ENERGY SAVING STUDY IN A HOTEL HVAC SYSTEM

J.S. Hu, Philip C.W. Kwong, and Christopher Y.H. Chao†

Department of Mechanical Engineering, The Hong Kong University of Science and Technology
Clear Water Bay, Hong Kong

ABSTRACT

Energy conservation is one of the key issues for environmental protection and sustainable development. Currently, about 17% of the total energy is being consumed for heating, ventilation, air conditioning (HVAC) and refrigeration in Hong Kong. Therefore, energy saving in the HVAC systems of buildings is an important topic. In this paper, a study on the energy saving in a hotel HVAC system was carried out. The cooling load features of the hotel were analyzed. Retrofitting strategy of the HVAC system in the hotel was then designed. It included replacement of the chillers and pumps followed by adopting a newly designed control scheme based on the pattern of the cooling load. The control scheme consisted of controls of the chillers, pumps and cooling towers. An intelligent algorithm was developed to ensure the chillers work at the highest COP under different conditions. It was found that with the new system, about 63% to 74% of the chiller/pump system energy could be saved in that hotel. The result shows that for buildings such as hotels, a good control on the operation of the chillers and pumps is crucial.

KEYWORDS

Energy Saving, Hotel, HVAC, Control Scheme

INTRODUCTION

Since the International Oil Crisis in 1973, energy has become such an important issue that strongly affects people's lives and the policy of every country. Enormous efforts have been devoted in the past decades on energy resources and energy efficiencies. Currently, a large amount of energy is being consumed by heating, ventilation and air conditioning (HVAC) systems in buildings. According to the statistics from the Hong Kong SAR government, about 17% of the total energy, which is about 30% of the electric energy (Chow 2006) is being consumed by HVAC systems in buildings. Therefore, energy conservation of HVAC systems in buildings will clearly have a sizeable impact on total energy consumption.

Up to date, a lot of efforts have been made in various buildings to minimize the energy consumption in HVAC systems. For example, Marriott (2006) proposed three approaches that can be easily applied in buildings to improve the energy efficiencies of HVAC systems. The approaches are optimizing the supply air temperature, recovering energy from condenser water and making use of the geothermal heat pump system. Chan (2006) proposed an optimum control logic for the HVAC system of a building in Hong Kong, which minimized the mismatch of cooling load demand and chilled water flow demand. Around 435,000 kWh was saved by the developed control logic from June 2003 to May 2004. Montgomery and Baker (2006) conducted a practical study on the effect of cleaning coils of air handling unit on building HVAC systems in New York City. The building has a total area of 111,500 m^2 and was served by four air handling units with the total capacity of 2,023 kW. It was found that the cleaned coils of the air handling units saved about $40,000 in 2005. Pressure drop of air through the air handling units was decreased by 14% and the thermal efficiency of the cooling coils was increased by 25%. Montgomery and Baker's work provided a valuable understanding on the effect of cleaning coils on energy saving in HVAC systems. Mathews et al. (2002) developed a simulation tool, QUICKcontrol. It estimates the effect of different control strategies on the energy saving performance in various buildings. Effects of control strategies such as fan scheduling, set point setback, economizer cycle, new set point, fan control, heat plant control, etc. can be investigated in detail via

† Corresponding Author: *Tel: + 852 2358 7210, Fax: + 852 2358 1543*
E-mail address: meyhchao@ust.hk

this simulation tool. Mathews et al. used this simulation tool to study the energy saving potential in a conference center in South African. A new control strategy was developed with the aid of this simulation tool. It was predicted that about 58% of the HVAC system energy could be saved. Chan (2006) and Mathews et al. (2002) showed that besides the energy efficiency of the machines (chillers, pumps, fans, etc.), control strategy also plays a very important role on HVAC energy consumption. Kim et al. (2001) conducted a computational fluid dynamic simulation for analyzing the indoor cooling/heating load. It was coupled with a radiative heat transfer simulation program and a simulated HVAC control system. The output of the simulated HVAC control system can be fed back to the boundary condition of the CFD simulation program and the indoor environment was simulated. New control signal can then be determined based on the indoor environment. Energy saving performance of the control strategy can be investigated accurately. With the same simulation program, thermal comfort can also be estimated by the calculated indoor status using PMV based approach. In review of the previous studies on energy saving of HVAC systems, most were conducted in office buildings. Only a few studies were carried out in hotels. Hotels may consume a large amount of energy in some tourist cities and hence it is also an important issue. In this paper, a practical study on energy saving in a hotel was carried out. Chillers, pumps and the control system were retrofitted based on the analysis of the characteristics of hotel cooling load. Energy conservation performance of the retrofit was investigated.

