



GHE Analysis

Ground Heat Exchanger Design & Simulation

SOFTWARE USER MANUAL

Version 2.4 · June 2026

gheanalysis.com

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Why a new design tool for ground source heat pump systems?

Ground-source heat pump (GSHP) systems remain a specialised segment of HVAC engineering, often perceived as complex and intimidating by practitioners new to the field. As a result, geothermal solutions are frequently overlooked during the early stages of project development. Conversely, when they are considered, system components are often oversized as a conservative response to limited experience with geothermal systems, resulting in unnecessarily high capital costs. This tendency not only undermines the economic competitiveness of geothermal systems, but also slows the broader adoption of a technology with tremendous potential to reduce energy consumption, peak electrical demand, and greenhouse gas emissions.

At the same time, students and practitioners entering the field rarely have access to powerful yet accessible tools that clearly bridge the gap between theoretical concepts and practical design workflows. It was with this challenge in mind that the development of GHE Analysis began in 2021. Since then, the software has been adopted by students, engineers, and consultants around the world. Its development has benefited from my dual experience—first as a geothermal industry consultant and now as a professor at Polytechnique Montréal. This unique perspective has shaped both the interface and the methodology of the software, helping to strike a balance between academic rigor and practical usability.

Addressing the challenges outlined above, GHE Analysis provides an intuitive, fast-learning design environment powered by a high-performance simulation engine built upon decades of academic research. Its primary objective is to allow designers to focus on the key physical processes governing GSHP performance rather than on software complexity. By making advanced design methods more accessible, the software promotes accurate, cost-effective system designs and helps prevent the systematic oversizing that has historically affected many geothermal projects.

GHE Analysis is developed and distributed by a spin-off company originating from Polytechnique Montréal. Over the years, many of my graduate students have contributed to scientific publications related to the software's underlying models, and these research contributions have been extensively incorporated into the software (see the [References](#) section at the end of this manual). Whenever applicable, a portion of the revenues generated by GHE Analysis is shared with students whose research has contributed to its development. This model reflects my commitment to ensuring that academic contributions are recognized and rewarded beyond the publication of scientific work.

Since the release of version 1.0, I have received invaluable feedback from users across the geothermal industry. I would like to express my sincere gratitude to the many academic and industrial users of GHE Analysis who, since 2021, have suggested improvements, reported issues, and actively contributed to the software's evolution. Their continuous input has played a fundamental role in the development and maturity of version 2.4, and I am deeply thankful for their trust, support, and collaboration.

Professor Philippe Pasquier, eng., Ph.D.

Lead Programmer, P³ Geothermal



How to cite GHE Analysis

If GHE Analysis or this user guide supported your work, please cite it. Two distinct works can be referenced — the **software** itself and this **user guide** — so please choose the citation that matches what you used (or cite both). Acknowledging this work sustains its continued development and the open sharing of the research behind it.

Citing the software

Pasquier, P. (2025). *GHE Analysis – Interactive simulation of ground-source heat pump systems*. P³ Geothermal inc. DOI [10.5281/zenodo.15660727](https://doi.org/10.5281/zenodo.15660727)

Citing this user guide

Pasquier, P. (2026). *GHE Analysis User Guide* (Version 2.4). P³ Geothermal inc. <https://gheanalysis.com/pages/documentation>

Citing the underlying methods

The simulation models implemented in GHE Analysis are documented in a series of peer-reviewed publications. When a specific method is central to your own work — g-function construction, borehole thermal resistance, spectral EFT simulation, inclined boreholes, or standing column wells — please also cite the corresponding paper listed in the [References](#) section at the end of this guide.



Feature Overview

GHE Analysis version 2.4 brings a significantly expanded set of modelling capabilities, including geocooling (also known as passive or free cooling) and domestic hot water (DHW) simulation a new energy cost module, enhanced chart views, and deeper integration between all design steps. The table below summarises the principal features available in this release.

 GHE Analysis FEATURE OVERVIEW	
DESIGN & MODELLING	
Interactive borehole designer	✓
Interactive GHE designer	✓
Regular grid and irregular GHE layouts	✓
Site background image import and georeferencing	✓
3D borehole viewer	✓
2D thermal plume viewer	✓
GROUND HEAT EXCHANGER MODELS	
Single U-Loop	✓
Double U-Loop (adjacent & diagonal)	✓
Coaxial BHE	✓
Inclined boreholes	✓
Standing column well (<i>max. 1 SCW × 500 m</i>)	✓
SIMULATION	
Hourly fluid temperature simulation	✓
Regional groundwater flow	✓
Building & ground thermal loads (hourly and monthly)	✓
Temperature-dependent or constant COP & CAP	✓
Geocooling (also known as free or passive cooling)	✓

Domestic hot water (DHW)	✓
Heat-carrier fluid database	✓
Sizing — ASHRAE alternative method (1 to 50 years)	✓
Energy & peak-power breakdown (HP, pumps, auxiliary)	✓
Operating-energy cost with flexible tariff engine	✓
SPECIFICATIONS	
Maximum number of boreholes (standard)	625
Simulation of 625 – 3 000 boreholes	On request
Maximum borehole depth	500 m
Maximum simulation period	50 years
Operating system	Windows 10+
gheanalysis.com	



Quick start

Activating a professional licence - GHE Analysis runs in demonstration mode until a valid licence code is submitted. To activate the professional version, open the License Agreement dialog  from the main menu. In the dialog that opens, paste the licence code you received after purchase and click Validate License. Licence codes are available at gheanalysis.com. An active internet connection is required at validation time.

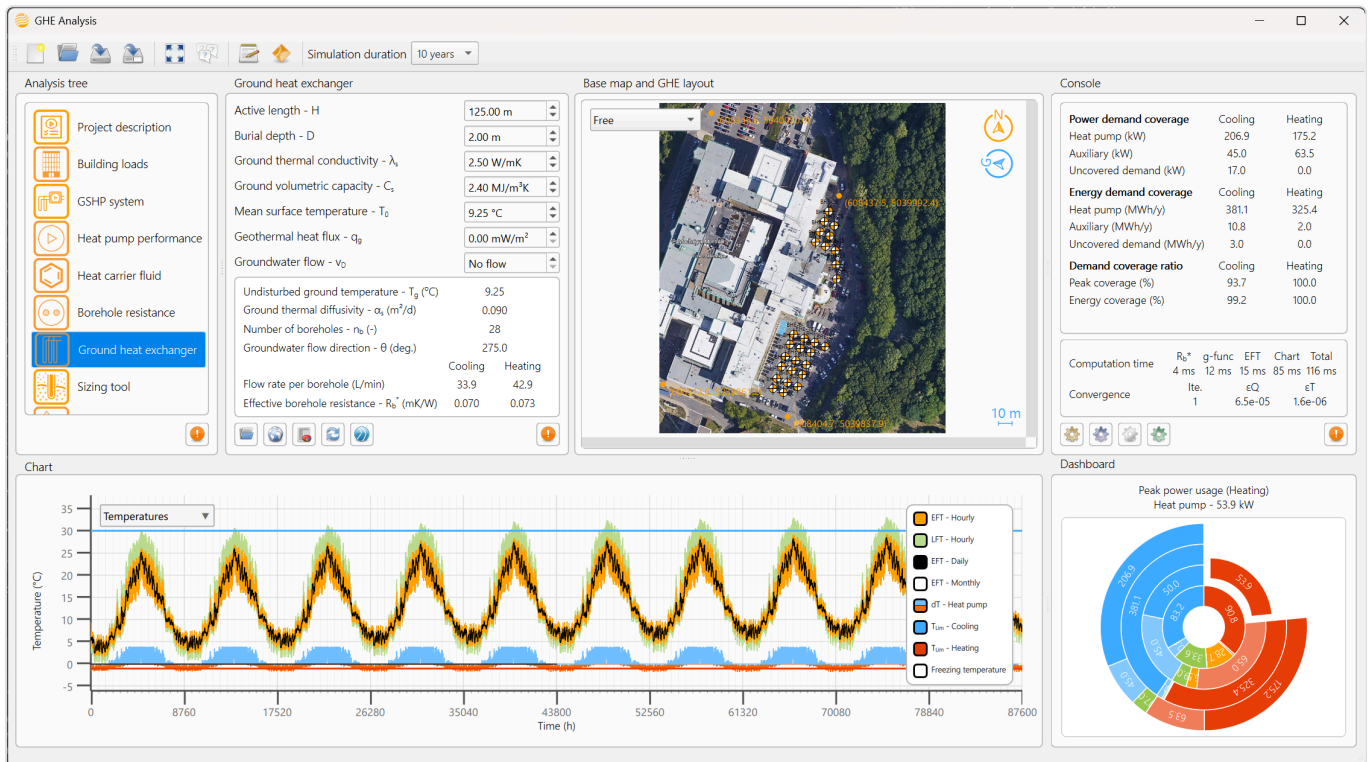


Figure 1 — GHE Analysis interface overview showing the analysis tree, the Ground heat exchanger panel and base map, the results within the Console and the entering fluid temperature chart

A typical analysis follows the steps of the analysis tree, from top to bottom. A first pass takes only a few minutes:

- **1. Describe the project** — enter the project and client information, validate the site address, and set the currency.
- **2. Provide the thermal loads** — type, paste or import the building's hourly or monthly heating and cooling loads.
- **3. Set the heat pump performance** — choose constant values, manufacturer or performance data, and set the temperature limits.
- **4. Choose the heat carrier fluid** — select the fluid and its antifreeze concentration.
- **5. Lay out the ground heat exchanger** — position the boreholes, optionally on a georeferenced base map.
- **6. Design the borehole** — set the pipe, grout and geometry to minimise R_b^* .
- **7. Size and review** — use the sizing tool for a starting length, then read the console and charts to confirm the entering fluid temperature stays within limits over the simulation horizon.

- **8. Cost the system** — define the energy tariffs to estimate the annual operating cost.

At any step, the help button  gives guidance on the current panel — the same content forms the chapters of this manual.

Panel layout. GHE Analysis uses a resizable split layout. Drag the dividers between panes to allocate more screen space to the element you are currently reviewing — for example, users may enlarge the chart area or expand the base map to improve the ease and precision of interactive borehole manipulation. This is particularly useful when working on a single screen.

