International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 2 Issue 12 (December 2012)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

Application of Air - Cooled Chiller for Comfort and Energy Saving

Yung-Chung Chang[1], Chiun-Ren Su[2], Jyun-Ting Lu[3], Ching-Liang Chen[4], Ching-Wei Chen[5], Cheng-Wen Lee[6], Jin-Kuei Lee[7]

[1] Professor, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[2] Student, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[3] Student, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[4] Student, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[5] Student,Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[6] Student, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC
[7] Student, Department of Air-Conditioning and Refrigeration, National Taipei University of Technology, Taiwan, ROC

Jyun-Ting Lu, rasheed@hotmail.com

Abstract. In this study, a frequency converter was used to carry out variable frequency control to the compressor with constant frequency of a small 3RT central air-conditioning air-cooled chiller, but the indoor blower and cooled water pump were still kept by constant frequency operation. It is to explore the energy-saving effect of chiller compressor and the cooling fan after being carried out the variable frequency control, on the premise of PMV, the index of thermal comfort, set to 0.5. The experimental results indicated that under constant frequency operation, the average power consumption of compressor was 2.62kW and the average power consumption of cooling fan is 0.33kW; under variable frequency operation, the average power consumption of compressor is 2.38kW and the average power consumption of cooling fan was 0.29kW. After variable frequency control, the compressor could save 9% power consumption, and the cooling fan could save about 14% power consumption, with remarkable energy-saving results.

Keywords: Air cooled chiller; Comfort; Variable frequency; Energy saving

1 Introduction

Since the air-conditioning electricity in the building power consumption accounted for the largest proportion, in order to reduce the increased cost of power generation due to overestimation of power consumption, Taiwan Power Company (TPC) proposed incentives so that users can amend the "contract capacity" to reduce the basic tariff, and TPC thus can improve the reliability of power supply. In this paper, the power consumption and space comfort of an air-cooled chiller was analyzed to identify its operation characteristics and power consumption situation, through variable frequency control technique to find out the minimum power consumption in line with index conditions of human comfort PMV, thereby reducing contract capacity and reaching the energy-saving purpose.

For theo peration characteristics and energy-saving practices of air-cooled chiller system, there are related literatures as follows:

Chang (2002) put forward the optimized operation method of a chiller could be divided into two stages, through the Optimal Chiller Sequencing (OCS) and the Optimal Chiller Loading (OCL) respectively to decide the minimum power consumption for the start and stop of the chiller, so that the chiller could operate under the optimal COP conditions, and meet the load required by air-conditioning to save energy [1].

Scholar Ashfaque (2009) proposed that most chillers operated under PLR with low operation efficiency and air-conditioning power consumption accounted for about more than 60% of entire building, but through pre-cooling and the heat recovery unit, the chiller could save 26 kW/m2/month and 42 kW/m2/month respectively [2].

Two scholars F.W. Yu and K.T. Chan (2007) brought forward the floating condensing temperature control. Through the way of spray, carried out the evaporative cooling to condensers to improve the COP of air-cooled chiller. Since the condenser cooling conditions were generally designed with ambient temperature of 35℃, and the high-pressure condensing temperature control was fixed at 50℃, which was unable to take full advantage of the cooling capacity of the condenser, so the COP could not be improved. With the load changes, in response to the environment by adjusting the cooling fan speed can improve the COP; the maximum COP of the air-cooled chiller occurred between 0.71~0.84 of PLR, the condensing temperature can be regulated by outdoor temperature; generally, COP is between 2.7 to 3.2, and the same of water-cooled chiller is between 4.2 to 5.4 [3][4][5].

Chang (2009) proposed using heat balance equation by means of regression to establish the air-handling unit load model of R2 higher than 0.9, and the evolution strategy was used to find the best operation setting parameters, so that the system could meet the space load demand and achieve the lowest power consumption [6].

Wang (2011) took 5% as basis every time to regulate the electric chilled water valve opening of the air-handling unit, and modulate the fan speed of the air-handling unit to control the PMV within 0.5 for the comfort of interior space. When the PMV is increased, the increase of space dry bulb temperature is lower than relative humidity; the dry bulb temperature rises about 2.5℃ every 90 minutes, and relative humidity rises to 5% RH every 15 minutes [7].

Shahin and Steve suggested that in naturally ventilated office building, there is a significant correlation between comfort and indoor dry bulb temperature, simplifying PMV index required by six variables, and R2 value is more than 0.9 [8].

Chen (2008) used the Ryodoraku to carry out the human response experiment, dividing the comfortable conditions into the changes in physical environment and in human response; moreover, explored the influence of physiological and psychological changes on comfort, drawing men and women do not have same feelings of comfort, and indoor comfort will impact the personnel work efficiency over time [9].

