DEU INTERNATIONAL SYMPOSIUM SERIES ON GRADUATE RESEARCHES-2022 ***DataScience***
December 2-3, 2022
Izmir Turkey

ENERGY EFFICIENCY IN BUILDINGS: A SIMULATION APPLICATION

First Author: Cem Yildiz

Distance Education Application and Research Center, Dokuz Eylul University

Izmir Turkey

cem.yildiz@ogr.deu.edu.tr

Second Author: Kaan Yaralıoğlu

Management Information System, Dokuz Eylul University

Izmir Turkey

k.yaralioglu@deu.edu.tr

Third Author: Vahap Tecim

Management Information System, Dokuz Eylul University

Izmir Turkey

vahap.tecim@deu.edu.tr

Fourth Author: Emre Karagöz

Distance Education Application and Research Center, Dokuz Eylul University

Izmir Turkey

emre.karagoz@deu.edu.tr

ABSTRACT : In buildings, which represent a significant proportion of energy demand, it is of crucial to manage energy as well as to use it efficiently and effectively. In this study, a simulation application has been developed to determine energy consumption in buildings and to understand the results of new energy policies. With the proposed platform, it is aimed to measure the energy consumption values between places that contain IoT technologies and where these technologies are not applied, and make them available to decision makers. The platform performs simulations of different energy consumption scenarios, including the effects of IoT functions, without reducing the quality of life of users in buildings. In line with the determination of the results of the simulation values to be obtained in different scenarios, it has been tried to create a decision support software that will support the decision making of the managers.

Keywords: Energy management, IoT, simulation

1. INTRODUCTION

The “World Population Prospects” report is published by the United Nations every two years (the report that should have been published in 2021 due to the COVID-19 outbreak was published in 2022). According to this report, the world population is 7.91 billion by 2022 and it is predicted that it will reach 8 billion by the end of 2022 (United Nation, 2022) . Again, according to the United Nations reports, while more than half of the world's population lives in urban areas, it is expected that the worldwide urban share will increase to two-thirds of the population in 2050. The unavoidable increase in the rate of urbanization increases the need for energy. Therefore, a properly structured energy management policy in buildings, which is defined by the International Energy Agency as “an enormous untapped source of efficiency potential”, becomes much more important. At this point, data is needed to evaluate the real effects of possible energy consumption and to create effective services. For this purpose, sensors, SoC (System of Chip) and communication modules, which form the building blocks of the Internet of Things, are used to obtain both real-time and heterogeneous data. However, the fact

that bringing together many sensors and related equipment is both physically and financially demanding makes the use of simulation techniques valid.

Simulation is defined as the process of designing a real or virtual system model in order to learn the behavior of complex production systems and to predict the output of the process (de Paula Ferreira et al., 2020). Simulation is an approach that supports decision making by analyzing constructs, solving possible problems, and evaluating different alternatives (Negahban & Smith, 2014). Some of the advantages of the simulation approach, which plays an important role in the optimization of the processes and the evaluation of their performance, are as follows (Banks, 2000);

- It allows the proposed changes on the system to be tested without allocating resources.
- It makes it possible to examine processes in real time, slowed down or accelerated time intervals.
- As a result of the analysis of different scenarios on the developed simulation model, it allows the discovery of new operating procedures and methods.
- It provides an understanding of the interactions between the variables that make up complex systems. This makes it easier to diagnose problems.
- Visualization/animation of simulation outputs provides a better understanding of the simulated system and elimination of previously unrecognized flaws.

The main goal of this study is to develop a simulation-supported decision support software to create possible energy consumption scenarios and to support the decision-making process of managers. The platform is powered by Internet of Things components that can collect real-time energy consumption data in different venues. In order to evaluate the proposed software, sensors and SoC components have been deployed and a space has been created where temperature and energy consumption values can be monitored.

The remainder of the work is organized as follows. Chapter 2 reviews the literature associated with the study. Chapter 3 deals with hardware-software architecture and simulation-based decision support system software, which make up the application part. Finally, Chapter 4 contains conclusions and recommendations.

