# An Intelligent Fuzzy Controller for Air-Condition with Zigbee Sensors

[1]Tzu-Ming Wang,  [1]I-Ju Liao, [2]Jen-Chi Liao, [2]Tain-Wen Suen, [1]Wei-Tsong Lee

[1]Dept of Electrical Engineering,

TamKang University,

Taiwan

E-mail: 495440264@s95.tku.edu.tw, ericwahahaha@gmail.com, wtlee@mail.tku.edu.tw

[2]Chung-Shan Institute of Science & Technology

Taiwan

E-mail: jenchili@ms65.hinet.net, tabsun@yahoo.com

*Abstract-In recent years, the research and development of energy-saving control in air-condition system has become a hot spot with the advance of science and technology. In this paper, we proposed a fuzzy control mechanism for air-condition system, which combines the fuzzy control and multi-point sensing technology. When people feel cooler or hotter indoor, the air condition should promptly detect the temperature variance and switch the temperate between hot and cool smoothly. Therein an intelligent fuzzy controller for air-condition with Zigbee sensors is used to provide the comfort and energy-saving benefit. Although traditional control system (shorten as TCS) and the proposed fuzzy control system (named as FCS) have a common goal of temperature control, they differ from each other in temperature switch decision made during the each ambient temperature phases. Under the operating policy to limit the air-condition power on/off power frequency, the simulation result present the FCS energy-saving ratio is about 1.3 times of the TCS. And FCS with 5 minutes control cycle has the best energy-saving rate. It's 2.7 times of FCS with 10 minutes control cycle for summertime in Taiwan.*

**Index terms*: Zigbee Sensor, Fuzzy Theory, Energy Saving.**

## I.    INTRODUCTION

In recent years, the research and development of energy-saving control in air-condition system has become a hot spot with the advance of science and technology. In the control process of

indoor temperature, there are many uncertain factors, such as the problem of indoor leakage, the number of rooms or person and thing in environment. And air-condition refrigeration capacity and compressor speed is non-linear. Those factors make it difficult to construct the precise mathematics model for the control system of indoor temperature. Conventional control strategy cannot meet the precise control demand for quick gaining requested indoor temperature. The research of advanced control strategy for the control of indoor temperature is needed [1]. Fuzzy theory expresses the human recognition uncertainty in a mathematical theory. Fuzzy control is an adaptive and nonlinear control basically, which gives robust performance for a linear or nonlinear plant with parameter variation []. Fuzzy theory extends the traditional binary logic math, which only has right and wrong values, to a gray area with continuous multi-value logic.

In this paper, the design process of intelligent fuzzy controller is given and the designed membership function is used to control simulative air-condition to acquire needed room temperature. In order to gain good control effect, the improved operation process is used. The rest of the paper is organized as follows: Section 2 presents the related work. Section 3 discusses the developed intelligent fuzzy controller for air-condition architecture, including a set of fuzzy controller membership functions used. Section 4 describes the simulation and provides a discussion of experiments results, followed by the conclusion.

## II.     RELATED WORKs

Traditional air-condition control systems use single sensor to sense the environmental temperature and humidity. However, the shortage is the fixed position sensors and the returned sensing information would be limited to the area around individual sensor. Furthermore, some sensors are even located inside the air conditioner, and that causes severely decrease in the data accuracy. Moreover, an inaccuracy feedback data will increase the energy wastage and decrease the comfort. In contrast, multi-point sensing, which sets different sensors in different positions according to the difference experiment environment size, shape and usages, can improve the sensing information accuracy. In this research, we use the multi-point sensing to get temperature and humidity coefficient in each sensing point and then apply fuzzy control to transform all environmental factors into appropriate instructions to dynamically adjust the operation speed of the fans and the air conditioning system.

