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Analysis of Energy Saving for Air-Cooled Scroll Chiller with Variable Speed

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Abstract. This paper is to study the variable frequency control against the compressor and the cooling fan of an air-cooled chiller, and continues to measure and collect the actual operating data, by use of such data as the chilled water supply/return temperature, chilled water flow rate, power consumption, and ambient wet-bulb temperature to conduct the COP analysis of the air-conditioning system. The experimental results show that proper use of the frequency converter to change the operation frequency of the compressor and of the cooling fan indeed can effectively enhance the COP of the air-cooled chiller operation, and reduce the power consumption of the compressor and the cooling fan of the air-cooled chiller to achieve the energy-saving effect.

Keywords: Air cooled chiller; Variable frequency control; Air-conditioning energy saving; COP

1 Introduction

With the rapid development of Taiwan's high-tech industry and the repaid economic growth, the air-conditioning industry has become the indispensable equipment of life and work for people in Taiwan. Taiwan's hot and humid, with average summer temperatures increased year by year, in order to enhance the quality of life and quality of work to make people's lives more comfortable and more efficient, whether industrial or residential application of air-conditioning equipment is constantly increased, while it is also the most energy-consuming device in the electrical equipment. In recent years, for the energy-saving work, different air-conditioning equipment and air-conditioning engineering installation are often proposed to improve its energy consumption.

The air-cooled chiller is generally used in small and medium-sized air-conditioning load, and the single chiller refrigerating capacity is most below 60RT. Comparing the air-cooled chiller to the water-cooled chiller of air-conditioning load, the air-cooled chiller has such advantages as low equipment cost, low maintenance cost, and low area ratio of system; however, in actual use as comparing with water-cooled chiller, due to the air-cooled using air as the heat transfer medium with low conductivity, so relatively, its heat transfer effect is worse, resulting in low coefficient of performance (COP) of the chiller that always has been criticized by users. If the operation capacity of the chiller compressor and the cooling fan can be adjusted to effectively improve the COP of chiller operation, the air-cooled chiller will be promoted more in use.

2. Frequency Converter Application

2.1 Chilled water system

Traditional refrigeration system uses a constant speed compressor to regulate the evaporation temperature by ON-OFF control. This control method makes the evaporation temperature more fluctuate, and easily affect the cooled environmental temperature. A compressor must continue to overcome the enormous moment of inertia produced by the rotor from standstill to rated speed in the work process; starting with load, the starting torque will be more than the running torque many times that not only will consume extra energy, but aggravate the wearing of the compressor; and it will produce a larger vibration, noise and impact of current during startup process, causing the fluctuations in the supply voltage. Therefore, using the variable frequency compressor instead of a constant-speed compressor can avoid the frequent starts and stops process [1][2].

The variable frequency compressor uses a controlled manner or means so that it can continuously adjust the rotation speed within a certain range in order to change the output energy. Based on the size of indoor air-conditioning load, a frequency converter is used to drive the compressor speed, to change the compressor work cycle and to achieve the energy-saving benefits. In addition, comparing to traditional ON-OFF control, it not only can reduce the start and stop times of the compressor, but also can more precisely control the thermostatic environment [1]. For the variable frequency scroll compressor in practical application, its COP can be increased by about 20% [1], with obvious energy-saving effect.

2.2 Cooling fan

The cooling conditions of air-cooled condenser will be affected by the dry bulb temperature of ambient air; when the outdoor dry bulb temperature is higher, its cooling is poor that increasing every 1℃ condensing temperature, the COP will be reduced by approximately 2.5 to 3% [3]. Therefore, we need to install the cooling fan to enhance the heat cooling efficiency. Changing the motor speed control is one of the fan energy-saving control practices [4][5]. It can be learned by the fan law that the shaft power is proportional to the third power of rotational speed, so the benefits are the best. By varying the rotational speed of the motor speed to reduce the amount of wind required by loads, its energy-saving effectiveness is very high.

