Intelligent Thermal Control Method for Small-Size Air Conditioning System

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Abstract: To decrease the energy consumption and maintaining the comfort of the area, a great deal of work has been done on HVAC control algorithms. A control system with the least enthalpy difference theory applied is proposed in this paper. By using the indoor air temperature and relative humidity as the feedback of the control system, the temperature set for the air conditioner is able to satisfy the indoor thermal comfort. The simulation and experimental results of this controller have shown positive energy saving while maintaining indoor thermal comfort.

1 INTRODUCTION

Due to the significant increase of energy consumption in buildings, energy saving strategies have become the first priority in energy policies in most countries around the world. In 2006, United States of America had used about 35% of the total energy for HVAC systems (US EIA, 2017). About 50% of the world's total electrical energy is consumed by HVAC systems (Fagan, Refai and Tachwali, 2007). However, most of the medium-small commercial building is still using small typed of HVAC control system.

Many approaches have been published by researchers including the algorithms to control the energy of HVAC systems. A classification of the control systems named model predictive control (MPC) were presented including classical control, hard control, soft control, hybrid control and other control techniques (Afram and Farrokh, 2014). The research then focused on the comprehensive review of MPC techniques and comparisons with other control techniques. Generally, MPC provides superior performance in terms of lower energy consumption, better transient response, robustness to disturbances and consistent performance under varying conditions. An HVAC control strategies which exploit the existence of a Wireless Sensor Network (WSN) which is capable of distributing temperature and zone occupancy information was analyzed. The research focused on a technique called "Adaptive Algorithm" which requires an additional parameter which is the expected residence time of the occupants for each zone to be controlled (Dimitris, Evangelos, John and Odysseus, 2014). An occupancy-based feedback control algorithm for variable-air volume HVAC systems that is applicable to the under-actuated case in which multiple rooms share the same HVAC equipment was implemented. Despite the inability to condition rooms independently, comfort was found to be well maintained and significant energy savings was offered (Jonathan, Saket, Siddharth, Rahul and Prabir, 2014).

In this paper, a method of using the least enthalpy difference theory is proposed. Focusing on small commercial buildings, experiments have been done to apply the least enthalpy difference algorithm which provides the optimal setting of the dry bulb temperature and relative humidity for the air conditioning system. With this, the intelligent sensing control system with the theory applied is built to obtain an energy saving algorithm.

2 METHODOLOGY

This study focused on reducing the energy consumption of HVAC system of small commercial buildings while maintaining the indoor comfort. The least enthalpy difference theory is introduced and

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implemented into the HVAC control system. Simulation and experiments are done to prove that the controller based on this algorithm shows a better result in energy saving and thermal comfort.

2.1 Theory

In this study, the least enthalpy difference theory is used as the algorithm of the HVAC control system. The algorithm uses the indoor air temperature and relative humidity as the feedback of the control system in order to maintain the indoor thermal comfort. According to ASHRAE Standard 55-2010, conditioned area with temperature and its relative humidity within the comfort zone boundary as shown in Figure 1 is defined as an area with 80% comfort. The comfort zone is set between 23ET* to 26ET* with a relative humidity ranging from 30% to 60%.

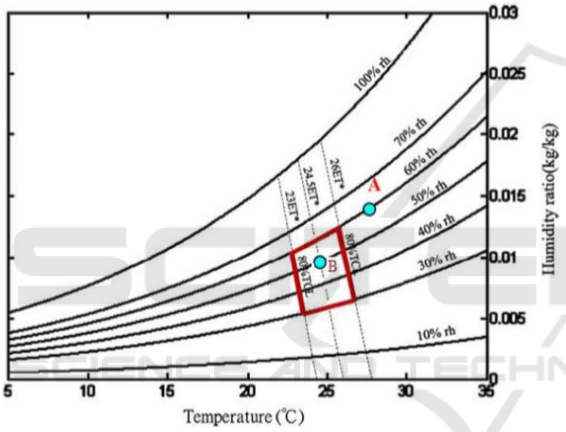

Figure 1: Psychrometric Chart.

