Proceedings of the 2014 Winter Simulation Conference
A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.

MONITORING OCCUPANCY AND OFFICE EQUIPMENT ENERGY CONSUMPTION USING REAL-TIME LOCATION SYSTEM AND WIRELESS ENERGY METERS

Nassim Masoudifar
Amin Hammad
Mandana Rezaee

Faculty of Engineering and Computer Science
Concordia University
1455 De Maisonneuve Boulevard West
Montreal, H3G 1M8, CANADA

ABSTRACT

Buildings are one of the major energy consumers because of the need to meet occupants requirements. The commercial/institutional sector accounted for 14% of total energy consumption in Canada in 2009 while office buildings consumed 35% of this amount. Auxiliary equipment used 19% of the total energy consumed in office buildings. Previous studies showed the impact of occupancy behavior on IT equipment energy consumption. This paper proposes a new method for monitoring occupant behavior and energy consumption of IT equipment. Analyzing the resulting data can help evaluating the occupancy behavior impact on energy saving. Two wireless sensor technologies are investigated to collect the required data and to build an occupancy behavior estimation profile: Ultra-Wideband Real-Time Location System for occupancy location monitoring and Zigbee wireless energy meters for monitoring the energy consumption of IT equipment. The occupancy behavior estimation profile can be used to reduce energy consumption based on real-time occupants' information.

1 INTRODUCTION

Energy consumption is widely increasing all around the world resulting in a global environmental problem. It is estimated that the world energy consumption will increase from 522 EJ in 2006 to 570 EJ in 2015 and 730 EJ in 2030 (Conti et al. 2013). Regarding the increasing demand for more realistic prediction of operational energy use in the institutional/commercial building sector, auxiliary equipment should not be disregarded since it typically accounts for 19% of the total energy used in this sector (Menezes et al. 2013). Occupancy information is an important variable which enables timely reaction to adjust energy load demands, drive a more optimized building operation schedule, and minimize energy consumption (Yang et al. 2012). The topic of occupancy-driven management has attracted considerable attention in academic research due to the potential energy savings. To lay the basis of occupancy-driven system operations, different solutions have been proposed to monitor the occupants in a building. Simulation results showed that occupancy-based control can result in 10–60% in energy saving (Tachwali, Refai, and Fagan 2007; Sun, Wang, and Ma 2011; Erickson et al. 2010; Li et al. 2011). However, these solutions have certain limitations in terms of their accuracy and intrusiveness. In recent years, a few researchers have attempted to use short-term monitoring for the purpose of base lining building energy use (Singh 2011). The objective of this paper is to monitor the behavior of building occupants and IT equipment energy consumption in order to create an occupancy profile.

978-1-4799-7486-3/14/$31.00 ©2014 IEEE

2 LITERATURE REVIEW

Occupant behavior refers to an occupant's movement, personal habits, and responses to his/her needs by interacting with the building systems which have direct and decisive impacts on the energy performance of buildings (Nguyen and Aiello 2013; Azar and Menassa 2011; Yu et al. 2011). Results from studies and implementation by academia and industry promised saving in the range of 2.7%-55% in energy consumption by considering occupant behavior. A number of academic studies have been done in order to test a variety of occupancy and energy consumption monitoring systems to collect real-time data and to create user profiles. A summary of these studies is presented in the following.

Barbato et al. (2009) used Passive Infrared (PIR) sensing to determine occupancy in their smart building system. Delaney, O'Hare, and Ruzzelli (2009) used PIR based wireless occupancy sensors to measure wasted energy in lighting. Erickson, Carreira-Perpinan, and Cerpa (2009) developed BODE project based on occupancy measurement, modelling and prediction for building energy savings that tracks users' movements in building spaces using a camera network solution. Kamthe et al. (2009) deployed a wireless camera sensor network for collecting data regarding occupancy in a large multi-function building constructing multivariate Gaussian and agent-based models for predicting user mobility patterns in buildings. CO_2-based occupancy detection has also been examined. This occupancy detection system suffered from high costs and privacy issues. Martani (2012) proposed a method using a number of Wi-Fi connections as an indicator to gauge the levels of activities within different spaces and to measure occupancy. Li et al. (2012) proposed a system using RFID technology to detect multiple occupants performing multiple activities (i.e., walking, seated, and standing). Harle and Hopper (2008) installed an ultrasonic personnel tracking system that provided three dimensional tracking to form a picture of how people work and what energy savings might reasonably be expected if device 'idling' can be presented. Kamthe et al. (2009) deployed a wireless camera sensor network for collecting data regarding occupancy in a large multi-function building constructing multivariate Gaussian and agent-based models for predicting user mobility patterns.

Some researchers used a combination of two methods to improve the accuracy of occupancy detection. Agarwal et al. (2010) introduced LIGHTing using two common sensing devices: (1) a light detector and (2) PIR sensor to detect people presence and to obtain a binary indication of occupancy (presence/absence). Newsham and Birt (2010) developed the Autoregressive Integrated Moving Average (ARIMA) model to forecast the power demand of the building. ARIMA uses contact closure sensors, PIR motion sensors, and a carbon-dioxide sensor. Padmanabh et al. (2009) studied the iSense system to recognize two states of a conference room (meeting state and no meeting state) by using a network of wireless microphones, PIR, and light and temperature sensors. Dong and Andrews (2009) used motion, CO_2 and acoustic sensors to detect occupancy.

Ultra-wideband technology (UWB) involves transmission of very short pulses over a very wide band of frequencies. UWB Real-Time Location Systems (RTLSs) have an accuracy of approximately 15 cm. UWB has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and a higher power. With conventional radio signals, reflections in congested environments distort the direct path signals, making accurate pulse timing difficult. While with UWB, the direct path signal can be distinguished from the reflections, making pulse timing easier (Ubisense 2013). Spataru and Gillott (2012) monitored and analyzed occupancy activities and equipment energy consumption in a test house using a UWB. They also measured and monitored the energy consumption in the house using a whole house circuit and appliance meters.

