 doi:10.20944/preprints201805.0479.v1

Energy Efficiency Management System Using WSAN: Investigation of Energy Consumption of Buildings

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This research presents alternative solutions for an Energy Efficiency Management System (EEMS) serving as a framework for optimizing the energy consumption algorithm and lowering energy consumption. First, a monitoring Wireless Sensor and Actuator Network (WSAN) is used for sensing, measuring, gathering data, and modeling all the dynamic disturbance parameters of the rooms in the building. Second, integrated software for metering and controlling the processes of digital data flow is used. Third, an alternative solution is proposed to reduce energy consumption. The primary benefits of this system are real-time monitoring; rapid, alternative solutions; and the ability to make a prudent decision on how to lower energy consumption. The system shows instant and accumulated solutions for short and long-term time planning. The solutions identified can be implemented in the same buildings under the same circumstances. The universities of Majmaah and Philadelphia have buildings with similar infrastructure. The system was applied to the buildings at Philadelphia University. The results were generalized to both universities. After implementation, the energy consumption of the EEMS using WSAN (based on the monitoring was reduced up to 23% when compared to that of the initial state.

Keywords: **real monitoring; energy efficiency management system; wsan; majmaah university**

I. Introduction

In both developed and third world countries, the 1973 oil crises spurred the revision of building energy codes to reduce energy consumption. That act aimed to support and follow energy-saving standards and regulations. In late 1970 and 1980, 17 European Countries followed these policies. In 2017, 7te USA has surpassed Saudi Arabia and Russia as the world's largest producer of oil and natural gas, respectively. Policymakers can reduce exposure to volatile energy prices by promoting energy efficiency [1]. On the other hand, the problem of global warming and the danger of greenhouse gases on earth's environment forced all countries to start reducing energy consumption by adopting new policies and forming new regulations that adopted in 2017 [2].

Most plans to reduce building energy use have been in the form of prescriptive energy codes for design and construction, or mechanisms, such as financial incentives from utility companies, to address specific building components, such as efficient lighting and Heating, Ventilation, and Air Conditioning (HVAC) equipment [3]. In developed countries, additional revisions to building energy standards were carried out and implemented worldwide in an effort to reduce CO_2 emissions. Since then, additional studies have shown a constant concern regarding building energy consumption standards. One-third of the world's countries have developed building energy codes. Nevertheless, due to economic reasons, the energy standards of developing countries have failed to achieve their target.

According to recent studies, the buildings in most countries consume almost 40 percent of the primary energy and are one of five primary users of energy [4]; building energy consumption can be improved by increasing efficiency. Thus, international efforts have focused on two directions: decreasing the consumption of energy (demand side) and trying to find another source of renewable energy (supply side) [5]. Creating Building Energy Codes (BECs) was one of the tactics implemented by developed countries to improve the building energy efficiency. Previous studies have shown that concern about climate change has promoted the use of energy efficiency standards, which are updated periodically. BECs have shaped the fundamentals of both the energy and environmental policies of the 1990s since an

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improvement in a buildings' efficiency controls the increase of CO_2 emissions through a reduction in energy consumption [6].

On the other hand, a number of barriers have emerged in developing countries that obstruct the efficient use of energy efficiency in buildings. These barriers include the absence of policies, appropriate financial support, and low gas and electricity prices. Moreover, the unsuccessful enforcement of such policies and the absence of experience in developing countries present other political and structural barriers [7].

Furthermore, the high cost of technologies utilized is deemed the primary barrier to implementing energy efficient technology. Such barriers to improving building energy efficiency raises another critical issue regarding the efficient allocation of resources. Substantial, upfront investment is needed to reduce energy consumption.

Energy efficiency become a challenging task for researchers, organizations and energy consumers. Wireless Sensor and Actuator Networks (WSAN) is a promising technology that is used for monitoring and controlling in the wireless environment. Based on the energy consumption, decisions made using central early programmed software [8].

WSAN can be implemented in different areas such as environment monitoring for energy savings and energy controlling [17]. Monitoring buildings for energy consumption is one of the primary implementations for WSAN.

