eVala – A web application for the assessment of the thermal effect of borehole fields in Helsinki, Finland

Kimmo Korhonen[1] and Nina Leppäharju[1]

[1] Geological Survey of Finland, PO Box 96, FI-02151 Espoo, Finland

kimmo.korhonen@gtk.fi

Keywords: shallow geothermal, web application, borehole field simulation, sustainable use, geothermal resources, Helsinki, Finland.

ABSTRACT

An increasing number of geothermal heating systems are being constructed in Helsinki every year while at the same time the city wants to guarantee that all landowners will have equal possibilities to utilize the geothermal resources in their land. This has led to the city to revise the guidelines for the planning and construction of geothermal systems. To help meet the requirements of providing a sustainability assessment as part of the permit application for geothermal systems, the Geological Survey of Finland has been developing a web application to calculate the thermal influence of a shallow or medium-deep geothermal borehole field in the bedrock. The purpose of the calculation that the web application provides is to show that the planned borehole field will not excessively consume the geothermal resources of the neighbouring plots. The ultimate goal is to increase the utilization of geothermal energy in Helsinki in a sustainable way.

1. INTRODUCTION

The annual heating demand of Helsinki is 7 TWh, of which 1.8 % was covered by shallow geothermal heating systems by the end of 2021 (Vähäaho et al., 2021). Being one of the 100 EU NetZeroCities that are committed to achieving carbon neutrality by 2030 (https://netzerocities.eu/mission-cities/), the City of Helsinki wishes to increase the share of geothermal heating in its heating mix. This means increasing the number of geothermal wells in Helsinki (Vähäaho et al., 2021) to tens of thousands. Such a high number of wells might already lead to problems in managing the shallow geothermal resources of the city.

As the number of shallow geothermal installations continues to rise, the likelihood of boreholes and borehole fields being constructed on neighbouring parcels also increases. In dense urban areas, this is may result in thermal interference between neighbouring systems, where one system affects the subsurface temperature field of another system. Such interactions are likely to reduce the efficiency of nearby systems over time. This presents challenges not only from a system design perspective, but also in terms of resource ownership and fair access perspective.

The City of Helsinki has acknowledged this problem and renewed the regulations for the building permit process for borehole systems (City of Helsinki, 2023). The new regulations aim to alleviate the anticipated problems and guarantee sustainability of the shallow geothermal resources. Especially, borehole fields of 10 or more boreholes have received special attention in the new regulations. A geothermal resource sustainability assessment is required to show that such systems will not deplete the geothermal resources underneath neighbouring plots. This aims to allow fair and equal access for all landowners to the geothermal resources underneath their plots.

However, the geothermal sustainability assessment required by the new regulations may pose a problem for many designers. This is because producing such an assessment requires complex calculations which are carried out using specialized software, requiring skills that designers may lack. This is why the Geological Survey of Finland (GTK) and the City of Helsinki started a co-operation project to develop a web application that will be freely available for everyone to produce geothermal sustainability assessments.

2. NEW REGULATIONS FOR BOREHOLE SYSTEMS

The new regulations (City of Helsinki, 2023) define the rules for constructing shallow and medium-deep geothermal systems in Helsinki. The regulations include fixed minimum distances between individual boreholes and small borehole fields (fewer than 10 boreholes). Special provisions apply to medium-deep boreholes (which are classified in the regulations as those exceeding 1,000 meters in depth) and larger borehole fields (10 or more boreholes). For these systems, building permit applications must include a sustainability assessment – a calculation demonstrating that the system will not extract so much heat as to significantly deplete the geothermal resources of neighboring properties. Importantly, this requirement does not limit the choices regarding borehole configurations or heat extraction profiles that designers can employ. The sole purpose of the assessment is to ensure that the geothermal reserves beneath adjacent plots are not unduly exhausted and fairness is guaranteed.

