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Review

A review on energy piles design, sizing and modelling

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ABSTRACT

Boreholes and energy piles coupled with ground source heat pump plants utilize renewable geothermal energy for buildings heating and cooling purposes and need proper design and sizing in order to end up with high plant efficiency. This paper conducted a review of available scientific literature, design standards and guidelines on energy piles performance within the framework of the *IEA-ECES Annex 31*. Main aspects covered were typical plant solutions, configurations of energy piles and their thermal response test performance, available analytical and numerical models with their main features and application in commercial software and design manuals. Four typical fundamental schemes of geothermal plant with energy piles were found, both suitable for cold and hot climate applications. Properly sized heat pump systems with energy piles were characterized with high overall system SCOP values higher than 4.5, while some case studies reported two times smaller SCOP values that illustrates the effect of proper design and sizing of such systems. The lack of specific heat extraction values which could be determined based on the climate and energy pile application show the need to develop general procedures for early stage energy pile sizing that would allow quick estimates of the heat extraction/rejection potential and system performance with reasonable accuracy for conceptual design. Most of available software is borehole oriented and will fit for energy piles sizing if software supports variable ground surface temperature boundary conditions, which, however is not implemented in most of software packages. Expected software features to be implemented are water advection and multiregional surface boundary heat transfer.

Contents

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1. Introduction

Recently adopted European Parliament directive 2010/31/EU [1] on energy performance of buildings highly promotes application of energy from renewable sources. Renewable energy becomes more accessible and its significance grows in the design of more energy efficient buildings. One widely utilized renewable energy source is geothermal energy, which can be efficiently utilized with ground-source heat pump (GSHP) coupled with ground heat exchanger (GHE). Recently published review on worldwide application of geothermal energy [2] revealed, that installed worldwide GSHPs capacity has grown 2.15 times in the period of 2005–2010 at a compound annual rate of 16.6% and there is an evidence of GSHP application in 78 countries around the globe.

Around 30 years ago, building pile foundations were first introduced as GHE in Austria [3] and further defined as energy piles. Nowadays, worldwide energy piles popularity is constantly growing and in Austria there are more than 100 000 of units installed [4]. Energy piles are known to be cost effective, as they combine two important properties in one solution – structural loadbearing and GHE i.e. thermal. Energy piles are being important research topic due to the complexity of their thermal behaviour.

As the layout of energy piles is generally defined by the foundation plan, thermal interferences between closely located adjacent piles appear. During the ground heat extraction process, the temperature of soil surrounding energy piles decreases with respect to the ground, pile and circulating fluid thermal capacitance and vice versa during the heat rejection process. Unbalanced operation of energy piles, where more heat is being extracted than rejected, in some cases may lead to a significant decrease in long-term energy performance. Therefore, to maintain stable operation of energy piles in a long-term perspective, consideration of seasonal thermal storage may become feasible. Additional thermal interference appear between energy piles ground surface boundary and building floor structure [5]. In cold climate zones, building floor heat loss may heat up the ground over the years and produce natural thermal storage effect, which may enhance thermal performance of energy piles significantly. Considering above-mentioned factors with varying variables like thermal properties of ground, grout, pipe, fluid, temperature boundary conditions, different possible energy pile configurations, distance between piles and their length, design and optimal sizing of energy piles and/or GSHP, the system with energy piles requires complex dynamic numerical modelling.

The goal of this paper is to report energy piles applications and their potential as a renewable energy solution. In this review different fundamental schemes of heat pump plants with energy piles, and various energy pile configuration types and their performance are studied. The study presents and discusses available modelling and software solutions and undergoes sizing and design techniques. As energy piles operation principle is similar to boreholes [5] with known differences in boundary conditions, possible implementation of knowledge obtained in borehole research for energy piles is also discussed. Available scientific literature and design guideline materials related to energy piles topic covered in this paper may further be classified into four major categories presented in Table 1.

In Section 2, relevant studies describing typical fundamental schemes of heat pump plants with energy piles are discussed. Additionally to fundamental schemes, plant performance examples found in scientific literature are also presented. Due to the limited availability of literature regarding energy piles, in some cases performance of borehole field plants is presented as an alternative to energy piles. Section 3 summarized studies regarding the performance of different energy piles configurations assessed with application of thermal response test (TRT). Summaries of literature review in categories of energy piles modelling and sizing are presented in Sections 4 And 5, respectively.

2. Fundamental schemes of plants with energy piles

Fundamental schemes of geothermal plants presented in this section support various types of ground heat exchangers including energy piles and boreholes. Fig. 1 presents one of most common application of energy piles in buildings, where most of the time indoor climate conditions are ensured with heating.

When secondary side demands heat, heat pump starts its operation and heats up the heat carrier in buffer tank. Whenever temperature in the tank drops below the set point value and operating heat pump is unable to further ensure the desired set point, built-in electrical heating coil or some other top-up heating starts its operation and heats up the volume of the tank to desired temperature value.

When secondary side demands cool, fluid circulating in energy piles loop is directed to the “free cooling” heat exchanger, where coupled secondary side circulating fluid is being cooled. Optional cooling circuit is connected through three-way valves in the heat pump loop, see Fig. 1. Three-way valves function is to reverse the flow in the heat pump loop, which results in reverse operation of the heat pump. Therefore, such plant can alternately heat or cool the volume of the buffer tank. Cooling circuit may be considered in buildings, where “free cooling” is unable to fulfil most of the cooling demand. Though, it should be noted, that such plant solution could not cool and heat a building simultaneously.

Two-storey residential building [6] located in Hokkaido, Japan operated according to the plant solution presented on Fig. 1. Measurements of a single heating period with duration of ca 5 month (December 2000–April 2000) revealed, that total of 26 energy piles 9 m deep managed to produce ca 18.3 MWh of heat i.e. 78 kWh per meter of pile length on the heat pump condenser side. Minimal outdoor air temperature during the heating period was ca −17 °C. Average heat pump coefficient of performance (COP) during operation was 3.9. Energy piles heating system seasonal coefficient of performance (SCOP), where ground loop circulation pumps electricity and system control is taken into an account was 3.2.

Plant scheme described on Fig. 2 can be applied in buildings, where both simultaneous heating and cooling demand are needed. Compared to previously presented plant scheme, there is an additional individual cooling machine and cold buffer tank considered in the design.

A good example of a building, where energy piles are used also for cooling is a terminal E of the Zürich airport [7]. Terminal was built in 2003 and it uses 306 concrete energy piles as a GHE in plant design to ensure heating and cooling. Heat pump with capacity of 630 kW covers 85% of the heating demand, where peak power loads are met with top-up district heating. Sizing and designing of the plant was performed with help of PILESIM software, which utilizes finite difference method based duct ground heat storage model (DST) [8]. Cooling demand of the building is mostly covered by energy piles ”free cooling“, where cooling secondary side is coupled with energy piles loop. Whenever “free cooling“ is not sufficient to maintain supply coolant temperature of 14 °C, heat pump starts its operation and cools down energy piles (evaporator) loop and heat pump excess heat is directed to the dry coolers located on the roof. Energy piles are 26.8 m deep with outer diameter ranging from 900 mm to 1500 mm, where each pile is equipped with 5 U-pipes fixed in the concrete reinforcement. Measurements of annual operation revealed, that heat pump managed to produce 2210 MWh, which is ca 73% of overall heat demand, where the remaining 27% were covered with top-up