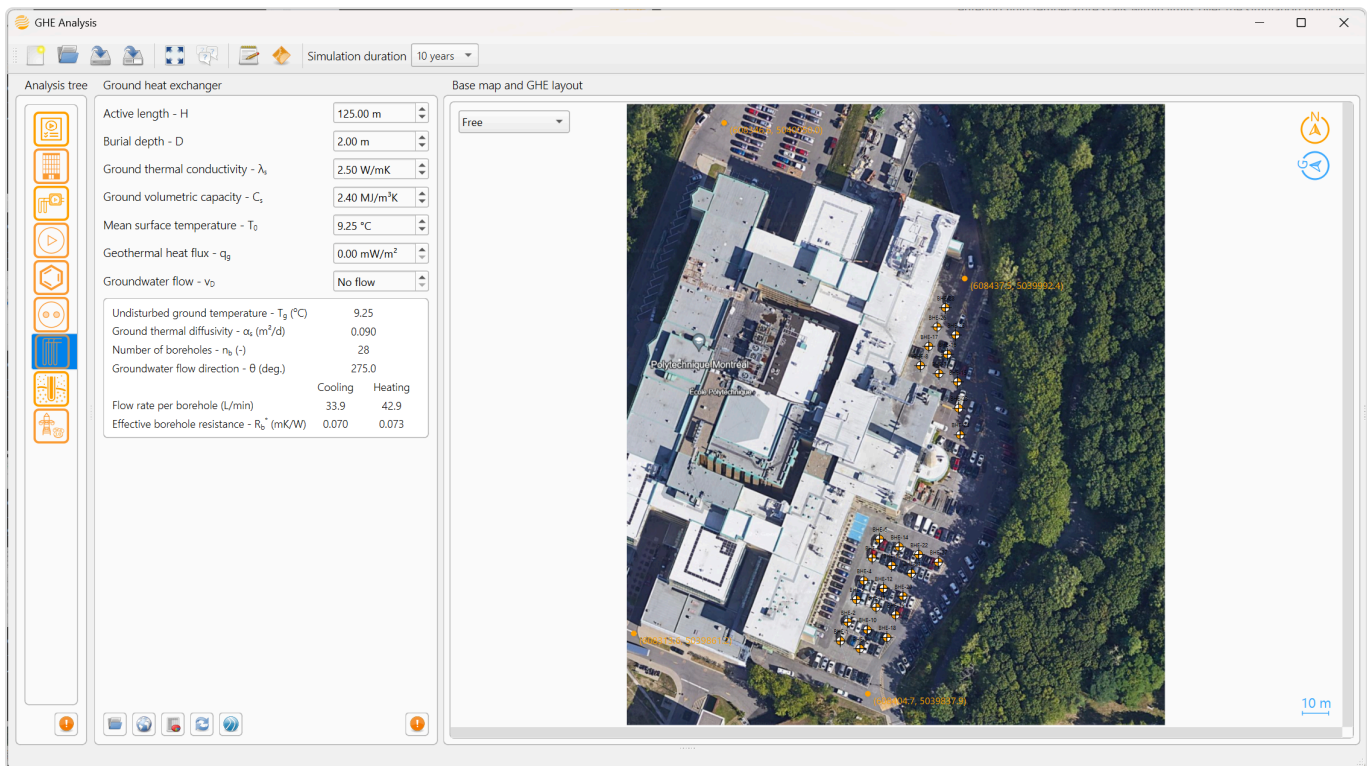


Figure 2 — Resizable split layout. Users can drag the orange panel dividers to dynamically reallocate screen space, enlarging charts, maps, or other workspace elements to improve visibility and facilitate interactive borehole manipulation.

Numerical input. The easiest way to modify numerical values is by using the mouse scroll wheel. Hover over any value field and roll the wheel to increment or decrement the value one step at a time. The $\uparrow$ / $\downarrow$ arrow keys work the same way when a field has focus, and you can always type a value directly. In the 3D borehole layout and groundwater flow views, combining the wheel with **Shift** or **Ctrl** also adjusts the scene orientation.



Saving, loading and exporting

GHE Analysis stores each project in a single file that captures the complete design state — inputs, loads, borehole layout, heat pump curves, base map, and energy cost rules. Simulation results are exported automatically to CSV whenever the project is saved.

Creating a new project - Select  to start a fresh project. All inputs are reset to their default values and the current simulation results are cleared. If the current project has unsaved changes, GHE Analysis will prompt you to save before proceeding.

Saving a project - Select  to write the project to its current location, or Save As  to choose a new name or folder. The file dialog filters for GHE project (***.ghe**) by default. If no file has been assigned yet, Save behaves like Save As.

The last folder used is remembered across sessions, so subsequent opens and saves start in the same directory.

Opening a project - Select Open  to browse for a `.ghe` file. GHE Analysis reads the file, restores all inputs and settings, and re-triggers the simulation so that the console and charts reflect the saved state immediately. The file dialog filters for GHE project (*.ghe).

The .ghe project file - The `.ghe` extension is associated with the GHE Analysis application icon  on Windows, so double-clicking a project file in Explorer opens it directly. A `.ghe` file is a compact binary archive (CBOR-encoded JSON) carrying the full project state:

- **Simulation parameters** — all entries of the internal parameter array (geometry, ground properties, fluid, boreholes).
- **Thermal loads** — hourly or monthly building loads as entered or imported.
- **Heat pump performance** — input mode, COP / CAP table.
- **Borehole field** — X, Y coordinates, azimuth and dip of every borehole, plus all GHE designer settings.
- **Base map** — the georeferenced background image, if one has been loaded.
- **Project description** — name, client, address, currency and general notes.
- **Energy cost rules** — all tariff rules, equipment presets and escalation rate.

Automatic exports on save - Each time a project is saved, GHE Analysis writes up to three files alongside the `.ghe` file (only if a completed simulation is available). The files are saved in the same directory as the `.ghe` file and contain:

FILE	CONTENT
<code>{project}.csv</code>	Hourly simulation results — one row per hour of the simulation horizon.
<code>{project}_EnergyCost.csv</code>	Hourly energy cost per source, with equipment and unit metadata. Written only when at least one tariff rule is defined.

FILE	CONTENT
<code>{project}.png</code>	Snapshot of the GHE designer canvas (borehole layout, base map, thermal plume).

These files are overwritten each time the project is saved. They are suitable for import into spreadsheets or post-processing scripts.

Hourly Simulation results - The hourly results file (`{project}.csv`) contains one header row followed by one row per simulated hour. Values are written with four decimal places. The number of rows equals the simulation duration in years $\times$ 8 760 hours. The columns are:

COLUMN	UNIT	DESCRIPTION
Time	h	Hour index (1 to $n \times 8\,760$)
EFT	°C	Entering fluid temperature at the heat pump
QbC	kW	Building cooling load (≥ 0)
QbH	kW	Building heating load (≥ 0)
QDHW	kW	Domestic hot water demand (≥ 0)
Qb	kW	Net building load (– cooling, + heating)
Qg	kW	Net ground load (+ cooling, – heating)
QHP	kW	Load served by the heat pumps
QAux	kW	Load served by auxiliary equipment
PLR	—	Part-load ratio
COP	—	COP at EFT
CAP	kW	Installed capacity at EFT
RbEff	m·K/W	Effective borehole resistance
QDHWdemand	kW	DHW demand at this hour
QDHWcovered	kW	DHW actually covered by the heat pumps



Project Description

The Project Description panel is the starting point of any GHE Analysis project. It records the administrative context of the design — project identity, site location and client — and provides a general notes field for capturing design intent and the mechanical assumptions that will shape the design. Although this information does not affect the simulation, it travels with the project file and ensures that the key decisions are documented alongside the results.

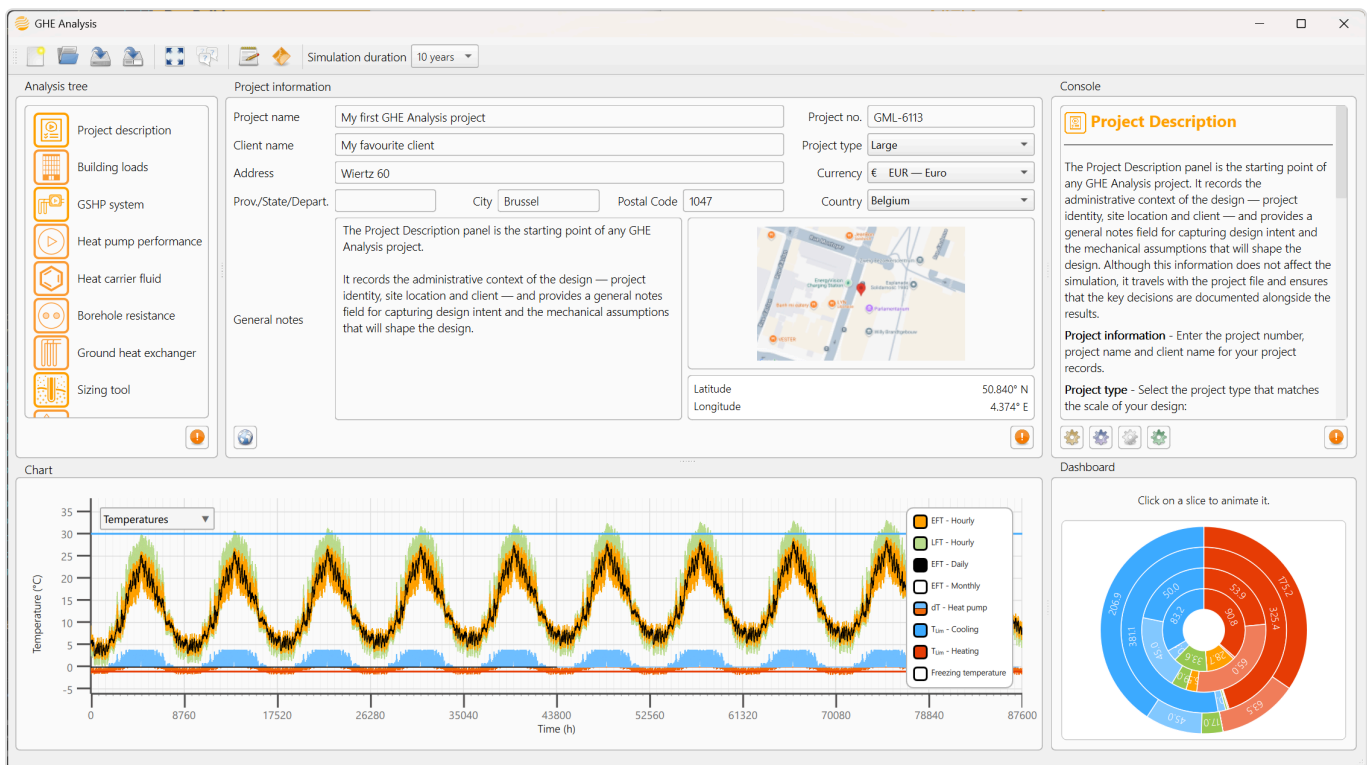


Figure 3 — Project Description panel — project name, client information, site address, location map and general notes

Project information - Enter the project number, project name and client name for your project records.