Lu (2008) proposed using Lagrangian method to solve for the optimal COP to carry out load shedding, and in the case where the chiller capacity is not the same, used capacity allocation to carry out load shedding, to avoid too large load shedding of the chiller of small capacity leaving the COP drop [10].

2. Thermal Comfort

In 1972, Fanger used questionnaires to do a series of human comfort reaction test, and finally put forward the human body's heat balance model, to get the Predicted Mean Vote (PMV) of thermal comfort and the Predicted Percentage of Dissatisfied (PPD) by way of regression, as shown in formulas (1) and (2).

$$\mathrm{PMV} = \left[0.303 \times e^{(-0.036 \times M)}\right] \times \left\{ \begin{array}{l} (M-W) - 3.05 \times 10^{-3} \times \left[5733 - 6.99 \times (M-W) - P_a\right] \\ -0.42 \times \left[(M-W) - 5815\right] - 1.7 \times 10^{-5} \times M \times (5867 - P_a) \\ -0.0014 \times M \times (34 - T_a) - 3.96 \times 10^{-8} \times f_{cl} \\ \times \left[(T_{cl} + 273)^4 - (\overline{\mathrm{T}}_r + 273)^4\right] - f_{cl} \times h_c \times (T_{cl} - T_a) \end{array} \right\} \qquad (1)$$

$$PDD = 100 - 95 \times \exp(0.03353 \times PMV^4 - 0.2179 \times PMV^2) \qquad (2)$$

Where,

M: Human metabolism (W/m2)

W: External energy influencing human body (W/m2)

I cl: Clothing isolation degree (m2K/W)

f cl: Clothing area factor

Ｔ a: Temperature (℃)

Tr: Average radiation temperature (℃)

v ar: Relative wind velocity(m/s)

Ｐ a: Water vapor partial pressure (Pa)

hc: Convective heat transfer coefficient (W/(m2K))

T cl: Clothing surface temperature (℃)

Six factors influencing the PMV are considering the dry bulb temperature of human skin surface and atmospheric cooling, the globe temperature of heat felt by receiving solar radiation, the relative humidity affecting the evaporation of sweat, the average wind velocity accelerating the evaporation of sweat, the clothing form providing warm and thermal insulation for body, and considering the intensity of personnel activity. ASHRAE Standard 55 set some human comfort range as shown in Table 1, suggesting keep the PMV between -0.5 to 0.5. The implications of the PMV indices are shown in Table 2; 0 is the moderate temperature [11][12].

ISO 7730 also set the universality of facilitating the use of relevant parameters, indicating the human activity as "met" from "W/m2", and clothing isolation coefficient as "clo" from "m2K/W" , as shown in Table 1.

Table1. Thermal Comfort Conditions of ASHRAE Standard 55 [12]

Comfort factors	Range
Metabolic rate	1.0met~1.3met
Thermal insulation	0.5clo~1.0clo
PMV	-0.5~0.5
PPD	<10%
Humidity ratio	≤0.012

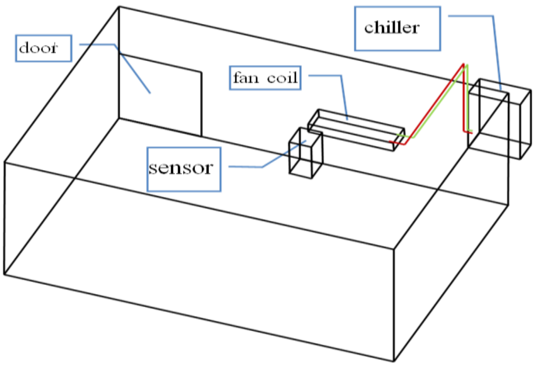
Table 2. Thermal sensation scale[12]

PMV	Thermal sensation felt
3	Hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

3. Experiment Results and Analysis

In this study, a small air-cooled air-conditioning system was used; its system structure and actual appearance are shown in Figures 1 and 2. The detailed specifications of its devices are shown in Table 3.

The comfort measurement equipment is shown in Figure 3[13], and the measurement method refers to the ASHRAE Standard 55 and the specifications set by ISO 7730; the PMV calculation program refers to the code released by ISO 7730 and which was changed to the Excel VBA computing program for continuous calculation use. The specifications of the measurement equipment are shown in Table 4.



