Experimental Comparison Between CAV Control and CO2 Ventilation Control Approaches with respect to energy saving of Air Conditioner

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Abstract

The objective of this study was to investigate the efficiency of the CO2 control ventilation to enhance energy saving compared with constant air ventilation (CAV) approach of air conditioner. To this end, a small air-conditioner room of 20 square meters was used as the testing room. A carbon dioxide (CO2) sensor was installed inside to measure indoor air quality while two enthalpy sensors were installed both inside and outside for indoor and outdoor air enthalpies online monitoring. The algorithm of CO2 control ventilation used is to compare the CO2 difference between inside and setpoint; when the inside CO2 concentration is lower than the setpoint, the controller will sent a signal to stop the fresh air intake and exhaust air fans. Measurement were conducted for three indoor temperature set points namely 24, 25 and 26 oC. The indoor CO2 level was set at 900 ppm, 800 ppm, 700 ppm and 600 ppm

The results of measured electrical power consumption showed that CO2 approach when compared to the CAV approach could save 21.82%, 18.28%, 2.26% and 0.45% and ventilator save 64.19%, 53.4%, 16.8% and 1.26%, for the four CO2 concentration indoor setpoints considered respectively. Simple mathematical relationships were also derived to estimate the energy saving using the CO2 control ventilation. This CO2 control ventilation could be mainly applied for the air condition room of Thailand.

Keywords: *Air-Conditioning , Ventilation Control ,CO2 Sensor*

1. Introduction

In Thailand the energy consumption of air conditioning systems is quite high accounting for 15% [1] of total energy consumption of the country. Various approaches and campaigns were introduced by the government to reduce electrical energy consumption such as switch off air conditioners during lunch breaks and 15 min before leaving offices and public buildings, set indoor temperature at 25°C, use of daylight etc. A common practice was used to control or limit the ventilation system which results in poor indoor air quality. Different research works considered different method to improve air quality and reduce energy. For instance, T. Leephakpreeda et al., 2001 [2] studied the occupancy-based control of indoor air ventilation for a classrooms. The results showed that by comparing the energy saving among the constant ventilation and the demand control ventilation (DCV) system, the DCV system could save more energy about 32% of electricity. Zhaojun Wang et al., 2009 [3] studied the night ventilation control strategies in office buildings. This study employed outdoor air with the temperature lower than the indoor air to use in the office building at the north of China during night time. The temperature was controlled at about 24 – 26 °C. It was found that with the night ventilation (NV) system, the cooling loads were reduced by 34.6%, 16.8%, and 20.8% on June 10, July 13 and August 11, respectively. C.Y.H. Chao et al., 2004 [4] developed a dual-mode demand control ventilation strategy for indoor air quality control and energy saving. The dual-mode was used to control the indoor air quality (IAQ) of the lecture theatre in Hong Kong University of Science and Technology and to save energy. The study compared the dual-mode demand control ventilation strategy with the fixed-rate ventilation control at fresh air flow rate 1,040 $l\ s^{-1}$ (8 $l\ s^{-1}$ per person for 130 person). A direct digital controller (DDC) was used for the fixed-rate ventilation control while for the dual–mode, a radon sensor was used together with CO_2 sensor. It was found that the decrease of energy was about 8.3-28.3 %. Bjørn Jenssen Wachenfeldt et al., 2007 [5] studied the air flow rates and energy saving potential in schools with demand – controlled displacement ventilation. In this study, the CO_2 sensor based demand controlled displacement ventilation (DCDV–CO_2) was compared with traditional constant air volume ventilation (CAV). The study took place at two Norwegian schools–Media School and Jaer School. It was found that DCDV–CO_2 reduced the ventilation air volume by 65-75 % in both schools compared to CAV that reduced the total heating energy demand by 21%. Shengwei Wang et al., 2004 [6] studied optimal and robust control of outdoor ventilation air flow rate for improving energy efficiency and IAQ. In their experimental study, the DCV and economizer for the energy saving were employed to improve IAQ in the winter in Hong Kong. In the winter, the enthalpy-based economizer was controlled from November to March. It was found that decrease of the total energy consumption was 41.7% when compared with the fixed minimum fresh air control. The CO_2 concentration was found 60 – 150 ppm lower than that with fixed minimum fresh air control. In the summer, the DCV and the IAQ was significantly found being able to save energy and the DCV and the IAQ can be acceptably maintained. A recent study was reported by V. Boonyayothin et al., 2011 [7]. Authors considered a prescribed controlled ventilation approach time to save energy. To the best of our knowledge, the use of outside air when the CO_2 is the air inside higher than 1,000 ppm which can reduce the cooling load of air-conditioning has not yet been investigated in Thailand. This is being the subject considered of this paper.

