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ENERGY EFFICIENCY OF A VARIABLE SPEED OF THE CENTRALIZED AIR CONDITIONING SYSTEM USING PID CONTROLLER

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Graphical abstract
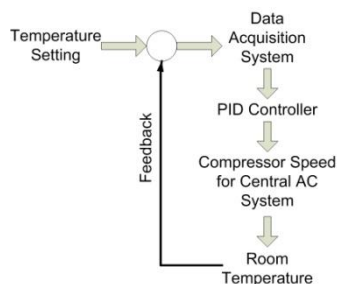
Abstract

PID control system for air-conditioning system in residence is presented in this manuscript. The control strategy is focused on low energy consumption and thermal comfort for indoor user. The algorithm is developed to control the compressor speed at an appropriate speed according to the temperature inside the controlled area using PID controller. Software is developed to measure and interface the system with controlling the system according to the algorithm. The temperature settings are 20, 22 and 24°C with internal heat load of 0 and 1000 Watt. The results obtained proved that the technique can lower the energy consumption and increased temperature control for better thermal comfort compared to on/off controller.

Keywords: PID control; energy saving; air conditioning

Abstrak

Sistem kawalan PID untuk penggunaan pada penghawa dingin kediaman telah dibentangkan pada manuskrip ini. Strategi kawalan memfokuskan kepada penggunaan tenaga yang rendah serta keselesaan haba untuk pengguna di dalam bilik yang dikawal. Algoritma telah dibentuk untuk mengawal kelajuan pemampat pada kelajuan yang sepatutnya berdasarkan kepada suhu di dalam bilik yang dikawal menggunakan kawalan PID. Sebuah Perisian telah dibentuk untuk mengukur dan mengeluarkan pemuka sistem serta mengawal sistem berdasarkan algoritma yang dibuat. Tetapan suhu ialah 20, 22 dan 24C dengan beban haba dalaman sebanyak 0 dan 1000 W. Keputusan yang diperoleh membuktikan bahawa teknik tersebut boleh mengurangkan penggunaan tenaga dan menambahkan kebolehan pengawalan suhu untuk memperoleh keselesaan haba yang lebih baik berbanding kawalan hidup/mati.

Kata kunci: Kawalan PID; penjimatan tenaga; penyaman udara

1.0 INTRODUCTION

Thermal comfort through the air conditioning (AC) system nowadays is a necessity and has become a living standard and expectations of human as occupants [1-3]. The usage of AC gives a considerable impact on energy consumption of the whole system. The design of an AC system should be fundamentally based on thermal comfort need of the human body, but the current trend on design seems to oversize the system to compensate for faster cooling time during peak temperature [4].

Energy consumption is directly related to the performance of the AC or known as the coefficient of performance (COP)[5-6], which is related to the energy consume by the compressor during rotational power consumption. The energy consumed could be reduced by decreasing the rotational speed of the compressor by implementing an inverter to control the speed. In the United States, energy usage of compressor in terms of COP was 4.14 in the late 1970s and improved to 5.86 in 1996. In 1997, the lowest energy usage was 7.17 COP [7].

The frequency of the inverter is directly proportional to the compressor speed [7-9]. The higher the frequency of the inverter, the higher the compressor speed. To obtain the highest frequency, the compressor should work at the appropriate speed to match the cooling load needed to cool down the room temperature to the temperature setting [7, 10].

This manuscript focused on the development of control system using the proportional-integral-derivative (PID) controller to obtain higher-energy saving with better temperature control for an AC system by implementing variable-speed compressor drive control. The result is compared to the common on/off controller.

2.0 COEFFICIENT OF PERFORMANCE

COP is known as the energy removed from the evaporation process divided by energy consume by the compressor is shown in Figure 1. The equation can be shown as [11]:
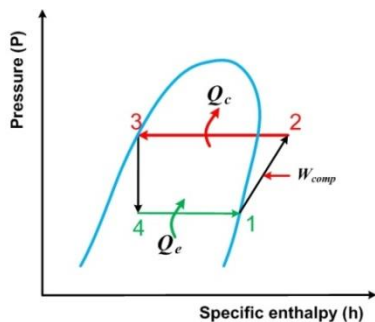

Figure 1 P-h diagram of simple vapor compression refrigeration cycle

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

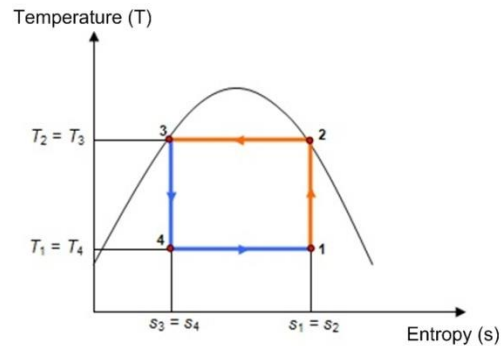while for Carnot refrigeration cycle is shown in Figure 2 [11]:

