A Study of Cooling Performance for Chillers at HRH Princess Maha Chakri Sirindhorn Medical Center, Thailand

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***Abstract*—Air conditioning system is an energy-consuming unit in most buildings. For hospitals, air conditioners are always turned on to provide reliable and continuous service for patients, leading to high amount of energy usage and great expense. In this research, chiller operations in HRH Princess Maha Chakri Sirindhorn Medical Center, Nakhon Nayok, Thailand, were investigated to determine cooling load of chillers and calculate cooling performance. Recommendations were provided to help improve chillers' efficiency and reduce energy consumption in the future. The system comprised 2 chillers, using centrifugal constant speed compressor, with the cooling capacity of 600 tons of refrigeration (TR). These chillers run simultaneously during the day while only one chiller was operated at night. Data was acquired by using internal monitoring software and external instruments which are ultrasonic flow meter, thermocouple and power meter. Results showed that the operation can be divided into 2 periods for different level of cooling loads, which are peak load hours (8 a.m.-6 p.m., 10 hours) and off-peak hours (6 p.m.-8 a.m., 14 hours). Highest cooling loads of CH1 and CH2 chillers were 478 and 438 TR respectively. The average cooling performance during peak load hours from both chillers were 0.735 and 0.967 kW/TR respectively. This indicates that the performance of the CH1 chiller was better compared with that of the CH2 chiller. In most cases, 600-ton chillers would work on part load condition, where cooling load is lower than cooling capacity, especially during the off-peak period; this makes inefficient energy consumption. Plotting results on pressure-enthalpy diagram suggested that the efficiency of chiller could be improved by lowering cooling water temperature, cleaning evaporator and condenser. Also, more energy could be saved when considering the use of variable speed drive (VSD) chiller over constant speed chiller.**

***Index Terms*—chiller, compressor, cooling load, cooling performance, enthalpy**

I. Introduction

Air conditioning system is an important unit which affects both buildings and environment. It uses more than 70 percent of total energy in most buildings [1, 2]. A good building system must consider the sustainability principles which include resource conservation, cost efficiency and design for human adaptation [3]. Energy conservation becomes one of major concerns for both industrial and city units especially when utility costs nowadays are high [4]. The key principles of energy conservation are the reduction of energy consumption and the efficient use of energy. Therefore, it is necessary for buildings to have a good air conditioning system that can work efficiently while consumes low amount of energy. This could help save a lot of the utility cost in a building.

Several researches were done to find variables that affect the performance of the chiller. Seo and Lee [4] studied the part load ratio and the operating characteristics of vapor compression chiller. They found that operating hours, cooling load and energy consumption were important factors affecting the chiller's performance. At low part load conditions, when the chiller worked in the load ratio range of 0 through 50%, the energy consumption was significantly affected by the chiller COP (Coefficient of Performance). Yu et al. [5] studied the simulation of chiller operation by varying COP. Results showed that reducing the condenser temperature could improve the chiller performance. Also, using the variable speed condenser could improve COP up to 84.8%. Avery [6] reported that the energy performance or COP of the chiller depends on the heat rejection medium, ambient conditions, compressor efficiency and the load carried by the chiller. Manimaran et al. [7] found that the performance of chillers increased significantly at all operating conditions when applying advanced chiller technologies such as chiller plant control, condensing temperature control and variable speed condenser fans.

By studying the chiller system of Her Royal Highness Princess Maha Chakri Sirindhorn Medical Center, there were two 600-ton chillers working in the centralized air conditioning system. During the night, the amount of air conditioner's usage was low, and chillers would work at part load condition, so only 1 chiller was used with the cooling capacity of 600 tons of refrigeration (TR). Two

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chiller units were used during the daytime with the total cooling capacity of 1,200 TR. This study investigates the cooling capacity of the chiller system at HRH Princess Maha Chakri Sirindhorn Medical Center to help improve the reduction of energy consumption and find the way to make the cooling system work more efficiently.

II. Equipment and Procedure

A. *Procedure of Chiller's Energy Measurement*

In this study, the energy of the chiller was measured in real operating conditions, divided into 3 parts. Firstly, the CH1 and CH2 chiller units were equipped with a set of tools and equipment for energy measurement. Data were recorded every 15 minutes for 5 days (Monday to Friday). Secondly, the main chiller controller was used to monitor the energy of CH1 and CH2 chillers, recorded hourly for 5 days (Monday to Friday). For the last part, water temperature and refrigerant pressure of both chillers were monitored by the main chiller controller from the chiller monitor, recorded hourly for 1 day.

