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Discussion on Energy-saving Applications of Fanless Cooling Tower

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Abstract: Cooling tower is essential to both industrial development and comfortable living. Its development is closely related to human civilization and quality of life. To achieve the cooling effects and the efficiency performance of high inlet/outlet water temperature difference (Δt) of cooling towers, a number of modern high technologies have been applied, while the design of cooling towers focuses on lightweight, compact size, elegant appearance, and durability. This study studied the performance of fanless cooling tower when applied in a chiller cooling water system of the central air-conditioning in a hospital and discussed the problems and solutions that the fanless cooling tower encountered during practical use and explored whether there is any room to improve energy conservation according to the data recorded in the process of operation. This study also verified the performance and advantages as specified by the manufacturer to provide a reference to the design and installation of same type cooling towers in the future.

Key words: Heat dissipation cooling, energy-saving, cooling tower, fanless

INTRODUCTION

Most of the early cooling towers achieve heat dissipation by natural ventilation, resulting in very large volume and expensive building costs. Moreover, the water temperature, wind speed and wind direction cannot be controlled due to natural ventilation. Thus, these cooling towers are only used in cooling water recycling in some power plants, some chemical equipments and for academic experimental purposes. After World War II ended in 1945, due to the aggressive industrial development and improved living standards across the world, the demand on cooling water increased dramatically. To achieve controlled, stable cooling water conditions and save water resources, cooling tower was widely used as it was the most economically suitable equipment. As a result, cooling tower has been developing along with the improving living standards and industrial development, and has been improved constantly. To achieve high inlet/outlet water temperature difference (Δt) efficiency performance and reduce noise, and to save water and power, after decades of research and development, the appearance and size of cooling towers have gradually reduced, and its efficiency has enhance. In addition, its performance, material, noise and cost reduction have also been significantly improved.

The current cooling towers, according to appearance, can be divided into the round and the square towers; the cooling methods include counter-flow, cross-flow counter flow, direct-communication and the spray cooling. In terms of purposes, the cooling towers can be divided into fanless, sealed, anti-white smoke, ultra-high, ultra-low noise and ultra-land efficiency towers. Different types of cooling towers can be selected according to different conditions. This study chose the application of a fanless cooling tower in the central air-conditioning cooling water system of a hospital as the target and discussed the characteristics as specified by the manufacturer that were better than those of the fan cooling tower (Chen, 2003):

- **Quiet design:** No fan, motor, reducer, rotating machinery with noise lower than the ultra-low noise cooling tower
- **Cooling method:** Cooling water spray kinetic ventilation without external power source
- **Suspension means:** No vibration, no shock absorbers needed
- **Water splash loss and dust prevention capacity:** Five-fold water blocker installed at the air vents of the tower top for liquid-water separation. In addition to dust prevention, the water splash loss is between 0.001~0.009% (as per spray pressure). Reduce more than 90% water splash loss than the traditional tower and reduce the transmission of Legionella bacteria
- **Structural method:** Modular unit design, stable performance, FRP material for air-conditioning equipment, entire structure made of hot-dip galvanized steel sheet materials. It has features of