According to the theory, if the measured temperature and relative humidity is at the outside of the comfort zone (point A) in the psychrometric chart, the enthalpy of point A will be calculated. The control system will then find a point B which is in the comfort zone and has the closest enthalpy value as point A. The temperature of point B will be set as the temperature of the air conditioner. In order to achieve this, 100 points are plotted in the comfort zone which means that there will be point B_1 to point B_{100}. Thus, when the surrounding temperature and relative humidity is measured as point A, one of the points B will be selected as the temperature of the air conditioner which is closest to point A.

2.2 Hardware Configuration

The control system includes a controller main system, MODBUS control module, temperature and humidity sensor and a power meter module. The main system consists of a temperature sensor, humidity sensor and CO_2 concentration sensor. There are also two sub-systems where each of them consists of a temperature sensor and a humidity sensor. The power meter records the energy consumption of every system and transfers the data to Cloud Smart Portal.

2.3 Simulation

Simulation has been carried out in the laboratory to compare the energy saving effect of the least enthalpy difference theory. Figure 3 shows the block diagram of the control system where the LED is the controller based on the theory. The original air conditioner control system operates without inserting the LED. The feedback of the whole control system is the temperature and relative humidity measured from the area. After passing through LED, there will be an input temperature for the air conditioner which is the temperature of point B as mentioned in Section 2.1.

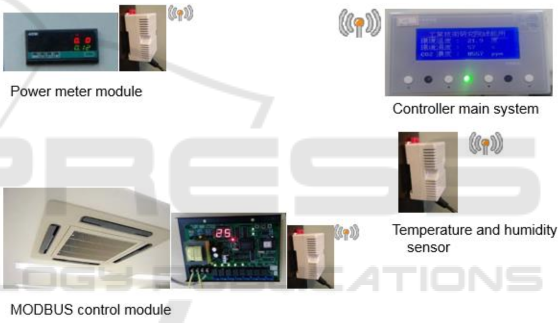

Figure 2: Hardware configuration of the control system.

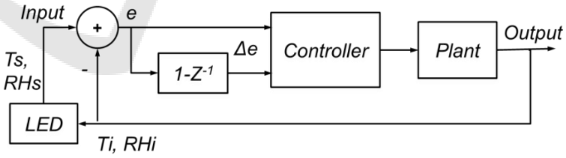

Figure 3: Block diagram of the controller.

From the simulation done, the difference in temperature detected from the surrounding after installing the LED can be observed. Figure 4 shows the difference in surrounding temperature (T_i) while Figure 5 shows the temperature set for the air conditioner by LED (T_s).

When the LED is not in used, the T_s is always set at 24°C and it remains the same throughout the operation time. When the LED is in used, the T_s is controlled according to the theory of the least enthalpy where it ranges from 23°C to 26°C.

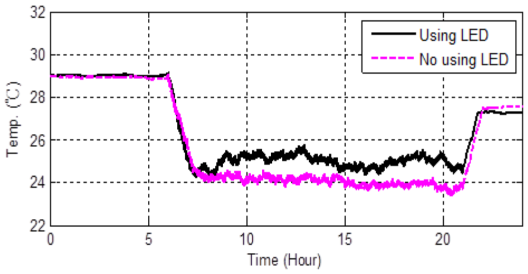

Figure 4: Difference in temperature with and without LED (Ti).

From the result of the simulation, we can observe a difference in energy consumption after installing the control system. According to Figure 6, the control system has shown a significant energy saving of 3kWh compared to the control system of the air conditioner itself.

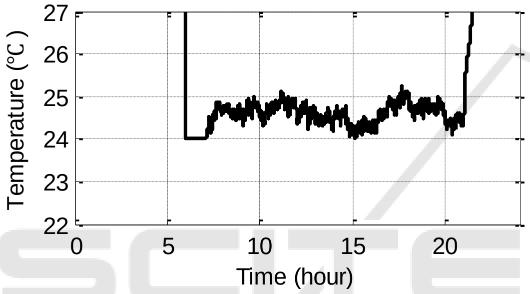

Figure 5: Setting temperature (Ts).