3. Experiment Results and Analysis

3.1 Experimental methods

The experimental method in this paper is to make variable frequency control against the scroll compressor and the condenser cooling fan of the maximum power consumption in the air-cooled chiller. The air-cooled chiller used is shown in Figure 1 and the rated capacity is 9,000 kcal/hr. Chilled water pipes are connected to a small cooling fan as shown in Figure 2; the experimental system structure is shown in Figure 3.The experiment was carried out in the following three stages:

1. The cooling fan operated by constant frequency (60Hz), and the compressor reduced 6Hz every 30 minutes from 60Hz until 40Hz.
2. The compressor and the cooling fan reduced frequency 6Hz synchronously every 30 minutes from 60Hz until 40Hz and 36Hz respectively.

Figure 1. Air-cooled chiller

Figure 2. Cooling fan

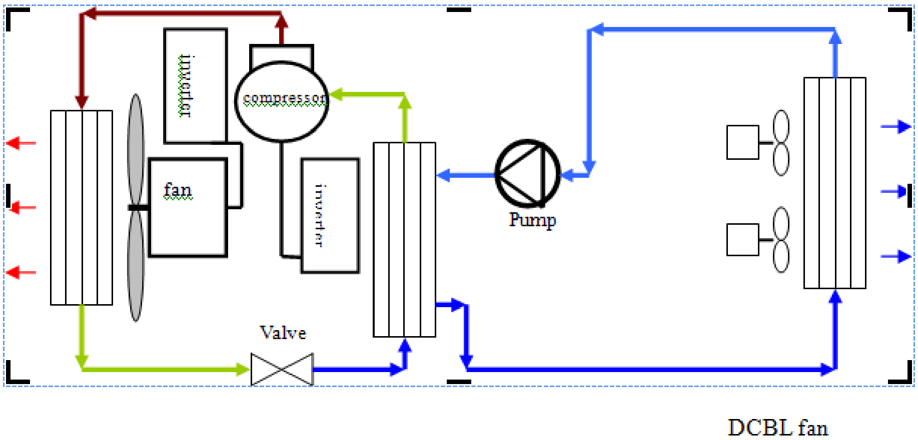

Figure 3. Experimental system structure

The experiment was conducted of three days on July 20 (11:00~19:00), 23 (11:00~19:00), and 24 (10:30~18:20), 2012. One minute as a sampling period for collection data was compiled and the ambient temperature and humidity in the period of eight hours for data collection are shown from Figure 4 to 5.

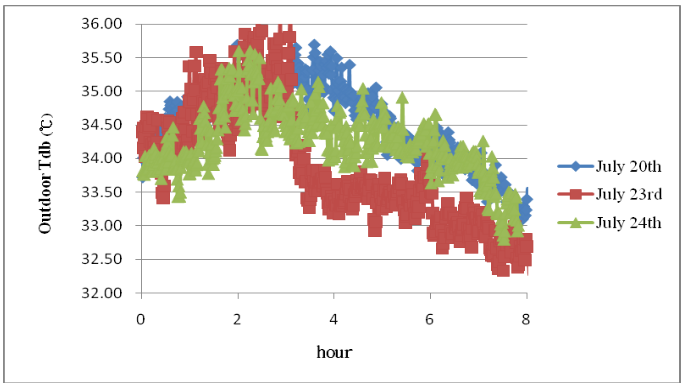

Figure 4. Outdoor dry bulb Temperature (Tdb)

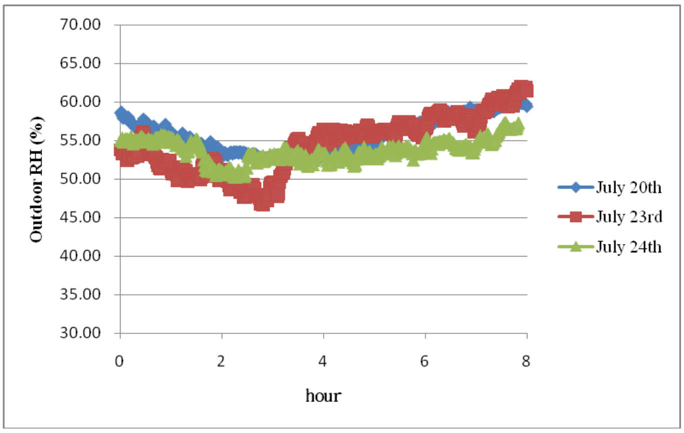

Figure 5. Outdoor Relative Humidity (RH)

