PERFORMANCE AND FEASIBILITY STUDY OF HYBRID GROUND SOURCE HEAT PUMP SYSTEM FOR A PUBLIC BUILDING BASED ON A BEIJING CASE

by

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With the increasing demand for renewable energy sources, shallow geothermal energy has become a reliable alternative energy source for building heating and cooling. In this paper, we present a methodology for estimating the shallow geothermal potential to meet heating demand for a public building. Firstly, the geothermal reserves and the cooling heating demand of the building are evaluated. Then the simulation model of hybrid ground source heat pump system is established, which aims at solving the problem of soil heat accumulation. Finally, one-year and five-year variation of performance parameters of hybrid ground source heat pump system are calculated. Our results indicate that hybrid ground source heat pump system could effectively solve heat accumulation problem and reduce traditional energy consumption.

Key words: *shallow geothermal, heat exchangers, geothermal estimation, heating and cooling demand*

Introduction

Shallow geothermal energy is a renewable and sustainable energy source that can be used for building heating and cooling. For a long time, building heating has relied on burning high grade energy sources such as coal and even natural gas, which is inefficient and highly polluting [1]. Geothermal energy, as a renewable low grade energy source, is not subject to the seasonal variations faced by other energy sources such as fossil fuels, wind, and mineral source energy [2-4]. The development and utilization of shallow geothermal energy are primarily based on hybrid ground source heat pump (HGSHP) technology, which consumes a small amount of electricity to convert low grade heat sources into high grade heat sources usable by buildings [4]. The energy underground structure is a new type of building energy-saving structure developed from traditional GSHP technology, which effectively addresses issues of insufficient drilling space and high costs associated with conventional ground source heat pumps [5]. The HGSHP systems, with their energy-saving and environmentally friendly advantages, have been widely adopted for building heating and cooling in most countries around the world. Zhang *et al.* [6-8] developed a Python code related to the total borehole length, which outputs the total BHE borehole length required for each building within a selected area. You *et al.* [9-12]

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conducted in-situ tests and discussed the possibility of regional shallow geothermal energy for a public building.

Therefore, the purpose of this study is to evaluate the performance and feasibility of the HGSHP system with cooling tower for a public building in Beijing. Firstly, the geothermal reserves and the cooling heating demand of the building are evaluated. Then the simulation model of HGSHP system is established. Finally, one-year as well as five-year variation of performance parameters of HGSHP system were compared and explored. These findings could provide some scientific bases on suitable application of HGSHP system with cooling tower for public buildings.

Building characteristics load and HGSHP models

Building load calculation

Engineering Project is a large-scale public building. The total heating demand area of the building is 10600 m^2. The building loads are simulated by using the building demand simulation software. Figure 1 shows the annual hourly loads and the cooling loads are shown as negative. The summer design cooling load was 1825 kW, whereas the winter design heating load was 1589 kW. The cooling period in Beijing lasted from June to August, whereas the heating period lasted from November to March. The cumulative cooling load and heating load reached 919600 kWh and 1157100 kWh, respectively.

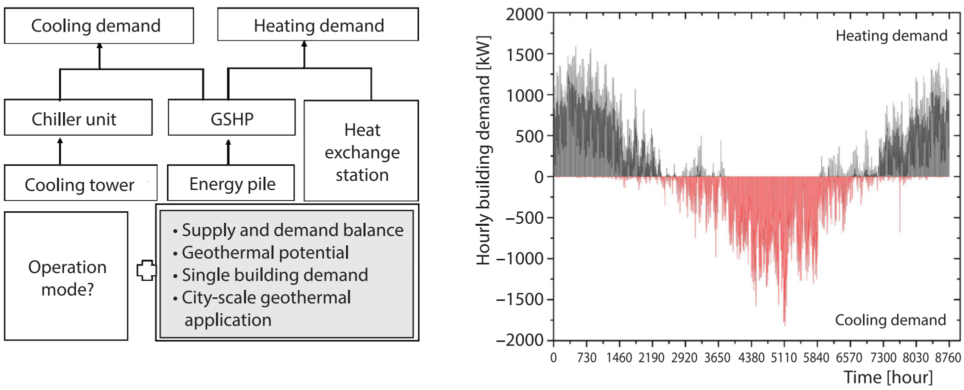

Figure 1. Hourly heating and cooling demand

Thermal balance calculation

The calculation of regional geothermal energy reserves is based on the thermal storage method, which evaluates the amount of geothermal resources beneath the building and the amount of recoverable geothermal resources, and the amount of resources calculated by the volume method cannot be fully extracted. The equations of the shallow geothermal deposit in this area are given:

$$Q_e = \sum_{i=1}^{n} C_1 A D_1 \Delta t \tag{1}$$

$$C = \rho_r C_r (1-\Phi) + \rho_w C_w \Phi \tag{2}$$

$$R = \frac{Q_k}{Q_r} \tag{3}$$

where Q_e is the geothermal potential, A – the area of calculation area, D – the thermal storage thickness, Δt – the temperature difference between thermal storage temperature and annual average temperature, C – the average specific heat capacity of heat storage rock and water, ρ_r – the density of heat storage rock, C_r – the specific heat of heat storage rock, ρ_r – the density of geothermal water, C_w – the specific heat of water, Φ – the porosity of heat storage rock, R – the geothermal resource recovery rate, Q_k – the heat that can be extracted from the well, and Q_r – the geothermal resources buried in underground thermal strata.

According to geological survey report, engineering pile perimeter soil layer are quaternary deposits:
– the 4 m pebble horizon,
– the 12 m chalky clay horizon, and
– the 10 m pebble horizon.

According to the calculation, the geothermal potential in this area is $2.61 \cdot 10^{11}$ kJ. The geothermal recovery rate is set as 15 %. The specific calculation is based on eqs. (1)-(3) of the thermal reservoir volume method. The amount of recoverable geothermal resources in this area is $3.92 \cdot 10^{10}$ kJ.

The HGSHP system simulation details

The soil layer and thermal conductivity are shown in tab. 1. The soil thermal properties used in the model are all obtained from the in-situ thermal response test. The undisturbed soil temperature is 14 °C. The depth of the borehole is 15 m. The heat exchangers in the boreholes are connected in series with double u-tubes. The inner and outer diameters of double U-shape pipe are 26 mm and 30 mm, respectively, the thermal conductivity of the pipe material is 0.42 W/mK.

Table 1. Soil layer property parameters

Soil layer	Depth [m]	Density [kgm^{-3}]	Heat capacity [Jkg^{-1}K^{-1}]	Thermal conductivity [Wm^{-1}K^{-1}]
Cobble-stone	4	2100	1200	1.8
Silty clay	12	2000	1400	1.2
Cobble-stone	10	2200	1200	1.8

Operation mode design

In the case of winter operation, the operation of the GSHP system is prioritized for building heating. When the heat exchange capacity reaches 10% of the rated heating capacity of the heat pump unit, the heating system is activated. Then heat Unit 1 starts operating. When the heat exchange capacity exceeds 60% of the rated capacity, one plate heat exchanger is activated. When heat pump Unit 1 reaches 60% of its operational efficiency and the first plate heat exchanger reaches full load operation, another plate heat exchanger is activated. All components of the heat exchange system work simultaneously to supply energy to the building.

In the case of summer operation, the operation of the GSHP system is prioritized for building cooling. When the heat exchange capacity reaches 10% of the rated heating capacity of the heat pump unit, the cooling system is activated. Once the operational efficiency of heat pump Unit 1 reaches 90%, the chiller is activated to share the cooling load. As heat unit 1 and the chiller reach 90% operational efficiency, heat pump Unit 2 is subsequently activated to optimize system cooling capacity.

Establishment of GSHP simulation system

The parameters and key inputs for each module were defined during the construction of the dynamic model for the HGSHP system. Several critical mathematical models were incorporated, including building structure and load module, HVAC module, weather data module, water and air system circulation module, otput module, fig. 2.