## III.    SYSTEM ARCHITECTURE

Temperature and humidity are barely possible to be absolutely uniform everywhere. In this paper, it is important to precisely and correctly get the environmental temperature and the humidity data to improve user's comfort. The proposed Fuzzy control mechanism, which combines the Fuzzy control and multi-point sensing technology, is as figure 1 shows. The temperature measurement is centigrade (℃), the humidity value and the operation speed unit of air conditioning systems and fans are percentage (%). Furthermore, the sensors in three different places have the combination of the temperature and humidity sensing capacity. As the temperature and humidity information feedback through wireless sensors, the receiver stores the data into the database. Fuzzy control mechanism would get the data in the database and compute the temperature and humidity parameters requested by the user and calculate the membership grade. Then we use fuzzy theory to calculate the operation speed of the air conditioning systems and the fans.
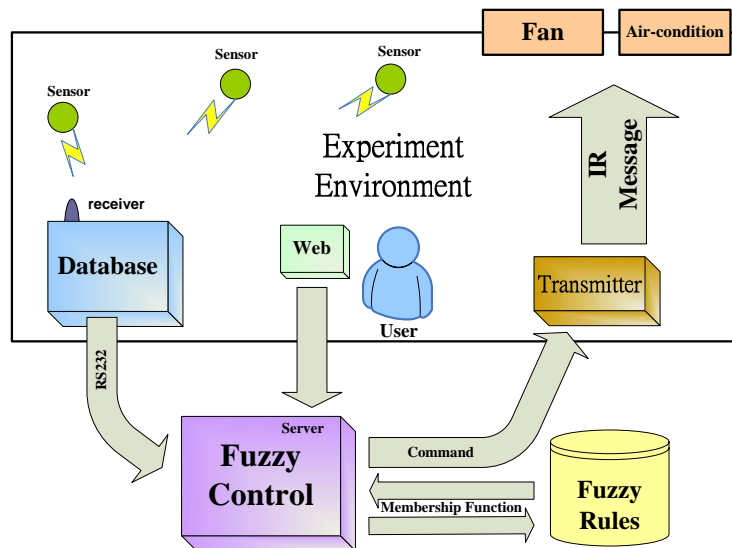


Figure 1.The proposed fuzzy and multi-point sensing controlling system structure

The receiver program is coded with BCB (Borland C++ Builder 6.0) and it stores the Zigbee sensor data in the database (MySQL 5.0). The fuzzy controller program is set to read temperature and humidity data from database through RS232 connection and run analysis once every 10 minutes. It also calculates the membership grade from the fuzzy mechanism, and then sends the transmitter the proper operation speed of the environment according to the fuzzy rules. The fan

and air-condition motors work with the actual controlling instruction through the IR messages requested from the transmitter program.

In table 1, fuzzy control system defines the temperature and humidity as the input values and generates the operation speed of the fans and the air conditioning system with three linguistic variables, which are high, medium, and low respectively as output values.

Temperature range retrieved from the sensor is between 10℃ to 55℃, and the humidity range is between 0% to 100%. The output operation speed of the air conditioning system and the operation speed of the fans is between 0% to 100%.

Table 1: The linguistic variables of input and output transformed to fuzzy theory

| Temperature | input | Low,Medium,High |
|---|---|---|
| Humidity | input | Low,Medium,High |
| Speed of air condition motor | output | Low,Medium,High |
| Speed of fan motor | output | Low,Medium,High |

AS many fuzzy theory applications to control the system, the geometric pattern of triangles are common used to determine the appropriate membership functions and control rules. In this paper, the geometric pattern of triangles is used to define the membership function of temperature, humidity, and operation speed of air conditioning systems and fans in fuzzy control. The membership function of temperature formula is shown in (1)(2)(3). The formula statement contains the linguistic variables of temperature (Linguistic variables of temperature $A$ and the temperature parameter $a$).

$$\mu_{Low}(A) = \begin{cases} 1 & ; \quad 0 \leq a < 22 \\ \dfrac{25-a}{3} & ; \quad 22 \leq a < 25 \\ 0 & ; \quad 25 \leq a < 28 \end{cases} \quad (1)$$

$$\mu_{Medium}(A) = \begin{cases} 0 & ; \quad 0 \leq a < 22 \\ \dfrac{a-22}{3} & ; \quad 22 \leq a < 25 \\ \dfrac{25-a}{3} & ; \quad 25 \leq a < 28 \\ 0 & ; \quad 28 \leq a \leq 32 \end{cases} \quad (2)$$

$$\mu_{High}(A) = \begin{cases} 0 & ; \quad 0 \le a < 25 \\ \dfrac{a - 25}{3} & ; \quad 25 \le a < 28 \quad (3) \\ 1 & ; \quad 28 \le a < 32 \end{cases}$$

In (4), the temperature member function parameters are set according to the figure 2.

$$\mu_{Low}(A) = \{1/19 + 1/20 + 1/21 + 1/22 + 0.67/23 + 0.33/24 + 0/25\}$$
$$\mu_{Medium}(A) = \{0/22 + 0.33/23 + 0.67/24 + 1/25 + 0.67/26 + 0.33/27 + 0/28\} \quad (4)$$
$$\mu_{High}(A) = \{0/25 + 0.33/26 + 0.67/27 + 1/28 + ... + 1/32\}$$

