

IT Tool For Decision Support In Sustainable Innovation Planning As Part of The Interreg Danube GeoHeCo Project

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Abstract: To support the decarbonisation of heating and cooling in the Danube Region, the Interreg Danube GeoHeCo project is developing a decision support tool for the planning of shallow-geothermal hybrid heating and cooling systems. The tool was primarily developed by the University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering (UNIZG-RF), with contributions from other project partners. This short paper presents an overview of the tool's core structure and functionality, which is aimed at an expert audience of planners and engineers. The tool links models for building loads, ground source heat pump performance, borehole heat exchanger (BHE) design and long-term ground temperature development into a single workflow that can be used directly in a web browser or locally via Python script. After entering site, building and technology data, users are able to generate long-term simulations of BHE performance, obtain information regarding the load sharing between heat pump and peak-load boiler, seasonal performance factors and multi-decadal ground temperature trajectories. In this way, the tool improves planning security, helps to verify the technical robustness of hybrid GSHP concepts and supports a wider deployment of shallow-geothermal solutions in the Danube Region.

Keywords: *shallow geothermal energy, hybrid heating systems, ground source heat pumps, decision support tool, web-based planning, Danube Region*

1. INTRODUCTION

The transformation of the European heating and cooling sector away from fossil fuels is one of the key challenges for energy and climate policy. Space heating accounts for almost 50% of final energy consumption in the EU – over 70% of which is covered by fossil fuels. Near-surface geothermal energy (often abbreviated as SGE) offers a widely available and efficient renewable resource that has been underutilized in many places to date (Ramos-Escudero et al., 2021).

SGE systems in the form of ground source heat pumps (GSHP) utilise heat stored near the surface and achieve seasonal performance factors of 3–5 with electric heat pumps. This makes them highly efficient solutions compared to combustion boilers, especially in cold climates. However, the environmental advantages of GSHP are often offset by high upfront investments (in particular drilling costs) and limited coverage of peak loads.

One of the promising approaches to overcoming these barriers is the use of hybrid heating systems consisting of GSHP and a peak-load boiler. In such hybrid solutions, the heat pump covers the base load, while an auxiliary boiler (gas or electric) supplies the comparatively few peak demand hours on very cold days at lower cost. Hybrid systems can be adapted more flexibly to existing infrastructure and permit smaller borehole heat exchanger (BHE) fields, which reduces investment costs (Beccali et al., 2022). At the same time, the majority of the energy supplied remains renewable.

Studies show that such hybrid heat pump systems – depending on control strategies and building standards – can significantly reduce primary energy demand and improve system performance compared to purely fossil fuel systems (Tihana et al., 2023).

Against this backdrop, the Interreg Danube Region project GeoHeCo aims to increase the deployment of shallow geothermal energy in the Danube Region (Interreg Danube Programme, n.d.). One of the central outputs of this transnational project is the development of an IT-based decision support tool, developed by Tomislav Kurevija, Marija Macenić, Luka Perković and others at the University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering (UNIZG-RF) along with the help of other project partners. It aims to assist planners and decision makers in the techno-economic planning of sustainable, hybrid geothermal heating and cooling systems. This short paper acts solely as a report of progress and presents the core structure and functionality of the web-based tool and discusses its contribution to sustainable innovation in regional heat planning, while omitting some details for purposes of brevity.

2. METHODOLOGY

2.1. Objectives and Approach

The tool is designed to provide an assessment in early planning phases of how a combination of shallow geothermal energy (SGE) and an auxiliary heat source can be sized and operated for a specific project. It is a web-based application that can be used via a browser without any specialised simulation software; however, the same calculation engine can also be run locally as a set of Python scripts. The tool is still in development, although internal beta tests have already begun, and the tool should be available for general public use after the project ends.

The user guidance is stepwise: first, all required project input data are collected, then the tool automatically runs the calculation models and provides various results, such as indicators and diagrams (in form of .png files). It is important to note that the tool is mainly intended for an expert audience, such as geothermal planners, HVAC engineers, and energy consultants. An understanding of the underlying physical principles and familiarity with the required input parameters is a prerequisite for its correct application.

2.2. Inputs

Project-specific parameters are entered via a structured user interface if used through the web version or manually via editing certain Python script lines if used through the local version. The acquisition of these parameters in the first place requires technical expertise and access to specific project documentation.

BHE type and pipe configuration: The tool supports single U-tube (1U), double U-tube (2U), and coaxial (CXA) probes. Users specify pipe nominal diameter and the Standard Dimension Ratio (SDR). The properties of the backfill material (grout) are also of importance. These parameters can usually be obtained from manufacturer technical data sheets.

