# APPLICATION OF LAKE-WATER HEAT-PUMP SYSTEM FOR DISTRICT HEATING AND COOLING IN SOUTH CHINA

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## ABSTRACT

In recent years, many ground water heat pump systems have been constructed in China, but surface water heat pump (SWHP) systems are very rare. In south China, surface water resources are very ample. Water temperature at the depth of 3 m from the surface of many lakes and rivers changes less than air temperature does during heating and cooling seasons. SWHP systems at these situations thus are suitable to be developed in south China.

A district heating and cooling (DHC) system which utilizes lake water as heat sources and sinks of heat pump has been constructed in Xiangtan, a city in Hunan province in south China. Mengze Lake, which is 82,000 $m^2$ in area and 3 m in average depth, is located among several buildings. An open-loop system with relatively low initial cost was proposed in 2002. After one year investigation of the key technical problems, the central plant was designed, constructed and has been operating since summer 2003. This paper introduces the basic scheme of the system, and it also presents the performance and operating experience of the system. The possibility of improving its efficiency and reliability is also discussed.

## 1 INTRODUCTION

Ground-source heat pump, which includes ground-coupled heat pump, ground water heat pump and surface water heat pump, can significantly reduce energy consumption for heating and cooling of buildings and $CO_2$ emissions (ASHRAE Handbook 1995). Application of GSHP would contribute much to energy conservation and environmental protection.

In recent years, air-source heat pumps and ground-water heat pump system are popular in south China. However, the performance and the capacity of air-source heat pumps decrease rapidly with increasing air temperature during cooling season, and with decreasing air temperature during heating season. Ground water heat pumps can only be built in area with abundant ground water resources.

Surface water bodies can serve as good heat sources and sinks if utilized properly. Kavanaugh investigated the operation of water-to-air heat pumps and direct cooling system with water of southern lakes in USA (Kavanaugh 1990). In Turkey, experimental study of Seyhan River and dam lake as heat source and sink for heat pump has been carried out (Buyukalaca and Ekinci 2003). Aittomaki studied the possibilities of using lake water as heat source for heat pump heating in cold climatic conditions (Aittomaki 2003). In Toronto, a direct cooling system which will draw near-freezing water from the depth of 83 m below the surface of Lake Ontario as an alternative source of air conditioning for downtown Toronto office buildings will go into operation (Tom Davey 2003).

Over 70 percent of surface water resources of China lie in south China. Water temperature at the depth of 3 m below the surface of many lakes and rivers doesn't change much during heating and cooling seasons. SWHP systems thus have good prospects for application in south China.

Xiangtan, with a population of over one million, is located in the east of Hunan province, China. People in Xiangtan put much importance on energy conservation and environmental protection. Chinese-Deutschland environment and cooperation convention was held in this city in October, 2004. Under such background, the owners of four buildings which would be built around lake were inclined to build a lake water heat pump system for district heating and cooling instead of initial scheme in which distributed air-source heat pump units were planed to be utilized.

## 2 THERMAL CHARACTERISTICS OF LAKE

Usually used heat sources and heat sinks for water source heat pump are surface water, ground water, and wastewater. Water source heat pumps offer many performance advantages over air source heat pumps due to outstanding heat transfer properties of water and much more favorable temperatures of water used. Therefore, thermal characteristics of lake water will directly affect the performance of system.

Like many cities in the Yangzi river valley, Xiangtan has a hot summer and cold winter climate. Average temperature of August (the hottest month) and January (the coldest month) is 29.1℃ and 5.6 ℃, respectively. Cooing degree-days for 26℃ base temperature and heating degree-days for 18℃ base temperature are 218 ℃・d and 1353 ℃・d, respectively. Cooling and heating seasons extend from mid-May to mid-October and the ending of November to mid-March, respectively.