Despite demanding the sustainability assessment, the regulations do not specify the format of the assessment or the methodology used to produce it. Moreover, preparing such an assessment is a complex task, and many designers may lack the necessary resources and expertise to carry it out. For example, software like the Earth Energy Designer (Hellström and Sanner, 1994) which is commonly used by designers does not include the capability of estimating the thermal influence between two borehole fields. An expert assessment, similar to that presented by Randow et al. (2022) might be preferred by all stakeholders. However, such an assessment requires the use of specialized software and skilled labour.

Here we present an alternative solution which is a web application that provides users with a PDF report that includes contours of the temperature drops of 1, 2, and 3 degrees caused by the designed borehole system after 25 and 50 years of operation. Specifically, the two degree drop is considered as the limiting case. That is, borehole systems should not drop the temperature beneath surrounding plots more than 2 degrees.

The web application, developed in collaboration with the City of Helsinki, generates PDF reports that are accepted as the required sustainability assessments for building permit applications. The application, named eVala – an acronym derived from the Finnish phrase *energiakaivokentän vaikutusalueen laskentetyökalu* (which can be roughly translated as a computational tool for assessing the influence of borehole fields) – is accessible at https://evala.gtk.fi. eVala sovles the problem of acquiring appropriate software and training for producing the sustainability assessment and provides a standardized format for it.

3. SOFTWARE DEVELOPMENT

The web application is being developed for the Microsoft Azure Web Hosting platform, which hosts all web services provided by the Geological Survey of Finland. It follows the typical web application architecture consisting of a frontend that serves as the user interface, a backend that manages interactions, and app functions that implement the core functionality.

The frontend and backend components of the web application are being developed by Solita, a subcontractor specializing in software development and cloud hosting solutions. The core calculation functionality including borehole field simulation and PDF report generation is being developed by the Geological Survey of Finland. The City of Helsinki has been contributing in a consultative capacity.

The borehole field simulation is based on the infinite line source (ILS) model at the moment. The ILS solution has proven to be a very cost-effective way to simulate the operation of borehole fields. Other solutions, such as the Finite Line Source (FLS) solution, which is capable of modelling also inclined boreholes, has been tested but the implementation is currently too resource demanding to be taken into production use. The web application must be capable of calculating temperature change fields for borehole fields as large as 500 boreholes covering 20 hectares (which leads to tens of thousands of calculation points). Solving such a large problem demands heavy computation. The current ILS solution completes this maximum-case computation in about 75 minutes which is still acceptable as the minimal Azure App Service plan is used. The FLS solution would require more computational power and, thus, also a more costly App Service plan.

At the time of writing of this paper, the software project is in the testing phase. The production phase is scheduled to begin in July 2025, at which point the web application will be officially launched and made available to the general public.

4. THE WEB APPLICATION

The web application is designed to be used as a step-by-step process, guiding the user through a series of pages in a logical sequence. From the landing page, the user is first prompted to log in to the GTK web services (https://geo.fi). Upon successful registration, the user is directed to the first page, where identifying information for the project under design is entered (Fig. 1). (The application is currently available only in Finnish.)

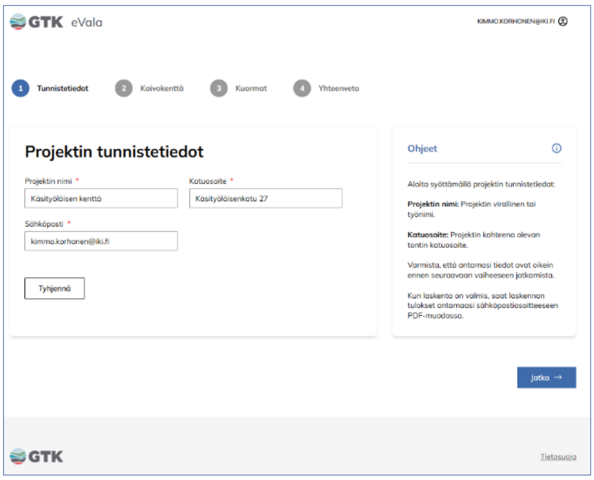


Fig. 1. The first page of the web application asks the user to enter project information (projektin tunnistetiedot) including the name of the project (projektin nimi), its street address (katuosoite), and the e-mail address (sähköposti) of the user to whom the PDF report will be sent. (Clicking "Tyhjennä" clears the form while clicking "Jatka" takes the user to the next page.)

