Effect of Thermally-Enhanced Backfilling Materials on the Performance of Earth-Air-Tunnel-Heat-Exchanger System: A Review

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Abstract

Building cooling and heating consume around one-third of total primary energy consumption. Renewable and passive systems can reduce the building cooling and heating energy demand. Earth air tunnel heat exchanger (EATHE) is one of the promising passive techniques which can serve the purpose of space heating and cooling using constant temperature of underground soil. It is a promissing passive technique for space heating and cooling but it required long pipes and large land area for installation of pipes. Various studies have been conducted in last few decades to investigate the various parameters that may reduce the length of pipe and land area requirement. In this article, the effect of thermal properties of soil on the performance of earth air heat exchanger systems have been reviewed. This review article shows that length of pipe and land area requirement for EATHE pipe installation can be substantially reduced by using thermally enhanced backfilling material at the vicinity of the EATHE pipe.

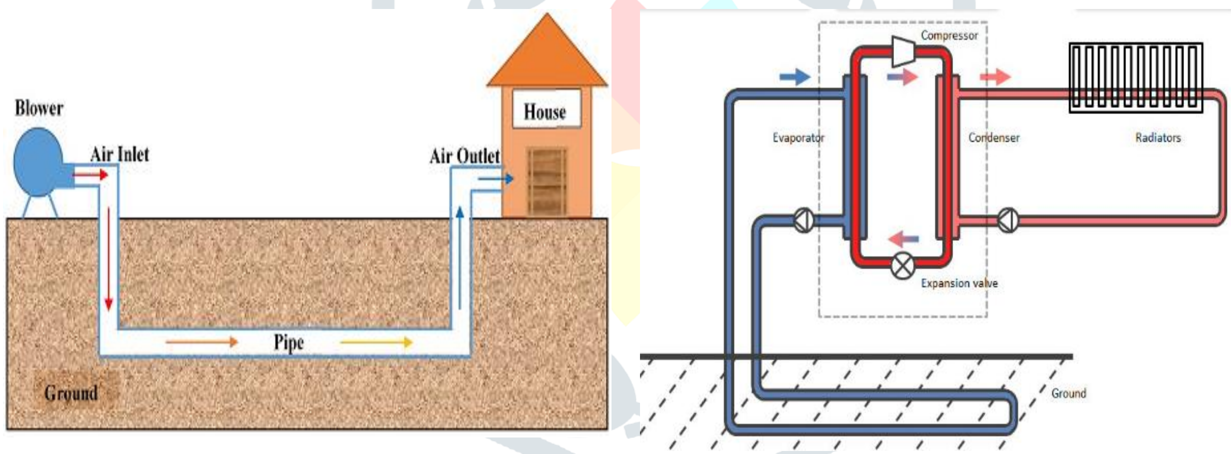
Keywords: EATHE system**,** thermal properties of soil, pipe length, land area requirement, thermally-enhanced backfilling materials.

1. INTRODUCTION

In recent past years, the energy demands in buildings have raised significantly due to increasing population and better living standards. Space cooling and heating utilised about 33% of total energy consumption world over [1,2] . For space heating and cooling, conventional HVAC systems are used which are energy intensive and harmful for the environment. Various passive systems are being investigated to meet the cooling and heating requirements and minimise primary energy consumption. Various passive methods are available for building's thermal management.

Geothermal energy is a vast and promising source of renewable energy. Earth's thermal energy can be used in two ways for building cooling and heating i.e. (i) Earth air tunnel heat exchanger (EATHE) [3–5] and (ii) Ground source heat pump (GSHP) [6,7].

In EATHE system, pipes are buried at 3-4 m depth where the underground temperature remains fairly constant round the year and the air is blown through the pipes to exchange heat with the soil as shown in Figure 1(a). This heat exchange produces cooling effect in summer and heating effect in winter. In GSHP system, water or refrigerant or anti-freeze liquid flows through buried vertical or horizontal pipes in closed loops to exchange heat with the soil as shown in Figure 1(b). GSHP and EATHE both exchange heat with the ground but installation and operating cost of EATHE system is lesser than GSHP system. The initial cost of EATHE system is high but its operating cost is low therefore it can save high grade energy[8–10].