Beforetime, there was no detailed report about thermal characteristics of Mengze Lake. Therefore, lake water temperature was monitored to study thermal characteristics of the water body. As Mengze Lake is a shallow lake, temperatures at different depths fluctuate very slightly. So, temperature at the depth of 1 m from the surface is regarded as average lake water temperature. Initial measurements showed that lake water temperature does not fluctuate considerably in a day due to large thermal capacity of water body. Therefore, temperature at a fixed time of a day (10:00 AM) could be regarded as average temperature in a day.

Monitor of lake water temperature lasted one year. Measurements showed that minimum and maximum lake water temperature in a year is 6.8℃ and 29.2℃. Daily minimum, maximum, and average air temperatures were obtained from data of "typical meteorological year" of Xiangtan for the purpose of comparing water temperature with air temperature. Lake water temperature is about 1.5—3 ℃ higher than daily average air temperature in most time of heating season. The reasons of such behavior are thermal inertia of water body and heat absorption from solar radiation. In most time of cooling season, water temperature is 3.5—5℃ lower than daily average air temperature. Such thermal characteristics of lake water are very favorable for improving performance of system.

## 3 THE BASIC SCHEME

Four buildings, Civic center, TV station, Theater and Supermarket, are located around the lake.

Distance between central plant located under ground and any building of these four buildings is within 280 m. District heating and cooling with lake water heat pumps is thus suitable for this group of buildings. Cooling loads and heating loads of four buildings total 14,300 kW and 6,870 kW, respectively. As Civic center and Theater don't simultaneously need air conditioning in a day, cooling loads for DHC system are reduced to 12,400 kW. Initial investments are saved in comparison with traditional distributed plants.

A simplified system schematic is shown in Figure 1. Generally speaking, open-loop system is restricted to warm climates like climates in south China. In view of minimum lake water temperature is 6.8℃; ice accumulation will not occur if auxiliary heat is provided to lake water with extremely low temperature for an open-loop system. So, scheme employing open-loop system with low initial cost was adopted.

Lake water pumps are located in the plant where is 110 m away from the lake, and at almost the same level as the lake water surface. Though lake water quality is relatively good, water cleaner after which lake water is directly pumped into heat pumps was installed. The tailor-made water cleaner can remove suspending particles and floating alga in lake water. Lake water is sucked at depth of 3 m from surface and is discharged to the lake 92 m away from the point at which it was sucked.

