

Indoor weather related to the energy consumption of air conditioned classroom: Monitoring system for energy efficient building plan

W Rattanongphisat^{1,2,4}, A Suwannakom¹ and A Harfield³

¹ Department of Physics, Faculty of Science, Naresuan University, Phitsanulok, Thailand

² Center of Excellence for Energy Technology and Environment, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand

³ Department of Computer Science and Information Technology, Faculty of Science, Naresuan University, Phitsanulok, Thailand

E-mail: warapomr@nu.ac.th

Abstract. The current research aims to investigate the relation of indoor weather to energy consumption of air conditioned classroom by design and construct the indoor weather and energy monitoring systems. In this research, a combined temperature and humidity sensor in conjunction with a microcontroller was constructed for the indoor weather monitoring system. The wire sensor network for the temperature-humidity sensor nodes is the Controller Area Network (CAN). Another part is using a nonintrusive method where a wireless current transformer sending the signal to the data collection box then transmitted by the radio frequency to the computer where the Ethernet application software was installed for the energy monitoring system. The results show that the setting air temperature, outdoor ambient temperature and operating time impact to the energy consumption of the air conditioned classroom.

1. Introduction

The record shows the increase of the global surface temperature of nearly 1°C during 1880-2010 [1]. Evidently, the increase of CO₂ level has shown that it is relevant to the climate change. The highest temperature in Thailand sets a new record this summer, April 2016, for 44.5 °C and other countries in Southeast Asia set similar new records. A significant impact of the indoor weather is the human comfort and because more than half of human activities take place in building thus affects to industrial, public sector and residential buildings. Air conditioning systems become necessary as can be seen by high demand in the market. Consequently, energy consumption rapidly increases. The measuring of energy consumption for educational buildings in Osaka City University found that the air conditioning system consumed nearly 60 per cent of the total building energy consumption [2]. In the view of building energy management, more data recorded would greatly contribute to the better energy analysis and control thus results in the energy efficient building [3]. Although, the two factors,

⁴ Address for correspondence: Department of Physics, Faculty of Science, Naresuan University, Phitsanulok, Thailand. Center of Excellence for Energy Technology and Environment, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand. Email: warapomr@nu.ac.th.



education and economic, are considered relevant to the pattern of energy use, it was found that those factors failed to change the customer behaviour for energy conservation. This reveals that social, personal and psychological are more relevant to customer habit pattern. The role of energy monitoring is significant to building energy planning and efficiency. A research reports on the possibility of reducing energy consumption in residential housing with the use of smart meters or advance metering infrastructure and community based social marketing [4]. It was reported that there was 20% peak demand reduction, 10% peak demand shifting and 10% average total energy use reduction from the household participating in the program. Another benefit of the monitoring system is that customers could see how rapid the energy consumption increase during different electrical appliances operation thus awareness has been raised. Other study showed an enhancement of energy efficiency in the Heating Ventilation and Air Conditioning system (HVAC) by the wireless technology [5]. The employment of wireless sensor network included temperature sensors, CO₂ sensors and webcam for controlling the HVAC suggested that the operation of HVAC during the occupation of the room show the wide range of energy reduction. An overview of data collection for building monitoring is reported [6]. Various approaches for energy efficient in air conditioning are summarized and reported [7]. Building energy management system is widely accepted that it could help deduct the energy consumption of the building. Particularly, the building energy management system involved with the heating, ventilation and air conditioning system (HVAC). Air conditioning system control temperature, part of air humidity and could integrate with air quality and circulation for a conditioned space. The level of awareness on building energy consumption and efficiency varies from one country to another country. Different building policies and measures were adopted as to promote building energy efficiency. Many countries achieved the energy reduction according to the analysis of official recorded data from the past to recent date. Building code and building labels and certifications are the two key parameters for the successful of the building energy efficiency [8]. The HVAC system consumes high energy thus requires first attention among the electrical appliances in building. Regarding the old and oversize system, high energy and cost were spent unnecessary. A proposal of zone operation was considered to solve or improve energy efficiency of central heating and cooling systems. The predicted mean vote index is an important key to indicate thermal comfort and use to control HVAC by developing Artificial Neural Network (ANN) model to indicate the suitable time for turning on and off [9].