Project type - Select the project type that matches the scale of your design:

- **Screening** - a quick, preliminary assessment of a potential project.
- **Small** - 1 to 4 boreholes.
- **Intermediate** - 1 to 80 boreholes.
- **Large** - 1 to 1 000 boreholes.

Separating projects by size lets GHE Analysis tailor the interface and the design workflow to the task at hand: each level keeps the available options to those relevant at that scale, making the design process as simple and direct as possible.

Site location and map - Provide the project address, city, postal code, province/state and country, then press Validate address button . It sends the address to an online mapping service, which returns the site latitude and longitude and displays a location map. An active internet connection is required; if the address cannot be resolved,

refine it - a complete street address gives the best result - and validate again. The coordinates are stored with the project for documentation.

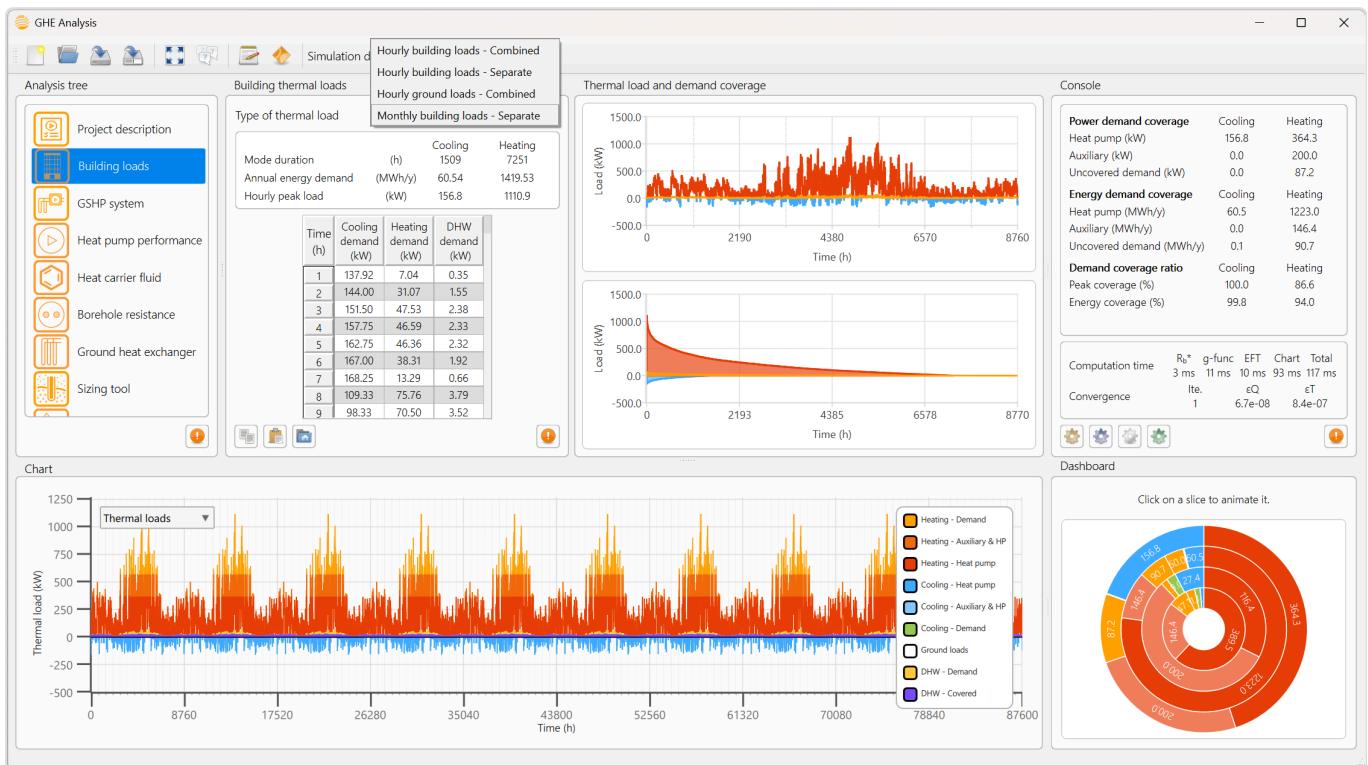
Currency - The currency selected here is used throughout the project wherever monetary values appear, in particular in the Energy Cost and cost-estimation tools. Choose it before entering tariffs or unit prices so that every figure is expressed in the same unit.

General notes - Use the General notes field for any information that may influence the design of the GSHP system. Because the building's mechanical and HVAC characteristics ultimately drive the ground loads, this is the natural place to capture the context a designer will need later: the distribution system and its supply and return temperatures (for instance a low-temperature radiant floor versus fan-coil units), the simultaneity of heating and cooling, the domestic hot water strategy, indoor setpoints and ventilation loads, and any existing or backup equipment. Site constraints, client requirements, regulatory considerations, hydrogeological observations, and expected load diversity or future expansion also belong here. This text travels with the project and is a convenient place to document the reasoning behind your design choices.



Building thermal loads

To start the analysis you must first provide some thermal loads. Loads can be entered manually, pasted from the clipboard using the / buttons, or imported from a CSV file using the Import thermal loads button.



Type of thermal load - GHE Analysis can work from the building's thermal loads — using the heat pump performance curves to derive the corresponding ground loads — or directly from ground loads obtained from a separate calculation, in which case the Heat pump performance tab is disabled.

GHE Analysis supports four input modes:

- **Hourly building loads - Combined:** a single net hourly load column. Loads are positive for heating, negative for cooling.
- **Hourly building loads - Separate C/H + DHW:** three columns — cooling, heating, and domestic hot water (DHW) hourly loads. All values are positive. The DHW demand is tracked separately and displayed as its own series on the charts.
- **Hourly ground loads - Combined:** a single net hourly load column where loads are applied directly to the ground (HP performance tab disabled). Loads are positive for heating, negative for cooling.
- **Monthly building loads - Separate:** five columns — monthly cooling demand, cooling peak, heating demand, heating peak, and DHW demand. All values are positive. Monthly energy values are converted to an equivalent hourly profile and replicated over the simulation period. If a month has simultaneous cooling and heating demand, the net demand drives the fluid temperature simulation; the dominant mode determines the peak

load, applied for up to 2 hours. If the peak power multiplied by 2 hours would exceed the total net monthly demand, the peak duration is automatically reduced so that the energy balance remains exact and all base-load hours remain in the correct operating mode (heating or cooling). DHW demand is spread uniformly over all hours of the month.

When an hourly mode is selected, the table accepts 8 760 rows (one per hour of the year). When a monthly mode is selected, the table accepts 12 rows (January to December). Thermal loads are stored with a precision of 0.01 kW.

Data import - Data are pasted or imported starting at row 1; any rows beyond 8 760 are discarded, and missing rows are set to zero. The Import thermal loads button  reads ordinary CSV files. The column separator — comma, semicolon or tab — is detected automatically, a header row is recognised and skipped, and European number formats (a comma as the decimal mark and spaces as thousands separators, e.g. 1 234,56) are accepted. In practice you can export a column of loads straight from a spreadsheet or energy-model report and import it without reformatting. The expected column count and order depend on the active mode:

 Building Thermal Loads DATA IMPORT FORMAT			
MODE	# COLUMNS	COLUMN SEQUENCE	LOADS SIGN
HOURLY MODES — 8 760 ROWS			
Hourly – Combined (+/-)	1	Net load	+ heating – cooling
Hourly – Separate C/H + DHW	3	Cooling Heating DHW	All positive
Hourly – Ground combined (+/-)	1	Net ground load	+ heating – cooling
MONTHLY MODE — 12 ROWS			
Monthly – Separate	5	Cool. demand Cool. peak Heat. demand Heat. peak DHW demand	All positive
gheanalysis.com			

A warning is shown if the row or column count does not match expectations; missing columns are set to zero.

Domestic hot water (DHW) - When domestic hot water (DHW) loads are provided (an Hourly Separate or a Monthly mode), the hot-water demand changes the heat exchanged with the ground at each hour. The following modeling strategy is used by GHE Analysis:

- **In cooling**, DHW is produced by recovering heat at the condenser (desuperheating). The amount that can be recovered is bounded by the heat the cooling cycle is already rejecting to the ground, so DHW coverage can never exceed what the condenser actually produces. Recovering this heat for hot water reduces the rejection seen by the borehole field.
- **In heating**, DHW is produced with the spare capacity that remains once the building's heating load is fully met. If the heat pumps are already running at full output — and auxiliary heating is being called upon — no spare capacity is available and no hot water is produced by the ground-source equipment during that hour.
- **In both cases**, the extra electricity used to make hot water is added to the system total and is reflected in the seasonal COP. The DHW COP values used for these calculations are entered in the Heat pump performance panel.
- **When a geocooling system** type is selected in the GSHP System panel, the compressor is bypassed during geocooling hours. Because hot-water production relies on the compressor, no DHW is produced during those hours, and the DHW symbol is hidden from the system diagram while a geocooling system type is active.



Summary & charts: hourly load profile and demand duration curve

GHE Analysis provides a utility to visualize and analyze the thermal loads of your project. The page contains a summary showing the number of hours per year in cooling and heating, the annual energy required by the building, and the thermal peak load for each mode of operation. When a time step has zero building load, it is not counted in the heating or cooling hours.

