Smart Energy Management System using Wireless Sensing and Actuator Network

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Abstract

This work presents the use of the Internet of Things (IoT) concept as a tool for developing a wireless network of sensors and actuators to propose a technological update in air conditioning units installed in Saudi educational, industrial, and residential buildings. One way to improve modern buildings› energy efficiency is to apply control and decision mechanisms to decrease power consumption. Data are collected over several months using a Wireless Sensor and Actuator Network (WSAN). Gathered data then applied to an Energy Efficiency Management System (EEMS) to find suitable solutions to have a maximum energy efficiency ratio. The WSAN hardware system is installed in the Engineering Building of Suhag University. The WSAN is linked to the EEMS software for monitoring and recording data received from sensors. The collected data are analyzed, and energy efficiency solutions are applied. Results were promised, and the efficiency ratio reached 23%.

Keywords: Real Monitoring; Energy Efficiency Management System; WSAN; Suhag University

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1. Introduction

Energy is essential in the world we live in, as many of the tasks we carry out depend on it, and it is there that more and more research is being done for new means and methods to make the energy supply as sustainable as possible. There is an increasing need to rationalize and manage energy consumption efficiently, and it is known that it is essential to monitor consumption to analyze and reduce it to do more with less.

In Saudi Arabia, and mainly in vision 2030, attention is given to reduce the dependence on oil and to implement more efficient energy resources[12].

In terms of energy consumption, residential buildings are responsible for at least 40% of the energy used in most countries [1]. Research on this topic is overgrowing in the most developed countries globally, such as the United States or China, where there is rapid growth in intelligent systems so that they can contribute to the regression of climate change and an increase in energy efficiency.

Efficiency in buildings brings considerable reductions in energy consumption and economic benefits. It is estimated that measures to reduce demand without grid costs can almost halve the expected growth in electricity demand worldwide. However, it is vital to introduce new consumption habits, primarily to mitigate peak situations. For this, it is necessary to have information for consumers [2].

However, the idea of efficiency should not be associated with a lack of comfort since acceptable levels of efficiency can be achieved by taking simple measures, such as purchasing equipment with high energy efficiency, keeping doors and windows closed when the air conditioner is working, taking advantage of the natural light for ambient lighting, among others. These measures intend not to deprive people of comfort but to maintain the same level of comfort with the lowest possible energy expenditure [3], [4].

In Saudi Arabi buildings, it appears that the majority of energy costs are due to the use of air conditioning units. Increasingly accessible, air conditioning units are present both in homes and in work environments, and their use aims to ensure a pleasant room temperature, favoring comfort, productivity, health, and well-being [5,10].

The study stages can be summarized as:

1. Analyze strategies and technologies that allow achieving the Energy Efficient concept, with its difficulties and virtues in its implementation.
2. Assess the impact on the building's consumption, different usage patterns, passive measures and energy efficiency.
3. Technical, financial and environmental comparison of a building with a solution based on current regulations and practices and a building with an energy efficiency solution.
4. Attempt to apply the strategies and technologies mentioned above to a real case study at MU and the respective interpretation and analysis of the results obtained.

According to statistics, it is estimated that air conditioners' energy consumption for maintaining thermal comfort represents 40% to 70% of the total consumption of the building [6,11]. Preliminary architectural design and non-optimized refrigeration facilities, without automation, often lead to energy waste. An example: in most building environments with window air conditioners, over-cooling occurs, i.e., in the less hot hours of the day, the ambient temperature drops below the comfort temperature. After all, it is not practical to adjust the thermostat for each appliance throughout the day. This energy for cooling beyond the comfort point is a waste of energy.

Wireless Sensor and Actuator Networks (WSAN) is a promising technology used to monitor and control the wireless environment. Based on energy consumption, decisions made using central early programmed software [7,8,9]. WSAN can be implemented in different environmental monitoring areas 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 actuator nodes that are communicated wirelessly [18].

The Wireless Sensor Network (WSN) actively shares wireless technology benefits by building a comprehensive tent work that does not require wires and can be implemented in any desired location such as buildings and houses [19]. Moreover, WSN can be applied to WSANs and Wireless personal area networks (WPAN), which are the most complex applications in 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 [21-24].

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].

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

This paper aims to design, implement, and deploy an energy monitoring and control platform using WSAN 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. SWAN for remote energy consumption monitoring and energy management is designed to achieve the goal mentioned above; testing and deploy the developed platform into two different rooms: classrooms and faculty offices rooms; Understanding user behavior w.r.t energy usage and optimal design EEMS that stimulate energy saving.