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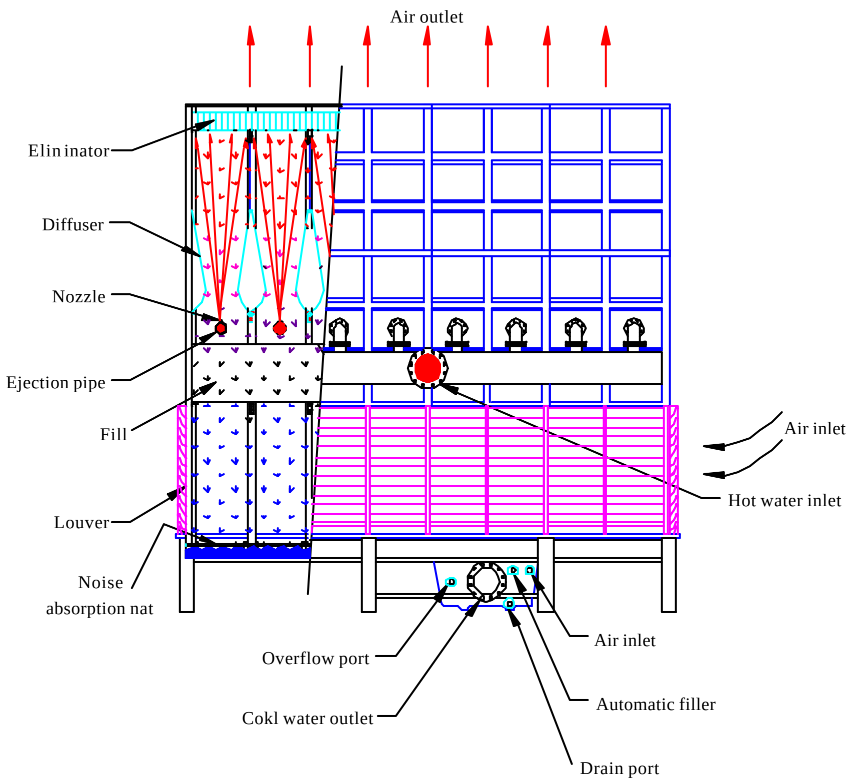

Fig. 1: Appearance and components

long-term corrosion and erosion resistance, long service life, and integrated into the building design for beautiful appearance

- **Power consumption:** No fan, higher head required; equivalent total power consumption with traditional water cooling tower
- **Operating and maintenance costs:** Composed of static components made of corrosion-resistant materials. Thus, there is no wear and tear, and low maintenance fee

This study only discussed whether there are rooms for improvement of energy efficiency of the fanless cooling tower.

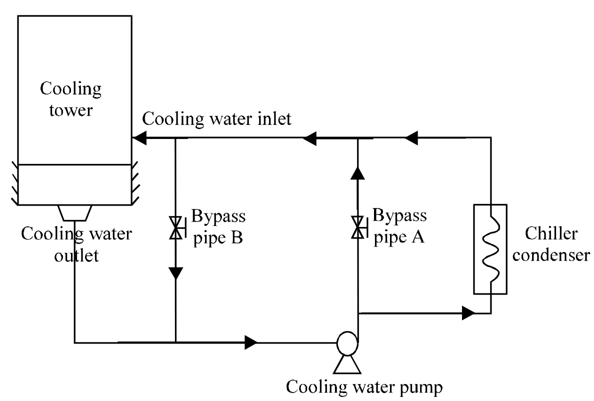

Fig. 2: Circulation pipeline installation system

Components and principles of fanless cooling tower: The components of fanless cooling tower include the body, water dish, wind board, noise reduction blanket, heat dissipation materials, diffuser, nozzle group and water blocking boards, as illustrated in Fig. 1. The circulation pipeline installation system is mentioned in Fig. 2 (Chen, 2003).

The heat dissipation principle of fanless cooling tower is to apply hydromechanics (Mott and Hsu, 2005) to form water screen by spraying cooling water out of the nozzles under the pressure of cooling water pump. The flow of water screen creates the pressure difference inside and outside the cooling tower to inhale the external air into the cooling tower. Then, by diffusers, the inhaled external air regularly passes through the heat dissipation materials to allow the cooling water in full contact with the external air to transfer the heat into the external air in the cooling water spraying and falling process, thus achieving the cooling effects. Therefore, no fan or transmission equipment is used in fanless cooling tower to prevent problems including mechanical noise, vibration and maintenance of fan cooling towers (Qi and Liu, 2008; Qi *et al*., 2007; Jin *et al*., 2007).

MATERIALS AND METHODS

The discussion on fanless cooling tower energy-saving applications is to understand: the role of Bypass pipe A and bypass pipe B as illustrated in the circulation line installation system diagram in Fig. 2 and the effect of the installation of frequency converter in the cooling water pump on the central air-conditioning cooling water system, the room for improvement in energy conservation after the application of frequency converter, and the impact of fanless cooling tower inlet water pressure on the changes of inlet/outlet water temperature difference (△t).

