Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2850 – 2858

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Energy Savings by Fuzzy Base Control of Occupancy Concentration in Institutional Buildings

Yazeed Yasin Ghadi*[a], M.G. Rasul[a], M.M.K. Khan[a]*

[a]*Central Queensland University, Bruce Highway, Rockhampton, 4702, Queensland, Australia*

Abstract

As a part of global efforts to minimize reliance of fossil fuel and in order to minimize greenhouse gas emissions, smart buildings become a part of the solution as it is able to utilize real life events such as daylight, the usage of ambient air and it also is able to perform a head count and then adjust accordingly the heating ventilation and air conditioning HVAC system and the lighting system as well. Consequently this paper analyzes and presents the effect of building occupancy concentration on total electric energy demand. The case study was performed at Building 19 of Rockhampton campus of Central Queensland University using EnergyPlus simulation engine. Results indicated that energy savings of about 24% can be achieved at 25% occupancy level and 14% at 50% occupancy concentration using fuzzy based control system.

Keywords: HVAC, Occupancy level, HVAC, Head count

1. Introduction

Australian building sectors are gaining momentum due to Australia strong economy and the country's political stability. The rapid growth in buildings affected Australia energy consumption. According to Green Building Council [1]: Australian building sector represents near 20 % of the country's total energy usage which is responsible for approximately 23% of Australian total Greenhouse gas emission (GHG). In addition, commercial buildings represent nearly 50% of the current amount at 10% of the country's total energy usage, whereas institutional buildings represents nearly 25% of total energy consumption [2]. Buildings' energy consumption is resulted from combustion of fossil fuel in order to generate electricity to power buildings' facilities, interfaces and systems such as heating, ventilation and air-conditioning (HVAC), electro-mechanical lifts and elevators and buildings' lighting system. Taking into account that

---

* Corresponding author. Tel.: +61434724265; fax: +0-000-000-0000 .
E-mail address: y.ghadi@cqu.edu.au.

doi:10.1016/j.egypro.2017.03.628

Australian electricity considered the biggest energy source within commercial buildings which accounts for nearly 65% of the building's total energy next to gas which represents 25% of this total, followed by petroleum products at 7% and last is coal at 3% [3]. According to Shan et al. [4], in institutional buildings 40% of total energy consumption comes from HVAC and 28% of energy consumption comes from lighting. Thus Improving buildings' energy performance in Institutional buildings is a major objective for researchers in order to reduce energy bill and to reduce also greenhouse gas emissions (GHG) due to a high potential to reduce their energy consumption by 6%-29% using unconventional control systems such as Fuzzy based control system which is able to consider real life events such as introducing daylight to the institutional buildings, using ambient air, and occupancy density [5, 6].

Building energy efficiency advancements deliver a high prospect for building owners and developers to minimize buildings' operation cost, as well as increasing the value of buildings' asset. Smart buildings nowa days become a prospect of the coming generation of buildings, which powered by intelligent control system based on real time events to assure accurate and efficient energy system. Currently, the idea of smart buildings has been a major topic between researchers, design engineers and stake holders and also it introduced and discussed different research topics in various numbers of literatures.

Numerous attempts have been made in order to develop advanced and innovative fuzzy based control system and technology in the field of smart buildings. Examples of these efforts are: Robol et al. [7] have proposed control strategy in order to estimate and project indoor thermal comfort based on wireless sensor networks, Yao et al. [8] also have developed a control mechanism for indoor thermal management system within smart buildings based on predictive power admission control. In addition Liu et al. [9] have designed and installed a fuzzy logic controller in order to reduce energy consumed by light by introducing day light into a building. In regards to buildings' occupancy density, Ioannou and Itard [10] have presented the results of a research study in Monte Carlo sensitivity by analysing factors relating to building occupant's behaviour that affects the annual heating energy consumption. Furthermore, Yang et al [11] have presented a detailed study of buildings energy consumption profile of three institutional buildings in Singapore based on buildings' occupancy density.

