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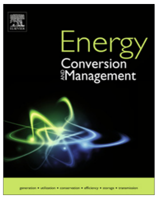

Evaluation of ground source absorption heat pumps combined with borehole free cooling

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A B S T R A C T

Ground source absorption heat pumps (GSAHPs) extract less heat from the ground than ground source electrical heat pumps (GSEHPs) and therefore require fewer boreholes and can reduce the deterioration in heating performance. GSAHP integrated with borehole free cooling is proposed to reduce the thermal imbalance further and keep the heat pump system working efficiently for a longer period. Dynamic simulations of different applications in three typical cities are conducted in TRNSYS to investigate the potential of GSAHP + borehole free cooling. The results show that the soil temperature reduction for GSAHP can reach 6–7 °C after 10 years but can be reduced to 0–3 °C by floor radiation cooling, and the coefficient of performance (COP) and heating capacity can be kept at a high level. Moreover, the unguaranteed heating hours can be greatly reduced, while the guaranteed cooling hours are in the range of 800–1500 in different areas. Additionally, the primary energy efficiency of GSAHP with heating only is 95–120%, while that of the hybrid GSAHP + borehole free cooling can reach 111–156% in typical cities. The proposed system provides additional cooling and indoor comfort while also reducing the underground thermal imbalance, slowing the deterioration of soil temperature and system performance, improving the heating reliability, and reducing the system's energy consumption.

1. Introduction

1.1. High energy consumption of heat supply

Large amounts of energy are used for heating and domestic hot water. It was reported that heating consumed approximately 226.2 million tons of standard coal in 2006, comprising 40% of the whole building energy consumption in China. Moreover, the energy consumption for domestic hot water was approximately 35 million tons of standard coal in the same year [1]. The energy consumption for heating and domestic hot water is predicted to increase rapidly, considering that building areas are increasing rapidly, and the requirements of indoor environments are gradually improving.

1.2. Problems of ground source heat pump in cold regions

The main heating solutions in China are boilers and electrical heat pumps. However, boiler heating systems have poor energy efficiency and contribute markedly to air pollution. The efficiency of a coal boiler is usually between 60% and 85%, while that of a gas boiler is usually above 85%. Recently, ground source heat pumps (GSHPs), which are regarded as a renewable energy utilization technology, have been extensively used for heating buildings [2,3]. However, the heat extracted from and rejected to the soil is usually not equal in heating-dominated buildings (this phenomenon is known as the thermal imbalance of GSHP systems [4]) and will ultimately lead to a gradual decrease in soil temperature after a long-term heat extraction because the temperature recovery ability of soil is limited. As a result, the energy performance and heat output of the GSHP will deteriorate year by year until the heating reliability cannot be guaranteed or the GSHP cannot function normally [5]. The problem is especially obvious for buildings with only heating requirements (no cooling is supplied in the summer), such as those found in cold and severely cold regions.

1.3. Current solutions and the disadvantages

Increasing borehole spacing can improve the soil recovery ability and slow down the deterioration, but it requires more occupied area of boreholes and the improvement is very limited [6]. Auxiliary boilers are also used to undertake the peak load to reduce the heat supplied by GSHP, which will reduce the advantages of GSHP when the heat load is much higher than cooling load [7]. Another approach is using solar energy storage through the ground heat exchangers [8–10]. Its reliability is seriously affected by the weather. Moreover, high initial investment and installation space

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Nomenclature

K	heat exchange coefficient, W/(m^2 K)
$Q_{cooling}$	accumulated supplied cold, kW h
$Q_{heating}$	accumulated supplied heat, kW h
Q_g	heat consumption of generator, kW h
q	hourly heat load, kW
S	area, m^2
T	temperature, °C
W	electricity consumption, kW h

Abbreviations

AHP	absorption heat pump
ASAHP	air source absorption heat pump
COP	coefficient of performance
GSAHP	ground source absorption heat pump
GSEHP	ground source electrical heat pump
GSHP	ground source heat pump
PEE	primary energy efficiency

Greeks

η	efficiency

may be the important concern to popularize these systems. Ground source absorption heat pump (GSAHP) proposed in the previous study was assessed to be able to effectively reduce the thermal imbalance in heating-dominated buildings with both heating and cooling demands [11]. However, in the cold and severely cold regions, many buildings are not equipped with cooling systems for the summer because the cooling load would be small most of the time. Under this circumstance, the imbalance will be much more serious, even for the GSAHP systems, since there is only heat extraction in winter and no heat rejection in summer.