(a) (b)

Fig. 1: Geothermal energy application for building cooling and heating (a) EATHE system [11]**, (b) GSHP system** [12]

2. EFFECT OF SOIL PROPERTIES

Performance of EATHE system is mainly depends on soil thermal properties such as thermal diffusivity, density, thermal conductivity, specific heat capacity etc. [5,13–18]. Mathur et al. [19] investigated the thermal performance of EATHE systems by considering three different soil thermal diffusivities of 1.37×10^{-7} m^2/s, 4.37×10^{-7} m^2/s and 9.69×10^{-7} m^2/s. Study shows that the soil with higher thermal diffusivity has a faster heat transfer rate and can transfer more amount of heat through the nearby soil to the outer subsoil quickly.

Agrawal et al. [20] developed two identical experimental setups of EATHE system and compared the performance of dry and wet soil EATHE system and observed that the average heat transfer rate and COP of wet system increased by 24.1% and 24.0% respectively compared to the dry system. Misra et al. [21] found that for the same cooling performance, the pipe length can be reduced by 14 m with wet EATHE system as compared to dry EATHE system.

3. BACKFILLING MATERIALS FOR GROUND HEAT EXCHANGERS

In the ground-coupled heat exchanger (GCHE), the heat transfer rate between fluid and soil depends on soil thermal properties. Therefore, the thermal performance of ground heat exchanger can be improved susbstantially by enhancing thermal properties of soil (or filling material) in the vicinity of pipe. To increase the thermal conductivity of soil in the vicinity of pipe, various thermally enhanced backfilling materials have been developed which are easy to install as well as cost-effective [22].

Allan and Kavanaugh [23] considered silica sand, silicon carbide, steel grit and alumina grit as filling materials in order to improve the thermal conductivity of cementitious grouting material. The thermal conductivity of neat cement grouts was 0.87 W/m-K while the cementitious back-filling material had thermal conductivity 1.7-3.3 W/m-K. It was found that the 22 to 37% reduction in bore length was possible by using cement-sand grouting material instead of neat cement (cement + water only) grouts. Wang et al. [24] observed that with increase in bentonite percentage (by weight), thermal conductivity of sand-bentonite mixture first improves until 12% of bentonite percentage (2.15 W/m-K) , then after it starts decreasing rapidly. At optimal sand-bentonite backfill material, heat transfer rate between fluid and ground increased up to 31 % compared to ordinary sand-clay material. Yu and Huang [25] tested different samples of the sand-bentonite mixture and observed that 18.18% is the optimum proportion of bentonite in sand-bentonite mixture.

Cuny et al. [26] considered the effect of coating soil on the energy performance of an EAHE in their numerical study. Three different types of coating soils viz. sand, a mixture of sand-bentonite and in-situ earth at different parts of the buried EAHE pipe as shown in Figure 2 were investigated. The effect of soil moisture content were also evaluated by considering two soil moisture contents (minimum and maximum measured in-situ). The difference in thermal performance of sand for minimum and maximum moisture content in soil, sand-bentonite and earth respectively, were recorded to be 15.5%, 1.16%, 10.21% for heating operation, while for cooling operation it was 13.61%, 0.8%, 9.13% respectively.

