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Performance of a residential ground source heat pump system in sedimentary rock formation

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HIGHLIGHTS

- A case study of in-service geothermal heat pump for residential house.
- Real time monitoring data that describes the GHE performance.
- Geothermal installation under sedimentary shale rock formation.
- Strategies to reduce barriers for geothermal installation.

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ABSTRACT

The use of ground-source heat pump system has been widely adopted over the past decades due to its potentials to provide renewable and low carbon footprint energy source for building's heating and air-conditioning needs. This paper reports the design and post construction monitoring of a vertical ground-coupled heat pump system installed adjacent to a three-floor residential house located in Cleveland, OH, USA. The system operates under the special geological condition with shallow depth out-crop of sedimentary shale rock formation typical of Northeastern Ohio, USA. A comprehensive monitoring program was installed to collect data on the operation and performance of the ground-coupled heat pump system. The data recording was initialized in Oct. 2012 and has been in place ever since. Overall, the monitoring data shows that the ground heat pump achieved very good performance. The coefficient of performance (COP) of ground coupled heat pump system ranges from 3 to 4. The heat pump satisfies most of the house heating requirements, including severe cold winter, during the monitoring period. This case study demonstrates the feasibility of ground-coupled heat pump system in providing Heating Ventilation and Air Conditioning (HVAC) source for residential building for either heating dominant or cooling dominant conditions under sedimentary rock geological conditions. The possible solutions to decrease the initial investment are proposed in the study.

1. Introduction

The pressing needs in providing sustainable energy supply have promoted the development of many types of renewable energy technologies over the past decade. According to the reports by the REN21 (Renewable Energy Policy Network for the 21st Century) committee (Renewable 2014-Global Statue Report), renewable energies have contributed about 19% of the global energy consumption in 2012 [1].

As an important source of renewable energy, geothermal energy has attracted significant attention due to its potentials in both industrial and residential applications. In general, the geothermal resources can be utilized with three types of settings: high temperature (>300 °F (150 °C)) electric power production, intermediate- and low-temperature (<300 °F (150 °C)) direct-use applications, and ground-source heat pump (GSHP) application (generally <90 °F (32 °C)) [2]. Among these, the two applications with relatively high temperature are limited to locations where a sustained high heat flux persists at reasonable depth such as the mountain areas in the States of Utah, Colorado, Nevada, of USA. Compared with high temperature geothermal resource, the use of GSHP is more widely spread over the world. In United States, there are

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about 85,000 ground-source heat pump systems installed annually, contributing to the reduction of 1,242,528 tons CO_2 emissions every year [3]. Space heating and cooling and providing hot water account for about 40% and 50% of energy usage in commercial and residential building in 2010, respectively [4]. These energy needs are primarily by use of natural gas or electricity, where there are projected increases in the natural gas price (by about 35%) and households number (by about 25 millions) in the next twenty years [4]. The development of GSHP system provides a potential green solution to reduce the fossil fuel consumption for building operations.

GSHP system is a central heating or cooling system that transfers heat from or to the ground. It is a shallow geothermal source technique that was firstly applied in residential buildings, and then spread into commercial buildings [2]. According to their behaviors as heat source or sink, the GSHP systems can be divided into three categories (Fig. 1): ground-water heat pump systems (GWHP), ground-coupled heat pump systems (GCHP), and surface water heat pump systems (SWHP). Among these, vertical GCHP (Fig. 1(c)) is a popular option as it requires relatively small space for installation, utilizes the relatively stable underground temperature for heat extraction/injection and therefore achieves high performance [2]. Compared with the open loop systems (GWHP systems), GCHP and SWHP systems utilize closed loop heat exchangers which reduce the risk of underground water pollution.

The design of heat exchanger is a complex process that needs to take many aspects into consideration, such as energy demand of the building, the initial investment, undisturbed ground temperature and other influencing factors (including the geological conditions, geometric parameters, material properties of the pipe, refill and fluid, flow rate, inlet temperature, etc.). Hence, for most GCHP projects, the *in situ* Thermal Response Test (TRT) is carried out before installation. It is an indirect but simple and effective approach to determine the borehole thermal resistance and ground thermal conductivity [5].

