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Recent research and applications of ground source heat pump integrated with thermal energy storage systems: A review

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HIGHLIGHTS

- Ground source heat pump combined with thermal energy storage (GSHP–TES) systems.
- Theoretical and practical understandings on GSHP–TES systems.
- Outline review of the available studies and identify the future research opportunities.

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ABSTRACT

As a renewable energy technology, ground source heat pump (GSHP) system is high efficient for space heating and cooling in buildings. Thermal energy storage (TES) technology facilitates the efficient utilization of renewable energy sources and energy conservation. It is expected to be more prevalent in the future. GSHP application is growing rapidly as it is integrated with TES system. During the last decade, a number of investigators have conducted the studies on the designing, modeling and testing of TES assisted GSHP (GSHP–TES) system. This paper presents a review on the research and applications of GSHP integrated with TES system, including various cooling and heating storage technologies. The studies on the GSHP–TES systems are categorized into five groups including: GSHP integrated with ice storage tank, GSHP integrated with solar collectors, GSHP integrated with soil, GSHP integrated with water tank and GSHP integrated with phase change materials (PCM). However, there are still several challenges for the applications of GSHP–TES systems, such as the mechanisms, thermodynamics and performance of the unsteady and transient heat transfer of underground soil and the thermal storage process as well as control strategies of the GSHP–TES systems. Addressing these problems will strengthen the theoretical and practical understandings and facilitate more extensive applications of GSHP–TES systems.

1. Introduction

Energy shortage is one of the most serious problems along with the development of the modern society. Renewable and sustainable energy offers a viable and potent solution to counter the effects of this problem. GSHP systems are clean technologies by using the renewable energy resources. Due to their higher energy utilization efficiencies, they have been used for years in developed and developing countries replacing or supplementary to the conventional air conditioning systems. Because of the unbalance of cooling and heating demands in the residential and commercial buildings during a year, the GSHP systems must be integrated with other supplementary energy storage systems in cooling-dominated or heating-dominated areas. It is well known that TES systems are strategic and necessary technologies for the efficient utilization of

Abbreviation: ASHP, air source heat pump; COP, coefficient of performance; EPC, exergetic performance coefficient; GCHP, ground couple heat pump systems; GSASHP, ground-air source heat pump; GHE, ground heat exchanger; GSHP, GSHP; HP, heat pump; HSGSHPS, hybrid solar GSHP system; ISCS&GSHP, integrated soil cold storage and ground-source heat pump; LHEST, latent heat energy storage tank; PCM, phase change materials; SAASHP, solar-assisted-air source heat pump; SAHP, solar-assisted heat pump; SAGSHP, solar-assisted-GSHP; SAGSHPGHS, solar assisted ground-source heat pump greenhouse heating system; SESHPS, solar-earth source heat pump system; SGCHP, solar-ground coupled heat pump; SGSHP, solar GSHP; SGCHPS, solar-ground coupled heat pump system; SPF, seasonal performance factor; SSHP, solar source heat pump; TES, thermal energy storage; UTES, underground thermal energy storage; VDSC, vertical double-spiral coil.

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renewable energy and energy conservation [1]. Therefore, the combination of GSHP and TES system is an effective mean to address problems resulted from cooling and heating imbalance in different areas. TES systems enable greater and more efficient usage of these fluctuating energy resources by matching the energy supply with the demand. The TES technologies integrated with GSHP systems include ice storage tank, solar collectors, soil, water and phase change materials (PCM). The ice storage tanks are used for cooling purpose while solar collectors are used for heating. The soil, water and phase change materials can be used either for cooling or heating purpose.

In recent years, most studies have concentrated on enhancing the performance of GSHP systems, improving the accuracy of the models and design methods. There are also a number of researches reported on the theoretical analysis and experimental study on TES systems. It is necessary to combine GSHP with TES to meet the actual needs. Gao et al. [1] reviewed the development from GSHP to UTES in China and other countries, especially as to soil/rock UTES. Omer [2] reviewed GSHPs systems and their applications, while he mainly focused on the types of heat pumps especially used for GSHP and their efficiency. Sanner et al. [3] studied the current status of GSHPs and underground thermal energy storage (UTES) in Europe. However they reviewed the underground TES system only. Yang et al. [4] reported the current status of GSHPs in China, but they just addressed an integrated soil cold storage and GSHP as GSHP–TES system. Yang et al. [5] reviewed the models and systems of vertical-borehole ground coupled heat pumps. Sarbu et al. [6] provided a detailed literature review of the GSHP systems and their recent advances. Hybrid ground couple heat pump systems (GCHP) are presented in this paper, which employed a supplemental heat rejecter or heat absorber to decrease the initial cost of the GCHP system and improve the system performance for buildings in warm or cold climate areas with unbalanced loads. Supplemental heat rejecter was cooling tower and heat absorber was solar collector, but they were not used as thermal energy storage system. Zhai et al. [7] summarized the main integrated approaches of GCHP systems based on the available researches. GCHP systems integrated with TES technologies were involved including solar energy and phase change material. The author also pointed out that thermal storage was implemented only by means of the ground heat exchangers instead of auxiliary thermal storage devices in some GCHP systems. But the reviews on GSHP systems integrated with TES technologies were very few. This paper presents the research and applications of GSHP integrated with TES systems from the existing literature. It could be helpful to strengthen the theoretical and practical understandings on GSHP–TES systems and facilitate more extensive applications of the systems.