The top chart shows the **hourly load profile** over the year. Cooling loads appear in blue and heating loads in red. When DHW loads are present and a Separate mode is active, an additional orange series is superimposed showing the DHW demand. When a **monthly input mode** is used, the profile consists of flat plateaus representing the average monthly load for each month, each ending with a two-hour peak matching the peak value entered in the table.

The bottom chart shows the **demand duration curve**: cooling and heating loads are plotted as blue and red filled areas respectively, each ordered from peak to base load. Unlike the top chart, the x-axis here does not represent calendar time — it represents the **number of hours at each demand level**. Heating and cooling loads are sorted independently, each from the highest to the lowest value, and placed side by side: the heating segment spans all annual heating hours and the cooling segment spans all annual cooling hours. The total x-axis extent therefore equals the sum of operating hours shown in the summary panel, which is generally less than 8 760 because hours with zero load are excluded. When DHW loads are present, an orange line is added showing the DHW duration curve. The Y-axis of both charts automatically expands to accommodate the DHW peak if it exceeds the heating peak.



GSHP in practice: thermal load quality and GHE field sizing

The thermal loads exchanged with the ground greatly influence the thermal response and therefore the sizing of a GHE. Under certain conditions, a 10% error on the thermal peak or on the average load can lead to a 10% error on the field size. The thermal loads used must therefore be calculated with great care and not be based on rough estimates. A few design principles deserve particular attention:

- **Thermal balance of the ground.** A strongly heating- or cooling-dominant building will progressively cool or warm the ground year after year. Recognising this imbalance early - and, where appropriate, correcting it - is central to a durable design. The balance can be restored on either side of the equation: on the ground side

with hybrid equipment, heat recovery for DHW, or a supplemental heat rejecter; and on the building side by improving the envelope, adding solar shading, limiting heat gains or losses.

- **Peak versus energy.** The peak load governs the worst-case fluid temperature and the short-term safety of the system, while the annual energy balance governs the slow drift of the ground temperature over the system's life. Both matter, and a field sized for one can disappoint on the other.
- **Realistic profiles, not rules of thumb.** Equipment rarely operates at its rated block load. Diversified, hour-by-hour profiles that reflect occupancy, ventilation schedules and the simultaneity of zones give a far more honest picture of what the ground actually experiences than a single design-day figure.
- **Part-load reality.** A GSHP system spends most of its hours operating well below peak. Loads that capture this part-load behaviour, rather than a handful of design-day values, lead to sizing and energy estimates you can defend to a client or reviewer.

In short, the quality of a GSHP system design is bounded by the quality of the loads it starts from. Time invested in a credible load profile is repaid in a field that is neither undersized - and at risk of breaching its temperature limits - nor oversized and uneconomic.



GSHP system

The GSHP System panel describes how the heat pumps are connected to the building and to the ground loop, and sets the circulation flow rates and pumping power that determine the parasitic (pumping) energy of the system. A schematic diagram on the panel updates as you change these choices.

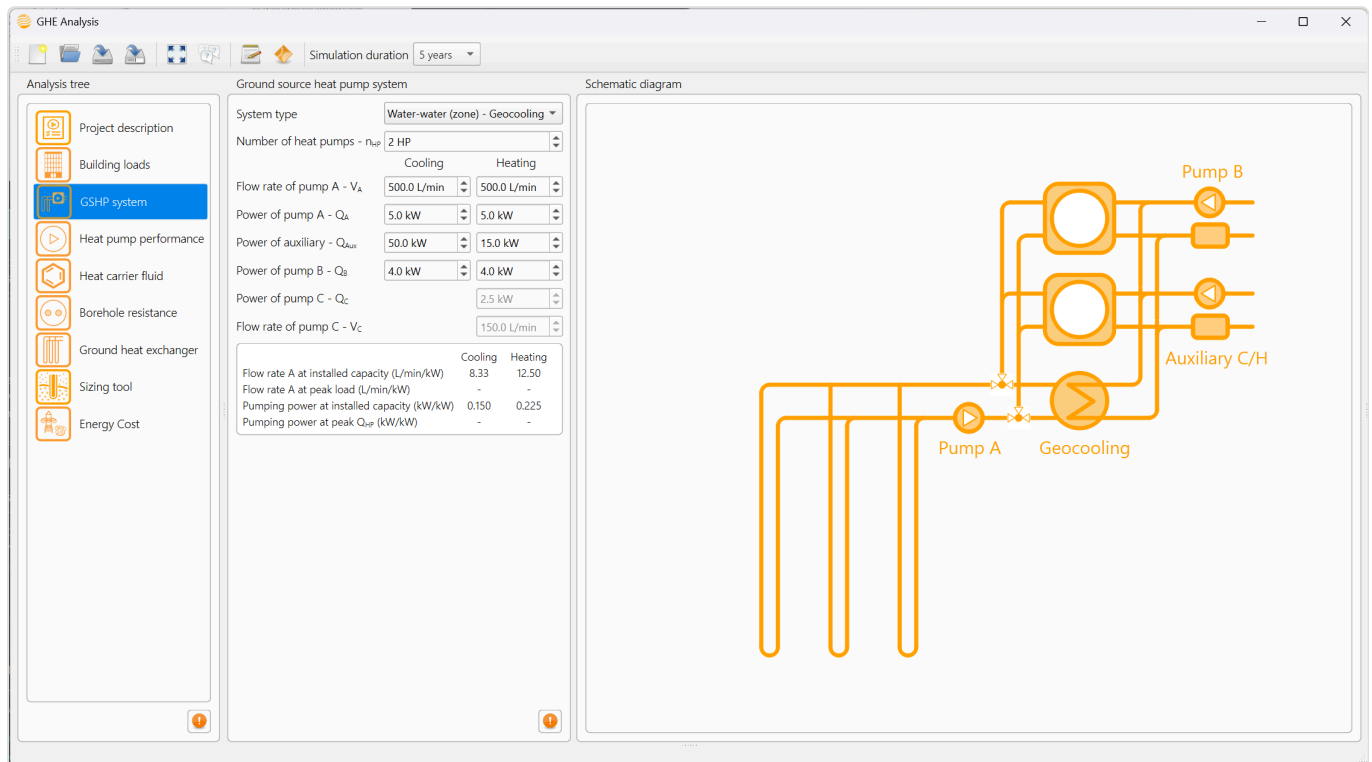


Figure 5 — GSHP system panel — system type selector, pump configuration and schematic diagram of the heat pumps and ground loop connection

System type - The system type sets how the heat pumps serve the building and how the ground loop is operated:

- **Water-air (zone)** — distributed water-to-air heat pumps, typically one or more per zone, sharing a common ground loop and delivering air locally.
- **Water-water (zone)** — distributed water-to-water heat pumps serving hydronic equipment within each zone.
- **Water-water (loop)** — a central water-to-water plant serving a building distribution loop.
- **Geocooling variants** — in cooling, the building is cooled directly by the ground loop with the compressor bypassed (so-called direct, passive or free cooling). During geocooling hours the heat pumps draw no compressor power, which can dramatically lower cooling energy; domestic hot water cannot be produced in those hours because it relies on the compressor.

Circulation flow rates - The source-side and load-side flow rates are entered for cooling and heating for the installed capacity. Specifying the flow at two operating points lets GHE Analysis represent how the circulators are staged or modulated across the load range rather than assuming a single fixed flow. Flow rate also feeds back into the borehole calculations through the Reynolds number and the convective resistance R_f .

Pumping power - The pumping power is the electrical power drawn by the circulators per unit of flow capacity. Together with the flow rates and the hourly loads, it sets the pumping energy that is added to the system's electricity consumption and folded into the seasonal COP.

Schematic diagram - The schematic redraws itself to reflect the selected system type and the presence of auxiliary or DHW equipment, giving a quick visual confirmation that the configuration matches your intent.

GSHP in practice: pump sizing, hybrid systems and seasonal efficiency

Pumping is the parasitic load most often underestimated in GSHP system design. Oversized circulators, excessive antifreeze, or flow rates pushed well beyond what turbulence requires can quietly erode the seasonal efficiency a good ground field was meant to deliver. Aim for the lowest flow that keeps the loop turbulent at peak, control the flow rate where possible, and remember that geocooling — where the site permits it — is often the single largest efficiency opportunity in a cooling-dominant building, since it serves the cooling load with circulators alone.

Balanced ground loads first, hybrid equipment second. The most robust design strategy is to size the borehole field so that the annual ground loads are as balanced as possible between heating and cooling: a balanced field shows little long-term EFT drift and keeps the heat pumps efficient over the whole life of the system. When a balanced field cannot also cover the heating and/or cooling peaks within the temperature limits, the economical answer is often a **hybrid system** — the GSHP carries the bulk of the load while auxiliary equipment handles the extremes: a fluid cooler (dry cooler or evaporative cooling tower) to shed excess heat where cooling dominates, or an auxiliary heater to cover the heating peaks where heating dominates. As a rough trigger, supplemental rejection becomes attractive when one mode exceeds roughly 60 % of the total annual ground energy exchange, since the field would otherwise drift warmer (or cooler) year after year.

A particularly effective variant is to size the GSHP and borehole field to cover **100 % of one mode** and to meet the other mode with the GSHP plus an auxiliary system. Capping the field at the smaller of the two seasonal demands removes the long-term thermal drift and shifts capital cost from permanent drilling to above-ground equipment that is easier to maintain and replace.



Heat pump performance

The coefficient of performance (COP) and capacity (CAP) of GSHPs are highly influenced by the entering fluid temperature (EFT). GHE Analysis supports four input modes for heat pump performance, ranging from a simple constant value to a full temperature dependent COP and CAP.