The other input and output parameters of member function for humidity, air-condition motor speed and fan motor speed are as Fig.2 and Fig.3.
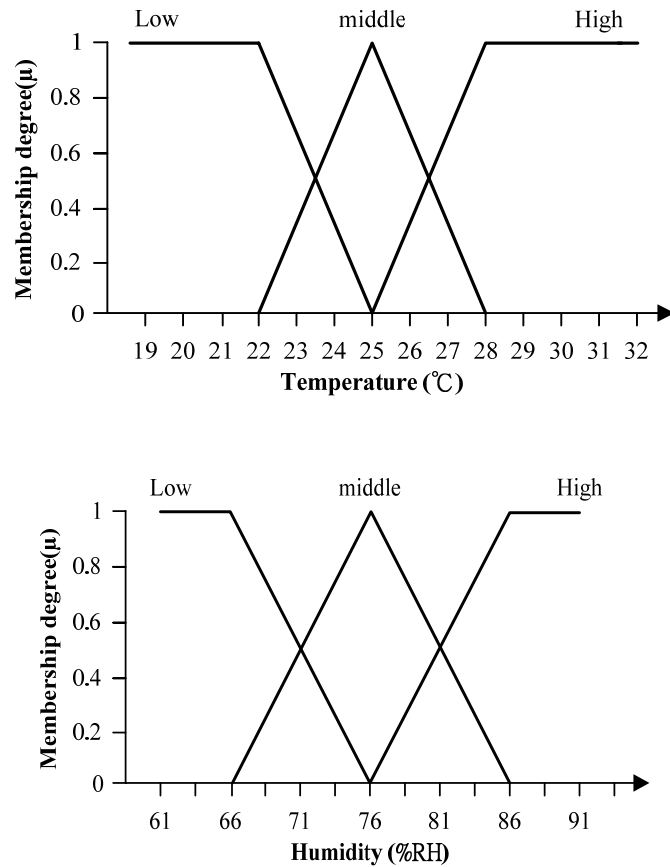




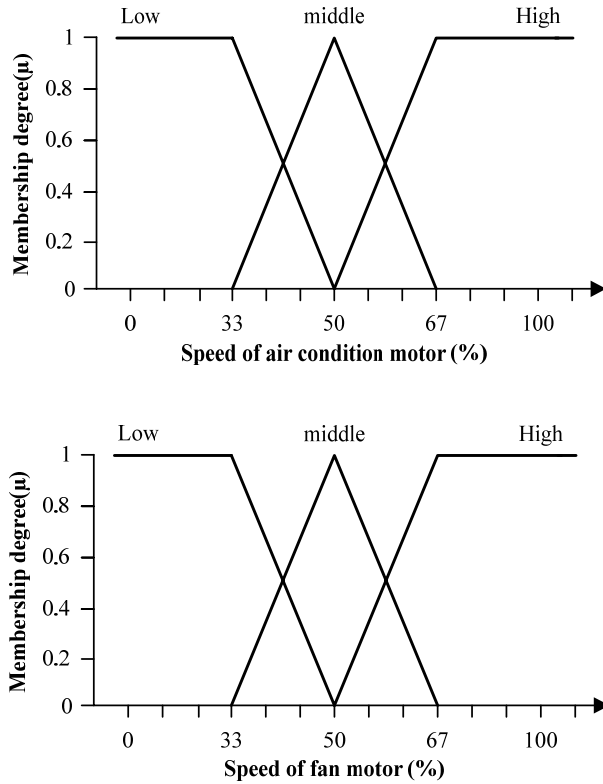Figure 2.  The membership function of the input parameter

Figure 3.  The membership function of the output parameter

In practice, the challenge is how to control the traditional air-condition because we can't control compressor in air-condition machine directly. When the machine power is on or off in short period, it would decrease the energy-saving performance. Therefore, we design an operating policy to limit the air-condition power on/off power frequency. We define a parameter named Fuzzy sample time and set it at least 5 minutes at start and the air-condition compressor open time is defined in (6).

$$\text{Compressor open time} = \text{Speed of air condition motor}(\%) \times \text{Fuzzy sample period} \quad (6)$$

For example, if the Fuzzy sample period is 5 minutes and Speed of air condition motor is 70%, the Compressor open time would be 3 minutes and 30 seconds.
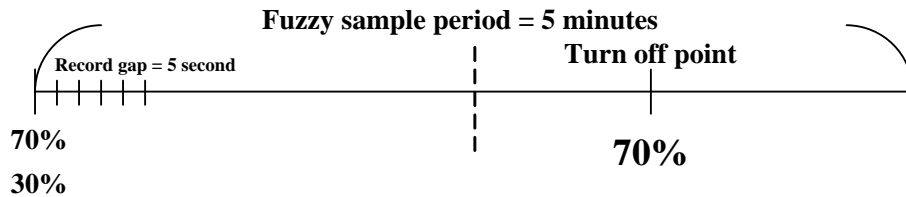
Figure 4.  The power on/off operation policy

With the operation policy as figure 4, the compressor startup would be set as temperature is 20℃ and to send IR message to closed the compressor when temperature is 30℃.

