A Wireless Sensor Network for Energy Efficiency in an Educational Environment

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Abstract — **Following design and implementation of a Wireless Sensor Network (WSN) in an educational environment, measurements on the electricity consumption are collected and analyzed. This WSN is developed as part of the EnPROVE project (www.enprove.eu). The WSN is used to measure multiple parameters in a university building. The building is divided into various zones. Each zone represents an area with uniform specification. The measured parameters include lighting and HVAC (Heating, Ventilation, and Air Conditioning) data. In particular data about presence (representing occupancy), temperature, light level, light actuation and windows open/close status are collected. Light, temperature and occupancy measurements in conjunction with electricity consumption are the subject of analysis in this paper. Further analysis is conducted on the impact of changing the timeout of the automated light actuation on the electricity consumption.**

Index Terms — **Energy efficiency, power management, wireless sensor network (WSN), measurement and analysis, energy-efficient building**

I. Introduction

The concept of Wireless Sensor Networks (WSN) is established on the collaborative collection of a large number of sensor nodes. The sensor nodes not only collect sensing data, but also process and communicate the data. The sensors deployed in WSN are small in size, low power, low cost and multifunction [1]. Wireless sensor nodes in WSN are positioned in distance from the location where the incident is anticipated to occur [1], [2]. Multiple sensors can be used to detect the incident and carry out partial data processing, while the central node hosts the major part of the computations and transmits sensed data to the base station [1], [2]. The outcome of such sensor nodes is a time series of sensed data.

The challenge in WSN is the power source capacity that each sensor node can take on board. The on board power source has a very limited capacity. Thus, the network designer needs to decide on a trade-off point where the frequency of data collection (i.e. low throughput) or delays in data transmission does not undermine the network lifetime. The position, location and orientation of sensors and their communication topologies and protocols need to be carefully measured, designed and engineered to prevent conflict.

Depending on the application and the purposes of the WSN, it may include various numbers of the same type of sensor or a combination of various types of sensors. Temperature, light, pressure, noise, movement and presence are few types of the sensors often used in WSN [1]. The applications of WSN cover a wide range of domains [3] ranging from health [4–6] to military [7], [8].

A recently growing application of WSN is in the area of homes and offices. For example, embedded wireless sensor nodes in appliances utilize users with a service by which they can manage and control devices remotely [9]. Alternatively, the appliances may be designed so that they communicate with each other and act as self-organized components of a smart home environment [10], [11]. While a number of research and pilot studies are conducted in the area of smart homes and environment, little work has been dedicated to the services that WSN alone could provide on monitoring energy consumption and energy savings without sophisticated data analysis.

Major part of the previous work in the area of improving or optimizing energy consumption in buildings has concentrated on the adoption of artificial intelligent concepts such as intelligent Decision Support Systems (DSS). Research has been carried out on a DSS for making buildings more energy efficient. This DSS assists the decision maker with various investment budgets to improve the building energy consumption [12]. Other research has been conducted on an intelligent Building Energy Management System (BEMS) [13]. The core decision support model embedded in this system is based on rule sets [13]. Previous attempts at the adoption of WSN for monitoring buildings include its adoption for the purposes of maintaining the stability of Torre Aqua heritage building [14].

Due to the nature of occupancy patterns and the amount of electricity consumption in educational buildings, this research focuses on deploying a WSN for monitoring electricity consumption in an educational building. To serve this purposes, the data gathered on lighting, temperature, occupancy, and electricity consumption during the initial auditing period will be analyzed. A change made to the lighting systems of the building and its impact on the electricity consumption will be studied for a three-month period similar to the initial auditing period.

This research is conducted under the umbrella of the EnPROVE (www.enprove.eu) project. This project is focused on predicting energy consumption models. It provides users with a decision support tool and suggests various renovation scenarios.

Design, development and deployment of a WSN in the educational building are discussed in Section II. The paper will then continue by exploring the measurements and data collected from sensors and meters in Section III. Data are analyzed in Section IV. Discussion is provided in Section V. Limitations of the study and their impacts on the analysis are then discussed in Section VI. Finally, the paper concludes in Section VII by the conclusion of the study.

