Integration of borehole thermal energy storage in a heating and cooling production system: a case study

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Abstract
Research illustrated that the hydronic optimisation of complex heating or cooling systems has a great potential for energy savings. Next, geothermal energy storage systems are interesting technologies for maximising energy recovery and use of renewable energy, as they can be used both for heating and cooling. However, due to their complexity, their full potential is often not achieved because of improper hydronic design and control.

To illustrate the importance of hydronics and the optimisation potential in these systems, a case study is elaborated with the Hysopt software, which is able to analyse the hydronics of such complex systems including combined demand of heating and cooling. It is shown that the primary energy ratio of the overall heating system can be increased up to 28pp, the CO₂ reduction up to 38% and the energy cost savings up to 19%, and that the thermal energy balance of the subsurface can be improved up to 34pp.

Key Innovations
- Hydronic and control related design optimisation of a BTES integrated system
- Design options to maintain a thermally balanced subsurface

Research Implications
To accurately simulate the behaviour of a BTES integrated heating and cooling system, the correct hydronic design and control settings are crucial.

Introduction
The hydronic optimisation of hybrid heat production systems showed great potential for energy savings (Van Riet et al., 2019). Including geothermal energy storage systems, like a BTES system, in a hybrid heating and cooling production system can increase the energy efficiency by temporarily storing excess heat for later use. However, by integrating geothermal storage, the complexity increases because of the desired thermal balance of the subsurface, the different operating conditions, and the control strategy (Zhai et al., 2011). The lack of attention to proper hydronic integration and technical implementation of the control is often the downfall of such complex systems, leading to failure or unfavourable operating conditions (Gao et al., 2017).

In this paper, the functionality of integrating and optimising BTES heating and cooling systems in the proprietary software Hysopt is illustrated with an extra focus on the combined demand of both heating and cooling.

Figure 1: The reference schematic and design conditions combined with the adaptations of all the different variants. The dashed squares visualise the place where the adaptations occur and the solid squares visualise the adaptations.

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Case description and performance criteria
The selected case study has two heating circuits (domestic hot water (DHW) included) and two cooling circuits, each with different temperature levels and thermal powers. A gas boiler and a ground coupled heat pump (GCHP) are used to provide heating. A chiller and the combination of the GCHP with BTES are used to provide the desired cooling. The reference schematic and design conditions are visualised in Figure 1. In the figure, the adaptations of the five simulated variants to the reference are also visualised.

To discuss the results of the annual simulations, the data is summarised into the following Key Performance Indicators (KPI’s), listed in the heading of table 1. The share of the GCHP (‘HP’) and BTES (‘BS’) in the delivered heating (‘H%’) and cooling (‘C%’) is illustrative for the % of renewable energy. The primary energy ratio (PER) considers the overall efficiency based on an electrical conversion efficiency of 40%, whereas the CO2 emission reduction to the reference scenario (‘CO2 %’) is calculated with the SAP 10 emission factors (0.210 kg/kWh gas and 0.233 kg/kWh electricity). Furthermore, the calculated energy cost savings (€%/€) assume an electricity price of 0.10 €/kWh and a gas price of 0.05 €/kWh. To quantify the thermal balance of the subsurface, the energy balance ratio is calculated as follows (Gao et al., 2017):

\[ \Psi = \frac{\text{extracted}_\text{cooling} - \text{extracted}_\text{heating}}{\text{extracted}_\text{cooling} + \text{extracted}_\text{heating}} \]  

(1)

Concepts and evaluation
The simulation results of the reference and the five variants are summarised in Table 1.

<table>
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<th>% HP H</th>
<th>% HP C</th>
<th>% BS C</th>
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<th>CO2 %</th>
<th>€ %</th>
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</table>

(‘CO2%’) is calculated with the SAP 10 emission factors (0.210 kg/kWh gas and 0.233 kg/kWh electricity).

The potential is illustrated by a representative case study, systems, like the integration of BTES in a hybrid system. This paper proposes a simulation-based methodology to optimise complex hydronic design heating and cooling systems, like the integration of BTES in a hybrid system. The potential is illustrated by a representative case study, showing an increased energy performance up to 28pp, a CO2 reduction up to 38%, energy cost savings up to 19% and an improved thermal balance of the subsurface up to 34pp.

References

