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Energy Performance of Fuzzy Logic Controllers in Smart Buildings

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ABSTRACT

This article presents simulation study on using fuzzy logic based controllers in order to determine building's occupancy level and hence its effect on energy usage. The projected results of energy savings then is used to determine and investigate the proposed fuzzy logic based control system environmental and economic aspects. The proposed system energy performance are measured based on the system occupancy density level, daylight utilization and natural ambient air and humidity. The simulation and modelling engines used in this article are MATLAB and energy plus. Results showed that 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).

Keywords: Daylight, Occupancy Level, Fuzzy Logic
JEL Classifications: K32, O13

1. INTRODUCTION

The commercial buildings sector in Australian use a significant quantity of energy which normally leads to negative influence on the environment including significant greenhouse gas emissions and production of non-environmental materials. The building sector today consumes 40% of the world's total fossil fuel energy (Eicker and Pietruschka, 2009). Additionally, the Australian commercial buildings consume about 61% of total energy use by the buildings sector (Deuble and de Dear, 2012). Moreover Australian commercial buildings' greenhouse gas emissions have grown by 87% between the year 1990 and 2010 (The Australian Government, 2010). The building sector is also responsible for nearly 27% of the country's total greenhouse gas emissions and that includes commercial buildings that accounted for 10% of the country's total greenhouse gas emissions (Soni et al., 2016).

In last 5 decades, there are countless researches activity have been carried out regarding the enhancement of building management system in effort to achieve a very effective solutions and means to overcome high energy demand while keeping effective building operation, services and normal working hours. At the starting of the researching work concerning the buildings industry signs of fast development powered by the high growth and improvement of micro-computers, controllers and subsequent personal computer (PC) (Salami et al., 2011; Chua et al., 2013b). Consequently, most of control strategies are ranging from pneumatic to conventional digitally based controller. The existence and improvement of direct digital controller led to the way how recent building is controlled and managed. Its increasing effectiveness and capability to embed real-time controller has sparked a significant range of control strategies. The wide range readiness of open regular communication protocol has elevated the building management and control system to high accuracy and elevated level of automation. This fact allows the installation of more accurate and the control system of high-tech building (Agency, 2016).

Subsequently, efforts move further until the realization of embedding ‘intelligence’ into building management and automation system can be achieved. The development of intelligent building management and automation system (IBMAS) has been motivated by today’s challenges including the continuous increase of organizational complexity, economic activities, oil price, comfort demand, device retrofits and the list could continue. Consequently, many researchers took part in an innovative design of IBMAS that able to deliver alternative solution to some of the previously mentioned issues. In addition high level of contribution in IBMAS industry which can be credited back to the past decade, there are still a big place of improvements that can be added. Heating, ventilation, air conditioning (HVAC) systems controller and microcontrollers are important examples because HVAC systems are purely nonlinear in their operation. Consequently, this research project will investigate, design, evaluate and develop the use of fuzzy logic based controllers for buildings HVAC system and light control (Atmaca and Atmaca, 2016).

In Australian subtropical regions, demand on HVAC is rising which leads to more electricity consumption. Smart buildings and buildings’ intelligent control systems have the ability to save energy by applying a set of rules which are based on real life events such as weather data, sun radiation, occupant’s density and etc. Further study is thus necessary for designing an advanced fuzzy logic controllers for smart buildings in subtropical climate which will be addressed in this study.

The article provides an investigation based on simulation tools to determine the influence of occupants’ level on energy usage records of Rockhampton campus of Central Queensland University Queensland, Australia (The IT Building, 19). The research case was built on using simulation engine EnergyPlus which used the building profile as building’s floor-plan, 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 that were provided by the university’s facilities management team. The second part of this article presents the projected energy savings using the proposed advanced add on fuzzy proportional integral derivative (PID) controllers.

2. OCCUPANTS’ DENSITY EFFECTS ON LIGHTING AND *HVAC* SYSTEM OPERATION

Number of occupants or density level affects the way that lightings’ and HVACs’ systems operate. This part presents the method of valuing occupants’ functions and thus energy demand. The controllers use inputs provided by random number generator depends on the infrastructure facts and operational pattern. Results are provided on regular buisness hours (8 am to 8 pm).

2.1. Effect of Occupancy Level on Lighting Load

The optimal situation could be to install a sub main meters to measure energy that used by lighting systems 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 nonappearance of actual data loggers. The building’s spaces are categorised into different zones. The designed lighting watts/m^2 for these zones as provided from the university’s divisions 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/m2. Energy consumed by lighting system is calculated using equation 1 (Ramasubramanian et al., 2009).