In this paper, the WSAN method is used to gather data and model all of the building's dynamic disturbance parameters. The optimization problem is solved by benchmarking performance based on a numerical study.

2.Problem Formulation and Motivation

In buildings, energy efficiency is directly related to the rational use of energy; that is, energy efficiency and the reduction of costs associated with energy consumption are among the main objectives for our entire society [26,27,28].

Energy efficiency being a significant factor, as this work seeks to find a solution that allows the use of the most efficient equipment and an improvement in the user's daily comfort.

The WSAN system developed within this paper helps the user to have greater energy efficiency on the use of energy, allowing more savings on electricity bills each month and greater convenience; that is, it can trigger the system whenever you want, activating which appliances you want to turn on or off, using available solar radiation.

To contribute to solving the problems mentioned above, 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 various 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 on 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 presentation 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.

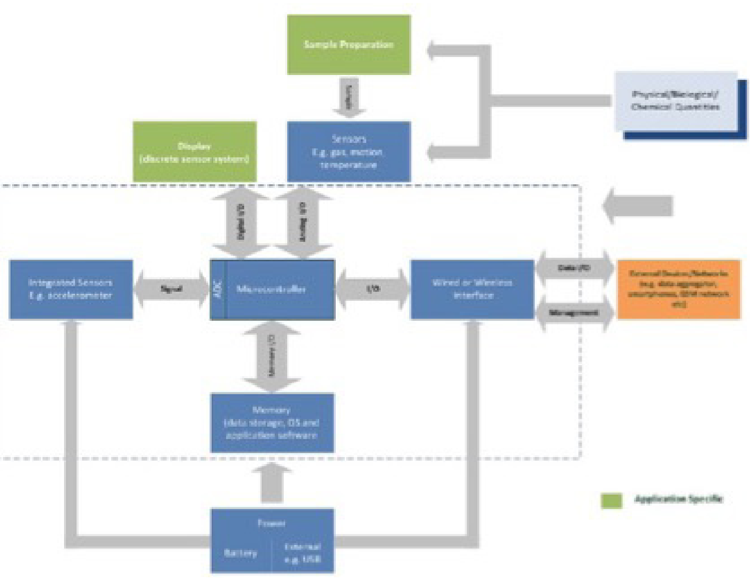
Having data regarding energy consumption collected over a period of time is an efficient way to plan and make future decisions. However, this approach stops high energy consumption rates during times of sensing and monitoring. Thus, real-time monitoring implements smart technologies.

3. Energy efficiency systems using WSAN.

3.1. WSAN software and hardware overview

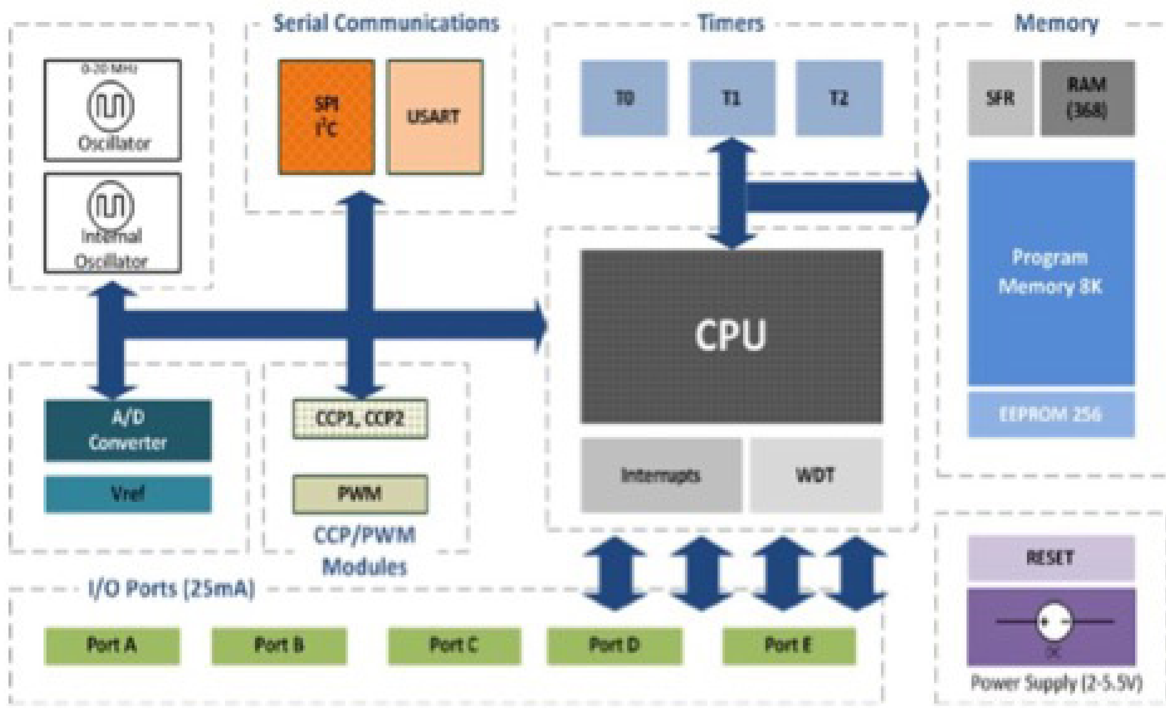
The main components of any WSAN are: Sensors, connected interfaces, microcontrollers (MC), storage device, digital and analog I/O, enclosures, and mountings into an integrated system [29]