3 METHODOLOGY

Figure 1 illustrates the different data sources that can be used to analyze the occupancy behavior based on the locations of the occupants of an office and their IT equipment and energy consumption. The following are the main data sources: (1) An UWB provides the identity and the location of the occupants at different points of time. By analyzing the UWB RTLS data, the following question can be answered: How many people are in the office for a specific time? Who is where and for how long at any time? In other words we can obtain occupants' detection, identification and localization. (2) Energy meters provide real-time equipment energy consumption data simultaneously providing the answers for the following question: Which device is using how much energy at specific times? By combining the location data and energy consumption data, the answers for the following questions can be also found: Who is doing what? How much energy is used by each occupant? How much energy is wasted by each occupant? (3) The BIM model of the office includes architectural elements, furniture, IT equipment, and wireless sensor networks to evaluate occupant behavior. Each occupant is assigned to a specific zone within the office that includes the IT equipment used by that occupant. Occupancy profiles can be constructed from the UWB data.

An experimental study with the objective of monitoring IT equipment energy consumption and occupant behavior is proposed in order to minimize energy consumption in office buildings. To evaluate the impact of occupancy behavior on IT equipment energy consumption, a test in one of the research offices at Concordia university is carried out for one week to collect the required data as a sample to create office occupancy profile. Two wireless sensor technologies are used for monitoring occupant behavior and energy consumption of IT equipment (i.e., monitors, computers, and printers). UWB RTLS is used for occupancy location monitoring and Zigbee wireless energy meters are used for monitoring the energy consumption of IT equipment. UWB provides the identity and location of occupants at short time intervals. The occupants are required to wear UWB tags during the test. On the other hand, energy meters provide instantaneous and cumulative equipment energy consumption data simultaneously providing the information of how much energy is consumed by each device. Energy meters should be attached to the IT equipment in the office which are in use by the occupants.

The update rate for UWB and Zigbee energy meters should be in the same range (e.g., one reading per minute). In this test the update rate is set in accordance with the occupants movements duration and energy consumption reading fluctuations. For example, printing a few papers may take about one minute and occupants movement within the room to collect the printed papers may also take about one minute.

The data recorded by the UWB logger can be used to create the daily and weekly users' profiles. Assuming that the occupants' pattern of using the space and IT equipment is constant throughout a certain period of time, these profiles can be used to estimate the long-term energy consumption. The overall occupancy profiles were created based on the collected data of the occupants of the office on an hourly basis for each day during the test week and different occupancy maps and charts for each day were created. Although the overall occupancy profiles contain valuable information, probabilistic individual occupancy profiles can be also useful to identify the specific needs of each occupant. To find the probability of occupancy, location data were categorized based on the IDs and a profile was created for each occupant. The profiles include the time each user was present in the office in every hour in different days. This procedure is summarized in Figure 2.

The office area is divided into different zones. Each occupant is assigned to a specific zone within the office which are defined based on occupant's zone that includes the IT equipment used by that occupant as shown in Figure 6 (b). For each time step, there are three possible states for each occupant: (1) in the office and within his/her zone, (2) in the office but not in his/her zone, and (3) absent. Each of these states has an impact on the likelihood of energy consumption. Energy consumption is most likely to occur during state 1. When an occupant is in state 2 or absent, it is important to find out if any energy consumption has occurred or not. Figure 3 shows the procedure of calculating the total waste of energy periods. In the first step, there are two possibilities, whether the occupant was in the office or not. The presence of the occupant in the office would result into one of these following scenarios which are being in his/her zone or out of zone. Next, there is the possibility of waste of energy during the times in which the occupant was in the office but not in his/her zone and the equipment was on. On the other hand, if the occupant is absent or out of his/her zone the possibility of waste of energy may occur if the equipment assigned to the occupant was on assuming that the computer is not used for extensive computation.

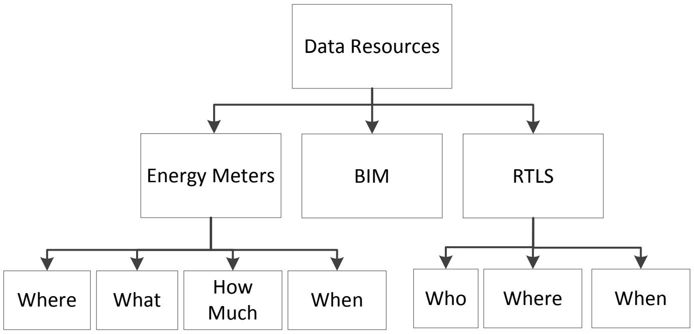


Figure 1: Data resources.

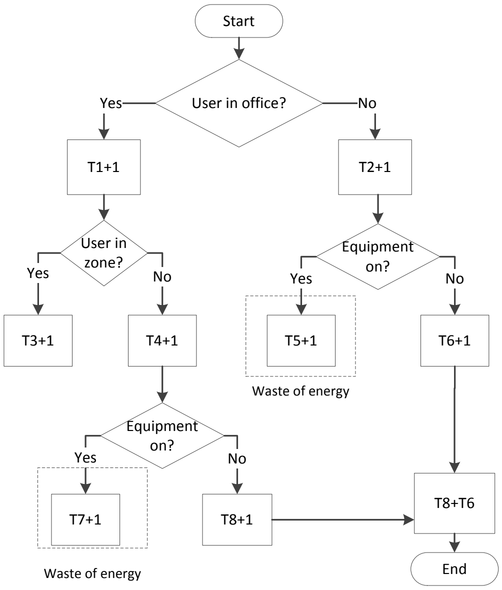


Figure 3: Total waste of energy procedure.

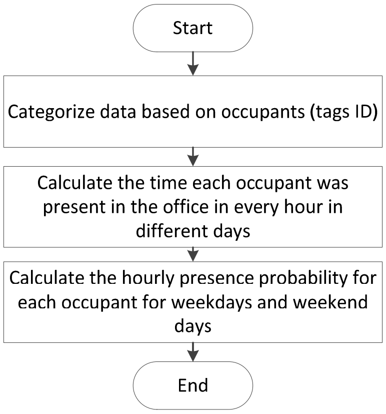


Figure 2: Procedure to find the probabilistic individual occupancy profiles.