2. LITERATURE

Today's conditions force all organizations to seek new ways to reduce their energy consumption, regardless of size or activity. In this direction, various studies have been carried out to ensure energy efficiency.

Shi & Chen (2021) proposed a control strategy regarding HVAC (air conditioning systems) management, which is responsible for 40% of the total energy consumption used in a building. The study includes a whole building simulation model to evaluate the performance of 12 HVAC systems. The most striking aspect of the study is that switching on/off air conditioning systems may be more costly than working 24/7.

Suciu et al.(2019) created an IoT and cloud-based energy monitoring and simulation platform for companies to monitor their energy consumption and production. They stated that the reports obtained from the platform will help validate new energy policies before they are implemented and simulate economic efficiency in various investment scenarios.

Brundu et al. (2017) within the smart cities paradigm, they have presented an IoT-supported software infrastructure that enables simulations of data management and energy policies. The case study of the application was supported by approximately 4000 IoT devices. The accuracy of the simulation models was ensured by comparing the simulated values with the data collected from the sensors.

According to Vázquez-Canteli et al. (2019) combined CitySim (building energy simulator) and TensorFlow (machine learning library) software to create an integrated simulation environment.

3. APPLICATION

Increasing energy cost and demand has led many organizations to develop smart control approaches to monitor, control and save energy. However, both ensuring the continuity of life comfort of users and reducing energy consumption are one of the difficulties in front of these approaches. It is important to monitor and control power consumption values such as instantaneous, maximum and total in order to operate an effective energy efficiency system in buildings.

The platform to be realized is structured to meet the information requirements stated below;

- Transmission of consumption and environment parameters obtained through sensors to a central server for analysis at certain time intervals
- Visualization of instantaneous energy consumption amounts and energy efficiency provided by the IoT platform by using sensor telemetry as inputs
- Determining the energy consumption that may occur at the end of the scenario by designing possible scenarios with unreal data (whether there is a person in the room, the energy consumption of the room, the energy consumption threshold of the room) and predicting how much energy will be saved with the developed IoT functions
- Using the obtained outputs for decision support mechanism with reporting and visualization methods

Figure 1 shows the hardware and software architecture of the platform realized according to the specified system requirements.