The tested fanless cooling tower is installed in a hospital and is applied in its central air-conditioning cooling water system. Its appearance is mentioned Fig. 3a and the cooling water system diagram is mentioned in Fig. 3b.

The hospital's central air-conditioning is composed of a 300RT rotary, a 520RT centrifuga l and a 600RT centrifugal chiller. As mentioned in Fig. 3b, the 520RT and 600RT centrifugal chillers share a 750RT fanless cooling tower, which is the subject of this test.

Bypass pipe A: Bypass pipe A is mounted on the entrance side of the 520RT (R123 refrigerant) centrifugal chiller condenser in Fig. 4a. To accurately control the flow, balance valve is used as the water switch to accurately control the water flow. The test method is to divide the balance valve opening into 8 parts. Starting from 0, each switch opens 1/8 and record a total of nine cooling tower

Fig. 3a: Fanless cooling tower appearance

inlet/outlet water temperatures in Fig. 4b, and cooling tower inlet pressures in Fig. 4c. In addition, chiller-related data, such as the chiller condenser inlet/outlet temperature in Fig. 4d, chiller power consumption in Fig. 4e and external air temperature and humidity in Fig. 4f, are observed and recorded for reference.

As illustrated in Fig. 4b, the cooling tower inlet/outlet water temperature difference (△t) remains at 3°C when the cooling tower inlet pressure increases to 1.55 kg cm^{-2} and

