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Undisturbed Ground Temperature in Urban Environment

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ABSTRACT

Undisturbed ground temperature is important design parameter for borehole heat exchangers in ground coupled heat pump systems. Ground temperature is commonly determined as an average value based on the measured temperature of circulating fluid in the borehole prior to the thermal response test. Still, the shape of temperature profile along borehole depth is not uniform and is affected by geothermal and surface heat flux characteristic for urban areas.

Temperature profile obtained by fiber optic measurement on 130-meter deep borehole is numerically replicated. Analysis has been conducted to evaluate temporal and spatial influence of surface heat source on resulting temperature profiles and estimated average underground temperature. Noticeable temperature increase diminishes after 30 years of surface heat flux while the spatial effects can be traced on distance larger than 10 meters. Not accounting for a local increase of temperature can lead to the erroneous sizing of borehole field, especially for shallow boreholes.

1. INTRODUCTION

Sizing of ground coupled heat pump system requires knowledge of thermal loads of the building and underground properties on considered location. Underground part of unknowns is described by effective thermal conductivity and volumetric heat capactiy of the underground, thermal resistance of the borehole heat exchanger and undisturbed ground temperature. For smaller systems, values of the thermal conductivity can be approximated based on the expected geological conditions on the site. Underground temperature, if unknown, is sometimes replaced by yearly average air temperature. The latter is acceptable for shallow depths and small geothermal gradient. Kurevija et al. (2011) showed that neglecting the geothermal gradient can lead to oversizing of the borehole field in the range from 4.3 to 7.1 %, depending on the field layout. Numerical analysis conducted by Dehkordi and Schincariol (2014) showed clear correlation between long term heat extraction rate and absolute value of undisturbed ground temperature. Modelling of the ground temperature using energy balance of ground surface requires detail meteorological data for given location. In the shallow zone it is possible to predict the soil temperature down to 1 °C difference (Badache et al. 2016). For relatively deep zones influence of the diurnal and seasonal changes of ambient air temperature is negligible and local temperature is affected by existing geothermal gradient.

When vertical boreholes are considered, ground temperature is obtained from initial phase of thermal response test when water is circulated through the borehole which reached thermal equilibrium with surrounding ground after drilling and grouting works. Gehlin and Nordell (2004) showed that pump work and initial temperature fluctuations need to be considered when taking conclusions from circulation test. If temperature profile of ground temperature is of interest than downhole temperature logging can be used. More advanced methods exist, like wireless probes (Arzanbal et al. 2019) or fiber optic cable (Fuji et al. 2009). Undisturbed ground temperature profile is useful as it can be used to assess geothermal gradient and extrapolate ground temperature for different depths. In urban environment, due to anthropogenic activities, elevated ground temperatures and negative ground temperature gradients can be expected (Vieira et al. 2017). Rybach et al. (2011) showed deviation of 2.2 °C from expected underground temperature for location in Meilen (Switzerland) and Menberg et al. (2013) reported difference from 3 to 7 °C between urban and rural areas in Germany.

Similar phenomenon are reported by Soldo et al. (2016) for urban locations investigated in Croatia as part of “Research and the promotion of use of shallow geothermal potential in Croatia” where fiber optic cables were used for investigation of ground thermal properties. In this research temperature profile obtained on 130-meter deep borehole is numerically replicated. Analysis has been conducted to evaluate temporal and spatial influence of surface heat source on resulting temperature profiles and average underground temperature.

2. METHODOLOGY

2.1 Location and measurement

Exploratory borehole is located in Zagreb, Pannonian part of Croatia, along the Sava River, where material with intergranular porosity dominate and location represents sedimentary cover with coarser-grained sediments. On the premises of the Faculty of Mechanical Engineering and Naval Architecture (University of Zagreb) double polyethylene U-pipe (32x2.9 mm) borehole heat exchangers is installed into 130 m deep grouted borehole. Heat exchanger is equipped with fiber Multimode 50/125 fiber optic cable and coupled to the AP Sensing Linear Pro Series DTS instrument. Undisturbed ground temperature was measured for 120 hours without water circulation. Thus, no heat gains due to pump work were present. All temperature measurements were carried out with spatial resolution of 2 m and an integration time of 300 s.