3.2 Data Analysis

3.2.1 Constant frequency compressor and variable frequency cooling fan

The compressor operated by constant frequency (60Hz), and the cooling fan reduced frequency 6Hz every 30minutes from 60Hz until 36Hz, as shown in Figure 6. Theoretically, the cooling fan continues to drop frequency that the cooling effect of the chiller condenser will continue to reduce; in same load, the temperature of the refrigerant entering the evaporator will increase, inducing the chilled water to raise the temperature of the evaporator, and also allows to reduce the output refrigerating capacity of the chiller. The chilled water supply temperature, as shown in Figure 7, and the chilled water return/supply temperature difference, as shown in Figure 8,presented in this experimental process show in the case of certain load, chilled water supply temperature rose about 0.5℃, and the chilled water return/supply temperature difference narrowed that means the high-pressure temperature of the condenser rose due to the reduction of the cooling capacity, resulting in increase of the low-pressure temperature of the evaporator, so that the output refrigerating capacity of the chiller decreased.

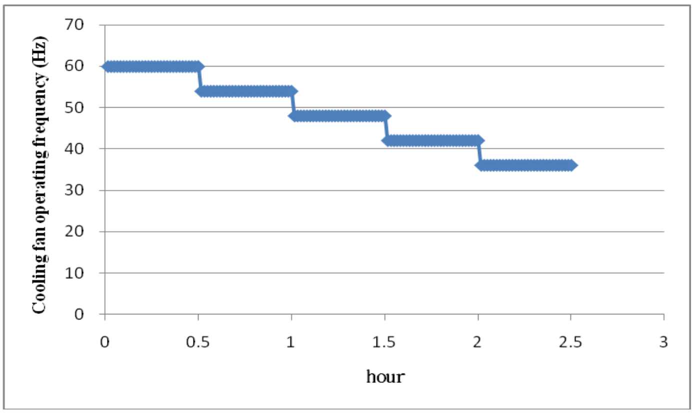

Figure 6. Cooling fan frequency decrease

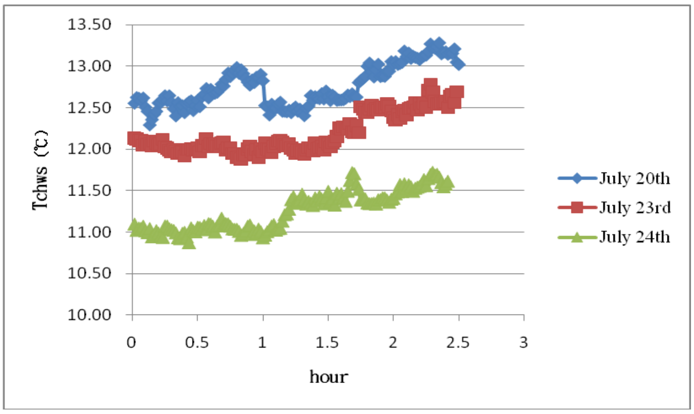

Figure 7. Tchws based on constant frequency compressor and variable frequency cooling fan

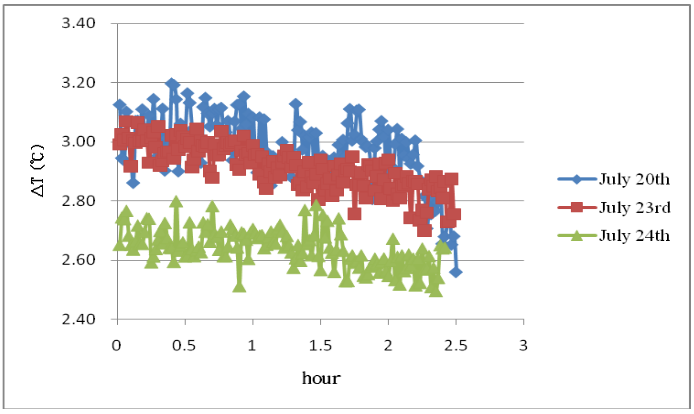

Figure 8. △T based on constant frequency compressor and variable frequency cooling fan