II. Design and Development

A. Building and Zones

The building that is the subject of this study consists of two open-area partitioned offices, three single person office rooms, a conference room and an open-area kitchen as shown in Fig. 1. Since certain areas in this building have identical characteristics to other areas, in terms of light level, temperature and other characteristics, these areas are audited as placeholders for other zones that are not audited. These areas are called "audited zones". This approach helps to minimize the cost of implementation and the number of sensor nodes needed. The zones for which their data is replaced by the data from audited zones are called "proxy zones".

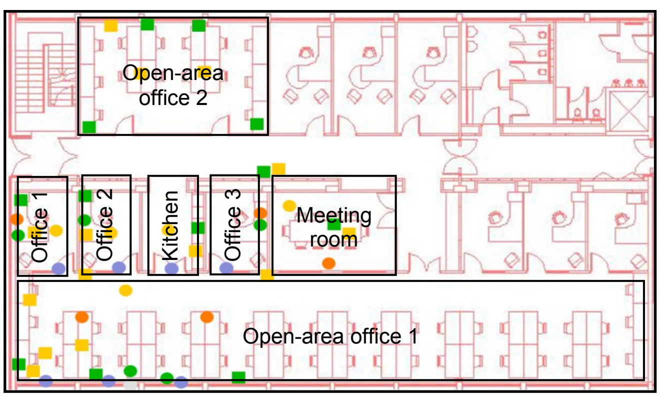

Fig. 1. Floor plan of the area under study with various color-coded sensor nodes

Office 1, office 2, office 3, kitchen and the meeting room each is considered one audited zone. These zones are placeholders for other zones. The open-area office 1 consists of three audited zones and six proxy zones. Similarly, open-area office 2 consists of one audited zone and one proxy zone.

The kitchen and open-area office 1 and 2 have automated on/off lights while the other zones have manual switches. Green, red and blue circles in Fig. 1 denote the presence, temperature and windows open/close sensor nodes, respectively. Amber and green squares stand for light and light actuation sensor nodes.

The open-area office 1, is generally more occupied than office 1 and office 2, as these two offices are single-person offices. The open-area office 1 is used by students, staff and visitors throughout the day and late evenings when students work on their projects.

B. WSN

Various sensors including temperature, presence, light, light actuation and windows open/close are deployed as part of this WSN. However, due to the limited scope of this paper, only data from presence (i.e. occupancy), temperature and light sensors are analyzed as they have a direct and significant impact on the consumption of electricity. To analyze the impact of light actuation and windows open/close status on the electricity consumption, a much larger data set and therefore a much longer auditing period is needed. Furthermore, since the impact of these parameters is not directly related to the electricity consumption, sophisticated data mining and statistical analysis have to be applied to the data set, which is not the purpose of this paper. The deployed sensor nodes are shown in Fig. 2. Careful attention was dedicated to the locations of sensor nodes to make sure they capture realistic data. For example the light sensors not being located in the shadow, temperature sensors not being located near a heating source and presence sensors being located in a place where they can detect presence accurately.

Fig. 2. Sensor nodes

The WSN deployed requires a machine, to act as a gateway (or a base station), with Ubuntu Operating System (OS) and Java6 installed on it. These two software are required to allow for programming the sensor nodes that have TinyOS running on them. The gateway (i.e. Ubuntu machine) also needs to have JDBC driver for MySQL to allow data transmission between the sensor nodes and the gateway.

From infrastructure perspective, data captured by the sensors are sent to the gateway (or the base station) with the Ubuntu OS running on it where signal processing is carried out on the received data. Raw data are stored in a database (labeled "Raw database" in Fig. 3) on a server with MySQL. There is a script running on this server by which raw data are converted to processed data as shown in Fig. 3. The processed data consist of one record per minute per zone per sensor. That is one presence, one temperature, one light, one light actuation and one windows open/close status (if they exist in the zone) records per zone for each minute. Total number of records for each type of sensor is 1440 per day (24 hours x 60 minutes). When querying data from a proxy zone, data collected from audited zones are represented. These processed data are then analyzed using various tools suitable for different purposes. For the purposes of this paper, light and temperature data are analyzed using spreadsheet software. Since the purpose of this paper is to analyze these data and their impact on the electricity consumption, sensors [15] are installed on the distribution board to record the electricity consumption in the building under study.

