Full Paper

INDOOR TEMPERATURE CONTROL AND ENERGY SAVING POTENTIAL OF SPLIT- TYPE AIR CONDITIONING SYSTEM USING FUZZY LOGIC CONTROLLER

Henry Nasution[a,b*], Afiq Aiman Dahlan[a], Azhar Abdul Aziz[a], Ulul Azmi[a], Amirah Haziqah Zulkifli[a], Herlanda Windiarti[c]

[a]Automotive Development Centre, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Mechanical Engineering, Faculty of Industrial Technology, Universitas Bung Hatta, Padang 25132, Sumatera Barat, Indonesia
[c]Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Teknikal Malaysia, Melaka 75450, Malaysia

Graphical abstract
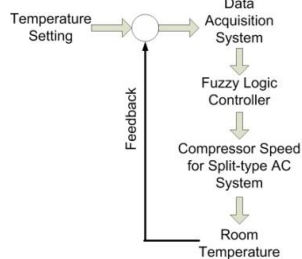
Abstract

Variable speed compressor (VSC) offers a wider range of cooling capacity control according to the cooling load of the system. The on/off controller consumes larger energy as the compressor is always working at maximum speed despite the cooling load and continuously on and off to prevent from over cool the room. This study focused on the implementation of VSC to increase energy efficiency with better temperature control inside the room for split unit air conditioning system. The experiments are done at room temperature of 23 and 24°C with internal heat load of 500 and 1000 W. The proposed system indicates as much 37% of energy saving as compared to on/off controller.

Keywords: Air conditioning; variable speed; fuzzy logic controller; energy efficiency

Abstrak

Kelajuan pemampat boleh ubah (VSC) menawarkan kapasiti penyejukan yang lebih besar berdasarkan kepada bebanan suhu pada sistem. Kawalan hidup/mati menggunakan tenaga yang lebih banyak kerana pemampat sentiasa bekerja pada kelajuan maksimum sungguhpun bebanan suhu yang berlainan dan berterusan hidup/mati untuk mengelakkan penyejukan terlebih pada bilik. Kajian ini memfokuskan kepada implementasi kelajuan VSC untuk menambah kecekapan tenaga serta pengawalan suhu bilik yang lebih baik untuk sistem penyaman udara jenis berpisah. Eksperimen dijalankan pada tetapan suhu bilik 23 dan 24°C dengan bebanan suhu dalaman 500 dan 1000 W. Sistem yang dicadangkan menunjukkan penjimatantenaga sehingga 37% berbanding menggunakan kawalan hidup/mati.

Kata kunci: Penyaman udara; kelajuan boleh ubah; kawalan logik kabur; kecekapan tenaga

1.0 INTRODUCTION

The application of air conditioner (AC) has expanded thoroughly out the year with a variety of applications such as houses, buildings, and hall. The main AC design consideration is providing better thermal comfort at low energy consumption. This in return will make the humans inside the room feel comfortable.

Traditionally, split unit AC system operates at maximum constant speed until it reaches the cooling capacity needed to cool down the room. It operates by turning the compressor on and off continuously until temperature setting is achieved. This causes high energy consumption as the current spike during turning on of the compressor. Malaysia commonly uses this type of AC because of the capital cost despite the high energy consumption used by the AC system [1].

Variable speed drive of the compressor (VSC) implementation is seen as the solution to the problems. VSC continuously varies the compressor speed according to the cooling load which results in less energy consumption and better temperature control [2-4]. The compressor speed is varied by changing the frequency that drives the compressor.

The system operates by converting the fixed the frequency of the electrical supply into a variable frequency output. The system's driver can control the frequency so that the compressor speed operates at the desirable speed by changing to a lower frequency to get lower compressor speed and higher frequency to have higher compressor speed. The output can also enabled the variable torque as required by a system so that it matches the amount of energy required to the amount of energy needed depending on the workload.

Many types of conventional and intelligent compressor have been studied such as PID [1, 5, 6], rule-based [7] and fuzzy controller [8-12]. PID controller is the most widely used caused by simple design structures at good control system performance and

low cost. The VSC load matching capability save much energy at better thermal comfort in AC system using PID controller [13]. Proper selection of proportional (P), integral (I) and derivative (D) gain for the controller has made his experiment get better temperature control and energy saving.

