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Performance analysis of a district cooling system based on operation data

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Abstract

District cooling system (DCS) is recognized to be highly energy efficient compared to equivalent conventional systems being operated at individual buildings. In this paper, it was verified from the performance analysis of a DCS plant based on current operation data. The seasonal coefficient of performance (COP) for the centrifugal chillers was 5.16. The value was lower compared to the design one but still higher with respect to the conventional system. Furthermore, the seasonal energy efficiency ratio of the cooling source system (EER_{sys}) reached 3.85. The analysis showed that the lower value associated with the low occupancy ratio and lower temperature difference between the supply and return water. Our work was much significant in the planning and operation for the plant at the next stage. On the other hand, the operation experience was also worth considering for other projects.

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Keywords: Operation data;District cooling;COP;EER_{sys};

1. Introduction

District cooling system (DCS) becomes increasingly popular for its high energy efficiency. It appears to be a promising energy saving measure for high density business areas especially in Hot Summer Cold Winter zone and Subtropical zone. The results show that the energy efficiency for cooling in DHC systems is superior to that in the

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Nomenclature

DCS	district cooling system
COP	coefficient of performance (COP) for the centrifugal chillers
EER_{sys}	energy efficiency ratio of the cooling source system

case of individual cooling systems because of the ‘‘concentration effect’’ and ‘‘grade of operation’’ [1]. A further study shows that energy conservation measures on the demand side would decrease energy consumption by 23.9% when electric driven heat pumps are used as the heat source[2]. However, the two large and well-known projects in China, were claimed the price for cooling taken from DCS too expensive. It is almost the same with or even higher than the local electricity price compared to only half or one third of the electricity of a traditional cooling system [3]. For many reasons such as that DCS is not well designed or operated and the energy efficiency is lower than that expected [4]. For most DCS projects, there are few English literatures about the analysis of their energy efficiency based on actual operating data. Thus, the so-called high efficiency can’t be verified and it’s hard for the designers to realize their mistakes in design phase, such as over sizing the capacity of the equipment. Based on those facts, operating data are collected to evaluate the actual performance of the DCS plant.

2. Methods

In this paper, we take a DCS plant in Hot Summer Cold Winter zone as an example. The data were uploaded by sensors embedded in the system. The DCS plant was developed in an area of 166,667m^2 that will actually comprise a floor area of 1,000,000 m^2. The predicted total cooling demand of this area was 116MW. Considering simultaneity usage coefficient of 0.7, the design values are 77.9MW for the cooling load and 49.0 MW for the heating load. The cooling load is produced by five centrifugal chillers, two direct-fired absorption chillers, five steam-operated absorption chillers and one flue gas/hot water with direct-fired type absorption chiller. Table .1 shows the main units in the plant.

Table 1. Main units in the DCS plant

Chillers	Number	Rated cooling capacity（kW）
Centrifugal chillers	5	6329
Direct-fired absorption chillers	2	5815
Steam-operated absorption chillers	5	6978
Flue gas/hot water with direct-fired type absorption chillers	1	1745
Total		77910

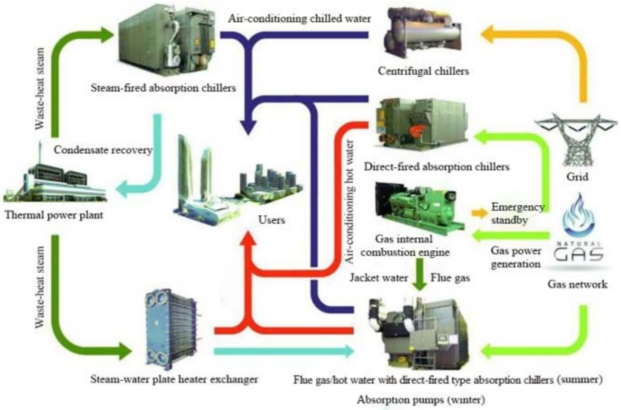

Fig. 1. Schematic diagram of the DCS plant

Fi.1 illustrates the design of the DCS plant. In the cooling season, the chilled water was produced by four different types of chillers, which were driven by waste-heat steam came from thermal power plant, natural gas, electricity and heat recovered from the internal combustion engine, respectively. The ratios of cooling load produced by four sources with respect to the total cooling demand are 44%, 14%, 40% and 3%, respectively. In fact, the plant also supplies hot water in winter. The hot water mostly comes from steam through heat exchangers. Only the performance of the cooling system in the summer is analyzed in this paper.

