Peer-reviewed Conference Contribution

# Long-term numerical investigation of Northern Gateway Heat Network

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Considering climate change and countries' measures towards greenhouse gas emissions (e.g., European energy and climate targets of achieving net-zero greenhouse gas emissions by 2050) [1], it is crucial to implement renewable energy sources and district-level heating and cooling systems. Many district-level heating and cooling systems have been established in Europe. However, just a limited number of them are renewable energy source based. One of the most efficient ways of heating and cooling supply is to use geothermal energy as it is renewable, sustainable, and environmentally friendly. Groundwater heat pumps (GWHPs) utilise low-temperature sources to provide heating and cooling to buildings, which makes them a highly efficient, environmentally friendly, and low-carbon technology suitable for both small and large-scale applications.

Northern Gateway Heat Network project, which is a groundwater-based heat pump system aiming to provide heating and domestic hot water to around 300 dwellings, offices, and healthcare buildings, is considered as a case study in this research. It was designed to supply 75% of the total heating demand with an 800-kW output heat pump benefitting from the groundwater extracted from the depths between 135m and 200m at around 12.5°C. BH1, BH2 and BH3 are the injection wells, whilst BH4 and BH5 are the abstraction wells (see Figure 1) [2, 3].

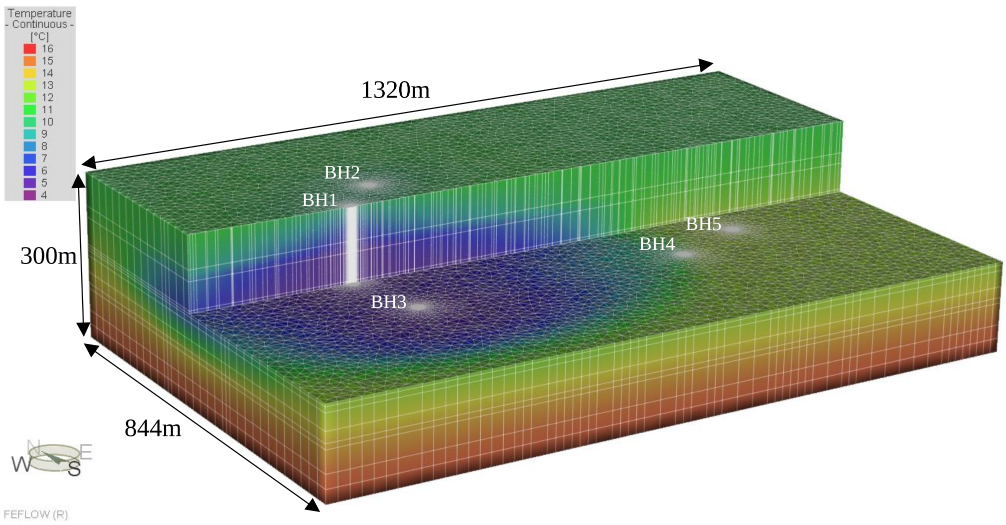


**Figure 1: Simulation result of thermal evolution throughout the soil in continuous space heating at the end of 100 years.**

A 3D finite element modelling was carried out in FEFLOW [4] to investigate the thermally affected zone and the possibility of thermal feedback resulting from water injection temperature affecting abstraction temperature. The 3D modelling aims at investigating the impact of the system in the long term (100 years) and how to improve the system's efficiency and sustainability by considering four different scenarios: (1) continuous space heating (12 months), (2) space heating (10 months) and recovery (2


DOI: https://doi.org/10.59490/seg23.2023.539

months), (3) space heating (10 months) and cooling (2 months) and (4) aquifer thermal energy storage (swap injection and abstraction wells in 2 months cooling period) (ATES).

The results suggest that thermal feedback occurs after almost 60 years for the actual case (continuous space heating), which decreases the system's efficiency. Figure 1 illustrates the thermal plume development after 100 years of space heating operation (cold water injection at 5°C). Although the spacing between the production and injection wells is around 530 m, the abstraction temperature was affected by the cold-water injection, and it decreased by almost 10% at the end of 100 years of simulation at BH4.

The space heating and recovery, and space heating and cooling also witnessed a decrease in water extraction temperature at BH4. The injection temperature was set to 35°C for the space cooling period. Adding two months of recovery or two months of space cooling delayed the thermal feedback time by 17% and 8%. The results show that the system can supply two months of space cooling without a need for an additional supply from the heat pump. Furthermore, when two months of space cooling is added, the thermal energy gain increases by 20% compared to space heating-only operation. The ATES operation also increased the thermal energy gain by 173% thanks to the stored energy in the ground and higher volume of water extraction during the space cooling period. Table 1 shows the thermal energy gain from each well in each scenario, calculated considering the thermal feedback impact.

**Table 1: Heating, cooling and recovery periods applied, and simulation results obtained for 100 years of thermal energy gain from each well under different operation types.**

<table>
<tr><th>Operation type</th><th>Heating period (months in a year)</th><th>Cooling Period (months in a year)</th><th>Recovery period (months in a year)</th><th>BH1 (GWh)</th><th>BH2 (GWh)</th><th>BH3 (GWh)</th><th>BH4 (GWh)</th><th>BH5 (GWh)</th><th>Total (GWh)</th></tr>
<tr><td>Continuous space heating</td><td>12</td><td rowspan="2">0</td><td>0</td><td colspan="3" rowspan="3">NA</td><td>182</td><td>190</td><td>372</td></tr>
<tr><td>Space heating and recovery</td><td rowspan="3">10</td><td>2</td><td>168</td><td>172</td><td>340</td></tr>
<tr><td>Space heating and cooling</td><td rowspan="2">2</td><td rowspan="2">0</td><td>222</td><td>226</td><td>448</td></tr>
<tr><td>ATES</td><td colspan="3">167</td><td>250</td><td>265</td><td>1016</td></tr>
</table>

This paper highlights the long-term numerical investigation of the Northern Gateway Heat Network, considering different scenarios, including continuous space heating, space heating and recovery, space heating and cooling, and ATES. It also discusses the thermal impact and thermal plume development in different scenarios and how the thermal plume affected the system efficiency due to thermal feedback. The results indicate that the GWHP system can provide direct space cooling, thereby significantly increasing the sustainability and efficiency of the system. Moreover, the application of the ATES system further improves the system's sustainability and efficiency.

**Contributor statement**

All authors conceived of the presented idea. Taha Sezer developed the theory and numerical model with the help of the supervisory team, Rao Martand Singh, Liang Cui, and Abubakar Kawuwa Sani. The authors reviewed and approved the final version of the paper.

**Acknowledgements**

The authors thank Michael Woods for sharing technical data and David Boon for contributing from a geological perspective of the site.

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