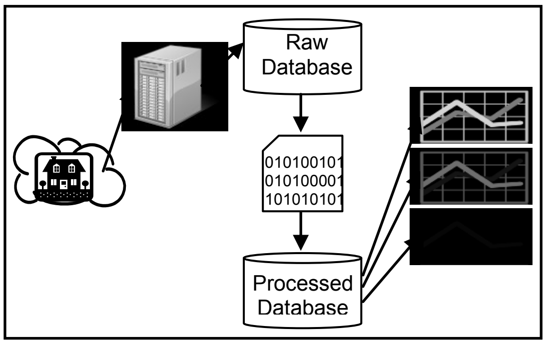

Fig. 3. WSN Infrastructure

III. Measurements and Data

Measurements gathered from audited zones in office 1, office 2 and open-area office 1 are replicated to the proxy zones in these areas. Then the complete data set is considered for analysis. Data from office 3, meeting room, kitchen and open-area office 2 are anticipated to follow similar pattern to the zones being studied. Thus, these zones are excluded from analysis.

Data are gathered for an initial three-month auditing period between 5th of December to the 5th of March. Data and measurements will be provided in terms of lighting, temperature and occupancy inside the zones.

The lights used in all three offices are OSRAM FH 840 14W HE Lumilux Cool White [16] fluorescent lamps. In their datasheet these lamps are described to be 20 per cent more efficient than T8-lamps.

All three areas under the study are heated by conventional radiators that can be controlled at individual level. The size of the radiators is dependent on the size of the room and the standards being in place.

Presence sensors are fixed in locations from where near-real data on the occupancy can be measured.

The electricity consumption data are gathered by sensors attached to the distribution board. Two phases of electricity consumption data collection include the initial period which is identical to the initial auditing period (before changing the light timeout) and the second three-month period (after changing the light timeout) during the year following initial auditing phase for a similar season.

A. Lighting

The amount of light perceived by the sensors inside the areas being studied is graphed in Fig. 4. The measurement unit for light is Lux and as shown in this Figure, the open-area office perceives more light than the other two offices. There is a period of time between the 11th and the 17th of December when no light is detected in any of the areas. This could be due to technical issues experienced by the gateway receiving and transferring data to the database. Excluding the faulty period, minimum light detected in the open-area office is about 136 Lux, while the maximum is about 690 Lux. The maximum figures for the light perceived in office 1 and office 2 are approximately 192 and 143 Lux, respectively. There are times where no light is detected in any of the two offices.

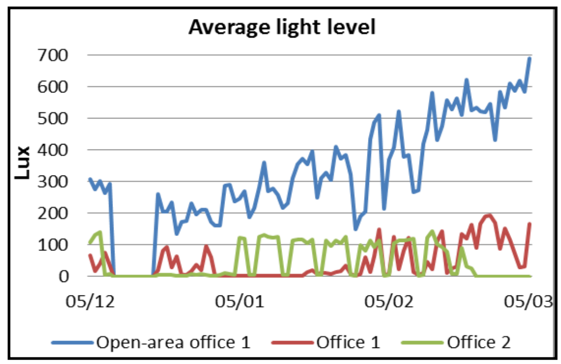

Fig. 4. Average light level for three areas

B. Temperature

The temperature data collected by the sensors in the three areas under the study are graphed as shown in Fig. 5. Excluding the data detected when the gateway had difficulties functioning as anticipated, the values detected for temperature vary between 25°C and 30°C in all three zones.