Since the chilled water return/supply temperature difference slightly decreased, in the case of a constant flow of chilled water, the refrigerating capacity decreased too as shown in Figure 9.The individual power consumption of the compressor and the cooling fan must be included in the calculation of the power consumption, and the summation of the two was taken as the radix to calculate the system COP. Under the declination of the refrigerating capacity, the frequency of cooling fan was reduced, so that overall power consumption decreased, as shown in Figure 10. Due to the cooling fan power consumption was only 10% of overall power consumption, the curve of system COP almost remained constant, as shown in Figure 11.

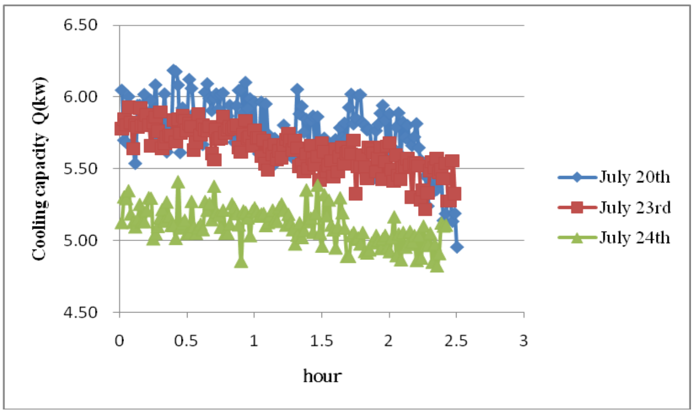

Figure 9. Cooling capacity Q(kW) based on constant frequency compressor and variable frequency cooling fan

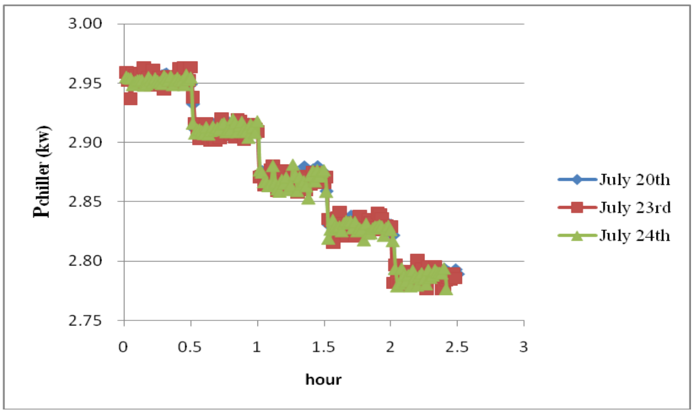

Figure 10 . Power consumption based on constant frequency compressor and variable frequency cooling fan

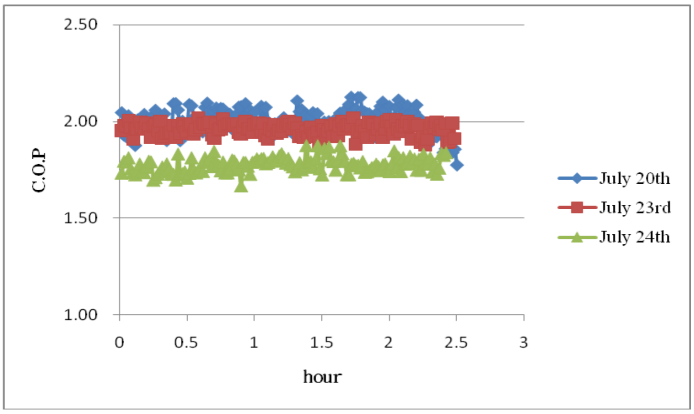

Figure 11. Coefficient of Performance (C.O.P) based on constant frequency compressor and variable frequency cooling fan