However, in Australia there is a lack of research activity concerning buildings' occupancy density. An example of this, very few studies [12] have reviewed a detailed study concerning about energy efficient buildings via retrofitting of existing buildings. Huang et al. [13] also have presented a review on energy and carbon performance evaluation for buildings and urban precincts which was focused on this technique. Hence this research article analyses and investigates the affect institutional buildings' occupants' density have on the buildings' total energy consumption including the effects on HVAC system and lighting system under Australian subtropical climate.

Institutional buildings classic design generally, assumes that all classes, rooms, laboratories and hall ways are fully occupied specially during working hours. Thus, this is not the case; the previously mentioned spaces within institutional buildings are often left empty or partially occupied during working hours. Based on the previous fact it will be more energy efficient if the control system (BMS) considers only occupied rooms to switch on HVAC and lighting and turn off all unoccupied rooms. Consequently, knowing of occupancy level/concentration in buildings are very important in order to increase buildings' energy efficiency. In case of knowing buildings occupancy level, certain strategies can be applied in order to operate HVAC and lighting system optimally. The lack of efficient sensors in order to obtain occupancy data makes the control strategy based on occupancy density is very difficult to approach. In modern buildings motion detectors deliver an accurate method to sense occupancy and perform head count but they do not provide in which part of the building they go since their output is a binary process [14]. Having the ability to project occupants' motion and the space usage configurations prove to be the main tool for demand control ventilation (DCV). Occupancy count can be done by modelling footsteps of occupancy where data is taken using sensors, which helps attenuate lighting and HVAC control system pattern as building usage patterns varies with time.

This paper presents a simulation study of the effect of occupancy level on energy usage pattern of Building 19 at Rockhampton campus of Central Queensland University, Queensland, Australia. The study was based on simulation using EnergyPlus simulation engine and enhanced by the building's profile such as building's floorplan, number of occupants who use the building during working hours, real energy demand, HVAC system, lighting system and etc. The occupant projection is performed by the simulation engine which was able to generate a random number of occupants based on information has been provided by the university's facilities management team.

2. Occupants' Density Effects on Lighting and HVAC System Operation

Head count or occupancy density affects the operation of lighting system, and HVAC system. This section describes the methodology for valuing activity wise energy consumption. The inputs of the controller come from the random number generator based on the infrastructure details and operational pattern. Results are presented on normal operation hours (8 AM to 5 PM).

2.1 Lighting load

The optimal situation could be to install a sub main meters to measure lighting energy at each floor every. In practice this facility does not exist and the most of buildings uses an estimation model to evaluate lighting energy in the absence of actual data loggers. The building's spaces are categorized into different zones. The designed lighting watts/m^2 for these zones as provided form the university's department of facility management taking into account that, dimensional change in the count and lightings' fixture power rating, available watts/m^2 is different from original design watts/m^2. Energy consumed by lighting system is calculated using equation 1 [15].

$$E_{light} = \sum_{n=1}^{N}\sum_{i=1}^{I} U_{in} W_i A_i h_n$$

Where N is the number if zones, U is lighting utilization factor, W_i is designed watt/m^2 of zone I, A is total flor area and h is working hours.

On this study samples were taken based on duration of usage at 3-5 hours of usage instead of 9 the normal working hours in order to estimate energy used by lighting system which was calculated for the sampling duration based on equation 1.

