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Smart Energy Efficiency Optimization System for Saving Energy in University Buildings Using WSAN

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Abstract Optimization of energy efficiency in Majmaah University (MU) administrative buildings using a wireless sensor and actuator network (WSAN) is an efficient method for managing the power consumption. To do so, this article proposes a framework for optimizing the energy consumption in the selected buildings by modeling all the disturbance parameters based on the building dynamics. Then the optimization problem is solved to benchmark its performance on a numerical study. Therefore, an energy management system is used to suggest or execute energy saving procedures. This work aimed to convert traditional University buildings into a smart buildings through adding several controlled energy saving device. All energy saving device are controlled by a software called energy efficiency management system (EEMS) that is serving as a framework for optimizing the energy consumption algorithm and lowering energy consumption. Mainly, the system contains three main layers: pervasive layer, controller, and application layer. The system performance is measured through an analytical comparison between the energy consumption of the building by several device without monitoring system and added energy saving electrical devices and the energy consumption of the building with the proposed monitoring EEMS. The result shows energy efficiency of 23%.

***Index Terms*— Energy Efficiency, WSAN, EEMS, Building Energy Consumption**

I. INTRODUCTION

A "s we know", Oil and gas are the largest sources of the energy that used for the production of electricity in Saudi Arabia. Data published in Reegle 2013 confirmed that 57% of electricity generation source is the oil and 43% come from the second primary source gas. Both resources produce total installed power generation capacity about 45000 MW. The consumption of energy (per capita electricity consumption) increases day by day due to different factors like increasing use of energy-intensive appliances such as air-conditioners and ovens and subsidized tariffs. Subsidizing the electricity tariffs is also a factor for the intensive use of electricity in the domestic and industrial sectors. The governmental buildings consume about 11% of the total national energy consumption, and 60% of this percentage is lost due to the misuse of the light and air conditions Farajallah Alrashed 2014. This loss could be reduced by using a smart system that monitor and control operation of light and air conditions in all governmental buildings.

Since 2004, the oil and gas consumptions are experienced rapid growth in the Kingdom of Saudi Arabia. The consumption increased at the period from 2004 until 2014 of 198.7% with an annual rate of 19.9 %. Due to increasing of the populations and industry, the consumption of oil is to be increased by 50% in 2020.

Several factors play a significant role in increasing the

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growth in electricity consumption that can be summarized as follows as presented in Obaid 2008, BP Statistical Review of world 2015 and Alyousef 2011:

1- Urbanization, subsidized tariffs and greater use of energy-intensive appliances.

2- The increase in energy consumption by residential sector (50% and more of the total national electricity consumption)

3- The inefficient use of power which in turn is associated with extremely subsidized tariffs as also highlighted by Alyousef and Stevens. Based on the statistics represented in the work Farajallah Alrashed 2014, 11% of electricity is consuming by the governmental sector. Maybe the electricity consumption by residential sector is high comparing to the governmental sector; but the minimization the power consumption by governmental sector by 25% will lead to saving energy 0.55 Per capita electricity consumption kWh, day.

The technological innovation has increased swiftly since the beginning of the 21st century, which leads to improving the standard of living. In particular; wireless communication is regarded as one of the most important technologies that even changed our way of life as mentioned in Chris Joseph.

The use of well-known technology: Wireless Sensor Network (WSN) technology is an efficient way to control and monitor energy consumption and to measure the energy efficiency. [M. I. M. Rawi 2010].

WSN actively takes functional advantages of the wireless technology by building a comprehensive tent work that needs no any wires and can be implemented in any desirable locations [Ian F. Akyildiz 2006]. Moreover, SWN can be applied over the wireless sensor and actuator networks (WSANs) and Wireless personal area networks (WPAN) which are the most critical applications in the modern life [Paulo Neves 2008]. This participation in the transition toward the smart public infrastructure as well as other technologies, such as agricultural and industrial.

The green and sustainable economy for the human being future can be claimed that it depends on the Smart WSAN (SWAN) because it develops various infrastructures, production processes, and services [Report by a Panel of Experts].

Achieving green and sustainable economy are regarded as the most desired aim for any country in this world. In fact, in the developed countries, the investment in these technologies is growing up rapidly to achieve the emerging requirements for reduced and more responsive power consumption with a relatively low-cost investment in "greening" [Report by a Panel of Experts].