2. Experimental methodology

A small air conditioned room of 20 m^2 surface area (50 m^3) located in an office building was considered; the installed air-conditioner was 5.276 kW, A small chamber of 3.5 m^3 volume was built adjacent to the room to control fresh air conditions and ensure higher CO_2 gas in the room than 1,000 ppm. A small window type air-conditioner (2.345 kW) was installed. The room load of incandescent light was 400 W (20 W/m^2). The fresh air and exhaust air are constant at a flow rate of 13.89 $l.s^{-1}$ calculated from ASHRAE Standard 62-1989[8] (air ventilation rate of 9.2 $l.s^{-1}$ per person in an office building). The supply CO_2 gas in the room is constant at a flow rate of 0.0075 $l.s^{-1}$. It was calculated using 1.2 met physical activity of the occupants and by considering the number of person in the space equal to 1.51 person based on the standard number of people in office building 7 person/9.02 m^2 [9] [10]. The room windows were covered by plywood panels and well sealed with silicone to avoid air leakage.

Temperature and relative humidity sensors were installed outside and inside the room, whereas the CO_2 sensor was installed inside the room. The temperature and relative humidity are measured and signaled to the controller continuously every 1minute. The CO_2 sensor measure and signal it to the controller. The controller analyzes the calculated enthalpy [11] and compared the enthalpy between the outside air and the inside air. When the CO_2 inside the room is higher than the specified one (900 ppm in this test), the controller command the fresh air and exhaust air fan to operate.

Data are recorded continuously every 1 minute. The specifications of the external temperature and humidity sensor are: SIEMENS, Model: QFA3160, range 0-2000 ppm, 0-50 ºC , 0-100 % RH, error ±50 ppm @ 23ºC, ± 3 ºF@ 60ºF, ±2% RH. The internal CO_2, temperature and humidity sensor specifications are: SIEMENS, Model:N474 , range 0-2000 ppm, 0-50 ºC , 0-100 % RH, error ±50 ppm @ 23ºC, ± 3 ºF@ 60ºF. ±2% RH. The controller is Easylo, Model: 30 p, range 0-10 V, 4-20 mA, error ±0.005 V, ±0.01 m A.

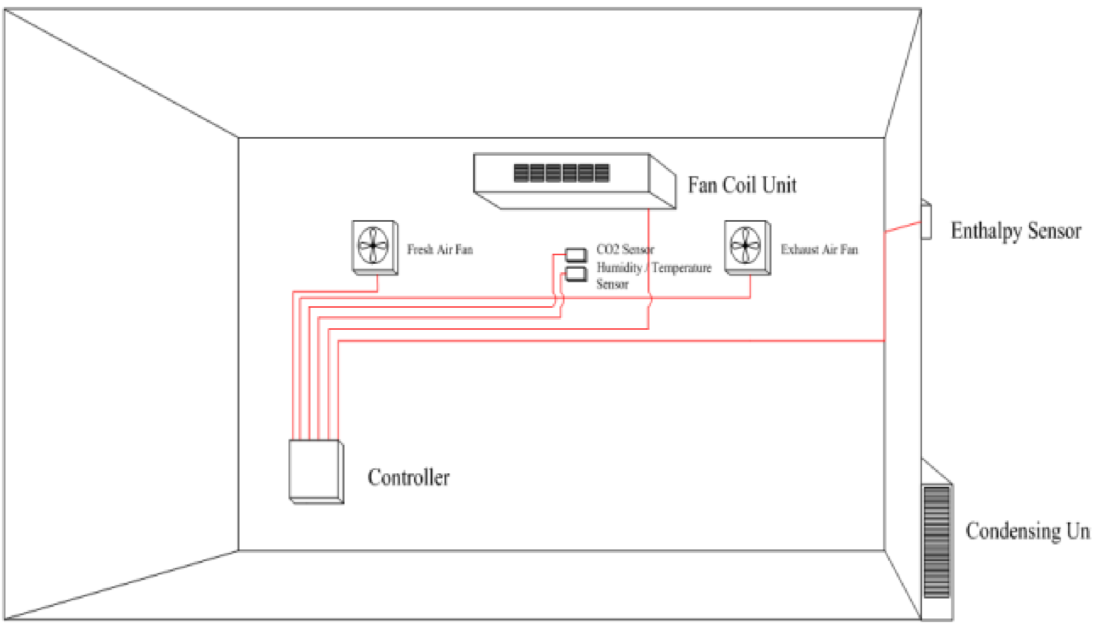

Figure 1 Schematic diagram of the experimental.