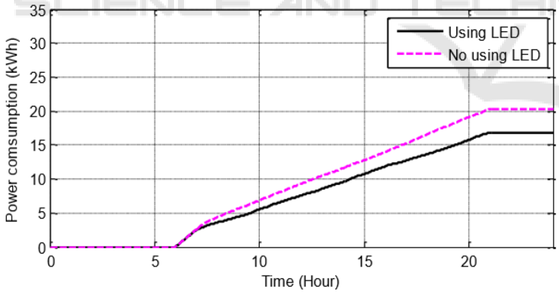

Figure 6: Difference in energy consumption.

2.4 Experiment

After obtaining positive results from the simulations, experiments were performed in a coffee shop by setting up the control system in the air conditioner of the shop. Figure 7 shows the shop selected while figure 8 shows the installation of the control system. In the month of July, ten working days have been selected as the experiment period. The operating hour of the shop is from 7.30am to 7.30pm every day. The area of the shop is about 59.5m^2 with a capacity of 3 workers and 20 customers.

Figure 7: Coffee shop selected for the experiment.

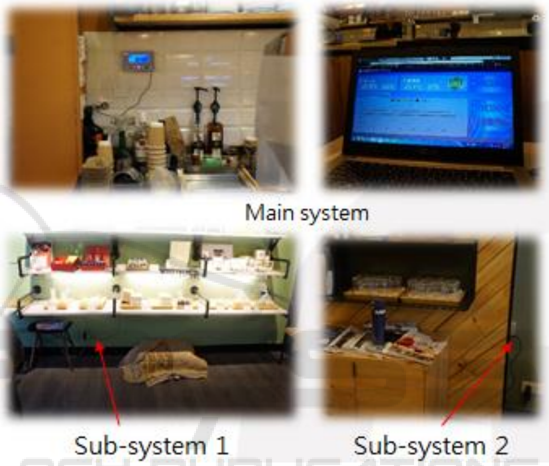

Figure 8: Control system in the shop.

Experiments 1 to 5 were carried out without using the least enthalpy difference theory on 5th July, 7th July, 8th July, 11th July and 12th July. Thus, the controller of the air conditioner itself was used. For these five experiments, the controller set the temperature of the air conditioner at 24°C without obtaining the surrounding temperature and humidity of the shop as feedback of the control system. The energy consumption of the shop for these five days is calculated and tabulated. Some other parameters such as temperature, relative humidity and concentration of carbon dioxide are also recorded.

As for experiments 6 to 10, they were done on 1st July, 4th July, 13th July, 17th July and 18th July with the theory of least enthalpy difference applied. The original control system of the air conditioner is replaced with our control system. By using the theory, the temperature of the air conditioner is set ranging from 23°C to 26°C according to the surrounding temperature and humidity. The energy consumption and other parameters are also recorded.

3 RESULT

3.1 Experimental Result

The data obtained from each of the experiment is rearranged and graphs are plotted. Graphs plotted for experiment 1 and experiment 6 are shown as examples.

Figure 9 to 12 shown the parameters recorded for experiment 1 (5/7) during the operation hour of the coffee shop which is from 7.30am to 7.30pm. For experiment 1, the least enthalpy difference theory is not applied where LED is not in used.

Figure 13 to 16 shown the parameters recorded for experiment 6 (1/7) during the operation hour of the coffee shop. For experiment 6, the least enthalpy difference theory is applied where the LED installed is on. The average value of each parameter is obtained and tabulated as shown below.

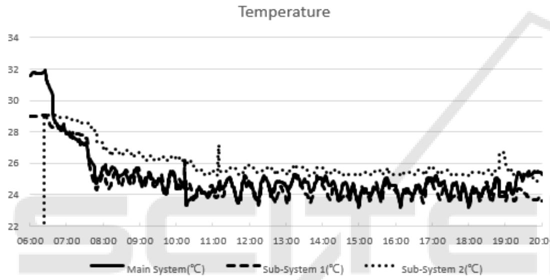

Figure 9: Temperature of experiment 1.