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

Here N represents building’s zones, U is the lighting usage factor, W_i is the expected designed W/m^2 by zones, A_i is the gross floors area, and h here represents business hours (Baniyounes et al., 2012).

In this study samples were taken based on duration of usage at 3–5 h 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. Effect of Occupancy Level on Cooling Load

The building space is air-conditioned centrally using a chiller delivering water to 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 (Ramasubramanian et al., 2009). Heat gain or what is known as cooling gain of air-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 (Yang et al., 2000) Indoor cooling load is a result of occupants’ density, lighting system and equipment such as computers. While the main contributors of outdoor cooling load are ventilation, infiltration, conduction and radiation. The indoor cooling load can be calculated using equation 2 while the outdoor cooling load can be calculated using equation 7.3 (Motuzienė et al., 2016).

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

Here Ha represents occupants’ number, 1.2 is the ballast multiplication losses factor for ballast losses (Chirarattananon and Taweekun, 2003) 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 $Q_e = \sum_{1}^{N} h_n (Q_v + Q_i + Q_c + Q_r)$ (3)

Where Q_e is outdoor heat load Q_v is energy consumed by ventilation, Q_i is infiltration heat load Q_c is heat transfer due to conductivity, and finally Q_r is resulted radiant heat gain.

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 (De Wit et al., 2001). System analysis was performed using energy plus simulation tool (Energy Plus, 2018). 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 occupancy mean data pattern were generated as in Department of Energy (DOE) building energy efficiency code (Title 24). The code indicates occupants' activity and behaviour (Huang, et al., 2006). 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. Operation schedules were defined to the model according to regular operation variation in institutional buildings' normal working hours as shown in Table 1 which 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.

The techniques that listed in the previous table 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.

4. RESULTS AND DISCUSSIONS

4.1. *Occupancy* Level Control Performance

The system's simulation tool evaluated HVAC's and lightings' energy consumption, considering occupants' level changes. Add on Fuzzy-PID controllers are re-programmed so it can carry on this calculation. The fuzzy-based controllers' inputs are e-R and its errors variation *Δ-eR* which represents the difference between buildings past occupant and building's current occupant. In addition, the membership functions of add on fuzzy based-PID controller's input and output are presented in Figure 1. The controllers' inputs and outputs contain the following values:

Negative-High (N-H), Negative-Medium (N-M), Negative-Low (N-L), Zero (Z), Positive-Low (P-S), Positive-Medium (P-M) and Positive-High (P-H) is represented in Table 3 (Ali and Kim, 2015). The outputs of add on fuzzy based-PID controller is the essential power change based on occupancy level which requires to maintain indoor thermal and visual comfort level.

Table 1: Occupants and occupants' activity schedule

Energy plus parameters	Description	Ranges
Lighting schedule	Hours of operation	Low: >5 h/day, 10 months a year Medium: 5–7 h/day, 10 months a year High: Full-day, 12 h/day 10 months a year
Equipment schedule	Hours of operation (plug load usage)	Low: >5 h/day, 10 months a year Medium: 5–7 h/day, 10 months a year High: Full-day, 12 h/day 10 months a year
People schedule	Occupants density (ratio of head counted population to maximum occupants)	Low: >50% of total occupants, 10 months a year Medium: 50% of total occupants, 10 month a year High: >100–50% of total occupants 10 month a year

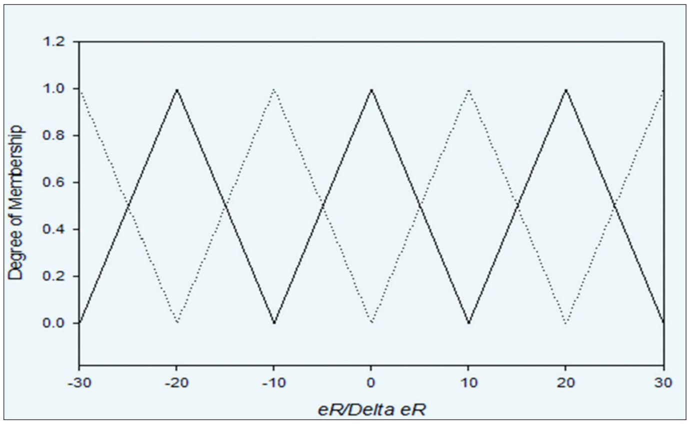
Table 2: Building energy plus profile

Energy plus 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/person/h Medium: 70 kWh/person/h High: 170 kWh/person/h
Infiltration and ventilation	Ventilation rate and openings infiltration	Low: 0.15 CFM/head Medium: 0.38 CFM/head High: 0.75 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/class/h Medium: 150 kWh/class/h High: 200 kWh/class/h