Figures 1. The air-conditioning system configuration diagram

Figures 2. The fan coil and the inverter configuration diagram

Table 3. The specification of chiller

Item	specification	
Compressor (screw)	power	2.7 kW
Cooling fan	Air flow	5560 CFM
Chiller pump	Power	0.88 kW
Refrigerant	HCFC	R-22
Chiller pump	Flow	27.7 LPM
Cooling load	3RT	
Fan coil type	ceiling and floor type fan coil	

The specifications of the measurement equipment are shown in Table 4.

Table 4. The specification of PMV system[13]

Sensor type	Specification
Temperature Sensor - PT100	-50℃~180℃
Anemometer-KIMO Class 200	0~20 m/s
Honeywell Digital Humidity/Temperature Sensors	-50~100℃, 0~100%RH
Wet Bulb Temperature Sensor-TOA KEIKI	OD:150 mm/thickness:0.5 mm/material : Cu (JCSS-0110,ISO 9001,JISZ-9901)
Recorder-M-SYSTEM	I/P:PT100 sensor or 0VDC ~ 5VDC

International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 2 Issue 12 (December 2012)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

The experiments in this paper was divided into four projects, namely the compressor and the cooling fan by constant frequency and variable frequency operation respectively, of which the frequency was reduced by 3Hz every time, once every 10 minutes, with the change range between 0Hz and 40Hz, as shown in Table 5. A recorder was used to record the power consumption of both the compressor and the cooling fan, and the chilled water supply/return temperature, as well as the changes of the ambient temperature, through the code provided by ISO 773, by means of Excel VBA took such data as the indoor dry bulb temperature, globe temperature, relative humidity and average wind velocity to calculate the PMV, and observe the changes in indoor comfort.

Table 5. Experimental procedures on July 6

	The frequency of the compressor (Hz)	The frequency of the cooling fan (Hz)
Case 1	60	60~40
Case 2	60~40	60
Case 3	60~40	60~40
Case 4	60	60

Figure 3 shows the power consumption of both the compressor and the cooling fan, and changes of the PMV in such four experiments. From the results of experiments, under the condition that the combination of experiment 2 and experiment 3 could keep the comfort PMV=0.5 more than experiment 1 or experiment 4; both experiment 1 and experiment 4 kept the compressor and (or) the cooling fan with constant frequency leading to too low chilled water temperature, resulting in a waste of energy.

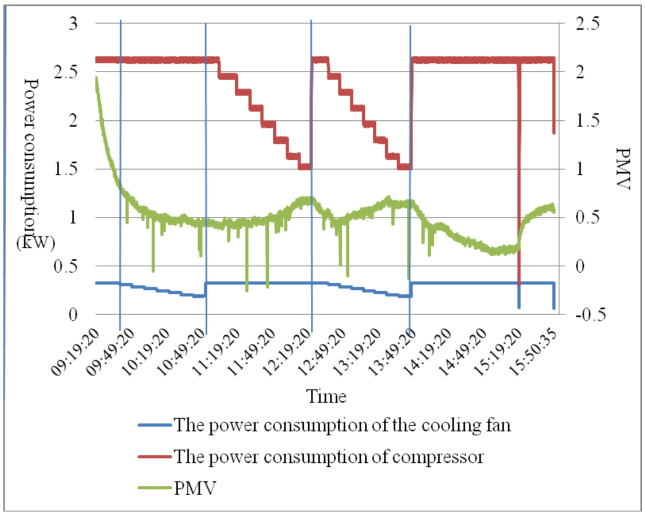


Figure 3. The power consumptions and the PMV of variable frequency control on July 6

Figure 4 indicates the power consumption statistics of the compressor and the cooling fan in variable frequency control. Figure 5 shows the comparative power consumption of both constant frequency and variable frequency operation. From the figure, variable frequency control can save energy more than constant frequency control does, and the energy-saving situation is shown in Table 6. Under the premise that the space comfort PMV keeps at about 0.5, through variable frequency control, the compressor can save about 9% power consumption and the cooling fan can save 14%.

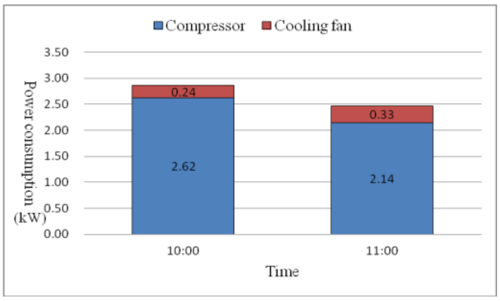


Figure 4. The power consumption for variable frequency control on July 6

International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 2 Issue 12 (December 2012)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