Fig.1. High-level sensor system architecture



`Using smart sensing requires MC or microcomputers to compute internal devices. The MC contains Program and data memories, interrupt handling, microprocessors, and peripherals, including I/O interfaces, as shown in figure 2. This MC is essential for smart sensing [30].

Fig. 2. Block diagram of a microcontroller



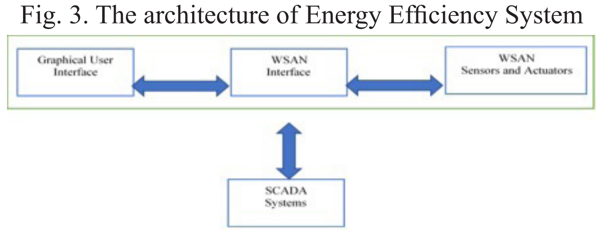
The input and output of MC are controlled by the specific tasks performed based on the MC design. In sensing applications, the input usually is data received from sensors. Due to the specific WSAN tasks, MC internal devices and software are defined in advance [30].

The MC used in the proposed system is The Arduino I/O Board. The Arduino I/O board is mainly programmed using the open-source Arduino programming language. The figure shows the Arduino UNO R3 board. The WSAN main actions are performed using at least one coordinator sensing node and actor nodes that are communicated wirelessly. The Wireless Sensor Network (WSN) actively shares wireless technology benefits by building a comprehensive tent work that does not require wires and can be implemented in any desired location such as buildings and houses [33].

3.2 WSAN implementation

The proposed architecture of the Energy Efficiency System is shown in Figure 3

Fig. 3. The architecture of Energy Efficiency System



The measured energy of the sensors is integrated and connected to the actuator module for transmitting the measured values data wirelessly. The actuator modules are linked with different sensors and interconnected in the form of mesh topology to have reliable data reception at a centralized coordinator. The maximum distance between the adjacent actuator nodes is less than 10 m. The actuator coordinator has been connected through the USB cable of the host computer, which stores the data into a computer system database. The collected sensor data have been sent to an internet gateway for controlling energy consumption.

To sum up, the sensors sense the physical variables of interest, which is the device energy around its sensing range, and report them to the controller, which evaluates collected data by comparing set points. If required, it sends control signals to the actuators. The actuators disconnect the devices which have energy consumption more than the threshold level.

SCADA stands for supervisory control and data acquisition, a term that describes the essential functions of a SCADA system. SCADA is used to control equipment across WSAN to collect and record data about measured and sensed signals representing power consumption.

Fig.4 (a) The Z-Wave sensor

Fig.4(b) The gateway.