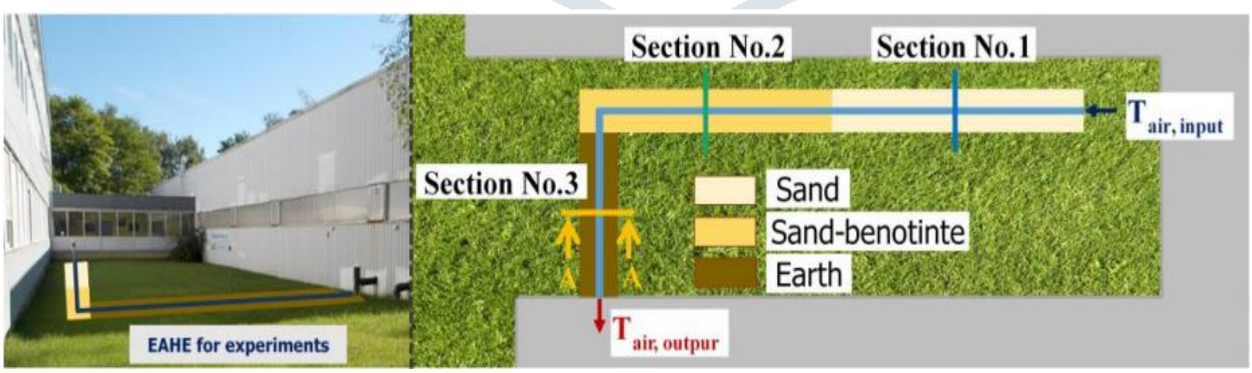


Fig. 2: EAHE system with different soil coatings at different pipe length [26]

Maatouk C. [27] conducted laboratory study to determine the thermal conductivity of various grout mixtures (cementitious grout with bentonite, silica sand and graphite) and experimental results demonstrated that thermal conductivity of the grout can be increased up to 4 W/m-K without graphite doping and up to 10 W/m-K with doping of graphite. D'Angelo [28] also used the wax-sand composite backfill for laboratory scale experiment of GSHE and found that wax-sand composite backfill could result in 50-60% improvement in heat dissipation from the GHE. Thermal conductivity of wax-sand composite backfill was found approximately double (0.46 W/m-K) compared to dry sand backfill (0.24 W/m-K).

Sipio et al. [29–31] used thermally enhanced backfilling material (TEBM) to enhance the heat transfer of the horizontal ground heat exchanger systems**.** For the field test, five trenches were used with different backfilling materials including natural material and commercial products. Five backfilling materials were (i) fine sand 0-1 mm (fs0-1mm) (ii) fine sand 0-1 mm with 15% bentonite (fsB15) (iii) sand 0-5 mm (s0-5mm) (iv) sand 0-5 mm + 15% bentonite (sB15) (v) sandy clay (sc). It was found that the pure fine sand and pure sand alone have the lowest thermal conductivity with values less than 1.3 W/m-K and sandy clay material have the highest thermal conductivity with values up to 2.0 W/m-K, while the 15% bentonite mixed sand have thermal conductivity values in between these two.

Cook and Uher [32] evaluated the effect of metallic fillers (steel and copper fibers) in concrete. It has been observed that using steel fibers in concrete in volume percentages up to 8% could offer thermal conductivity increase of 25 to 50%, while copper results 500-600% increment. But, cost of metals being higher compared to that of ordinary sand and it restrains the use of metallic fibers as a filler in cementitious grouts.

Al-Ameen et al.[33] tested various materials such as sand, crushed basalt, broken brick, crushed concrete, and metallic by-products including copper slag, aluminum slag, mill-scale and iron ores (fine and pellets) as backfilling material (as shown in Figure 3) for ground heat exchanger system. It was observed that the thermal capacity of the HGHE system can be doubled using copper slag and aluminium slag, compared to the use of sand alone.

Fig. 3: Different backfilling materials for ground heat exchanger [33]

From the previous studies, it is observed that heat transfer rate between flowing fluid and soil or grout may be increased by using thermally enhanced backfilling materials in the vicinity of the pipe surface. Sand-bentonite and the sand-cement mixture is a good option for using the backfilling material. Though, sand-bentonite, sand-cement, bentonite and cementitious grout with graphite and metals (particularly copper) are promising backfilling materials providing substantial improvements in thermal conductivity, but increase the cost of GHE system. Therefore, cost analysis need to be carried out and should be incorporated in the design of EATHE system consisting of backfilling material.

4. CONCLUSION

This study reviews the various thermally enhanced backfilling materials which improve the performance of ground heat exchanger. Thus, it is concluded that the performance of EATHE system can be improved by providing soil of good thermal conductivity and higher moisture content in the vicinity of EATHE pipe.

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