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Heat pump efficiency with energy geostructure: Numerical long term modelling

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Energy geostructure are a group of technical methods aiming to use the geotechnical structures as heat source exchangers for a geothermal Heat Pump (HPg) [1]. As with any heat pump system, the goal is usually to extract soil energy in order to heat buildings. HPg system efficiency is described by the COP factor (Coefficient of Performance) defined as the ratio between the quantity of useful energy for building heating Q_h and consumed electric power W. Its value has a great influence on the economic sustainability of geothermal systems. This efficiency is strongly correlated to the temperature lift between the cold and hot sources of HPg. However, while operating, HPg will drain energy from the soil, decreasing soil temperature, increasing the temperature gap, and decreasing the COP factor. Such thermal anomalies are supposedly dissipated through seasonal operations of the system. However, inappropriate conditions might result in a multiyear soil temperature shift [2] and durable degradation of HPg efficiency [3]. Specifically, energy geostructure are often installed as dense networks, such as pile groups. Such proximity might generate thermal interaction and affect the surrounding soil temperature [4, 5]. In the case of an underground water table, seepage might help to dissipate the thermal anomaly [2], but it will also generate stronger and more directional thermal interaction [5, 6].

Based on numerical modeling [5], we were able to predict the COP evolution for a small energy pile. We propose now to use this modeling process to predict the COP evolution of a more realistic geothermal installation. The study case model is based on a housing building constructed in Gonesse France, in 2012 [7]. The model represents a group of 20 energy piles, each 12 m long, used to heat 1000 m² of housing with a peak heating demand of 15,5 kW. The system is supposed to be used at peak power supply for 12 hours out of 24 hours during four consecutive weeks. The final resulting COP is considered an indicator of installation performance. We studied the effects of pile proximity (inter-pile distances from 1.2 m to 6 m) and seepage velocity (from 0 m/day to 2 m/day). We expect to observe a beneficial effect of the water movement as it renews the soil energy around the pile. Also, we expect to observe a negative effect of the pile proximity, as the thermal anomalies will have a cumulative effect on the soil temperature drop.

All the numerical modeling is realized with CESAR-LCPC software, which is a FEM software specialized for civil engineering problems [8]. It has the possibility of treating diffusive problems such as thermal problems or hydraulic diffusion in porous media. Also, CESAR-LCPC could be used with a Python script interface, which is useful to describe the needed iterative process and conduct the parametric studies. The numerical modeling processes principally aim to solve the thermal problem in the soil and foundation systems. It takes into account heat transfers from conduction defined by Fourier's law: $\vec{J}_{cond} = -\lambda \cdot \overrightarrow{grad}\, T$ (λ has the material thermal conductivity), and the heat transfer due to underground water displacement (advection phenomenon) defined has $\vec{J}_{adv} = c_v \cdot T \cdot \vec{V}$ (with c_v the volume thermal capacity and $\vec{V}$ the underground water flow velocity). The seepage velocity field is then computed preliminarily in order to take account of the disturbance effect due to the structure. The thermal load applied to the model Q_c results from the heating demand from the building, Q_h as the thermodynamic law states energy conservation: $Q_h = W + Q_c$, knowing the definition of the COP factor. Staffell and al. [3] proposes an empirical relationship between the COP factor and the temperature lift between the hot and cold sources of HPg. Completing the problem by adding a few simple thermal resis-

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tive equations and assuming a hot source at 40°C, we can solve the overall equation in order to compute the COP factor depending on the soil temperature.

The results show, as expected, a progressive COP decrease during the 4 weeks as long as soil temperatures decrease. Moreover, in the case of a seepage velocity below 0.2 m/day, the temperature and COP factor tend to decrease without a steady state. Figure 1 summarizes the numerical results, showing the final COP value depending on seepage velocity and interpile distance. It shows that the absence of seepage will have a negative impact on system efficiency as long as the pile proximity. Logically, in a smaller group, a cluster effect will intensely affect soil temperature, while the absence of seepage won't renew soil energy. We can conclude that in cases of slow seepage (below 0.2 m/day), it is possible to improve system efficiency by opting for more distant piles. Also, for seepage over 0.5 m/day, the distance between piles in the same group will have a limited impact on the heat pump's efficiency.

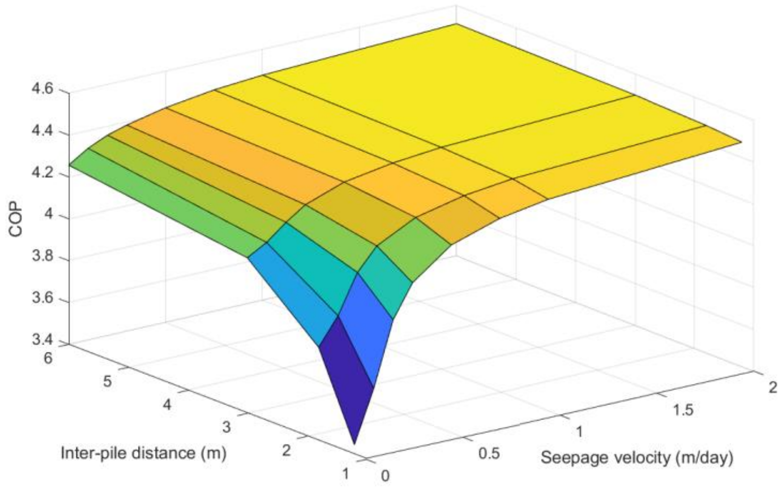

Figure 1: COP after one month of peak use depending on seepage velocity and interpile distance.

In an extended study, this modeling process has been complemented with summer mode ability and used for longer simulations, allowing the study of a multi-year thermal shift and various seasonal activation patterns (balanced and unbalanced, peak use, etc.).

Contributor statement

Conceptualization, Formal analysis, Software and Writing: Authors 1 2 and 3; Supervision and Validation: author 4

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