Indeed, many of the industries/public services providers are still quiet to adopt wireless within their systems/production processes. As it is their impression that WSANs are not dependable (i.e., their availability, reliability, maintainability, and maintenance support performance are not at the satisfactory level), and no critical system operation should depend on it [Richard 2007].

As mentioned in De Guglielmo 2012, WSAN can be defined as a group of sensors and actors grouped together by wireless medium for sensing purposes.

In [D. De Guglielmo 2012], for improving the energy efficiency, the building management systems (BMS) is used based on WSAN. The algorithm proposed in this work required dynamically arranging transmissions from sensor nodes without the need for synchronization. However, this method suffers from instability and needs more control options.

The use of Zigbee as a wireless technology for a solution to control different areas is an efficient method for this purpose. At the same time, IEEE 802.15.4 can be used for energy consumption controlling in the home, governmental and commercial buildings in automatic way.

Farajallah Alrashed, Muhammad Asif 2014 showed The Residential buildings are investigated for some of the important features related to the residential energy consumption. The work is based on an analysis of the monthly electricity for several buildings. In this work, the WSAN is not implemented. The work has an interesting statistics about energy consumption in KSA. In our work, the day consumption is considered using WSAN.

Developing novel energy management solutions for improving energy performance at minimal cost and demonstrating their effectiveness in real cases. Understanding user behavior and inducing behavior change through user-centric feedback mechanisms, retrofit advice, and energy management solutions working with stakeholders and assessing the full market potential of the developed solutions designing personalized energy feedback and energy management options and having strong impact and dissemination plan through public lectures, educational programs, Internet, and social networks working closing with public sector and government and using the collected and processed results and designed methods to inform new energy policies enlarging this work to cover a wider range of sectors, such example a series of hotels, the ministry of education buildings across all over the cities, and ministry of health hospitals all around KSA creating an efficient power

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consumption map, which controls the users power consummated in an efficient way.
AL-Qawasmi 2018, in all works, already developed and used a WSAN for special case regarding the efficiency of conditioners due to their high energy consumption. In this work, the efficiency of management system to save energy through controlling is considered

II. PROBLEM FORMULATION

The Energy consumption per million population in KSA comparing to Middle East region is about 7 billion kWh per million population. This article aims to design and implement energy monitoring and management solutions using Smart wireless sensor and actuator network (WSAN). The expected achieved technology is capable of supporting the transitions to environmentally friendly building sectors to be able to manage and control their energy consumption. Thus, the work surveyed the KSA capacities and potentials in the field of wireless technologies for energy monitoring and control, identify key stakeholders and potential applications to form and implement SWSAN critical mass, which will result in significant reduction in residential and small/medium business energy consumption helping in reducing the dependency of importing energy.

Developed energy management tools are deployed in both two Majmaah buildings and used to monitor energy consumption for 12 months. The results used to model residential user behavior w.r.t energy usage and design adequate energy feedback mechanisms to stimulate energy savings.

Additionally, the gathered data used to find the optimum plan in term of power efficiency and control, for example, to remotely control on/off states of appliances (including air conditioning) when the rooms are not in use.

The research represents a necessary and an important step in order to identify and manage the current state of energy consumption and gives the solution to transfer such sector toward the efficient way of using electricity, which means studying the required theoretical acknowledged area, design a proficient scenario, and then the hardware implementation and data collection.

While residential energy monitoring via WSAN is not new, it has not been implemented in the KSA context. One obstacle is a lack of cost-effective WSN solutions. The work reviewed the existing capacities and potentials in the area of WSN in the region. Some of the identified stakeholders, when approached, may feel reluctant to share their data and knowledge even on the basic level. In order to achieve the research objectives, the following activities are implemented:

1. Detailed analysis of the current state of affairs w.r.t energy management solutions in KSA and the Arabic Gulf, as well as latest international research;
2. Detailed survey of current WSAN technologies that could be potentially used as a basis for WSAN solutions tailored for the energy management;
3. Deployment of a two-stage WSAN in our targeted buildings: (i) stage one involved monitoring of energy consumption, (ii) stage two involved actuation of the automatic shutdown of appliances that are not in use, following analysis of stage one data gathered through monitoring.
4. Demonstration of energy savings achieved in targeted buildings as a result of the introduction of a WSAN
5. Design of energy feedback mechanisms that stimulate energy saving
6. Recommendations of activities based on observed knowledge and studies to key stakeholders in KSA and the immediate region

The results were generalized to both universities. After implementation, the energy consumption of the EEMS using.