The process of Using Sensing Nodes to sense the energy consumption and actor nodes for decision making represents a network for environmental monitoring. Fig. 1 shows a typical WSAN architecture [17].

The WSAN main actions are performed using at least one coordinator sensing node and actor nodes that are

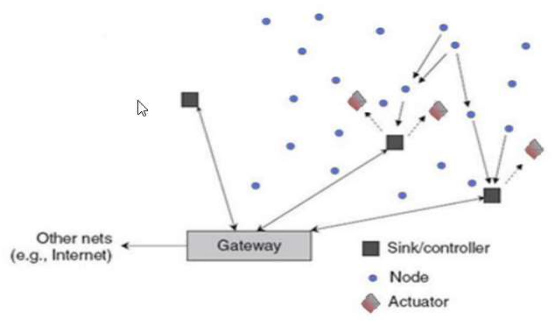

Figure 1. The architecture of a wireless sensor actor-network [17]

Communicated wirelessly.

The Wireless Sensor Network (WSN) actively shares the benefits of wireless technology by building a comprehensive tent work that does not require wires and can be implemented in any desired location such buildings and houses [19]. Moreover, WSN can be applied to WSANs and Wireless personal area networks (WPAN), which are the most complex applications in the modern life [20]. Using smart technologies such as WSAN is an essential step in achieving a sustainable economy. The intelligent infrastructure for industrial, agricultural, and governmental systems develops different infrastructures, production processes, and services [21].

The system provides an opportunity to monitor energy consumption, and users can monitor and inspect the results visually. Moreover, the use of WSAN eliminates the technical and protocol differences of communicated devices [22].

One of the particular applications of WSAN is asynchronized time implementation for energy consumption measuring. WSANs have been extended from Wireless Sensor Network (WSN) due to its heterogeneous node structure. WSAN contains a collection of static sensors and mobile actors. The actors are active elements and less based on the energy resources than passive sensors. Actors have high processing and communications capapbilities.

An actor performs actions in the event area based on the sensors information. The existing sensor network protocols may not perform well because of real time application of WSAN. However, these applications require energy and delay aware mechanisms to perform reliable actions in the event area. Unfortunately, these types of mechanisms in WSANs are still undeveloped [9].

This paper presents a necessary and essential step in identifying and managing the current state of energy consumption. This paper provides solutions regarding efficient ways of using electricity through theoretical study, design proficiency, hardware implementation, and data collection.

The goal of this paper is to design, implement, and deploy an energy monitoring and control platform using WSAN in order to manage the energy consumption in large and small-scale buildings in an optimum way, i.e., the most efficient way to consume the energy sources in the KSA buildings. In order to achieve the above mentioned goal, a SWAN for remote energy consumption monitoring and energy management is designed; Testing and deploy the developed platform into two different rooms: classrooms and faculty offices rooms; Understanding user behavior w.r.t energy usage and design optimal EEMS that stimulate energy saving

The WSAN method is used for gathering data and modeling all of the dynamic disturbance parameters of the building. The optimization problem is solved by benchmarking performance based on numerical study.

II. Problem Formulation

Oil and gas remain the most significant sources for primary energy used in the production of electricity in KSA. Based on data published in [10], 57% of electricity generation comes from oil, and 43% from gas. These two, primary resources provide a total, installed power generation capacity of approximately 45000 MW. The consumption of energy (per capita) increases daily due to various factors such as increased use of energy-intensive appliances, including air conditioners and ovens. Subsidizing tariffs on

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electricity is also a factor regarding electrical usage in domestic and industrial sectors. Governmental buildings consume approximately 11% of the total, national energy consumption; 60% of this consumption can be attributed to the misuse of lighting fixtures and air conditions [6]. In administrative buildings. such loss can be mitigated through the use of a smart system that monitors and controls the operation of light and air conditions. In administrative buildings, smart light fixtures, windows, motion sensors, etc. can be used to increase energy efficiency. In the administrative buildings at Majmaah University (MU), energy efficiency can be achieved to reduce the power consumption [11].