B. *Measuring Equipment*

Chiller is used to produce cold water in air conditioning systems. The required parameters in measuring its energy are the flow rate of the cold water, the temperature of the inlet and outlet water and compressor's electrical value. The flow rate of the cold water and the temperature of inlet and outlet water were used to calculate the cooling load of chillers. Compressor's electrical value was used together with the cooling load to evaluate the performance of the system. The power should not exceed 0.7 kW/TR. Equipment that were used are listed below:

a. Ultrasonic flow meter: The operating principle is based on the reflection of the ultrasonic wave when colliding with the particle in the fluid. Since the particle's velocity is equal to the fluid velocity, the reflected velocity of the wave would be different from the initial velocity. The change in frequency is directly proportional to the flow velocity of the fluid. Thus, the fluid flow rate could be determined.

b. Power meter: Power meter is a tool that can measure the power requirements of both 1 and 3 phase frequencies at 50 Hz directly, while other methods require measuring the voltage, current and further calculations. In case of a 3-phase alternating current, this equipment makes the calculation of electricity consumption more convenient.

c. Thermocouple: Thermocouple is a temperature sensor which is suitable for measuring the temperature with high sensitivity and wide range (temperature range:-200 to 400 ℃). The error value is ±0.55 ℃.

C. *Measuring Locations*

Position 1: Measure the flow rate of cold water. The ultrasonic flow meter will be installed outside the cold-water outlet. The unit of the flow rate is gallon per minute.

Position 2: Measure inlet/outlet water temperature for both evaporator and condenser using thermocouple. The value is obtained in degree Fahrenheit.

Position 3: Measure the electrical power of the chiller continuously with a power meter (unit kWh).

III. Results and Discussion

A. *Results of Chiller's Energy Measurement*

Inlet and outlet temperature of the condenser and evaporator were measured and recorded hourly. The data recorded are shown in Fig. 1.

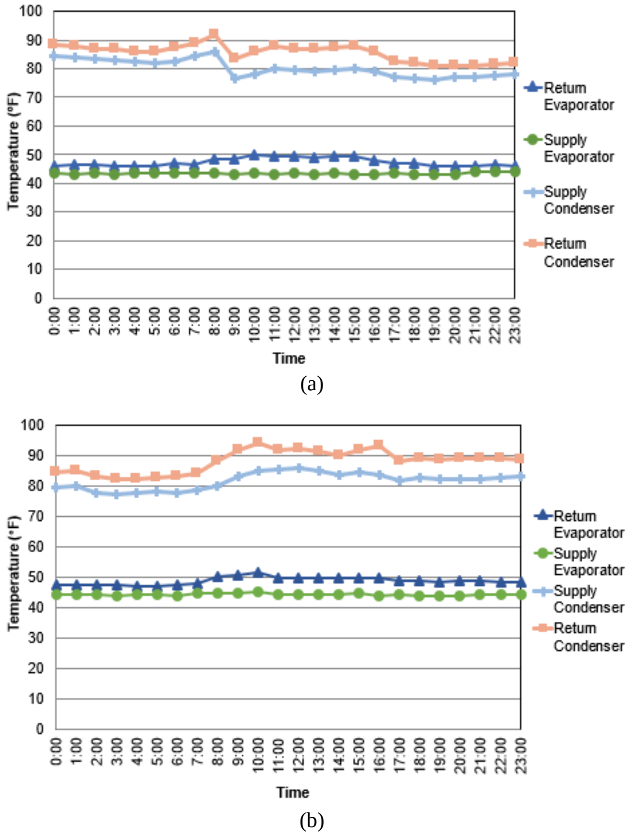


Figure 1. Inlet/outlet temperature for condenser and evaporator: (a) CH1 chiller and (b) CH2 chiller.