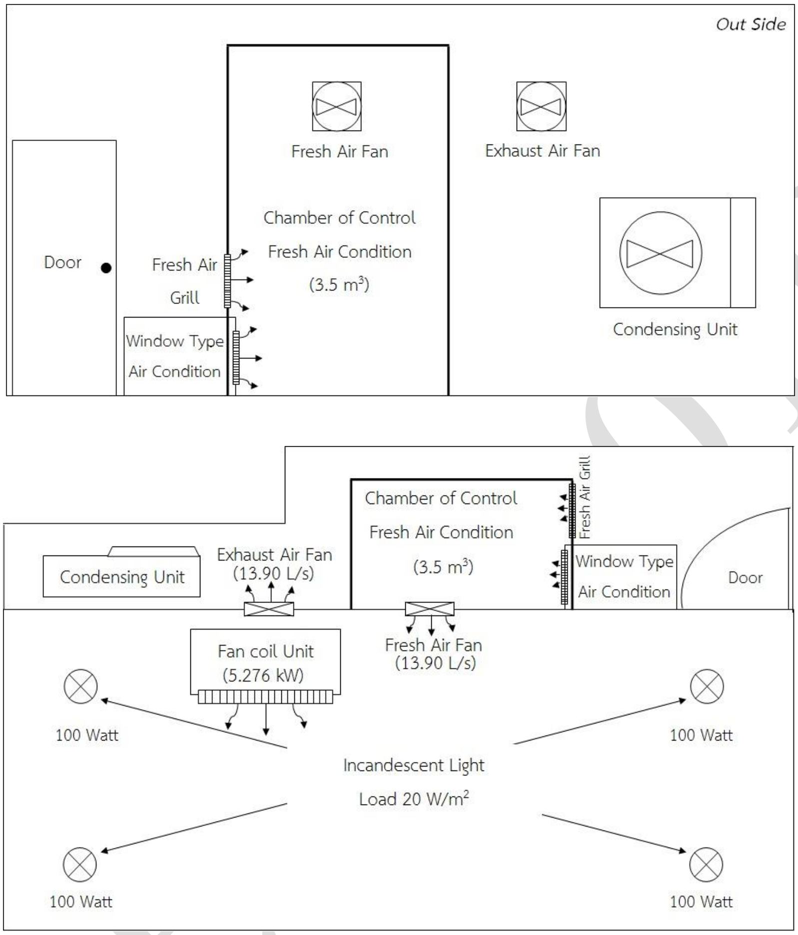

Figure 2 Floor (top) and side (bottom) plan of the experimental room

3. Results and disscussion

In this serie of experiments, in addition the three indoor air temperatures considered (24 ºC, 25 ºC and 26 ºC) tests were conducted with CO_2 level in the room non-controlled and controlled at 900 ppm, 800 ppm, 700 ppm, 600 ppm. Test were conducted on the (CAV and CO_2 VA) approaches investigated separately during several days with relatively similar ambient conditions that can allow subjective and quantitative analysis. In case of controlling CO_2, comparison is made with the constant air ventilation. The results can be summarized as follows.