## IV. SIMULATION AND EXPERIMENT

In this section, we present simulations examining the energy-saving performance of fuzzy air-condition controller with Zigbee sensors. The simulations are made with a simulation system developed in C++ language and has fuzzy rules to calculate the proposed membership function corresponding to the air-condition operation mode parameters. There will be 6 parameters in three sensors, and each parameter has 3 linguistic variables.

Fig.5, fig.6, and table 2 are the power consumption comparison for air-condition motor and fan motor between the proposed system and traditional control system. With combing the multi-point sensing hardware and fuzzy control program, we can achieve better result.
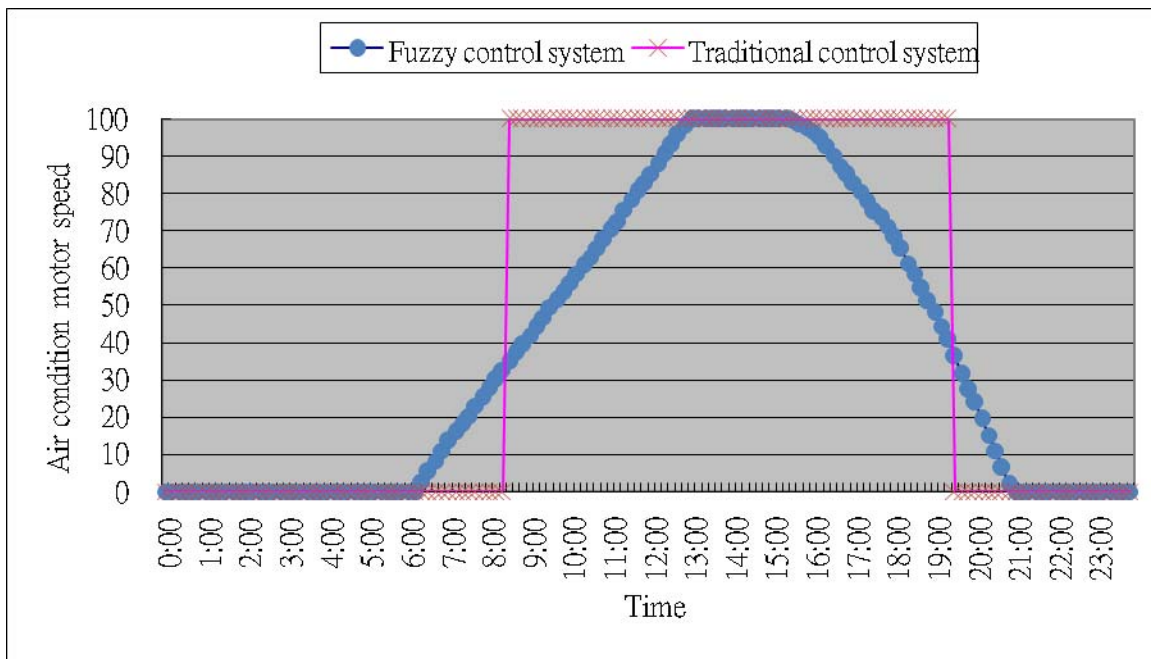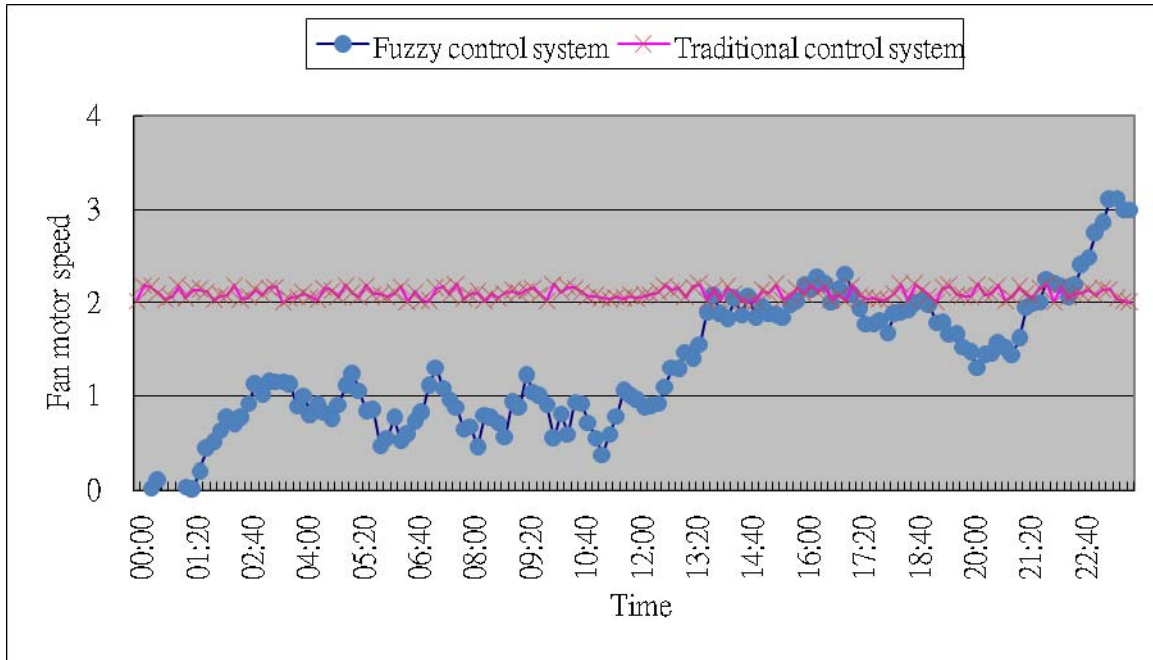


