

Peer-reviewed Conference Contribution

Finding common ground: identifying shallow geothermal potential for the city of Cambridge, UK

Nikolas Makasis^{1,*}, Monika Johanna Kreitmair¹, Rebecca Ward², and Ruchi Choudhary³¹ University of Cambridge, UK² The Alan Turing Institute, UK³ University of Cambridge, The Alan Turing Institute, UK* Corresponding author: nm735@cam.ac.uk

Urban expansion and extensive anthropogenic utilisation of the subsurface can lead to thermal changes in the ground, as structures such as basements, sewage systems, and tunnels reject or absorb heat to/from the ground. This phenomenon, known as Sub-surface Urban Heat Island, has been widely documented and studied in recent years [1,7]. Investigations have shown that significant soil and groundwater temperature anomalies can be caused, with local hotspots and temperature differences up to 20 °C [6]. These ground temperature anomalies can affect, for example, ground- and drinking water quality, ecosystem biodiversity, and geothermal energy utilisation, with the latter being the focus of this work.

The city of Cambridge, UK, shown in Figure 1-left, is adopted as a case study site, and a novel scalable large-scale subsurface modelling methodology [4] is used to obtain an understanding of the ground thermal state, accounting for natural and anthropogenic influences. The geology for the region is obtained by importing historical borehole records for the wider Cambridge area into the British Geological Survey (BGS) Groundhog® Desktop Geoscientific Information System and constraining the lithologies using BGS generated superficial deposit and bedrock geology maps, producing a 3D lithological profile. Water table readings from borehole wells supplied by the Environment Agency are used to create hydraulic head and water table maps for the region. Hydraulic and thermal properties for the materials in the domain were obtained from available literature* [2]. The main anthropogenic features are basements, assumed to be heated at 18 °C, and sewers, assumed linked with building density and at 15 °C. Following the methodology, the domain is separated into 1096 blocks, each 200m by 200 m laterally and 100 m in depth, clustered into 10 *archetypes*. Each archetype comprises a set of features resulting in a ground thermal state common across all blocks within an archetype [4].

Having thus obtained the spatially varying ground temperature, the performance of typical shallow geothermal systems throughout the domain is assessed, initially investigating the theoretical geothermal potential. Figure 1-middle, shows the amount of heating power a typical 100 m double U-loop borehole can supply, providing a constant ground load from 1st of October to 31st May over a 50-year operation period. The power is computed using the Finite Line Source model and g-functions [5], setting a lower limit of -2 °C for the ground loop circulating fluid temperature. The results show that hydro-geological features and anthropogenic thermal influences in the region can result in spatial variation of geothermal potential of up to 0.3 kW, or about 1746 kWh per year. A sensitivity analysis indicates that no single feature dominates in the contribution to the magnitude of geothermal potential, suggesting that both natural and anthropogenic sources are important influences on how much energy the ground can provide.

Extending the analysis by incorporating estimated residential heating demand data [3], Figure 1-right shows the percentage of residential demand that can be fulfilled using geothermal boreholes, assuming these are drilled in suitable parking and non-major road areas for each block, at a minimum spacing of 6 m to avoid thermal interference. The calculations use g-functions to compute how much of the estimated heating demand a single borehole can supply, using half-hour demand distributions for 50 years (repeated annually), and multiplied by the estimated number of boreholes in each block to determine the total geothermal energy that can be supplied. For a large portion of the modelled domain, the entirety of the residential heat demand is expected to be feasibly fulfilled

using shallow geothermal energy. Certain areas, mostly agricultural and green spaces with no to low demand, contain no suitable borehole drilling locations, i.e., parking or road areas (a conservative assumption adopted in this study), resulting in no energy being supplied geothermally (light gray). Average demand supplied within the remaining region is 91%, with a standard deviation of 21%.