Figure 2 T-s diagram of reversed Carnot cycle

$$COP_{carnot} = \frac{T_1(s_1 - s_4)}{(T_2 - T_1)(s_1 - s_4)} = \frac{T_1}{T_2 - T_1} \qquad (2)$$

where;

h_1 = enthalpy at inlet compressor (kJ/kg)
h_2 = enthalpy at outlet compressor (kJ/kg)
h_4 = enthalpy at inlet evaporator (kJ/kg)
Q_e = refrigerating effect (kJ/kg)
W_{com} = compression work (kJ/kg)
T_1 = evaporating temperature (°C)
T_2 = condensing temperature (°C)
s_1 = entropy at the inlet compressor (kJ/kg.K)
s_4 = entropy at the inlet evaporator (kJ/kg.K)

3.0 PID CONTROLLER

PID controller is universally used algorithm for control strategy. It can be defined as [12-13]:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \qquad (3)$$

The use of proportional control (P) requires just one variable to be selected, the proportional gain K_p, for the control system to satisfy the required dynamic behavior. The use of a proportional plus integral gain (PI) or proportional plus derivative gains (PD) controller requires the selection of two variables, K_p and K_i or K_p and K_d, respectively. With a PID controller, three variables have to be selected: K_p, K_i and K_d. For a digital PID controller [11-12] the controller gains KP, KI and KD can be determined from the analog controller gains using the following relationships:

KP = K_p
KI = $K_i \times \Delta t$
KD = $K_d / \Delta t$

where Δt is the sampling time (minute).

The use of proportional control (P) requires just one variable to be selected, the proportional gain K_p, for:

$$u_P(t) = (K_P \times e(t)) \qquad (4)$$

$$u_{PI}(t) = [K_P \times e(t)] + [K_I \times (\sum_{i=1}^{n} e(t-i) \times \Delta t)] \qquad (5)$$

$$u_{PD}(t) = [K_P \times e(t)] + \left[K_D \times \left(\frac{\Delta e(t)}{\Delta t} \right) \right] \qquad (6)$$

$$u_{PID}(t) = [K_P \times e(t)] + [K_I \times (\sum_{i=1}^{n} e(t) \times \Delta t)] + \left[K_D \times \left(\frac{\Delta e(t)}{\Delta t} \right) \right] \qquad (7)$$

where;

e (t) = setpoint temperature (t)
     – measured temperature (t)
Δe = e(t) – e(t-1)

4.0 EXPERIMENT SETUP

Temperature and pressure represented by *T* and *P* respectively in Figure 3. T_1 and T_2 are input and output temperatures at the compressor respectively; T_3 and T_4 are input and output temperatures at the condenser respectively; T_5 and T_6 are input and output temperatures at evaporator respectively; and T_7-T_{11} is room temperature distribution measurements. P_1 and P_2 are input and output pressures at the compressor respectively; P_3 is input pressure at the condenser, and P_4 is input pressure at expansion valve. Thermocouple type T and ICs temperature sensor is used to measure the temperatures, while Bourdon gauges is used to measure pressure of the system. Energy consumed is measured by PCI-1711/PCLD-8710 that interfaced to the computer. The experiments are conducted with on/off and PID controller respectively with temperature setting of 20, 22 and 24°C with internal heat loads of 0 and 1000 W.

