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Numerical Modeling of a Paraffin-based Concrete Thermal Storage System

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ABSTRACT

Ground source heat pump systems (GSHPs) are considered a clean and sustainable alternative to conventional heating and cooling technologies and are becoming more popular as concerns of greenhouse gas emissions increase. GSHPs use the ground, which remains at a relatively constant temperature throughout the year, as a heat source in the winter heating season and as a heat sink in the summer cooling season. However, the repetition of heating/cooling cycles can lead to thermal imbalance in the ground over a period of years causing a failure to operate in the long term. Another challenge with GSHPs is the drilling space, which is largely a function of the number of borehole heat exchangers required to meet different building loads, and is often unappealing in densely populated cities. To combat these challenges, hybrid GSHP systems that integrate a thermal energy storage (TES) medium such as phase change material (PCM) offers a viable and economically beneficial retrofit option compared to conventional GSHPs. The latent heat storage medium (PCM) goes through melting/freezing cycles for charging/discharging of heat. Each PCM is characterized with a specific phase change temperature and thermophysical properties which render its selection very critical depending on the building loads and operating conditions. Determining the thermodynamic performance of the hybrid GSHP as a function of PCM material is required to fully understand the implications of integrating the proper material that is safe, sustainable and capable of meeting the different building loads. In this study, three different paraffin based PCMs with different latent heats and melting temperatures (6.5ºC, 15ºC, and 24ºC) are being investigated for three types of building: heating dominant, cooling dominant and balanced. A numerical model based on finite element analysis is developed for a storage tank with a 0.5-m diameter and 1-m height, and is validated with an experimental setup equipped with temperature sensors at different radial positions and depths. The tank is filled with concrete and contains twelve pipes of 5.08-cm diameter that are 1 m long (four borehole heat exchangers and eight paraffin based PCM pipes). Each BHE includes a 1.27-cm u-shaped pipe. Based on the numerical results, a proper selection of PCM type is a crucial factor which highly depends on heating/cooling loads and has a great impact on the temperature distribution, heat release/extraction and ultimately the overall performance of the hybrid GSHP system.