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Feasibility study on two schemes for alleviating the underground heat accumulation of the ground source heat pump

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ABSTRACT

The long time running of the ground source heat pump (GSHP) system in cooling dominated areas will cause heat accumulation and then the temperature increase under the ground, resulting in the cooling performance degradation of the GSHP system, as well as other problems, such as the change of thermal and microbial environment, and even the organic carbon reserves in the soil. In order to attemper the heat accumulation, a scheme that the cooling tower be operated in transitional (mid) seasons is proposed for the hybrid GSHP system assisted with cooling tower. The temperature difference (Δt) between the air wet-bulb temperature and the ground temperature is defined as the threshold for the cooling tower to start up in transitional seasons. It has been found that the scheme can effectively alleviate the increase of the ground temperature by simulating the system performance with TRNSYS software. However, the system's total power consumption in 30 years increases due to the extra running time of the cooling tower. $8\sim12\,^{\circ}$C is found to be the optimum range of Δt for the studied hybrid GSHP systems by comparing the system performances under different set values of Δt. In order to find further efficient scheme, a hybrid GSHP system combined with a chiller cooling system is also proposed and studied. However, the simulation result shows that the system power consumption has not got down effectively, for the reason that the energy efficiency ratio (EER) of the chiller used in the TRNSYS model is lower than that of the heat pump.

1. Introduction

Ground source heat pump (GSHP) has been developed rapidly and applied widely in China in recent years (Geng, Sarkis, Wang, Zhao, & Zhong, 2013; Qi, Gao, Liu, Yan, & Spitler, 2014). However, there exists a problem of load imbalance in the application of GSHP system in the cooling load dominated areas. The long-time running of the GSHP system will result in a surplus of heat being accumulated in the ground. Consequently, the ground temperature gradually increases, which deteriorates the performance of the GSHP system in terms of capacity and energy efficiency (Lee & Lam, 2012; Zheng, Zhang, Liang, & Qian, 2013), and also other problems, such as the change of thermal and microbial environment, and even the organic carbon reserves in the soil (Han & Dong, 2013). In order to attemper the heat accumulation under the ground, hybrid ground-source heat pump (HGSHP) is usually adopted, which is generally referred to GSHP with cooling tower in cooling load dominated areas (Kavanaugh & Rafferty, 1997). The advantages of HGSHP for reducing initial costs and ground area requirement compared with conventional GSHP have been discussed in ASHRAE manual (ASHRAE, 1995).

Some researches have been conducted on the performance of HGSHP system. Man, Yang, and Fang (2008) studied the performance of a HGSHP system installed in hot-weather areas with a practical hourly simulation model. Their simulation results showed that the HGSHP system could effectively solve the heat accumulation problem and reduce both initial and operating costs compared with conventional GSHP system. Hackel and Pertzborn (2011) studied three HGSHP systems including two cooling tower assisted systems. Considering the economic and environmental performances of the HGSHP systems, some improved design and operation strategies were proposed in their study. Sagia, Rakopoulos, and Kakaras (2012) improved the design of cooling tower in a HGSHP system through the performance comparison among systems with different auxiliary cooling ratios (ACRs). Furthermore, Sayyadi and Nejatolahi (2011) optimized thermodynamic and thermoeconomic performances of a HGSHP system in a multi-objective optimization process using the genetic algorithm.

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Nomenclature

Q	Air-conditioning load or heat exchange under the ground, kW
P	Power consumption of the heat pump, kW
N	Number of boreholes
H	Borehole depth, m
B	Borehole spacing, m
Cp	Specific heat of fluid, kJ/kg K
m	Mass flow rate (if its air it's the dry air mass flow rate), kg/s
T	Temperature, °C
γ	Ratio of flow rate to design flow rate
$h\ (T)$	Heat transfer coefficient between the fluid and the air at the given temperature T, W/(m^2 K)

Subscripts

h	Heating condition
c	Cooling condition
s	Absorption/dissipation from/to source
b	Borehole
a	Air stream
design	Design condition
f	Fluid flowing through the coils (typically water)
in	Condition at the inlet to the device
out	Condition at the outlet from the device
sat	Saturated air condition

Cui, Zhou, and Liu (2015) constructed the models of parallel and serial HGSHP systems assisted with cooling tower in TRNSYS software. They studied the performances of the two systems in 20 years' running time to find the optimum ACR.