3.1 The results at inside air temperature controlled at 24 ^oC

We remind that in this case, the ventilators will not run when the CO_2 of the inside air is lower than the CO_2 setpoint. Figure 3 shows the amount of CO_2 within the room. At 800 ppm and 900 ppm, the amount of CO_2 in the room was relatively constant throughout the 24 hours, but at 600 ppm, 700 ppm and without CO_2 control the amount of CO_2 in the room changes between day and night or continuous ventilation following the variation of the outside air. In fact at low CO_2 level, ventilators bring more air from the outside into the inside so that cannot control the amount of CO_2 at the setting one. Figure 4 shows the hourly variations of the enthalpy of outdoor air and room air calculated using measured temperature and relative humidity data, the amount of outside CO_2in various amounts similarly between 82. 28kJ/kg to 82. 83kJ/kg and the inside CO_2 in the control is similarly between 51.64 kJ/kg to 51.93 kJ/kg. Figure 5 shows the enthalpy differences between the inside air and outside air tend to follow the outside enthalpy. The higher difference is during the day. As a result, the cooling load of the air conditioning during the day is more than during the night. The average calculated enthalpy difference of the CO_2 in the control volumes various between about 30.35 kJ/kg to 31.17 kJ/kg, different percentages is 2.63, which is very close. Figure 6 shows the electricity consumption of the air conditioner including the ventilation fans. Obviously the higher electricity consumption is during the day. The trend of energy consumption followed well the difference of enthalpy between the inside air and the outside air. The average hourly electrical energy consumption while controlled the amont of CO_2 at 900 ppm, 800 ppm, 700 ppm, 600 ppm and without controlled is 1,191.48 Wh, 1,238.22 Wh, 1,478.80 Wh, 1,506.28 Wh and 1,514.70 Wh, respectively. The electrical energy consumption at low and uncontrolled CO_2 levels is higher due to the higher ventilation rates which increases the cooling load. Figure 7 shows the analysis of energy savings from using the enthalpy control system compared with the CAV system that open the ventilator fan all times. Found that during at noon the energy saving is more effective than at night. Controlling high CO_2 are saving energy more than controlling low CO_2. The average energy saving of the air conditioner that controlled amount of CO_2 at 900 ppm, 800 ppm, 700 ppm and 600 ppm are about 21.26%, 18.19%, 2.32%, and 0.54%, respectively, so the implementation should be controlled at around 800 ppm to 900 ppm. Figure 8 shows the relationship between the enthalpy difference and the electrical energy saving rate with the CO_2 control system for the CO_2 controlled at 900 ppm, 800 ppm, 700 ppm and 600 ppm. Based on the plots, simple mathematical equations are derived that could be used to analyze the results of the energy saving by using the CO_2 control system when the difference of the outside air enthalpy and inside air enthalpy ($\triangle h$) and ventilation rate (L/s) are known.

At CO_2 900 ppm: ESR/V (Wh/L/s) $= 0.9009 \triangle h - 0.1475$ at $R^2 = 0.7688$ (1)

At CO_2 8 00ppm: ESR/V (Wh/L/s) $= 0.6387 \triangle h + 3.3457$ at $R^2 = 0.7976$ (2)

At CO_2 7 00ppm: ESR/V (Wh/L/s) $= 0.3488 \triangle h - 6.3183$ at $R^2 = 0.7312$ (3)

At CO_2 6 00ppm: ESR/V (Wh/L/s) $= 0.1314 \triangle h - 2.7139$ at $R^2 = 0.6744$ (4)

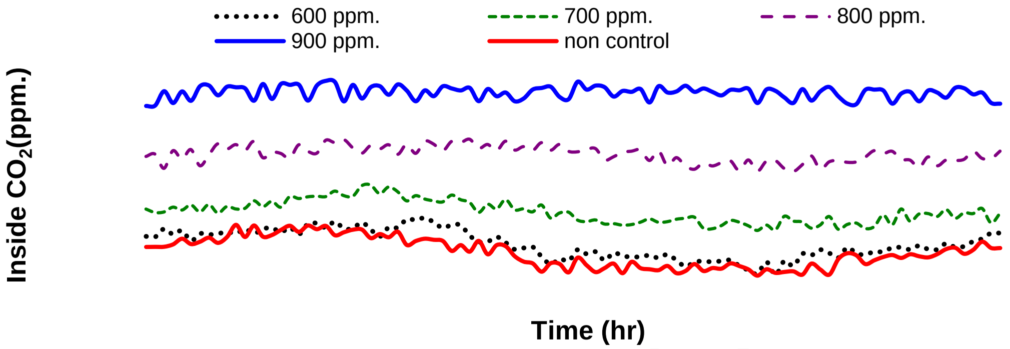

Figure 3 Variations of inside CO_2 at the room temperature 24 °C.

