with a graphical menu that contains energy-efficient building designs. It provides thermal and luminous simulations as a result of weather data values obtained: illumination values, daylight factor values or air temperature values. The main purpose of DesignBuilder is to improve energy production by analyzing weather factors like temperature, light.

Power forecasting is a crucial factor for planning the operations of a photovoltaic (PV) system. With the development of PV technology, large-scale grid-connected PV power systems have been built around the world in recent years. Since the power produced by a PV system depends critically on the variability of solar irradiance and environmental factors, unexpected variations of a PV system output may increase the costs for the electricity system by increasing requirements of primary reserves, as well as placing potential risks to the reliability of electricity supply.

DesignBuilder can be used in order to simulate the power production potential of a Photovoltaic solution. Solar panels can be added on an existing building block or directly on the ground. Furthermore, electric load centers, inverters and storage systems can be edited to fit various configurations specific to investment scenarios in renewable energies [22].

For the simulation of energy production potential in a region, weather files can be downloaded from the EnergyPlus website [23] and used within DesignBuilder. A more accurate alternative is to monitor weather conditions using calibrated sensors and generate weather files based on collected data.

C. *Business Intelligence for investments*

The Smart Energy Business Intelligence relies on data collected through IoT devices, simulation data describing the energy production potential in the region and user inputs regarding the investment. The data collected by IoT devices can be downloaded from Grafana and uploaded to the Business Intelligence (BI) tool, or it can be provided by the user based on the past energy bills, in energy or monetary units. If a file is uploaded, the BI tool parses the consumption history data and calculates the average consumption for certain timeframes. As in the case of the data collected by IoT devices, the simulation data generated by DesignBuilder can be uploaded to the BI tool and the energy production potential is calculated for a certain timeframe. The architecture of the Business Intelligence tool is presented in Fig. 4.

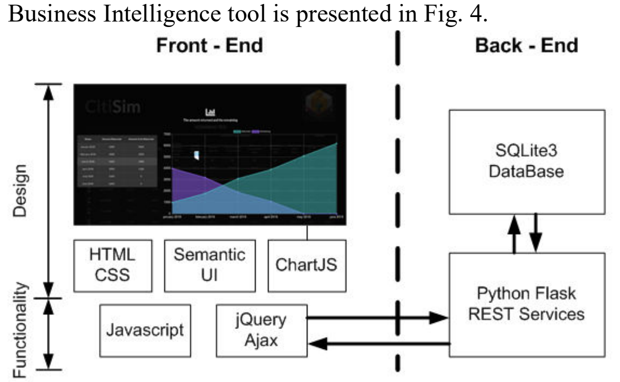


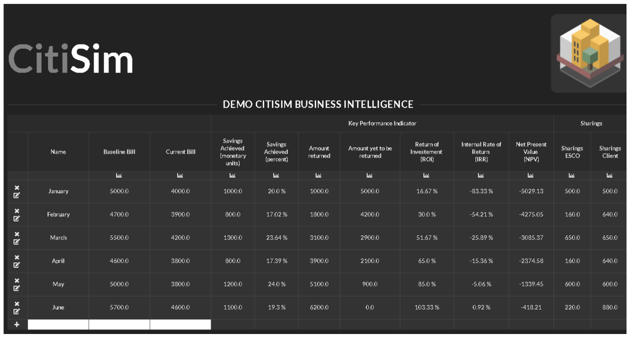
Fig. 4. Business Intelligence tool architecture

The BI tool for KPIs scenarios simulation was developed using open source web technologies and is based on a REST architecture.

Several frameworks were combined for the front-end, beginning with SemanticUI for the structure and styling of each page, ChartJS for the graphical data representation and finishing with jQuery and Ajax for asynchronous calls of the back-end services.

The back-end is composed from a SQLite3 database and Python Flask REST services for data fetching and processing.

The BI tool provides scenario-based KPIs such as the Return of Investment (ROI), Internal Rate of Return (IRR), Net Present Value (NPV) and the distribution of savings between the Energy Service Company (ESCO) and the client. These KPIs can be visualized using tables, graphs and diagrams, and the values from multiple scenarios can be compared. The interface for KPIs visualization is presented in Fig. 5.



			Key Performance Indicator							Sharings	
Name	Baseline Bill	Current Bill	Savings Achieved (monetary units)	Savings Achieved (percent)	Amount returned	Amount yet to be returned	Return of Investement (ROI)	Internal Rate of Return (IRR)	Net Present Value (NPV)	Sharings ESCO	Sharings Client
January	5000.0	4000.0	1000.0	20.0 %	1000.0	5000.0	16.67 %	-83.33 %	-5029.13	500.0	500.0
February	4700.0	3900.0	800.0	17.02 %	1800.0	4200.0	30.0 %	-54.21 %	-4275.05	160.0	640.0
March	5500.0	4200.0	1300.0	23.64 %	3100.0	2900.0	51.67 %	-25.89 %	-3085.37	650.0	650.0
April	4600.0	3800.0	800.0	17.39 %	3900.0	2100.0	65.0 %	-15.36 %	-2374.58	160.0	640.0
May	5000.0	3800.0	1200.0	24.0 %	5100.0	900.0	85.0 %	-5.06 %	-1339.45	600.0	600.0
June	5700.0	4600.0	1100.0	19.3 %	6200.0	0.0	103.33 %	0.92 %	-418.21	220.0	880.0

Fig. 5. Interface for KPIs visualization

For KPI forecasting, additional user input is required, such as the value of the investment, rules for the sharing of savings between involved parties and duration of the contract etc.

IV. CONCLUSIONS

The IoT and Cloud-based energy monitoring and simulation platform developed within the CitiSim project aims to facilitate resource optimization within enterprises and provide means of substantiating decisions to invest in energy efficiency measures.

From a functional perspective, the integration between the components (energy production and consumption monitoring, energy production simulation and business analytics) provides added value in comparison with existing solutions. Various Energy Management Systems, simulation solutions and Business Intelligence tools are available on the market, but they are not designed to operate as a toolchain. In this context, the CitiSim IoT and Cloud-Based Energy Monitoring and Simulation Platform provides a viable solution that generates awareness regarding consumption/production patterns and energy production potential. Moreover, it provides economic KPIs for the substantiation of investment decisions, thus enhancing the success rate of energy efficiency projects. As future work, the platform will continuously be updated to provide support for a broad range of IoT data acquisition devices, such as smart meters already deployed by energy providers.

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