After successfully entering the project information, the application allows the user to enter the second page (Fig. 2). In this page the user specifies the borehole field. This involves entering the identifiers, collar locations, lengths, tilt angles, and azimuths of each borehole in the field using the form shown in Fig. 2. The form also allows the user to upload the boreholes from a text file.

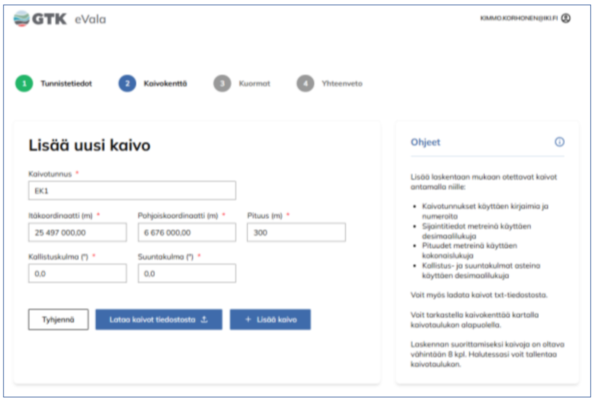
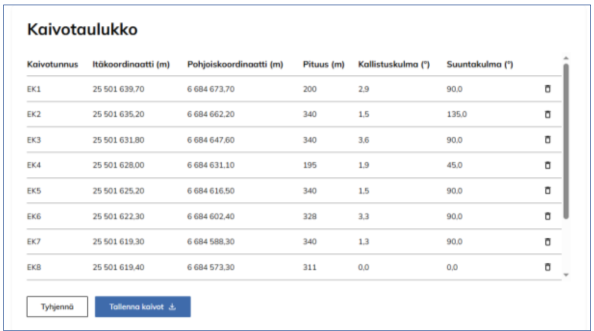


Fig. 2. The top of the second page of the web application features a form ("lisää uusi kaivo", which means "add new borehole") that allows the user to input the boreholes in the borehole field. ("Kaivotunnus" translates to "borehole identifier", "itäkoordinaatti" and "pohjoiskoordinaatti" are easting and northing. "Pituus" is length. "Kallistuskulma" and "suuntakulma" are tilt and azimuth. Clicking "Tyhjennä" clears the form while clicking "Lataa kaivot tiedostosta" uploads the boreholes from a text file. Clicking "Lisää kaivo" adds the specified borehole to the table.)

The boreholes entered by the user are then displayed in the borehole table shown in Fig. 3. The user can delete boreholes by clicking the trash can icon and export the boreholes to a text file.


Kaivotaulukko

Kaivotunnus	Itäkoordinaatti (m)	Pohjoiskoordinaatti (m)	Pituus (m)	Kallistuskulma (°)	Suuntakulma (°)
EK1	25 501 639,70	6 684 673,70	200	2,9	90,0
EK2	25 501 635,20	6 684 662,20	340	1,5	135,0
EK3	25 501 631,80	6 684 647,60	340	3,6	90,0
EK4	25 501 628,00	6 684 631,10	195	1,9	45,0
EK5	25 501 625,20	6 684 616,50	340	1,5	90,0
EK6	25 501 622,30	6 684 602,40	328	3,3	90,0
EK7	25 501 619,30	6 684 588,30	340	1,3	90,0
EK8	25 501 619,40	6 684 573,30	311	0,0	0,0

Tyhjennä
Tallenna kaivot

Fig. 3. The second page of the web application also features the borehole table (kaivotaulukko), located below the borehole creation form shown in Fig. 2. The table lists the boreholes entered by the user. (Clicking "Tyhjennä" clears the borehole table while clicking "Tallenna kaivot" exports the boreholes in the table to a text file.)

At the bottom of the second page (Fig. 4), there is summary information and a map that displays the locations of the boreholes contained in the table. This allows the user to make sure that everything has been correctly understood by the web application.