In this paper, the indoor weather and energy monitoring system of an air conditioned classroom, at the Department of Physics, Naresuan University was designed and fabricated. A combined temperature and humidity sensor in conjunction with a microcontroller which connected through the Controller Area Network (CAN) was installed for the indoor weather monitoring system. A nonintrusive method using a wireless current transformer and Ethernet application software connection was employed for the energy monitoring system. The visualisation of the energy consumption as well as the indoor temperature and humidity and how they related to the occupant use of energy. That could raise the occupancy awareness. Furthermore, the data analysis could be further used for the energy efficient building planning.

2. Methodology

The two monitoring systems were designed and constructed for monitoring the indoor weather and energy consumption of air conditioned classroom. The dimension of the auditorium classroom is 15.3×19×5.5 m³. The function of this classroom includes lecturing, seminar, student camp meeting and scientific movie show. In the current test of the monitoring system, the lecture and seminar are the main activity considered.

2.1. Indoor weather monitoring system

A 172-seat air conditioned classroom was selected to investigate the relation of indoor weather to energy consumption. The HIH6131 temperature-humidity sensors in conjunction with STM32F072CBT6 microcontroller connected through the Controller Area Network (CAN) for the

indoor weather monitoring system. The specification of a combined temperature-humidity sensor is shown in table 1 as well as the equation for this sensor written in equation (1) and (2) [10]. The integrated temperature and humidity sensors are installed at various positions in the classroom as can be seen in figure 1. The data from the sensors communicate with microcontroller and the Controller Area Network then transfer via wireless router thru the internet network for collecting and showing on the computer screen in real time.

$$\text{Humidity (\%RH)} = ((\text{Humidity 14 bit ADC output}) / (2^{14} - 2)) \times 100 \quad (1)$$

$$\text{Temperature (C}^\circ\text{)} = ((\text{Temperature 14 bit ADC output}) / (2^{14} - 2)) \times 165 - 40 \quad (2)$$

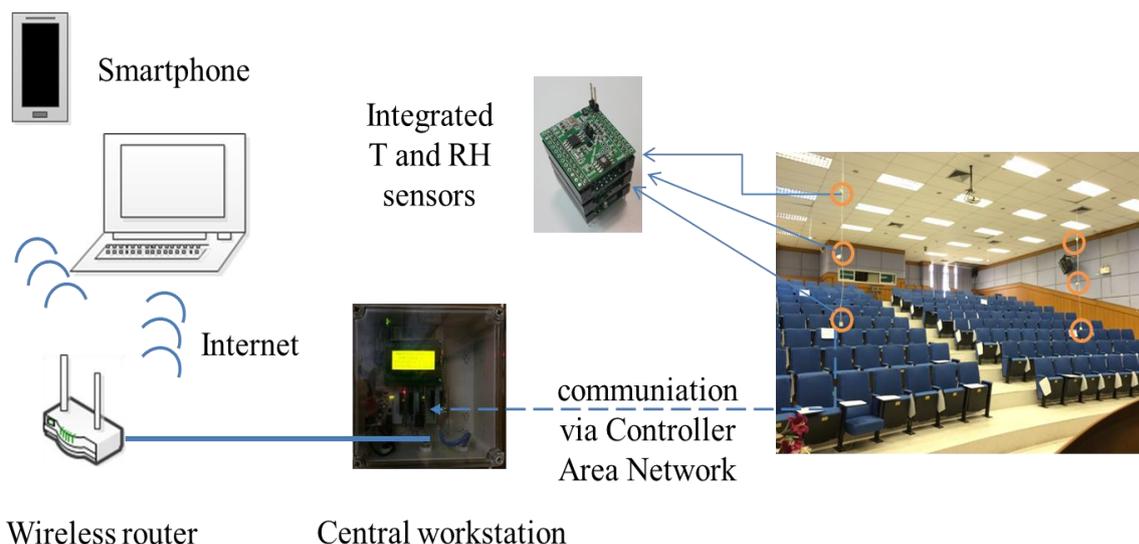


Figure 1. The indoor weather monitoring system for an air conditioned classroom.