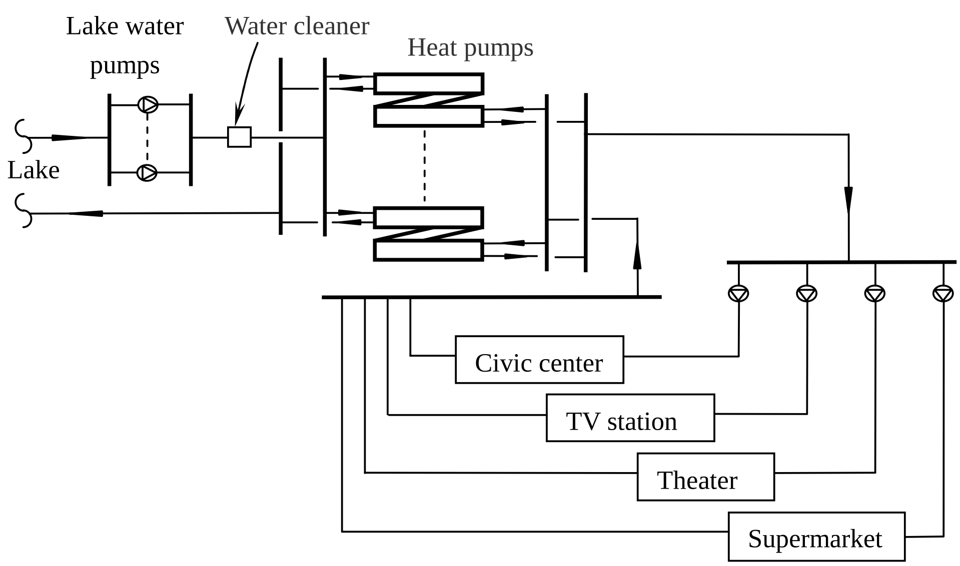


**Fig. 1. DHC system schematic with lake water heat pumps**

**Fig. 2. Discharge port**

**Fig. 3. Appearance of screw heat pump**

Eight valves are employed for the purpose of switch between cooling mode and heating mode of 14 screw heat pumps in plant. Pipes carrying lake water and cold (hot) water are buried directly outdoor about 1.5 m below the ground. Figure 2 and Figure 3 depict the views of discharge port and screw heat pump.

## 4 SYSTEM PERFORMANCE

Unlike deep ground and groundwater temperature, surface water temperature is influenced considerably by changes of weather in a year. The deeper or larger the lake is, the less the influence is. Some large, deep lakes can be used with extremely high heat pump efficiency, even in direct cooling application. To insure heat pumps against low efficiency under bad weather conditions, simulation of lake water temperature field was done at the beginning of design stage. A 2D model for temperature distributing in lake was developed. Typical meteorological data of cooling and heating seasons, building loads and initial lake water temperature were inputted into program. Simulation results of the program indicated that entering water temperature of heat pumps is not higher than 30.7℃ during most time of cooling season and not lower than 8.5℃ during most time of heating season. As a whole, entering water temperature is favorable for keeping heat pump efficiency at a normal level.

Nominal cooling capacity and input power of a screw heat pump of which R-22 is used as working fluid are 894 kW and 220 kW, respectively. Actual input power of heat pumps and lake water pumps was calculated from measurement of supply voltage and the current. Output capacity was determined from temperature and flow rate measurements of circulating water between buildings and heat pumps. In view of lake water pumps between lake and heat pumps consume considerable energy; system performance is evaluated from the following equations:

$$COP_{cool} = \frac{\dot{m} C_p (T_{ei} - T_{eo})}{W_{comp} + W_{pumps}} \quad (1)$$

$$COP_{heat} = \frac{\dot{m} C_p (T_{co} - T_{ci})}{W_{comp} + W_{pumps}} \quad (2)$$

where $\dot{m}$ and $C_p$ are, respectively, mass flow rate and specific heat of water, and $T_{ei}$ , $T_{eo}$ , $T_{ci}$ , $T_{co}$ are, respectively, temperature of water at the evaporator inlet and outlet and at the condenser inlet and outlet.

It should be noted that, in Eqs. (2), auxiliary heat provided to lake water in extremely cold days in winter is not considered. COP of heat pump ($COP_{hp}$) is also calculated for the sake of comparison between heat pump performance and system performance. Figure 4 and Figure 5 present, respectively, $COP_{cool}$ and $COP_{hp}$ in cooling season and $COP_{heat}$ and $COP_{hp}$ in heating season at various lake water temperatures.

As a whole, system performance and heat pump performance are all higher than performance of air-source heat pump. Water- source heat pump systems have the advantages over distributed air-source heat pumps though pumping power is considered. Applying lake water heat pump for district heating and cooling eliminates some defects of air-source heat pump such as defrosting in cold weather, low COP and reduced indoor comfort conditions under unfavorable air temperature.