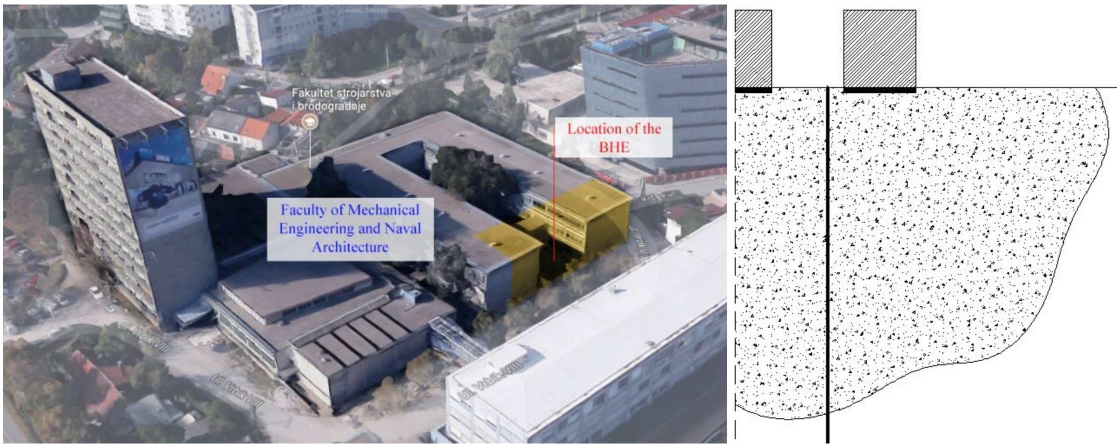

Figure 1: Faculty building, location of BHE and highlighted modelled part of the building in yellow (left) and 2D domain with BHE marked with black line (right)

2.1 Modelling

In order to analyze the influence of surface heat source on resulting temperature profiles, 2D model is created in *Ansys Fluent* numerical package. Modelled domain includes two building parts of the Faculty surrounding the green area, where borehole heat exchanger is installed, and underground domain of 400 m width and 200 m depth to minimize the effect of boundaries on the temperature profile. Ground mesh consists of 1x1 meter squares. Boundary condition set on the surface is constant temperature of 11.6 °C, left side of the domain is set as symmetry boundary condition, while the temperature profile on right side and bottom is defined in accordance with the measured geothermal gradient. Result of such prescribed boundary conditions is undisturbed ground temperature profile without negative thermal gradient. Ground properties of the underground such as density (1950 kg m^{-3}) and heat capacity (1420 J kg^{-1} K^{-1}) are based on core sampling results referenced in literature (Kurevija et al. 2011) while thermal conductivity (1.5 W m^{-1} K^{-1}) is averaged value for the first 15 meters obtained by distributed thermal response test. Since the effect of surface heat sources manifests in topmost ground layers, thermal parameters of top layers are used for whole domain.

Main faculty building (shown on Figure 1) is built in 1960's and width of the building section of interest is 7 meters, as is the spacing between two sections. All buildings surrounding the location of interest are built afterwards. Underneath the building sections constant heat flux of 2.35 W m^{-2} is defined. Using described initial and boundary conditions transient simulation is conducted in order to replicate measured temperature profile.

3. RESULTS

3.1 Measured undisturbed ground temperature profile

Exact part of fiber optic cable installed in the ground was determined using standard deviation of temperature recordings over time. Recorded temperatures below 2 meters depth were obtained with standard deviation of 0.023-0.028 °C.