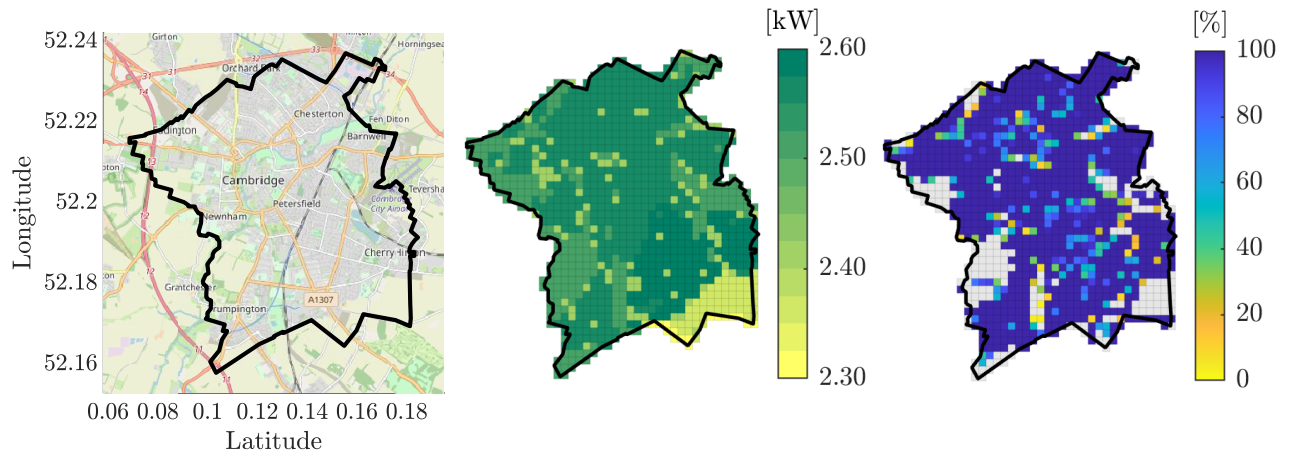


Figure 1: The case-study area (left panel), the theoretical geothermal potential per borehole (middle panel), and the estimated amount of residential heating demand that can be fulfilled using ground-source heat pumps (right panel).

As the world urgently seeks to transition to a more sustainable energy infrastructure, utilising different clean energy technologies in a more extensive and organised way becomes increasingly necessary. Geothermal energy technologies can be particularly suited for coordinated large-scale utilisation, due to the significant capital costs and the continuous nature of the ground, acting as a shared resource for large communities. This work briefly demonstrates the capacity that geothermal technologies have to fulfil a significant portion of the residential heat demand at large scales, using the city of Cambridge as an example, and that organisations or governments can take advantage of the potential that exists in finding common ground.

Data Availability Statement

*To undertake the subsurface modelling, many resources were used to identify the hydro-thermal properties of all materials, the details of anthropogenic infrastructure, land cover, etc. A complete list will be made available in the near future in an upcoming journal publication by the authors.

Contributor statement

N. Makasis and M.J. Kreitmair: Conceptualisation, Formal Analysis, Investigation, Methodology, Visualisation, Writing. R. Ward: Data curation, Writing – Review and Editing. R. Choudhary: Conceptualisation, Supervision, Funding Acquisition, Writing – Review and Editing.

Acknowledgments

This work was supported by CMMI-EPSCRC: Modeling and Monitoring of Urban Underground Climate Change (EP/T019425/1), by the Centre for Smart Infrastructure & Construction (EP/N021614/1) and the Centre for Digital Build Britain at University of Cambridge, as well as AI for Science and Government (ASG), UKRI's Strategic Priorities Fund awarded to the Alan Turing Institute, UK (EP/T001569/1). The authors would like to thank the British Geological Survey, the Environment Agency, and the University of Cambridge Estates for supplying information and relevant data to enable accurate modelling of the geothermal systems in this work.

References

- [1] Bidarmaghz, A., Choudhary, R., Soga, K., Kessler, H., Terrington, R. L., & Thorpe, S. (2019). Influence of geology and hydrogeology on heat rejection from residential basements in urban areas. *Tunnelling and Underground Space Technology*, 92(July), 103068.
- [2] British Geological Survey. (2022). *GeoReports: Temperature and Thermal Properties (Detailed) This* (Issue October 2020). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://shop.bgs.ac.uk/resources/shop/doc/example/product/modules/C011.pdf
- [3] Canet, A., Qadrdan, M., Jenkins, N., & Wu, J. (2022). Spatial and temporal data to study residential heat decarbonisation pathways in England and Wales. *Scientific Data*, 9(1), 1–17. <https://doi.org/10.1038/s41597-022-01356-9>
- [4] Kreitmair, M. J., Makasis, N., Bidarmaghz, A., Menberg, K., Choudhary, R., & Soga, K. (2023). Finding common ground: a methodology for city-scale subsurface thermal modelling. *Urban Climate*, 49:101513. <https://doi.org/10.1016/j.uclim.2023.101513>.
- [5] Lamarche, L., & Beauchamp, B. (2007). A new contribution to the finite line-source model for geothermal boreholes. *Energy and Buildings*, 39(2), 188–198. <https://doi.org/10.1016/j.enbuild.2006.06.003>
- [6] Menberg, K., Bayer, P., Zosseder, K., Rumohr, S., & Blum, P. (2013). Subsurface urban heat islands in German cities. *Science of the Total Environment*, 442, 123–133. <https://doi.org/10.1016/j.scitotenv.2012.10.043>

-
- [7] Previati, A., Epting, J., & Crosta, G. B. (2022). The subsurface urban heat island in Milan (Italy) - A modeling approach covering present and future thermal effects on groundwater regimes. *Science of the Total Environment*, 810, 152119. <https://doi.org/10.1016/j.scitotenv.2021.152119>