The screenshot shows a software interface titled "BHE Configuration". It contains several sections:

- Configuration name:** A text input field containing "Conf 2".
- Pipe type:** A dropdown menu labeled "Select type:" with "Double u-tube" selected.
- Pipe configuration:** Four circular diagrams representing different pipe layouts in a borehole:
 - Configuration A: Pipes touching (labeled "Pipes touching").
 - Configuration B: Pipes evenly spaced (labeled "Pipes evenly spaced", highlighted with a green border).
 - Configuration C: Pipes against borehole wall (labeled "Pipes against borehole wall").
 - Custom configuration: Labeled "Custom configuration Please enter the distance value (x) in the form below".
- Pipe details:** Fields for:
 - Nominal Diameter: "DN_40" mm.
 - SDR: "SDR_11".
 - dist between the centers of the borehole and pipe: "256" mm (for custom configuration).

A "Save" button is located at the bottom right of the interface.

Figure 1: BHE parameters and configuration interface.

Primary fluid: The heat carrier fluid is typically a glycol-water mixture. Users specify the glycol-to-water ratio (typically 30% glycol, providing frost protection to approximately -8 to -10 °C) and the reference flow velocity.

Location and building: Climate (temperature data) and heating/cooling load profile of the building to be supplied. Ambient temperature data are typically sourced from standard meteorological databases (e.g., PVGIS), while the building's thermal load characteristics are typically derived from a formal energy certificate (e.g. *Energieausweis*) or a dedicated building energy simulation.

Geothermal system: Planned borehole heat exchanger field and soil properties. The most important soil parameters are the undisturbed ground temperature and the ground's thermal conductivity. Even though these parameters can be estimated from geological maps for preliminary studies, they are best determined via an in-situ Thermal Response Test (TRT) for accurate BHE sizing (Kurevija et al., 2018).

Borehole field configuration

☐ Uniform grid

☐ User defined

NUMBER OF BOREHOLES

DOMAIN WIDTH [M]

DOMAIN LENGTH [M]

SPACING IN X DIRECTION [M]

SPACING IN Y DIRECTION [M]

34

200

100

6

6

BHE Configuration

[1] Conf 2

Mark

Unmark

Clear selection

0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198
6	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
42	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
48	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
54	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
60	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Borehole depth

single value or comma separated list

120

m

Bore diameter

250

mm

Save and continue

Figure 2: BHE field configuration interface.

Technology and costs: Characteristics of the heat pump (capacity, COP curves) and the peak-load boiler are taken from the respective manufacturer's product documentation.

The tool's heat pump model uses a temperature-dependent COP lookup table, where the user provides COP values at several entering fluid temperatures (EFT, usually sourced from the manufacturer's datasheet).

Although the underlying calculation engine also fully computes the Levelized Cost of Heat (LCOH), accounting for discounted CAPEX covering the BHE field, heat pump, and auxiliary source, as well as fixed and variable OPEX with energy price escalation, and uses it as the objective function to identify the optimal combination of borehole depth and bivalent temperature, this result is not yet presented to the user in the current web interface and therefore will not be further described in the scope of this paper.

Additional operational parameters required by the tool include: the minimum heat pump inlet temperature (i.e. the minimum permissible brine temperature, here 0 °C), the maximum heat pump outlet temperature (35 °C), the secondary system efficiency (0.9 for the KUZ case), and the ambient temperature thresholds at which heating (15 °C) and cooling (20 °C) are switched on.

2.3. Calculation Model

Based on the inputs, the tool performs a series of model calculations:

Thermal load profile: Climate and building data are used to generate an hourly load profile for heating and cooling.

Heat pump and auxiliary boiler model: For each time step, the tool calculates the GSHP heat output and the corresponding electric power demand. A simple bivalent control strategy is implemented: the heat pump operates up to its rated capacity, and the auxiliary heat source is activated only during peak load periods at low ambient temperatures.

Ground and BHE model: To ensure long-term functionality of the borehole field, the tool implements a g-function-based ground model. This approach is well-suited for simulating the thermal interferences between multiple boreholes in an array (Zhang et al., 2018). The model checks whether minimum brine temperatures remain within permissible limits over the full 25-year simulation horizon, and whether the ground thermally regenerates in summer through the cooling mode.

After completing the simulations, the tool presents the results in a compact format, including BHE parameters, long-term temperature simulations, heat-balance indicators, and bivalent-operation analysis.