Table 1. Specification of combined humidity and temperature sensors [10].

Criteria		Specification
Voltage		2.3 – 5.5 Vdc
Current	Sleep mode	1 μ A
	Full operation mode	650 μ A
Measurement	Time	50 ms
	Range	5 $^\circ$ C – 50 $^\circ$ C
Temperature	Accuracy	\pm 0.5 $^\circ$ C
Humidity	Range	10 - 90 %RH
Humidity	Accuracy	\pm 4% RH

2.2. Energy monitoring system

An auditorium classroom equipped with an individual air conditioner was selected to demonstrate the energy monitoring system. The air conditioner is TRANE model no. TTV 250 AD11A0A00A, fan motor 3.7kW using R-22 refrigerant. The energy monitoring system incorporates with the wireless current (CT) sensors, CT1 56/3000 from Midori Co.Ltd., and operating software for power and energy display were installed at the demonstrating room and monitoring room respectively as shown in figure 2. The data are stored in a cloud system. The smart CT sensors clamp around the electric cable in the electric control box as to measure the power consumed by the air conditioner. Three CT sensors were used to measure the current of the 3-phase 4 wires power line. Data then send to the collection terminal box wirelessly and through the laptop computer for real-time monitoring. The SMV Ethernet

program developed by Midori company was installed and used for displaying the real-time power and energy consumption daily.

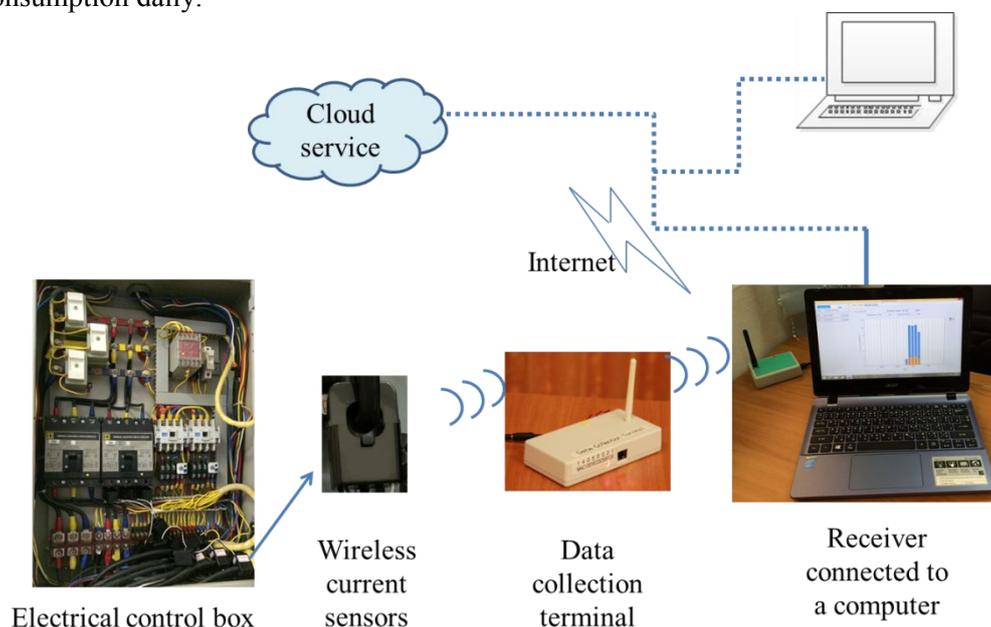


Figure 2. Energy monitoring system.

3. Results and Discussion

Figure 3 shows the period where the teaching class and seminar were took place in the classroom during the weekday. From Monday to Friday, it can be observed that heavy use was on Monday, Thursday, Tuesday and Wednesday respectively while less activities is on Friday. Although, the time table is fixed for this classroom during the semester, the room may be booked for other activities such as student science camp, student meeting and special lecture from an invited speaker. In that case, the daily load profile of the air conditioned classroom can be different from what is shown in figure 3. The energy monitoring data collection can be used to analyse the pattern of energy utilization and also suggested the efficient use of the demonstrated classroom.