The rated temperature of supply and return cold water are 5.5 ℃ and 12.5 ℃, respectively. The condenser inlet and outlet temperature are 37℃ and 32 ℃, respectively. In order to reduce the diameter of cooling water pipes, the cooling water system is divided into two parts. The number sets of variable-frequency cooling water pumps, fixed-frequency primary chilled water pumps and cross-flow cooling tower groups correspond to the chillers one by one. The secondary chilled water pumps are controlled through pressure differential between the main supply and return pipeline.

3. Results and discussion

Although the plant has been installed at present, the devices were partially operating in the cooling season in 2016 because of the unexpected occupancy ratio. Coincided with maintenance of steam pipe network and the current high price of natural gas, there were only two centrifugal chillers in operating to supply cooling in the summer.According to the running records of the plant, the cooling season started from June 1, 2016 to October 22, 2016, a total of 144 days, 2790h. Table.2 shows the mainly indicators of plant during the period. The end users were composed of the opera house, the museum and the centralized laundry room, added up to a total area of 100000 m^2. The plant provided a total cooling load of 8.14 million kWh to users. The total electricity consumption was 2.11 million kWh. The electricity consumed by centrifugal chillers was 1.58 million kWh, accounting for 75% of total electricity consumption. It can be seen from Fig. 2 the rest was consumed by primary chilled water pumps, secondary chilled water pumps, cooling water pumps and cooling tower fans, which was accounted for 4%, 9%, 7% and 5%, respectively. It's obvious that chillers consumed most of energy among the energy consumption equipment. Meanwhile, the electricity consumption by secondary chilled water pumps and cooling water pumps was relatively higher than others. A further analysis suggested that the mean COP of the centrifugal chillers was 5.16 and the EER_{sys} was 3.85. The cold source production indicator was 28.93W / m^2, which was much lower than the design value. The main reason was that the actual simultaneity usage coefficient of the cooling load between users was much smaller compared with the original one. It was caused by nonuniform cooling demand of the complicated users. Especially in the early and late cooling season, the plant often had to keep running for some of users at low load. It would lead to a relative smaller cooling area and a longer cooling time. In consequence, a low cold source production indicator would be calculated.

According to the Fig.3(a), the daily cooling demand varied between 3749 ~ 161244 kWh in the cooling season. The pattern of cooling demand is similar to Gaussian distribution. The cooling load was small in the early and late cooling season, even approaching zero in the later days. In the middle of the cooling season, there were two peaks in July and August because the extreme meteorological conditions then. The record showed that the instantaneous peak cooling load was 13496kW, which only accounted for 17% of the design load because of the unexpected occupancy ratio.

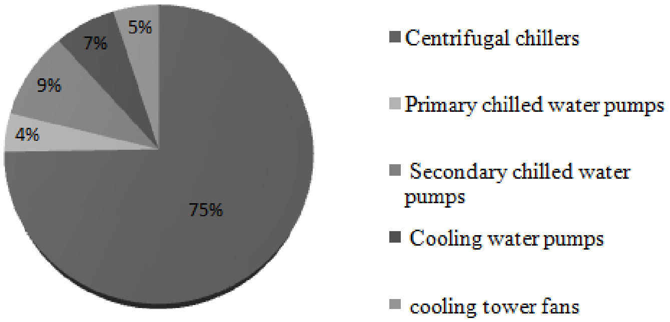

Fig. 2. Energy consumption ratios of different devices

Table 2.The mainly indicators of the DCS plant in 2016

Indicators	Value	Unit
Total cooling load	8143033	kWh
Total electricity consumption	2113114	kWh
Total electricity consumption of centrifugal chillers	1578930	kWh
Total electricity consumption of primary chilled water pumps	87949	kWh
Total electricity consumption of secondary chilled water pumps	201163	kWh
Total electricity consumption of cooling water pumps	140732	kWh
Total electricity consumption of cooling tower fans	103909	kWh
Running time	2790	h
COP of centrifugal chillers	5.16	
Energy efficiency ratio of the cooling source system(EER_{sys})	3.85	
Area of end users	100949	m^2
Cold source production indicator	28.93	W/m^2