1.4. Objectives of this work

Aiming at further slowing the deterioration caused by the underground thermal imbalance of GSAHP with heating only in cold regions, the GSAHP was integrated with borehole free cooling (borehole direct cooling) using the heating terminal in this work. Borehole free cooling in summer, which uses the heating terminals in winter, can provide additional cold for the building while supplementing a substantial amount of heat into the soil underground, which can reduce the soil temperature reduction and keep the heat pump system working efficiently for a longer period.

The object of this work is to investigate the effect of the proposed system by comparing the difference on soil temperature, heating performance, heating reliability and system energy efficiency between GSAHP and GSAHP + borehole free cooling applied in cold regions.

2. GSAHP integrated with borehole free cooling

The previous work indicates that a heating system combining a traditional boiler with an air source absorption heat pump (ASAHP) or GSAHP has great energy saving potential [11–13]. Although the COP of GSAHPs is lower than that of ground source electrical heat pumps (GSEHPs), GSAHPs are still highly competitive from a primary energy viewpoint, taking the efficiency of electricity generation into account [11]. Compared with conventional GSEHPs, GSAHPs extract less heat from the ground during the heating season. Consequently, the reduction of the soil temperature and system performance of the GSAHP will be less severe than that of the GSEHP system.

A schematic diagram of the proposed GSAHP integrated with borehole free cooling is shown in Fig. 1. The heating terminal can be the radiator, fan coil, and radiant floor. As floor radiation cooling requires relatively higher-temperature cold water [14], it is quite suitable for borehole free cooling and is chosen for this analysis.

In winter, valve 1 is open and valve 2 is closed to operate the heat pump mode (Fig. 1(a)). The GSAHP can be either direct-fired or driven by a conventional boiler, a city heat network, solar energy, waste heat, etc [12,13]. In summer, valve 1 is closed and valve 2 is open to activate the borehole free cooling mode (Fig. 1(b)), which means that the cold water leaving the ground heat exchanger is supplied directly to the heating terminal rather than the GSAHP.

In the cold and severely cold regions, many buildings are not equipped with cooling systems for the summer because the cooling load would be small most of the time. However, it would be much more comfortable for the occupants inside if some cooling capacity were to be supplied to these buildings, even if the spacing cooling is not completely guaranteed. In this regard, the borehole free cooling can be highly beneficial, requiring only the low energy consumption of the water pumps. The indoor heat removed by borehole free cooling is stored underground, which can reduce the thermal imbalance of GSAHP with only heat extraction from soil in winter.

3. Methodology

To investigate the performance of GSAHP + borehole free cooling applied in different areas, typical cities in cold and severely cold regions are selected. Next, the GSAHP + borehole free cooling systems in different areas are dynamically simulated, the results of which are compared with the simulation results for GSAHP systems with heating only. Through dynamic simulations, the soil temperature and the water temperature of the borehole outlet under long-term operation can be obtained. Moreover, the variation of heating COP and heat output can also be used to analyze the heating reliability and system energy efficiency. In addition, the cooling capacity provided by borehole free cooling in summer is calculated to estimate the available guaranteed hours of space cooling.

3.1. Heat load simulation of typical cities

Three typical cities (Beijing, Shenyang, and Harbin) in northern China are selected for this case study. The geographical location of these three cities are illustrated in Fig. 2(a), and the corresponding outdoor temperatures are shown in Fig. 2(b), including the maximum air temperature in summer, the minimum air temperature in winter, and the annual average air temperature.

A typical 5-floor building with a total area of 5000 m^2 is modeled in the dynamic energy simulation software DeST [15]. The hourly building heat loads are calculated for different cities with different heating period, and some of the results are listed in Table 1. The maximum heat load is used as the design load to