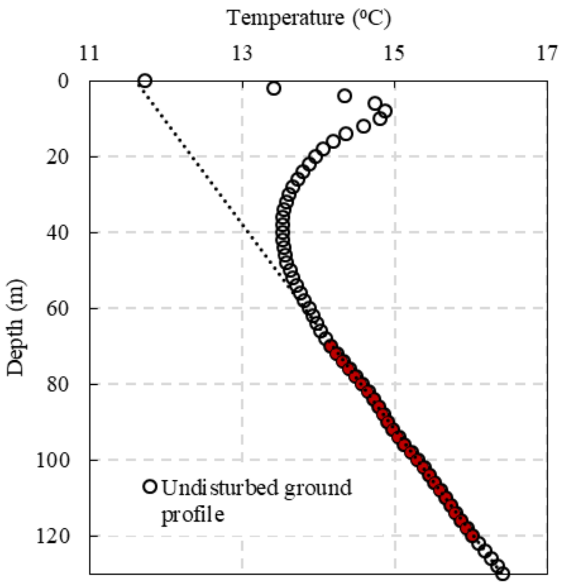

Figure 2: Measured undisturbed ground temperature profile and highlighted segment used for determination of geothermal gradient

Figure 2 shows obtained temperature profile with indicated segment from 70th to 120th meter used for determination of geothermal gradient. Squared coefficient of determination for that part of temperature profile is 0.9993 and value of geothermal gradient is found to be 0.037 °C m^{-1}. Extrapolation of geothermal gradient to the ground surface results with temperature of 11.6 °C that corresponds to the yearly average air temperature for given location. Deviation from geothermal gradient in layers between 10 and 50 m depth is attributed to the heat sources on the surface and minimum local temperature of 13.52 °C is found at the depth of 42 meters.

3.2 Results of numerical simulation

Figure 3 displays temperature profiles in the underground for three different time instances. On the left, undisturbed ground temperature distribution is shown based on initial conditions and on the right two different time instances are shown where negative gradient is present.

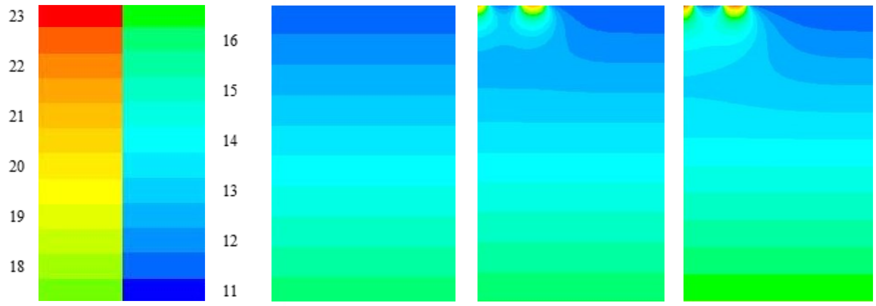

Figure 3: Temperature distribution in undisturbed ground (left), after 10 years (center) and after 50 years (right) following constant surface heat flux of 2.35 W m^{-2}

Quantitative representation of same data is showed in Figure 4. On the left hand side temporal change of the temperature profile on borehole location is presented. Measured profile, marked by black dots, is replicated successfully in top most and bottom part of the ground. In middle part, between 10 and 40 meters there are some differences in absolute values attributed to the simplifications introduced during modelling. There is no significant difference between temperature profiles after 40 and 50 years, while in first 30 years depth and magnitude of thermal disturbance is influenced by temporal component.