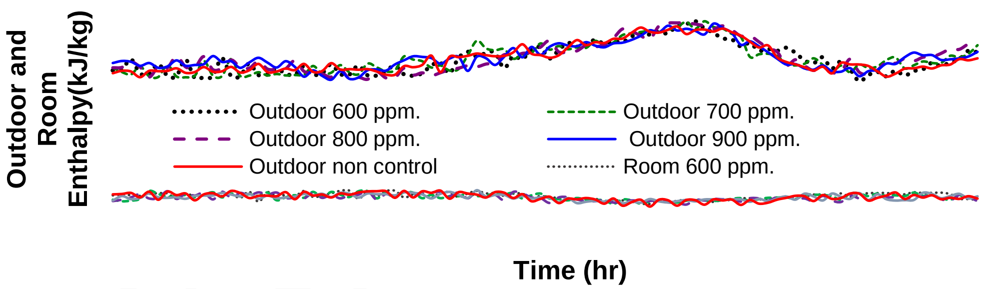

Figure 4 Variations of the enthalpy of outside and inside airs at the room temperature 24 °C.

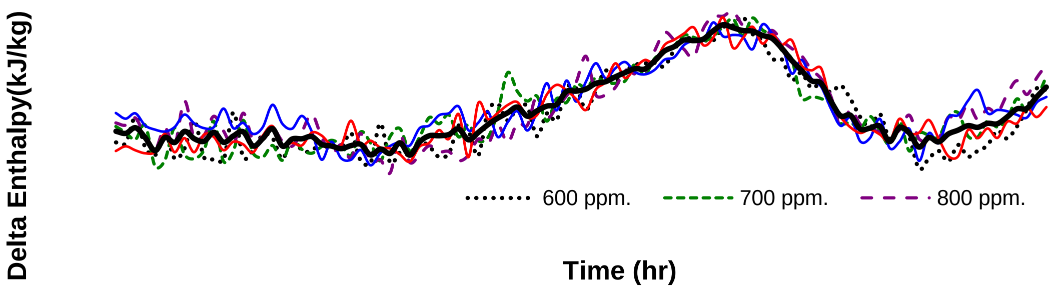

Figure 5 Variations of enthalpy difference between the inside and outside airs at the room temperature 24 °C.

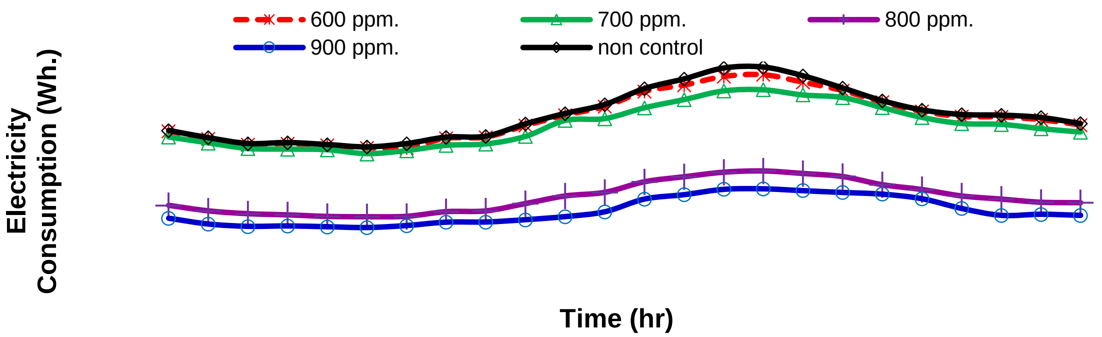

Figure 6 Variations of the electricity consumption of the air conditioner and fans at room temperature 24 °C.

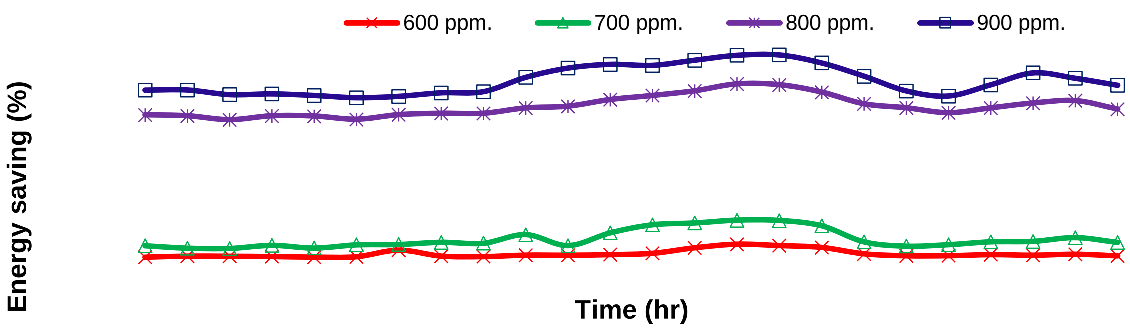

Figure 7 Variations of the percentage of the energy saving with the CO_2 control system at room temperature 24 °C.