The compressor speed controller made up of the ICs temperature sensor, a computer with a subroutine of on/off and PID installed an inverter and compressor with coupled electric motor. The ICs temperature sensor monitors the room condition and gives a signal to the computer so that the computer can produce the proportional electrical signal. The signal is filtered using optoisolator and lowpass filter to minimize noise before it reaches the control system. The output signal of the computer is the function of error of the conditioned system. On/off and PID controllers supply the signal output to the inverter which varies the frequency so that the compressor speed can be the controller. The frequency is linearly proportional to the control signal. Frequency of 50 Hz is supplied to the system for on/off controller and 5 to 50 Hz for the PID controller so that the compressor speed is modulated depending on the controlled space.
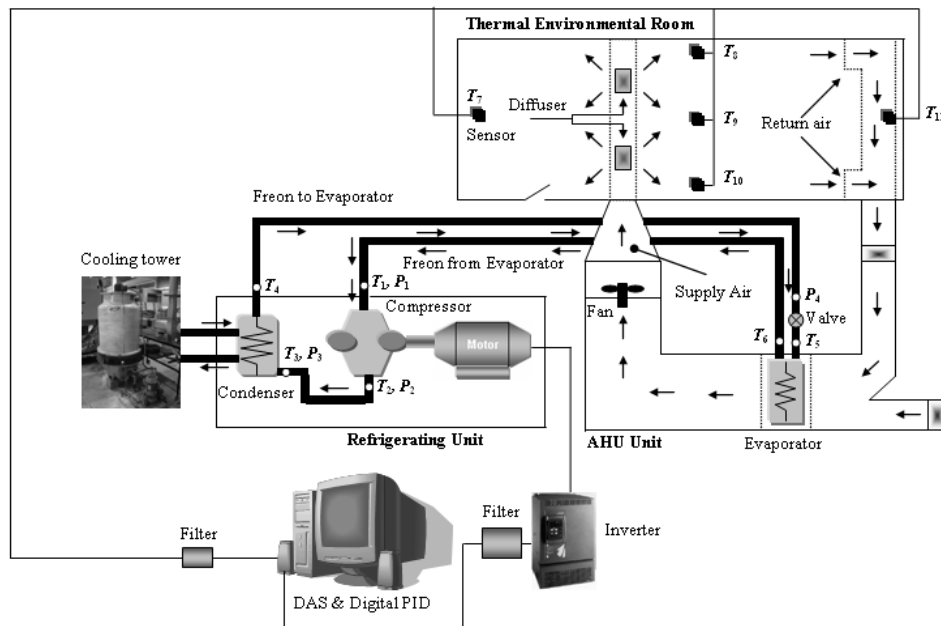

Figure 3 The experimental setup

5.0 ENERGY ANALYSIS

Energy saving is the terms of saving using a percentage unit between on/off controller energy consumption and PID controller energy consumption and can be described as:

$$\text{Energy saving} = \frac{(\text{On/Off energy}) - (\text{PID energy})}{(\text{On/Off energy})} \times 100 \quad (8)$$

6.0 RESULTS AND DISCUSSION

6.1 Room Temperature Distribution

Figure 4 – Figure 6 shows the motor speed and temperature responses at temperature setting of 20, 22 and 24°C. The inverter frequency is set at maximum initially at 50 Hz, and the compressor speed reduced by the temperature decrease and reached the temperature setting. The PID controller varies its compressor speed according to the temperature of the controlled room. Lower temperature setting required longer cooling time and longer maximum compressor speed, thus higher- energy consumption too. It is also observed that increasing the internal heat load affects the room- temperature cooling time and energy consumed.
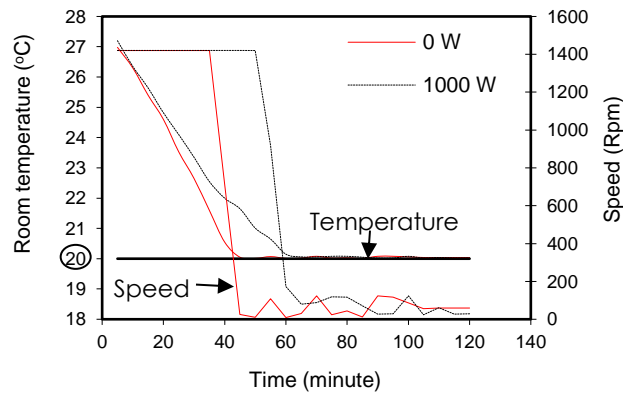

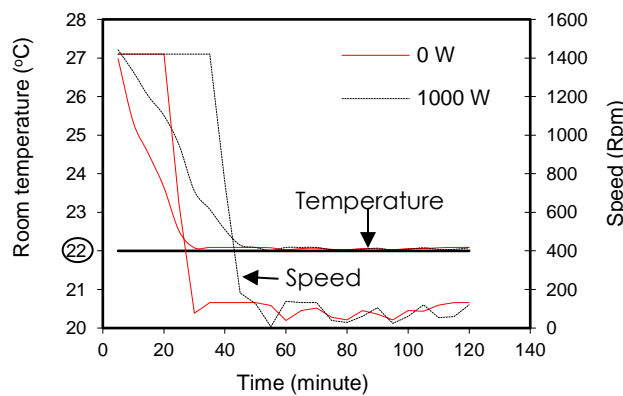**Figure 4** Motor speed and temperature responses at temperature setting 20°C