This paper therefore presents a comprehensive review on previous studies associated with the investigation and evaluation of GSHP–TES systems. The organization of this paper is presented as follows. In Sections 2 and 3, the specific research works on the applications of GSHP integrated with TES systems for cooling and heating are reviewed respectively. The studies on the applications of GSHP integrated with TES system for cooling/heating in buildings are reviewed in Section 4. Finally, the discussions and conclusions are given in Section 5.

2. GSHP integrated with ice storage for cooling

The unitary utilization of GSHP systems cannot balance the cooling and heating underground in cooling-dominated areas. Ice storage system could be used as supplement technology for cooling purpose in some cases. If a cooling storage system charges cooling during off-peak period and discharges cooling during on-peak period, the peak load and total electricity fee will be reduced obviously.

By ice storage technology, cooling energy is produced and stored in an insulated storage tank at night. It is then extracted for cooling during on-peak period, typically daytime. Therefore, the ice storage technology is an alternative strategy to reduce the high peak-load demand for space cooling. There are many applications of GSHP integrated with ice thermal storage systems in buildings.

Zhang et al. [8] studied the operation modes of a GSHP integrated with ice storage system based on an air-conditioning project for a 2,160,000 m^2 commercial building in Beijing (39.92°N; 116.46°E), China. A schematic of GSHP system integrated with ice storage was shown in Fig. 1. They analyzed the design scheme of the combined system and explored the optimized operating mode by technical and economical comparisons. They concluded that the investment of the integrated system was increased by 107.5% and the average annual operation fee was decreased by 37.85% compared with conventional air conditioning systems. The payback period was 4.7 years. But the data was based on load ratio of 100%, 60% and 30%, it did not cover all the operation condition. More load ratio could be studied to enhance the comprehensive of the study.

A cylindrical heat source model of the soil heat transfer of GSHP was developed [9]. By numerical simulation of finite difference, the authors analyzed the variation curves of entering and leaving temperatures of cooling water and the ground temperature field of GSHP system before and after coupled with an ice thermal storage system. It recommended that reduced the numbers of boreholes and increased the distance of boreholes for this integrated system can balance the heat and cold underground. Installing cooling tower or heat recovery system for cooling-dominated areas was also a proposal method on solving underground heat imbalance problem.

In the previous references [8,9], researchers studied the GSHP integrated with ice storage system and indicated that it was an energy saving technology. Though the initial cost is higher than conventional air-conditioning system, the integrated system could save operation electricity fee by shifting peak load. But the ice storage system could not operate with the common unit and need a special unit with three operating modes. It also increases cost of investment and complexity of the system. GSHP integrated with ice storage system is recommended to use in cooling-dominated areas. The optimal ratio of ice storage to cooling capacity when GSHP system integrated with ice storage is essential and affects the operation modes of the whole system in different seasons. Underground heat imbalance problem is also a considerable factor during long period operation. A summary of GSHP integrated with ice storage for cooling systems is listed in Table 1.

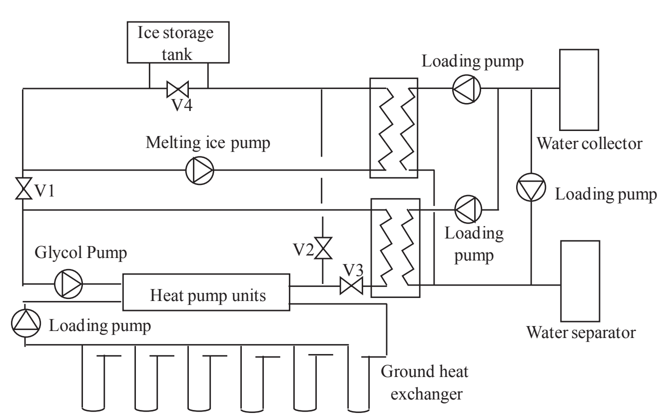

Fig. 1. Schematic of GSHP system integrated with ice storage [8].