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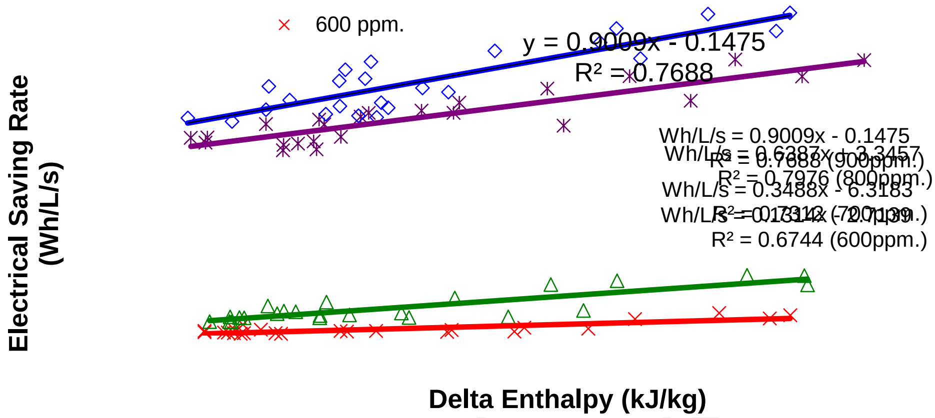

Figure 8 Relationships between the enthalpy difference between outside and inside airs and the electrical saving rate with the CO_2 control system at room temperature 24 °C.

3.2 The results at inside air temperature controlled at 25 °C

Figures 9 to 11 presents the different results as discussed is section III.1. The observations made are still valid. However lower electrical energy is measured due to the higher indoor set point.

The relationships between the enthalpy difference and the electrical energy saving rate with room controlled at 25 °C are as follows :

At CO_2 900 ppm: ESR/V (Wh/L/s) = 0.7469 $\triangle$h +5.4009 at R^2 = 0.8731 (5)

At CO_2 8 00ppm: ESR/V (Wh/L/s) = 0.4614 $\triangle$h +8.5699 at R^2 = 0.7577 (6)

At CO_2 7 00ppm: ESR/V (Wh/L/s) = 0.3026 $\triangle$h – 4.4507 at R^2 = 0.6997 (7)

At CO_2 6 00ppm: ESR/V (Wh/L/s) = 0.0753 $\triangle$h – 1.2286 at R^2 = 0.6867 (8)

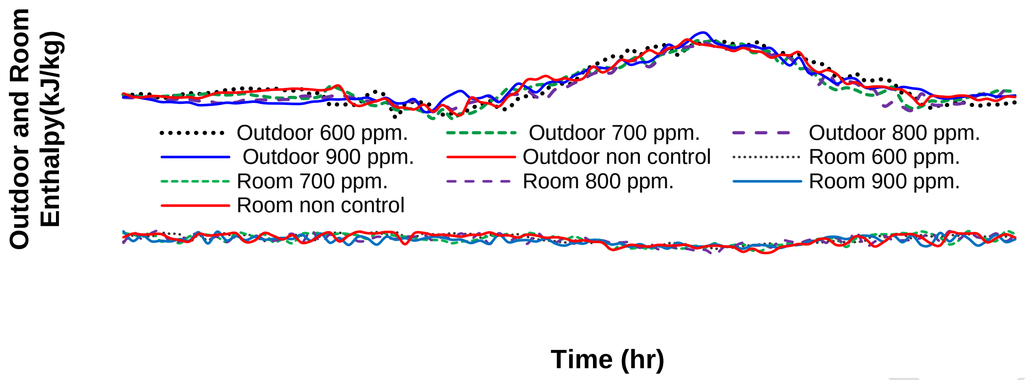

Figure 9 Variations of the enthalpy of outside and inside airs at the room temperature

25 °C.