However, the PID controller is very complex to design for a nonlinear system such as a building at the open area. Fuzzy logic controller (FLC) offers better control for a nonlinear system such as AC system. The controller can be express in a heuristic environment of the occupants in relating thermal comfort [14], thus offering better temperature control. FLC happened to be a popular control method for AC system [8-12, 15].

This study is focused on the development of variable speed compressor for split unit AC system. The FLC controller is implemented to control the compressor speed to obtain energy saving and compared to the on/off controller. The simple installation of the system with higher energy saving is the main advantages of the proposed system. This study is the extension paper from previous work [15].

2.0 FUZZY LOGIC CONTROL ALGORITHM

Figure 1 shows the components involved in designing the FLC controller. The components are input and output variables, fuzzification, inference mechanism, rule base and defuzzification [16]. The input variables are received by the FLC and converted to the fuzzifier. The fuzzy associate memory (FAM) relates the input and output and it is defuzzify for obtaining crisp value [1]. The error of reference and measured temperature is e while Δe is the rate of change of the difference between present error and the previous error. The ΔZ is the output variable which is in this case is voltage signal to the compressor.
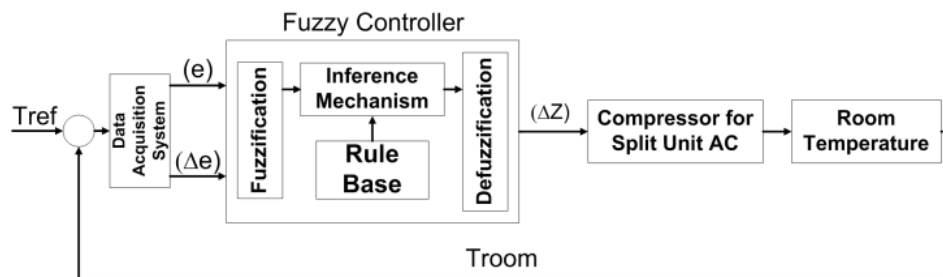

Figure 1 Split unit AC control structure

Membership function of e, Δe and ΔZ is shown in Figure 2 and Figure 3. H (Hot), N (Normal), C (Cold), NE (Negative), NO (Normal), PO (Positive), SL (Slow), NM (Normal), and FT (Fast) represent the fuzzy sets of the controller which is related to the input and output variable. The universe of discourse for e is -2°C to 2°C,

Δe is -2°C to 2°C, and ΔZ are 0 to 5 Vdc depending on the thermal comfort in the room and the voltage for data acquisition range. The triangular method is used for the membership function because it has a good performance [17, 18].
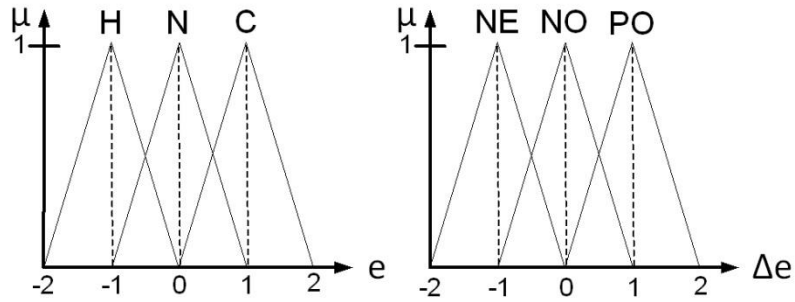
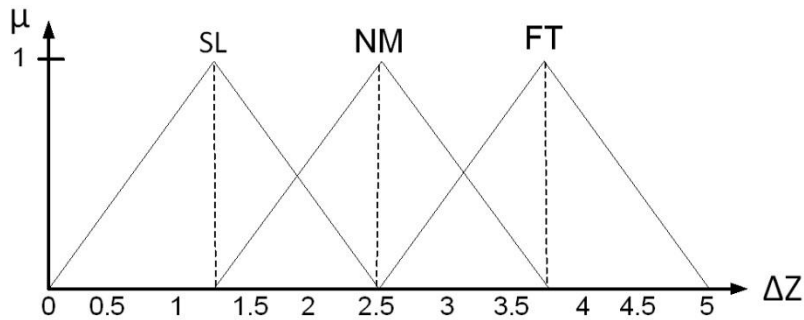**Figure 2** Membership function of the input variables e and Δe