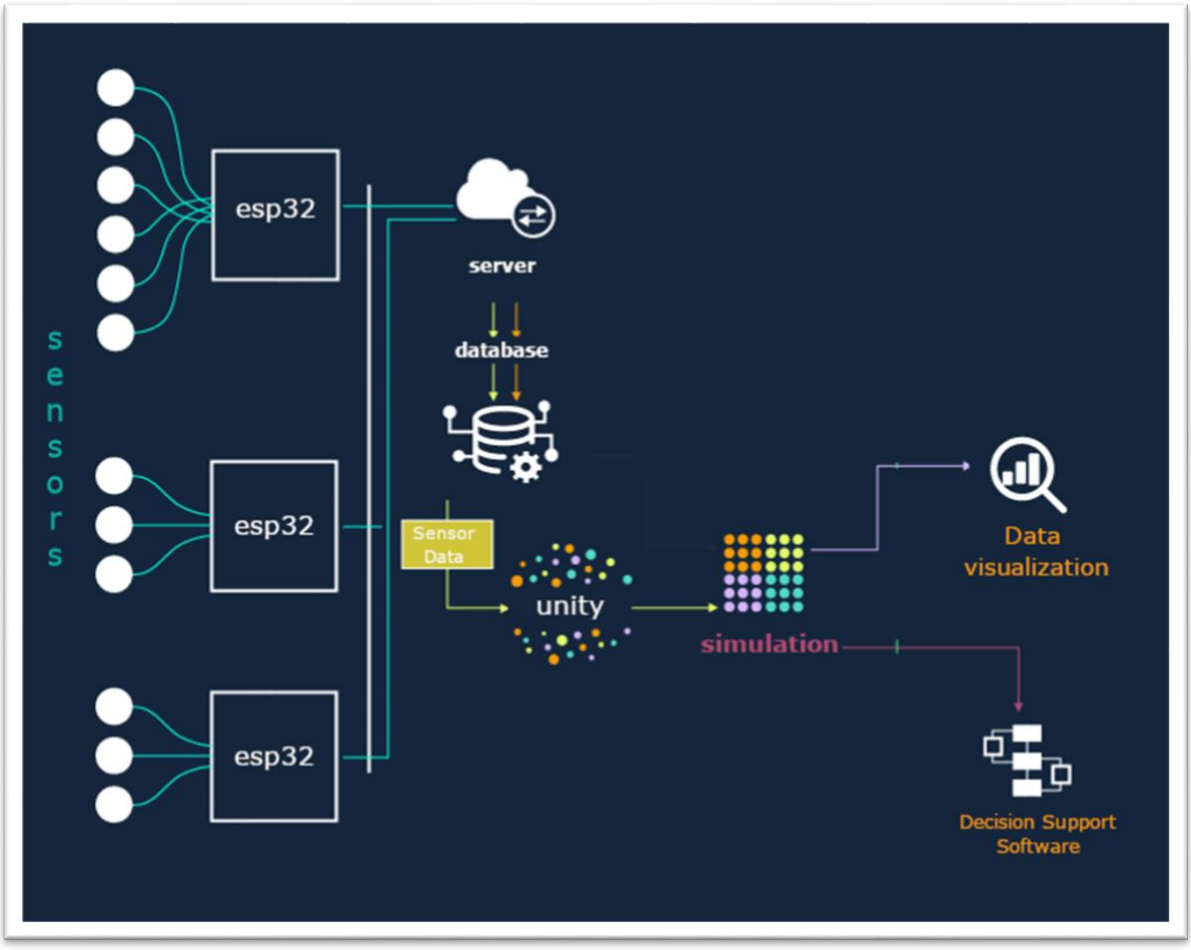


Figure 1. Architectural Scheme

The remainder of the section contains detailed descriptions of the layers.

Hardware and Software Architecture

The structure that constitutes the hardware leg of the platform consists of IoT components that collect the data in the environment and the server where this data is hosted. IoT components consist of a set of sensors and development boards.

Development Board (SoC) are physical structures created by gathering the components required for the programming of microcontrollers under a single roof (Tummala & Madisetti, 1999). Microcontrollers programmed through development boards perform the tasks of receiving and controlling and transmitting data by remote or direct connection. The development boards contain ports that allow sensors and other hardware to be connected quickly, depending on the intended use.

Sensors, current and temperature sensors are used to obtain the requested ambient data.

Server virtualization has been carried out in order to meet the functionality and performance requirements of the system. The concept of server virtualization; It is the conversion of a physical server's system resources and processing power into multiple virtual machines on a shared basis, through software. Configurable resources and processing power make it easy for the system to respond instantly to hardware needs and adapt to variable workloads.

The characteristics of the physical server used as the service platform and the virtualized server are given in Table 1.

Table 1. Server Features

	Physical Server	Virtual Server
Processor	16	4
Memory	80GB	12GB
Storage (Local)	2.7TB	500GB
Processor	16	4

The software was implemented using the simulation application UNITY software. Although Unity is a software development platform that is often used as a game development engine; It provides very successful results especially in the creation of three-dimensional scene designs, educational simulation, interactive digital content and script-based functions (Nicoll & Keogh, 2019).

Development

A Linux-based (CentOS) virtual server was built and a MySQL database was installed on it to host the temperature, current and voltage telemetry to be used for simulation. The server, which is virtualized on the physical structure specified in Table 1, uses the PHPMyAdmin platform to manage database operations online and control data status.

The communication between the data collection module and the database was carried out using the HTTP POST method. With the created PHP scripts, new data can be registered or updated. In this way, the simulation application can perform comparison scenarios on real data.

The application steps developed on UNITY are as follows (Figure 2).