Greater consumption of oil-generated electricity affects the environment. The third world countries are doing their best to achieve sustainable economies. As a part of the middle east world, Jordan and KSA are attempting to increase investment in smart technologies that aid in monitoring energy consumption and reduce the need for oil to serve as the sole source for power generation.

Most Developing countries are trying to implement renewable energy resources as a unique solution to reduce the dependence upon oil as a primary resource. Nevertheless, the use of renewable energy resources must be combined with a reduction in energy consumption to reduce the dependence upon oil as a primary resource.

In 2030, KSA envisions investment in energy efficiency measuring and power saving technologies to be a primary objective: "Business Environment, Restructure Our Economic Cities, Create Special Zones And Deregulate The Energy Market To Make It More Competitive"[12].

To contribute in solving the above-mentioned problems, the EEMS combines software with WSAN is implemented to provide a decision maker with direct and real data from sensor nodes [13]. The system is complex regarding the need to synchronize the two systems and provide additional control options. Today, organizations use IEEE802.15.4 and ZigBee to deliver practical solutions for a variety of areas including consumer electronic device control, energy management, home efficiency, commercial building automation, and industrial plant management [14]. Monthly records are provided and analyzed based upon the analysis of several, monitored buildings [15].

The EEMS for controlling buildings that are presented in this work contain Cyber-Physical System (CPS) architecture-based manufacturing systems, which are integrated and implemented with WSAN. This makes the management system more adaptive to different applications [16]. Combining the feedback process directly with the CPS using WSAN increases energy efficiency significantly, up to several rates.

Having data regarding energy consumption that has been collected over a period of time is an efficient way to plan and make future decisions. However, this approach will not stop high-energy consumption rates during times of sensing and monitoring. Thus, real-time monitoring will use smart technologies.

III. ENERGY EFFICIENCY SYSTEMS USING WSAN

The designed WSAN monitoring system architecture contains three phases, as shown in Figure 2.

A. Sensing and actuating phase (Pervasive Layer)

In this phase, sensors provide Graphical User Interface (GUI) data about the energy consumption in different rooms on different floors within the building. The sensing process is continuous and is provided every half an hour. The sensed devices include an air-conditioner, printer, and light fixtures within offices and classrooms. All sensors are linked to each other using wireless transmission with a WSN specification having a range up to 10 meters among devices.

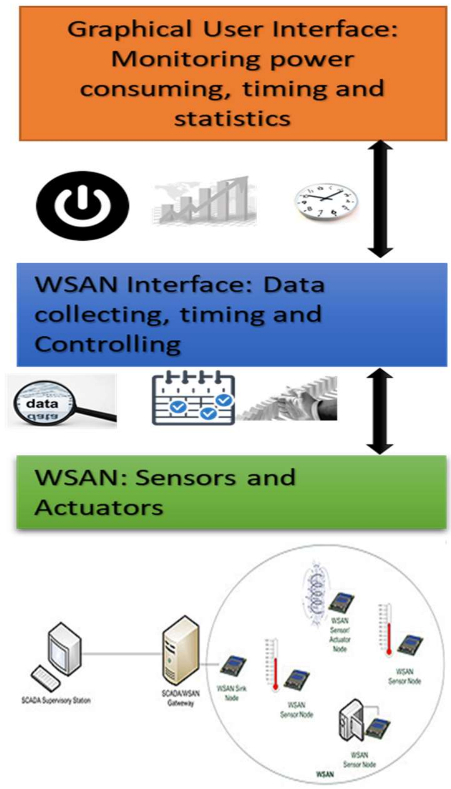

Figure 2. The architecture of Energy Efficiency System

The WSN is a coordinator that controls the other devices for connection and data exchange. It is similar to Bluetooth Protocol using Master and slaves network architecture [23].

B. WSAN interface phase (Controlling):

In this phase, the WSAN interface is acting as a gateway for supporting the controlling mechanism provided by actors and gathering data by sensors. In this phase, integration to wireless networking protocol is performed.