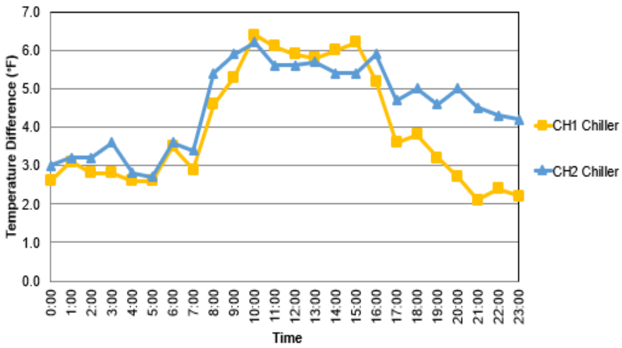
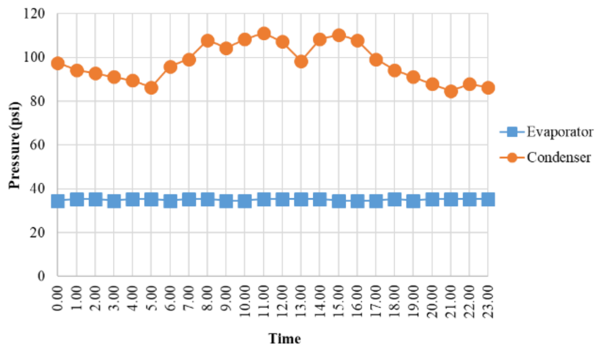


Figure 2. Difference between inlet water and outlet water temperature of the evaporator in one day.

For the temperature measurement of the cold-water system, this is shown as the temperature difference between the inlet and outlet of the evaporator. The purpose of temperature difference measurement in this part is to find the cooling load in TR as shown in Fig. 2.

Pressure of R134a refrigerant at the evaporator and condenser for both chillers were recorded hourly. This is shown in Fig. 3. For the CH1 chiller, the evaporator pressure was in the range of 34.6-35.4 psi, while the condenser pressure was in the range of 84.7-111.1 psi. For the CH2 chiller, the evaporator pressure was in the range of 35.9-39.1 psi, while the condenser pressure was in the range of 86.1-116.5 psi. It could be seen that the pressure of the condenser for both chillers were at their maximum during 8 a.m.-6 p.m., when the power consumption was high. This is called the peak load period. These pressure data would be used for creating P-h diagram for further analysis.



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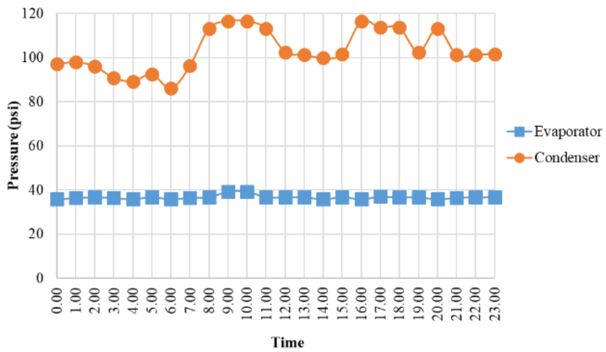

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Figure 3. Pressure of R134a refrigerant: (a) CH1 chiller and (b) CH2 chiller.

B. *Chiller's Load*

From the result of the energy measurement of CH1 and CH2 chillers, each with the cooling capacity of 600 TR. Results can be used to calculate the cooling load of chillers by using equation (1) and can be graphed as shown in Fig. 4.

$$h = c_p \rho \, q \, dt \qquad (1)$$

where

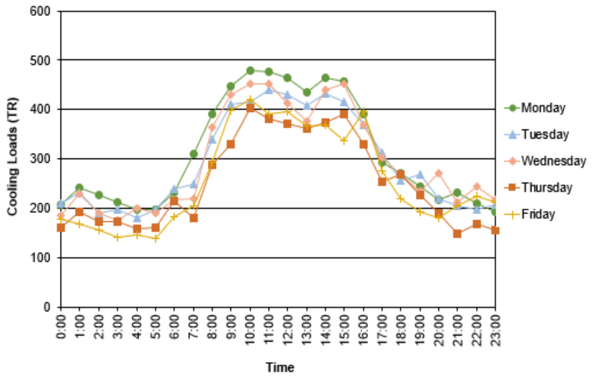
h = heat load (Btu/h)

c_p = specific heat, 1 (Btu/lb_m ℉) for water

ρ = 8.33 (lb_m/US gal) for water

q = water volume flow rate (US gal/min)

dt = temperature difference (℉)



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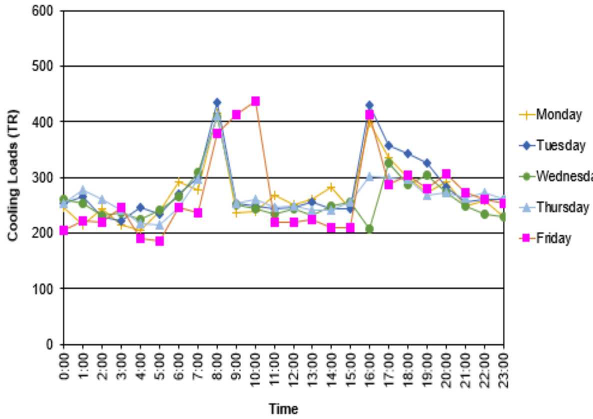


(b)

Figure 4. Cooling loads: (a) CH1 chiller and (b) CH2 chiller.