Figure 5. The machine motor speed comparison

Figure 6. The fan motor speed comparison

Table 2: Ratio of the energy-saving of proposed system to traditional controlling system

| Total operating volume of air conditioning system in our controlling system | Total operating volume of air conditioning system in traditional controlling system | energy-saving ratio (%) |
|---|---|---|
| 5516 | 6600 | 16.425 |
| Total operating volume of fan in our controlling system | Total operating volume of fan in traditional controlling system | energy-saving ratio (%) |
| 225 | 288 | 21.931 |

In (7), we define the energy saving rate as performance metric to evaluate the practical experiment results.

$$\text{Energy saving rate} = \frac{\text{Speed ratio without fuzzy - Speed ratio with fuzzy}}{\text{Speed ratio without fuzzy and multi sensing}} \quad (7)$$

$$\sigma_1 = \frac{\sqrt{\sum_{t=1}^{n}(T_{at} - T_{bt})^2}}{n} \quad (8)$$

$$\sigma_2 = \frac{\sqrt{\sum_{t=1}^{n}(T_n - T_{avg})^2}}{n} \quad (9)$$

*Ta* : Temperature of node a.        *Tb* : Temperature of node b.

*Tn* : Temperature of node n.        *Tavg* : Average temperature of nodes.

We compare our algorithm with normal situation with (6) to ensure the power on/off frequency policy. The variance between every sensing node and other ones is retrieved with (7). We test two sets experiment data with 25 degrees for traditional control system (shorten as TCS) and the fuzzy control system (named as FCS). The feeling cold threshold value is set as 22 degrees, the environment temperature default value is 25 degrees and feeling heat threshold value is defined as 28 degrees (all parameters could be changed by user requirements but here we set these parameters just for performance comparison). These sets run for 24-hours and get about 20,500 records for each sensor. The TCS case runs from 4 o'clock on October 25, 2009 to 3:59 on October 26, 2009. And the FCS case starts at 4 o'clock on October 20 until 3:59 on October 21, 2009. Actual parameter results are shown in table 3.

Table 3: Temperature variance and energy saving rate

|  | FCS | TCS |
|---|---|---|
| Temperature variance | 0.003345 | 0.004 |
| Used power | 5.7 kw | 6.9 kw |
| Energy saving rate | 17.39% ||