The alternating current measurement using wireless smart current sensors and calculation procedure in the software developed by Midori company for power and energy consumption analysis were calibrated with the measurement from a Yogokawa power meter. The test were carried out during term time from September to December 2015. The data analysis reveals that the ambient temperature does relate to the temperature setting of the air conditioner and results in the amount of consumed electricity. The different between the outside and inside temperature show the altered requirement of energy which can be seen in figure 4. The analysis on the past year recorded data, the ambient temperature and humidity taken from the meteorological station in Phitsanulok province, can be seen from figure 5 and figure 6. The pattern of environmental ambient temperature and relative humidity shows that the temperature is quite high throughout the year as well as relative humidity. Thus, it can be seen from the results that the energy consumption tends to be increased when the gap between the average ambient and room temperature is higher. Another point is that the compressor running time is definitely correlated to the energy consumption when the average room temperature reached the setting point then the fan is only operated thus during this period the lower energy consumption can be observed. Prior study by the authors suggested the improvement of energy efficient use for this air conditioned classroom can be found when the temperature set point of an air

conditioning system increase by 1-2°C as to reach the thermal comfort of people who lives in hot and humid climate.

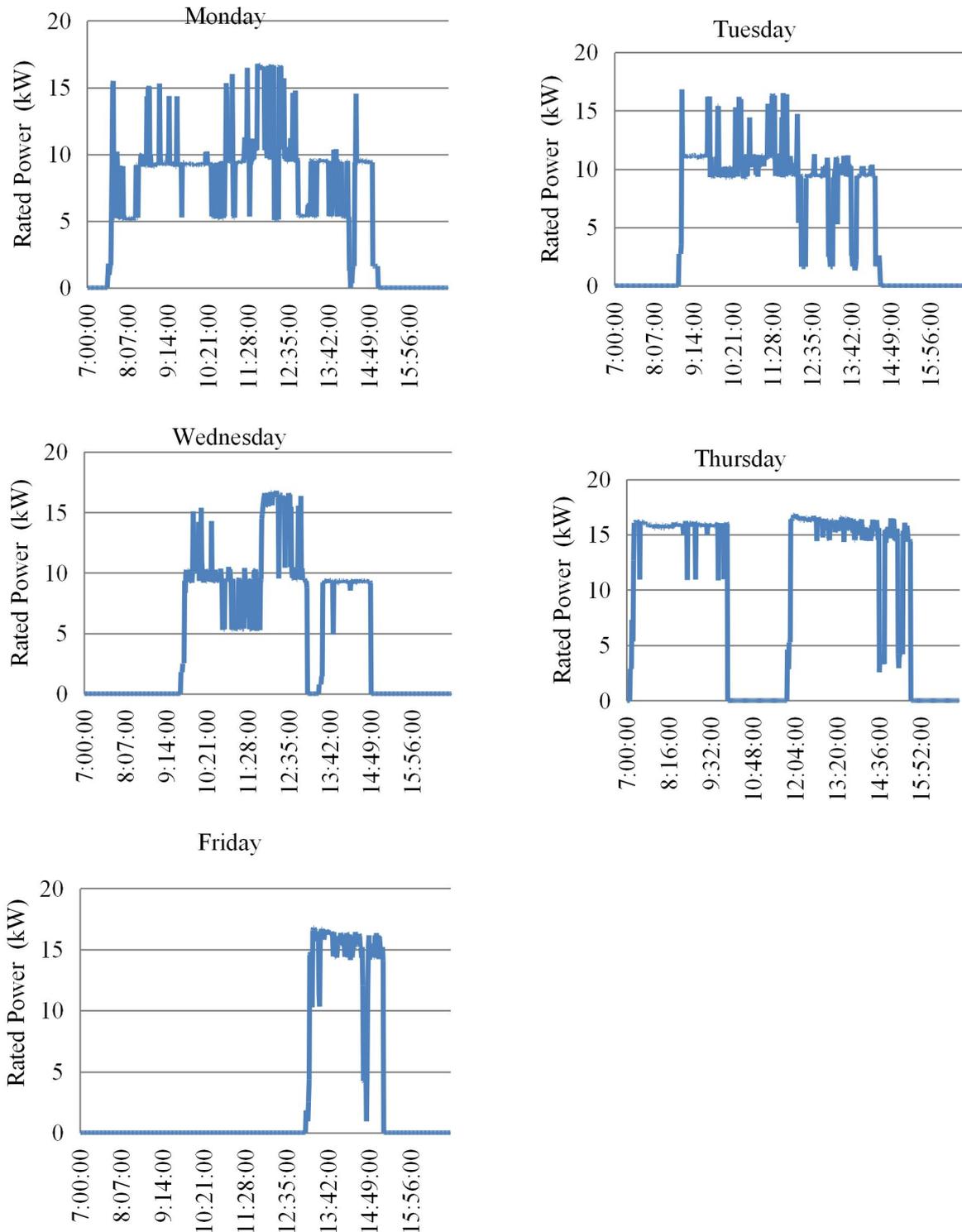


Figure 3. Rated power during weekday

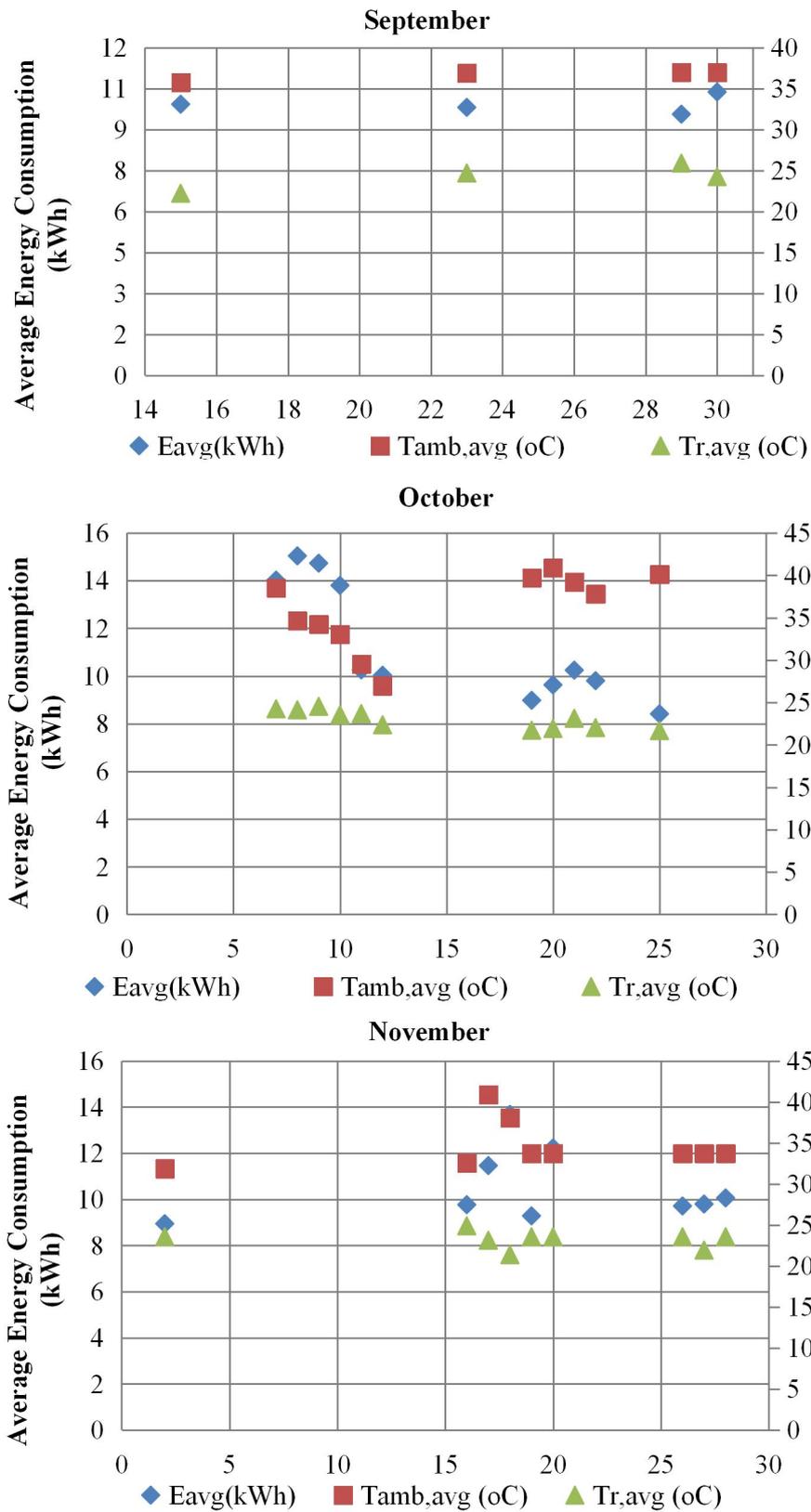


Figure 4. Energy consumption versus temperature during term time.

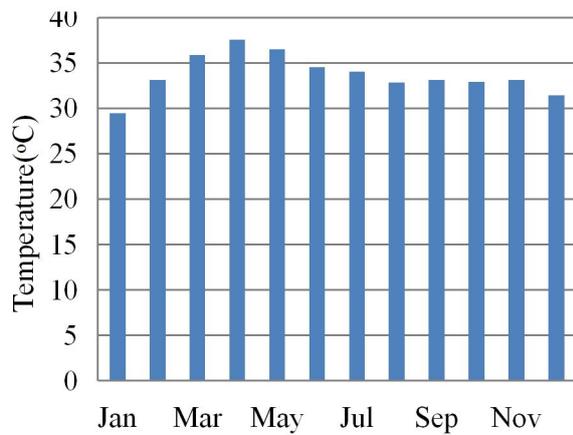


Figure 5. The average maximum temperature at Phitsanulok province in the past year.

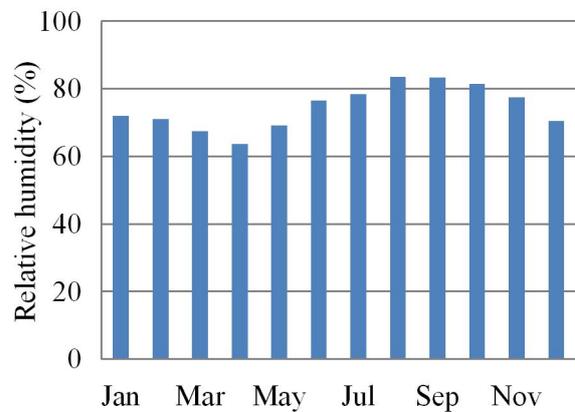


Figure 6. The monthly average relative humidity at Phitsanulok province in the past year.

The measuring power results in the average hourly energy consumption during the first semester last for 4 months from September to December 2015 is shown in figure 7. The rated energy consumption within an hour use of air conditioner varies from the minimum of 8kWh to the maximum of 15 kWh depended on the outdoor weather.