C. Implementation Layer (Applications):

The software used is suitable for web browsing and smartphones. It is connected to the system to support secure access. The control room equipped by a control software connected to the WSAN for auto and manual decision making in case of increasing the energy consumption and reaching the preassigned threshold levels. The control logic basic algorithm is presented in figure 3.

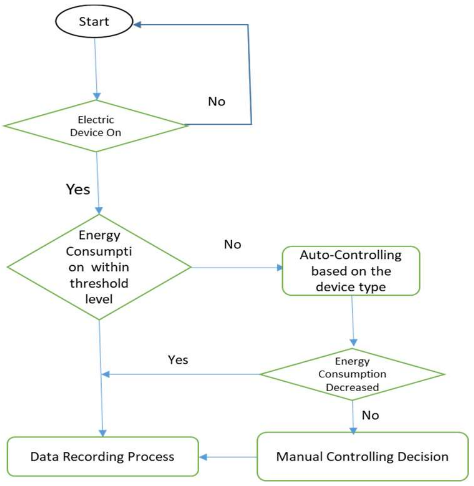

Figure 3. Control logic implemented for several devices.

The adaptability of any wireless system is critical toward achieving a highly dynamic environment. Some factors can be applied to attain a high level of energy efficiency [24].

• *Avoid useless activity*. This notion is critical regarding dynamic power management, link layer protocols, and adaptive error control. Useless activities can occur for different reasons at all levels of the system and are unnecessary in a high power operational mode and when applying error control to error-resilient data [24].

• *Scheduled operations*. Communications are scheduled promptly so that differences in power states are exploited as much as possible. This notion has a significant relationship with the QoS model because timing limitations in multimedia connections are likely to be constraining factors in anticipated power reduction.

• *Reduce the amount of data*. This factor is an essential requirement and is applicable in all stages of the system. This factor links to the compromise between communication and complexity [24].

The WSAN is implemented with the cooperation of the PUSPC group -Philadelphia University- to monitor the daily power consumption data for its buildings.

Due to similarity in their university buildings (Majmaah and Philadelphia), the data recorded and monitored in the Philadelphia building is used as a reference for Majmaah University's (MU) buildings.

Figure 3 shows a part of the components of the WSAN system. The WSAN system has been designed for the measurement of the energy of the assigned rooms' appliances and turn off the device when it does not work. The energy measurement is done by interfacing with fabricated sensing modules. The details of the design and development of the sensing are as follows:

1- Z-Wave Presence Detector (HSP02)
2- Environmental Sensors Humidity and temperature
3- Raspberry Pi
4- Z-Wave USB
5- RFXCOM LAN 2-port with the transceiver
6- HomeSeer
7- Vera 3 (Includes WiFi Interface, 4 LAN ports, 2 USB ports, more RAM 128 MB)
8- Single Appliance Monitor
9- Pack Appliance Monitors

The above-mentioned complex of devices is repeated for every room in the building with minor changes based on the operated electrical devices in the room.

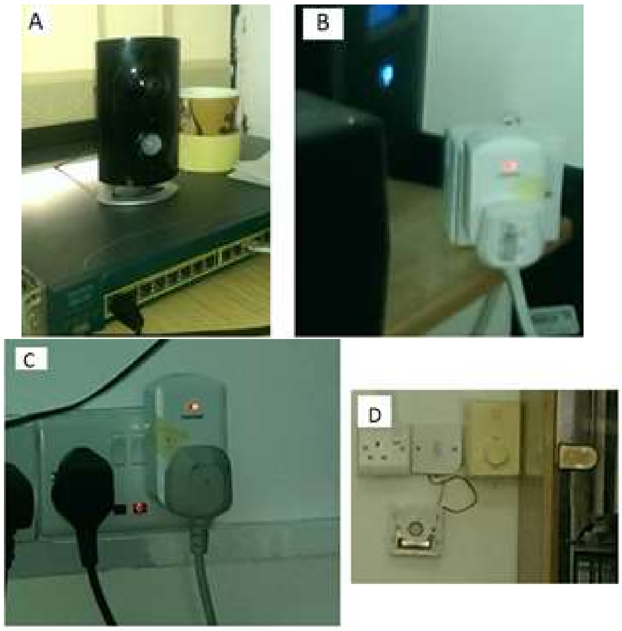

Fig. 3. Picture of the WSAN components (a) Wave presence detector (b, c) Energy Monitor (d).