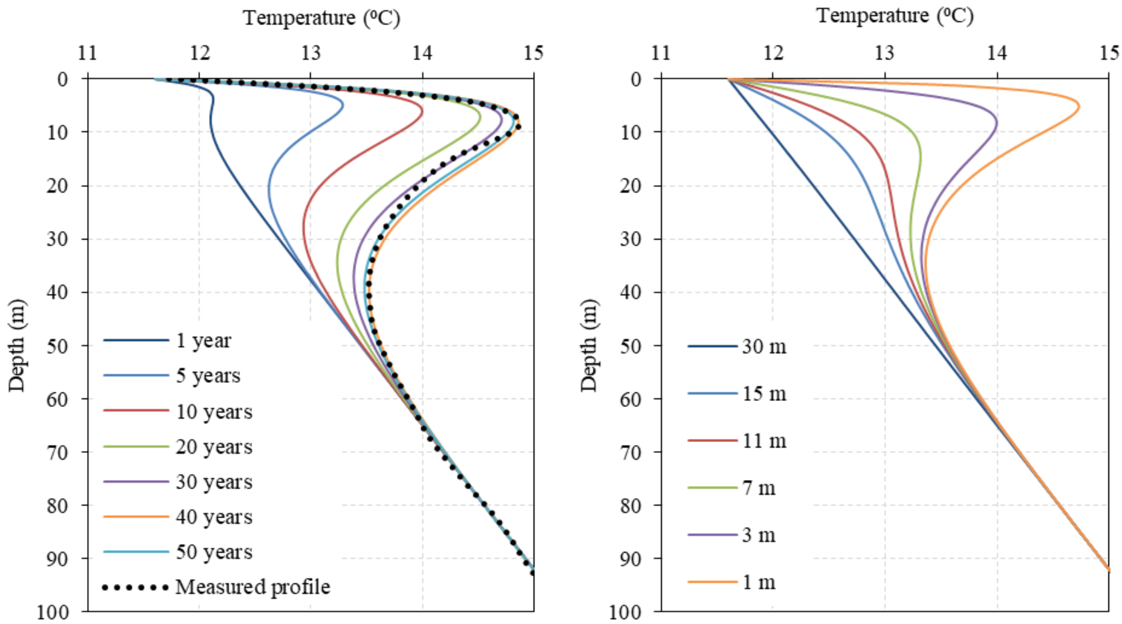

Figure 4: Temporal (left) and spatial (right) influence of surface heat flux after 50 years on the temperature profile of the underground

Spatial analysis, on the right side of the Figure 4, shows that after 50 years thermal disturbance vanishes somewhere between 15 and 30 meters away from the heat source. Drilling the borehole heat exchanger 1 meter away from existing building is not common, but at distance of 3 meters from heat source local temperature difference can be up to 2 °C. When borehole heat exchangers are considered, average underground temperature is value of interest. Temperature profiles for different temporal and spatial conditions are averaged over 50 and 100 meters depth to highlight the difference in contrast to undisturbed condition. Two sets of curves are presented on Figure 5: dashed lines correspond to relative temperature difference when 100 meter deep borehole is considered and solid lines when shallower, 50 meter deep boreholes, are of interest. Since the negative gradient is present in upper layers, deeper the borehole, less significant is present deviation of temperature profile. After 30 years, average temperature difference is around 0.82 °C for shallow and 0.4 °C for deep borehole. Dehkordi and Schincariol (2014) showed that in long-term use percentage difference in underground temperature is equal to percentage difference in heat extraction rate. For Zagreb location 1 °C difference results with approximately 7 % difference in heat extraction rate per meter of the borehole. When utilization of shallow geothermal is considered for heating dominated building, placing the boreholes closer to existing building can result with smaller needed total length of borehole heat exchangers. On the other hand, if cooling needs are greater, placing the boreholes away from the building is recommended. Also, when conducting the thermal response test one should be careful with choice of location for the test borehole in order to have representative undisturbed ground temperature.

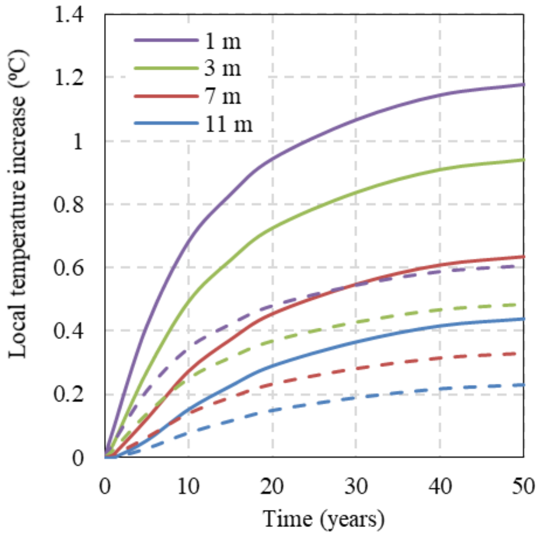

Figure 5: Local average temperature increase for 100 meter depth (dashed lines) and 50 meter detph (solid lines)