III. THE RESEARCH METHODOLOGY

The steps used in this research are: Literature survey to identify most effective sensing and communication technologies;

- Laboratory design of the energy monitoring platform;
- Laboratory testing of the designed solutions, their robustness, and effectiveness Deployment on two different sites.
- Surveys of the sites and periodic interviews with the residents after each intervention Development of the data repository at MU for collecting and processing the data
- Development of data analytics for identifying main usage patterns and main consumers
- Development of feedback mechanisms based on the collected quantitative and qualitative data
- Assessing the value of the feedback and smart control functionality via energy behavior change.

The methods of implementation and rationale for such methodology is based on the targeted sector. Accordingly, there are two different sectors which are classified as commercial and residential.

• The governmental sector (MU) consists of two

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separated university buildings with different functions in each building. The first building in this sector consists of the university's administration, managerial offices, and some colleges (College of Engineering and others). The selected number of the offices is 20 offices divided to 10 at the administration level and ten offices in the management level. The College of Engineering consists of ten labs and fifteen classrooms.

The second building consists of two different Colleges; Medical applied science. Business Management, Quality deanship, and others. Twenty offices, ten classrooms, ten labs selected. Several factors play a significant role in increasing the growth in electricity consumption that cab summarized as follows [Ubaid, R. R 2008]:

1- Urbanization, subsidized tariffs and greater use of energy intensive appliances.

2- The growth of energy consumption by residential sector (more than 50% of the total national electricity consumption)

3- The inefficient use of power which in turn is associated with extremely subsidized tariffs as also highlighted by Alyousef and Stevens. Based on the statistics represented in work of Ministry of Water and Electricity 2009, 11% of electricity is consuming by the governmental sector as shown in figure 3

The Energy consumption per million population in KSA comparing to Middle East region is shown in figure 1.

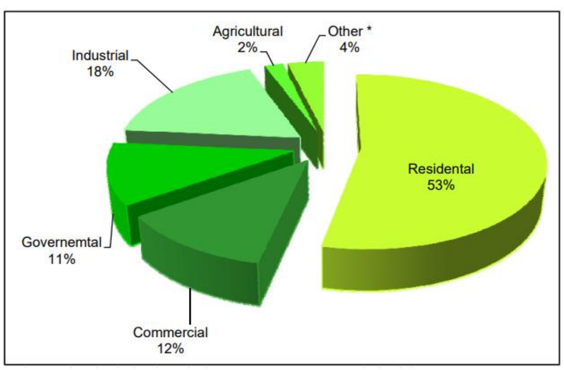

Fig. 1. Distribution of Electricity Consumption by Category of Consumers

IV. 4. THE PROPOSED SYSTEM

The needed hardware per single unit (a flat, a lab or an office in a sector) could consist of the following:

- Monitoring equipment: total for one single unit
- 2 Pack Appliance Monitors
- Single Appliance Monitor
- Base Pack (Display, Transmitter, Data Cable)
- Home Energy Management Platform
- Vera 3 (Includes WiFi Interface, 4 LAN ports, 2 USB ports, more RAM 128MB)
- RFXCOM 433 MHz Interface
- Z-Wave USB
- Raspberry Pi
- Environmental Sensors
- Temperature and Humidity (THGR810)
- Z-Wave Presence Detector (HSP02)

To implement the energy management network; electric current consumption monitoring devices are installed and connected with the main servers to gather and manipulate the data of the consummated electrical energy. During the recording process and gathering data, maintenance for the system is performed.

Collected data is analyzed to find out the optimum consumption plan to be deployed in the next stage for the whole targeted research network. Taking into consideration that the optimum energy consumption depends on each use's energy allowance.

V. EXPERIMENTAL RESULTS

In this section, some preliminary results are shown by monitoring the energy consumption of engineering building in Philadelphia University during one academic year tracing the change in the consumption during the different seasons. The primary energy requirement of all the building, for each month, corresponds to the overall electricity need. So, air conditioning, lighting, printing, ventilation, and auxiliary equipment in an academic building are considered. Figure 2 shows the energy consumption for 9 months, in which the average energy consumption is relatively low during the winter and spring days. However, the consumption sparked to double or triple value during the summer. These results show the areas where there is the maximum energy consumption when the air conditions are working in the 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. 2. Picture of the WSAN components (a) Wave presence detector (b, c) Energy Monitor

Figure 3 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 building and the usage of equipment such as AC, lighting, copier, etc. Some loads work for a short time, and these loads make a jump in the total energy consumption.