From the result, it was found that the load of both chillers in the hospital could be divided into 2 periods: peak load hours (8 a.m.-6 p.m., 10 hours) and off-peak hours (6 p.m.-8 a.m., 14 hours). During the peak load hours, both chillers run simultaneously due to high usage of the refrigeration system. At the off-peak hours, where the air conditioning demand was low, only one chiller was used.

For the CH1 chiller, it was found that the highest peak load during 8 a.m.-6 p.m. (10 hours) was 478 TR. During the period of 6 p.m.-8 a.m. (14 hours) which was the off-peak period, the cooling load decreased. At that time, the maximum cooling load was 272 TR. The data can be graphed as shown in Fig. 4.

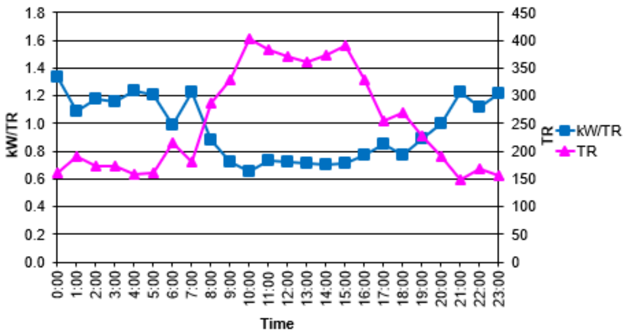
Considering the cooling load of the CH2 chiller, Fig. 4 shows that at 7 a.m., the chiller load started to increase and reached its peak before 10.00 a.m. at 438 TR. Afterwards, the load suddenly dropped and stayed low. This is due to insufficient cooling loads of the CH2 chiller and the CH1 chiller was activated to increase the cooling load to meet the demand. Since the CH1 chiller is the main cooling unit, the load of the CH2 chiller decreased and worked as a supplementary unit. At 4 p.m., the demand started to decline and the CH1 chiller was turned off. The CH2 chiller again worked as the main unit, the cooling load hence increased. During the off-peak period, the maximum cooling load was 326 TR.

C. Chiller's Performance

Chiller's performance can be calculated by comparing the cooling output from the evaporator with the compressor's power input. Results can be shown in various terms which are kW/TR, coefficient of performance (COP), and energy efficiency ratio (EER) and is shown in Table I. The cooling performance of both chillers (in kW/TR) during peak load and off-peak period could be shown in Fig. 5.

TABLE I. POWER USAGE AND PERFORMANCE OF CH1 AND CH2 CHILLERS AT EACH PERIOD

Chiller	Time	Power (kW)	TR	Performance		
				kW/TR	COP	EER
CH_1	8 a.m.- 6 p.m.	276.683	380.975	0.735	4.816	16.433
	6 p.m.- 8 a.m.	197.837	211.475	0.966	3.742	12.768
CH_3	8 a.m.- 6 p.m.	260.054	275.758	0.967	3.705	12.642
	6 p.m.- 8 a.m.	232.952	263.913	0.895	3.965	13.528



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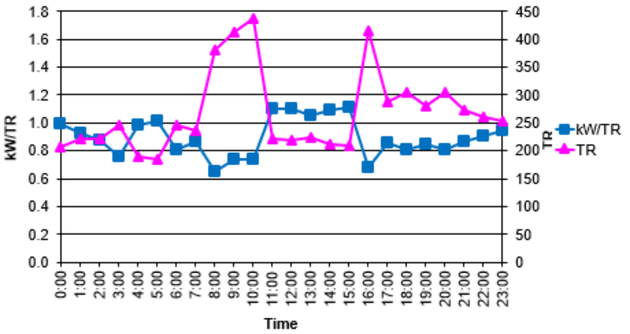


(b)