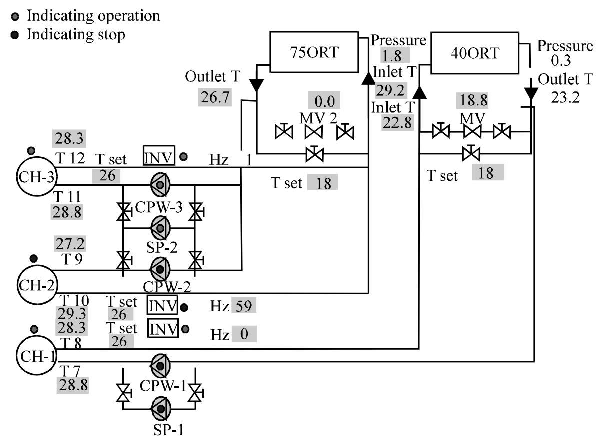

Fig. 3b: Central air-conditioning cooling water system

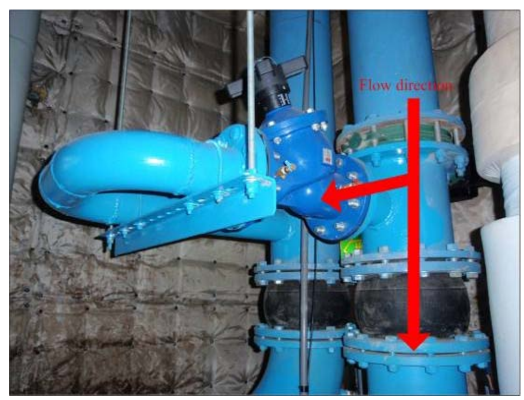

Fig. 4a: Bypass pipe A

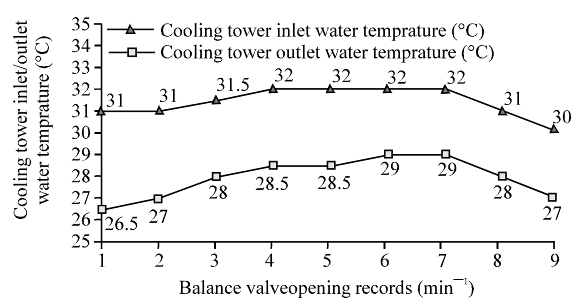

Fig. 4b: Cooling tower inlet/outlet water temperature

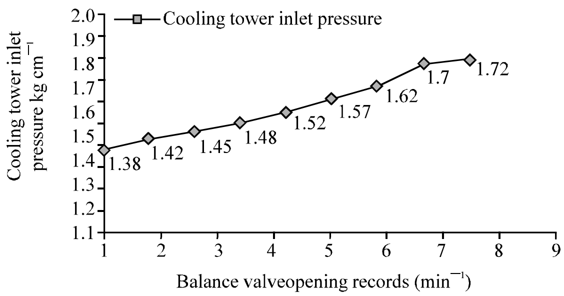

Fig. 4c: Cooling tower inlet pressure

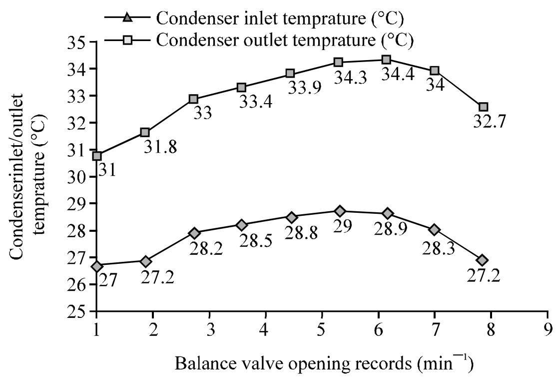

Fig. 4d: Chiller condenser inlet/outlet temperature

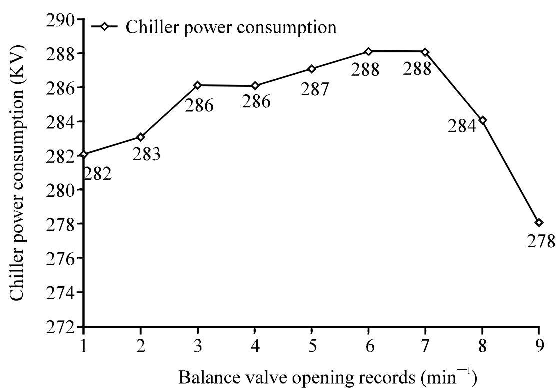

Fig. 4e: Chiller power consumption

above. Comparing with Fig. 3-5, the constantly increasing cooling tower inlet pressure does not mean the relative increase of cooling tower inlet/outlet water temperature. The increasing cooling water pump power consumption cannot increase the cooling tower efficiency in given pressure.

According to the above analysis and comparison with chiller condenser inlet/outlet temperature in Fig. 4d, chiller power consumption in Fig. 4e and external air humidity in Fig. 4f, the data curves, mentioned in Fig. 4b, change along with the external air humidity, which is due

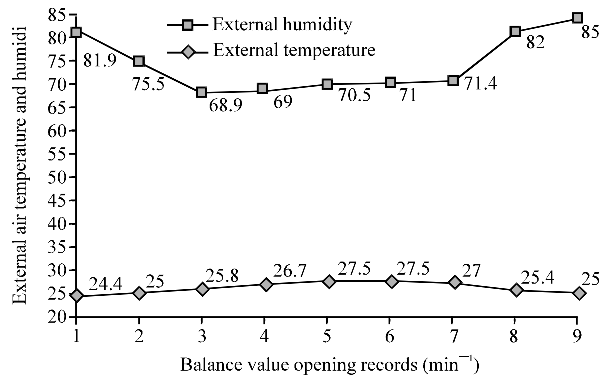

Fig. 4f: External air temperature/humidity records

Fig. 5: Bypass pipe B

to the load rather than the changes of cooling tower inlet pressure. The cooling tower inlet/outlet water temperature difference (Δt) is thus somewhat related to cooling tower inlet pressure.

Bypass pipe B: Bypass pipe B is mounted on the entrance side of the 750RT fanless cooling tower in Fig. 5. As it is located in the inlet end of the cooling water pump, it may result in excessively high chiller condenser inlet water temperature when switched on, activating the chiller protection switch to stop the chiller due to rising pressure inside the condenser. However, when the external air temperature is extremely lower in winter, it should be opened appropriately to raise the condenser inlet temperature to avoid the chiller protection switch from stopping the chiller due to low pressure. Therefore, the water switch should use the proportional two-way valve to control the flow. It is noted that, the switch-on and off control of the proportional two-way valve should be controlled by the temperature sensors installed in the external part of the cooling tower outlet pipe rather than the temperature sensors installed inside the room or the