Figure 3 Membership function of the output variable ΔZ

Table 1 Fuzzy rule set

ΔZ		e		
		H	**N**	**C**
	NE	SL	SL	SL
Δe	**NO**	SL	SL	SL
	PO	FT	NM	SL

The 3 x 3 rule matrix with 9 rules referring the input and output of the FLC is applied with Mamdani inference mechanism [15], while the centroid method is applied for defuzzification as it gives stable steady-state result [19] and less complex than other method [20] and works in any situation [16]. The fuzzy rule set is shown in Table 1.

3.0 AIR CONDITIONING PERFORMANCE

The coefficient of performance (COP) is express for calculating the efficiency of an AC system. The COP can be stated by the proportion of heat removal from the evaporator divided by energy required by the compressor or:

$$\text{COP} = \frac{Q_e}{W_{com}} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \qquad (1)$$

where h_1 (kJ/kg) is compressor inlet, h_2 (kJ/kg) is compressor outlet, h_4 (kJ/kg) is enthalpy of the evaporator inlet, Q_e (kJ/kg) is the refrigerating effect and W_{com} (kJ/kg) is the work done by the compressor.

Energy consumption by the compressor is the product of power and operation time of the split unit AC system. The equation is:

$$P = \frac{I \times V \times PF}{1000} (kW) \qquad (2)$$

$$Energy = P \times t \, (kWh)$$

where I is the current (Ampere), V is the voltage while PF is the power factor. Thus energy saving can be expressed as:

$$\text{Energy saving} = \left[\frac{(\text{Existing Split AC}) - (\text{FLC Split AC})}{\text{Existing Split AC}} \right] \times 100 \qquad (3)$$

4.0 EXPERIMENTAL SETUP

Figure 4 show the schematic diagram of the split unit AC system on the experimental rig. The temperature and pressure point is shown with simulation room of size 2 m long, 1 m wide, 2 m high and 4 m³ volumes was used. The room is located in the Thermodynamic Laboratory of Mechanical Engineering Faculty,

Universiti Teknologi Malaysia, with low ventilation and unexposed to solar radiation.

Type T thermocouple and Bourdon pressure gauge are used for measuring temperature and pressure of the AC system respectively. The refrigerant used is R-22 and refrigerant flow meter is placed before the expansion valve. A power meter is used to measure the electric consumption of the AC system.

The VSC system is consists of LM35DZ temperature sensor inside the room while FLC algorithm is applied

to a computer. The inverter used is Optidrive E2 Single Phase Input and Output while the split unit system compressor is 746 W (1 Hp) hermetically sealed rotary compressor type. The temperature data logger TC-08 and USB-4716 is used to monitor the data from the AC system. Other data is directly measured with eyes at 5 minutes interval.
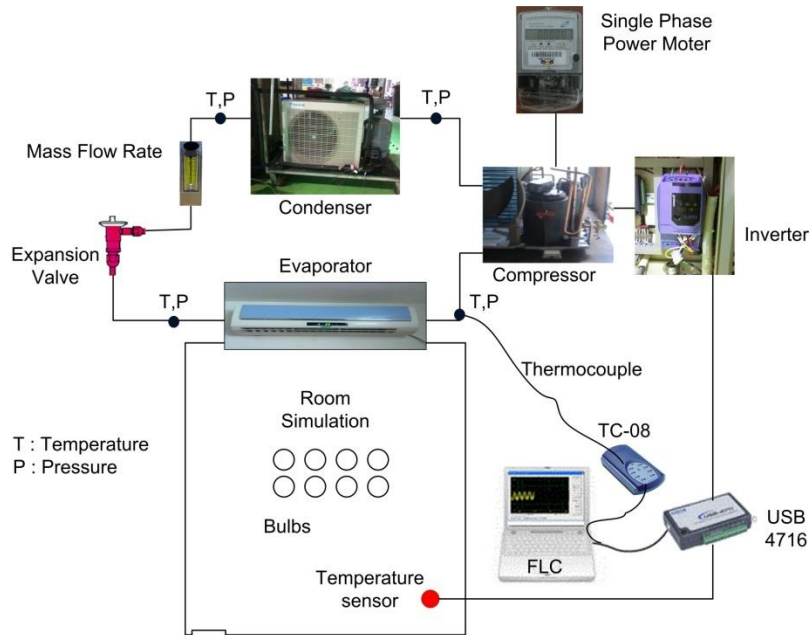