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3.2.2 Variable frequency compressor and constant frequency cooling fan

The cooling fan operated by constant frequency (60Hz), and the compressor reduced frequency 6Hz every 30 minutes from 60Hz until 40Hz, as shown in Figure 12. When the compressor started to convert the frequency, the chiller refrigerating capacity started to decrease and the first reaction was the rising of the chilled water supply temperature, as shown in Figure 13, in the case of a constant load, because the refrigerating capacity decreased, resulting in narrowing the difference between the chilled water return and supply temperature, as shown in Figure 14.

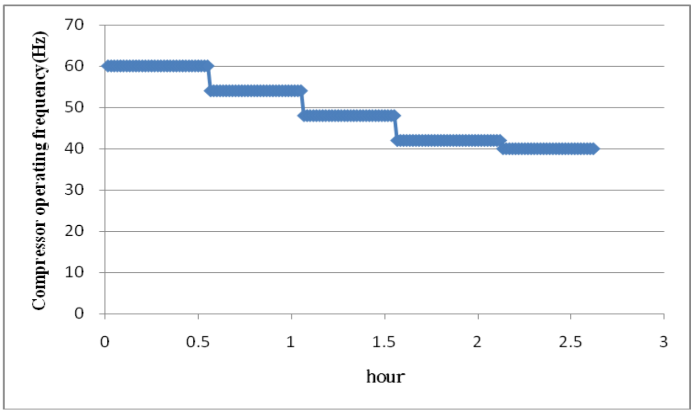

Figure 12. Frequency of compressor decrease

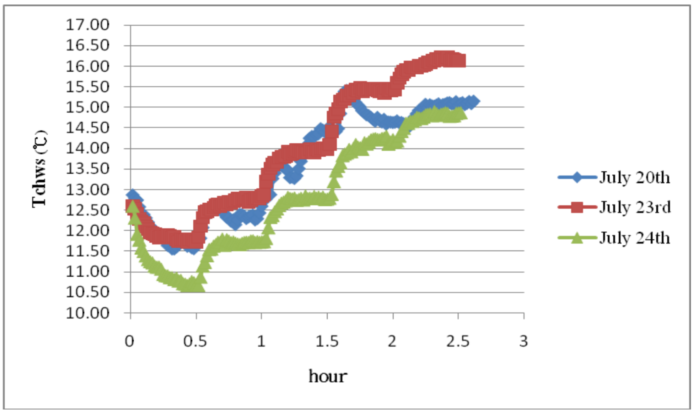

Figure 13. Tchws based on variable frequency compressor and constant frequency cooling fan

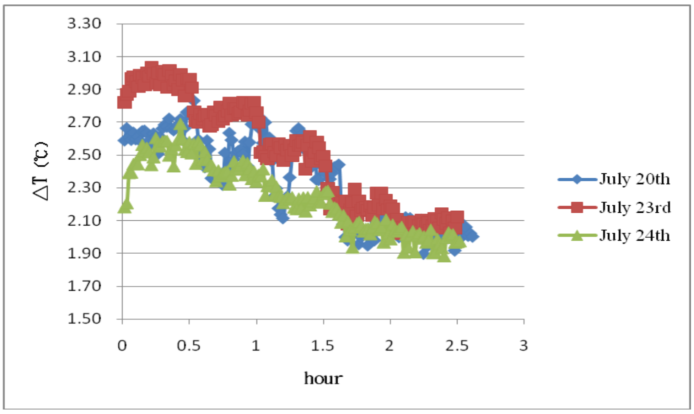

Figure 14. △T based on variable frequency compressor and constant frequency cooling fan

Reduced frequency of the compressor caused the refrigerating capacity to decrease and under the constant chilled water flow rate, the refrigerating capacity downward trend will be presented as the same of chilled water return/supply temperature difference, as shown in Figure 15; the compressor reduced frequency such that the overall power consumption dropped significantly, as shown in Figure 16. Although the refrigerating capacity decreased, total power consumption also dropped to significantly improve the COP, as shown in Figure 17.