The most common connection between the ground heat exchanger (GHE) and the cooling tower in HGSHP system is parallel configuration (Kavanaugh & Rafferty, 1997). In which, the cooling tower is designed according to the load difference between heating and cooling. However, the heat accumulation still exist for the reason that the cooling season is usually much longer than heating season in cooling dominated areas. In order to dissipate the surplus heat accumulated under the ground, a scheme that the cooling tower be operated in transitional season is proposed in this paper. There are few researches about this issue have been covered so far. The scheme can also be applied to the conventional GSHP system, in which a cooling tower needs to be connected to the GHE to form a fluid circulation for heat exchange. As an extension, the other HGSHP system configured with chiller cooling system is also proposed to attemper the heat accumulation under the ground. With TRNSYS software, the feasibilities of the two schemes are investigated.

2. Air conditioning load of the studied building

The studied building is a multistoried building with an air conditioning zone of 3000 m^2 office area in the first and second floors in Chongqing, located in the Southwest of China, where the climate is characterized by hot summer and cold winter. The detailed description of the building can be found in article (Cui et al., 2015). The hourly air-conditioning load of the building is calculated with TRNBuild (a part of TRNSYS for simulating multi-zone buildings (Klein et al., 2004a, 2004b). The calculated results, together with the corresponding ambient temperature variation which is derived from weather data, are shown in Fig. 1.

In the figure, the positive value represents cooling load while the negative value represents heating load. It can be seen that the load difference between cooling and heating is so large that long-time running of the conventional GHSP system will cause serious heat accumulation under the ground. Therefore, HGSHP system should be adopted for this building to solve this problem.

3. Mathematical model of the system

3.1. Water-to-water heat pump

Type 668 is a simplified water-to-water heat pump model, based on user-supplied performance data containing heating and cooling capacity related to power consumption. It performs linear interpolating according to the entering source and load temperatures.

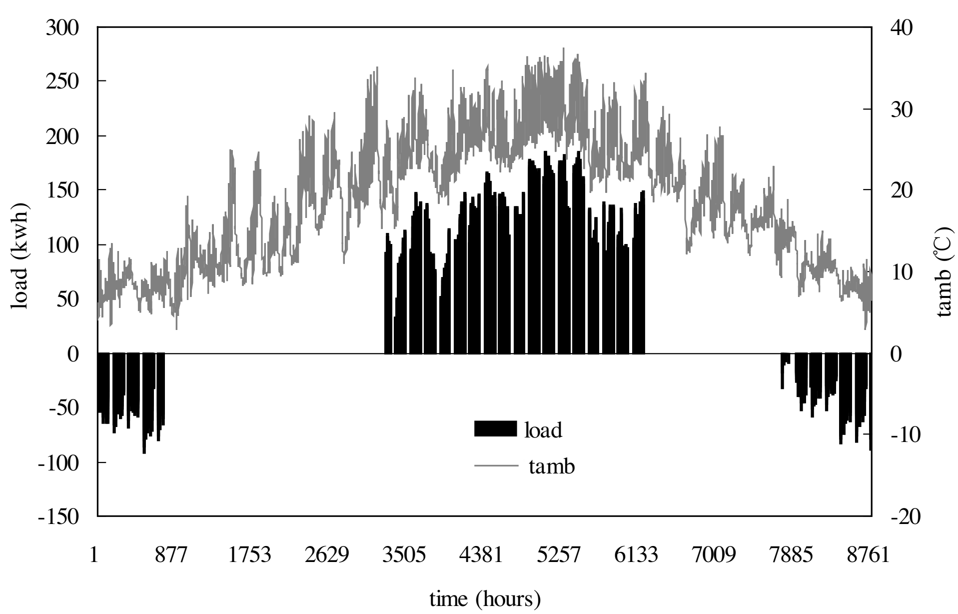

Fig. 1. Ambient dry-bulb temperature variation and load distribution of the studied building.