Figure 4: (a) UWB sensor, (b) UWB slim tag (Ubisense, 2013).

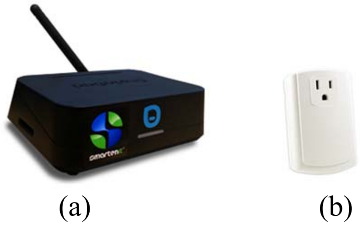


Figure 5: (a) Zigbee gateway, and (b) Zigbee energy meter (Smartenit, 2013).

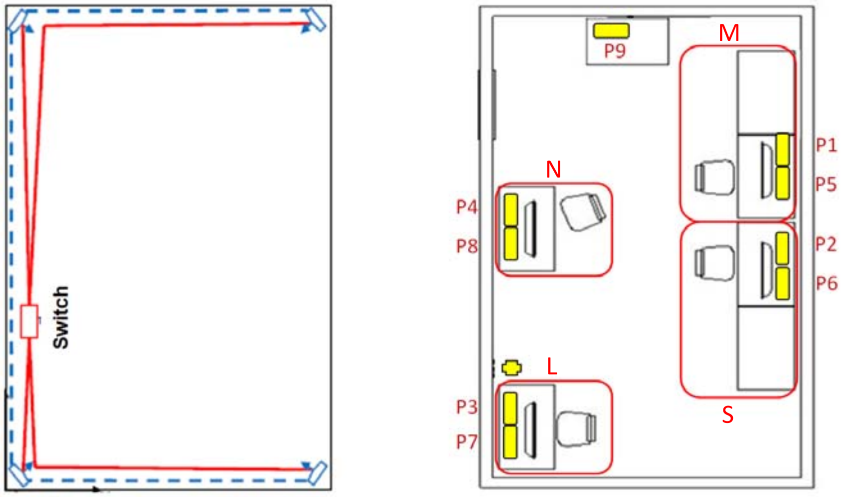
4 IMPLEMENTATION

The key components of the UWB RTLSs are: Tags, sensors, network components, and platform server. The sensors and tags are illustrated in Figures 4(a) and (b), respectively. The sensors detect the signals and calculate the positions of the tags. The sensors used in the test are placed above the detection area in which the tags are tracked and are arranged to work in a location engine cell. Each cell has a single master sensor and a number of slave sensors. The location engine cell divides time into time slots and allocates appropriate time slots to the tags according to their requested update rate (Ubisense 2013).

Zigbee is the wireless technology used to monitor energy consumption of IT equipment in the test. ZigBee Home Automation offers a global standard for interoperable products enabling smart homes that can control appliances, lighting, environment, energy management and security, as well as the expandability to connect with other ZigBee networks. A Home Area Network (HAN) of smart appliances that support the ZigBee Smart Energy standard ensures the integration and interoperability with smart energy devices (ZigBee 2013). A ZigBee gateway and an energy meter are shown in Figures 5(a) and (b), respectively. The Zigbee gateway provides a means to access the Zigbee network remotely via the

Internet whereas the Zigbee energy meters enable remote control and energy monitoring of appliances. The energy meters join the network as a ZigBee router and then facilitate the joining of other devices, thus extending the entire network (Smartenit 2013).

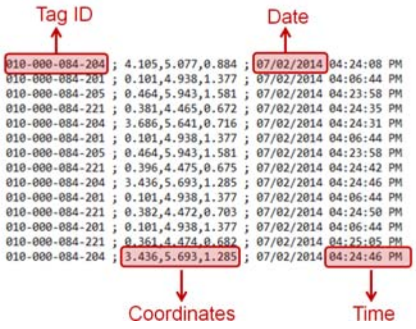
The Zigbee energy meters and UWB data must be separately processed to provide the location and energy measurement data, respectively. The data can be fused to understand the occupants energy consumption paterns. In this test, the logger applications gather location and the IT equipment energy consumption data into CV-based Excel sheets. Furthermore, some processing is required to provide the UWB and Zigbee energy meters datasets which are aligned in terms of time such as: data synchronization, averaging (one reading per minute), and filtering (false readings). This processing assures providing reliable data for the analysis. Since a huge amount of information is saved in Excel files, to improve the efficiency and convenience, Visual Basic for Application (VBA) is used. VBA is an effective tool to automate the frequently used repetitive calculations. The advantage of using VBA in data processing and the visualization of test data is that it provides a tool to automatically generate customized reports, charts (occupancy charts and maps and energy consumption charts).



(a) Distribution of UWB sensors. (b) Distribution of Zigbee energy meters.

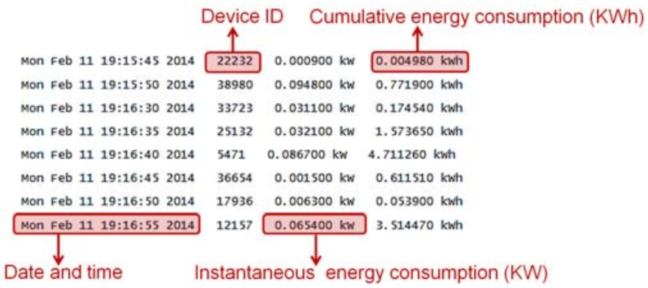
Sensor -- Timing cable — Data cable Zigbee Gateway Zigbee energy meter

Figure 6: Layout of implementation of wireless sensor networks.



```
010-000-084-204 ; 4.105,5.077,0.884 ; 07/02/2014 04:24:08 PM
010-000-084-201 ; 0.101,4.938,1.377 ; 07/02/2014 04:06:44 PM
010-000-084-205 ; 0.464,5.943,1.581 ; 07/02/2014 04:23:58 PM
010-000-084-221 ; 0.381,4.465,0.672 ; 07/02/2014 04:24:35 PM
010-000-084-204 ; 3.686,5.641,0.716 ; 07/02/2014 04:24:31 PM
010-000-084-201 ; 0.101,4.938,1.377 ; 07/02/2014 04:06:44 PM
010-000-084-205 ; 0.464,5.943,1.581 ; 07/02/2014 04:23:58 PM
010-000-084-221 ; 0.396,4.475,0.675 ; 07/02/2014 04:24:42 PM
010-000-084-204 ; 3.436,5.693,1.285 ; 07/02/2014 04:24:46 PM
010-000-084-201 ; 0.101,4.938,1.377 ; 07/02/2014 04:06:44 PM
010-000-084-221 ; 0.382,4.472,0.703 ; 07/02/2014 04:24:50 PM
010-000-084-201 ; 0.101,4.938,1.377 ; 07/02/2014 04:06:44 PM
010-000-084-221 ; 0.361,4.474,0.682 ; 07/02/2014 04:25:05 PM
010-000-084-204 ; 3.436,5.693,1.285 ; 07/02/2014 04:24:46 PM
```