4.2. Energy Index and Savings

Figure 2 shows that the building total electric load over the year 2016 was 64,3572 kWh. During the season of excessive demand for cooling that happens between January-April and September-December, the building maximum energy demands was notices throughout March recording 68352 kWh followed by February recording 65140 kWh, after that was April recording 61,920 kWh.

Figure 1: Membership functions of various occupancy levels



During winter season where there is the demand on air HVAC is minimum, the minimum electric load was in the month of June at 42,688 kWh followed by the months of July at 45,013 kWh and the month of August at 48,000 kWh respectively.

Figure 2 also demonstrates the building total-electric energy load based on approximate 50% occupancy density, the gross electric-demand that year decreased from 64,575 kWh to 55,319 kWh which shows 15% energy saving. Also it shows that, the most energy-savings was recorded during December recording at 39,525 kWh which is 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 (Baniyounes et al., 2013). 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% occupancy rate as similar results were noted. The total annual load was 46,8432 kWh which accounts for 24% of total electric demand (at full occupancy

Figure 2: Building 19 total electric load at different occupancy level

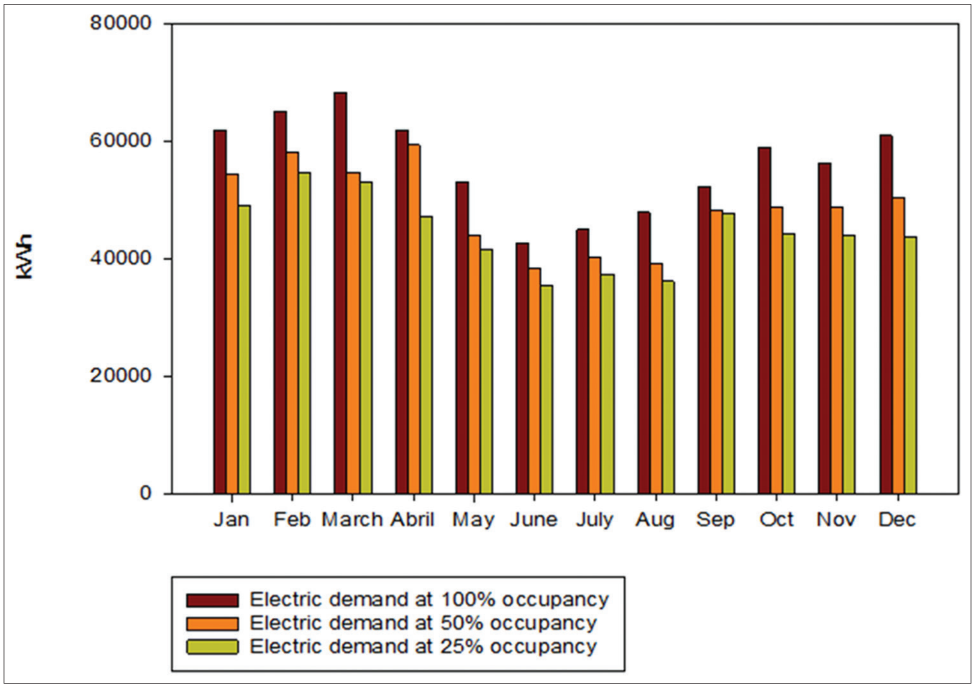


Table 3: Fuzzy control rules for local various occupancy levels

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

NH: Negative high, NM: Negative medium, NL: Negative low, Z: Zero, PM: Positive medium, PH: Positive high level). The month of December results was still at the top due to the holiday's season at 41,882 kWh and the least savings was in the month of March which accounted for 22% energy savings compared to the full occupancy rate.

The total amount of energy usage concentration is considered as an indicator of the annual electricity consumption of HVAC and lighting system in kWh per area in m^2 i.e., normalized electricity consumption. The limitation of energy use intensity is that it does not consider elements which involve energy consumption of HVAC and lighting system efficiency, for example, changes in building cooling load which the HVAC system need to handle and strategies to meet any given building cooling load (Baniyounes et al., 2013).