3. RESULTS

As an example of the IT Tool capabilities, the Austrian pilot site in the scope of aforementioned Interreg Danube GeoHeCo project, the Cultural Centre Güssing (KUZ), was selected. The model configuration followed the following design: a refurbished cultural and event complex 3,436.45 m² gross floor area, supplied by 34 vertical borehole heat exchangers (120 m depth), coupled to a 163.8 kW brine-to-water heat pump and complemented by a 210 kW district-heating interface for bivalent operation.

The BHE-parameter plots generated by the tool (Figure 3) confirm that the selected 2U configuration leads to acceptable hydraulic losses and a realistic thermal resistance for the given pipe dimensions and flow conditions.

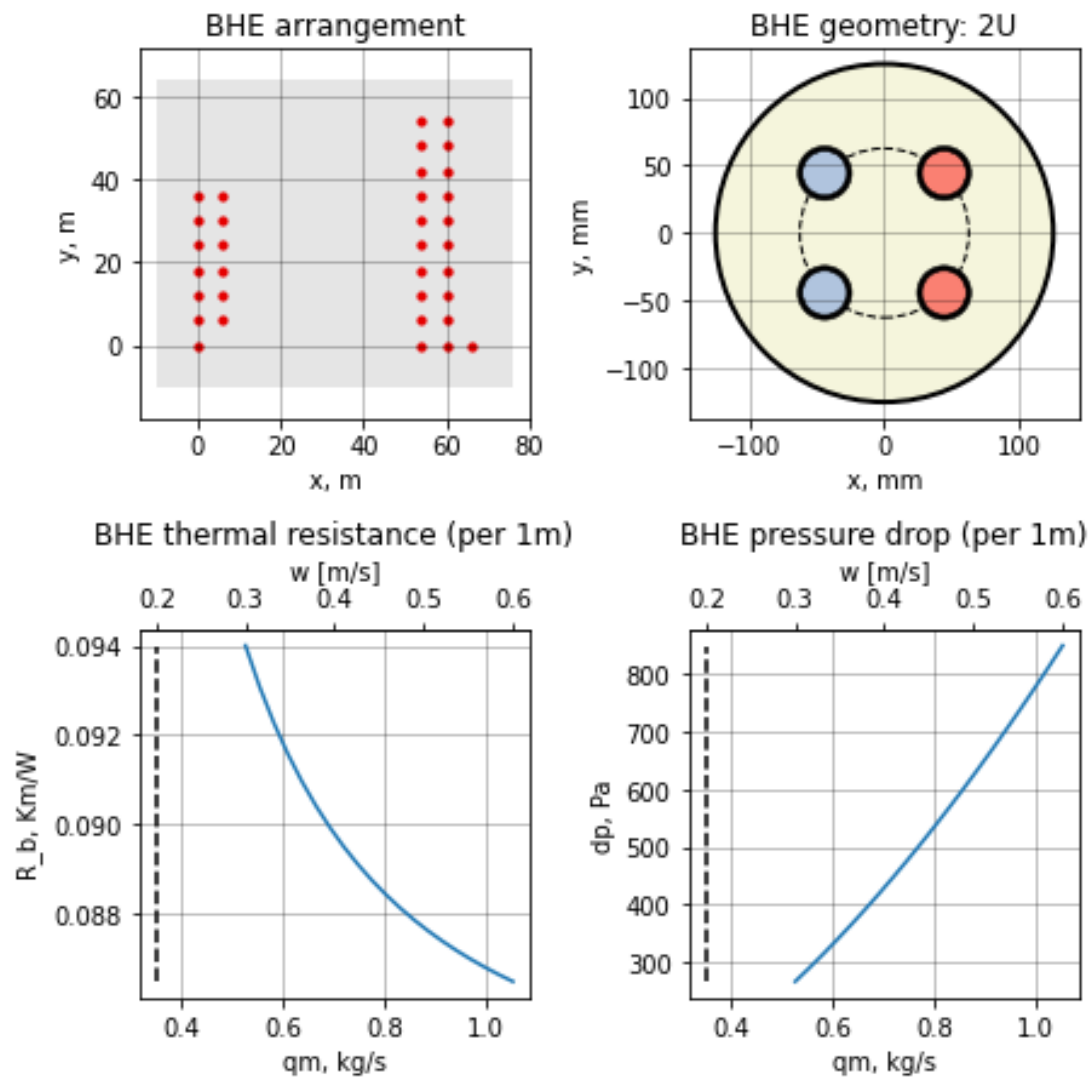


Figure 3: BHE parameters and configuration for the KUZ pilot site.