2.2 Cooling load

The building space is cooled centrally using a chiller with air handling units have been installed in different zones. It would be perfect if energy loggers were installed to determine the cooling system energy demand. Consequently estimation models are essential to compute the amount of used energy based on heat gain equations [15]. Heat gain or what is known as cooling load of conditioned space can be projected based on heat gain equations. The total cooling load (Q_{tot}) is the sum of internal cooling load and external cooling load [16]. Internal cooling load is a result of occupants' density, lighting system and equipment such as computers. While the main contributors of external cooling load are ventilation, infiltration, conduction and radiation. The internal cooling load can be calculated using equation 2 while the external cooling load can be calculated using equation (3).

$$Q_i = \left(\sum_{n=1}^{N} \sum_{i=1}^{I} U_{in} W_t A_i h_n \right) * 1.2 + \sum_{n=1}^{N} \sum_{d=1}^{D} U_{dn} P_d C_d h_n + \sum 0.15 * H_a h_n \qquad 2$$

$$Q_e = \sum_{1}^{N} h_n \left(Q_v + Q_i + Q_c + Q_r \right)$$

Where Ha is number of occupants, 1.2 is a multiplication factor for ballast losses [17], D is the number of equipment (PC's) U_{dn} is utilization of equipment of sample d and period n, P_d is the power consumed by devise d and C_d is number if occupants using devises and H_a is head count.

While $Q_e = \sum_{1}^{N} h_n \left(Q_v + Q_i + Q_c + Q_r \right)$ 3

Where Q_e is external heat gain Q_v is ventilation energy, Q_i is infiltration heat gain Q_c is conductive heat gain and Q_r is radiant heat transfer

3. Occupants Variation Pattern and System Control

The control strategy will start with basic gathered data analysis which was based on collecting and then assessing reasonable ranges of occupants' density in order to build a model parameters by identifying the main model parameters which represents building's occupants profile [18]. System analysis was performed using EnergyPlus simulation tool [19]. Randomly generated lists of occupants' activity inputs were created containing a detailed list of equipment such PC's and temperature and humidity set points.

The average values for occupancy pattern were created through a review of Department of Energy (DOE) building energy efficiency code (Title 24) as it specifies occupants' activity and behaviour [20]. Furthermore, the inputs have been categorised into low (25% of occupancy), medium (50% of occupancy) and high ranges (near 100% of occupancy) of head counts compared to any regular institutional building's occupancy profile.

The previous technique will identify ranges of data that are intended to represent accurate and reasonable estimations of classic occupant behaviour and activity level such as variation of temperature and relative humidity settings, windows' opening, number of occupied class rooms and etc. Operation schedules were defined to the model according to regular operation variation in institutional buildings' normal working hours as shown in Table 1which defines the schedules that are used to model occupants' activity and Table 2 which defines loads that are affected by the activity level caused by the presence of occupants taking into account all receptacle outlets and plugged-in load are ignored.

Table 1. Occupants and occupants' activity schedule

EnergyPlus Parameters	Description	Ranges
Lighting schedule	Hours of operation	Low: less than, 5 hours/day, 10 month a year. Medium: 5-7 hours/day, 10 month a year. High: Full-day, 12 hours/day 10 month a year.
Equipment schedule	Hours of operation (plug load usage)	Low: less than, 5 hours/day, 10 month a year. Medium: 5-7 hours/day, 10 month a year. High: Full-day, 12 hours/day 10 month a year.
People schedule	Occupants density (ratio of head counted population to maximum occupants)	Low: less than, 50% of total occupants, 10 month a year. Medium: 50% of total occupants, 10 month a year. High: less than 100%-50% of total occupants 10 month a year.

Table 2. Building load

EnergyPlus Parameters	Description	Ranges
Temperature set point	Temperature set points 20-22 C° in winter and 25-27 C° in summer	Low: 20 - 22 C° Medium: 22-24 C° High: 24-27 C°
Relative Humidity set point	Relative Humidity set point ranging from 40-70%	Low: 40-50% Medium: 50-60 % High: 60-70%
Occupant density	Occupant density- person /m^2 .	Low: 20 people/ 100 m^2 Medium: 40 people/ 100 m^2 High: 70 people/ 100 m^2
Occupants heat gain	Sensible and Latent heat gain- change caused by each occupants	Low: 32 kWh/ per person/hr Medium: 70 kWh/ per person/hr High: 170 kWh/ per person/hr
Infiltration and ventilation	Ventilation rate and openings infiltration	Low: 0.15 CFM/head Medium: 0.38 CFM/head High: .75 CFM/head
Lighting and solar irradiance heat gain	Sensible heat gain- change caused by lighting system and solar irradiance measured each class per hour	Low: 100 kWh/ per class/hr Medium: 150 kWh/ per class/hr High: 200 kWh/ per class/hr