It can be seen from the Fig.3 (a) and (b) that the changes of cooling demand and electricity consumption were nearly synchronous. The two showed a close correlation, which may be explained from a relatively stable EER_{sys} in the Fig.6. We can see that the total electricity consumption swelled in the early 60 days, peaking on the 50th day. Then it fluctuated around 20000kWh until another peek appeared. After that the electricity consumption went down to zero, which indicated the end of the cooling season.

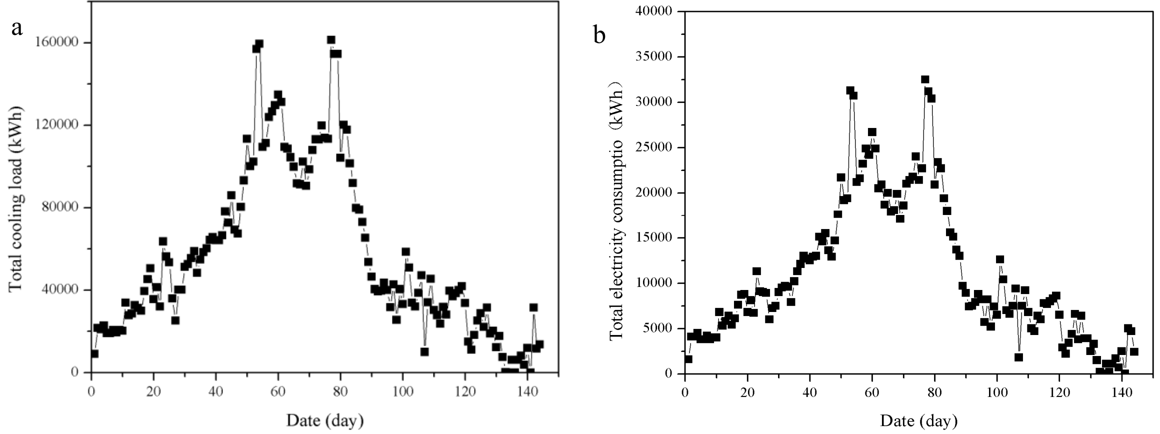

Fig. 3. (a) Total cooling load of each day ; (b) Total electricity consumption of each day