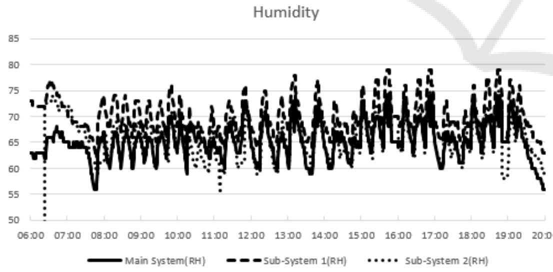

Figure 10: Humidity of experiment 1.

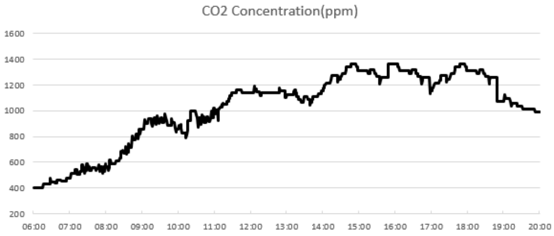

Figure 11: CO_2 concentration of experiment 1.

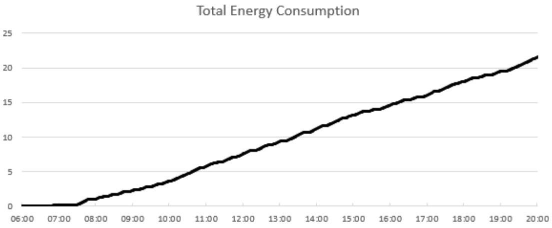

Figure 12: Total energy consumption of experiment 1.

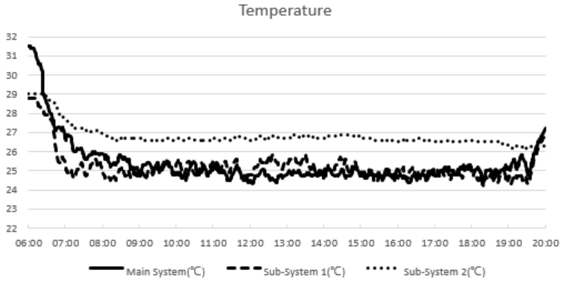

Figure 13: Temperature of experiment 6.

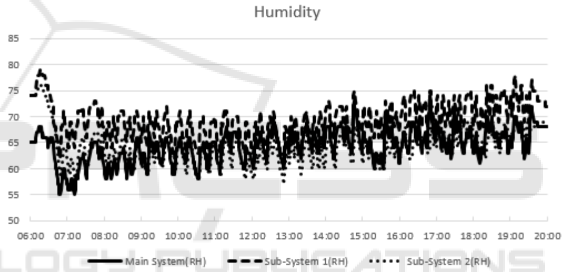

Figure 14: Humidity of experiment 6.

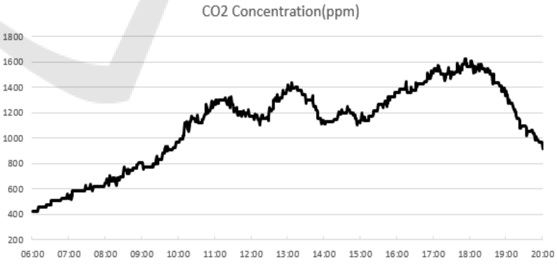

Figure 15: CO_2 concentration of experiment 6.

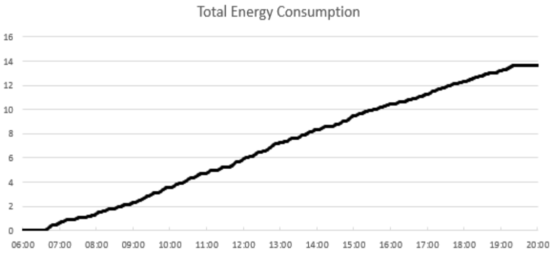

Figure 16: Total energy consumption of experiment 6.