Figure 7: Sample location raw data.



```
Mon Feb 11 19:15:45 2014  22232  0.000900 kw  0.004980 kwh
Mon Feb 11 19:15:50 2014  38980  0.094800 kw  0.771900 kwh
Mon Feb 11 19:16:30 2014  33723  0.031100 kw  0.174540 kwh
Mon Feb 11 19:16:35 2014  25132  0.032100 kw  1.573650 kwh
Mon Feb 11 19:16:40 2014  5471  0.086700 kw  4.711260 kwh
Mon Feb 11 19:16:45 2014  36654  0.001500 kw  0.611510 kwh
Mon Feb 11 19:16:50 2014  17936  0.006300 kw  0.053900 kwh
Mon Feb 11 19:16:55 2014  12157  0.065400 kw  3.514470 kwh
```

Figure 8: Sample Zigbee energy meters raw data.

5 CASE STUDY

A case study was carried out to demonstrate the feasibility of the proposed method.

5.1 Test Design and Data Acquisition

The test has been carried out for a week of data acquisition from four office occupants wearing slim tags. Four tags with an individual update rate of 2 readings per minute are registered in the Ubisense Location Engine and then selected in the logger application for logging. Simultaneously, energy meters were attached to the occupants' IT equipment with an individual update rate of 1 reading per 45 seconds. The layout of implementing these wireless sensor networks is shown in Figures 6(a) and (b). The energy meters were attached to the IT equipment four monitors, four computers, and a printer. The specifications of the equipment are listed in Table 1. The layout of implementing UWB sensors is shown in Figure 6(a). A sensor cell, consisting of four sensors and four tags, was used to log the data. Four sensors were fixed at the four corners of the office ceiling and were connected with data and timing cables. The power of the sensors was supplied by a Power over Ethernet (PoE) switch. Timing cables were used to connect the sensors to synchronize the signals from a tag to different sensors. The sensors were calibrated using a tag as a reference point with a known position. The solid lines show the data cables connecting the sensors with the PoE switch, whereas the dotted lines show the timing cables. Figure 6(b) shows the layout of implementing Zigbee energy meters. A wireless Zigbee energy meter network including a gateway and nine energy meters was used to measure energy consumption of IT equipment.

5.2 Location Data Processing and Analysis

As shown in Figure 7, occupants' 2D location and time data were logged including the UWB Tag ID, coordinates, date, and time in each of the readings. Figure 8 shows a sample IT equipment energy consumption data including device ID, date and time, instantaneous energy consumption and cumulative energy consumption.

5.2.1 Occupancy Maps

A worksheet was developed in Excel to analyze and visualize the collected data. Occupancy maps were created to show occupants' locations in the office based on UWB coordinates (X, Y) during each day of the test period. As shown in Figure 9, each symbol indicates one of the occupants (i.e. S, M, L, and N) and each point indicates the location of a specific occupant at a certain time (i.e. every minute). The distribution of occupants' locations in each map demonstrates the variety of occupants' presence and locations in every day of the week. For example, all occupants came to the office during weekdays except occupant S who was absent on Monday. During the weekends, occupant L did not come to the office while occupant N came on both days and occupant M and S came on Saturday and Sunday, respectively. The number and the density of each occupants' locations show the length of the time that they were on the office. However, it is not possible to determine the times at which each occupant was in the office from these occupancy maps.

5.2.2 Occupancy Charts

Charts were developed to illustrate occupants' daily presence as shown in Figure 10. The charts show that the occupants left the office many times during the day and sometimes they only came to the office for a few minutes (e.g. occupant L at around6 PM on Monday). Moreover, they had different daily patterns for the times they came and left the office. For example, occupant S came to the office at around noon and was the last one who left the office on Friday. On the other hand, on weekend days, only two occupants came to the office on each day and stayed for a short period of time. Occupant N came to the office every day and spent more time in the office compared to others.