In the long-term simulation (Figure 4), the brine temperatures show a stable seasonal pattern over the 25-year horizon, indicating that the borehole field is not over-exploited and that the minimum brine temperature constraint is respected throughout.

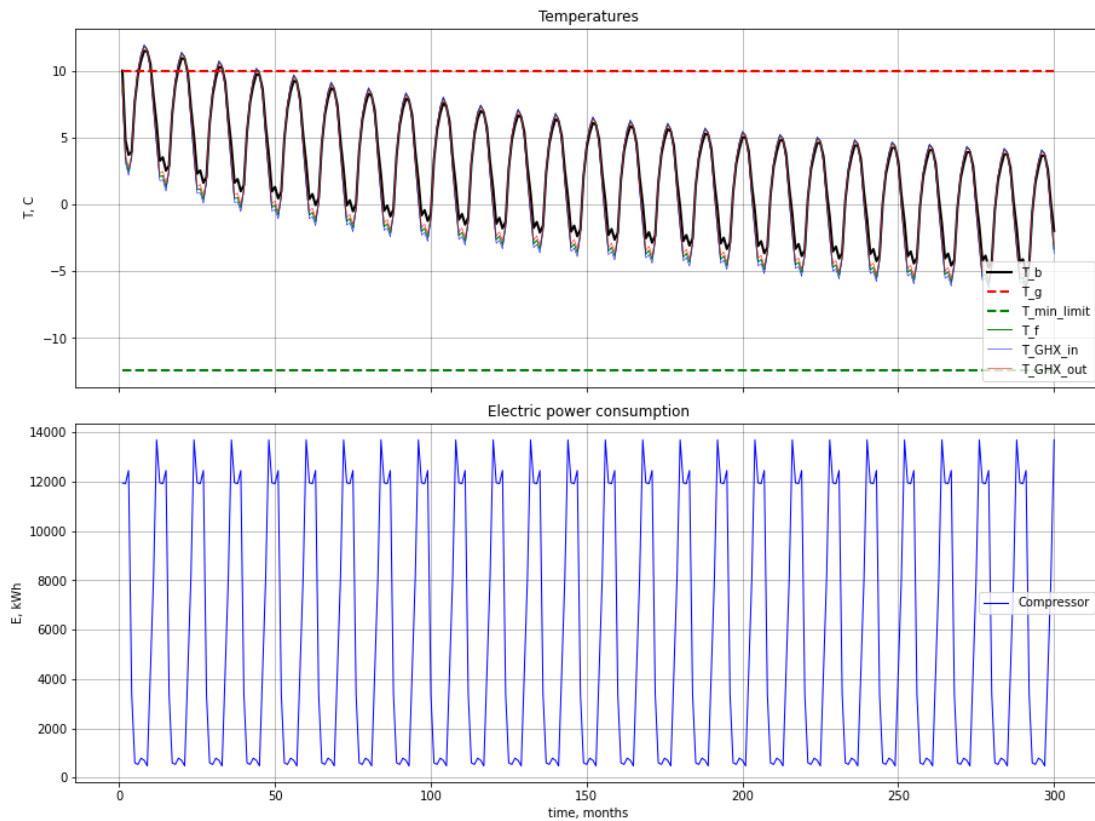


Figure 4: Long-term ground and fluid temperatures and HP compressor power consumption.

The corresponding g-function curves (Figure 5) underline that the field is predominantly conduction-dominated, with negligible groundwater advection contribution at this site.