In Table 3, the FCS temperature variation is lower than TCS and saving about 17.39% power consumption. The above result shows that the FCS could detect the environment temperature more accurately and do better operation for air-condition system to provide users more comfort under the predefined threshold and power on/off frequency policy  condition
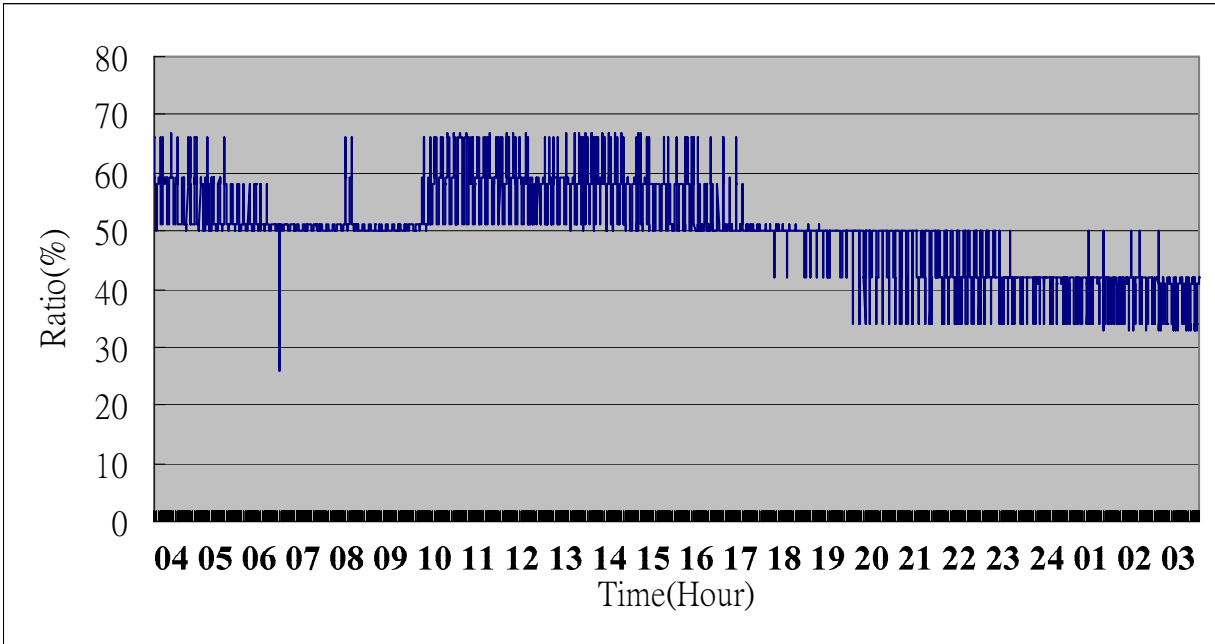
Figure 9.  Operating ratio of FCS

