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Geothermal heat pump plant performance in a nearly zero-energy building

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Abstract

On the behalf of reaching EU directive 2010/31/EU energy performance targets and fulfilling nearly zero-energy energy buildings (nZEB) requirements by the end of 2020, utilization of renewable energy sources becomes important. Renewable solar and ground energy can be efficiently utilized by a hybrid geothermal heat pump with a solar thermal storage, which is expected to yield high seasonal coefficient of performance (SCOP) making it attractive to consider in nZEB design. This numerical study investigates the impact of various ground heat exchangers and thermal storage options along with their possible combinations on heat pump plant heating/cooling performance in the design of commercial hall-type nZEB located in cold climate of Hämeenlinna, Finland. Components applied in a numerical study were energy piles, vertical boreholes (heat wells), solar collector and/or exhaust air heat as a thermal storage source. A whole year dynamic simulations were performed in IDA-ICE simulation environment, where detailed custom ground-source heat pump (GSHP) plants were modelled. Results revealed GSHP plant to be favorable heat source option in nZEB design. Application of thermal storage enabled to reduce energy piles field by more than two times. Proposed exhaust air thermal storage option performed highly efficient in comparison to solar thermal storage.

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Keywords: heat pump plant; energy piles; boreholes; nZEB; thermal storage; IDA-ICE; whole building simulation

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1. Introduction

European Parliament directive 2010/31/EU [1] raises the level of ambition in buildings energy performance and requires all new buildings built to be nearly zero-energy buildings (nZEB) by the end of 2020. On achieving nZEB requirements consideration of renewable energy sources such as geothermal and solar in the design is expected. Geothermal energy can be efficiently utilized with a ground source heat pump (GSHP) and according to a review on worldwide application of geothermal energy [2] total installed worldwide GSHPs capacity has grown 2.15 times in the period of 2005 to 2010 and application of GSHP is registered in 78 countries around the globe.

High annual GSHP SCOP values up to 4.5 and overall geothermal plant SCOP values up to 3.9 (with control and distribution losses) were obtained by measuring the performance of actual GSHP installations [3-4]. Though, in most cases, operation of a heat pump is accompanied by the unbalanced geothermal energy extraction/injection that leads to a significant loss in long-term operation performance [5]. In order to maintain stable long-term operation of GSHP plant and improve geothermal energy yield along with seasonal coefficient of performance (SCOP), a source of thermal storage should be considered in the plant design. Numerical study conducted by Reda [6] presents the benefits of solar thermal storage in a GSHP plant with a borehole field type ground heat exchanger (GHE), where application of solar thermal storage helped to improve GSHP plant SCOP from 1.6 to 3.0. Allaerts et al. [7] modelled the performance of a GSHP plant with dual borehole field and active air source storage in TRNSYS, where cooling tower i.e. dry cooler was applied as a thermal storage source. As a results of thermal storage application, overall size of borehole field was reduced by 47% compared to the same capacity single borehole field plant without thermal storage.

GSHP plant performance is also depended on the type of GHE considered in the plant design. Typical closed loop GHEs are classified by the position of installation - horizontal and vertical. Horizontal GHE is generally cheaper to install compared to vertical GHE, but requires more land area for the installation. As the horizontal GHE installation depth is generally very shallow (when installed in soil medium) i.e. just below the soil freezing depth, which e.g. in Estonia is ca 2 meter below ground surface, it’s performance is very depended on the outdoor air temperature fluctuations, intensity of solar radiation incident on the ground surface and even presence of snow on ground surface. On the other hand, single vertical 100 meter deep borehole would be less impacted by the outdoor air temperature variance and solar radiation, as it is mostly exposed to the temperature of its surrounding medium. In buildings with limited land area, vertical GHE in form of a borehole reaching up to 400 meters in depth might be a solution instead of horizontal GHE installation. However, drilling very deep boreholes might be not only very expensive, but also drilling depth might be limited by the government regulations in the region of interest. In this case, field of multiple shorter boreholes (not exceeding the drilling depth limit) spaced at known distance to each other might be considered as a GHE alternative.

In buildings with pile foundations, installation of heat exchange piping into foundations piles enables the foundation piles to perform as a ground heat exchanger similarly to previously described field of boreholes. Geothermal pile foundations are known also as geothermal energy piles [8]. As the installation of heat exchange piping into foundation pile compared to the drilling of a new borehole is much cheaper, energy piles tend to be a very cost effective GHE solution. As the layout of energy piles is generally defined by the foundation plan, thermal interferences between closely located adjacent piles appear. Thermal interferences may also appear in field of boreholes, depending on the spacing between them. Sizing and assessment of borehole field or energy piles performance is generally carried out with help of numerical modelling regarding which more detailed aspects are described in previously conducted study by Fadejev and Kurnitski [9].

From the perspective of thermal storage application, not all types of GHEs would benefit from a thermal storage due to varying thermal losses intensity, GHE storage capacity and peak heat extraction/rejection rates. To consolidate previous statement, assuming that the same exact amount of heat is stored in a single borehole GHE compared to the same amount of heat stored in a GHE consisting of multiple boreholes and total length of single borehole is equal to the sum of multiple boreholes, field of multiple boreholes would be capable of extracting more heat compared to a single pile due to rejected storage heat of boreholes located in the centre of the field still can be utilized by the boreholes located at the edges of borehole field in the process of storage heat dissipation.

In cold climate regions, where indoor climate conditions are generally ensured with heating, operation of GSHP plant during the heating season cools down the ground surrounding GHE. Installing a “free cooling” heat exchanger