4. CONCLUSION

Reported undisturbed ground temperature profile shows evidence of negative gradient characteristic to urban environment with artificial heat flows from the surface. Numerical 2D model was used to simulate long term effect of faculty building on surrounding ground. Temperature profile was successfully replicated, enabling the evaluation of the size of the temperature zone affected by heat transferred from building to the ground. Results presented in this paper are site specific and different geological conditions or heat flux will result with different absolute temperature values. Still, conclusion can be made that neglecting local temperature increase can lead to noticeable over-sizing or under-sizing of the system, although the thermal disturbance does not spread in space at significant distances and majority of local temperature change takes effect in first 30-40 years. Shallow boreholes are more sensitive to the negative gradient phenomenon and latter is even more pronounced in areas where multiple heat sources begin to interfere creating larger local temperature increase. For single heat source and given conditions on the location, heat extraction rate can differ up to 7 % for borehole 3 meters away from the building.

ACKNOWLEDGEMENTS

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REFERENCES

Dehkordi, S.E., Schincariol, R.: Effect of Thermal-hydrogeological and Borehole Heat Exchanger Properties on Performance and Impact of Vertical Closed-loop Geothermal Heat Pump Systems, *Hydrogeolgy Journal*, **22**, (2014), 189–203.

Fujii, H., Okubo, H., Nishi, K., Itoi, R., Ohyama, K., Shibata, K.: An Improved Thermal Tesponse Test for U-tube Ground Heat Exchanger Based on Optical Fiber Thermometers, *Geothermics*, **38**, (2009), 399–406.

Gehlin S., Nordell, B.: Determining Undisturbed Ground Temperature for Thermal Response Test, *ASHRAE Transactions,* **109**, (2003), 151–156.

Kurevija, T., Vulin, D., Krapec, V.: Influence of Undisturbed Ground Temperature and Geothermal Gradient on the Sizing of Borehole Heat Exchangers, *Proceedings,* World Renewable Energy Congress, Linkoping, Sweden, (2011), 1360–1367.

Martos, J., Montero, Á., Torres, J., Soret, J., Martínez, G., García-Olcina, R.: Novel Wireless Sensor System for Dynamic Characterization of Borehole Heat Exchangers, *Sensors,* **11**, (2011), 7082-7094.

Menberg, K., Bayer, P., Zosseder, K., Rumohr, S., Blum, P.: Subsurface Urban Heat Islands in German Cities, *Science of the Total Environment,* **442**, (2013), 123–133.

Messaoud, B., Parham, E. N., Mohamed, O., Zine, A., Louis, L., A new Modeling Approach for Improved Ground Temperature Profile Determination, *Renewable Energy*, **85**, (2016), 436-444.

Rybach, L., Bayer, P., Rivera, J.A., Blum, P.: Influence Factors in the Depth Domain of Borehole Heat Exchangers – Global Warming and Urban Heating, *Proceedings,* European Geothermal Congress, Strasbourg, France, (2016), 2–5.

Soldo, V., Borovic, S., Leposa, L., Boban, L.: Comparison of Different Methods for Ground Thermal Properties Determination in a Clastic Sedimentary Environment, *Geothermics*, **61**, (2016), 1–11.

Vieira, A., Alberdi-Pagola, M., Christodoulides, P., Javed, S., Loveridge, F., Nguyen, F. Cecinato, F., Maranha, J., Florides, G., Prodan, I.,Van Lysebetten, G., Ramalho, E., Salciarini, D., Georgiev, A., Rosin-Paumier, S., Popov, R., Lenart, S., Poulsen, S.E., Radioti, G.: Characterisation of Ground Thermal and Thermo-mechanical Behaviour for Shallow Geothermal Energy Applications, *Energies*, **10**, (2017), 2044-2095.