4. Results and Discussions

The proposed control system has been considered for Building No. 19 at the Rockhampton campus of Central Queensland University as shown in Figure 1. In this research the analyzed simulation results cover from the beginning of January 2014 till the end of December 2015.

Figure. 1. Building no 19; at Rockhampton Campus of CQUniversity.

The system simulation engine calculated the HVAC and lighting system energy demand, taking into account occupants' density variation. Anadd on fuzzy based -PID controller is reprogrammed in order to perform this calculation. The fuzzy based controller inputs are *eR* and the error changing *ΔeR* which represents the difference between buildings past occupant and building's current occupant. In addition, the membership functions of the add on fuzzy based -PID controller's input and output are presented in Figure 2. The controllers' inputs and outputs contain the following values:
Negative High (NH), Negative Medium (NM), Negative Low (NL), Zero (Z), Positive Low (PS), Positive Medium (PM) and Positive High (PH).as shown in Table 3. The output of add on fuzzy based -PID controller is the essential power change based on occupancy level which required to maintains indoor thermal and visual comfort level.

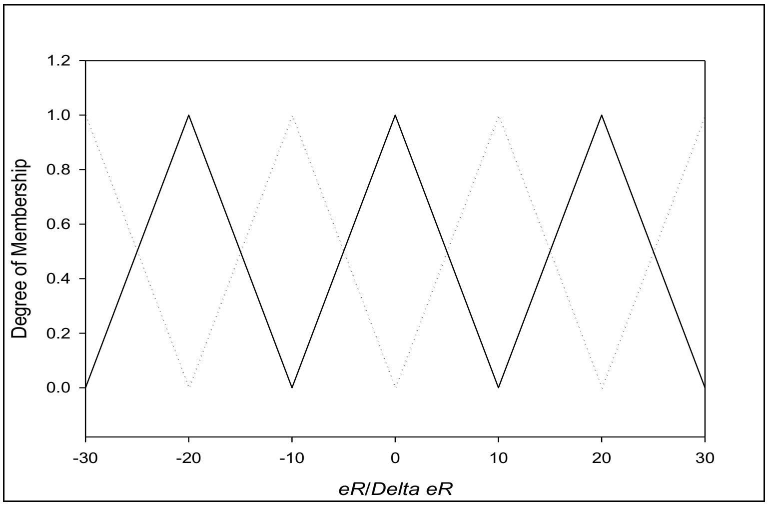

Figure 2. Membership functions of various occupancy levels

Table 3. Fuzzy control rules for local various occupancy levels

Required change in energy		eR						
		NH	NM	NL	Z	PL	PM	PL
ΔeR	NH	NH	NH	PH	PH	PH	PH	PH
	NM	NH	NM	Z	PM	PM	PH	PH
	NL	NH	NM	NH	PH	PM	PH	PH
	Z	NH	NM	NH	Z	PL	PM	PH
	PL	NH	NH	NM	NH	PL	PM	PH
	PM	NH	NH	NM	NM	ZE	PM	PH
	PL	NH	NH	NH	NH	NH	PH	PH

Figure 3, shows that, the building total electric load during the year was 643572 kWh. During the season of high demand for cooling which occurs from January to April and September to December, the building maximum electric load was during the month of March at 68350 kWh followed by the months of February at 65139 kWh, then the month of April at 61920 kWh. During winter season where is the demand on air HVAC is minimum which occur, the minimum electric load was in the month of June at 42688 kWh followed by the months of July at 45013 kWh and the month of August at 48000 kWh respectively.