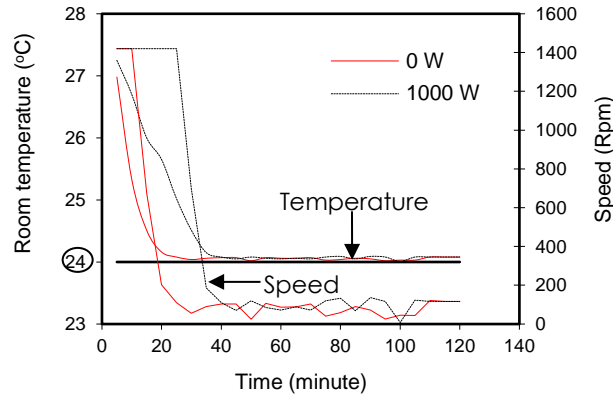**Figure 5** Motor speed and temperature responses at temperature setting 22°C

Figure 6 Motor speed and temperature responses at temperature setting 24∘C
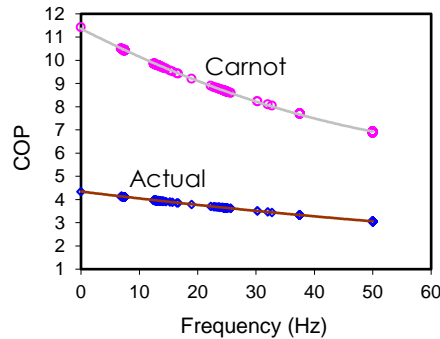

Figure 7 The actual and Carnot COP

6.2 Coefficient of Performance

Figure 7 shows the actual and Carnot COP against frequency of the inverter. The average values of actual and Carnot COP is 3.05 to 4.34 and 6.88 to 11.39 respectively. With variable-speed compressor, volumetric and isentropic efficiencies and COP increases when the compressor speed is reduced. The COP is inversely related to the frequency, the higher the frequency, the smaller is the COP and vice versa. In general, all COPs are almost inversely proportional to the frequency. The increase in COP indicates the reduction in energy and greater energy- saving potential.

6.3 Energy Consumption and Energy Saving

Figure 8 and 9 shows the energy consumption of on/off controller and PID controller with different internal heat load and various temperatures setting using Eq. 8. It can be observed that the energy saving could be achieved from 28.46 to 55.61% by implementing variable-speed compressor using PID controller. It is also observed that higher internal heat load consumed higher energy to cool down the controlled room.

The basic difference between variable-speed refrigeration using PID controller and conventional refrigeration systems using on/off or thermostat controller is in the control of the refrigerant capacity. In variable-speed refrigeration, the refrigerant capacity of the refrigeration system is matched to the load by regulating the speed of the compressor motor in such a way that the refrigerant capacity of the system tracks the load dictated on it by varying operating conditions.
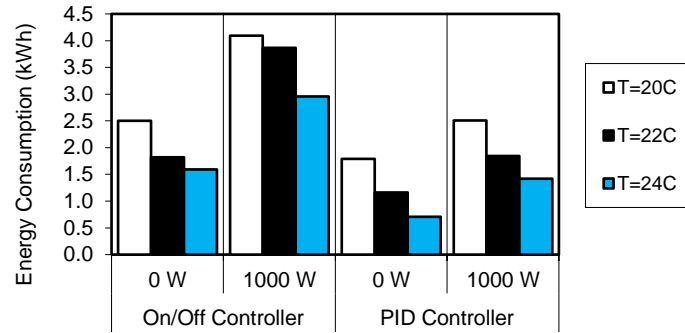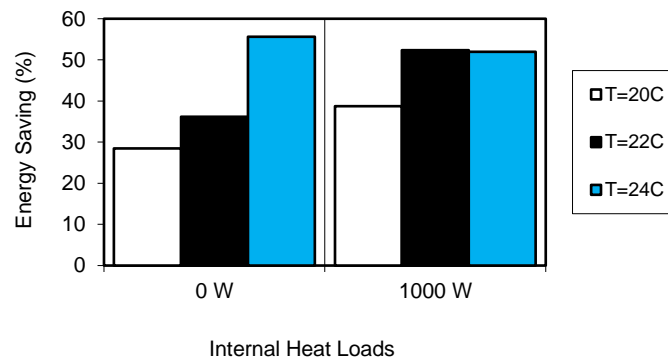
Figure 8 The energy consumption distribution

Figure 9 Energy saving

7.0 CONCLUSION

Study on PID and on/off controller to control the compressor speed of an AC system so that the room temperature can be maintained close to the setpoint temperature. The PID controller shows an excellent energy saving and temperature control compared to on/off controller. This manuscript shows the experimental results of both controllers in terms of performance, room temperature and energy consumption. The analysis shows that the PID controller obtained the highest energy saving compared to on/off controller. This study proves that the application of variable-speed compressor could obtain significant energy saving when implemented with a suitable control strategy.

Acknowledgement

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