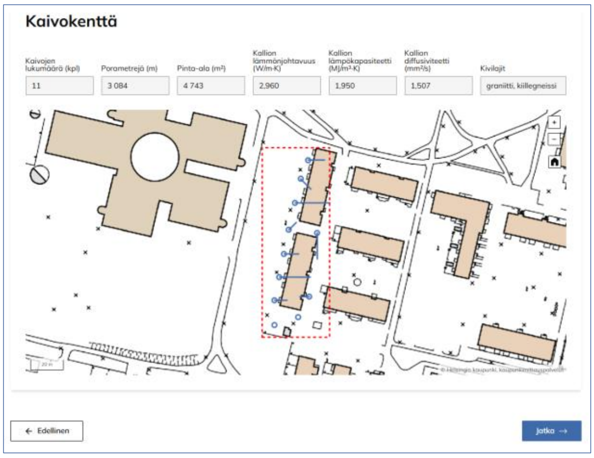


Fig. 4. Summary information about the borehole field (kaivokenttä) together with a map showing the locations of the boreholes (as blue circles) entered to the borehole table are displayed at the bottom of the second page. ("Kaivojen lukumäärä" translates to "number of wells", "porametrejä" is drilling length, "pinta-ala" is area. "Kallion lämmönjohtavuus", "kallion lämpökapasiteetti", and "kallion diffusiviteetti" translate to "bedrock thermal conductivity", "bedrock heat capacity", and "bedrock thermal diffusivity", respectively. "Kivilajit" means rock types. "Graniitti" is granite, and "kiillegneissi" is mica gneiss. Clicking "Takaisin" takes the user to the previous page while clicking "Jatka" takes the user to the next page.)

Once at least eight boreholes have been entered, the web application allows the user to proceed to the third page (Fig. 5). This page involves specifying the heat pump performance coefficients (seasonal COP and EER), together with the monthly heating and cooling demands of the building that will utilize the borehole field. The frontend updates the monthly geothermal energy values whenever changes are made to the performance coefficients or loads. The user can also import the heat pump performance coefficients and building loads from a text file.

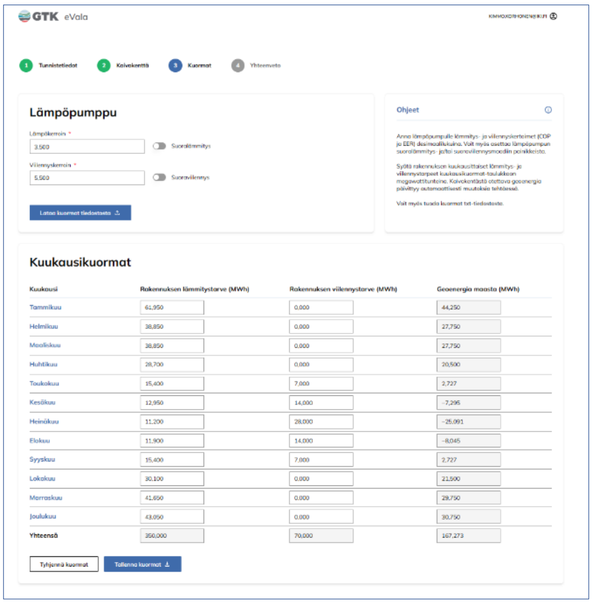


Fig. 5. On the third page of the web application the user inputs the seasonal performance coefficients of the heat pump. (“Lämpökerroin” and “viilennyskerroin” are the heat pump heating and cooling performance coefficients. Switching on “suoralämmitys” or “suoraviilennys” puts the heat pump to direct heating or cooling mode, respectively.) On this page, the user also enters the monthly heating and cooling demands of the building in MWh. (“Kuukausikuormat” translates to “monthly loads”. “Kuukausi” is month, “rakennuksen lämmitystarve” and “rakennuksen viilennys-tarve” are the building heating and cooling demands, respectively. “Geoenergia maasta” translates to “geothermal energy from the ground”. “Yhteensä” means “in total”. Clicking “Tyhjennä kuormat” sets all loads to zero while clicking ”Lataa kuormat tiedostosta” imports the heat pump performance coefficients and monthly loads from a text file.)