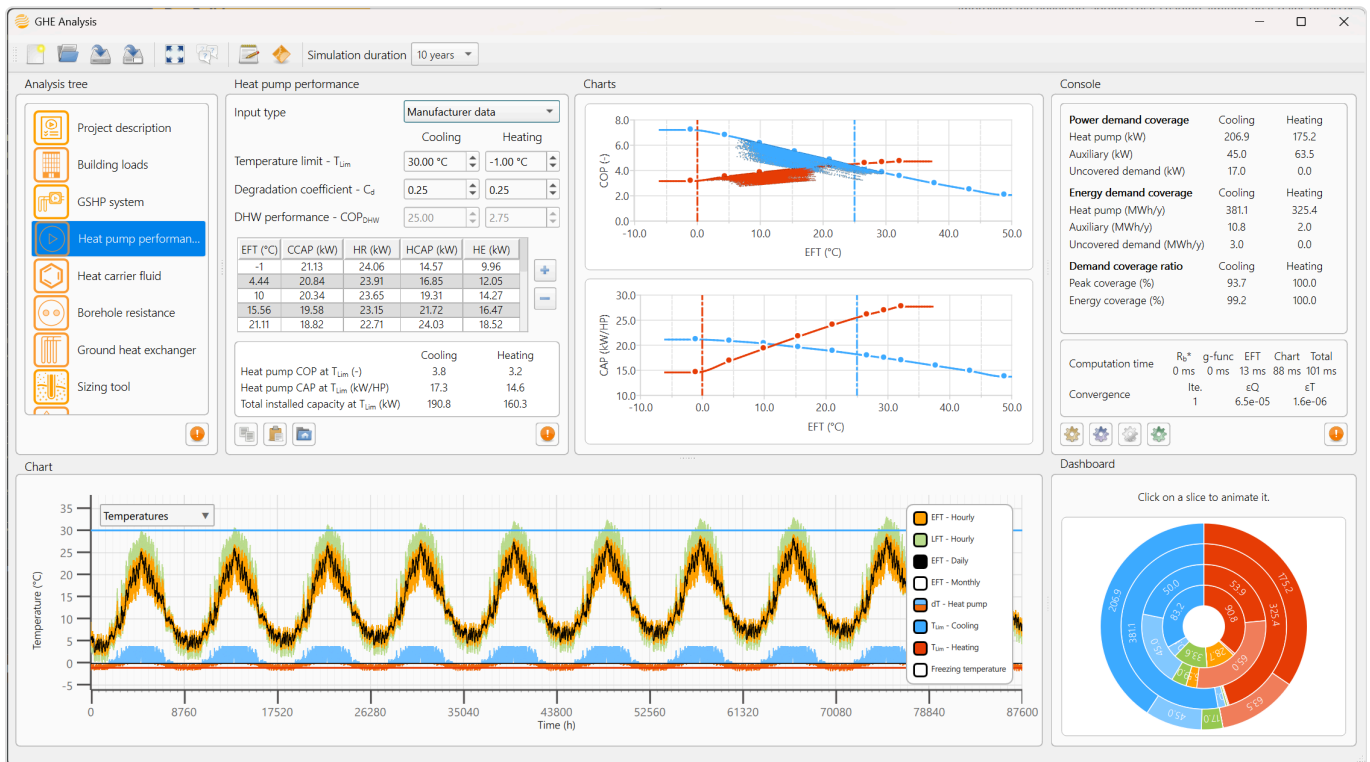


Figure 6 — Heat pump performance panel — COP and capacity curves as a function of entering fluid temperature (EFT) with temperature limit settings

Temperature limits (T_{Lim}) - These fields allow you to specify the entering fluid temperature beyond which the operation of the GSHP is not recommended or even impossible. In the current version of GHE Analysis, no control measure stops the GSHP if EFT exceeds T_{Lim} . It is therefore the user's responsibility to modify their design in order to maintain the fluid temperature within a range suitable for the selected heat pump. T_{Lim} is also used by the Sizing tool to determine the required borehole field length.

Degradation coefficient (C_d) - Part-load operation of a GSHP can lead to on-off cycles that degrade thermal performance. GHE Analysis accounts for this through a degradation coefficient (C_d) applied to the average part-load ratio (PLR) over each hour. A C_d value of 0 corresponds to zero degradation in heat pump performance. A value of 0.25 is recommended for most GSHPs (Fuentes et al., 2016).

DHW COP - When DHW loads are defined in the building loads panel (Hourly Separate C/H + DHW or Monthly mode), two additional fields appear: the DHW COP in cooling and the DHW COP in heating.

These values characterise the performance of the domestic hot water system and set how much of the hot-water demand can be met at each hour. Coverage is always bounded by what the cycle can physically deliver:

- **In cooling**, the hot water is made from heat recovered at the condenser (desuperheating), so it cannot exceed the heat the cooling cycle is already rejecting at that hour. At a DHW COP of 5, roughly four-fifths of each unit of hot-water energy comes from recovered heat and only one-fifth from additional electricity — recovering this heat also lightens the load on the ground.
- **In heating**, the hot water is made with whatever capacity remains once the building's heating load is fully met; when the heat pumps are already at full output, no hot water is produced that hour. At a DHW COP of 3, about two-thirds of each unit comes from the ground and one-third from electricity.
- When the building load is zero, or during geocooling hours when the compressor is bypassed, DHW coverage is zero.

The extra electricity used for hot water is added to the system total and reflected in the seasonal COP. These fields have no effect in the Hourly Combined or Ground load modes, and they are disabled when a geocooling system type is selected.

Input mode - Four input modes are available from the drop-down list:

- **Constant performance** — A single COP and CAP pair is specified for cooling and heating. Performance is assumed independent of EFT. This mode is appropriate for preliminary sizing when no manufacturer data is available.
- **Performance vs. temperature** — COP and CAP are entered directly as a function of EFT in the table (columns: EFT, CCAP, CCOP, HCAP, HCOP). Rows can be added with the  button, removed with the  button, pasted from the clipboard (Ctrl+V), or imported from a CSV or tab-delimited text file with the  Import button. GHE Analysis fits a smooth, shape-preserving (PCHIP) curve through the entered points.
- **Manufacturer data** — Raw data from a manufacturer's datasheet is entered in the table (columns: EFT, TC, HR, HC, HE, where TC is total cooling capacity, HR is heat rejected, HC is heating capacity, and HE is heat extracted). GHE Analysis automatically derives the cooling and heating COP from these values. Cells containing zero appear in orange to indicate missing data.



Summary & charts: COP and capacity curves versus entering fluid temperature

The two charts display the COP (top) and CAP (bottom) curves as a function of EFT. The solid lines are PCHIP interpolants of the entered data; the solid circles are the data points themselves. The vertical dashed lines mark T_{Lim} for cooling (blue) and heating (red). Small dots scattered around the curves represent part-load operating points; they are invisible when $C_d = 0$ or the heat pump operates at full load, as they then coincide with the manufacturer's curve.

The summary below the charts reports the COP and CAP of the GSHP at T_{Lim} for each operating mode. The total installed capacity equals the number of heat pumps (n_{HP}) multiplied by the individual capacity at T_{Lim} , i.e. $n_{HP} \times CAP(T_{Lim})$.



GSHP in practice: performance sensitivity to EFT, cycling degradation and model selection

The COP of a GSHP varies significantly with EFT. A 5 °C rise in EFT during cooling, or a 5 °C drop during heating, typically reduces the COP by 10–15 %. Oversizing the GHE to limit EFT excursions therefore directly improves system efficiency. The degradation coefficient C_d captures the additional performance penalty from cycling, which can be significant in buildings with low part-load fractions. Using manufacturer data rather than constant

performance values leads to more reliable energy predictions and avoids underestimating the electrical consumption of the GSHP system.

The choice of temperature limits has a large influence on field sizing: for a **heating-dominant building** — one whose annual ground load in heating exceeds that in cooling, so the field length is governed by the coldest EFT reached in winter — a 1 °C change in the minimum EFT limit in heating mode can produce a 10–15 % change in total borehole field length. Setting $T_{\text{Lim,H}}$ too high forces a significantly larger field; setting it too low risks allowing the EFT to drop below the heat pump's safe operating range during peak heating conditions. When setting $T_{\text{Lim,H}}$, maintain a safety margin of at least 5–6 °C above the freeze point of the heat carrier fluid. This margin is necessary because the fluid temperature inside the heat pump evaporator can fall locally below the leaving fluid temperature (LFT) at the heat pump outlet. The Fluid Type module computes the freeze point for the selected fluid and concentration; consult it when finalising $T_{\text{Lim,H}}$.

In practice, choose the input mode that matches the data you can defend: a manufacturer datasheet for a final design, and a constant COP only for a first screening. Keep in mind that the entering fluid temperature the heat pump sees is governed by the distribution side as much as by the ground — lower heating supply temperatures and higher cooling supply temperatures both ease the duty on the loop and lift the seasonal COP. Selecting equipment that performs well across the EFT range your field will actually produce is often more valuable than chasing a high rated COP measured at standard conditions.

A higher-COP heat pump typically commands a higher purchase price; it also exchanges less heat per unit of energy delivered to the building, which paradoxically increases the annual ground load and therefore the required borehole field length and its capital cost. Chasing a high rated COP to achieve operating savings can therefore trigger capital cost increases on both the equipment and the geothermal field that more than outweigh the savings. Life-cycle cost analysis - not rated COP alone - should drive the equipment selection decision.



Heat carrier fluid

The heat transfer fluid and its concentration have a significant impact on the flow regime and heat transfer of the GHE, as well as on the required pumping energy. GHE Analysis allows you to quickly compare the impact of the heat transfer fluid and its concentration on the thermal conductivity (k_f), dynamic viscosity (μ_f), density (ρ_f) and specific capacity (c_p), and thus to calculate the convective resistance (R_f) of the borehole heat exchanger as a function of the entering fluid temperature (EFT).