In next experiment, we use the heater to simulate the summertime temperature in Taiwan (as figure 10 shows). The FCS feeling cold threshold value, the environment temperature default value and the feeling heat threshold value are defined as last experiment (all parameters could be changed by user requirements but here we set these parameters just for performance comparison).
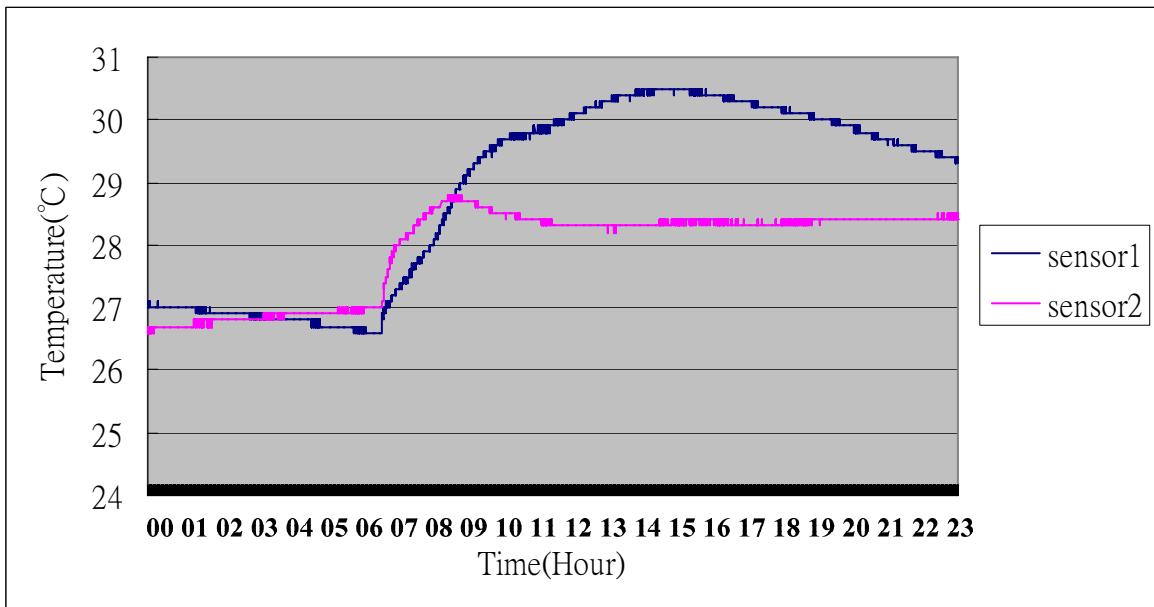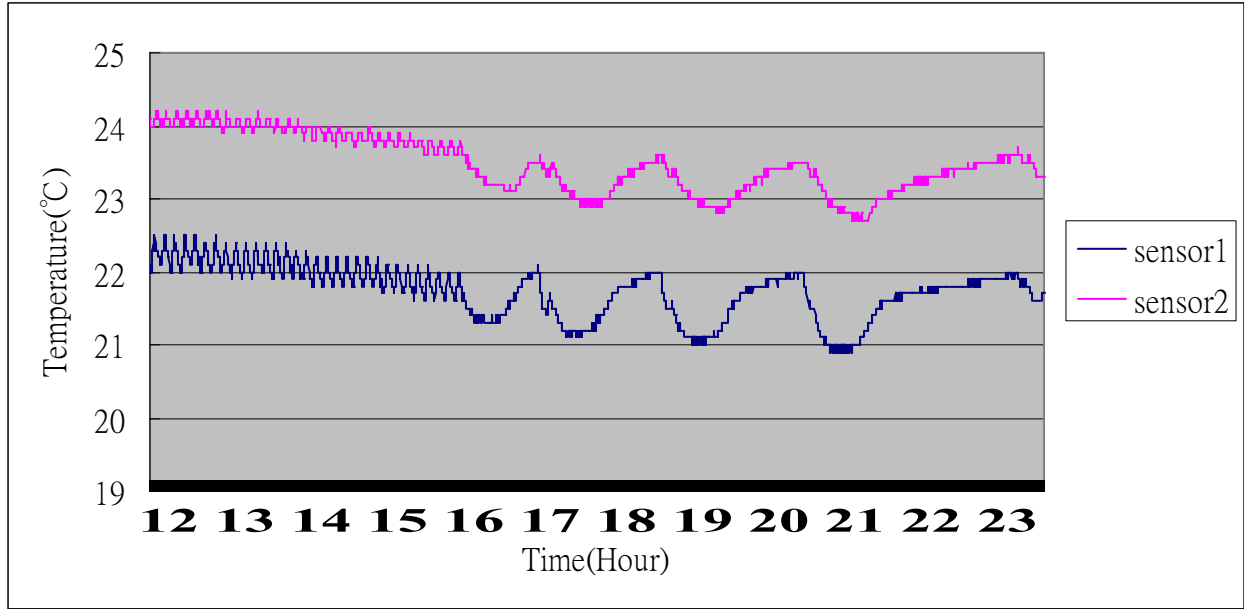


Figure 10.  Temperature after heater

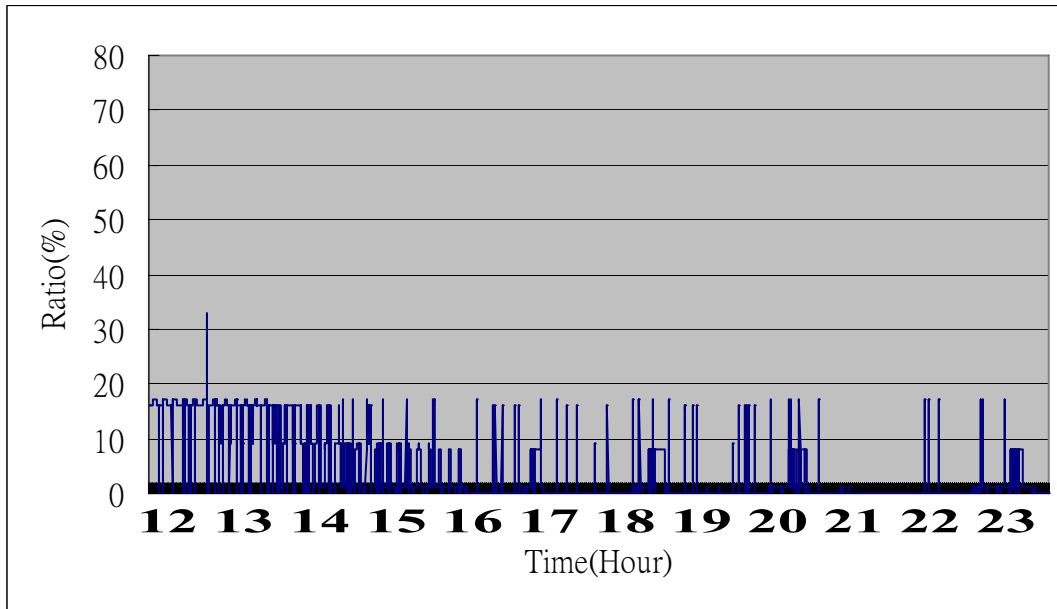Figure 12. Temperature of FCS (control cycle 5 minutes)