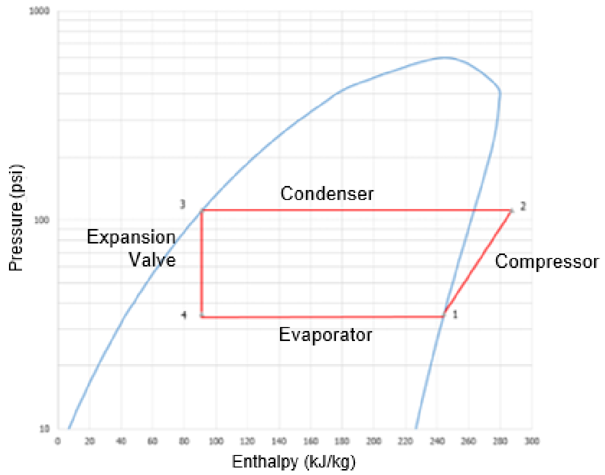
Figure 5. Cooling performance: (a) CH1 chiller and (b) CH2 chiller.

Results showed that the CH1 chiller had its best cooling performance during the peak load period which was at the average of 0.735 kW/TR. The average cooling load was 381 TR and the average power consumption was 277 kW. On the other hand, the cooling performance of the CH2 chiller during the peak load period was worse than that of the CH1 chiller. The CH2 chiller had an average cooling performance of 0.967 kW/TR. The average cooling load was 276 TR and the average power consumption was 260 kW.

During the off-peak period, the average cooling performance of the CH1 chiller changed to 0.966 kW/TR. This means that, during this period, the CH1 chiller consumed more energy when compared with the peak load period. The average cooling load was 211 TR and the average power consumption was 198 kW. For the CH2 chiller, the average cooling performance was 0.895 kW/TR. This is better than its performance during the peak load period because it was used as a supplementary unit to support the CH1 chiller at the peak load period. The average cooling load was 264 TR and the average power consumption was 233 kW.

D. Recommendations for Improving Chiller's Efficiency

In order to improve the efficiency of the chiller, pressure-enthalpy diagram (P-h diagram) were created for better understanding each stage of the chiller. Pressure data from section A were used to find the enthalpy for each stage by using saturated refrigerant-134a pressure table and superheated refrigerant-134a table. Examples of P-h diagram of both chillers could be shown in Fig. 6. By considering these diagrams, solutions for improving efficiency were proposed in the following sections.



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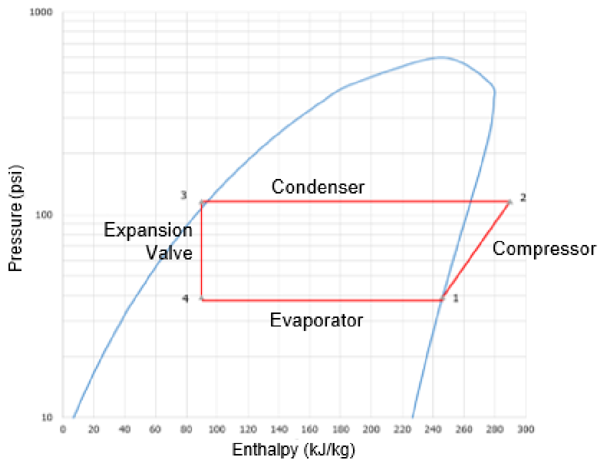

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Figure 6. Pressure-enthalpy diagram: (a) CH1 chiller and (b) CH2 chiller.

1) Lowering the coolant temperature at the Chiller

The low temperature coolant could receive higher thermal energy from the high temperature R134a refrigerant when the temperature difference is high.

Therefore, lowering the temperature of the coolant would help exchanging heat better and the condenser temperature could be reduced. Controlling the condenser temperature could increase the efficiency of the chiller [8]. This could reduce the condensing pressure of the R134a refrigerant, thus lowering the compressor's work. Therefore, the pressure will drop from P2 to P6 which results in a decrease of the refrigerant's enthalpy at the superheated vapor state from h2 to h6, as shown in Fig. 7.

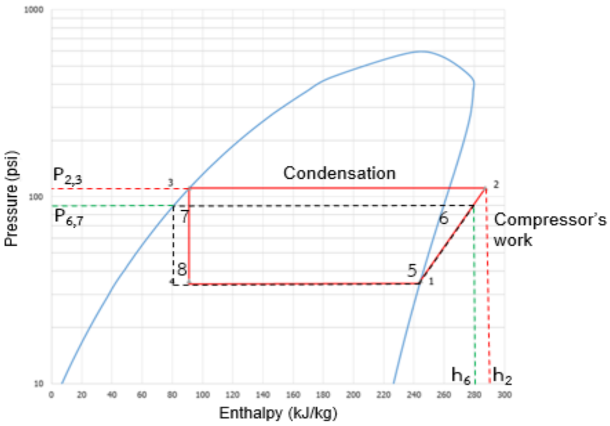

Figure 7. Change of P-h diagram when controlling the coolant temperature.