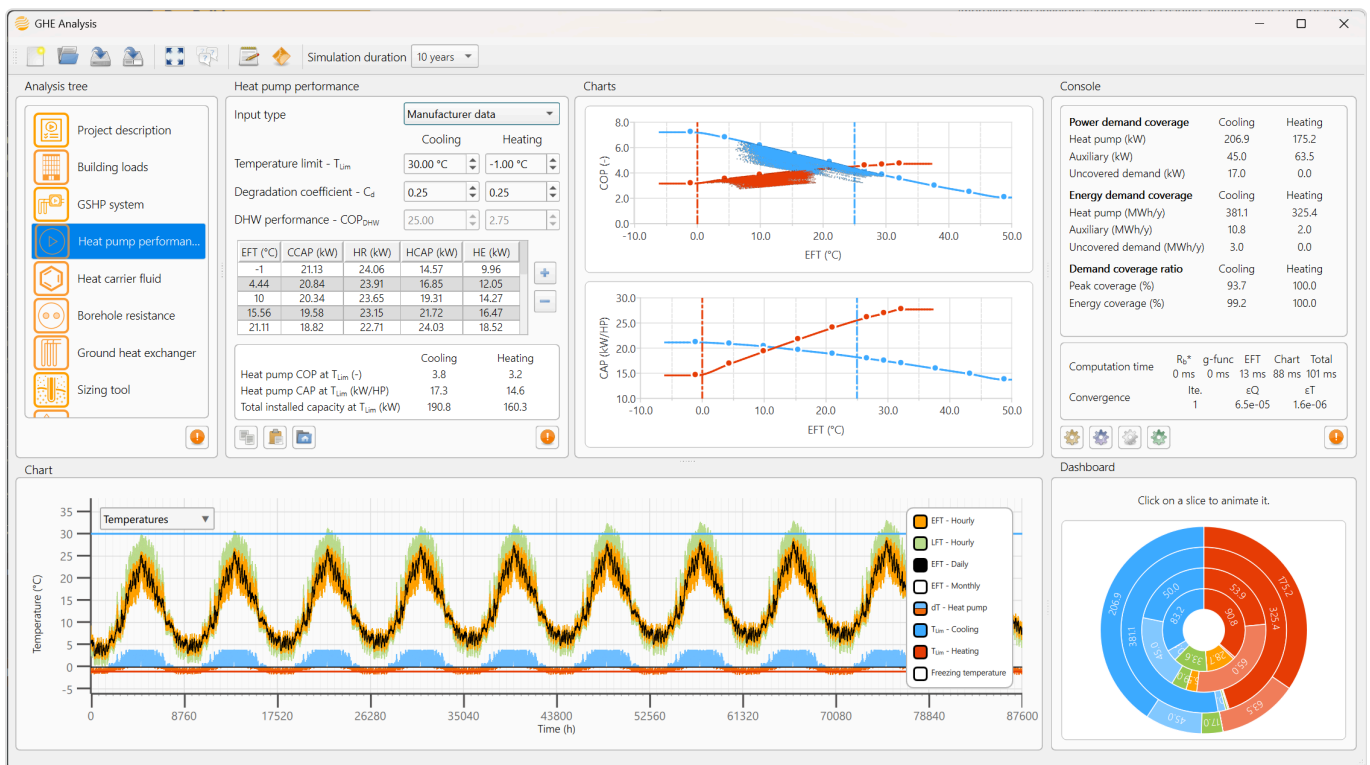


Figure 7 — Heat carrier fluid panel — fluid selector, antifreeze concentration spinbox and thermo-physical property charts (k , μ , ρ , c_p)

Heat carrier fluid - Thermo-physical properties of five fluids are integrated into GHE Analysis, making it easy to compare the impact of the fluid on system performance. The available fluids are pure water, ethylene glycol, propylene glycol, methyl alcohol and ethyl alcohol; their properties are computed from the Melinder correlations over the full temperature range.

Antifreeze mass concentration - This input box allows you to specify the mass concentration of antifreeze assuming that the solvent is pure water. The units of mass concentration are kg of antifreeze per kg of solution, reported as %.



Summary & charts: thermo-physical properties and convective resistance versus temperature

The page contains a summary showing the melting temperature of the fluid, the volume of fluid contained in the pipes, the different thermo-physical properties at T_{Lim} and the convective resistance of the geothermal well (R_f). The convective resistance R_f should be as small as possible in order to maximize the convective heat transfer in the pipes. The charts show the thermo-physical properties as a function of EFT while the vertical lines correspond to T_{Lim} for the cooling (blue) and heating (red) modes.



GSHP in practice: antifreeze concentration trade-offs, fluid selection and pumping costs

Antifreeze allows the heat pump to operate in heating mode at lower temperatures and thus extend its operating time. However, a high antifreeze concentration requires higher pumping energy and leads to a greater convective resistance R_f . This generally results in a larger and more expensive geothermal field, as well as higher pumping costs. Special care must be paid to the selection of antifreeze and its concentration, both during the construction phase and during the useful life of the GSHP system.

As a rule of thumb, the freeze (or burst) point of the fluid should sit a few degrees below the lowest temperature the loop will ever experience — and no lower. Over-concentrating "for safety" is a common and costly habit: it thickens the fluid, pushes the flow toward the laminar regime, raises R_f and pumping energy, and ultimately enlarges the field. The choice between propylene glycol, ethylene glycol and the alcohols is also governed by toxicity, local code and material compatibility, which often weigh as heavily as the thermal properties themselves.



Borehole designer

The effective borehole thermal resistance (R_b^*) of a borehole heat exchanger (BHE) significantly influences the heat exchange between the heat carrier fluid and the surrounding geological environment. R_b^* integrates the combined effect of borehole length, circulation flow rate and ground thermal conductivity into a single resistance value; it does not, however, account for the thermal capacity of the borehole components (pipes, grout, or fluid). By optimising the internal geometry of the BHE — pipe diameter, shank spacing, grout conductivity, and flow rate — the designer has direct control over R_b^* : a lower effective resistance reduces the required borehole field length and improves heat pump performance for the full system lifetime at a modest one-time investment.

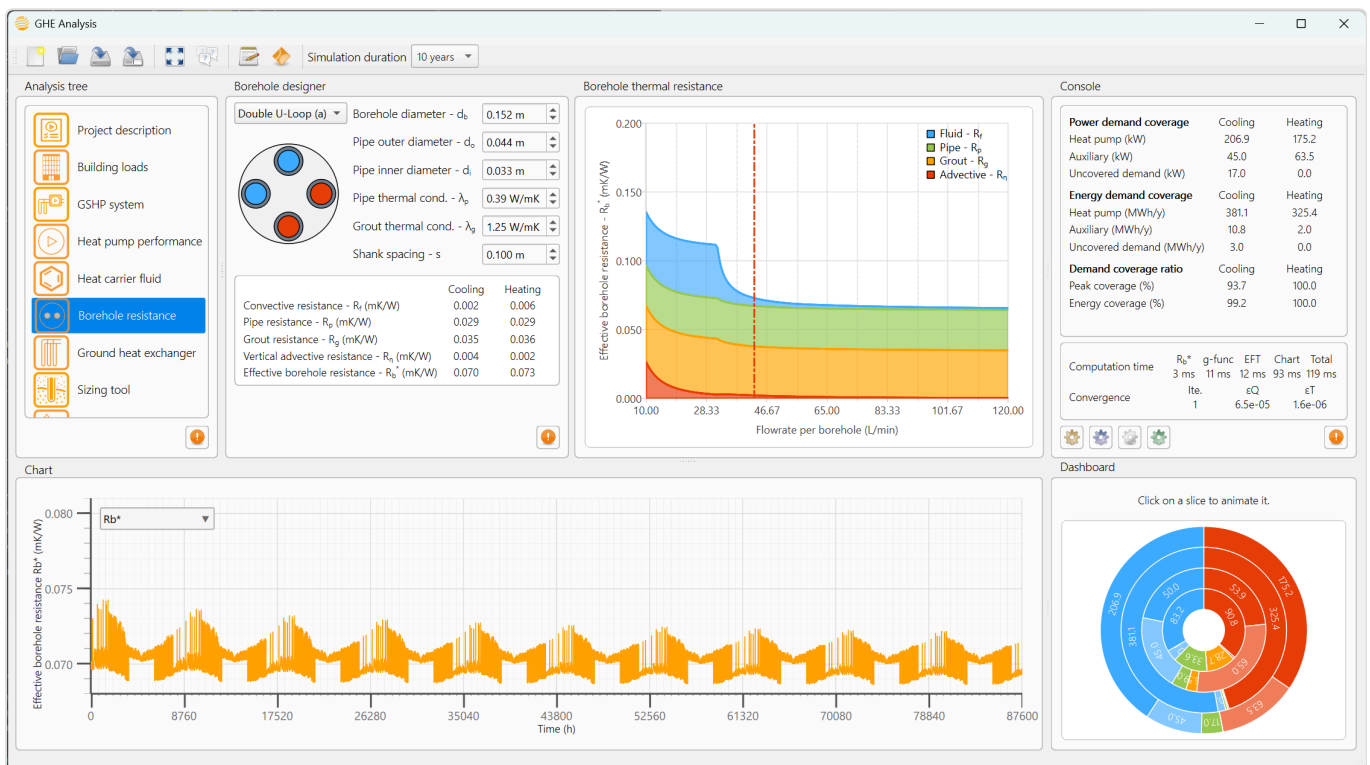


Figure 8 — Borehole designer panel — pipe geometry, grout properties and R_b^* charts as a function of flow rate and fluid temperature

Borehole heat exchanger type - The current version of GHE Analysis supports the simulation of the following five types of BHEs:

- **Single U-Loop** — one U-shaped pipe per borehole.
- **Double U-Loop (a)** — two U-loops with adjacent inlet/outlet pipes.
- **Double U-Loop (d)** — two U-loops with diagonal inlet/outlet pipes.
- **Coaxial** — concentric inner and outer pipes.
- **Standing Column** — a standing column well in center-in configuration.

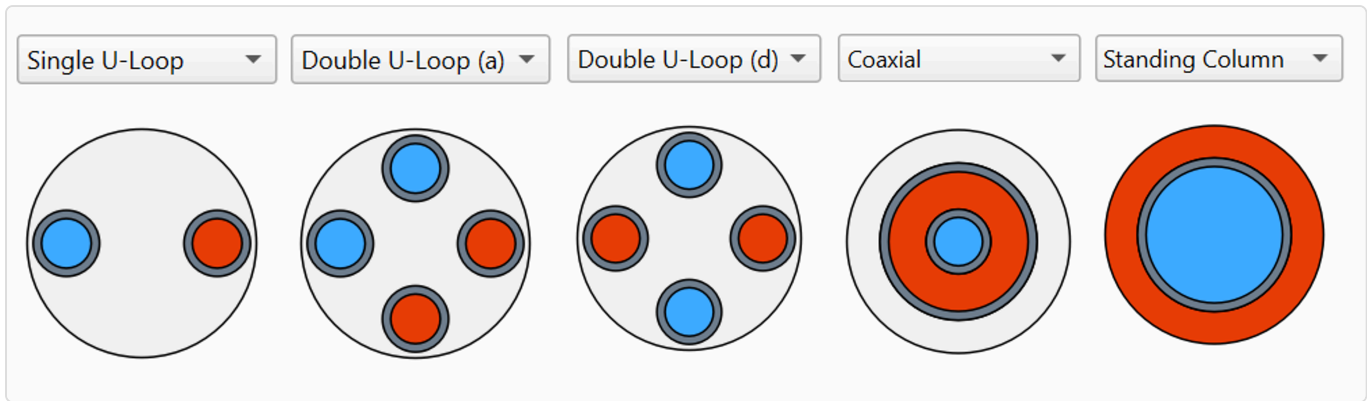


Figure 9 — The five borehole heat exchanger types supported by GHE Analysis — single U-loop, double U-loop with adjacent pipes, double U-loop with diagonal pipes, coaxial, and standing column well — each with its characteristic pipe arrangement inside the borehole

Borehole diameter (d_b) - In this input box, provide a borehole diameter that can be drilled by local contractors. If the outer diameter of the pipes and their spacing do not correspond to a possible geometric configuration, the value provided in this field could be refused by GHE Analysis.