HOTEL, CHILLERS AND PUMPS DESCRIPTION

The hotel is located in the East Kowloon area, Hong Kong, where it is located in the subtropical region. The monthly average temperature is ranging from about 15.9 to 28.8 ^{o}C throughout a year. The monthly relative humidity is about 68% to 83%. The hotel consists of 16 stories and has a total air-conditioned area of 24,326 m^2. It has about 400 guestrooms together with some restaurants, meeting rooms, function rooms, kitchens, offices and shops. Most of the area is opened for 24 hours a day.

The chillers of the hotel are located in a plant room on a lower level. Originally, there were 4 chillers having the refrigeration capacity of 1,235 kW, respectively. All the four chillers were air cooled chillers. The COP of two chillers was 3.7 and the COP of the other two was about 4.0. These chillers and the chilled water pumps have been operated for 17 years since 1988. The operation of the chillers was controlled manually by the operators according to the return temperature of the chilled water. When the return temperature of the chilled water was higher than 12 ^{o}C, one more chiller was put into operation. When the return temperature was lower than 11 ^{o}C, one chiller was turned off. Four centrifugal pumps with 37 kW each were used to drive the chilled water. The pumps were operated manually by the operators according to the number of the operated chillers.

RETROFIT OF THE CHILLERS, PUMPS AND CONTROL SYSTEM

The efficiencies of the devices were estimated to be low as the chillers and the pumps of the hotel were aged. The owner was eager to improve energy efficiency of the HVAC system to save the electric bill.

Before the retrofit of the HVAC system, an analysis was carried out. It was revealed that:

- The HVAC system has to be operated for 24 hours a day. Compared to the HVAC systems in office buildings, which are generally operated in office hours, there was a large room to save the energy in hotels. Although the chillers with higher COPs are more expensive, they are suitable for hotel applications and the payback period is reasonable. Based on such consideration, water cooled chillers were proposed to replace the original air cooled chillers.

- Cooling load of the hotel varies dramatically from season to season, day to night, and with the varying occupancy level. In most of the time, especially at night, the original chillers might operate with part load. Therefore, chillers with less cooling capacity were proposed to cater for the low cooling load period. This could ensure that the chillers can operate with almost the full cooling load in most of the time.

- Cooling load of the hotel may vary fast due to the possible sudden change in the occupancy level. For example, a group of tourists may check in or check out simultaneously. Manual control may not respond fast enough and may result in waste of energy. Therefore, an automatic control system was proposed.

- Based on the statistics from the Hong Kong Observatory, free cooling can be adopted for around 4 months in Hong Kong. Therefore, the control system should take into account the outdoor temperature to fully utilize free cooling for energy saving.

- Due to the large variation in the cooling load, flow rate of the chilled water should be carefully controlled. The pumps consumed a considerable amount of energy, which was about 20% of the chiller/pump system energy. In the past, chilled water flow rate was adjusted by valves. Energy was wasted via friction while water flowed through the valves. Frequency inverter based flow control system was proposed in order to reduce the pump energy together with the precise control of the chilled water flow rate.

Based on this analysis, retrofits of the chillers, pumps and control system were carried out as follows.

Chillers

Sixteen water cooled chillers were adopted to replace the original four air cooled chillers. Among the sixteen chillers, two have the cooling capacity of 1265 kW and COP of 5.88 each. The cooling capacities of the rest are 90 kW and the COP of around 4.55 each. It is seen that the energy efficiency of the new chillers are evidently higher than the original chillers. COP of the smaller chillers is somewhat lower than that of the larger chillers. However, their smaller cooling capacity can ensure the chillers operate with the full cooling load most of the time and thus the highest energy efficiency can be obtained.

Pumps

The original pumps have been operated for 17 years and their efficiency was estimated to be low. The pumps were replaced by four new pumps with similar capacities. A frequency inverter was installed in one of the pumps to cater for the large variation in cooling load. With this configuration, flow rate of the chilled water can be adjusted continuously.