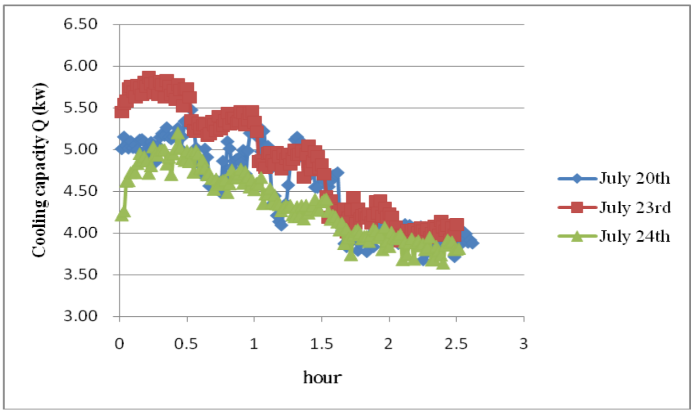

Figure 15. Cooling capacity Q(kW) based on variable frequency compressor and constant frequency cooling fan

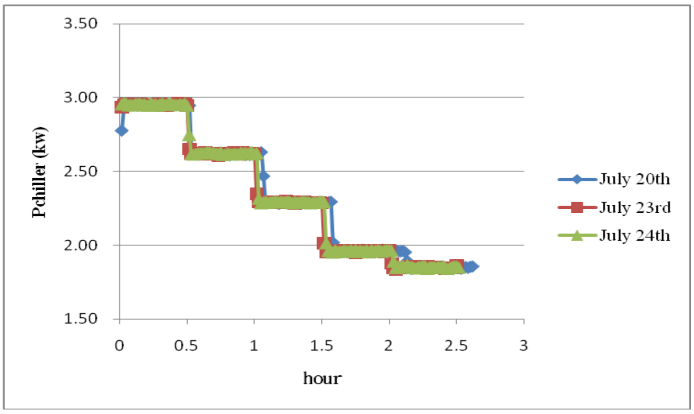

Figure 16. Power consumption based on variable frequency compressor and constant frequency cooling fan

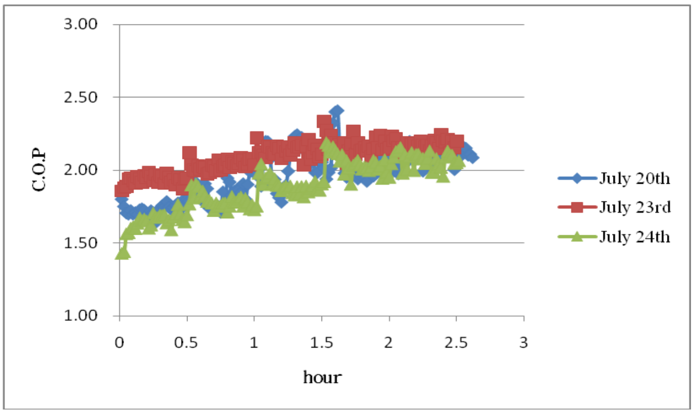

Figure 17. Coefficient of Performance (C.O.P) based on variable frequency compressor and constant frequency cooling fan

3.2.3 Variable frequency compressor and variable frequency cooling fan

The compressor and the cooling fan reduced frequency 6Hz synchronously every 30 minutes from 60Hz, until 40Hz and 36Hz respectively, as shown in Figure18. To the compressor and the cooling fan operated with reduced frequency synchronously, theoretically, if a constant load is maintained, the refrigerating capacity of the chiller will be decreased substantially. However, we have presented a phenomenon for explanation in previous section that the declined cooling capacity of the cooling fan showed less influences on the refrigerating capacity of the chiller. The chilled water supply temperature as shown in Figure 19, and the difference between the chilled water return and supply temperature as shown in Figure 20 are more affected by the declined capacity of the compressor. The case that the curve of the chilled water supply temperature will decline to rise shown in Figure 19 is because before doing this experiment, the compressor operation frequency is lower, so it needs to regulate to the highest frequency, and after it is stable, begin to drop the same.