Energy signature is used as a substitute to regular energy use intensity to assess the energy performance of HVAC and lighting systems with different design operation and operating modes (Zhao and Yu, 2015) alternatively, energy signature models had been used for a long time to evaluate and govern the energy performance of building in various climate conditions.

An energy usage pattern is the top fitting straight line sketched around annual approximate data points, individually of which signifies the energy usage of institutional building in respect to average external temperature at a given time intervals for example 1 h, 1 day or 1 month. It not the solitary unveiled the building total energy usage but as well as demonstrate the way climate stays affect energy usage pattern of HVAC (Yu, 2005 and Mendonça et al., 2015). Considering the energy usage of building and climate data, it is likely to measure the differences in the control of HVAC and lighting system. As the climate status affect the way of building HVAC and lighting load alternate, it is necessary to use energy usage pattern (signature) model to evaluate HVAC and lighting system energy efficiency operation while these works for varying building cooling and lighting load (Zhao and Yu, 2015).

The specification of the cooling and lighting energy consumption might be demonstrated as a climate load report that deliver the way energy consumption varies in respect to the weather index for example temperature, humidity, illuminances and etc. In this thesis, energy usage pattern were employed to specify yearly HVAC and lighting system electrical energy consumption taking into account different energy efficiency procedures. The simulation outcome proposes that energy usage pattern might be employed to classify the HVAC and lighting system energy efficiency and execution of add on fuzzy control. The key rule is, while using energy conservation measures will move near a descent in the slope of the energy usage pattern, this means conservation strategy is appropriate for minimizing HVAC and lighting system electrical energy usage while they work during the peak demand of HVAC load. In order to efficiently control yearly HVAC and lighting system electrical energy consumption, a number of reference energy usage patterns have been created to support various passive building cooling techniques such as the use of overhangs to protect from radiant heat gain. Here, the outcome of simulation process clarify how total HVAC and lighting system energy consumption differ in respect to climate portfolio taking into account different methods for base climate gain achieve.

Energy signature for the HVAC and lighting system energy consumption is compared with fuzzy logic based control energy consumption such as the usage of out-door air when its temperature and humidity falls between 20–26°C and 30–70% respectively as shown in Figure 3. Here, the usage of outdoor air yield the highest energy performance (the lowest energy consumption, kWh/m^2) compared to the existing control system. These simulated consumption data were correlated with the corresponding climate index. The coefficient of determination (R^2) varied from 0.92 to 0.97 indicating a strong correlation of the energy consumption with the climate index for example (temperature, RH and illuminance). It was found that the modelled results could provide a reasonably good indication of the annual electricity use.

Therefore, the energy signature model with different retrofit strategies can be used to identify the control technology although building occupancy profile may vary. With the index, it is likely to evaluate the level that HVAC and lighting electrical usage which might decrease when different energy conservation measures are implemented and recognize the fit techniques to efficiently decrease total electrical energy usage.

To evaluate the energy savings of the proposed fuzzy logic control system, an evaluation of the current the reference building's HVAC and lighting systems driven by the existing PID control system energy consumption and then the evaluation was compared to the reference building's HVAC and lighting systems driven by the new proposed control system energy consumption. Figure 4 shows a comparison between energy consumed by the reference building HVAC and lighting system with the existed PID conventional control system and the expected energy savings using fuzzy logic based control system.

According to the figure, the annual energy consumption using PID control system was approximately nearly 64,572 kWh while the annual expected energy consumption using the proposed control system will drop to 58000 kWh which accounts to approximately 9% of total energy used under the control of conventional PID controller. The maximum energy savings was expected to be in the months of July, June, May and August at 15%, 14%, 12% and 12% respectively due to the moderate external temperature. The lowest energy savings was expected to be in the months of January, February and December at 9%, 11% and 10% respectively.

5. CONCLUSION

This article presents the effect of occupancy concentration level on an energy savings of Building 19 at Rockhampton campus of central Queensland university, Queensland, Australia. The evaluated aspects in this article were concentrated on occupancy density effect on HVAC and lighting system energy demand. The 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