Figure 4 Schematic diagram of the experimental rig

The room temperature sensor emitted electrical signal to the controller and computer to analyze the data. The output signal of the error between set temperature and room temperature is generated to vary the compressor speed according to the error. The compressor speed is directly proportional to the frequency of electricity provided to the motor.

A constant speed compressor experiment on the split unit AC system is applied at frequency of 15, 20, 25, 30, 35, 40, 45 and 50 Hz. The split unit is the original unit with thermostat system and retrofitted with VSC controller. The data collected is to analyze the energy consumption, COP and energy saving. The experiments are executed for one hour with the temperature setting of 23 and 24°C according to ANSI/ASHRAE Standard 55 – 2004 and ASHRAE/IES Standard 90.1 – 1999, indoor design temperatures are: winter (20 to 23°C) and summer (23 to 26°C) [1] with the internal heat load according to the human metabolic rate. The metabolic rate was estimated from the rate of heat beats to be 260 W/m² during activities [21]. Therefore in this research, a 250 W lamp is substitute for one occupant. As this room is simulating for four occupants, the internal heat load is

500 W and 1000 W to get the effects of various numbers of occupants to the temperature distribution inside room.

5.0 RESULTS AND DISCUSSION

5.1 Constant Speed Performance

The experiments of varying compressor frequency between 15 to 50 Hz have been conducted with various temperature setting and internal heat load. Figure 5 shows the effects of various frequencies of the room temperature and energy consumption at steady state. It can be seen that as the frequency increased, the room temperature is increased and energy consumption is decreased.

5.2 Existing System Performance

Traditionally AC system is controlled by on/controller or called as thermostat which allowing two conditions of operations either compressor is on or off. The frequency is set at highest that is 50 Hz and as the

temperature reaches the temperature setting, the compressor is turned off. The compressor is continuously turned on and off until steady state is achieved. Figure 6 shows the room temperature at various temperature setting and internal heat load.
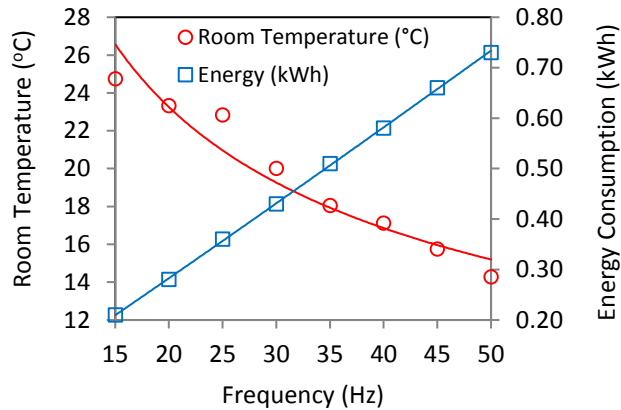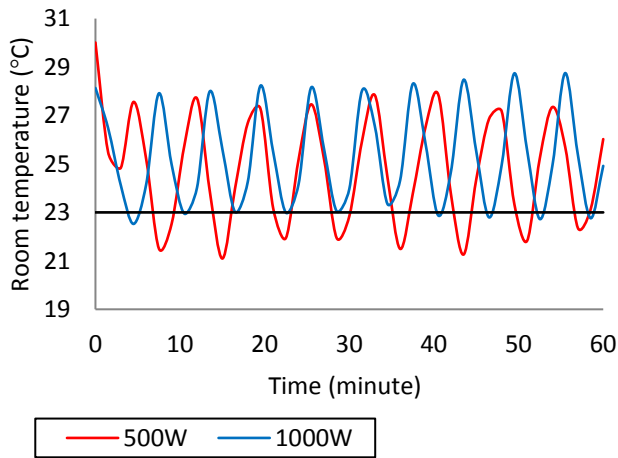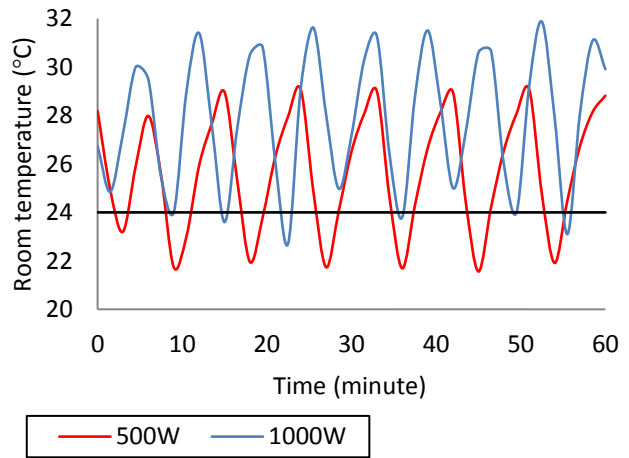