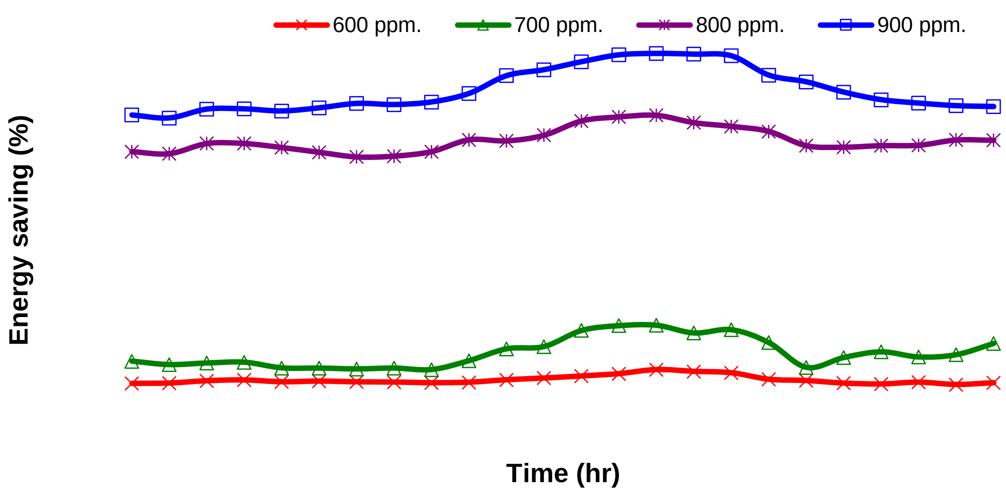

Figure 10 Variations of the percentage of the energy saving with the CO_2 control system at room temperature 25 °C.

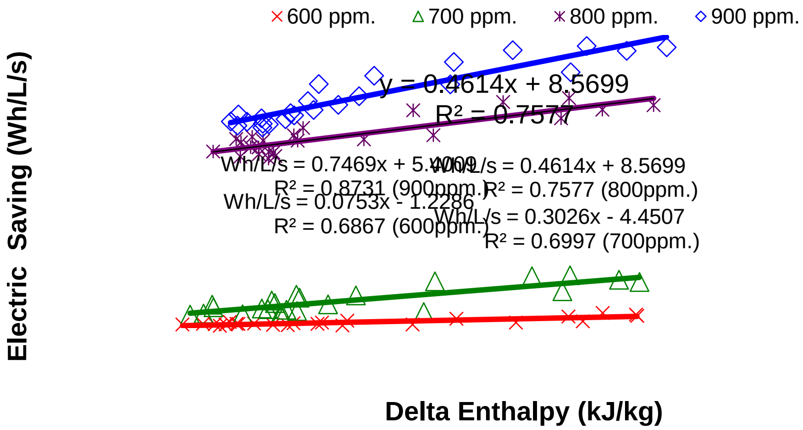

Figure 11Relationships between the enthalpy difference between outside and inside airs and the electrical saving rate with the CO_2 control system at room temperature 25 °C.

3.3 The results at inside air temperature controlled at 26 °C

Figures 12 to 14 presents the different results as discussed is section III.1. The observations made are still valid. The electrical energy consumption is lowest due to the higher indoor set point considered.

The relationships between the enthalpy difference and the electrical energy saving rate with room controlled at 26 °C are as follows :

At CO_2 900 ppm: ESR/V (Wh/L/s) = 0.5298 $\triangle$h +10.316 at R^2 = 0.8517 (9)

At CO_2 8 00ppm: ESR/V (Wh/L/s) = 0.5476 $\triangle$h +6.1496 at R^2 = 0.8627 (10)

At CO_2 7 00ppm: ESR/V (Wh/L/s) = 0.1825 $\triangle$h – 2.1789 at R^2 = 0.8650 (11)
At CO_2 6 00ppm: ESR/V (Wh/L/s) = 0.0604 $\triangle$h – 1.1132 at R^2 = 0.6140 (12)

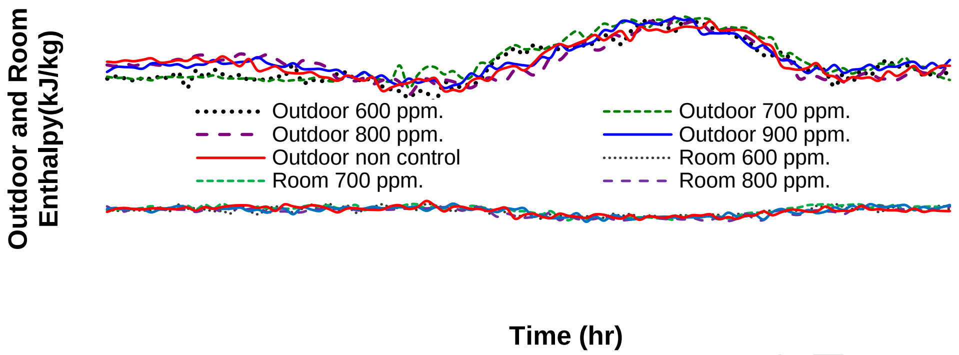

Figure 12 Variations of the enthalpy of outside and inside airs at the room temperature

26 °C.