Control System

To obtain a maximum energy saving performance, a programmable logic controller (PLC) and PC based control system was developed. PLC was used to collect signals from temperature sensors, pressure sensors, flow rate sensors, etc. and to control the operation of the chillers and pumps. PC with a developed supervisory control and data acquisition (SCADA) system was used to monitor the whole system and to adjust the parameters. The control system carries out the following functions.

a) *Operation of the Chillers*

Free cooling can be used in Hong Kong for about 4 months as mentioned above. In fact, more accurately, free cooling can be used on most of the evenings and mornings according to the weather conditions. Therefore, the controller will judge if the chillers need to be operated to save energy. A temperature sensor was installed outside the hotel. Ambient temperature is measured in real time manner. Chillers are operated according to the two prescribed setpoints, T_1 and T_2, where, $T_1 < T_2$. T_1 and T_2 are selected according to the thermal comfort of the clients based on the experience of the operator. If the temperature is lower than T_1, which means that temperature is low enough for thermal comfort, no chiller is turned on. If the temperature is higher than T_2, which means that the clients may feel hot, the chiller is turned on. If the temperature is between T_1 and T_2, cooling will be supplied at some specified time, e.g., lunch time, etc. T_1, T_2 and the time can be set through the SCADA system.

b) *Operate the Chillers with the Highest Efficiency*

Two larger chillers and fourteen smaller chillers were installed and the efficiencies of the chillers at different cooling load are different. Operating chillers with the highest efficiency can be a key issue for energy saving. For this purpose, a database of the efficiency of the chillers at different part loads was established. Real time cooling load is determined by the control system through the measurement of the supply and return temperature of the chilled water and the flow rate of the chilled water by an ultrasound flowmeter. The chiller (or the combination of the chillers) with the highest energy efficiency will be selected to operate according to the measured cooling load.

c) Chilled Water Temperature Setpoint

The temperature of the chilled water is important to the efficiency of the chillers. The higher the chilled water temperature is, the higher the efficiency of the chiller is. However, if the chilled water temperature is too high, the desired cooling capacity may not be offered. With the measured cooling load, the highest feasible chilled water temperature is calculated by the control system and it is then used as the setpoint of the chilled water. The PLC controller sets the setpoint of the chillers and the chillers change the chilled water temperature to the setpoint by the internal controllers.

d) Cooling Water Temperature Control

The cooling water temperature is important to the efficiency of the chillers. The cooling water is cooled in the cooling towers by fans. The supply temperature of the cooling water is limited by the ambient temperature. Improper setpoint of the supply cooling water temperature will cause the waste of the fan power. Therefore, setpoint of the supply temperature of the cooling water is adjusted in real time mode according to the ambient temperature. The number of cooling tower used and the fan speed are controlled in order to change the outlet cooling water temperature of the cooling tower to the setpoint.

Temperature difference of the cooling water through the condenser is controlled by adjusting the flow rate of the cooling water via frequency inverters. The optimum temperature difference is selected for the highest possible energy efficiency for chillers and pumps.

e) Chilled Water Pump

Frequency inverter is installed to adjust the chilled water pumps to minimize the pump energy. While the load varies, a constant pressure at the furthest point will be maintained by modifying the speed and the number of the motors. So the energy consumed on the valves will be minimized while maintaining the desired water flow rate.

The detailed flow chart of the control scheme is shown in figure 1. Figure 2 shows the schematic diagram of the new chiller/pump system.