Figure 5 Steady state room temperature and energy consumption at various frequencies

(a)   Temperature setpoint = 23°C

(b) Temperature setpoint = 24°C

Figure 6 Room temperature responses with thermostat

The main disadvantages of the on/off controller are that the discomfort to occupants inside the room occurred during the temperature is at the upper limit of temperature setting as it is not accordance with the temperature setting. This is because the thermostat is located inside the evaporator instead of inside the room itself. This type of system is not the best way to control the room temperature that is considered as nonlinear.

Equation (1) is used to calculate COP with average COP of 2.76 at both temperature setting and internal heat load. The COP is zero when the compressor is off.

5.3 Performance of VSC with FLC

Figure 7 shows the room temperature distribution at various temperature setting and internal heat load.

FLC is implemented to control the compressor speed according to the error between room temperature and temperature setting. The compressor is run at the maximum speed of 50 Hz and decrease as the temperature error between the temperature setting and room temperature is decreased. Moreover, the time taken to cool down the room is faster as the temperature sensor is placed inside the room instead of at the evaporator. After the room temperature is reached, the compressor works at low compressor speed to maintain the room temperature, thus lower energy consumption can be obtained.

The average COP for VSC setup is 3.07. Higher COP indicates lower energy consumption of the system. The COP is increased because of lower energy consumption and compressor speed.
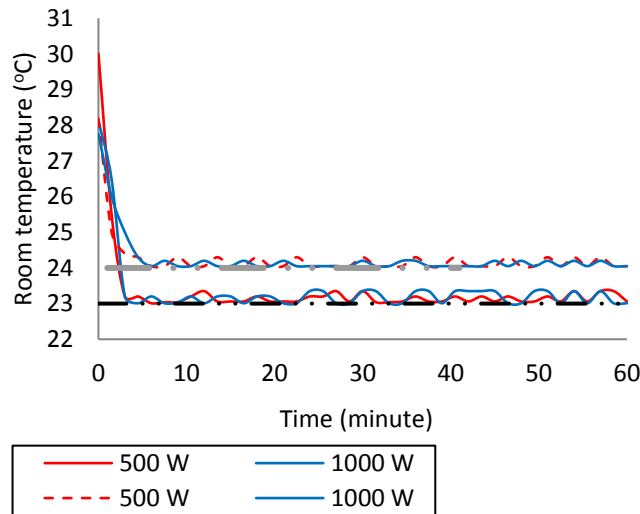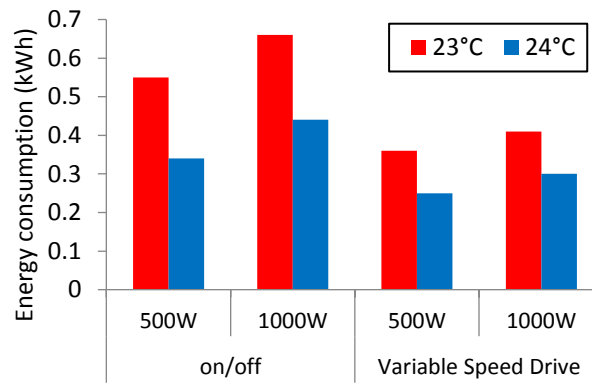
Figure 7 Room temperature responses with FLC

