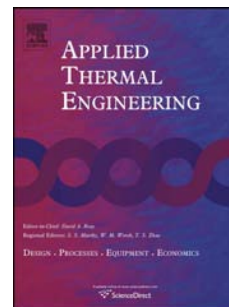


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MULTI-SCALE MODELING OF THE ENVIRONMENTAL IMPACT AND ENERGY PERFORMANCE OF OPEN-LOOP GROUNDWATER HEAT PUMPS IN URBAN AREAS

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ABSTRACT

Groundwater heat pumps are expected to play a major role in future energy scenarios. Proliferation of such systems in urban areas may generate issues related to possible interference between installations. These issues are associated with the thermal plume produced by heat pumps during operation and are particularly evident in the case of groundwater flow, because of the advection heat transfer.

In this paper, the impact of an installation is investigated through a thermo-fluid dynamic model of the subsurface which considers fluid flow in the saturated unit and heat transfer in both the saturated and unsaturated units. Due to the large extension of the affected area, a multiscale numerical model that combines a three-dimensional CFD model and a network model is proposed.

The thermal request of the user and the heat pump performances are considered in the multi-scale numerical model through appropriate boundary conditions imposed at the wells. Various scenarios corresponding to different operating modes of the heat pump are considered.

Keywords: Geothermal, Heat pump, Groundwater, advection, Thermal plume, Numerical simulation

1. INTRODUCTION

Among the available energy-saving technologies, heat pumps are expected to reduce significantly the primary energy required for heating and cooling with respect to traditional systems. When available, groundwater is used as heat source during winter operation and heat sink during summer operation, because of the nearly constant temperature and the more favorable heat transfer properties. A higher evaporation temperature in winter time and a lower condensing temperature in summer heat pump systems allow one to achieve higher coefficient of performance (COP). The temperature difference between extracted water and re-injected water causes a perturbation of the groundwater temperature field. This phenomenon may affect the performances of other heat pumps installed in the neighborhood.

This kind of systems are difficult to analyze experimentally, in addition, it is often desirable to evaluate them prior to its installation. Therefore, numerical modeling is a suitable research tool to investigate energetic, economic and environmental aspects of groundwater heat pump systems. Various modeling approaches have been used in the literature. Zhou Y. and Zhou Z. [1] used a convection-dispersion model to obtain the groundwater temperature field. The results obtained by the authors show that the extension of the thermal plume is significantly affected by the distance between the wells and by the variations of the thermal load. Furthermore, these authors show that heat transfer phenomenon is dominated by convection. Diao et al. [2] studied the conduction-advection problem considering a line heat source in 2D space medium by means of Green functions. The temperature field obtained by the authors illustrates the influence of the fluid flow on the heat transfer phenomenon. Molina-Giraldo et al. [3] developed an analytical model in order to evaluate the effect of heat conduction on the groundwater temperature distribution. The results obtained by means of a complete 2D model and a 1D model without the conductive term indicate that conduction is a relevant contribution. Therefore it is possible to conclude that a reliable model of heat transfer phenomena in the subsurface should include both convective and conductive terms.

In order to simulate realistic systems and operating conditions more refined tools have to be used at the expense of high computational cost. Several authors carried out numerical studies using commercial software FEFLOW [4]. Nam and Ooka [5] used FEFLOW to study the temperature behavior in a small area near wells with the aim of evaluating the maximum performance coefficient for both heating and cooling conditions. Lo Russo et al. [6] studied the temperature distribution in a urban subsurface using FEFLOW. The model considers a quite large domain in order to analyze possible effects that are produced by an installation in a public building. Numerical models developed using

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