IV. The Research Methodology

The WSAN technique that is presented in this paper connects WSANs with Ethernet/Internet to perform a sensor network on Web user interfaces accompanying the WSANs, as well as on an adapted websites to make the system function as a whole [26].

The energy saving algorithm that can be performed online to implement some steps that reduce energy demand. This technique is managed and controlled by the distribution of WSANs in the lecture halls, laboratories, and faculty members' offices in the assigned building using communication protocols such as ZigBee and 6LoWPAN. Such protocols are integrated into a large number of home automations. The WSNs consist of commercially available, low-cost devices that are small and low in power; they are integrated with computation, sensing, and radio communication capabilities [25].

In the proposed energy saving technique, these devices include nodes with integrated sensors for measuring energy. They have combined power switches and sensors to measure voltage, current, frequency, load, and power consumption.

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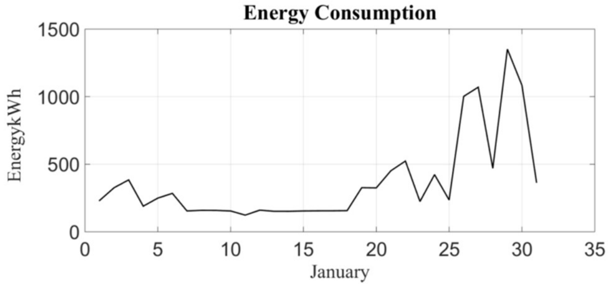