Figure 3 also, shows that, the building total electric load at 50% occupants rate, the total electric demand during the year droped from 643,572 kWh to 55,316 kWh which indicates an energy saving at 14% rate. It was observed that, the highest energy savings was in the month of December at 39,524 kWh which equal to 38% of energy savings at this month, followed by the month of March, then May, November followed by the month of October at 24%, 20%, 20% of energy savings respectively. The reason behind December has the highest energy savings due to the holidays season (Christmas and the new-year holidays). The least month of energy savings was in September where the start of the academic calendar.

A similar scenario was performed at 25% of occupancy rate as similar results were noted. The total annual load was 468432 kWh which account for 24% of total electric demand (at full occupancy level). The month of December results was still at the top due to the holiday's season at 41882 kWh and the least savings was in the month of March which accounted for 22% energy savings compared to the full occupancy rate.

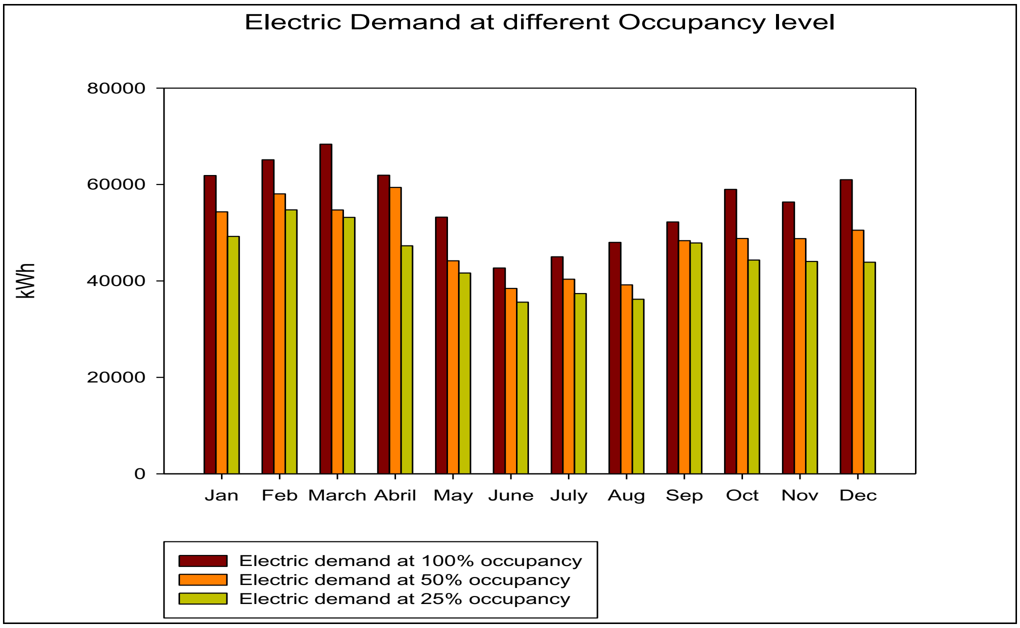

Figure 3. Building 19 total electric load at different occupancy level

5. Conclusions

In this article, the effect of Building 19 at Rockhampton campus of Central Queensland University, Queensland, Australia has been investigated based on simulated engine EnergyPlus. The examined parameters in this study were focused on occupancy density effect on HVAC and Lighting system energy demand. Selected data sets of occupancy pattern profile were selected based on; full occupancy level 100%, 50%, and 25% of full occupancy level. Results showed that considering occupancy level, building's control system will save 14% of total energy demand at 50 % of occupancy level compared to total energy demand at full occupancy level (100% occupancy level) and also it is able to save 24% of total energy demand at 25 % of occupancy level compared to full occupancy level energy demand (100% occupancy level). The results proof that smart buildings and buildings' intelligent control systems are able to save energy by applying a set of rules which are based on real life events such as the usage of daylight, weather data, sun radiation, occupant's density and etc.

