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The performance of an open-loop lake water heat pump system in south China

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Abstract

A district heating and cooling (DHC) system that utilizes lake water as heat source–sink of heat pumps has been constructed in Xiangtan, a city in Hunan province in south China. An initial analytical study had been carried out before the construction. In this paper, a simplified two-dimensional model is developed to simulate the steady lake water temperature (LWT) distribution during continuous operation. The simulation results indicate that the impacts of the discharge on entering water temperatures (EWT) and the ecological environment of lake are acceptable. Field test results showed that the COP values of the system were, respectively, 0.7–0.85 higher in cooling season and about 0.46 higher in heating season than those of the air-source heat pump (ASHP) units at the same sink and source temperatures. An acceptable payback period of 5.6 years was found through an economic analysis based on the comparison between the initial and operating costs of the system and those of the distributed ASHP units that would have been installed according to initial scheme.

Keywords: Heat pump; Lake water temperature; District heating and cooling; Performance

1. Introduction

Ground-source heat pumps, including ground-coupled heat pumps, groundwater heat pumps and surface water heat pumps (SWHPs) [1], help to reduce energy consumption for heating and cooling of buildings and CO_2 emissions.

Surface water bodies can serve as good heat sources and sinks if utilized properly [1]. Cantrell and Wepfer studied the feasibility of using shallow ponds for dissipation of building heat in north Ohio [2]. Aittomäki studied the possibility of using lake water as heat source for heat pump heating in cold climate [3]. Kavanaugh investigated the operation of water-to-air heat pumps and direct cooling system with water of southern lakes in USA [4]. In Turkey, experimental study of Seyhan River and dam lake as heat source–sink for heat pumps was carried out [5]. The lake-source cooling project at Cornell University uses the deep, cold water of nearby Cayuga Lake supplying over 63,306 kW of cooling for its campus [6].

The application of ASHPs in south China is rather popular. However, the performance and the capacity of ASHPs decrease rapidly with increasing ambient air temperature (AAT) during cooling season, and with decreasing AAT during heating season. Some heat pump systems in south China utilize groundwater as heat source–sink. Though groundwater is a very good heat source–sink for heat pumps, the application of groundwater heat pumps is restricted by local groundwater conditions and regulations. The surface water resources in south China account for about 70% of total surface water resources of China [7]. However, utilization of surface water as heat source–sink in heat pump systems is rare in south China.

Xiangtan, with a population of over one million, is located in the east of Hunan province, China. According to an overall planning made in 2001, City Hall, TV Station, Shop and Grand Theater, would be built around Mengze

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Nomenclature

B	average width of lake (m)
COP_c	coefficient of performance in cooling mode
COP_h	coefficient of performance in heating mode
c	specific heat of water (kJ/kg °C)
E	diffusion coefficient (m^2/h)
e_s	saturation partial vapor pressure at heated/cooled water surface temperature (mm Hg)
H	average depth of lake (m)
K	heat loss/gain coefficient of heated/cooled water body (W/m^2 °C)
L	length of every part of the line source (m)
m_{con}	flow rate of the water in condenser (kg/s)
m_{eva}	flow rate of the water in evaporator (kg/s)
P	atmospheric pressure (mm Hg)
Q_0	discharge volume flux (m^3/h)
T_0	discharge temperature (°C)
T_a	ambient water temperature (°C)
T_{ci}	inlet water temperature of the condenser (°C)
T_{co}	outlet water temperature of the condenser (°C)
T_{ei}	inlet water temperature of the evaporator (°C)
T_{eo}	outlet water temperature of the evaporator (°C)
T_s	heated/cooled water surface temperature (°C)
t	time (h)
U_w	wind speed 2 m above the water surface (m/s)
u	longitudinal velocity (m/h)
W_{com}	power consumption of the compressor (kW)
W_{pf}	power consumption of the lake water pumps (SWHP) or the fans (ASHP) (kW)

Greek symbols

ε	emissivity of water
θ	temperature difference between heated/cooled water and ambient water (°C)
θ_c	centerline temperature difference (°C)
ρ_0	discharge water density (kg/m^3)
ρ_a	ambient water density (kg/m^3)
ρ_c	centerline water density (kg/m^3)
σ	Stefan–Boltzmann constant, 5.67×10^{-8} W/m^2 K^4
τ	time-step (h)

Subscripts

0	discharge
a	ambient water
c	centerline

Lake, which is 67,000 m^2 in area and 3 m in average depth. Fig. 1 shows daily average AAT and daily LWT 1 m below the surface at 9:00 AM in 2001 obtained from local weather bureau and hydrological station, respectively. The LWT was 2–5 °C lower/higher than daily average AAT during most time of cooling/heating seasons. Sometimes the difference between the two was as high as 8 °C. The favorable LWT make Mengze Lake a good heat source–sink alternative to air for heat pumps. Thus, the investors of four buildings were inclined to build a lake water heat pump system for DHC instead of initial scheme that ASHP units would have been installed. The system has been operating since summer 2003. This paper presents the system introduction, the initial study and its practical performance based on field tests.

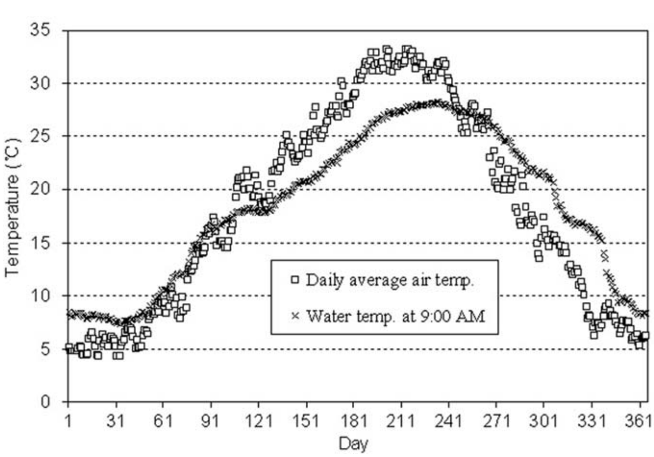

Fig. 1. Daily average AAT and LWT at 9:00 AM in 2001.

2. System description

2.1. System load

A program named HDY-SMAD [8] was used to predict the hourly cooling load in a cooling day and the hourly heating load in a heating day under respective design conditions. Table 1 gives gross floor area (GFA), peak cooling load and heating load per unit GFA (CLU and HLU), peak cooling load and heating load of four buildings. The peak cooling and heating loads of the plant were found to be 12,196 kW and 6953 kW, respectively. The diversity factors in cooling and heating seasons were 0.82 and 0.86 respectively.

2.2. System configuration

A simplified system schematic is shown in Fig. 2. The plant is located under a public square, which is nearly the center of the four buildings. The water intake 110 m away from the plant is located at the depth of 2 m from the water surface. Eight valves are employed for the switch between