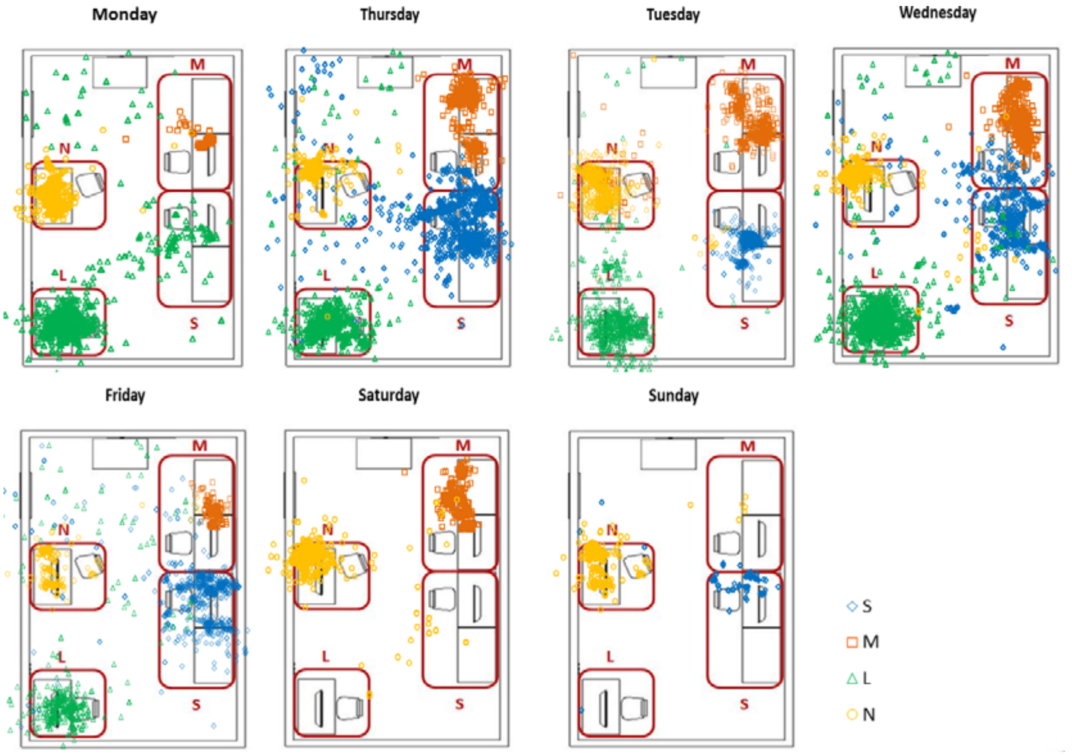


Figure 9: Occupancy map.

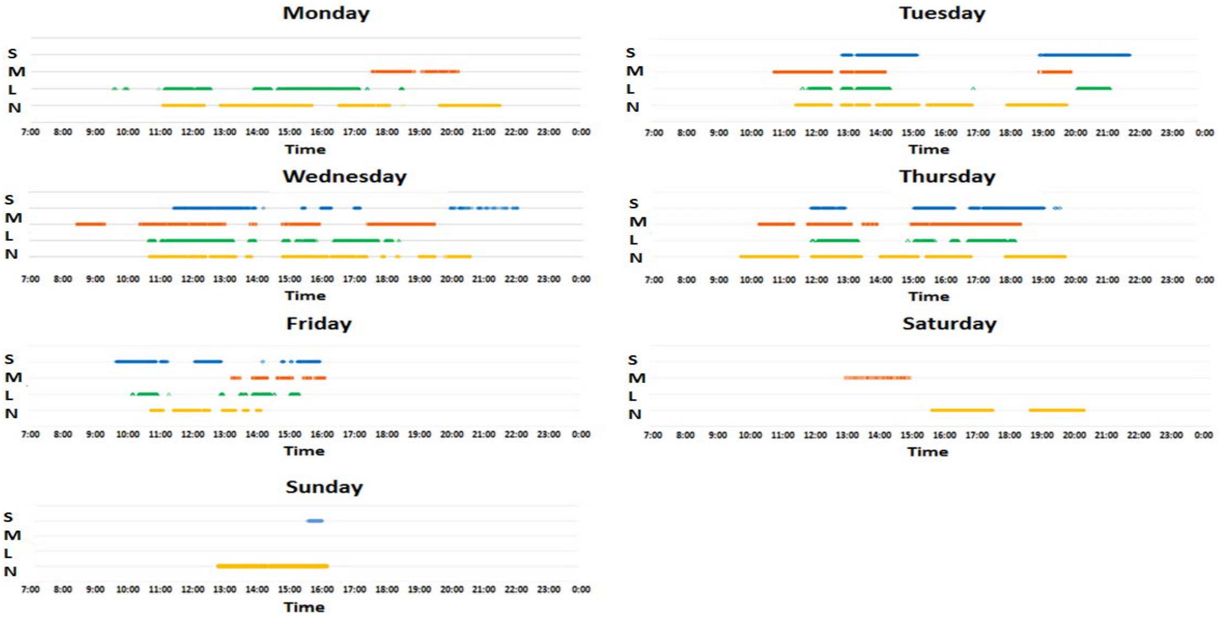


Figure 10: Occupancy charts.

5.2.3 Occupancy Profile

As explained in Section 3, the data gained from the UWB occupancy monitoring are used to create the daily and weekly user's profiles. Figure 11 shows the overall occupancy in the office for each hour of different days in the week considering all the occupants. For example, a value of 100% at 10 AM on

Wednesday means that all the occupants are expected to be in the office during that hour. As expected, a decrease in the number of occupants can be seen during the weekend. Figures 12(a) and (b) show the histograms of probabilistic individual occupancy profiles for each occupant in weekdays and weekend days. For example there is a 20% probability to find user S in the office at 10:00 AM in weekdays.

5.3 Zigbee Energy Meters Data Processing

Figure 13 shows daily electricity consumption for different monitors for different days of the week. The horizontal axis represents the time of day, whilst the vertical axis illustrates the cumulative energy consumption for monitors. The slope of the curve illustrates the energy consumption for each monitor; The steeper the slope, the greater the rate of energy consumption. For example, on Monday, we can see the slope of the curves for different monitors are different. Analyzing energy consumption data showed that computers and monitors with different specifications consumed different amounts of energy. The size and brand of the monitors have an effect on their energy consumption. Comparing the information from Table 1 with the measured energy consumption demonstrated that monitors with bigger screens consumed more energy than the ones with smaller screens. For instance in Figure 13 it is shown that the 19″ monitor of occupant N consumed approximately 60% less energy than the 24″ monitor of occupant S. However, although occupant L's monitor is smaller than that of the occupant N, it consumed more energy because it is an old monitor. Another point that can be obtained from the graphs is that occupant N never turned off her monitor during the test.

Similar graphs were created for energy consumption for computers. Comparing the slopes in Figure 14 indicates that the computers for occupants S, M and L had almost the same energy consumption whilst occupant N's computer, which is a newer system, used less. Focusing on the graph corresponding to Saturday and Sunday shows that occupant L turned off his computer during the weekend while the other computers were on. Moreover, monitors energy consumption varied regarding the percentage of brightness (i.e. 100%, 70%, 50%, 20%, 10%.) as shown in Figure 15.