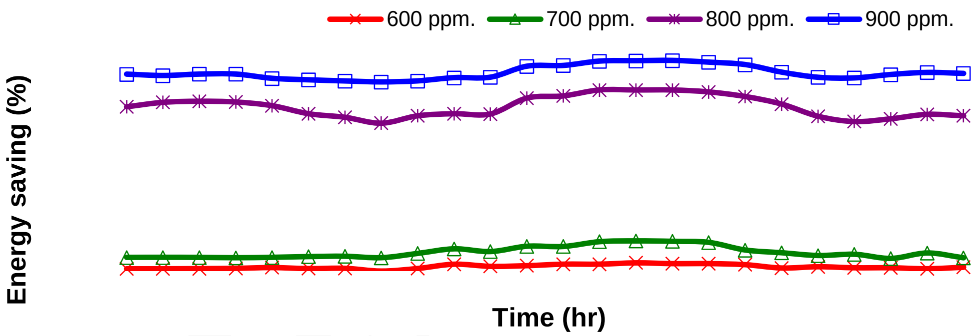

Figure 13 Variations of the percentage of the energy saving with the CO_2 control system at room temperature 26 °C.

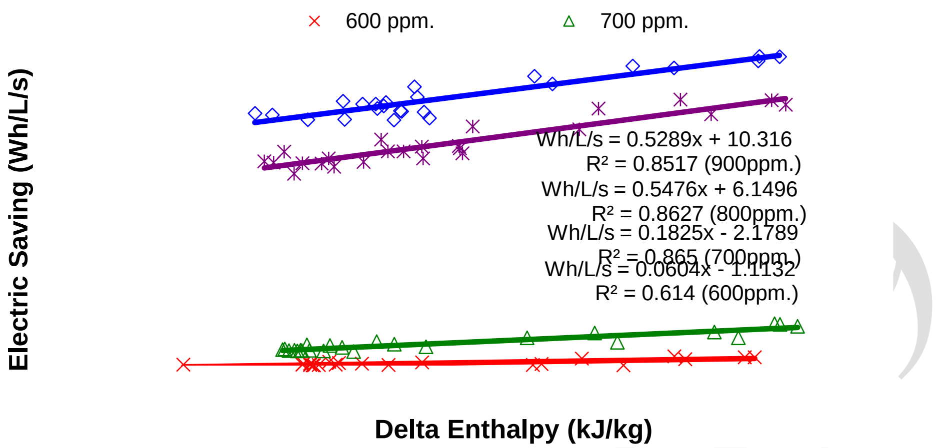

Figure 14 Relationships between the enthalpy difference between outside and inside airs and the electrical saving rate with the CO_2 control system at room temperature 26 °C.

4. Conclusion

When the CO_2 of the inside air is lower than the 1,000 ppm significant amount of electrical energy consumed by to air conditioner could be saved. The CO_2 control system was investigated in this paper using an experimental test rooms with controlled conditions. Performance was compared to the CAV control system. The average percentage of the electrical energy saving at the CO_2 control in the room at 900 ppm, 800 ppm, 700 ppm, and 600 ppm was about 21.82%, 18.28%, 2.26% and 0.45%, respectively. The average percentage of the electrical energy saving of the ventilator at the CO_2 control in the room at 900 ppm, 800 ppm, 700 ppm, and 600 ppm was about 64.19%, 53.4%, 16.8% and 1.26% ,respectively . Hence, the CO_2 in the room should be set at 900 ppm.

The electrical saving rate (ESR), during the CO_2 amount control at relatively 900ppm, can be found from the following equations:

- At room temperature 24 °C : ESR/V (kWh/L/s) = (0.9009 $\triangle$h – 0.1475)*hr/year/1000
- At room temperature 25 °C : ESR/V (kWh/L/s) = (0.7469 $\triangle$h +5.4009)*hr/year/1000
- At room temperature 26 °C : ESR/V (kWh/L/s) = (0.5298 $\triangle$h +10.316)* hr/year/1000

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