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Review

Ground heat exchangers: Applications, technology integration and potentials for zero energy buildings

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ABSTRACT

Ground heat exchanger takes the soil underground as heat source or sink to supply cooling or heating. It has been widely used in building heating and cooling systems due to high efficiency and environmental friendliness. This paper reviews the latest research on ground heat exchangers from several new perspectives and demonstrates their potentials in achieving zero energy buildings. Firstly, ground heat exchangers are classified into water-based and air-based ones based on the heat transfer medium. They can be used in a passive or active approach. Associated research and projects for each approach are introduced and analysed. Then the integration of ground heat exchangers with various cooling and heating technologies and related studies are reviewed. These technologies include solar thermal collectors, cooling towers, nocturnal radiative cooling technology, solar chimney, etc. Finally, a technical route for ground heat exchangers to help realize zero energy buildings is presented, which provides a promising solution to improve energy efficiency of buildings.

Contents

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Nomenclature

COP	Coefficient of performance
EER	Energy efficiency ratio
GHE	Ground heat exchange
GSHP	Ground source heat pump
HGSHP	Hybrid ground-source heat pump
PV	Photovoltaic
SAGSHP	Solar assisted ground source heat pump
TABS	Thermally activated building system
TB	Thermal Barrier
ZEB	Zero energy building

1. Introduction

Ground heat exchanges (GHEs) are buried underground and exchange heat with the surrounding soil via water or air [1]. They become increasing popular in building heating and cooling systems due to its long-term durability, high efficiency and environmental friendliness [1,2]. The high efficiency results from the stable temperature of soil below a certain depth (i.e. 10 m) underground, which is lower in summer and higher in winter compared with the outdoor air [3–5]. Due to the high thermal inertia of the soil, the temperature variation is largely delayed and almost completely immunes to the intensified solar radiation and fluctuated air temperature. The benefits of GHEs in improving the building energy efficiency have been demonstrated by many researchers [6–11].

Energy shortage and environmental pollution problems are concerned worldwide and it is generally believed that decreasing building energy demands is an effective solution to this problem [12–14]. Researchers around the world spare no effort to optimize the design and operation of buildings and their energy systems. Zero energy building (ZEB) therefore appears with much higher energy performance than conventional ones. Many applications [15–17] have demonstrated the benefits of ZEBs on mitigating the energy shortage and the environmental pollution. Some countries or institutions, which have ambitious targets on their future energy consumption, attempt to take ZEBs as their future building energy targets, such as Building Technology Program of Department of Energy in US and the EU Directive on Energy Performance of Buildings [18,19].

As a clean and sustainable energy technology, GHEs can be used to help achieve ZEBs. However, the potentials of GHEs in ZEBs are still not fully recognized and need to be further exploited. There are already some reviews on the applications of GHEs in buildings. However, most of them focus on ground source coupled heat pump (GSHP) systems, where GHEs are connected to the evaporators or condensers of heat pumps. The direct applications of GHEs (without heat pumps) for heating and cooling are rarely reviewed. In addition, many of these reviews pay more attention to the performance of ground source heat pump systems or GHEs, rather than the integration with various cooling/heating or renewable energy technologies.

To fill the above research gaps, this paper therefore presents a comprehensive review on the application of GHEs in buildings from several new perspectives and illustrates the potential for ZEBs. The GHEs are classified into two categories according to the heat transfer medium: water-based GHE and air-based GHE. Relevant studies are introduced in Section 2. The application of GHEs is separated into two approaches: active application and passive application. Associate research and projects are reviewed in Section 3 and Section 4. Then the integration of GHEs with various cooling/heating and renewable energy technologies is introduced in Section 5, including solar thermal collectors, evaporative cooling technology, nocturnal radiative cooling technology etc. The potentials of GHEs to realize ZEBs and a technical route are presented in Section 6. Finally, conclusions and recommendations on GHEs are summarized in Section 7.

2. Classification of GHEs based on heat transfer medium

GHEs, also called as ground source coupled heat exchangers, have been widely used for cooling and heating in buildings [1,20]. They can be classified into three categories according to the heat transfer medium: water-based GHEs, air-based GHEs and direct-expansion GHEs. The water-based and air-based GHE use the circulating water or air through the buried tube to exchange heat with the soil. For the direct-expansion GHE, the refrigerant from heat pumps flows through the pipe directly and the GHE functions as evaporators or condensers [21,22]. The direct-expansion GHE is not as popular as the former two categories. The following review therefore will mainly focus on the water-based GHE and the air-based GHE.

2.1. Water-based GHE

The water-based GHE refers to a high-density plastic tube buried underground, through which the water, anti-freezing liquid or mixture of them exchange heat with the soil [23]. The water-based GHE can be installed horizontally or vertically. The vertical GHE, also called as borehole heat exchanger, is more energy efficient and occupies much less area than the horizontal GHE. However, the capital cost is much higher due to the drilling expense of the boreholes [24].

A new type of water-based GHEs, energy pile (Fig. 1), has been used in buildings [25]. The high-density plastic tube is installed vertically in the building foundation during the concrete pouring. By installing the GHE in the building foundation, the drilling expense for boreholes can be eliminated or reduced. No or much

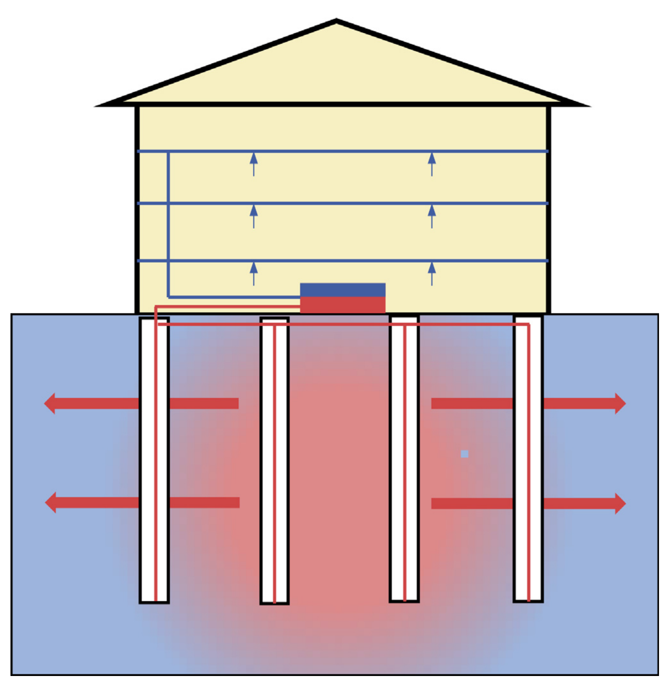

Fig. 1. Schematic diagram of energy piles with vertical GHEs.