Figure 3: Energy index using outdoor air and daylight

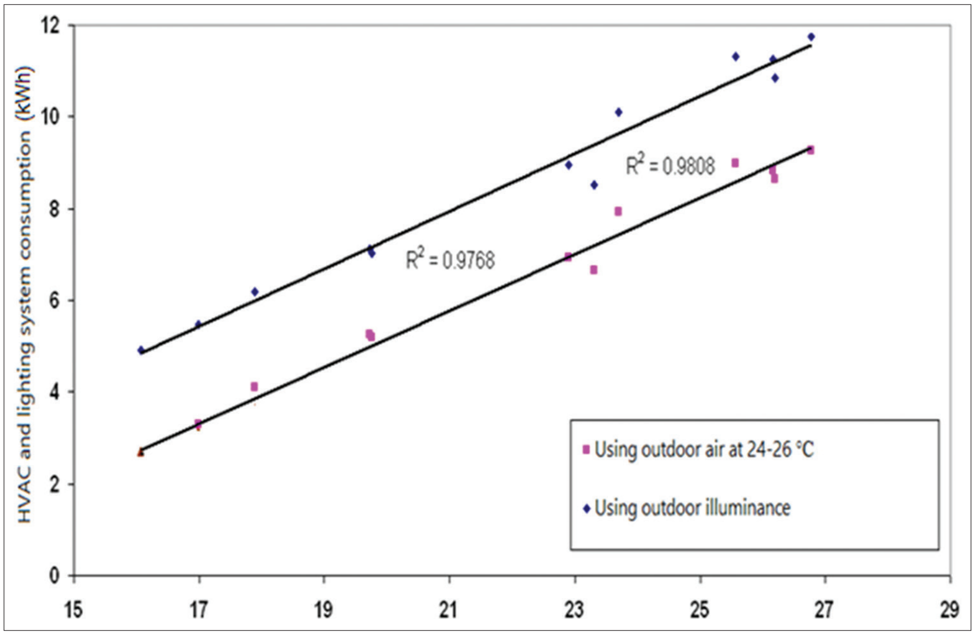
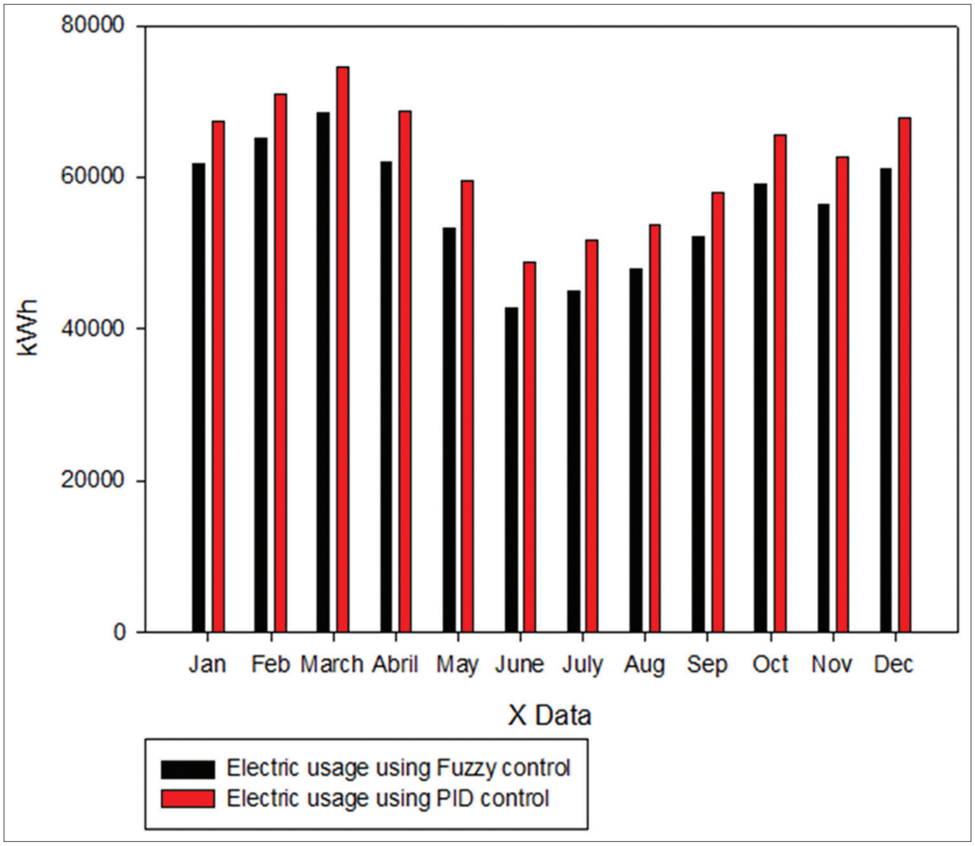


Figure 4: Energy savings proportional integral derivative verus fuzzy logic



to full occupancy level energy demand (100% occupancy level). Moreover, foe 100% occupancy level, the energy savings of 9%-14% can be achieved, with maximum energy savings in July (15%) and minimum energy savings in January (9%) if the proposed fuzzy logic controller can be introduced. 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 level and etc.