Pipe outer diameter (d_o) - Along with the pipe inner diameter (d_i), d_o is used to compute the pipe thickness and the pipe thermal resistance (R_p). The diameter and thickness of the pipe should match locally available pipes.

Pipe inner diameter (d_i) - This parameter is used to compute the Reynolds number (Re), which determines if a turbulent flow is fully developed in the pipes. This allows computation of the convective resistance (R_f) for any EFT. The pipe inner diameter is also used to compute the pipe resistance (R_p).

Pipe thermal conductivity (λ_p) - The pipe thermal conductivity is used to evaluate the pipe thermal resistance (R_p). For coaxial BHE, λ_p corresponds to the inner pipe. The most common material for piping is high-density polyethylene (HDPE) and the value provided for λ_p should come from the product data sheet.

Grout thermal conductivity (λ_g) - The grout thermal conductivity (or thermal conductivity of any filling material) is used to evaluate the grout thermal resistance (R_g).

Shank spacing (s) - In this field, the center-to-center distance between pipes must be provided.

Outer pipe outer diameter (d_{oo}) — coaxial BHE only - Along with d_{oi} , d_{oo} is used to compute the pipe thickness and the thermal resistance of the outer pipe (R_p).

Outer pipe inner diameter (d_{oi}) — coaxial BHE only - This parameter is used to compute the Reynolds number (Re) in the annulus, which determines if a turbulent flow is fully developed between the two pipes of the coaxial BHE. This allows computation of the convective resistance (R_f) for any EFT. Note that the Reynolds number indicated in the interface corresponds to the flow regime in the annulus, since the latter is generally more critical than that in the inner pipe.

Outer pipe thermal conductivity (λ_o) — coaxial BHE only - The outer pipe thermal conductivity is used to evaluate the pipe thermal resistance (R_p). For coaxial BHE, λ_o corresponds to the outer pipe.

Bleed flow rate (V_p) — standing column well only - The bleed flow rate is a key parameter of the efficiency of SCWs and is used to evaluate the borehole equivalent resistance (R_b^*). When Standing Column is selected, the valid range of certain parameters may be reduced, as the current simulation model supports a narrower parameter range.

Summary & charts: borehole thermal resistance breakdown and flow-rate sensitivity

GHE Analysis provides a summary to easily analyze the various resistances impacting heat transfer in a borehole heat exchanger. To facilitate the comparison of different configurations, the resistances R_f and R_p presented by GHE Analysis correspond to equivalent resistances obtained by dividing a given resistance by the number of pipes in the borehole.

The current version of GHE Analysis also shows the variation of R_b^* as a function of circulation flow rate for the limit temperature in heating mode. The red vertical line corresponds to the total circulation flow rate in heating mode divided by the number of wells (V_A/n_{HP}) and allows to easily illustrate the impact of the flow regime on R_f . The high values usually present on the left of the graph corresponds to laminar flow in the pipes, a situation that should be avoided during peak periods. If the flow rate per BHE is greater than 120 l/min, the R_b^* value at this flow rate is used for calculations.

Note that R_{η} is given by $R_b^* - R_b$. Also, for a coaxial BHE, the R_p value shown in the interface corresponds to the outer pipe resistance.

GSHP in practice: minimising R_b^* through grout selection, pipe spacing and flow regime

A high circulation flow rate generally ensures turbulent flow and low convective resistance R_f . However, beyond a certain threshold, further increasing the circulation flow rate leads to a marginal reduction in R_f , but to a very significant increase in pumping costs and energy consumption. Designers should therefore pay particular attention to not using unnecessarily high pumping rates.

The borehole's internal geometry offers some of the largest controllable gains in R_b^* : thermally enhanced grout and pipes held apart by spacers rather than resting against one another can each shave meaningful resistance and, in turn, shorten the field. Standard bentonite-based grout has a thermal conductivity of 0.7–0.9 W/m·K; thermally enhanced grouts reach 1.5–2.5 W/m·K by incorporating conductive fillers such as high-conductivity sand. This conductivity increase typically reduces R_b^* by 20–40 %, with a roughly proportional reduction in the required borehole field length — a significant capital saving on larger installations where the cost of thermally enhanced grout is small compared to the cost of additional drilling. A lower R_b^* is almost always worth pursuing, since it improves heat transfer for the entire life of the system at a modest one-time cost.

GHE Analysis provides a live design environment for high-performance BHEs: every change to pipe geometry, grout conductivity, or flow rate is instantly reflected in the R_b^* summary and the flow-rate sensitivity chart. This immediate feedback lets the designer compare alternatives — double U-loop versus coaxial, standard versus thermally enhanced grout, or target flow rate versus installed pump capacity — and quantify the benefit of each choice in terms of borehole field length and operating cost before any hole is drilled. Note that R_b^* integrates the borehole length, circulation flow rate, and ground thermal conductivity, but does not account for the thermal capacity of the borehole components — a limitation shared by all quasi-steady-state borehole resistance models.

TRT Measurements. In the field, R_b^* is measured by conducting a thermal response test (TRT) on a test borehole. The R_b^* value obtained from a TRT is valid only for the specific conditions of that test — the circulation flow rate, the heat carrier fluid, and the geometry of the test borehole — and should not be applied directly to a design with different parameters. Because GHE Analysis recalculates R_b^* at every simulation hour as a function of the

instantaneous fluid temperature and flow rate, it does not accept a single fixed experimental value from a TRT. The recommended workflow is to first enter the test conditions (borehole geometry, grout conductivity, pipe dimensions, fluid type and flow rate) so that the value computed by GHE Analysis matches the TRT measurement; once agreement is established, the designer can adjust individual parameters — for example increasing grout conductivity or exploring the effect of a higher design flow rate — to optimise the final borehole configuration. Comparing the TRT result with the value computed at the design flow rate can also help validate the grout thermal conductivity and pipe placement assumptions entered in the Borehole Designer.

Pipe placement and spacers. The R_b^* model assumes that pipes are symmetrically positioned inside the borehole with maximum shank spacing. In practice, pipes tend to cluster together once grouting begins unless spacers are systematically installed at regular intervals along the entire borehole depth. A set of pipes resting against one another can easily double the effective borehole resistance, erasing the benefit of a thermally enhanced grout. Specifying spacer installation in the contract documents and verifying it on site are therefore as important as the thermal design itself.

Grout quality and site execution. The thermal conductivity of the grout depends critically on the water-to-solids ratio and on thorough mixing. A poorly mixed or over-diluted grout can deliver a conductivity significantly below its product specification, permanently increasing R_b^* for the life of the installation. Site supervision during grouting is a worthwhile investment, particularly for projects where the borehole field was optimised using a high-performance grout specification.



Ground heat exchanger

GHE Analysis uses a high-performance simulation model that considers several factors, including the burial depth of the wellhead, the direction and magnitude of groundwater flow, and the position and thermal interactions between the boreholes of the ground heat exchangers (GHE). To simplify the design of GSHP systems on sites with complex geometries, the software allows users to import a base map and interactively position boreholes on it. Once the map is georeferenced, the coordinates of the wells can be exported directly in the project's Cartesian coordinate system. The software also includes a 3D borehole visualizer that makes it possible to view complex geothermal fields, including those with inclined boreholes.

One distinctive strength of GHE Analysis is its ability to incorporate groundwater flow directly into the thermal simulation. When a Darcy flux is present in the aquifer, flowing groundwater continuously replenishes the thermal energy drawn from or rejected to the formation, attenuating the long-term temperature build-up around the borehole field. Accounting for this effect produces more accurate EFT predictions and, on sites where groundwater is measurable, typically reduces the required total borehole field length — a direct capital cost saving. For large projects where significant groundwater flow may be present, the groundwater flux should be characterized as early as possible in the design process and incorporated into the model.