Figure 4 highlights the energy consumption before and after using the savings technique during an experiment we ran in our building over 9 months, while Fig. 5 summarizes the energy saving when the energy saving technique is used.

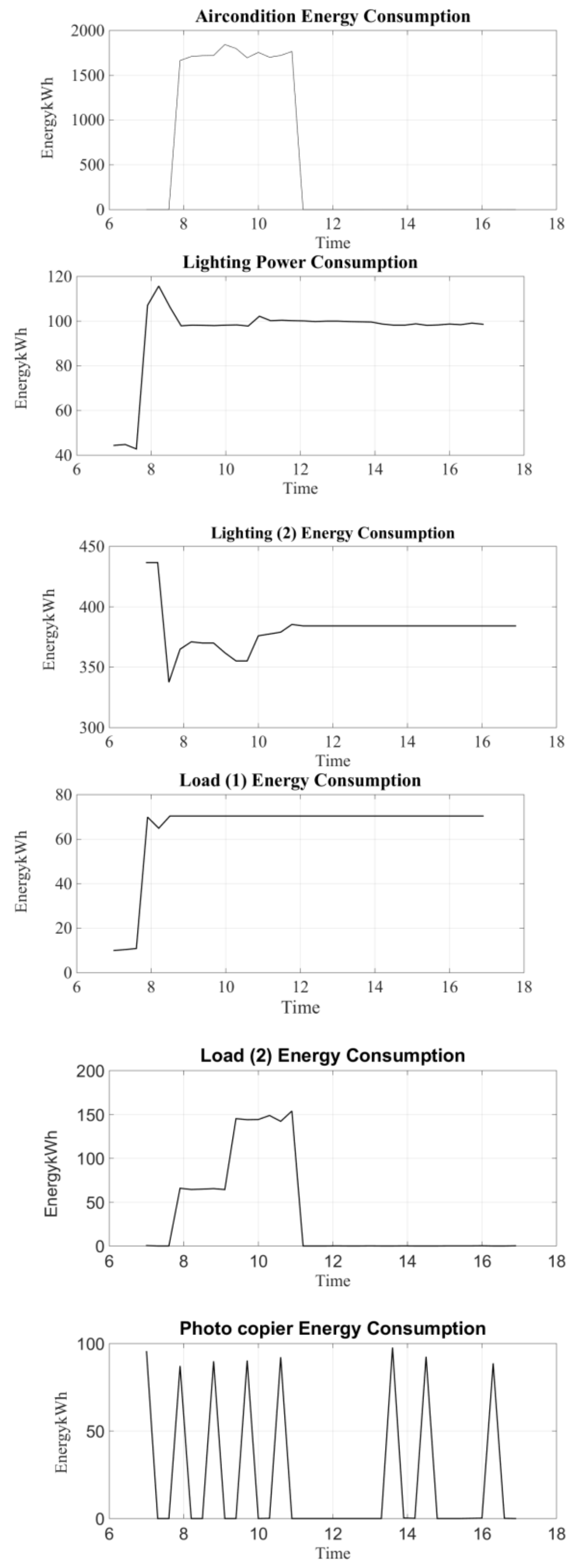

Fig. 3. The energy consumption for different loads in one working day

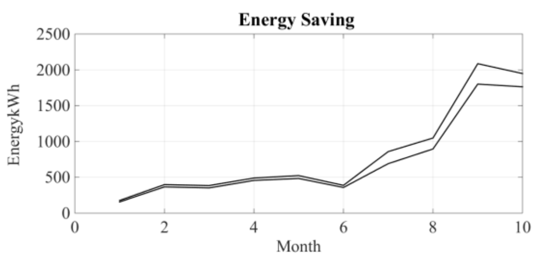

Fig. 4. The energy consumption before and after using the savings technique during an experiment we ran in our building over 9 months

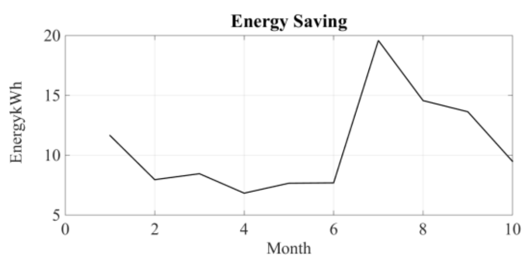

Fig. 5. The energy saving when the energy saving technique is used

VI. CONCLUSION

In this paper, an energy efficiency study for a university building has been presented. The real experiment has been conducted to 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 the 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, electric room equipment.

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