- In the application, space (floor, walls, people, data collection module, etc.) and scene (camera, light, etc.) elements were determined and objects connected to these elements were created.
- The created spatial and stage elements are located in both areas. In order to produce a comparative scenario, one of the rooms does not contain the data collection module and the

other is designed as the area where the functions connected to the data collection module operate.

- to save energy, functions such as turning off the lights when no motion is detected in the space containing IoT technologies and limiting the devices that consume excessive electrical energy are triggered, and the dimensions of the energy efficiency in the space are tried to be calculated.
- Interfaces were created with the dummy data values determined by the decision makers to create different scenarios. Through the values entered through the interfaces; It can show the estimated energy consumption values of the relevant space or the energy consumption difference between the two compared spaces based on time.
- The simulation includes a scenario structure that works by using random values as well as creating energy policies according to the variable values of the users. In this structure, the differences between the spaces are visually transmitted to the user in real time.



Figure 2. Simulation Screen Overview

The simulation process can be started after the users specify the specific variable values of the rooms from the input adding area located on the right, and enter the time value in which the simulation will continue in milliseconds. The user can assign different values to the variables during the simulation process.

On the left side of the application, there is a user interface that displays the variable values formed as a result of the determined scenario, the information area and the energy consumption difference values between the 2 places compared. In the information area, there are active camera information, random person assignment and activity status information of random camera functions. The consumption value of the determined time is displayed in the upper right part of the application screen. Just below are the buttons where the camera and random value assignment functions can be activated. On the left are the buttons that perform the activation functions of the scene light values (Figure 3).

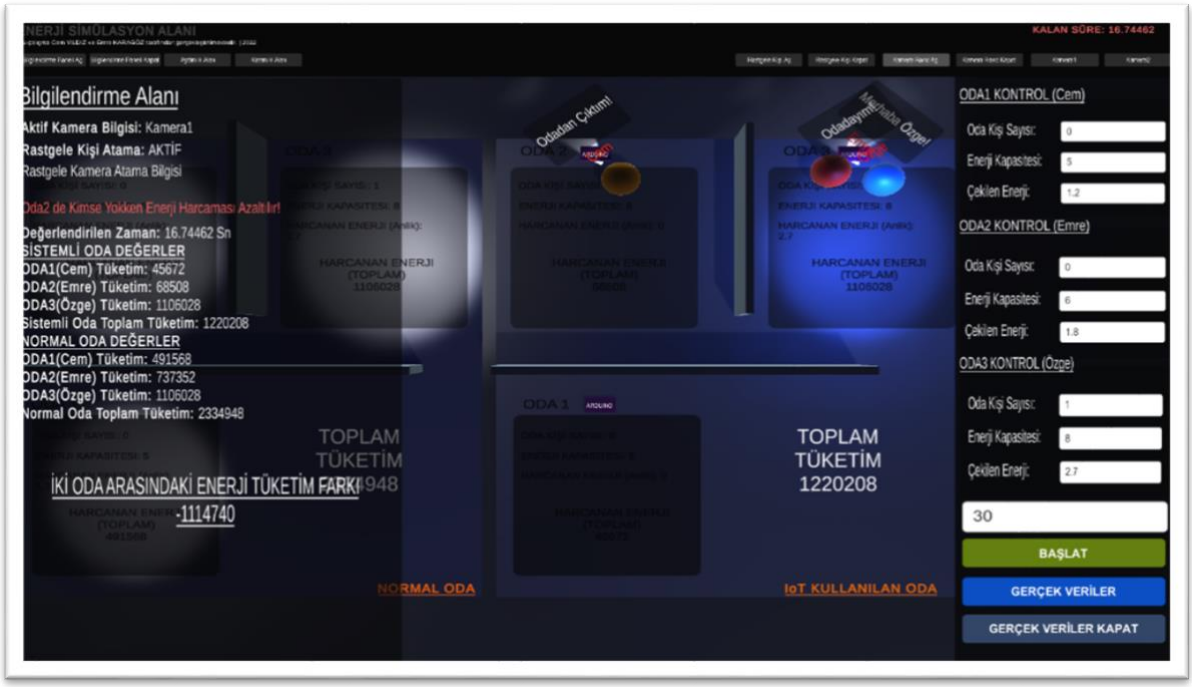


Figure 3. Simulation Interface

4. CONCLUSIONS

Energy Management Systems are an effective approach preferred for monitoring the energy consumption values of buildings, improving their energy efficiency and creating new models.