References

[1] Grean Building Council, A. Mid-tier Commercial Office Buildings Sector Report_FINAL. 2016 [cited 2016 23/07]; Available from: https://www.gbca.org.au/uploads/97/36449/Mid-tier%20Commercial%20Office%20Buildings%20Sector%20Report_FINAL.pdf.

[2] Australian government, D.o.I., Innovation and Scienc. . Commercial Buildings Baseline Study. 2016 [cited 2016 23/07]; Available from: http://www.industry.gov.au/ENERGY/ENERGYEFFICIENCY/NON-RESIDENTIALBUILDINGS/Pages/CommercialBuildingsBaselineStudy.aspx.

[3] Foran, T., et al., Understanding energy-related regimes: A participatory approach from central Australia. Energy Policy, 2016. 91: p. 315-324.

[4] Shan, K., et al., Building demand response and control methods for smart grids: A review. Science and Technology for the Built Environment, 2016(just-accepted): p. 00-00.

[5] Guan, J., N. Nord, and S. Chen, Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study. Energy and Buildings, 2016. 124: p. 99-111.

[6] Deb, C., et al., Forecasting diurnal cooling energy load for institutional buildings using Artificial Neural Networks. Energy and Buildings, 2016. 121: p. 284-297.

[7] Robol, F., et al. Wireless sensors for distributed monitoring of energy-efficient smart buildings. in Microwave Symposium (MMS), 2015 IEEE 15th Mediterranean. 2015. IEEE.

[8] Yao, J., et al., Power admission control with predictive thermal management in smart buildings. IEEE Transactions on Industrial Electronics, 2015. 62(4): p. 2642-2650.

[9] Liu, J., et al., Fuzzy logic controller for energy savings in a smart LED lighting system considering lighting comfort and daylight. Energy and Buildings, 2016. 127: p. 95-104.

[10]Ioannou, A. and L. Itard, Energy performance and comfort in residential buildings: Sensitivity for building parameters and occupancy. Energy and Buildings, 2015. 92: p. 216-233.

[11]Yang, J., et al., Energy performance model development and occupancy number identification of institutional buildings. Energy and Buildings, 2016. 123: p. 192-204.

[12]Zhou, Z., et al., Achieving energy efficient buildings via retrofitting of existing buildings: a case study. Journal of Cleaner Production, 2016. 112: p. 3605-3615.

[13]Huang, B., K. Xing, and S. Pullen, Energy and carbon performance evaluation for buildings and urban precincts: review and a new modelling concept. Journal of Cleaner Production, 2015.

[14]Erickson, V.L., et al. Energy efficient building environment control strategies using real-time occupancy measurements. in Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings. 2009. ACM.

[15]Ramasubramanian, S., et al. An activity based approach to minimize energy usage of service sector infrastructure. in Infrastructure Systems and Services: Developing 21st Century Infrastructure Networks,(INFRA), 2009 Second International Conference on, IEEE. 2009.

[16]Yang, H., J. Burnett, and J. Ji, Simple approach to cooling load component calculation through PV walls. Energy and Buildings, 2000. 31(3): p. 285-290.

[17]Chirarattananon, S. and J. Taweekun, A technical review of energy conservation programs for commercial and government buildings in Thailand. Energy Conversion and Management, 2003. 44(5): p. 743-762.

[18]De Wit, M., et al., Sensor, a population-based cohort study on gastroenteritis in the Netherlands: incidence and etiology. American journal of epidemiology, 2001. 154(7): p. 666-674.

[19]EnergyPlus. EnergyPlus. 2016 [cited 2016 24/07]; Available from: https://energyplus.net/.

[20]Huang, J., et al., Using EnergyPlus for California title-24 compliance calculations. Lawrence Berkeley National Laboratory, 2006.