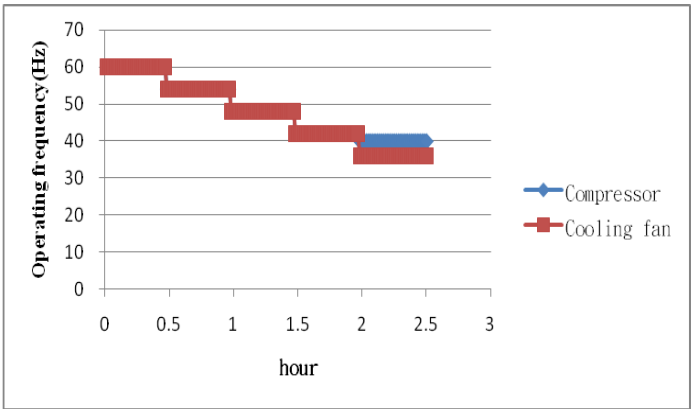

Figure 18. Frequency of cooling fan and compressor decrease

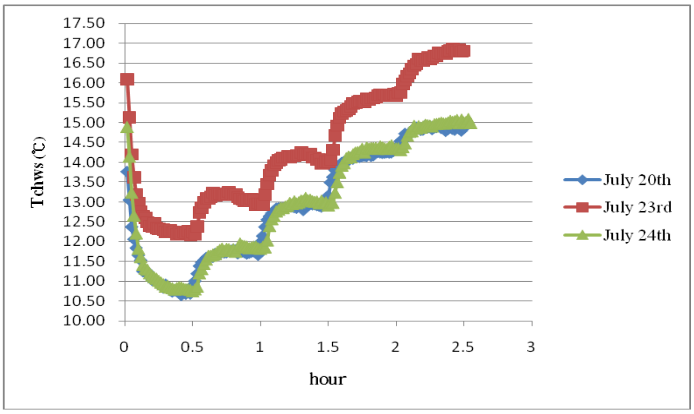

Figure 19. Tchws based on variable frequency compressor and variable frequency cooling fan

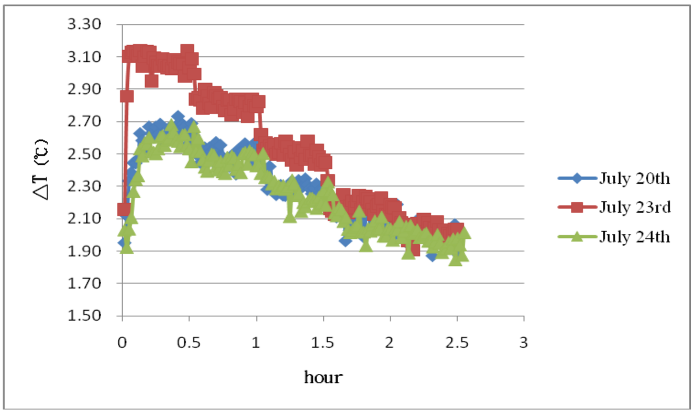

Figure 20. △T based on variable frequency compressor and variable frequency cooling fan

The refrigerating capacity of the chiller declined with the reduced capacity of the compressor as shown in Figure 21. However, because the compressor and the cooling fan reduced frequency, so that the overall power consumption dropped significantly as shown in Figure 22, and the system COP was more improved, comparing to the separate reduction of the compressor frequency, as shown in Figure 23.