At the bottom of the third page (Fig. 6), there is also a bar chart showing the building heating and cooling demands together with the calculated ground load. This allows the user to ensure that all information has been entered correctly.

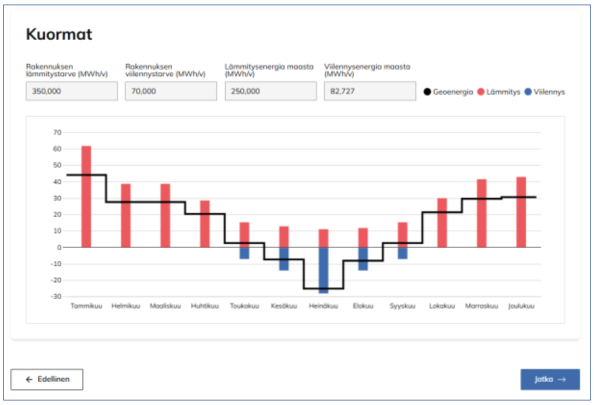


Fig. 6. Summary information about the loads (kuormat). This includes the ground load (geoenergia) shown as black lines, building heating demand as red bars (lämmitys), and building cooling demand as blue bars (viilennys). The summary also shows the total annual building heating demand (rakennuksen lämmitystarve), the total annual building cooling demand (rakkennuksen viilennystarve), the total annual heating energy from the ground (lämmitysenergia maasta), and the total annual cooling energy from the ground (viilennysenergia maasta). (Clicking “Takaisin” takes the user to the previous page and clicking “Jatka” takes the user to the next page.)

Once the third page has been completed, the user can proceed to the last page shown in Fig. 7. This page provides a final summary of the borehole and load information for the user to double check, and a button to start the calculation and report generation.

Fig. 7. The last page provides a final summary (yhteenveto) of the information entered and a button to start the assessment calculation and report generation (käynnistä laskenta).

The calculations take from one minute to an hour to complete on the current Azure App Service plan. The number of boreholes and the area covered by the them are the factors that determine how intensive the calculations will be. The maximum number of boreholes is 500 and the maximum area they can cover is 20 hectares. After finishing the calculations, the web application generates a PDF report and sends it to the user. This way the user can close the browser and does not have to keep it open and wait for the result to appear in the web application.

5. THE RESULTS

The results are compiled into a PDF document generated by the web application and delivered to the user via e-mail. This document is intended to be submitted as part of the building permit application. The document also includes all the user-provided input for documentation purposes.

The core of the assessment consists of the borehole field simulation results, presented as two contour maps. These maps illustrate the 1 K, 2 K, and 3 K temperature drop contours after 25 and 50 years of operation, based on the designer's proposed borehole field. The figures support the evaluation of whether the design excessively utilizes geothermal resources beyond the property boundary. Figs. 8 and 9 display the results for the example introduced in Figs. 1–7.

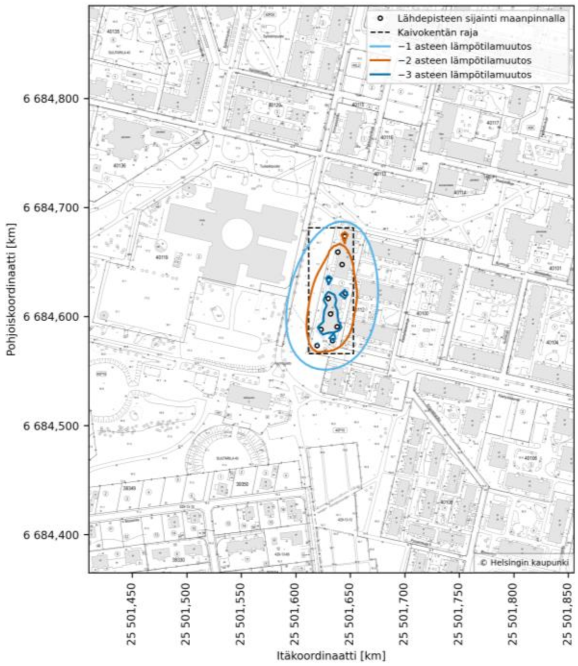


Fig. 8. Contour lines of temperature drops of 1 K, 2 K, and 3 K after 25 years of borehole field operation. ("Lähdepisteiden sijainti maanpinnalla" translates to "location of sources at ground surface". "Kaivokentän raja" translates to "borehole field boundary". "−1/−2/−3 asteen lämpötilamuutos" translates to "temperature change of −1/−2/−3 degrees".)

