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N. Massarotti, P. Nithiarasu, and I. Vušanović (Eds.)

Foundation Slabs as an Energy Geo-Structure in a Moderate Climate

Lazaros Aresti, Georgios Florides, Paul Christodoulides
Faculty of Engineering and Technology, Cyprus University of Technology, Limassol, Cyprus;
lg.aresti@edu.cut.ac.cy

ABSTRACT

Shallow geothermal energy is a type of Renewable Energy, used in dwellings through the employment of Ground Source Heat Pumps (GSHPs). GSHPs are coupled with the Ground Heat Exchangers (GHEs), which are responsible for the heat transfer to/ from the ground. GSHPs have not seen a major advancement in terms of wide implementation, as compared to other Renewable Energy Systems, due to the higher costs associated with them. However, the use of the foundation elements as GHEs, can contribute in a significant reduction of the costs and investment. This study computationally investigates the use of an Energy Geo-Structure (EG) system, namely the foundation slab, of a residential dwelling in Cyprus, using the COMSOL Multiphysics software. A single-family house was designed in accordance with the typical Cyprus construction elements for nearly Zero Energy Building (nZEB) characteristics. Initially, the heating and cooling loads were estimated and used as inputs to analyse the performance of the proposed system. The system under examination demonstrates steady performance and relative high Coefficient of Performance (COP) values, making it a viable renewable energy source solution for building integration.

Key Words: G*round Heat Exchanger; thermo active structures; energy geo structures; foundation GHE; foundation slab GHE;*

1. INTRODUCTION

In recent years, an increase in the popularity of Renewable Energy Systems (RES) towards the as part reduction of fossil fuels and CO2 emissions. Ground Source Heat Pumps (GSHPs), which exploits Geothermal Energy, are such examples, where the systems are utilized for space heating and cooling. In these systems, heat is transferred through a network of tubes specifically designed and place, called Ground Heat Exchangers (GHEs). GHEs function like conventional heat exchangers, where essentially, they absorb or release heat to or from the ground. Although their higher performance, compared to conventional systems, such as even the Air Source Heat Pumps (ASHPs), they have failed to flourish due to the high initial costs associated with them. GHEs are classified into two primary categories: horizontal and vertical (or borehole). The vertical kind is considered the conventional type, and it requires less ground surface area compared to the horizontal types [1].

To reduce the initial costs, recently, GSHP systems have been used in building foundations as Thermo-Active Structure (TAS) systems or Energy Geo-Structures (EGs). These systems have various applications including the energy piles, diaphragm walls, retaining walls, shallow foundations, etc. [2]. EGs are essentially foundations (with reinforced concrete or other material), that are incorporating geothermal pipes. The standard dimensions for energy piles typically range from 10 to 40 m in depth [3] and 0.3 to 1.5 m in diameter [4]. Various pipe configurations can be employed for an EGs system depending on the available space, type, and thermal requirements.

The use of foundation slabs as GHEs, has not been yet implemented in the Mediterranean island of Cyprus. Therefore, this study is intended to evaluate the potential benefits of implementing such systems. Aresti et al. [5] conducted a first examination and preliminary assessment on the energy piles system. The objective of this research is to significantly broaden the initial discoveries and, furthermore, investigate the capacity of GSHP systems by using the foundation slab in a moderate climate, such as in Cyprus, within the context of a Zero Energy Building.

2. METHODOLOGY

For this study, a computational method was selected using the COMSOL Multiphysics software, and based on the convection–diffusion equation. The 3D transient convection–diffusion equation for an incompressible fluid is used for all domains [6] (shown in equation 1), except the pipes, where a simplified 1D version is applied described in equation 2 as:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u \cdot \nabla T + \nabla q = Q \tag{1}$$

$$\rho A c_p \frac{\partial T}{\partial t} + \rho A c_p u e_t \cdot \nabla_t T = \nabla_t \cdot (Ak \nabla_t T) + \frac{1}{2} f_D \frac{\rho A}{d_h} |u| u^2 + Q_{wall} \tag{2}$$

where ρ is the density, A is the pipe area, q is the Fourier's heat conduction, c_p is the specific heat capacity at constant pressure, T is temperature, t is time, ue_t is the tangential velocity, k is the thermal conductivity, f_D is the Darcy's friction factor, Q is the heat source, and Q_{wall} is the heat source described with the heat conduction equation.

The geometry is presented in Figure 1, where the foundation slab is included as well as he surrounding soil. The top surface of the foundation slab is assumed as insulated. One significant distinction in the foundation slab, in this example, is the system's extremely shallow depth of only 1 meter, where the ground temperatures and the foundation slab temperatures are influenced by the ambient temperature, and therefore the ambient temperature was used as a boundary condition on the upper surface of the ground domain. The pipes are placed on the lower surface of the foundation slab, represented by lines, and follow a "serpentine" configuration.