Figure 8 Energy consumption

5.4 Energy Analysis

Figure 8 and Figure 9 are the energy consumption and energy saving of the on/off controller compared to FLC system. Different temperature setting and internal heat load do give different results. The results show that the FLC controller is always have lower energy consumption compared to on/off controller mainly because the lower compressor speed in maintaining the room temperature and no current spikes caused by the on and off behavior of the compressor. Energy saving achieved is between 26 to 37%. Some related research on energy-saving measures that have been made using inverter technology include adjustable fan speed, refrigerant flow control, indoor temperature control (thermostat), and water flow control, control of dampers, evaporator and expansion valve [1]. As an example, by using refrigerant flow control and variable air volume (VAV) system which adopted inverter technology resulted in energy savings of 22.2% and 11.7%, respectively [22], and 20% [23]. In addition, the programmable thermostat control method gave 12% energy saving [24] while the two position control method gave 22.8% saving [25].
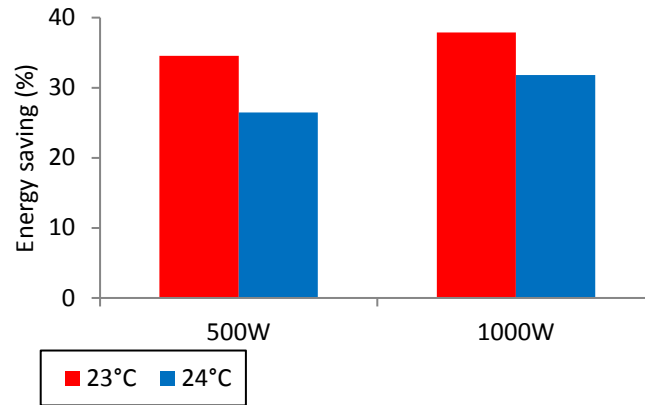
Figure 9 Energy saving

6.0 CONCLUSION

An experiment on the split unit AC system with VSC using FLC is done to study the effects on AC performance and energy consumption. The implementation of VSC has proved that energy saving could be achieved up to 37% depending on the cooling load and temperature setting. The FLC control the speed of the compressor depending on the cooling load thus lower energy consumption can be achieved, increasing the energy efficiency of the whole system.