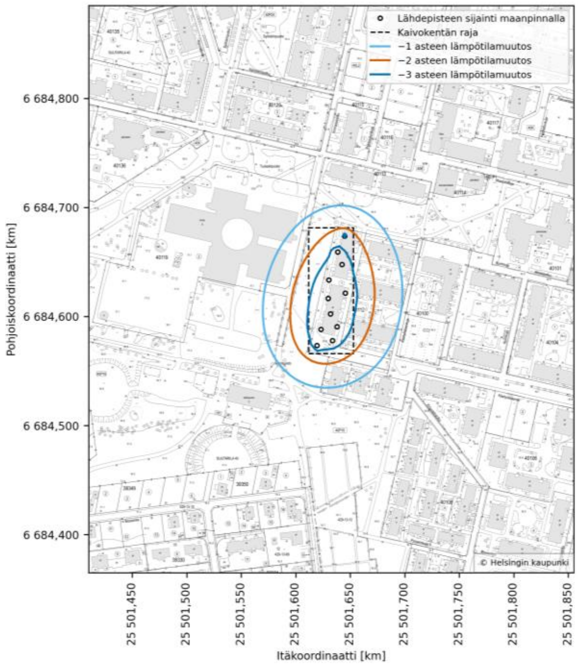


Fig. 9. Contour lines of temperature drops of 1 K, 2 K, and 3 K after 50 years of heat extraction. (See Fig. 8 for legend entries.)

6. CONCLUSION

A web application called eVala has been developed by the Geological Survey of Finland, together with the City of Helsinki and Solita, to provide geothermal sustainability assessments for building permit applications of shallow and medium-deep geothermal systems in Helsinki. The goal is that with the help of this web application and the calculations it provides, the City of Helsinki can ensure that geothermal resources are not unduly exhausted over the parcel boundaries.

The web application works as a step-by-step process. The user proceeds from entering the input information of the geothermal design to starting the calculation. The application sends the calculation results to the user's e-mail after the calculation is finished.

The final phase of the software project which is called the production phase is assumed to begin in July 2025. This phase will include technical support to the users, bug fixes and further improvements to the web application. The improvements will specifically concern the borehole field simulation code. The number of users of the web application is not expected to raise above 100 annually.

REFERENCES

Vähäaho, I., Koskinen, K.-R., Laiho, T., Linden, A., Luomanen, J., Pölkki, M., Rantanen, I. and Tolkki, T.: Maalämpökaivot yleisillä alueilla Helsingissä (in Finnish), City of Helsinki, Publications of the Urban Environment Division 2021:20, (2021).

Hellström, G. and Sanner, B.: Software for dimensioning of deep boreholes for heat extraction. *Proceedings of CALORSTOCK'94*, Espoo, Finland, (1994), 195–202.

Randow, J., Chen, S., Lubashevsky, K., Thiel, S., Reinhardt, T., Rink, K., Grimm, R., Bucher, A., Kolditz, O. and Shao, H.: Modeling neighborhood-scale shallow geothermal energy utilization: a case study in Berlin, *Geothermal Energy*, 10, (2022).

Helsingin kaupunki: Maalämpöohje suunnittelijoille (in Finnish), City of Helsinki, Urban Environment Division, (2023).

Acknowledgements

We thank Mirjam Orvomaa, Pyry Lehtonen, and Asta Harju of the Geological Survey of Finland Information Solutions team. We also thank Tapio Linna, Timo Tolkki, Risto Ojala, and Petri Perkiömäki of the City of Helsinki. The web application was written and designed by Topi Penttinen, Jussi Laine, and Virve Johansson of Solita.