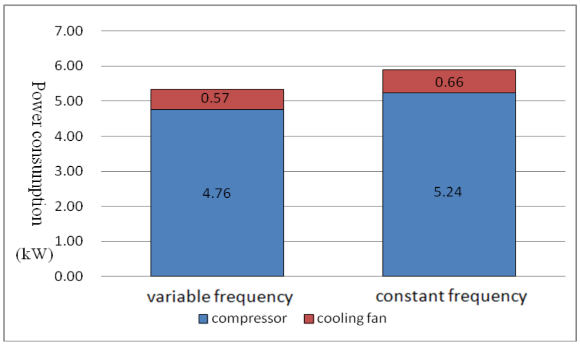


Figure 5. The power consumption between constant/variable frequency control

Table 6. The energy saving of variable frequency control

	Variable frequency control	Constant frequency control	Saving rate (%)
	A (kWh)	B (kWh)	(B-A)/B
The total power consumption of the compressor	4.76	5.24	9%
The total power consumption of the cooing fan	0.57	0.66	14%

4. Conclusions

The central air-conditioning in buildings is considerable energy consumption, but a small central air-conditioning system not only meets the needs of independent users who do not have to share the cost of repairs and maintenance, and can always decide to turn on or off by themselves. The efficiency of the air-cooled chiller is less than the same of water-cooled, but in the placewith harsh climatic conditions and lack of water resources, there is the value of its existence.

For the compressor used in this study under constant frequency operation, the chilled water temperature will reach the set temperature and shutdown to protect the system every eight minutes or so. However, under constant frequency experiment, start and stop are quite frequently, affecting the mechanical life. The air-cooled chiller used in this study under the condition of constant frequency operation has made the space to be maintained at the optimum

thermal comfort, the operating value of PMV=0, the dry bulb temperature of 24℃ to 25.6℃, and relative humidity of 59.7RH% to 71.5RH% recommended by ISO 7730, but the way increasing the PMV from 0 to 0.5 where human body does not feel obviously uncomfortable reached a staggering saving rate in the two hours of the experiment that the compressor saved 9%, and the cooling fan saved 14%. This also proves that variable frequency operation can easily achieve the energy-saving effect.

5. References

[1] Chang, Yung-Tsung, 〝The Optimal Load Distribution of Chiller Group〞, Journal of Refrigeration & Air-Conditioning Technology, October 2002, Pages 87-92.

[2] Ashfaque Ahmed Chowdhury, M.G. Rasul, M.M.K. Khan, 〝Modeling and analysis of air-cooled reciprocating chiller and demand energy savings using passive cooling〞, Applied Thermal Engineering, Volume 29, Issues 8–9, June 2009, Pages 1825–1830

[3] F.W. Yu, K.T. Chan, 〝Improved energy performance of air-cooled chiller system with mist pre-cooling〞, Applied Thermal Engineering, Volume 31, Issue 4, March 2011, Pages 537–544

[4] F.W. Yu, K.T. Chan, 〝Simulation and electricity savings estimation of air-cooled centrifugal chiller system with mist pre-cooling〞, Applied Energy, Volume 87, Issue 4, April 2010, Pages 1198–1206

[5] F.W. Yu, K.T. Chan, 〝Part load performance of air-cooled centrifugal chillers with variable speed condenser fan control〞,Building and Environment, Volume

42, Issue 11, November 2007, Pages 3816–3829

[6] Chang, Tse-Wen, 〝Optimal Operation Parameter Setting of Chilled Water System Using Evolution Strategy〞, master's degree thesis of master program, Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, 2009, Pages 46-57.

[7] Wang, Chun-Hung, 〝Demand Response Considering Thermal Comfort of HVAC〞, master's degree thesis of master program, Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, July 2011, Pages 44-69.

[8] Shahin Heidari, Steve Sharples, 〝A comparative analysis of short-term and long-term thermal comfort surveys in Iran〞,Energy and Buildings, Volume 34, 2002, 607–614.

[9] Chiang, Che-Ming, 〝A Study on the Influence of Regulating Indoor Temperature of the Working Environment on Human Responses〞, master thesis, Graduate Institute of Architecture, National Chengkung University, June 2008, Pages 5-12~6-6.

[10] Lu, Hai-Jen, 〝Design and Implementation of Optimal Load Shedding of the Demand Response〞, master thesis, Graduate Institute Automation Technology, National Taipei University of Technology, July 2005, Pages 55~62.

[11] ISO 7730, 〝Ergonomics of the thermal environment-Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria〞, Geneva: International Standards Organization, 2005.

[12] ANSI/ASHRAE Standard 55, 〝Thermal Environmental Conditions for Human Occupancy〞, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004.

[13] Chiang, Yen-Te, 〝Application of PLC Control System with Fuzzy Algorithm on Thermal Comfort of HVAC〞, master's degree thesis of master program,

Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, July 2011, Pages 41-54.