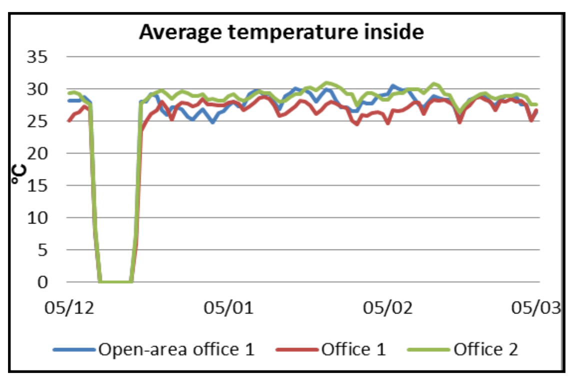

Fig. 5. Average temperature for three areas

C. Occupancy

Multiple presence sensors are used to detect the presence of someone in the areas being studied. Presence is considered as the occupancy of the area. About 40% occupancy is detected for the open-area office 1. Office 1 and office 2 are found to be 12% and 14% of the time, respectively. These figures include weekends and public holidays.

D. Electricity consumption

The amount of electricity consumed for the three months auditing period in the open-area office 1, and office 1 and office 2 are shown in Table I. Electricity data for office 1 and office 2 are measured by one sensor, thus the data are aggregated.

TABLE I. ELECTRICITY CONSUMPTION IN THREE AREAS BEFORE CHANGING LIGHTS TIMEOUT

	05/12-05/01	05/01-05/02	05/02-05/03	Total
Open-area office 1	104.578 kWh	124.642 kWh	125.758 kWh	354.978 kWh
Office 1 and Office 2	20.1184 kWh	21.5316 kWh	26.5764 kWh	68.2264 kWh

After the initial electricity consumption data being collected (See Table I), the lights automatic timeout was changed from 15 minutes to 5 minutes to assess its impact on the electricity consumption. This was only done in the open-area office 1 as this office is the only office equipped with automated lights. The two single person offices have manual light actuation in place.

Electricity consumption data for the same areas are measured again for a similar period in the following year (after changes made to the lights timeout). This period is three month beginning on the 15th of October i.e. about three weeks earlier than the previous year. Due to the logistics and other operational challenges, this period is the closest possible period to the initial auditing period. The electricity consumption data for this period are represented in Table II.

TABLE II. ELECTRICITY CONSUMPTION IN THREE AREAS AFTER CHANGING LIGHTS TIMEOUT (THE FOLLOWING YEAR)

	15/11-15/12	15/12-15/01	15/01-15/02	Total
Open-area office 1	146.076 kWh	103.261 kWh	164.091 kWh	413.428 kWh
Office 1 and Office 2	20.128 kWh	17.872 kWh	30.342 kWh	68.342 kWh

IV. ANALYSIS AND RESULTS

A. Lighting and temperature data

The light data perceived by the sensors in the open-area office 1 are generally larger than those received from the other two offices. This could be due to a number of factors. For instance, the open-area office 1 has large windows to natural light on one side, while the offices only have windows facing open-area office 1. Thus, these offices only receive small portion of the natural light. From Fig. 4, it is clear that when the amount of light detected in the open-area office 1 is reduced, the amounts of light in the two offices also are also reduced. Another reason for detecting larger light data in the open-area office 1, could relate to the number of fluorescent lamps used in this area.

In contrast to the light data, the temperature data do not vary as much between the three areas for the audited period. Towards the end of the auditing period, the data appear to be quite similar. This could be due to the seasonal changes, when the radiators are off for most of the day. Examining data closely reveals that the general temperature is slightly higher in the open-area office 1. This difference is minimal and could be due to the fact that this office is more occupied than the two offices as shown by the occupancy data.

B. Electricity consumption before and after changing the lighting timeout

The data show that for three months period prior to changing the timeout of the automated lights, 354.978 kWh and 68.2264 kWh of electricity were consumed for the open-area office 1 and the two offices, respectively. The minimum consumption for both areas is detected during the month of December and early January. This is in accordance with the holidays when only few people use the building.