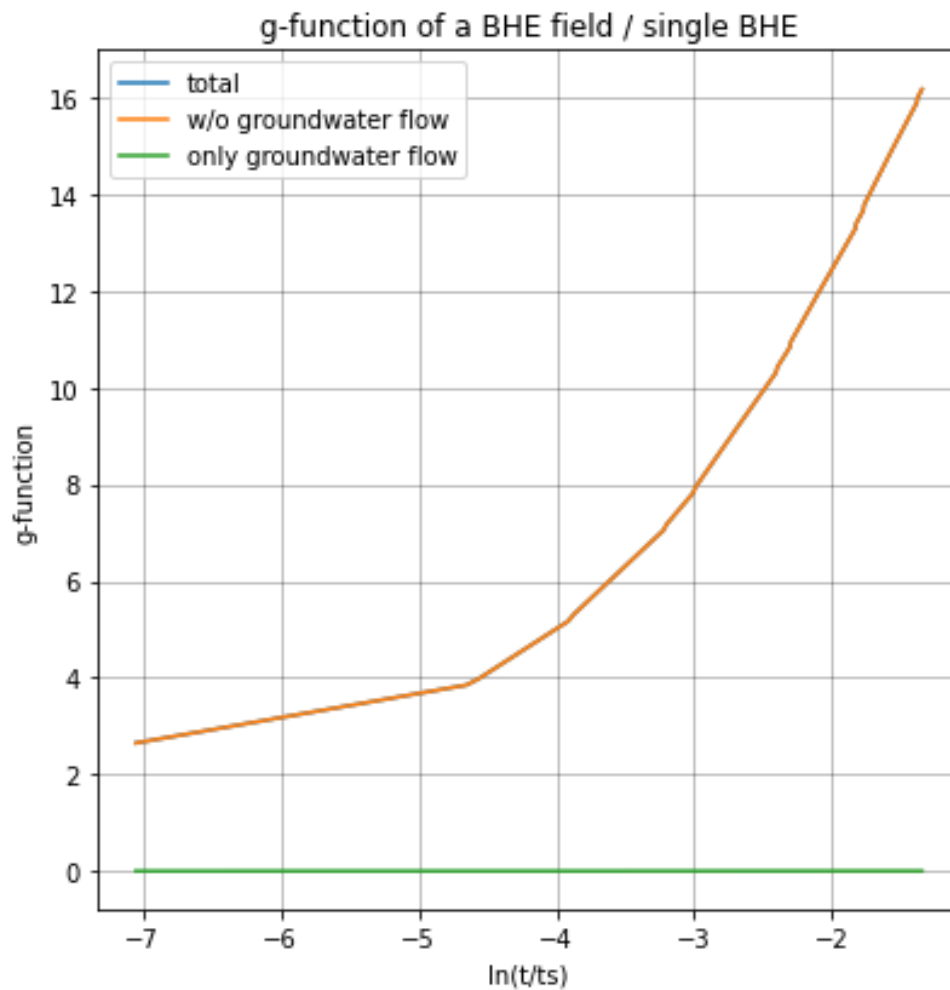


Figure 5: G-function of the BHE field and single BHE for the KUZ pilot site.

The heat-balance time series (Figure 6) illustrate how the heat pump covers the bulk of the building load, with the auxiliary source activated only during the coldest hours. The coefficient of performance (COP) varies seasonally, with higher values during mild periods and lower values during peak heating demand; the simplified flat COP input (4.4) used for this run represents a conservative assumption.