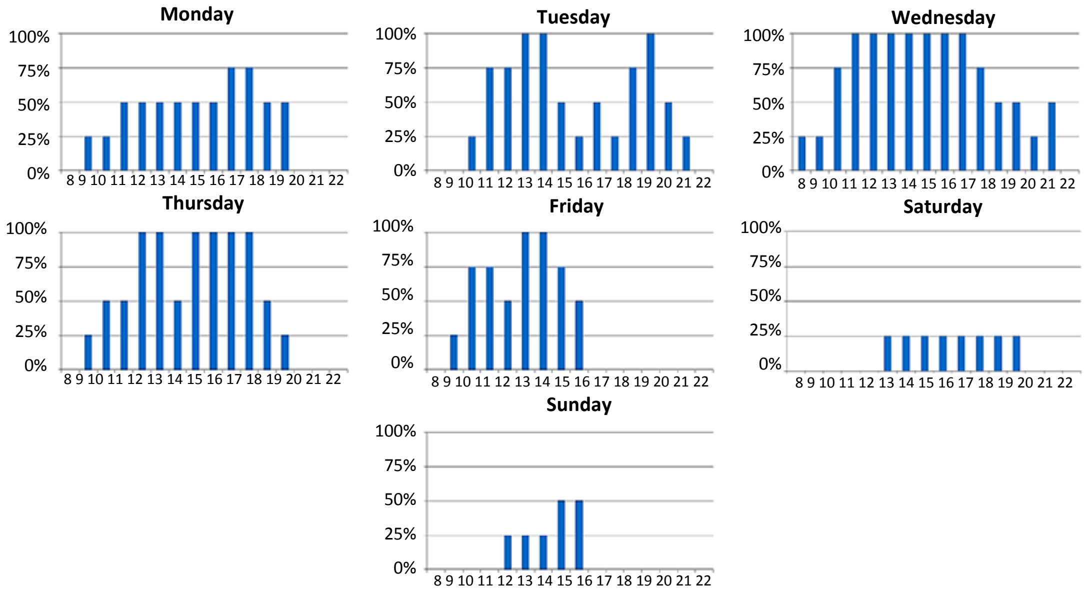
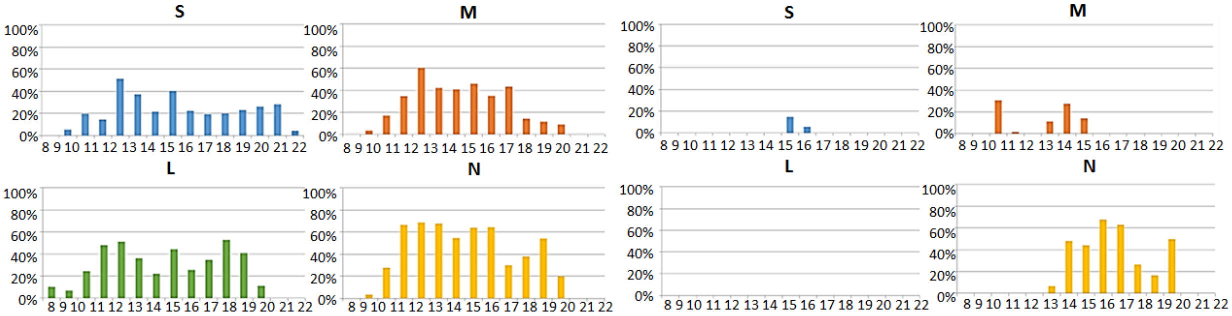


Figure 11: Overall occupancy profile.



(a) weekdays (b) weekend days

Figure 12: Probabilistic individual occupancy profiles.

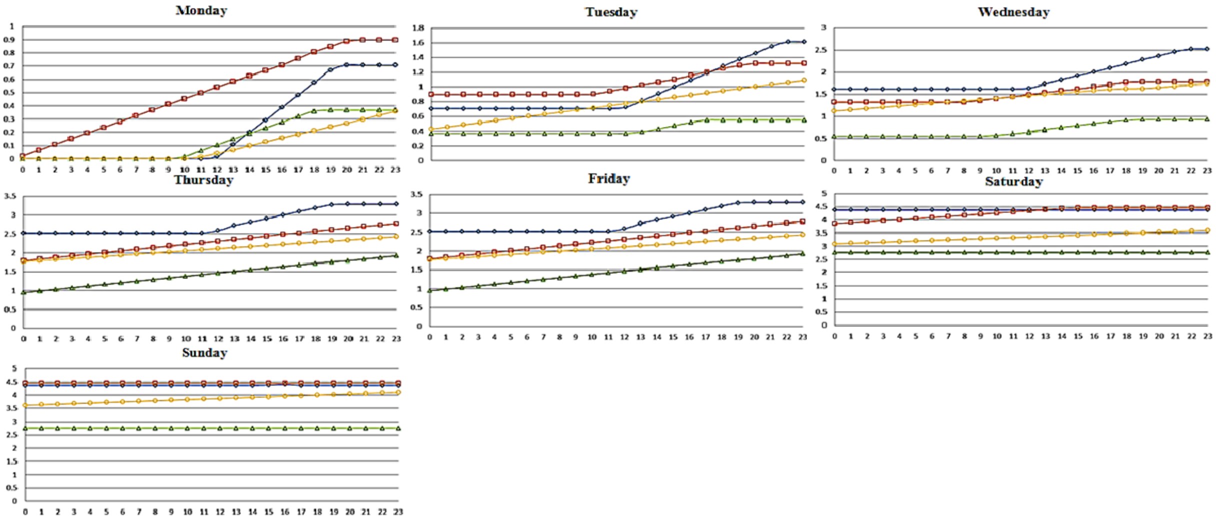


Figure 13: Energy consumption of monitors.