To analyze the impact of changing the timeout of the automated lights from 15 minutes to 5 minutes, electricity consumption data are collected from a similar period of time in the year following the initial measurement. The electricity consumption for the two offices is found to be similar to the initial measurement. It is found that the electricity consumption for the open-area office 1 has increased. This area is where the timeout was modified. Since the presumption is that reducing the timeout on the lights means less energy consumption, this finding is not what was anticipated.

V. DISCUSSION

Further analysis on the light data show that the availability of windows in the open-area office 1 where walls are 30 meters apart has a significant impact on the amount of light perceived. The data also show an increase in the amount of light detected as the season changes towards spring and summer, as anticipated. The impact of the seasonal changes on the amount of light perceived in the offices that have no direct window to the natural light is not significant. Investigating the same phenomena for the temperature, it is clear from the data that as the time progresses towards spring, the temperature data are more harmonized and the changes in the temperature are reduced. Some variation is also observed in the temperature data for first two months. Thus, it can be concluded that during December and January relatively high temperatures (when the radiators are on) are followed by relatively low temperatures (when the radiators are off). This could reflect the difficulties experienced in establishing a stable temperate in the large office.

Changing the timeout of the automated lights was anticipated to have reduced the amount of electricity consumed. To validate this assumption, electricity consumption data for the areas under the study are collected. These data are gathered over two similar periods in two consecutive years. The amount of electricity consumed by the two offices in second year remains very similar to the figures for the first year. However, there is an increase in the amount of electricity consumed in the open-area office 1. The total electricity consumption in this office for the first year (prior to changing the timeout) is 354.978 kWh, while this figure increased to 413.428 kWh for the year post changing the timeout on the automated lights. Given that only this office is equipped with the automated lights, it is worth noting that the two offices with manual light actuation seem to have consumed the same amount of electricity. However, more detailed analysis on the occupancy and other influential factors after changing the timeout should be conducted before reaching any valid conclusion.

Considering the electricity consumption data in conjunction with the occupancy rate in the areas under study may reveal interesting insights into the electricity efficiency in buildings. However, further data on the number of people occupying each area, the number of devices being plugged in and a number of other factors should be analyzed before reaching a conclusion on the efficiency.

VI. Limitations

The analysis of the electricity consumption before and after the changes made to the lights timeout is limited due to the lack of data about occupancy, temperature and light for the after case. One approach to validate the analysis is to assess the changes in the occupancy rate, light level and temperature and then explore the electricity consumption. This was not feasible for this study as the WSN was removed from the building after the initial three-month period.

Another limitation of the study is due to the fact that the data for the before and after cases are gathered from two consecutive years and for periods that are about three weeks different in time. A number of factors could impact the results for example the changes in season over the three weeks difference, changes made to the occupancy pattern and rate. However, no major changes were made to the environment under study over the course of year. Alternative approaches to setting up the test include using two identical buildings for the study. This option was not feasible as this building is unique and no other building with similar characteristics was found. Another approach would be setting up the test for two consecutive periods following each other, with no time gap. However, this option would limit the study by the fact that seasonal changes could skew data to a great extent. Thus, the studied periods are found to be the closest periods.

VII. Conclusions

A WSN is designed and implemented to gather data on occupancy, light and temperature from an educational building. Data are gathered for a three-month period and from the audited zones in an open-area office and two single-person offices. These data are replicated for the proxy zones to provide a complete data set for analysis. Also, electricity consumption data for the same period are also collected and analyzed.

The open-area office being studied is equipped with automatic lights that turn all the lamps off after 15 minutes of no presence detected. This figure is changed to 5 minutes. The electricity consumption data are gathered for another three-month period during similar seasons to the first data collection phase. Unlike the assumptions, this change did not decrease electricity consumption. However, more thorough studies must be conducted to analyze other influential parameters, such as occupancy rate, for the second period before a conclusion can be drawn.

Further research in this area may involve exploring the most efficient office set-up so that the rate of occupancy and the electricity consumption are optimized. Furthermore, future studies may consider using multiple parameters (e.g. light actuation) to build a comprehensive model for analyzing electricity consumption.

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