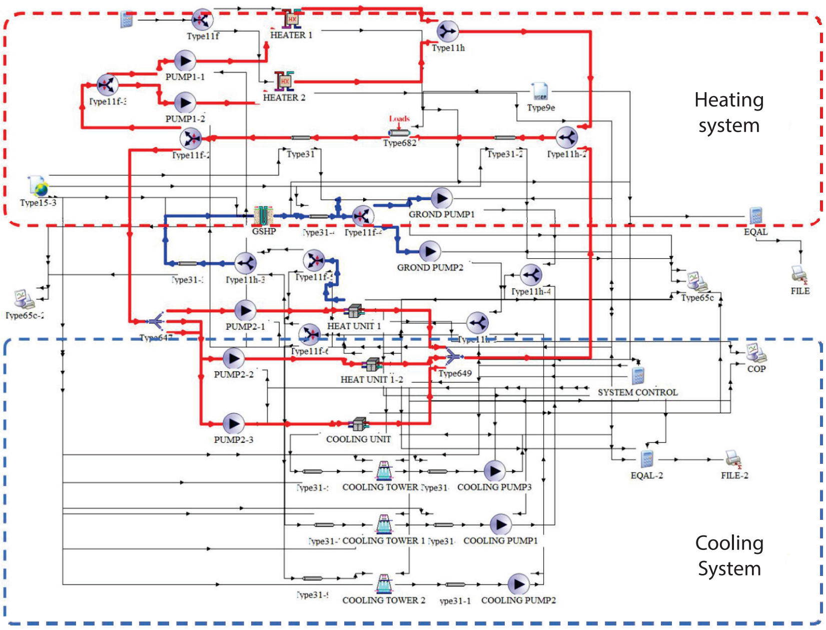

Figure 2. Simulation platform of HGSHP System

Annual intermittent operation mode and long-term operation

After one year, fig. 3, the average soil temperature reached 14.83 °C, an increase of 0.83 °C compared to the previous period, with the temperature difference remaining within an ideal range. During winter, the minimum outlet water temperature was 1.53 °C, indicating a risk of freezing. In summer, the outlet water temperature ranged between 9.1 °C and 26.52 °C. At the end of the annual intermittent operation mode, the soil temperature reached 14.83 °C, outlet water temperature was 13.36 °C and the outlet water temperature was 7.81 °C.

After five years, fig. 4, the average soil temperature reached 15.64 °C, an increase of 1.64 °C, with the temperature difference remaining within an optimal range. During winter, the minimum outlet water temperature was 1.4 °C, indicating a risk of freezing. In summer, the outlet water temperature ranged from a minimum of 4.22 °C to a maximum of 28.53 °C. At the end of the long-term operation mode, the soil temperature reached 15.64 °C, outlet water temperature was 14.16 °C and the outlet water temperature was 8.57 °C. The average ground temperature in the long-term operation mode increased by 0.8 °C compared to the annual operation mode, essentially maintaining the thermal balance of the ground.

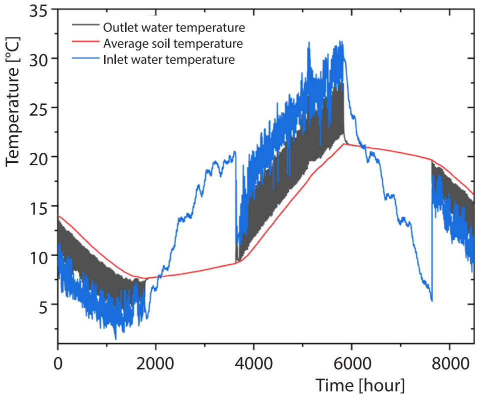

Figure 3. Annual mode operation mode effect

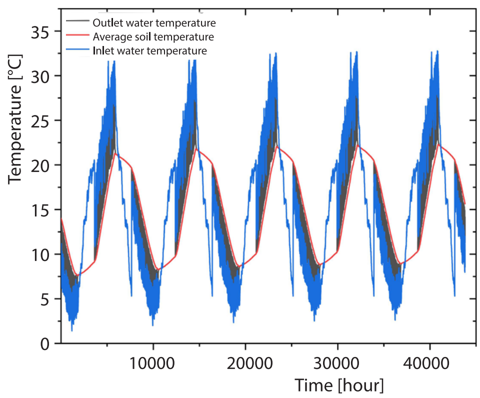

Figure 4. The long-term operation mode effect

Conclusion

This study proposed intermittent operation strategies of a HGSHP system with double-cooling towers to solve the problem of soil heat accumulation. A public building was selected as a case study, and the system's performance was modeled by using heat transfer efficacy simulation software under both annual intermittent operation mode and long-term operation mode. These findings underscore the feasibility of utilizing HGSHP systems for heating and cooling in cold area. However, the potential risk of soil freezing due to excessively low temperatures warrants further attention. Additionally, optimization of operational strategies remains a critical area for future research.

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Nomenclature

C_r – specific heat, [kJkg^{-1}°C^{-1}]
C_w – specific heat of water, [kJkg^{-1}°C^{-1}]

Greek symbols

ρ_r – density of heat storage rock, [kgm^{-3}]
ρ_w – density of geothermal water, [kgm^{-3}]
Φ – porosity of heat storage rock, [%]

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