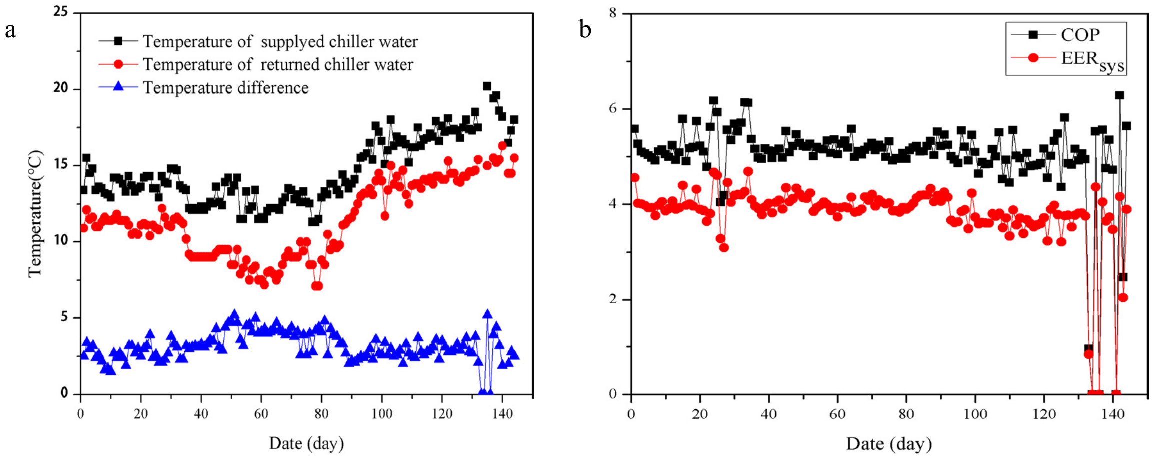

Fig. 4. (a) Temperature of supplied and returned chiller water and their difference; (b) COP of centrifugal chillers and EERsys

Fig.4 (a) shows that the temperature of return chilled water was within 11.3℃ ~ 20.2 ℃ and the temperature of supply water was within 7.1℃ ~ 16.3 ℃. Both temperatures were generally higher than the design value of 12.5℃ and 5.5℃. Also, the temperature difference between the supply and return water fluctuated within 1.5℃ ~ 5.2 ℃, which was much lower than the design value of 7 ℃. It can be concluded that temperature difference would get smaller if the cooling load was small. This was much attributed to the over flow, resulting from the excessive frequency set of pumps manipulated actually by operators not by the changing cooling demand. On the other hand, the frequency conversion of pumps was limited under the low load condition. It is recommended to improve the level of automation system. Meanwhile, the load forecast should be based on the historical record and whether forecast so as to improve the accuracy set for pumps and chillers.

Fig.4 (b) shows that the COP and EER_{sys} also had a nearly same stable changing tendency. The two just floated around 5.1 and 3.9, respectively. It proved that centrifugal chillers were absolutely predominant among the energy consumption devices once again. In fact, the COP of the centrifugal chillers was 6.2 at full load rate under ideal running condition. It's obvious that the COP was much lower than the design one for many reasons, such as excessive condensation temperature. Although the EER_{sys} was lower than the design value, it's still higher relative to the energy efficiency ratio of 3.15 ~ 3.85 when users built cold source system by themselves [5]. However it was lower than 4.8, which was the yearly mean COP of heat pump using wastewater as a heat source in Korea[6]. Above fact shows the advantages of district cooling system in terms of high-energy efficiency in some extend.

We also noticed that the EER_{sys} fluctuates greatly in the early and late cooling season. The highest and lowest value appeared too in those periods. The highest value was due to the fact that the air temperature was lower in the early and late cooling season, which resulted in a lower condensing temperature for chillers. Correspondingly, the COP and EER_{sys} would increase if the pumps run properly. On the other hand, the lowest value appeared because the sets of pumps' frequency and running chillers were man-made for simplified automatic control system during the installation process. When operators predicted the cooling demand just according to their experiences, it would lead to more on-off of chillers and over flow of pumps especially at low load. As a result, the COP and EER_{sys} decreased. In conclusion, sophisticated control will be more significant at low load.

4. Conclusions

As the energy company charges users according to their total air-conditioning area, they did not care about the amount of the cooling load provided by DCS plant. Therefore, heat metering devices installed in the buildings were in idle. It's a pity that there were not enough data for our judgment of the cold loss in the cold water transmission process. Through the analysis based on the operation data, local research combined with theoretical analysis for the DCS plant in the cooling season of 2016, we got the following conclusions:

- The cold source production indicator for the whole cooling season was 28.93 W / m^2, which was much lower than the design value because of the low actual simultaneity usage coefficient and low occupancy ratio currently;
- The seasonal COP and EER_{sys} in the whole cooling season were 5.16 and 3.85, respectively;
- The phenomenon of large flow rate with low temperature difference was much serious in the actual running process. It was recommended to improve the level of automation and the accuracy of load forecast.

It can be concluded that there are some unavoidable problems during the life cycle of the DCS, such as the low occupancy ratio. However, the performance of the DCS still shows its advantages in high-energy efficiency. Furthermore, energy efficiency will increase much if refined operating strategies are implemented. This is also our research target for the next stage.

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