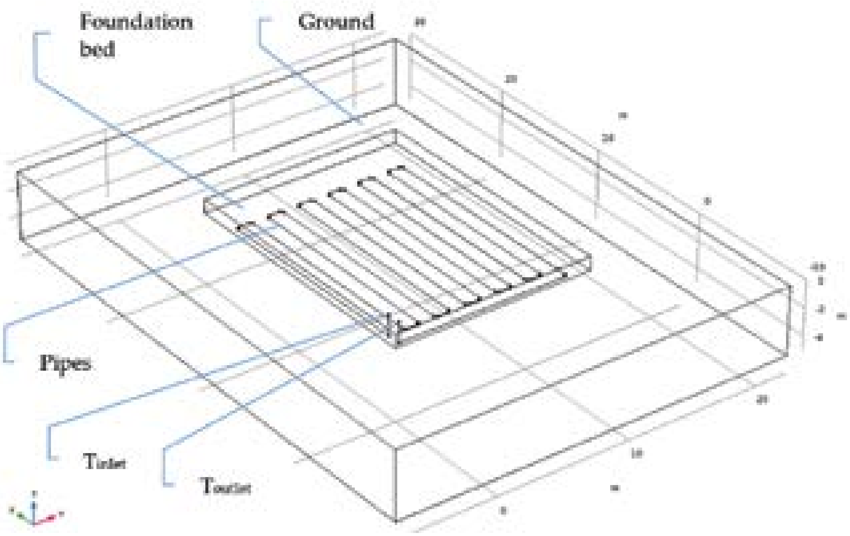

FIGURE 1. Computational model geometry and boundary conditions

3. RESULTS

The computational model is verified and validated in previous work (not shown here), and is modified to satisfy the theoretical residential model under examination. The initial computational results are represented in Figure 2, where the GHE's inlet and outlet temperatures, as well as the coefficient of performance (COP) of the GSHP is presented. By monitoring the outlet temperature, during both winter (February) and summer (July), the system consistently maintains an almost steady condition, with an observed high performance, with COP values of 4.6 in winter and 4.8 in summer.

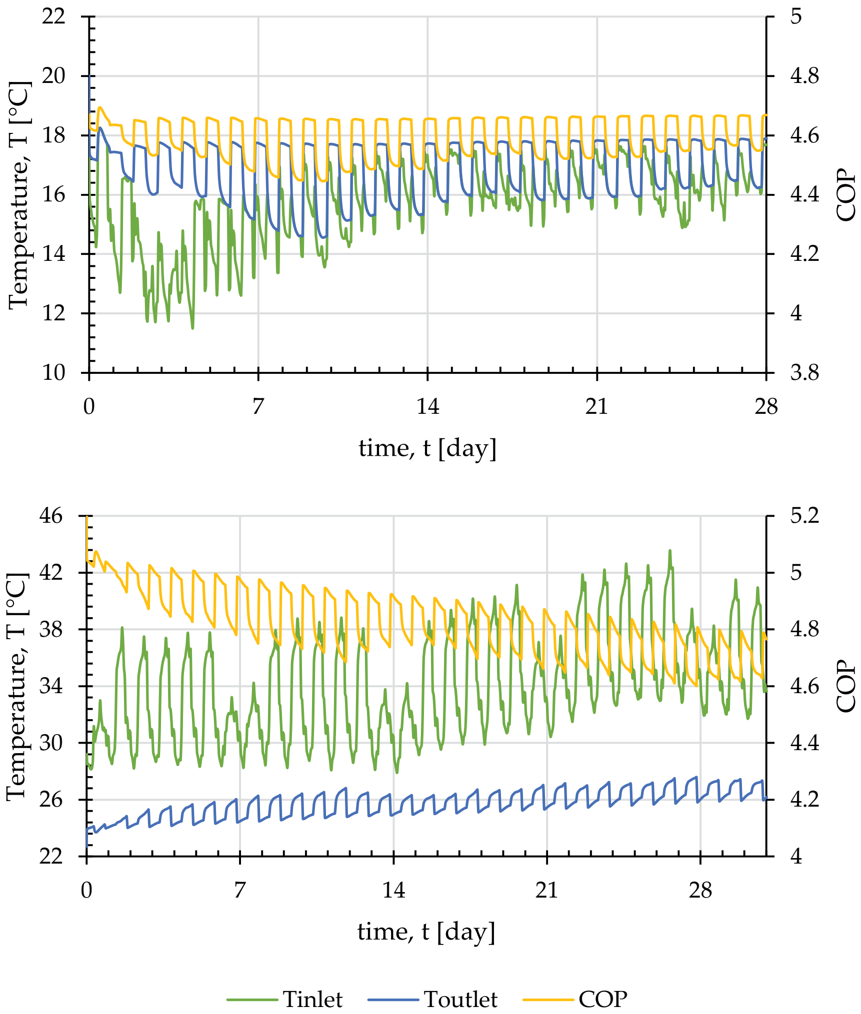

FIGURE 2 Inlet and outlet temperatures and COP values for the months of (top) February and (bottom) July.

One factor that required further investigation, is the rise in temperature of the top surface, representing the surface in contact with the dwelling's internal area. An elevation in the temperature of the dwelling's floor surface would negatively affect the cooling loads, since the heat energy rejected in the ground would circulate back through the foundation bed. This issue might be resolved by installing an insulation layer on the floor of the dwelling, the same technique applied as the rood of the dwelling.

4. CONCLUSIONS

An initial investigation for the use of the foundation slab as an Energy Geo-structure (EG) element was conducted in this research with the use of computational methods. COMSOL Multiphysics was used as the software, where the developed model, introduced the ground temperature characteristics and the local ambient temperature of a specific site. The hourly Ground Heat Exchanger's inlet and outlet temperatures were simulated for the two months, with the maximum demand in summer (July) and winter (February), based on the specified calculated loads. The results obtained indicate that the system exhibit a high coefficient of performance (COP) and maintain an almost constant conditions, with COP values ranging from 4.6 to 4.8.

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