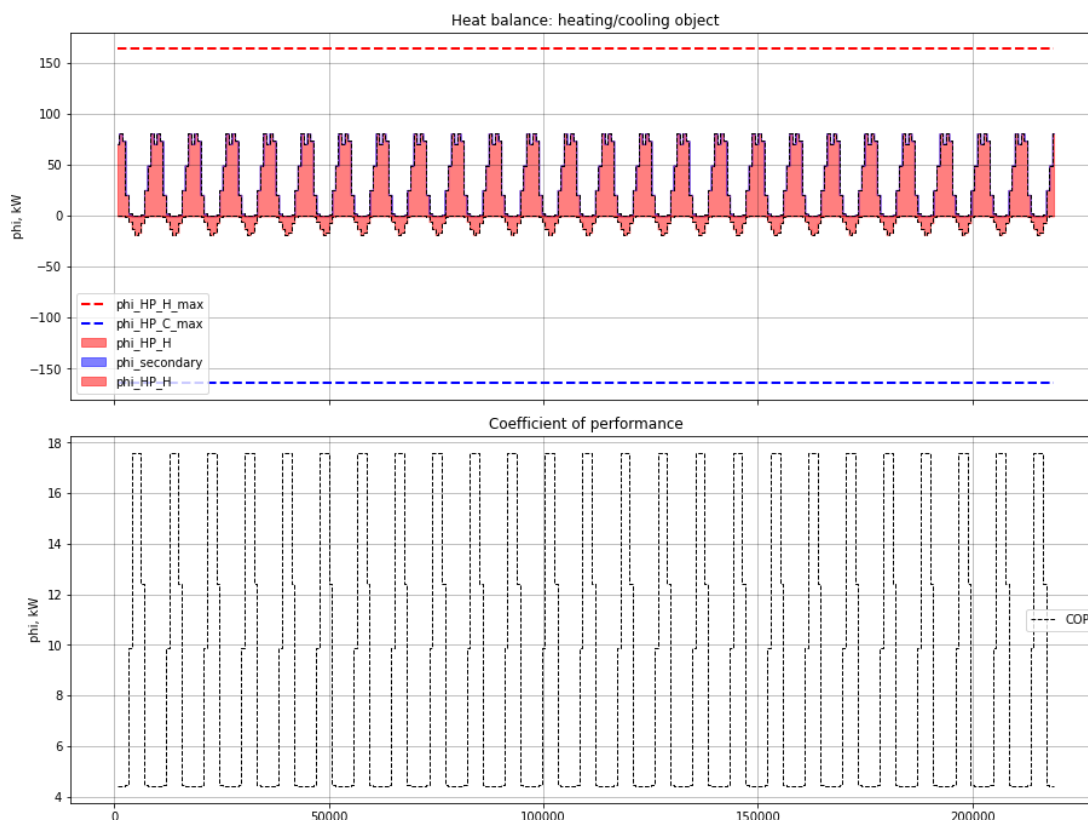


Figure 6: Monthly heat balance and coefficient of performance over the simulation period.

Yearly heat-balance diagrams (Figure 7) confirm the high share of the geothermal system in meeting the annual heating demand, with the electric energy split between compressor and circulation pump.

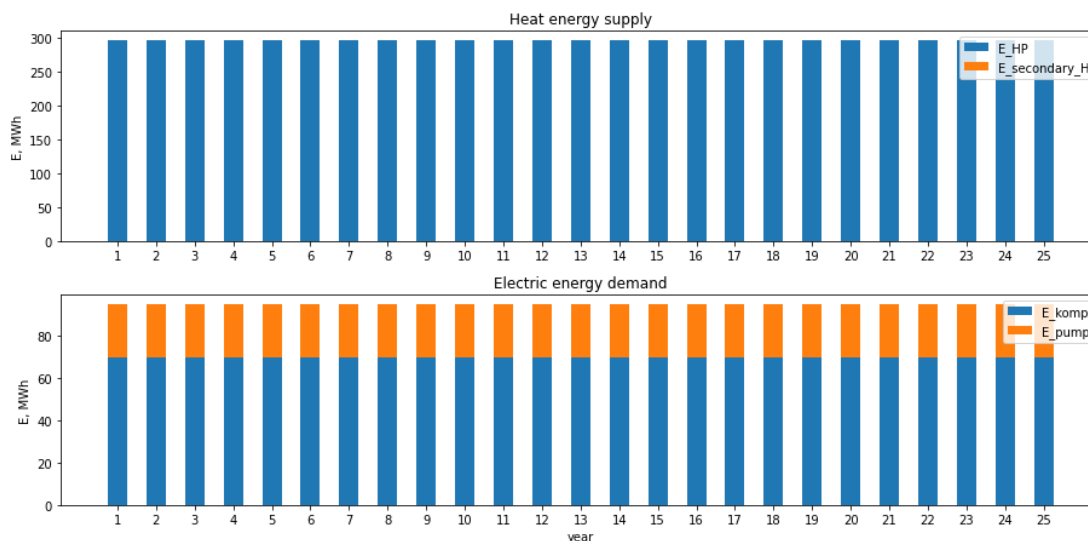


Figure 7: Yearly heat energy supply and electrical energy demand over the 25-year simulation.

The synthetic TRT analysis (Figure 8) provides additional confidence that the BHE field is correctly dimensioned, by fitting the g-function model to the simulated temperature response.