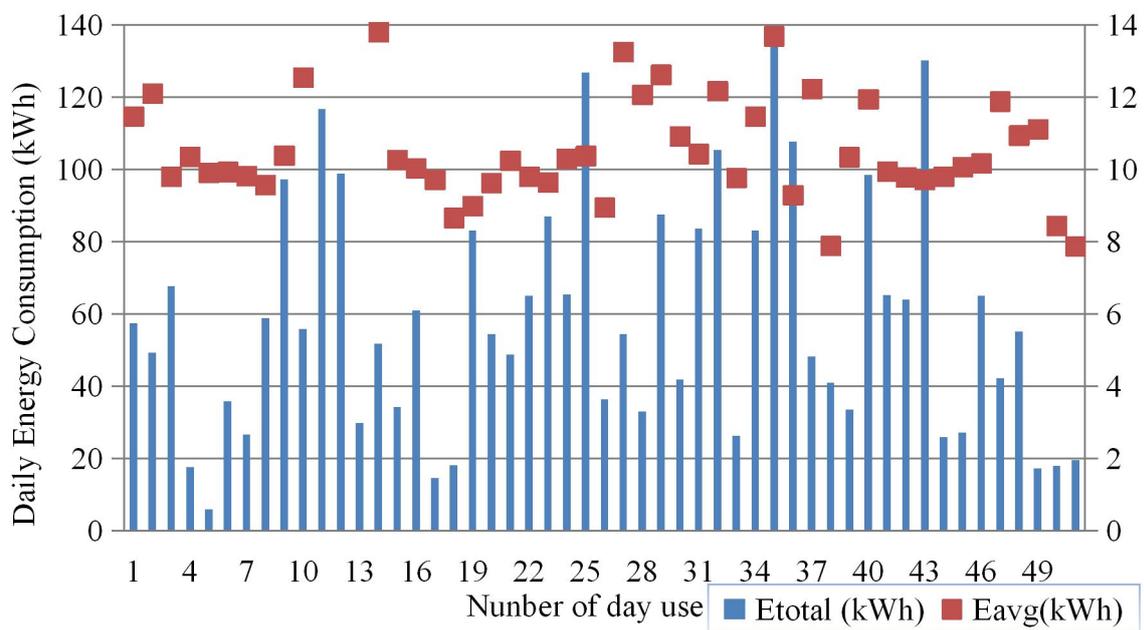


Figure 7. Energy consumption during the term time from September to December 2015.

Considering the applications of the monitoring system, an air conditioned space for various activities from low activities such a residence to high activities such an indoor gym can be beneficial by closely monitoring the real time rated power. It can be used to adjust the appropriate temperature setting on the HVAC system to reduce the energy consumption. Furthermore, the data obtained from monitoring can assist in efficient energy utilization planning (by setting usage policies). Although, the temperature - humidity sensors are cheap, the controller network is relatively expensive. However, the

sharing of the controller network for several air conditioned room or for the large and high energy consumption air conditioned room could be considered to receive high profit.

4. Conclusions

The average energy consumption of the air conditioning system is 10.30 kWh which ranges from minimum to maximum of 8 and 15 kWh. The results showed the relation of indoor weather and energy consumption as well as understanding the characteristic of energy consumption by the air conditioner in the educational building. The data analysis can be used to plan for the energy efficient building by cutting down the energy use. The energy can be monthly saved for 206 kWh by switching off during noon for only one hour when the room is unoccupied. Further study will need to be carried out on the reduction of energy consumption by increase the temperature set point combined with some ventilation strategies.

Acknowledgments

This research project was financial supported by Naresuan University under the project code R2558B010. Highly thanks to Midori Co.Ltd. for supporting the smart sensors and operating software. Special thanks to Prof. K Tanaka for technical suggestion and Mr. O Hanaoka for the CT sensor technical support. Further thanks to our students in the Energy Technologies Building Laboratory, ARM Laboratory and Mobile Computing Lab for their assistant in the lab.

References

- [1] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151
- [2] Yuan J, Farnham C, Emura K 2015 Development and application of a simple BEMS to measure energy consumption of buildings *Energ Buildings* **109** 1–11
- [3] Levermore G J 1992 Building energy management systems: an application to heating and control London : E & FN SPON, 275-315
- [4] Anda M, Temmen J 2014 Smart metering for residential energy efficiency: The use of community based social marketing for behavioural change and smart grid introduction. *Renew Energ* **67** 119-27
- [5] Leavey A Fu Y Sha M Kutta A Lu C Wang W Drake B Chen Y Biswas P 2015 Air quality metrics and wireless technology to maximize the energy efficiency of HVAC in a working auditorium *Build Environ* **85** 287 –97
- [6] Guerra-Santin O Tweed CA 2015 In-use monitoring of buildings: An overview of data collection methods *Energ Buildings* **93** 189–207
- [7] Chua K J Chou S K Yang WM Yan J 2013 Achieving better energy-efficient air conditioning – A review of technologies and strategies *Appl Energ* **104** 87–104
- [8] Allouhi A, Fouih Y El, Kousksou T, Jamil A, Zeraouli Y, Mourad Y 2015 Energy consumption and efficiency in buildings: current status and future trends *J Clean Prod* **109** 118-130
- [9] Garniera A, Eynardb J, Caussanel M, Grieu S 2015 Predictive control of multizone heating, ventilation and air-conditioning systems in non-residential buildings *Appl Soft Comput* **37** 847–62
- [10] Honeywell Humidicon Datasheet <http://sensing.honeywell.com/honeywell-sensing-humidicon-hih6100-series-product-sheet-009059-6-en.pdf>