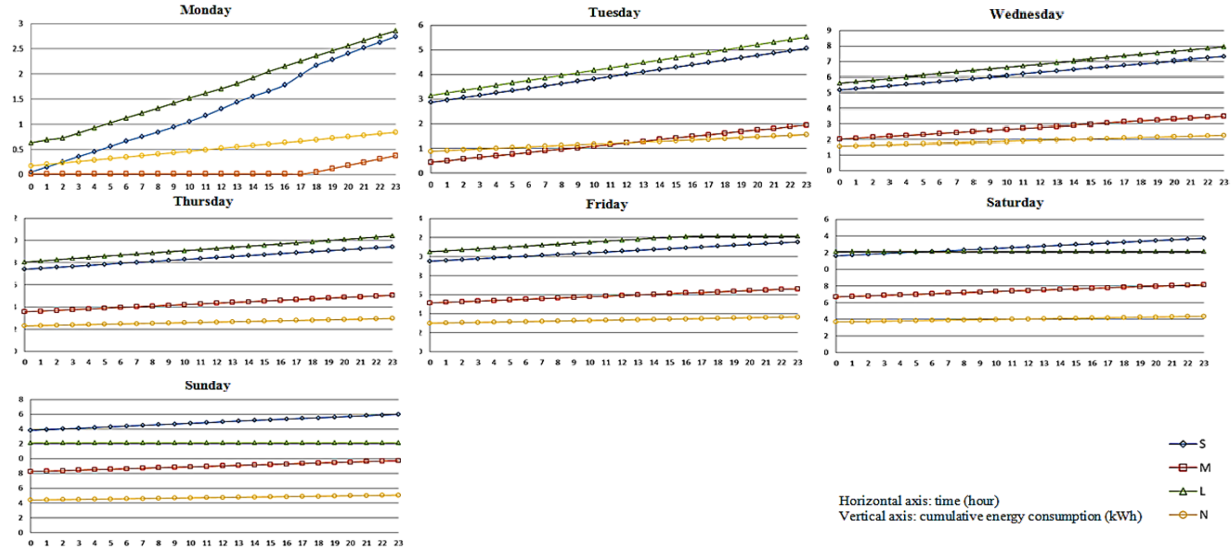


Figure 14: Energy consumption of monitors.

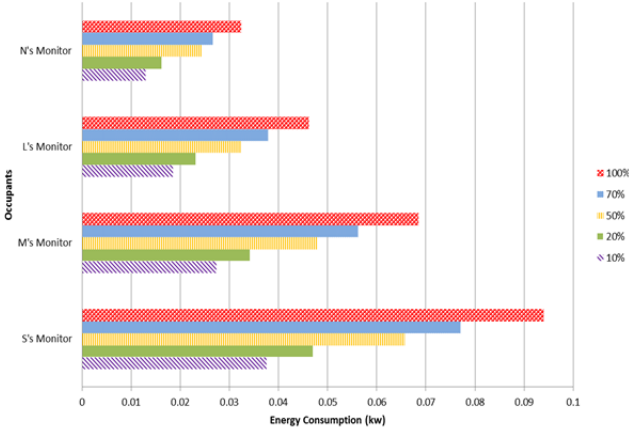


Figure 15: Comparisons between monitors energy consumption.

Table 1: IT equipment specifications.

Equipment	Specifications	Energy meters
Computer	Dell Precision T3500	P_1
	Dell AS501	P_2
	Dell Precision T3500	P_3
	HP Z210	P_4
Monitor	Dell AX510, 23 inch	P_5
	Dell AS501, 24 inch	P_6
	IBM 9494, 18.1 inch	P_7
	Dell1908FPc, 19 inch	P_8
Printer	HP Laserjet P2055dn	P_9

5.4 General Observations

Monday was selected as a sample for the observations. Regarding the occupancy chart, Figure 10, occupant L, N, and M entered the office at around 9:30 AM, 11 AM, and 5 PM, respectively. It seems that L left the office from 1 to 2 PM for lunch while N went for lunch at 12:30 PM and came back at 1:00 PM. L left the office in the evening at 7 PM. N left at around 10 PM and M stayed in the office for about 4 hours. Observing the energy consumption chart for monitors, it is shown in Figure 13 that L's monitor was on since 10 AM until 7 PM. Moreover, regarding Figure 14, L's computer was on all day long. S's monitor was on from noon until about 8 PM resulting in a rise in his monitor energy consumption and his computer was on all day long although he was not in the office on Monday. Looking at occupancy map in Figure 9, it is shown that L was in S's zone for a period of time and probably was using his equipment resulting in increasing its energy consumption.

In order to calculate the waste of energy related to occupants' behavior, we chose occupant L behavior on Monday. As explained in Section 3 in order to calculate the total waste of energy during this day, first the time L was in the office has been calculated (T1=291 m). Within this time, he spent T3=243 m in his zone and T4=48 m out of his zone. He turned on his monitor once he arrived to the office and turned it off when he left the office while his computer was running all day long. Therefore, during the time he was in the office and he was in his zone, his monitor and computer were on for a period T7=48 m. Moreover, his equipment were running during the time he was not in the office between 9:35 AM and 6:38 PM. In addition his computer was running even after he left the office till next day. Table 2 shows the summary of the calculation of waste of energy. In conclusion, it is estimated that if occupant L turned off his monitor and computer during the time he was not in the office or in his zone, about 0.38 kwh and 6.58 kwh have been saved, respectively.

6 CONCLUSIONS AND FUTURE WORK

This paper proposed a new method for monitoring occupant behavior and energy consumption of IT equipment. Analyzing the resulting data can help evaluating the occupancy behavior impact on energy saving. Two wireless sensor technologies were investigated to collect the required data and to build an occupancy behavior estimation profile: Ultra-Wideband Real-Time Location System for occupancy location monitoring and Zigbee wireless energy meters for monitoring the energy consumption of IT equipment. The estimated occupancy profile can be used to reduce energy consumption based on real-time occupants' information. In the future work, this profile can be used to proactively optimize the building energy consumption while responding to comfort preferences of the occupants and to support the implementation of demand-driven HVAC, lighting, and IT equipment operations.

Table 2: Time and KWh waste of energy.

	Occupant in office (min)				Occupant not in office (min)		Total time of waste of energy (min)	KWh of waste of energy
	Occupant in zone		Not in zone					
	Eq. ON	Eq. OFF	Eq. ON	Eq. OFF	Eq. ON	Eq. OFF		
Monitor	243	0	48	0	246	903	48+246=294	0.38
Computer	243	0	48	0	1149	0	1149+48=1197	6.58

ACKNOWLEDGEMENT

We would like to acknowledge the help of the students who participated in the data collection test performed in this research.

REFERENCES

Agarwal, Y., B. Balaji, R. Gupta, J. Lyles, M. Wei, and T. H. Weng. 2010. "Occupancy-Driven Energy Management for Smart Building Automation." In *Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 1-6. ACM.