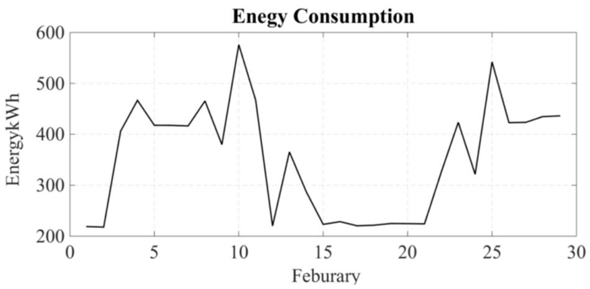

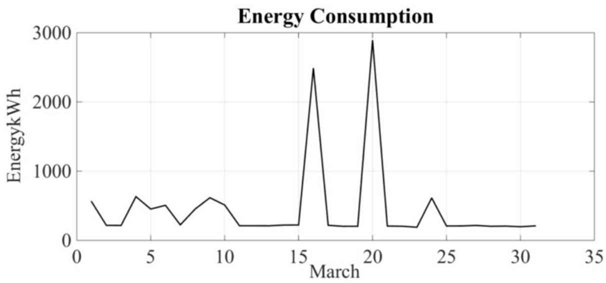

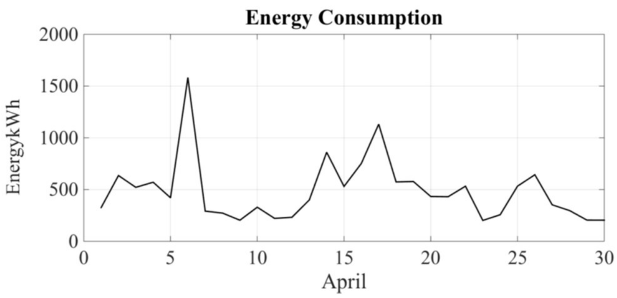

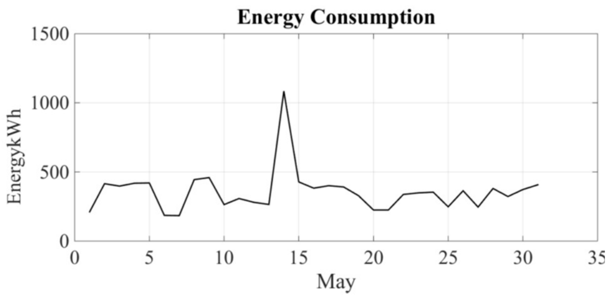

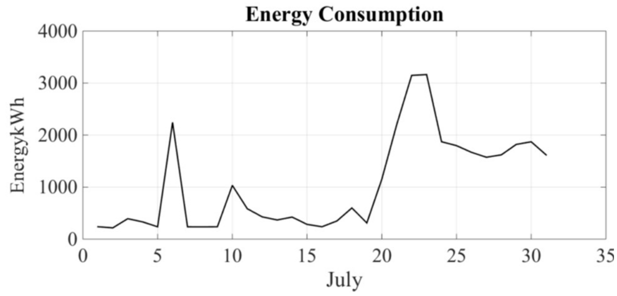

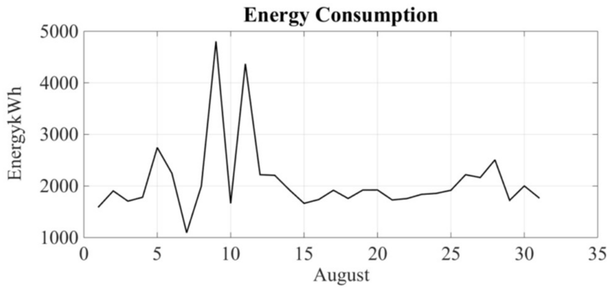

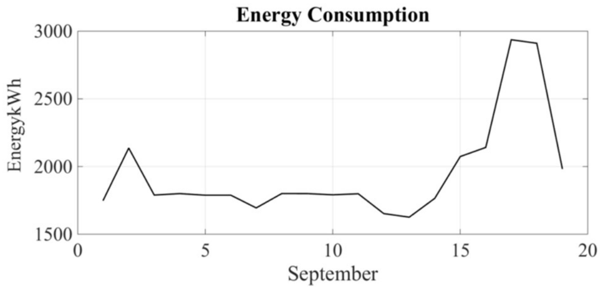

Fig 4. The energy consumption of the building in 9 months.

Data from the sensors are stored in distributed repositories, such as a gateway and internal/external servers [26].

The two sensor networks do not have the interoperability to communicate with one another, but they can control switches and gather, analyze, and present sensor data from both installed wireless devices.

V. EXPERIMENTAL RESULTS

In this section, some preliminary results are shown by monitoring the energy consumption of the Engineering building at Philadelphia University during one academic year, tracing the changes in the consumption during the different seasons. The primary energy requirement for the entire building for each month corresponds to the overall electricity need. Thus, air conditioning, lighting, printing, ventilation, and auxiliary equipment in an academic building are considered. Figure 4 shows the energy consumption for 9 months, during which the average energy consumption is relatively low during winter and spring days. However, the consumption sparked the value by double or triple during the summer. These results show the areas where there is the maximum energy consumption when the air conditioners are working in classrooms, offices, and halls. Without energy optimization, it is normal to have energy consumption even though there are no student's courses or professors' activities occurring.