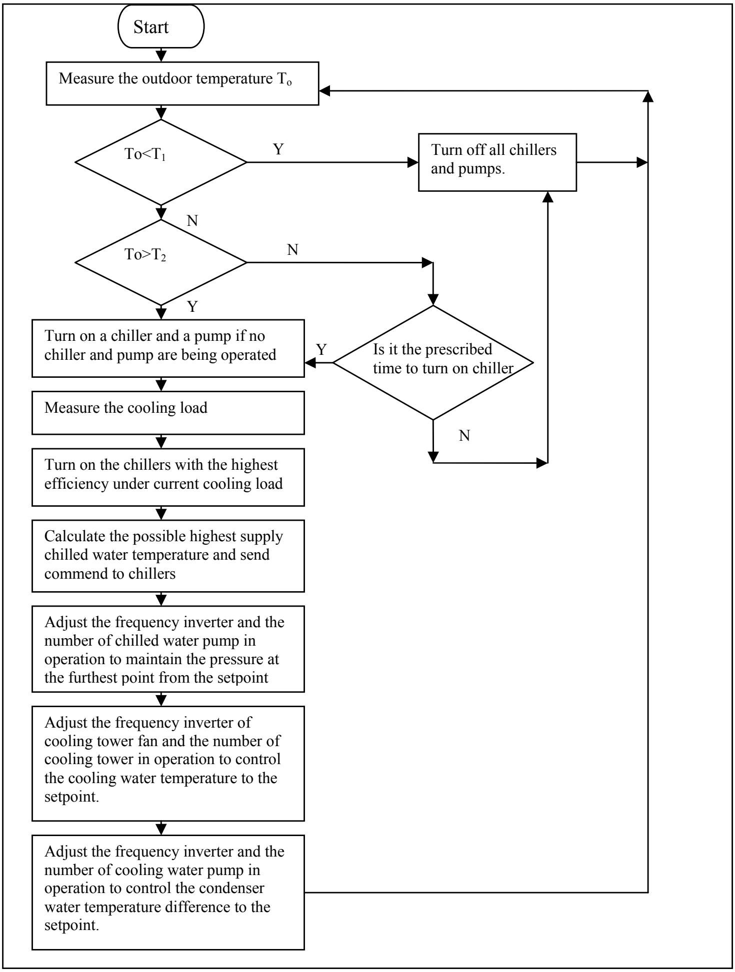

Figure 1: Flowchart of the Control Scheme

ENERGY SAVING PERFORMANCE

The new chillers, pumps and control system have started to operate since October 2005. It was found that the new system had much higher energy efficiency than the original system. Figure 3 shows the energy consumption of the new chiller/pump system of the hotel from October 2005 to August 2006. Energy consumption of the original system from October 2003 to August 2004 is also presented for comparison. During the two periods, the indoor temperature setting was the same. The monthly average ambient temperatures of the two periods were similar as shown in Figure 4. The average

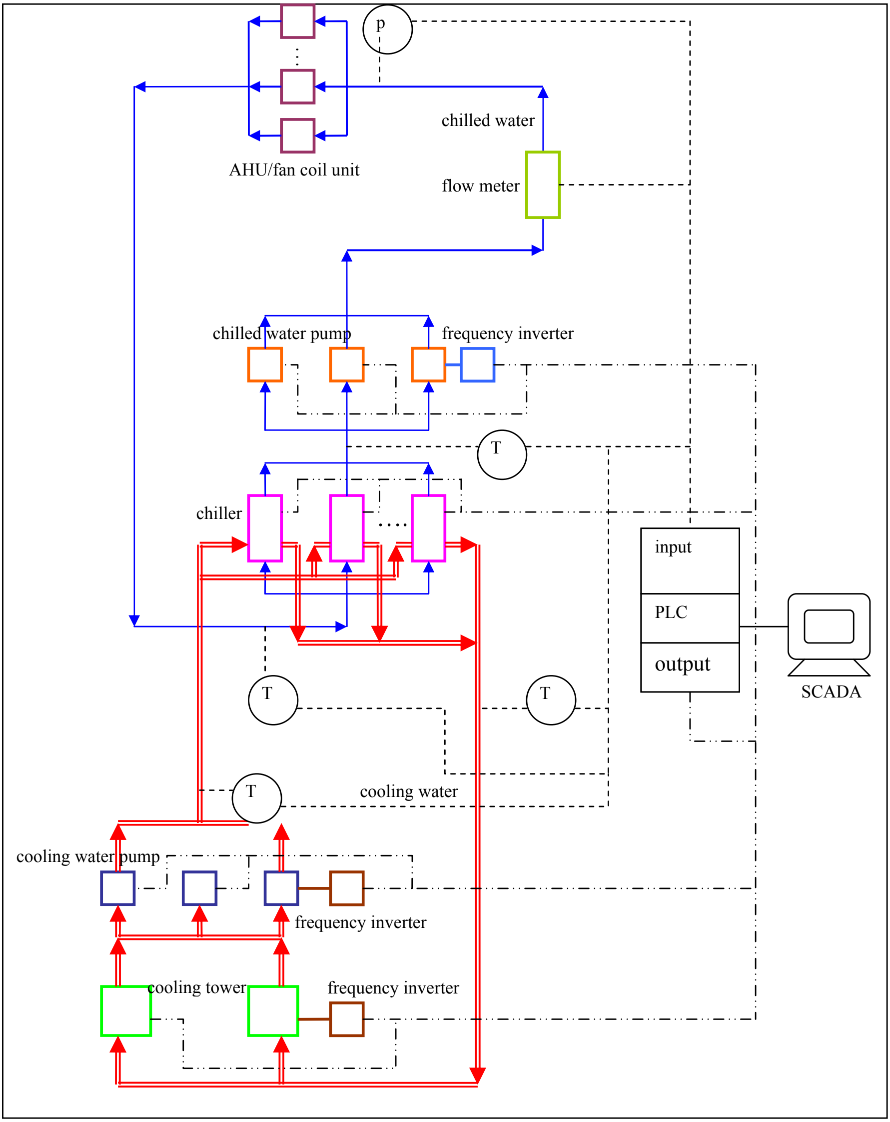

Figure 2: Schematic Diagram of the New Chiller/pump System

temperature from October 2003 to August 2004 was about 22.9 ^{o}C while that in the period from October 2005 to August 2006 was 23.1 ^{o}C. Although the ambient temperature was slightly higher when the new system was used, the energy consumption was much less than that when the original system was used as can be seen in figure 3. The monthly electric energy consumption by the chiller/pump system was about 433,255 to 841,969 kWh with the old system. While the monthly electric energy consumption decreased to 128,960 to 269,232 kWh with the new system. About 63% to 74% of the chiller/pump energy was saved.