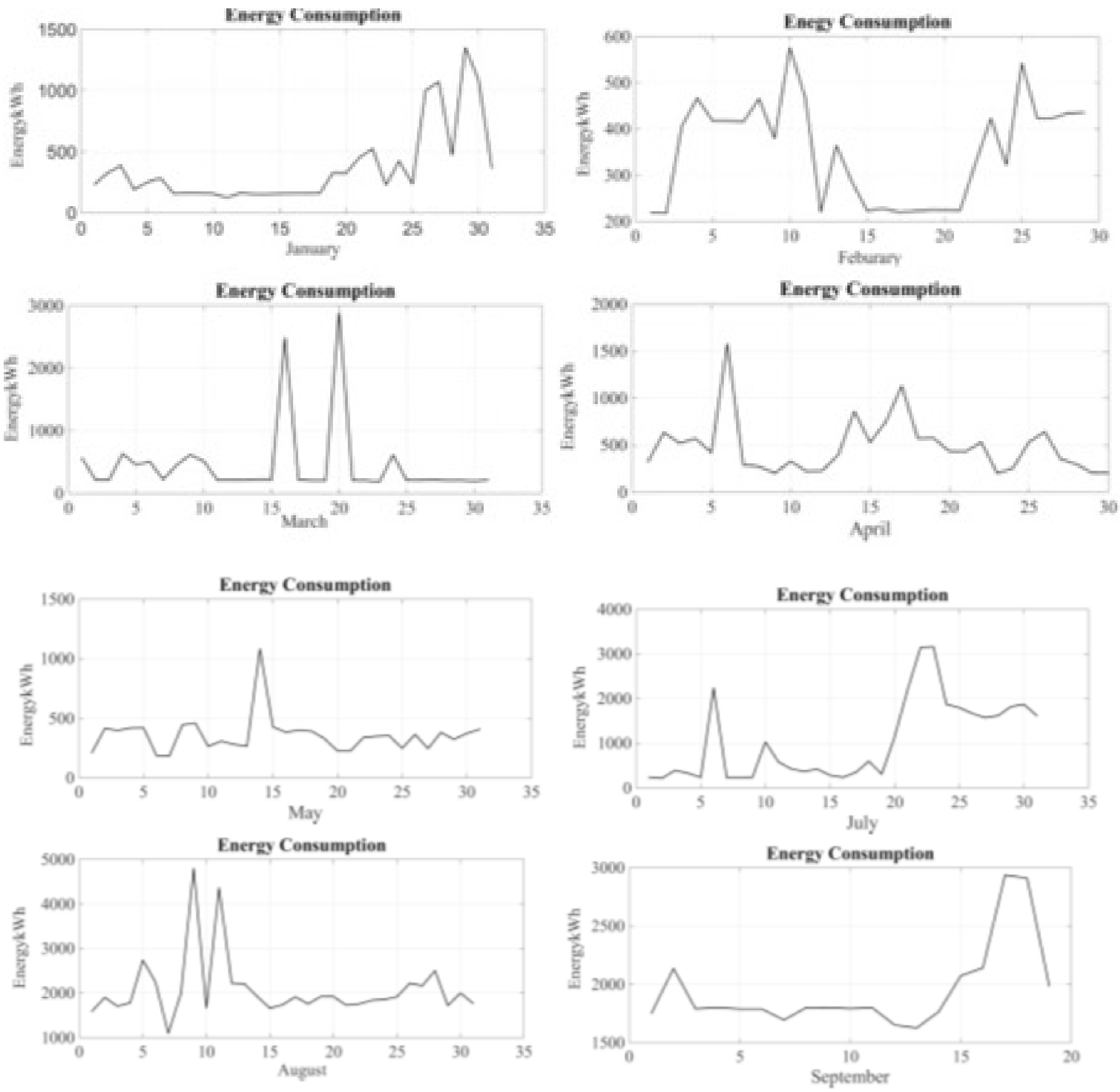
4. Experimental results

In this section, some preliminary results are shown by monitoring the energy consumption of the Engineering building at Suhag 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 5 shows the energy consumption for 9 months, during which the average energy consumption is relatively low during winter and spring days.

Energy consumption at EE is generally characterized by the lighting system and the use of necessary equipment (computers, fans, others) and air conditioning (restricted to administrative areas). The bathrooms have compact fluorescent lamps activated by presence sensors, which minimized the proposal to reduce the building's energy consumption [23].

The monitoring period after the interventions carried out at EE lasted six months,

Fig. 5. The energy consumption of the building in 9 months.



covering September 2018 to Jun 2019. This monitoring was carried out based on the analysis of energy consumption bills issued by the Electricity Company. During this period, it was possible to verify an average reduction of 10% in the consumption of electrical energy in the building, meeting the expectations initially proposed in the study regarding the reduction of 4 to 11% in the building's electrical energy consumption.

It is noteworthy that, due to budgetary limitations, the interventions covered the building partially. The results indicate two behaviors: in the first moment, again in the reduction of consumption, and in the last two months, a decrease that contradicts the trend obtained initially. Table 1 shows the data that served as a basis for comparing the values obtained with the actions carried out in the building. Figure 6 shows the percentage of energy consumption reduction from the year 2018 to 2019 when the WSAN system is used to optimize energy efficiency.