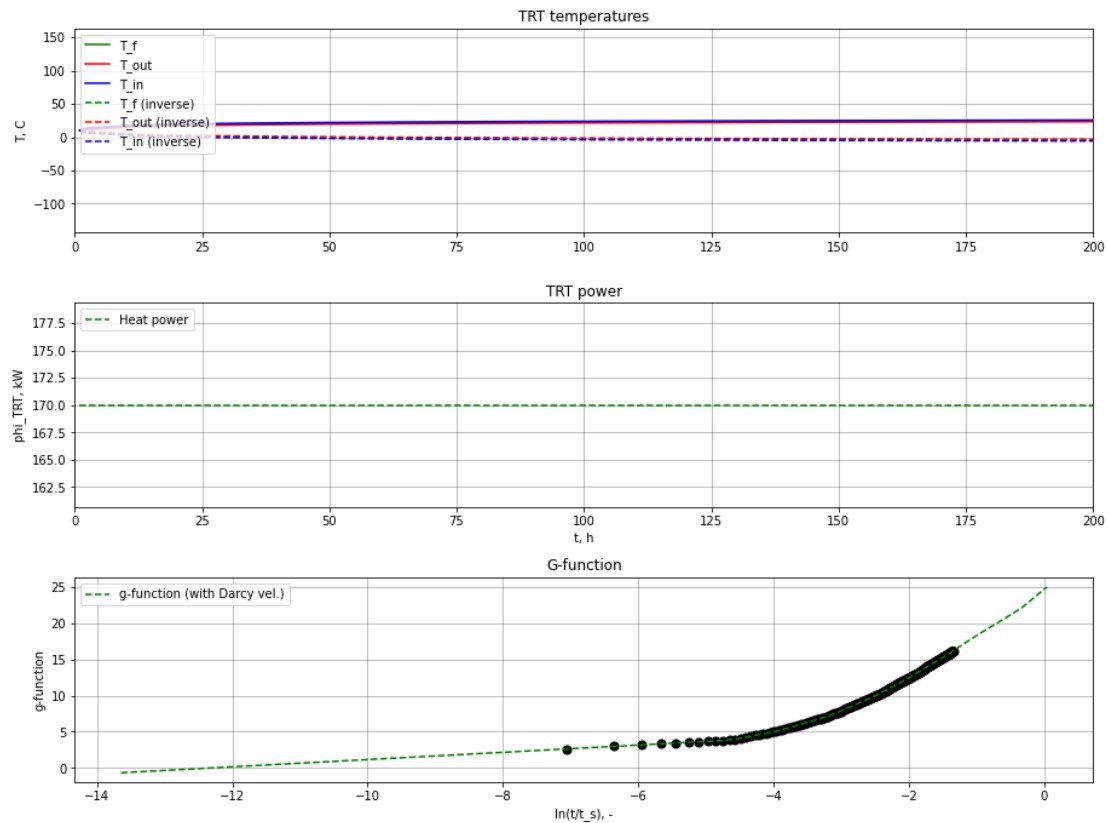


Figure 8: Synthetic Thermal Response Test (TRT) temperatures, power, and g-function.

Finally, the bivalent-operation analysis (Figures 9 and 10) visualises how different bivalence temperatures influence the split between heat-pump and auxiliary energy, enabling the planner to select the optimal bivalence point for a given site.