Table 1: Average temperature.

Experiment	Average Temperature (°C)		
	Main System	Sub-System 1	Sub-System 2
1 (5/7)	25.14	24.80	25.31
2 (7/7)	25.35	24.49	25.84
3 (8/7)	24.97	24.37	26.18
4 (11/7)	25.31	24.62	26.33
5 (12/7)	25.23	24.65	25.23
6 (1/7)	25.37	25.21	26.81
7 (4/7)	25.35	25.08	25.38
8 (13/7)	25.15	24.71	26.36
9 (17/7)	25.35	25.27	27.13
10 (18/7)	25.28	24.96	26.58

Table 2: Average humidity.

Experiment	Average Humidity (RH)		
	Main System	Sub-System 1	Sub-System 2
1 (5/7)	65.22	69.95	63.93
2 (7/7)	64.41	70.52	64.32
3 (8/7)	65.80	70.88	64.64
4 (11/7)	65.65	71.60	65.40
5 (12/7)	64.12	69.48	61.29
6 (1/7)	64.41	69.52	64.25
7 (4/7)	65.03	70.59	64.08
8 (13/7)	65.02	70.06	64.70
9 (17/7)	63.98	68.64	62.45
10 (18/7)	65.37	70.57	65.12

Table 3: CO_2 concentration.

Experiment	CO_2 Concentration (ppm)
1 (5/7)	1020.60
2 (7/7)	920.28
3 (8/7)	988.26
4 (11/7)	1131.44
5 (12/7)	1082.32
6 (1/7)	1108.41
7 (4/7)	1060.65
8 (13/7)	1006.44
9 (17/7)	1013.86
10 (18/7)	1047.72

Table 1 to table 3 show the average values of the parameters that are recorded on the respective experiment days during the operation hours. The energy consumption of the experiments and the energy saving effect of the controller are calculated and tabulated as below:

Table 4: Energy consumption of experiment 1-5.

Experiment 1 – 5 (Without LED)	
Date	Energy Consumption (kWh)
5/7	21.57
7/7	20.50
8/7	20.14
11/7	20.95
12/7	22.38
ΣkWh=105.54	

Table 5: Energy consumption of experiment 6–10.

Experiment 6 – 10 (With LED)	
Date	Energy Consumption (kWh)
1/7	13.62
4/7	18.65
13/7	18.65
17/7	13.61
18/7	18.49
ΣkWh=83.02	

$$\frac{105.54 - 83.02}{105.54} \times 100\% = 21.34\%$$

As shown in the table, the application of the least enthalpy difference theory has efficiently saved 21.34%.

3.2 Discussion

According to Section 3.1, the total energy consumption of experiment 1 to 5 is 105.54 kWh whereas the total energy consumption of experiment 6 to 10 is 83.02 kWh. From the result, we find out that the control system has saved 22.52 kWh of energy which is equivalent to 21.34% of energy saving.

By applying the least enthalpy difference theory, the setting temperature of the air conditioner varies from time to time according to the surrounding temperature and relative humidity. With this, the temperature set for the air conditioner ranges from 23°C to 26°C resulting in slightly higher surrounding temperature and with lesser fluctuations. Even though the surrounding temperature is slightly higher, it is still within the thermal comfort zone. When the theory is not in used, the temperature of the surrounding varies according to the amount of customers (CO_2 concentration) which shows a greater fluctuation. This shows that with the theory applied, the temperature set for the air conditioner is more stable and thus, consuming less energy and at the same time, maintaining the comfort of the indoor climate.

4 CONCLUSION

This research project has combined the thermal comfort and the least enthalpy difference theory to control the temperature of the air conditioner according to the change in surrounding temperature and relative humidity. Maintaining the thermal comfort, the theory has successfully shown an energy saving around 20%. In conclusion, the control system with the least enthalpy difference theory applied has efficiently reduced the energy consumption with the thermal comfort maintained.

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