Figure 13. Operating ratio of FCS (control cycle 5 minutes)

## V. CONCLUSIONS

In this paper, we proposed a fuzzy control mechanism for air-condition system, which combines the fuzzy control and multi-point sensing technology. When people feel cooler or hotter indoor, the air condition should promptly detect the temperature variance and switch the temperate between hot and cool smoothly. Therein an intelligent Fuzzy controller for air-condition with Zigbee sensors is used to provide the comfort and energy-saving benefit. Although traditional control system (shorten as TCS) and the proposed fuzzy control system (named as FCS) have a common goal of temperature control, they differ from each other in temperature switch decision made during the each ambient temperature phases.

Under the operating policy to limit the air-condition power on/off power frequency, the simulation result present the FCS energy-saving ratio is about 1.3 times of the TCS. And FCS with 5 minutes control cycle has the best energy-saving rate. It's 2.7 times of FCS with 10 minutes control cycle for summertime in Taiwan.

## REFERENCES

[1] Kai-Yuan Cai and Lei Zhang, "Fuzzy Reasoning as a Control Problem", Fuzzy Systems, IEEE Transactions on Volume 16, Issue 3, June 2008, pp. 600-614.

[2] Ramot, D., Friedman, M., Langholz, G. and Kandel, A., "Complex fuzzy logic", Fuzzy Systems, IEEE Transactions on Volume 11, Issue 4, Aug. 2003, pp. 450-461.

[3] Tanaka, K. and Sano, M., "On the concepts of regulator and observer of fuzzy control systems", Fuzzy Systems, 1994. IEEE World Congress on Computational Intelligence., Proceedings of the Third IEEE Conference on 26-29 June 1994, pp. 767-772 vol.2.

[4] Tao, C.W. and Taur, J.S., "Design of fuzzy-learning fuzzy controllers", Fuzzy Systems Proceedings, 1998. IEEE World Congress on Computational Intelligence., The 1998 IEEE International Conference on Volume 1, 4-9 May 1998, pp. 416-421 vol.1.

[5] Foulloy, L. and Galichet, S, "Fuzzy control with fuzzy inputs", Fuzzy Systems, IEEE Transactions on Volume 11, Issue 4, Aug. 2003, pp. 437-449.

[15]  Gill, K., Shuang-Hua Yang, Fang Yao and Xin Lu, "A zigbee-based home automation system", Consumer Electronics, IEEE Transactions on Volume 55, Issue 2, May 2009, pp.422-430.

[16] You Ke, Gao Runquan, Zhang Cuixia, Chang Minhui, Liu Ruiqiang and Wu Jiaxin, "ZigBee-Based Wireless Sensor Networks", Information Technology and Applications, 2009. IFITA '09. International Forum on Volume 1, 15-17 May 2009, pp.618-621.

[17]  Houde Han, Jun Ji and Ankang Kan, "Optimal Design and Energy Saving on Central Air Conditioning System of Ocean Going Ships", Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific 27-31 March 2009, pp. 1-4.

[18] Tao, D., Wei, P., Guoping, L., Jiang, H. and Xiyu, L., "Adaptive energy saving monitoring technology for air condition in telecommunication equipment room", Telecommunications Energy Conference, 2007. INTELEC 2007. 29th International Sept. 30 2007-Oct. 4 2007, pp.155-160.

[19] Liu Zuojun, Xie Wenlong and Huang Yalou, "The energy saving control of air condition system in intelligent building", Intelligent Control and Automation, 2002. Proceedings of the 4th World Congress on Volume 3, 10-14 June 2002, pp. 2240-2243 vol.3

[20] Schmidt, R.R. and Shaukatullah, H., "Computer and telecommunications equipment room cooling: a review of literature", Components and Packaging Technologies, IEEE Transactions on Volume 26, Issue 1, March 2003, pp.89-98.