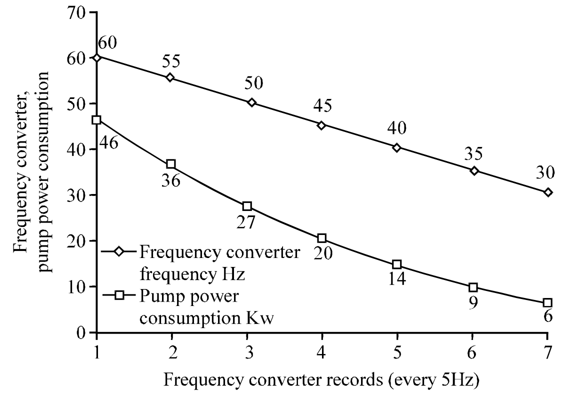

Fig. 6a: Frequency converter power consumption trend records

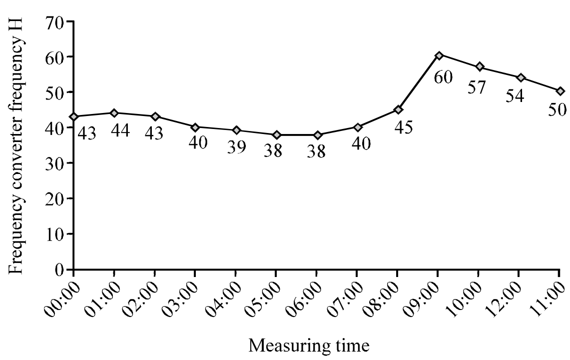

Fig. 6b: Cooling water pump frequency change trend diagram

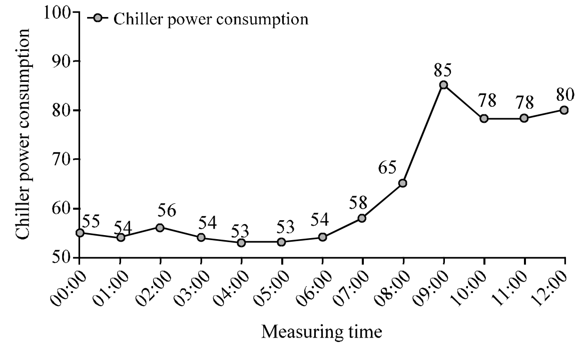

Fig. 6c: Chiller power consumption % trend diagram

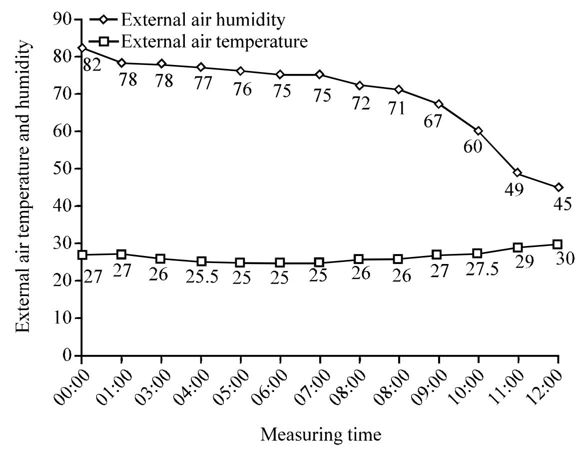

Fig. 6d: External air temperature/humidity trend diagram

chiller condenser entrance. This is because the proportional two-way valve may not switch on and off timely when the room temperature is higher than the external temperature during winter.

Cooling water pump with frequency converter: As marked by the sixth characteristic of fanless cooling tower as specified by the manufacturer, the fanless cooling tower requires no fan but relatively higher head and its total power consumption is equivalent to traditional water cooling tower. This section discusses the effect of installation of frequency converter (Serna-Gonzalez *et al*., 2010) in the pump on the cooling water system power consumption. The measured power consumption after frequency reduction by the frequency converter is shown in Fig. 6a. Compared with the actual operational records of cooling water pump frequency change trend diagram in Fig. 6b, chiller power consumption % trend diagram in Fig. 6c and external air temperature and humidity trend diagram in Fig. 6d, it can be known that the cooling water pump does have space to unload when the chiller is partially loaded while there is no space for energy conservation when the cooling water pump is fully loaded.

