Chair of Renewable and Sustainable Energy Systems
TUM School of Engineering and Design
Technical University of Munich

Master's Thesis

PDE-based optimization of vertical closed-loop geothermal systems using superposition methods

Background

Domestic heating and cooling represent a significant part of the overall energy consumption. In order to reduce CO2 emissions, an increased share of heating and cooling has to be covered with renewable energy. One of the options being imposed are vertical ground source heat pumps (GSHPs) or closed-loop shallow geothermal systems. These systems can operate in single mode, for heating or cooling, or as seasonal storage, i.e. borehole thermal energy storage (BTES) (see Fig.1). In both cases, the efficiency of the system depends on its operation and the design of the borehole heat exchanger (BHE) field. Therefore, to maximize the efficiency of the system, the spatial design of the BHE field and the operation of the system should be optimized. The underlying physics in the resulting optimization problem is subsurface heat transport, which can be described by partial differential equations (PDEs) and simulated with numerical methods, such as the finite element method (FEM). In several research studies [1-3], numerical models have already been used for the optimization of BHE fields. However, these methods have some limitations, e.g. they are computationally intensive or do not sufficiently explore the design space.

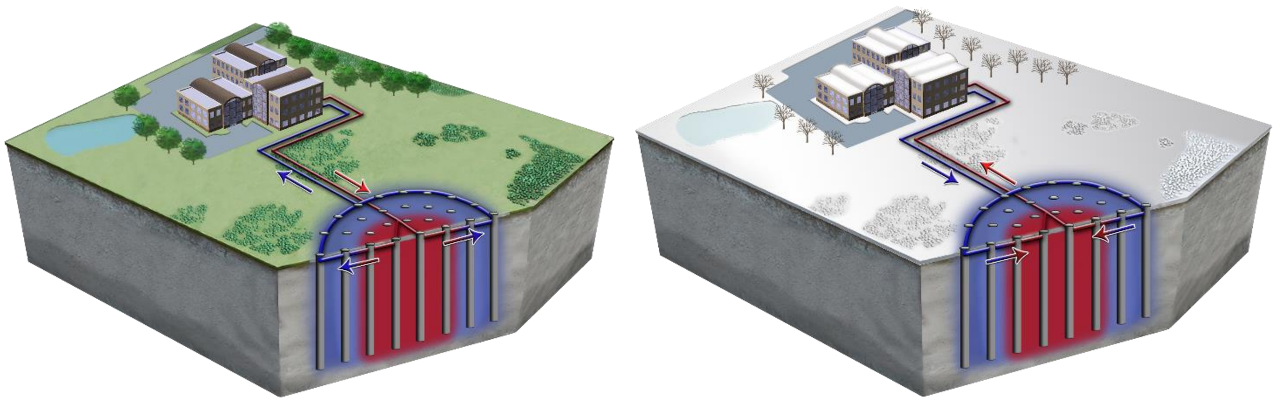

Fig.1. BTES operation in summer (left) and winter (right) [7].

Goals

The goal of this work is to develop and implement a new optimization approach for BHE fields based on numerical models of subsurface heat transport and superposition principles. The underlying PDEs will be solved numerically using some of the existing open-source tools, such as OpenGeoSys [4], or writing customized solvers in tools such as Firedrake [5] or FEniCS [6]. If the work is successful, there is the possibility of writing a publication, i.e. a paper-based final thesis report. The following tasks are included:

- Familiarizing with the functionality of GSHP/BTES and heat transport in subsurface (numerical models)
- Literature review on the existing PDE-based optimization approaches of BHE fields
- Implementation and testing of the numerical simulation of heat transport in subsurface
- Developing and implementing the new optimization approach (superposition)

– Testing the new optimization approach on a case study

Requirements

- Interest in mathematical modeling and numerical optimization
- Programming skills: Python (other languages might be considered)
- Experience in FEM and numerical simulations (PDEs)
- Experience in numerical optimization (is a plus)
- Knowledge of GSHP/BTES or subsurface heat transport (is a plus)
- CV and current grade report (above average GPA)

What we offer

- Exposure to state of the art research topics
- An international and multidisciplinary working environment
- Opportunity to publish in international journals
- Possibility of paper-based thesis

Contact

Smajil Halilovic, M.Sc.
Lichtenbergstr. 4a, 85748 Garching b. München, Raum 2016
E-Mail smajil.halilovic@tum.de

Literature

[1] Li, C., Mao, J., Zhang, H., Li, Y., Xing, Z., & Zhu, G. (2017). Effects of load optimization and geometric arrangement on the thermal performance of borehole heat exchanger fields. *Sustainable cities and society*, *35*, 25-35.

[2] Fujii, H., Itoi, R., Fujii, J., & Uchida, Y. (2005). Optimizing the design of large-scale ground-coupled heat pump systems using groundwater and heat transport modeling. *Geothermics*, *34*(3), 347-364.

[3] Schulte, D. O., Rühaak, W., Welsch, B., & Sass, I. (2016). BASIMO–borehole heat exchanger array simulation and optimization tool. *Energy Procedia*, *97*, 210-217.

[4] Kolditz, O., Bauer, S., Bilke, L., Böttcher, N., Delfs, J. O., Fischer, T., ... & Zehner, B. (2012). OpenGeoSys: an open-source initiative for numerical simulation of thermo-hydro-mechanical/chemical (THM/C) processes in porous media. *Environmental Earth Sciences*, *67*(2), 589-599.

[5] Rathgeber, F., Ham, D. A., Mitchell, L., Lange, M., Luporini, F., McRae, A. T., ... & Kelly, P. H. (2016). Firedrake: automating the finite element method by composing abstractions. *ACM Transactions on Mathematical Software (TOMS)*, *43*(3), 1-27.

[6] Logg, A., Mardal, K. A., & Wells, G. (Eds.). (2012). *Automated solution of differential equations by the finite element method: The FEniCS book* (Vol. 84). Springer Science & Business Media.

[7] https://underground-energy.com/our-technology/btes/