The concept of GCHP system was firstly proposed in 1912 [6]. It attracted a surge of interest in both theoretical study and experimental investigation after the establishment of the analytical theory of heat transfer in GCHP system by studies (i.e., Ingersoll and Plass [7]). Many researchers have explored the effective application of GSHP system in different countries, such as Italy [8–10], Canada [11,12], China [13–17], Turkey [18,19], Korea [20–22], Japan [23], Jordan [24], Spain [25–27], Cyprus [28], Serbia [29], and United States [30]. Progresses have also been made in the development of fundamental theory [31–33], geothermal heat exchanger pipe arrangement design [9–12,15,20–24,34–39], operation strategies [16,17,23], influencing factors [14,18,21,24,34–40], system performance and potential environmental impacts assessment [8,9,18,23,41,42] of GCHP systems. However, most of these studies are simulation-based research, and the model results typically are validated with analytical solution [35,38], lab-scale short term test [20,23] or *in-situ* Thermal Response Test (TRT) [14]. There are very limited cases reported on long-term field study of GCHP system performance.

Fannou et al. [11] presented a direct expansion geothermal heat pump system installed in Canada. Operation data over one month period indicates 70% reduction of electricity use compared with using electricity-based house heating system. Keçebaş et al. [18] built a model based on artificial neural network to optimize the geothermal heating system. By applying the data collected from in service system installed in Turkey during 2006–2010, they identified the key influencing factors as the ambient temperature and flow rate. Montagud et al. [26] conducted experimental measurement of a GSHP system in Spain over five year period and identified that the ground soil had stronger thermal recovery capability than expected. Ozyurt and Ekinci [19] illustrated the feasibility of ground source heat pump system in the coldest climate region of Turkey via five months laboratory test during the heating season. Rosiek and Batlles [27] demonstrated the application GCHP system (in southern Spain) in cooling season could contribute to 31%

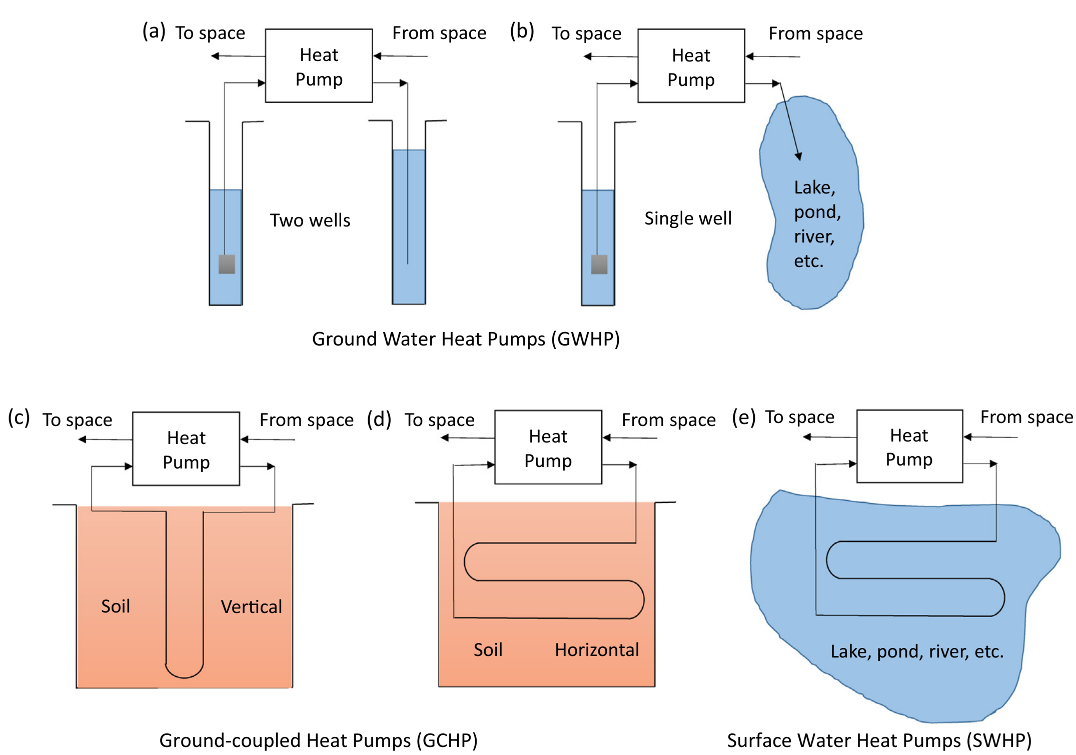

Fig. 1. Categories of ground-source heat pump systems.