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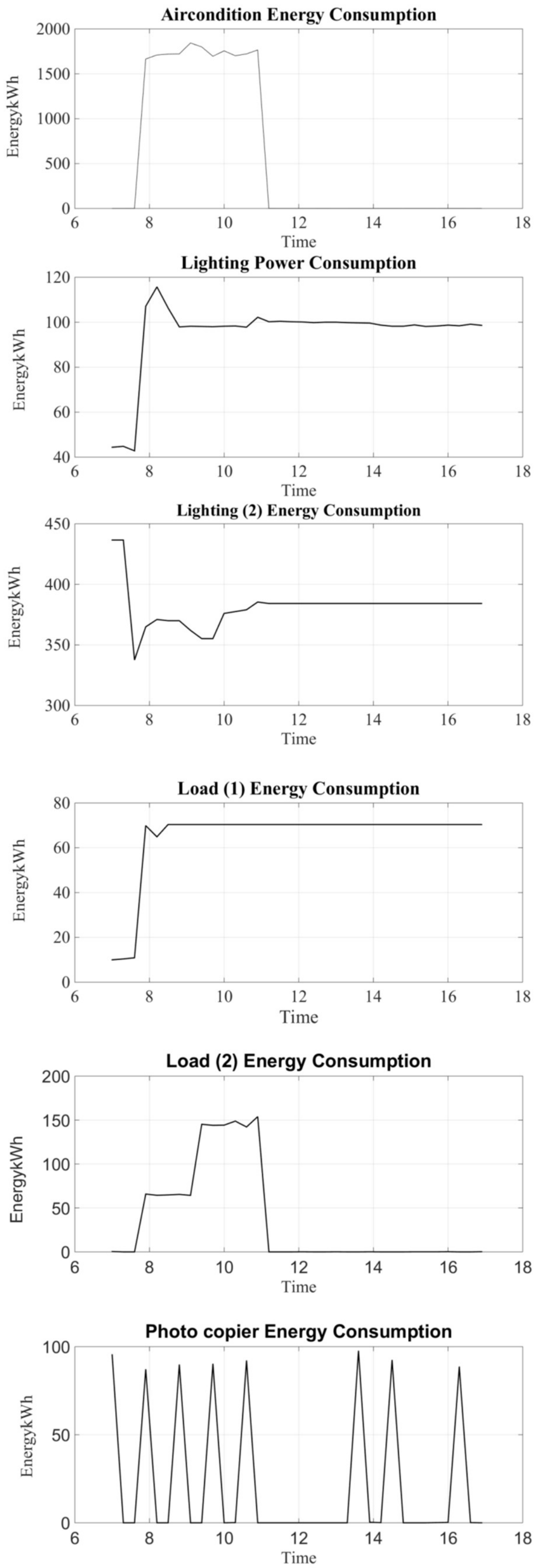

Fig. 5. Energy consumption for different loads in 1 day.

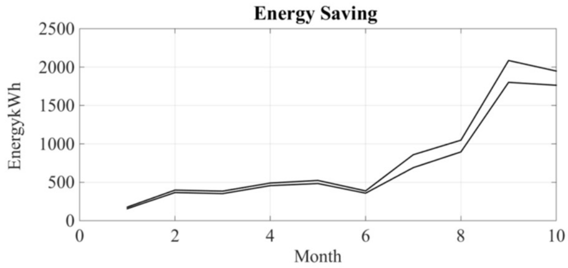

Fig. 6. Actual and optimized energy consumption over 9 months for the whole building.

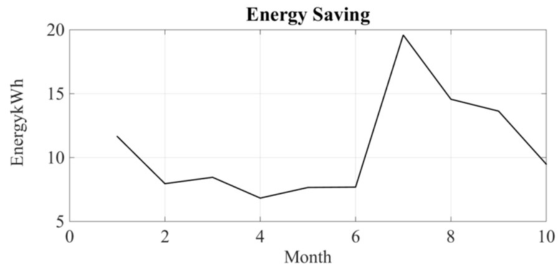

Fig. 7. Energy saving after using the optimization method.

Figure 5 shows the energy consumption for different loads in one working day. The energy consumption increases after 8 AM and changes according to the occupancy of the building and the usage of equipment, such as AC, lighting, and copiers. Some loads work for a short time. These loads cause a jump in the total energy consumption.

Figure 6 highlights the energy consumption before and after using the savings technique during an experiment we ran in our building over 9 months. Fig. 7 summarizes the energy saving when the energy saving technique is used.

VI. Conclusion

In this paper, an energy efficiency study for a university building has been presented. The real experiment has been conducted at the University of Philadelphia in Jordan to validate the proposed method. Different measurements for the building loads such as lighting, air conditions, and classrooms have been carried out. The results show energy consumption in different seasons and different day hours. In particular, the proposed methodology was able to achieve an average monthly overall energy saving of 23% for heating, cooling, lighting, auxiliary sources, and electric room equipment.

Acknowledgment

The authors acknowledge with thanks the Deanship of Scientific Research (DSR) at Majmaah University, Majmaah Saudi Arabia for technical and financial support through vote number 66\37 for this research project.

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