Azar, E., and C. Menassa. 2011. "Agent-Based Modeling of Occupants' Impact on Energy Use in Commercial Buildings." *Computing in Civil Engineering* 26 (4): 506–518.

Barbato, A., L. Borsani, A. Capone, and S. Melzi. 2009. "Home Energy Saving through a User Profiling System based on Wireless Sensors." In *Proceedings of the 1st ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 49-54. ACM.

Conti, J., P. Holtberg, J. A. Beamon, S. Napolitano, A. M. Schaal, J. T. Turnure, and L. Westfall. 2013. "The International Energy Outlook. " Washington, DC: US Energy Information Administration.

Delaney, D. T., G. M. P. O'Hare, and A. G. Ruzzelli. 2009. "Evaluation of energy-efficiency in lighting systems using Sensor Networks." In *Proceedings of the 1st ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, 61-66. ACM.

Dong, B., and B. Andrews, 2009. "Sensor-Based Occupancy Behavioral Pattern Recognition for Energy and Comfort Management in Intelligent Buildings." In *Proceedings of the 11th International IBPSA Conference on Building Simulation*.

Erickson, V. L., M. Carreira-Perpinan, and A. E. Cerpa. 2010. "OBSERVE: Occupancy-Based System for Efficient Reduction of HVAC Energy for Efficient Reduction of HVAC Energy." In *Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 1-6.

Erickson, V. L., Y. Lin, A. Kamthe, B. Rohini, A. Surana, A. E. Cerpa, M. D. Sohn, and S. Narayanan. 2009. "Energy Efficient Building Environment Control Strategies Using Realtime Occupancy Measurements." In *Proceedings of the 1st ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in* Buildings, 19-24.

Harle, R. K., and A. Hopper. 2008. "The Potential for Location-Aware Power Management." In *Proceedings of the 10th International Conference on Ubiquitous Computing*, 302–311.

Kamthe, A., L. Jiang, M. Dudys, and A. Cerpa. 2009. "SCOPES: Smart Cameras Object Position." In *Proceedings of the 6th European Conference on Wireless Sensor Networks*, 279-295. Berlin: Springer-Verlag.

Li, S., N. Li, B. Becerik-Gerber, and G. Calis. 2011. "RFID-Based Occupancy Detection Solution for Optimizing HVAC Energy Consumption." In *Proceedings of the 28th International Association for Automation and Robotics in Construction Conference*, 587-592.

Martani, C. 2012. "ENERNET: Studying the dynamic relationship between building occupancy and energy consumption." *Energy and Buildings* 47: 584-591.

Menezes, A. C., A. Cripps, R. A Buswell, and D. Bouchlaghem. 2013. "Benchmarking Small Power Energy Consumption in Office Buildings in the United Kingdom: A Review of Data Published in CIBSE Guide F." *Building Services Engineering Research and Technology* 34(1): 73-86.

Newsham, G. R., and B. J. Birt. 2010. "Building-Level Occupancy Data to Improve ARIMA-Based Electricity Use Forecasts." In *Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 13-18.

Nguyen, T. A., and M. Aiello. 2013. "Energy Intelligent Buildings Based On User Activity: A survey." *Energy and Buildings* 56: 244-257.

Padmanabh, K., A. Malikarjuna, V. S. Sen, S. P. Katru, A. Kumar, S. P. C. S. K. Vuppala, and S. Paul. 2009. "iSense: A Wireless Sensor Network Based Conference Room Management System." In *Proceedings of the 1st ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 37-42.

Singh, V. 2011. "Analysis Methods for Post Occupancy Evaluation of Energy-Use in High Performance Buildings Using Short-Term Monitoring." PhD thesis. Arizona State University. Phoenix, Arizona.

Smartenit. 2013. Accessed November 7. http://simplehomenet.com.

Spataru, C., and M. Gillott. 2012. "Using a RTL System Based on RFID Technology for Monitoring Occupants Domestic Energy Use and Behaviour." In *Sustainability in Energy and Buildings*, edited by N. M'Sirdi, A. Namaane, R. J. Howlett, and L. C. Jain, 471-480.

Sun, Z., S. Wang, and Z. Ma. 2011. "In-Situ Implementation and Validation of a CO2 Based Adaptive Demand-Controlled Ventilation Strategy in a Multi-Zone Office Building." *Building and Environment* 46 (1): 124-133.

Tachwali, Y., H. Refai, and J. E. Fagan. 2007. "Minimizing HVAC Energy Consumption Using a Wireless Sensor Network." In *Proceedings of the 33rd Annual Conference of the IEEE Industrial Electronics Society*, 439-444.

Ubisense. 2013. Accessed November , 2013. http://www.ubisense.net.

Yang, Z., N. Li, B. Becerik-Gerber, and M. Orosz. 2012. "A Non-Intrusive Occupancy Monitoring System for Demand Driven HVAC Operations." In *Proceedings of the Construction Research Congress*, 828-837. West Lafayette: ASCE.

Yu, Z., B. C. M. Fung, F. Haghighat, H. Yoshino, and E. Morofsky. 2011. "A Systematic Procedure to Study the Influence of Occupant Behavior on Building Energy Consumption." *Energy and Buildi ngs* 43 (6): 1409–1417.

Zigbee Alliance. 2013. Accessed November , 2013. https://www.zigbee.org.

AUTHOR BIOGRAPHIES

NASSIM MASOUDIFAR is currently a second year Master of Science student in Building Engineering at Concordia University. Her current research topic is energy consumption reduction in existing buildings. Her email address is n_masoud@encs.concordia.ca.

AMIN HAMMAD is a Professor at the Concordia Institute for Information Systems Engineering. His research focuses on sustainable infrastructure lifecycle management systems and investigates several methods and techniques including spatio-temporal information modeling and analysis, simulation, visualization, optimization, wireless communications, sensing, auto-identification, and real-time location tracking. His email is hammad@ciise.concordia.ca.

MANDANA REZAEE is currently a second year Ph.D. student in Civil Engineering at Concordia University. Her current research involves methods to save energy in buildings. Her email address is m_rezaee@encs.concordia.ca.