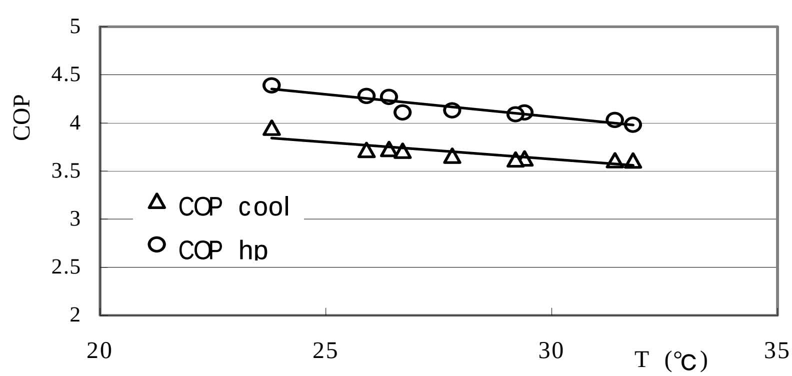


**Fig. 4. $COP_{cool}$ and $COP_{hp}$ in cooling season**

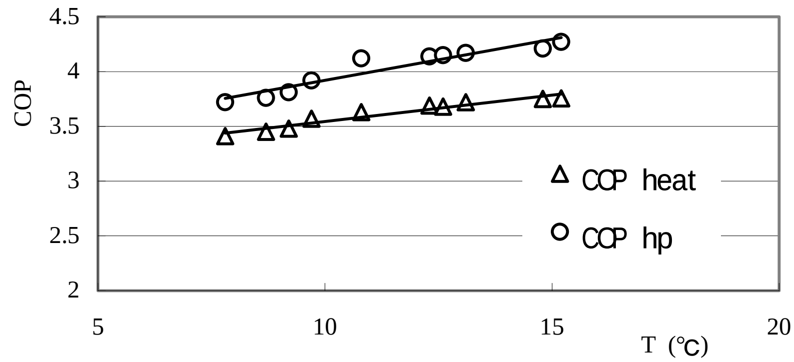


**Fig. 5. $COP_{heat}$ and $COP_{hp}$ in heating season**

As pumping power is taken into account, $COP_{heat}$ and $COP_{cool}$ are about 8—12% lower than $COP_{hp}$. The distance and the elevation between the water source and plant are two main factors that affect pumping power consumption. In our case, the length of suction pipe and discharge pipe is totally about 230 m, but the elevation can be neglected. Therefore, influence of pumping power on system performance is reduced to a certain extent.

## 5 DISCUSSION

When temperature of water source is not favorable sometimes in cooling and heating season, $COP_{cool}$ and $COP_{heat}$ will be rather low. If COP of system is reduced by 20—25% due to pumping power, measures should be taken to reduce pumping power. In some cases, installing variable speed device has become an effective method if controlled properly. For our system, needed flow rate of lake water for cooling exceeds that for heating, and cooling season is longer than heating season. Increasing △T between inlet and outlet of condenser in cooling mode will help to reduce pumping power consumption considerably. Thus, screw heat pumps with △T of 8℃ for condenser in cooling mode are chosen in this case.

It seems to be consensus that open-loop system is restricted to warm climate. The 1995 ASHRAE Application Handbook recommended that water temperature must remain above 5.5 ℃. When entering water temperature fall below 7℃, heat pump outlet temperature will fall below 4℃. It will be very possible that surface temperature of evaporator will drop to 0℃, and ice accumulation will occur. For our system, lake water will fall near 7℃ in extremely cold days in winter. For the sake of preventing ice accumulation and improving system efficiency in such weather days, device that will provide auxiliary heat to lake water was installed in plant. In winter 2003, total operating time of this device was only 9 days.

## 6 CONCLUSION

Before applying lake water heat pump system, characteristics of lake water temperature and local air temperature were studied. Measurements of water temperature during a year indicated that lake water temperature is favorable for cooling and heating. Open-loop system was adopted, and simulation of lake water temperature field was done at the beginning of design stage. Results of simulation showed that water body could dissipate condenser heat in summer effectively, and provide buildings with enough heat in most time of winter.

Though pumping power reduces COP of system, system performance excels performance of air-source heat pump. For a surface water heat pump application, pumping power requirement must be considered seriously in order to obtain relatively high COP of system.

Ample surface water resources and favorable water temperature of large water bodies bring good prospects of applying SWHP system in south China. Application of water-source heat pump, especially SWHP system, should be encouraged for energy conservation and environmental protection.

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