For this purpose, it is aimed that the energy efficiency that can be realized with the contribution of IoT components can be viewed by decision makers and to support their decision processes.

The developed software obtains the input values from 2 sources. The first of these sources is real data obtained from physical IoT devices and updated periodically in the database. These real data are taken as input values at certain intervals by the developed software and allow the visualization of the real situation and the monitoring of the energy consumption and savings amounts per room and in total by the managers.

The second source that the application feeds is the variable values determined by the users to be used in the simulation model. The information about whether there is anyone in the rooms in the model, the amount of energy consumed in the rooms and the energy consumption threshold values of the rooms are determined at different rates and at different time intervals, allowing various scenarios to be created.

In addition, the developed software can be used to see the effects of possible sensors or functions on the energy efficiency of the physical IoT device. At this point, what needs to be done is to add new functions and new variables to the codes of the software and update the software. UNITY offers a very flexible structure to developers in making such developments.

The software developed on the basis of the study;

- Visualizing energy consumption values
- Leveraging sensor data for simulation modeling
- Evaluating the applicability of energy models planned to be used in buildings
- Validating energy efficiency investment decisions in organizations

is considered to be beneficial.

The software developed on the basis of this study is modeled based on the energy consumption values of only 3 physical rooms. More comprehensively, simulation models that will enable more detailed analyzes on the energy savings of many physical locations within buildings can be visualized with the UNITY program and enhanced with many different functions. Likewise, simulation results obtained from different variable values and experience times can be added to the tables created in the database and presented to the decision makers as reports. The real energy expenditure data obtained can be used as teaching data for artificial neural network models and can be used for energy expenditure estimations of similar physical spaces by reaching variable coefficients.

Energy Management Systems will be able to achieve extremely strong structures by using especially IoT, Web technologies and simulation models in observation, reporting and forecasting processes.

REFERENCES

Banks, J. (2000). Introduction to simulation. *Proceedings of the 2000 Winter Simulation Conference* , 9–16.

Brundu, FG, Patti, E., Osello, A., Giudice, M. del, Rapetti, N., Krylovskiy, A., Jahn, M., Verda, V., Guelpa, E., Rietto, L., & Acquaviva, A. (2017). IoT software infrastructure for energy management and simulation in smart cities. *IEEE Transactions on Industrial Informatics* , *13* (2).

De Paula Ferreira, W., Armellini, F., & De Santa-Eulalia, LA (2020). Simulation in industry 4.0: A state-of-the-art review. *Computers & Industrial Engineering* , *149* , 106868.

Negahban, A., & Smith, JS (2014). Simulation for manufacturing system design and operation: Literature review and analysis. *Journal of Manufacturing Systems* , *33* (2), 241–261.

Nicoll, B., & Keogh, B. (2019). The Unity Game Engine and the Circuits of Cultural Software. *The Unity Game Engine and the Circuits of Cultural Software* , 1–21.

Shi, H., & Chen, Q. (2021). Building energy management decision-making in the real world: A comparative study of HVAC cooling strategies. *Journal of Building Engineering* , *33* , 101869.

Suciu, G., Necula, L., Iosu, R., Usurelu, T., & Ceaparu, M. (2019). IoT and Cloud-Based Energy Monitoring and Simulation Platform. *2019 11th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2019* .

Tummala, RR, & Madisetti, VK (1999). System on chip or system on package? *IEEE Design and Test of Computers* , *16* (2), 48–56.

United Nation. (2022). World Population Prospects 2022 Summary of Results.

Vázquez-Canteli, JR, Ulyanin, S., Kämpf, J., & Nagy, Z. (2019). Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities. *Sustainable Cities and Society, (2019), 243-257,45*.