2) Cleaning the condenser

Fouling or scales on the condenser tube surface could impede the heat transfer from the R134a refrigerant to the coolant from the coolant tower, resulting in a high condenser temperature. Therefore, cleaning the condenser will improve the performance of the condenser, increase the heat transfer rate, and thus lowering the condenser temperature. Reducing the condenser temperature can reduce the condensing pressure of the R134a refrigerant which results in a reduction of the compressor work. Thus, the pressure will drop from P2 to P6 which results in a decrease of the refrigerant's enthalpy at the superheated vapor state from h2 to h6 which is similar to the first recommendation shown in Fig. 7.

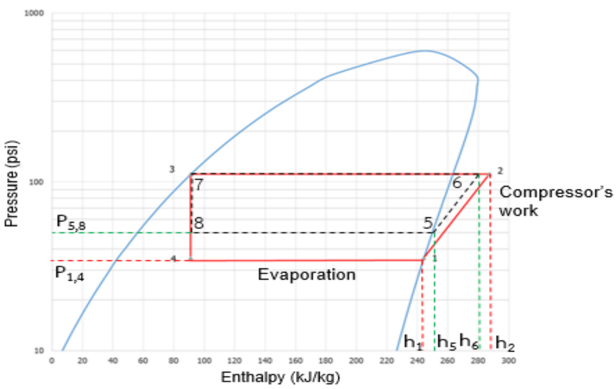

Figure 8. Change of P-h diagram when cleaning the evaporator.

3) Cleaning the evaporator

The evaporator works best when its panel is free of ice or scale. The R134a refrigerant vapor pressure can be increased by increasing the temperature of the evaporator. So, when the evaporator does not have ice or scale on the panel, the heat exchange would be better. Thus, the temperature of the R134a refrigerant at the evaporator will be higher which results in lowering the work of the compressor. This can be explained in Fig. 8.

4) Installing an automatic condenser tube cleaning system

An automatic condenser tube cleaning system can help clean and prevent fouling or scales on the inner surface of the condenser, while the chiller can still run during the cleaning process. This results in a higher performance, better cooling system and more energy saving.

An automatic condenser tube cleaning system will send the ball into the condenser for continuous cleaning and keep the condenser tube clean all the time. The chiller becomes more effective compared with the chiller before installing the cleaning system. It is reported that the coefficient of performance (COP) could be improved by 12% when applying the cleaning system [9]. Since the condenser tube is always clean, chiller could have a longer lifetime. This also reduces labor and maintenance cost for the chiller.

5) Installing the compressor speed regulator

Variable speed drive (VSD) chiller uses variable frequency drive (VFD) motor controller that can adjust the compressor speed to compress the refrigerant by the required load. It adjusts the speed of the compressor by adjusting the frequency of the current supplied to the motor by the actual load. Normally, when the chiller load is lower than 70 percent, the efficiency starts to decline rapidly [10]. This is the cause of energy loss in the air conditioning system. With the speed regulator, the chiller could run with higher efficiency under all operating conditions [5]. Hence, VSD chillers can perform better at part load than conventional chillers. The potential of energy saving for the VSD chiller is about 20 to 40 percent. The reduced electrical energy mainly depends on the operating load of the chiller.

IV. Conclusion

For the CH1 chiller at the peak load period, the average chiller load was 381 TR, while the average power consumption was 277 kW, and the calculated cooling performance was 0.735 kW/TR. The average chiller load during the off-peak period was 211 TR, the average power consumption was 198 kW and the cooling performance was 0.966 kW/TR.

For the CH2 chiller at the peak load period, the average chiller load was 276 TR, while the average power consumption was 260 kW, and the calculated cooling performance was 0.967 kW/TR. The average chiller load during the off-peak period was 264 TR, the average power consumption was 233 kW and the cooling performance was 0.895 kW/TR. Therefore, the CH1 chiller had better performance than the CH2 chiller.

When analyzing the results, the maximum chiller load was much less than the cooling capacity of 600 TR, especially at the off-peak period, when the chiller load was very low. Therefore, chiller mostly operated in a part load state, resulting in a high-power consumption. Future study could be done after improving chillers following proposed recommendations. The chiller performance could be investigated to see the efficiency and also the amount of savings that could be improved.

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