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Thermal performance of energy barrettes in an urban environment

E. Ravera[1,]*, A.F. Rotta Loria[2] and L. Laloui[1]

[1] Laboratory of Soil Mechanics, Swiss Federal Institute of Technology in Lausanne (EPFL), Lausanne, Switzerland
[2] Northwestern University, Department of Civil and Environmental Engineering, Mechanics and Energy Laboratory, IL, USA
* Corresponding author: elena.ravera@epfl.ch

Energy geostructures are renewable heating and cooling technologies that promise to massively decarbonize buildings with other shallow geothermal heat exchangers. However, the performance of these systems in urban environments can be affected by the presence of waste heat underground – a phenomenon associated with so-called subsurface urban heat islands. This study presents field experiments and 3-D time-dependent numerical simulations presented as a part of a broader study [1] to investigate the performance of energy barrettes: novel energy geostructures specifically targeting the structural support and renewable energy supply of tall buildings. This work particularly explores the performance of several energy barrettes included in a complex foundation located underneath the Testimonio II building ensemble in the Principality of Monaco – an extremely dense urban area. Testimonio II includes 348 housing units in two residential towers, a 50-place nursery, and a new site for the 700-student Monaco International School. The building has underground parking garages on multiple levels, supported by a complex foundation consisting of barrettes, piles, diaphragm walls, and slabs. Some of these foundation elements were thermally activated together with a vertical geothermal borehole field drilled underneath the building to contribute to its power supply.

Field experiments and numerical simulations were performed to investigate the behaviour of the considered foundation. The field experiments on energy barrettes consisted of thermal performance tests, which involve the continuous monitoring of key variables for the operation of geothermal heat exchangers and allow determining their energy performance over time. The developed tests involved the application of a constant heating power of approximately 3 kW to individual barrettes with different pipe configurations and/or geometries over timeframes ranging from 170 to 230 hours. Water with a flow rate of 0.2 kg/s was used as the heat carrier fluid. The equipment used for the tests made it possible to measure the inflow and outflow temperatures and the flow rate of the heat transfer fluid circulating in the pipes of the energy barrettes, as well as the outside air temperature. The resulting tests aimed at unravelling the thermal behaviour of energy barrettes as a function of the pipe configuration and the location of such heat exchangers at the site. Numerical simulations made it possible to obtain complementary information on the performance of the tested barrettes based on material parameters gathered through laboratory tests and the literature. The simulations were run with the software COMSOL Multiphysics (v. 5.5). Such simulations reproduced the energy barrettes, the ground, and the pipes embedded within them. The mathematical formulation employed for these analyses is presented elsewhere [e.g., 1] and thoroughly simulate mass transfer, heat transfer, and deformation phenomena within and around energy geostructures, such as barrettes.

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Figure 1 presents the results of the developed experiments on two energy barrettes constructed at the site (called C07 and C17). A different pipe configuration was mounted on each of the wider edges of these barrettes, yielding three types of U-shaped pipe configurations (called hereafter U1, U2, and U3, with the U1 configuration involving a shorter U-shaped pipe mounted on one side of one barrette, whereas U2 and U3 involving a longer yet equal U-shaped pipe mounted on one side of two barrettes installed in different locations of the site) and a W-shaped pipe configuration (called W hereafter). For all four tests, the measured initial ground temperatures are relatively high for a temperate climate like the one characteristic of Monaco. This result is attributed to the presence of waste heat in the underground of the considered urban area, which features one of the highest population and construction densities across the world.The influence of the pipe configuration can be analysed by comparing the temperature trend characterising the energy barrettes with the U1 and U2 or U3 configurations. Accordingly, it is possible to remark that the energy barrette with the U1 configuration achieves greater temperatures compared to the barrette equipped with the U2 configuration. This result is due to the different pipe lengths in play, which involve a smaller heat transfer for the barrette characterised by a shorter U-shaped pipe. By comparing the temperature trend characterising the energy barrettes with the W configuration with the others, it can be assessed that the considered pipe configuration is the one leading to the highest heat transfer with the ground because of the longest pipe length into play. The influence of the site location can finally be appreciated by considering the thermal response of the energy barrettes equipped with U2 and U3 configurations. Despite some differences in the initial temperature, the thermal response of the considered barrettes is approximately the same when superimposed in a unique graph. This result indicates relatively uniform thermal properties at the considered site. Differences between experimental and simulation results range up to 17% for all pipe configurations, primarily concentrated in the first 4 hours. Afterward, the disparities decrease significantly, limited to a maximum of 2%. The differences observed are due to potential discrepancies between the actual and modeled initial conditions (such as non-uniform ground temperature) and variations in the features of the pipes in the barrettes (such as heat exchanger positions and lengths). However, the results obtained demonstrate the effectiveness of the modeling approach in simulating energy barrettes in real-world scenarios.

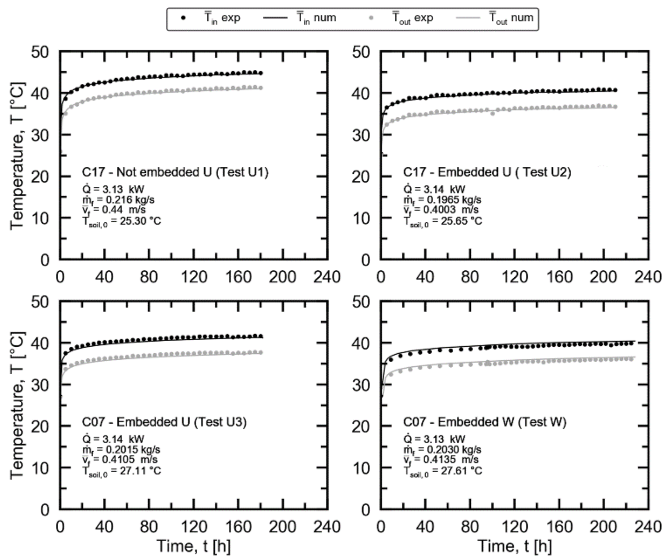

Figure 1: Comparison between the experimental and simulation results.

This study concisely investigated the thermal performance of rectangular energy barrettes using field experiments and 3-D finite element simulations. Conclusions of generalized relevance that can be drawn from this study are as follows:

- Significant subsurface temperatures are observed in the Principality of Monaco due to a subsurface urban heat island. This peculiarity does not change the thermal response of energy barrettes as compared to situations exhibiting lower ground temperatures, but it does reduce their cooling thermal potential – an aspect to be considered in design.
- For given thermo-hydraulic operational parameters, the thermal performance of energy barrettes equipped with W-shaped pipes is better than the performance of energy barrettes equipped with U-shaped pipes.

References

[1] Rotta Loria, A. F., Ravera, E., and Laloui, L. (2023) Thermo-hydro-mechanical behavior of energy barrettes: Field experiments and numerical simulations, *Geomechanics for Energy and the Environment*, 100451.