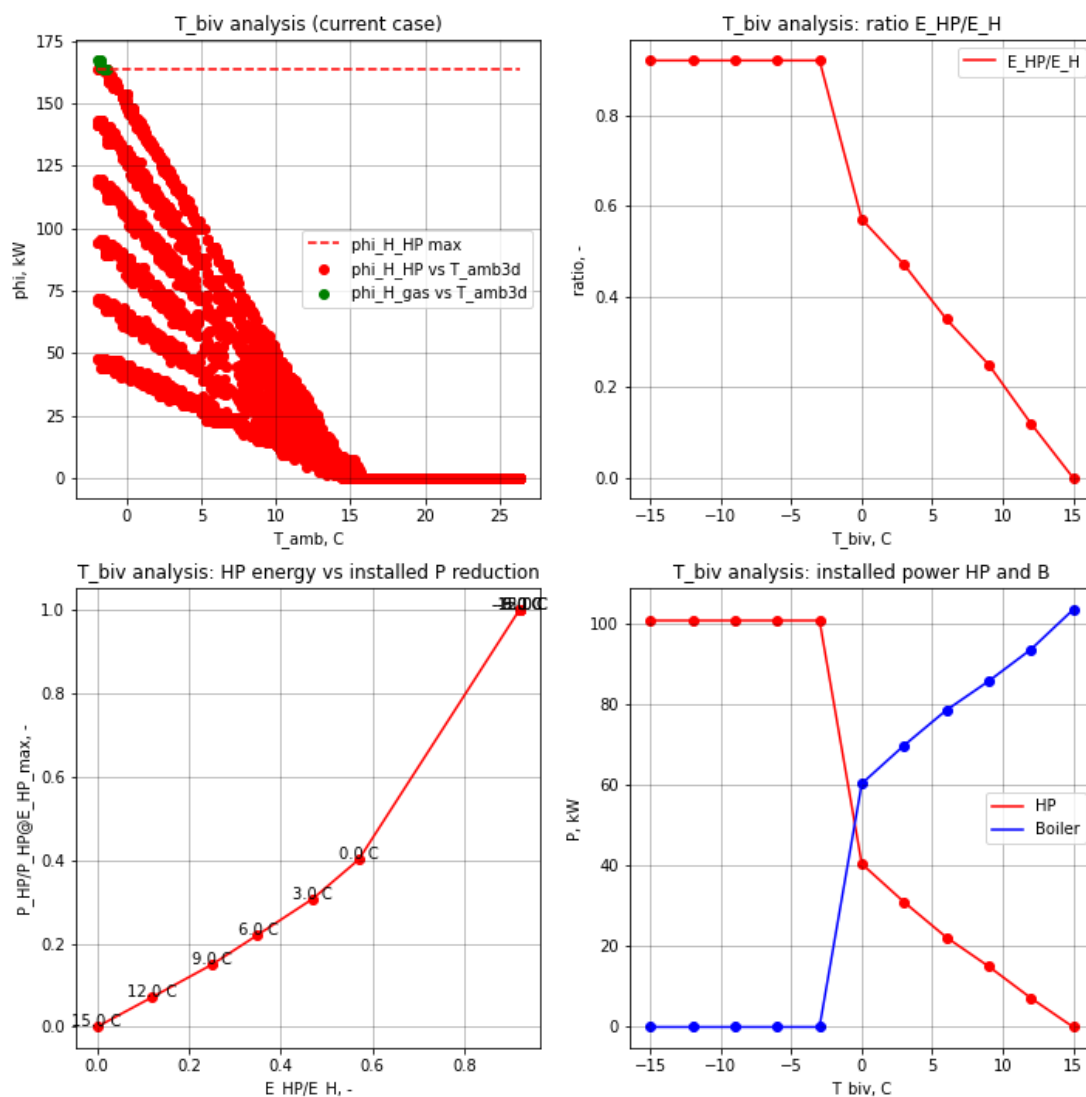


Figure 9: Bivalent temperature analysis: heat pump output, energy ratio, and installed power.

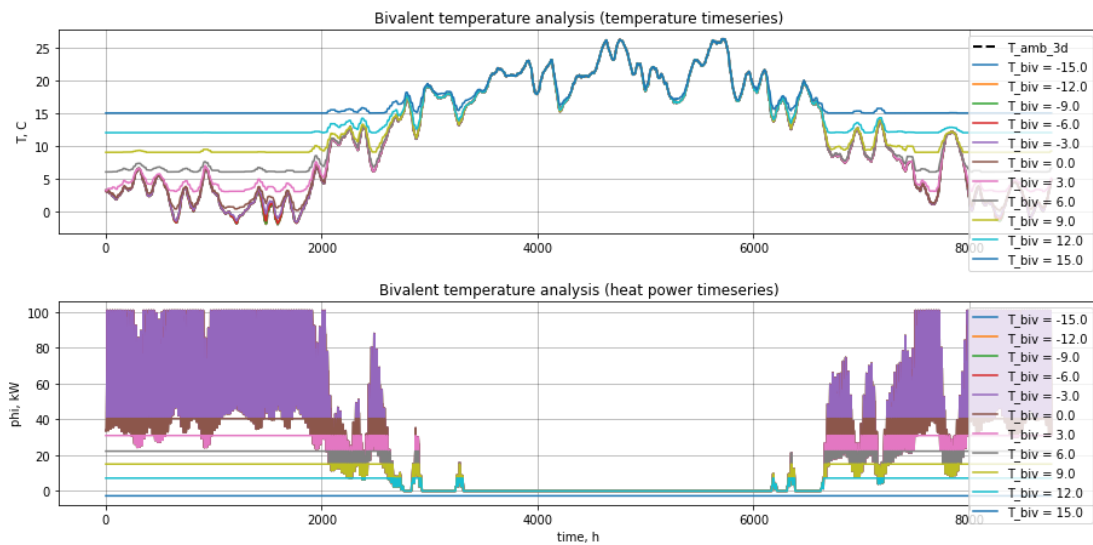


Figure 10: Bivalent temperature analysis: temperature and heat power time series.

4. CONCLUSION

Shallow geothermal energy in hybrid combination with peak-load boilers offers significant potential to advance the heat transition in the Danube Region. The web-based planning tool presented here, developed by UNIZG-RF as part of the Interreg Danube GeoHeCo project, addresses a critical gap by making sophisticated planning models accessible to an expert audience of engineers and planners. In a structured way, it demonstrates the technical feasibility and energy performance of GSHP hybrid systems, tailored to local site conditions. This empowers municipalities and planning professionals to implement innovative heating solutions with lower risk and contributes directly to scaling up renewable heating technologies in the Danube Region.

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