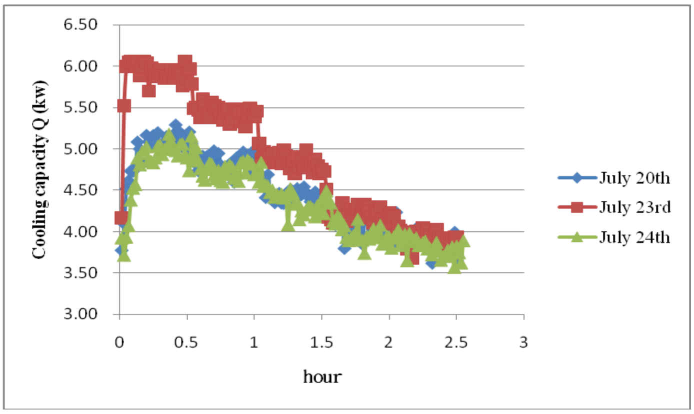

Figure 21. Cooling capacity Q(kW) based on variable frequency compressor and variable frequency cooling fan

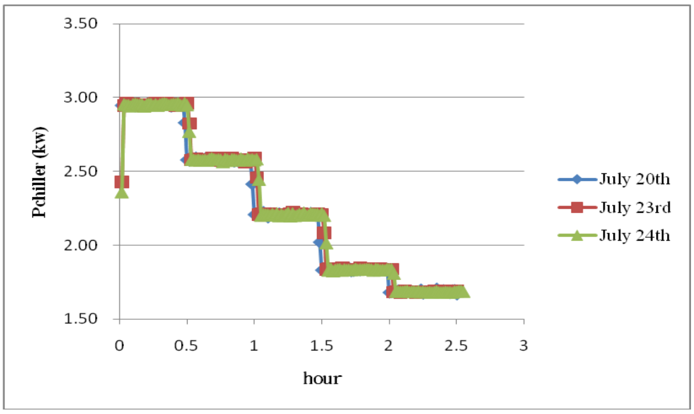

Figure 22. Power consumption based on variable frequency compressor and variable frequency cooling fan

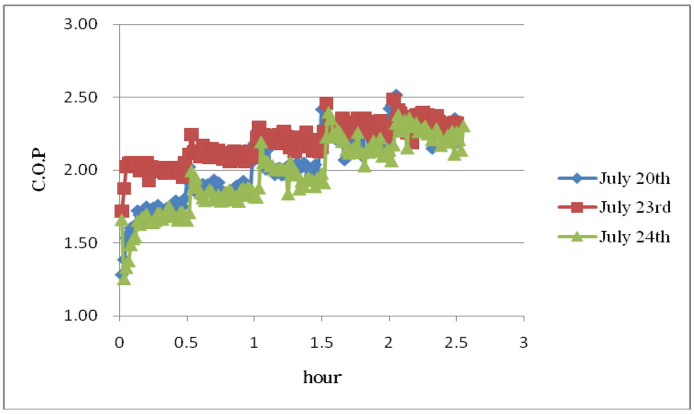

Figure 23. Coefficient of Performance (C.O.P) based on variable frequency compressor and variable frequency cooling fan

4.Conclusions

In this study, the variable frequency control was carried out against the compressor and the cooling fan of an air-cooled chiller to conduct the COP analysis of the air-conditioning system by use of such coefficient as the chilled water return temperature, the chilled water supply temperature, and power consumption. By the experimental results of this study shows that when reduces the operation frequency of a cooling fan, under little change of ambient wet bulb temperature, the reduced fan cooling capacity will less impact the condenser cooling, associated less impact on the COP of the chiller. From this phenomenon, we can infer that the condenser cooling fins should be the main cause of mainly affecting the cooling efficiency. If the heat transmission efficiency of the cooling fins is increased in the design, we can configure a cooling fan of smaller capacity to achieve the energy-saving benefits. The compressor converted with frequency in this study is a scroll-type compressor. Generally, in market application, the scroll compressor is used in an air-conditioning load below 30RT, and usually traditional on/off is set as the load control mode. But if in a same building, there are dozens of small air-conditioning chillers, to adjust the compressor load by traditional on/off control mode, it is considerable energy consumption for the building. The experimental results of this study show that adjusting the operation frequency of a scroll compressor can effectively improve the operating capacity of the chiller to achieve the appropriate energy-saving benefits timely.

5. References

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