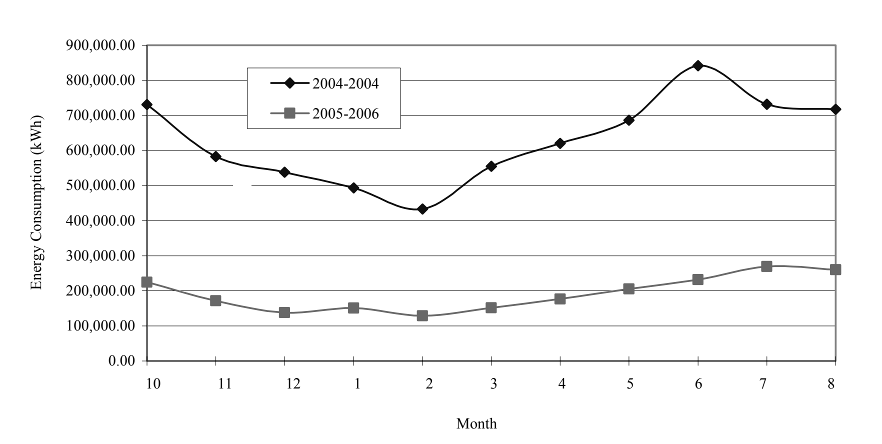

Figure 3. Energy Consumption in the Hotel by the Chillers and Pumps

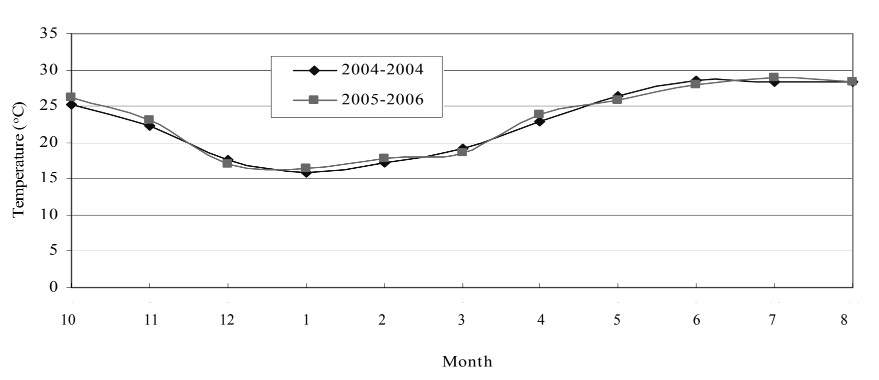

Figure 4. Monthly Average Temperature

In review the retrofit of the hotel HVAC system, the improved energy efficiency resulted from three aspects, i.e., improved energy efficiency of the chillers, improved energy efficiency of the pumps and the intelligent control system. Comparing the COPs of the original and the new chillers, it is seen that the new chillers has an energy efficiency about 18% to 36% higher than the original chillers which may contribute to about 14.4% to 28.8% of the total energy saving. The efficiency of the new pumps is estimated to be 30% higher than the original pumps. As the pumps generally consume about 20% of the total chiller/pump system energy, the replacement of the pumps contributes to about 6% of the total energy saving. Then, the remaining 27% to 45% of the energy saving should result from the intelligent control system. It is seen that a good control system is important to energy saving as well as the enhancement of the machines. The payback period of the system is predicted to be less than three years, which is quite acceptable.

CONCLUSION

Energy conservation of the HVAC systems in hotels is important to energy saving in tourist cities. In this paper, cooling load features of a hotel were analyzed. Retrofit of the HVAC system of the hotel was conducted including replacement of the chillers, replacement of pumps and installing a new control system with an intelligent control algorithm. This intelligent control algorithm ensures the energy is used with the highest efficiency. With the new system, 63% to 74% of the chiller/pump energy was saved. The result shows that a considerable amount of energy can be saved in hotels with a good control system and high efficiencies of the chillers and pumps.

ACKNOWLEDGMENT

This project was supported by the HKUST Research Grant ICL001.04/05.

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