RESULTS AND DISCUSSION

According to the test data of (Bypass pipe A), the installation of Bypass pipe A is to raise the inlet pressure of fanless cooling tower to the maximum pressure of the inlet/outlet water temperature difference (Δt) mainly because that the heat dissipation cooling efficiency depends on the spray kinetic energy. However, the cooling water pump is often designed excessively large or insufficient due to factors of head and pipeline resistance during general design and planning. Like the tested central air-conditioning cooling water system of certain hospital, two chillers (one for operation and one for standby) share a fanless cooling tower with considerations to negative impact on the inpatients and saving costs. However, since the two chillers have different tonnage and different condenser inlet/outlet

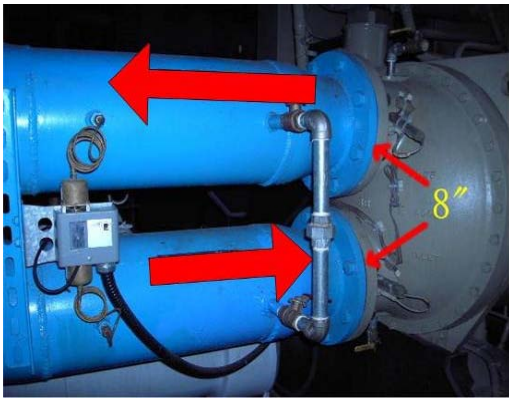

Fig. 7a: 520RT centrifugal chiller

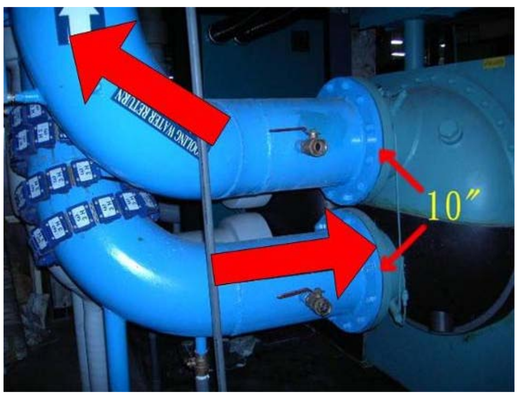

Fig. 7b: 600RT centrifugal chiller

pipes in Fig. 7a and b, cooling water pump of different horse power are used. The one with smaller condenser pipes is functionally equivalent to flow restriction, leading to relatively insufficient cooling tower inlet pressure and reduced efficiency. However, such disadvantage can be improved by installing the Bypass pipe A. Meanwhile, the pressure of chiller with larger condenser pipes to the cooling tower has surpassed the tested 1.55 kg cm^{-2}, therefore, there is no need to install Bypass pipe A and achieve the energy saving effects by frequency converter load reduction control.

Similar to the analysis in (Bypass pipe B), Bypass pipe B is useless when the external temperature is not lower than the chiller minimum cooling water or during the winter. However, it should be installed when switching on chiller in winter. The two-way valve temperature setting controlled by the temperature sensors should refer to the manual provided by the original chiller manufacturer.

In normal conditions, air-conditioning system operates for the most time under partial load, while the peak load time operation is lower than 20%. Hence, in 80% of the operation time, it has room for energy saving. According to the pump affinity laws, the relationships between flow Quantity (Q), Head (H), rotation speed (N) and Braking Horse Power (BHP) are as below (Tsai *et al*., 2004; Hung, 2004):

- $\frac{Q1}{Q2}=\frac{N1}{N2}$, water flow quantity is proportional to rotation speed
- $\frac{H1}{H2}=\left(\frac{N1}{N2}\right)^2$ head is proportional to the square of rotation speed
- $\frac{BMP1}{BMP2}=\left(\frac{N1}{N2}\right)^3$ the braking horsepower is proportional to cube of rotation speed

Hence, reducing pump rotation speed can reduce head and flow quantity and even considerably reduce power consumption. According to the pump affinity laws, the flow quantity is proportional to the cube of power consumption; therefore, the energy conservation efficiency is considerably high.