Acknowledgement

References

[1] Nasution, H. 2006. *Energy Saving of an Air Conditioning System using PID and Fuzzy Logic Controllers*. Universiti Teknologi Malaysia, Malaysia.
[2] Nasution, H., Jamaluddin, H. and Syeriff, J. M. 2011. Energy Analysis for Air Conditioning System using Fuzzy Logic Controller. *Telkomnika*. 9: 139-150.
[3] Abidin, N. Z. 1995. *Retrofitting of Compressor Motor in Air Conditioning Systems for Energy Saving*. Universiti Teknologi Malaysia, Malaysia.
[4] Park, Y. C., Kim, Y. C. and Min, M. K. 2001. Performance Analysis on a Multi-Type Inverter Air Conditioner. *Energy Conversion & Management*. 42: 1607-1621.
[5] Zhang, J., Qin, G., Xu, B., Hu, H. and Chen, Z. 2010. Study on Automotive Air Conditioner Control System Based on Incremental-PID. *Advanced Material Research*. 129: 17-22.
[6] Khayyam, H., Kouzani, A. Z., Hu, E. J. and Nahavandi, S. 2011. Coordinated Energy Management of Vehicle Air Conditioning System. *Applied Thermal Engineering*. 31: 750-764.
[7] Khayyam, H., Kouzani A. Z. and Hu, E. J. 2009. Reducing Energy Consumption of Vehicle Air Conditioning System by an Energy Management System. *IEEE The 4th International Green Energy Conference*. Beijing.
[8] Sousa, J. M., Babuska, R. and Verbruggen, H. B. 1997. Fuzzy Predictive Control Applied to Air-Conditioning System. *Control Engineering Practice*. 5: 1395-1406.
[9] Calvino, F., Gennusa, M., Roizzo, G. and Scaccianoce, G. 2004. The Control of Indoor Thermal Comfort Conditions: Introducing a Fuzzy Adaptive Controller. *Energy and Buildings*. 36: 97-102.
[10] Thompson R. and Dexter, A. 2005. A Fuzzy Decision-Making Approach to Temperature Control in Air-Conditioning Systems. *Control Engineering Practice*. 13: 689-698.
[11] Farzaneh, Y. and Tootoonchi, A. A. 2008. Controlling Automobile Thermal Comfort using Optimized Fuzzy Controller. *Applied Thermal Engineering*. 28: 1906-1917.
[12] Khayyam, H., Nahavandi, S., Eric, H., Kouzani, A., Chonka, A., Abawajy, J., Marano, V. and Sam, D. 2011. Intelligent Energy Management Control of Vehicle Air Conditioning via Look-Ahead System. *Applied Thermal Engineering*. 31: 3147-3160.
[13] Nasution H. and Hassan, M. N. W. 2006. Potential Electricity Savings by Variable Speed Control of Compressor for Air Conditioning Systems. *Clean Technologies and Environmental Policy*. 8: 105-111.
[14] Davis, L. I., Sieja, T. F., Matteson, R. W., Dage, G. A. and Ames, R. 1994. Fuzzy logic for Vehicle Climate Control, in: Fuzzy Systems. *IEEE World Congress on Computational Intelligence*. Orlando. 530-534.
[15] Henry N., Dahlan, A. A., Nasib, A. M., Aziz, A. A. and Sumeru. 2015. Performance of a Variable Speed of the Split Unit Air Conditioning System using Fuzzy Logic Controller. *Lecture Notes in Engineering and Computer Science: Proceedings of the International MultiConference of Engineers and Computer Scientists 2015*. Hong Kong. 253-257.
[16] Pasino, K. M. and Yurkovich, S. 1998. *Fuzzy Control*. Addison Wesley, United State of America.
[17] Dounis, A. I. and Manolakis, D. E. 2001. Design of a Fuzzy System for Living Space Thermal Comfort Regulation. *Applied Energy*. 69: 119-144.
[18] Bagis, A. 2003. Determining Fuzzy Membership Functions With Tabu Search-An Application to Control. *Fuzzy Sets and Systems*. 139: 209-225.
[19] Kolokotsa, D., Tsiavos, D., Stavrakakis, G. S., Kalaitzakis, K. and Antonidakis, E. 2001. Advanced Fuzzy Logic Controllers Design and Evaluation for Buildings' Occupants Thermal Visual Comfort and Indoor Air Quality Satisfaction. *Energy and Buildings*. 33: 531-543.
[20] Eker, I. and Torun, Y. 2006. Fuzzy Logic Control to be Conventional Method. *Energy Conversion & Management*. 47: 377-394.
[21] Wan, X. and Fan, J. 2008. A Transient Thermal Model of the Human Body–Clothing–Environment System. *Journal of Thermal Biology*. 33: 87-97.

[22] Zhou, Y. P., Wu, J. Y., Wang, R. Z. and Shiochi, S. 2007. Energy Simulation in the Variable Refrigerant Flow Air Conditioning System under Cooling Conditions. *Energy and Buildings*. 39: 212-222.

[23] Murakami, M., Terano, M., Mizutani, K., Harada, M. and Kuno, S. 2007. Fields Experiments on Energy Consumption and Thermal Comfort in the Office Environment Controlled by Occupants Requirements. *Building and Environment*. 42: 4022-4027.

[24] Ahmed, S. S., Majid, M. S., Novia, H. and Rahman, H. A. 2007. Fuzzy Logic Based Energy Saving Technique for a Central Air Conditioning System. *Energy*. 32: 1222-1234.

[25] Abidin, N. Z. 1995. *Retrofitting of Compressor Motor in Air Conditioning System for Energy Saving*. Universiti Teknologi Malaysia, Malaysia.