REFERENCES

Agency, 2016): Solar Heating and cooling Program Agency , I. E. (2016). Solar Assisted Air Conditioning of Buildings February 13, . Available from: viewed 12 October 2018 http://www.Task25.Iea-Shc.Org.[Last accessed on 2018 Oct 12].

Ali, S., Kim, D.H. (2015), Optimized power control methodology using genetic algorithm. Wireless Personal Communications, 83(1), 493-505.

Atmaca, A., Atmaca, N. (2016), Comparative life cycle energy and cost analysis of post-disaster temporary housings. Applied Energy, 171, 429-443.

Baniyounes, A.M., Liu, G., Rasul, M., Khan, M.M.K. (2012), Analysis of solar desiccant cooling system for an institutional building in subtropical Queensland, Australia. Renewable and Sustainable Energy Reviews, 16(8), 6423-6431.

Baniyounes, A.M., Rasul, M.G., Khan, M.K. (2013), Economical and Environmental Performance of Solar Desiccant Cooling in Subtropical Australia in Proceedings of the IASTED International Conference, Power and Energy Systems (EuroPES 2012). Naples, Italy: Iasted.

Baniyounes, A.M., Rasul, M.G., Khan, M.M.K. (2013), Experimental assessment of a solar desiccant cooling system for an institutional building in subtropical Queensland, Australia. Energy and Buildings, 62, 78-86.

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

Chua, K.J., Chou, S.K., Yang, W.M., Yan, J. (2013b), Achieving better energy-efficient air conditioning-a review of technologies and strategies. Applied Energy, 104, 87-104.

De Wit, M.A.S., Koopmans, M.P., Kortbeek, L.M., Wannet, W.J., Vinjé, J., van Leusden, F., Bartelds, A.I., van Duynhoven, Y.T. (2001), Sensor, a population-based cohort study on gastroenteritis in the Netherlands: Incidence and etiology. American journal of epidemiology, 154(7), 666-674.

Deuble, M.P., de Dear, R.J. (2012), Mixed-mode buildings: A double standard in occupants' comfort expectations. Building and Environment, 54, 53-60.

Eicker, U., Pietruschka, D. (2009), Optimization and economics of solar cooling systems. Advances in Building Energy Research, 3(1), 45-81.

Energy Plus. (2018), Available from: https://www.energyplus.net. [Last cited on 2018 Jul 24].

Huang, J., Bourassa, N., Buhl, F., Hitchcock, R., Ender, E. (2006), Using EnergyPlus for California title-24 Compliance Calculations. Cambridge, MA: Lawrence Berkeley National Laboratory.

Mendonça, P., Cruz, N., Macieira, M. (2015), Environmental and economic cost analysis of housing in temperate climate using an innovative lightweight partitioning system. International Journal of Sustainable Energy, 37, 1-16.

Motuzienė, V., Rogožaa, A., Lapinskienėa, V., Vilutienė, T. (2016), Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: A case study. Journal of Cleaner Production, 112, 532-541.

Ramasubramanian, S., Avinash, Y., Chitra, S.P., Geetha, T., Anand, S. (2009), An Activity Based Approach to Minimize Energy Usage of Service Sector Infrastructure. IEEE In: 2009 Second International Conference on, Infrastructure Systems and Services: Developing 21st Century Infrastructure Networks,(INFRA).

Salami, C.G.E. (2011), Entrepreneurial interventionism and challenges of youth unemployment in Nigeria. Global Journal of Management and Business Research, 11(7), 2-9.

Solar Heating and cooling Program Agency, I.E. (2016). Solar Assisted Air Conditioning of Buildings. Available from: http://www.Task25.Iea-Shc.Org.[Last accessed on 2018 Oct 12].

The Australian Goverment, D.o.C.C.a.E.E. (2010), National Greenhouse Accounts Factors 2010. Canberra: The Australian Government.

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

Yu, F.W., Chan, K.T. (2005), Energy signatures for assessing the energy performance of chillers. Energy and Buildings, 37(7), 739-746.

Zhao, Z., Yu, N. (2015), The application of advanced control technologies in air conditioning system–a review. Advances in Building Energy Research, 12, 1-15.