Figure 6b shows the cooling water pump frequency change trends. According to the analysis of actual operational test data, in case of cooling water pump with frequency converter control, the chiller mainly operates in partial load in the evenings and winter time. The cooling water pump has considerably good energy saving effects rather than the equivalent total power consumption with the traditional water cooling tower as specified by the manufacturer. In fact, the energy conservation rate is considerably high. When, the chiller operates in winter, the cooling tower inlet pressure reduces due to the load reduced operation of the cooling water pump, leading to lower heat dissipation effect of the cooling tower, while making the condenser inlet cooling water temperature sufficiently high to avoid the stop of chiller as a result of low pressure protection switch-off.

The cooling performance of fanless cooling tower changes along with the head. The nozzle head is in the range of 6~16 M, cooling tower with cooling performance between 40 ~100%. Only if the chiller load is between 40 ~100%, it can be regarded as operating to control the nozzle head. As mentioned in the frequency converter power consumption trend records in Fig. 6a, changing the frequency of the frequency converter can change the rotation speed of the cooling water pump to reduce the power loss of the pump accordingly. When the frequency of frequency converter drops from 60 to 30 Hz, the power consumption can be lowered from 46 to 6 Kw, namely, from 60 to 7.5 HP. This study further explored the possibility to reduce the frequency of the frequency converter, in other words, reducing the power consumption. In the early period of the test, it was reduced to 20 Hz, the chiller condenser inlet/outlet water temperature difference surpassed the original design values as the flow quantity was too low. To avoid the negative impact on chiller performance and pipeline scaling, the minimum frequency of the frequency converter is set as 30 Hz.

Comparing the chiller power consumption % trend in Fig. 6c, the cooling water pump frequency change trend in Fig. 6b and the external air temperature trend in Fig. 6d, there is space to reduce load for the cooling water pump when the chiller is partially loaded. However, there is no room for energy conservation for the cooling water pump when the chiller is fully loaded.

Taking the 750 RT fanless cooling tower of the hospital as an example, the power consumption of the cooling water pump can be lowered to 7.5 HP. However, the cooling water pump used in the general type 750 RT mechanical ventilation cooling tower is around 30~40 HP, with fan motor being at 25 HP. The power saved in case of partial loading operation is at most the 25 HP of the fan motor. The fixed power consumption of the cooling water pump is around 30~40 HP. As seen, the power consumption of fanless cooling tower is lower than the mechanical ventilation cooling tower (Wang, 2007). It is leading in the central air-conditioning system partial loading cooling water energy conservation.

CONCLUSION

The load of chiller changes along with external air temperature and on-site requirements, while the cooling tower heat dissipation changes accordingly. With different external air conditions in four seasons, as well in daytime to evening, the fixed wind (water) quantity of the general type cooling tower fans (pump) is not necessarily the optimized one. In fact, the average time of design external air temperature and humidity is less than 2.5% in a year. Therefore, in more than 97.5% of the operating time, the fan (pump) operates to create cooling water lower than the design values and wastes a large sum of energy. According to experiences, when the cooling water temperature drops by 1°C, the chiller can save energy by 1.5~2.5%. The cooling water inlet temperature should be reduced as possible in line with the chiller characteristics and the restrictions of the external air temperature and humidity. The optimized operation of cooling tower and the operation of chiller should be considered at the same time to improve the overall performance of the air-conditioning system.

The main reason for the low market share of fanless cooling tower, besides its expensive costs, is the lack of understanding by the public. This study expected that the example presented in this study can provide more knowledge on the cooling towers. There is room for improvement in the practical application of the fanless cooling tower. For example, the water collection pipes before the nozzle group inlet can be slightly modified to make the pressure of each nozzle even, while raising the breakwater to increase the heat dissipation cooling distance to improve overall efficiency. However, under rising environmental protection awareness, the fanless cooling tower of low noise and low pollution will be a feasible alternative.

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