Figure 7 shows the energy reduction in 2019 after the implementation of WSAN.

Table 1- Reduction in consumption compared to the previous year's reading.

Month	The year 2018 kWh	The year (2019 (kWh
September	4050	3570
October	4465	4080
November	4630	4140
December	4820	4255
January	2500	1850
February	3100	2000
March	3850	3500
April	3700	3250
May	4370	4030
June	3950	3600

Fig. 6. Reduction in consumption compared to the previous year's reading.

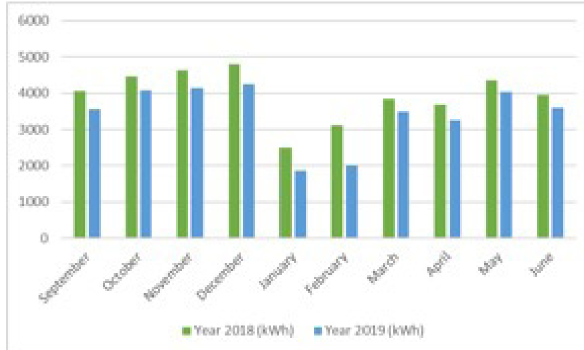


Fig. 7. Energy reduction in 2019

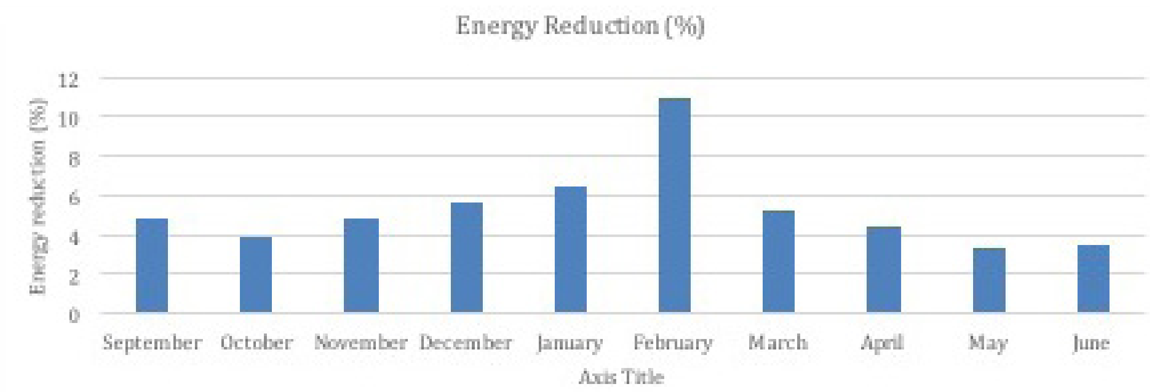


Table 2 Monthly electricity consumption of the EE building in kWh

Month	(kWh) 2015	(kWh) 2016	(kWh) 2017	(kWh) 2018	(kWh) 2019
January	2600	2550	2710	2500	1850
February	2320	2600	2920	3100	2000
March	3550	3620	4010	3850	3500
April	3570	3710	3805	3700	3250
May	3800	3700	4640	4370	4030
June	4050	4400	4211	3950	3600
July	3440	3600	3800	3550	3280
August	3900	4100	3920	3670	3140
September	4020	4150	4310	4050	3570
October	4150	4400	4650	4465	4080
November	4810	4970	4810	4630	4140
December	5100	5300	5170	4820	4255

Fig. 8. Monthly electricity consumption of the EE building in kWh

Table 2 and Fig. 8 show the EE building's consumption and electricity monthly from 2015 to 2019. It is important to note that electricity consumption is directly related to the number and hours of use of equipment installed in a given period.

5. conclusion

In this work, a decentralized and collaborative decision system for WSAN applications for intelligent buildings was proposed. This decision system aims to contribute to environmental sustainability by improving energy efficiency and, consequently, reducing the emission of polluting gases by buildings. This system was implemented to be associated with third-generation intelligent buildings' applications and implemented in RASSF to decentralize the application decision process.

Thus, this study aimed to act with practices in reducing energy consumption in the EE building. In addition, the energy efficiency approach has enabled cost reduction, modernization, and readjustment with the use of new equipment with more outstanding performance and durability. In the future, the obtained results can be used as a reference to generalize the WSAN concept in the college of engineering buildings in Majmaah. Moreover, a thorough analysis of the of the results of first stage and the second stage of the project will be conducted to assess the validity of the WSAN for the educational institutes.

Acknowledgments

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