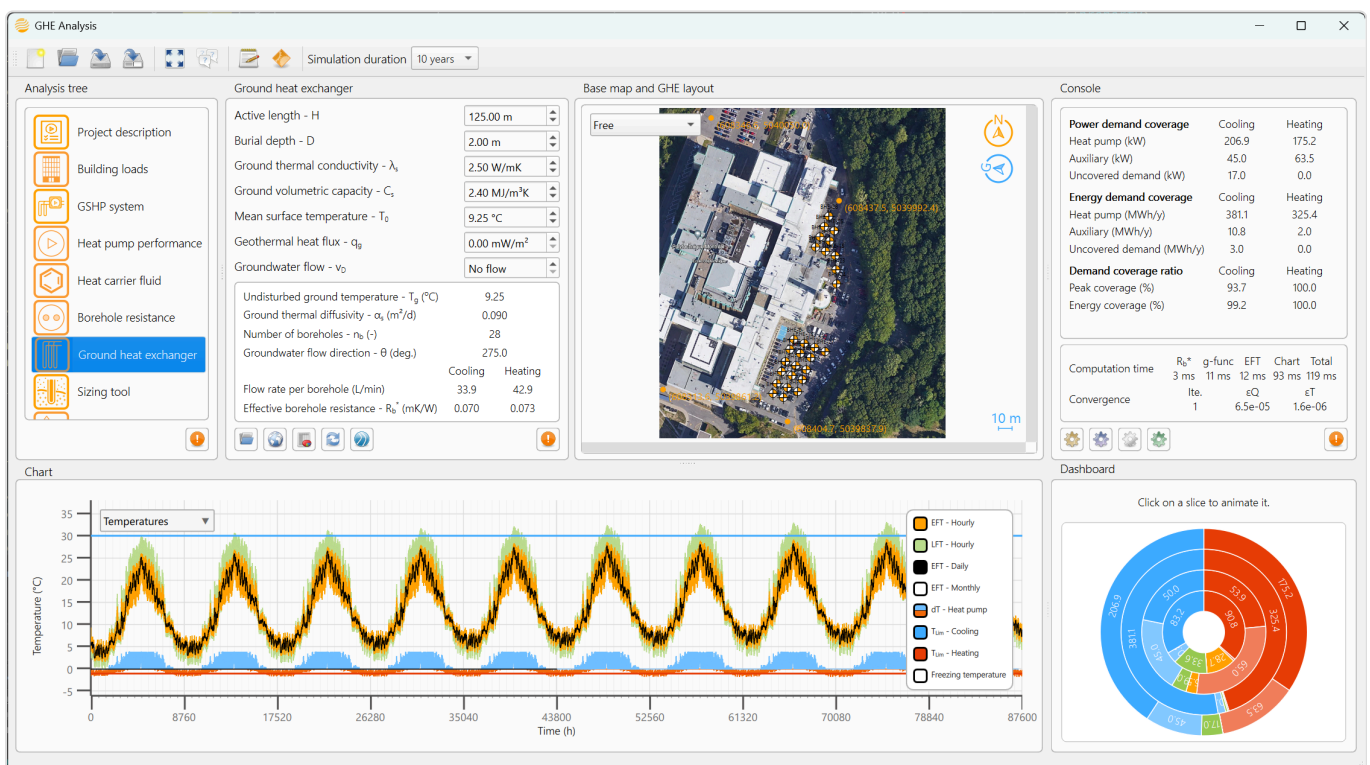


Figure 10 — GHE designer panel — interactive borehole layout on a georeferenced base map with 2D thermal plume overlay and field configuration controls

Base map and GHE layout - To streamline GHE design, the graphic scene includes a drop-down menu that provides quick configuration options for rectangular, hollow, L-shaped, elliptical, and inclined fields. Input boxes then allow you to interactively adjust the number of boreholes along the horizontal (H) and vertical (V) grid

directions, as well as the spacing between wells. For elliptical or circular GHE layouts, you can easily adjust the number of boreholes along the periphery (P), as well as the horizontal and vertical diameters of the ellipse.

Move, rotate, or stretch a group of boreholes - Select one or more wells by creating a selection box with the mouse, click and hold the orange area, and then move the rectangle to the desired destination. To rotate the group, click and hold the black dot in the lower-right corner of the rectangle, and then move the point. To stretch the selection rectangle, click and hold the black dot to the right or bottom of the rectangle, and then move the point.

Adding or removing a borehole - To add a single borehole at a specific location, simply double-click the window with the mouse. To remove a well or a group of wells, first select the wells to be deleted, then press the **Backspace** key.

Rotating the base map - To rotate the base map, press the **Shift** key and use the mouse wheel. Alternatively, you can press **Shift+M** or **Shift+K** simultaneously after selecting the base map.

Zooming - To zoom the base map, press the **Ctrl** key and use the mouse wheel. Alternatively, you can press **Ctrl+K** or **Ctrl+L** simultaneously after selecting the base map.

Changing the flow direction - To change the groundwater flow direction, press **Shift+Ctrl** and use the mouse wheel. Alternatively, you can press **Shift+Ctrl+K** or **Shift+Ctrl+L** simultaneously after selecting the base map. Note that rotation is done in 5° increments.

Add a base map - To add a base map, use the  button and select an image.

Georeferencing the map - In order to georeference the base map, you must select 4 points on the map and provide the coordinates of each point using the  button. Once this step is completed, the blue scale at the bottom of the map will be adjusted automatically.

Coordinates, azimuth and dip of inclined boreholes - To display the coordinates of each borehole in the local georeference system, click the  button to show or hide the table of coordinates. You can also copy the coordinates using the dedicated button located below the table. To specify the azimuth (clockwise relative to geographical north) and dip (positive relative to horizontal), double-click the corresponding cell and enter a value. If a borehole is not perfectly vertical, GHE Analysis will automatically use a moving inclined finite line source model. Note that this model is slower, so long simulation times may occur.

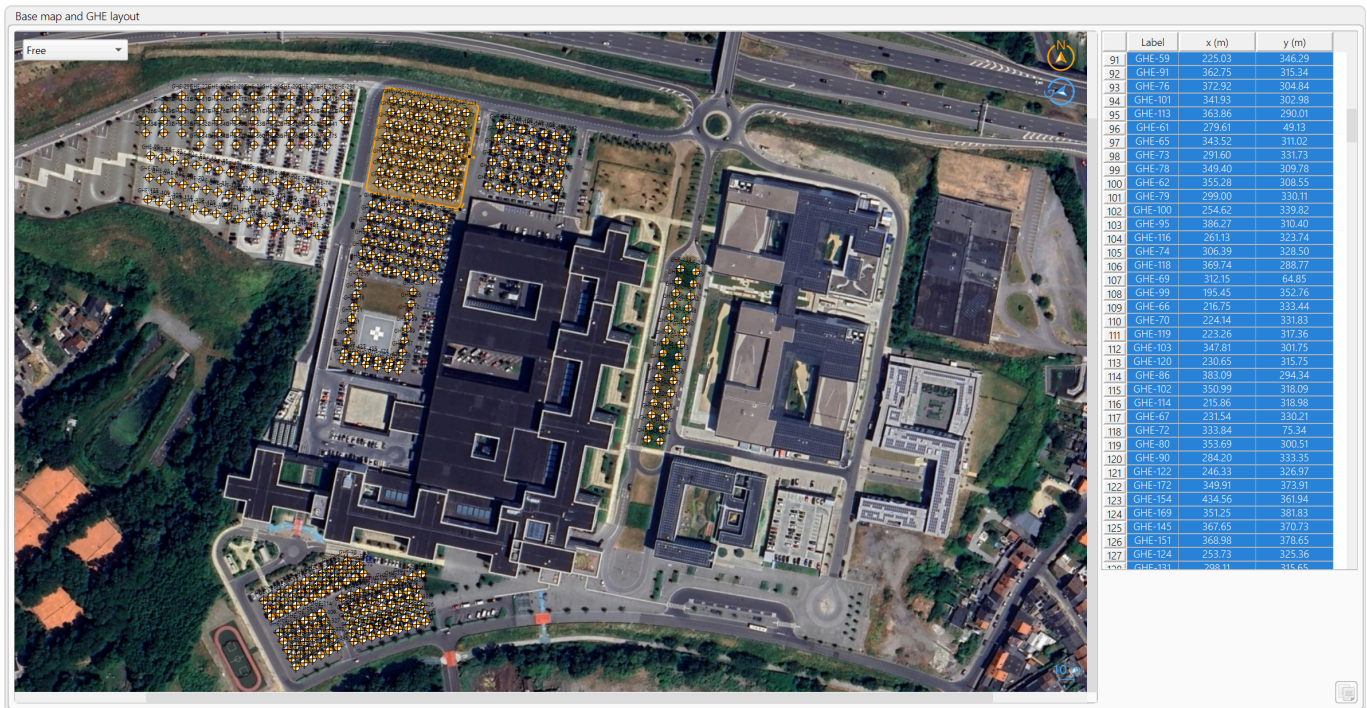


Figure 11 — GHE Designer — borehole coordinate, azimuth and dip table for a large and complex borehole field

3D borehole viewer - To activate the 3D borehole viewer, click the  button. This visualization mode is particularly useful when designing GHEs with inclined boreholes, or when illustrating the size and layout of geothermal systems to non-specialists.

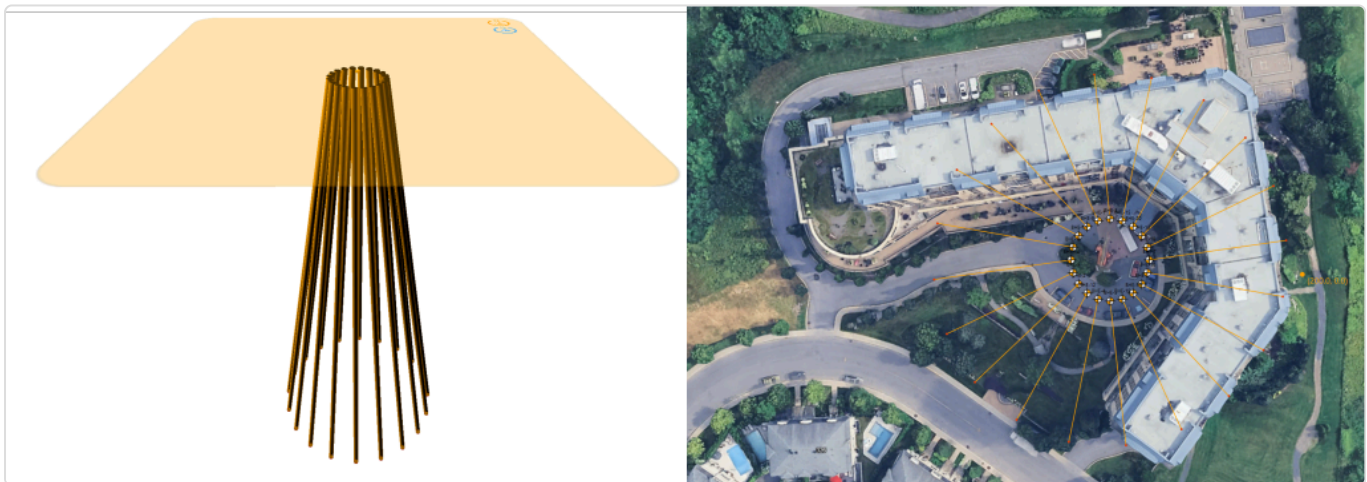


Figure 12 — GHE Designer — 3D borehole viewer showing the spatial layout and orientation of an inclined borehole field

Thermal plume viewer - To activate the thermal plume viewer, click the  button. Once enabled, a set of additional buttons appears, providing control over the thermal plume displayed in the window. These buttons allow you to choose between the ground temperature or the temperature change caused by the operation of the GHE, select the minimum and maximum range covered by the contour levels, select the number of contour levels for the plume, set the time corresponding to the thermal plume shown, and adjust the transparency of the contours.

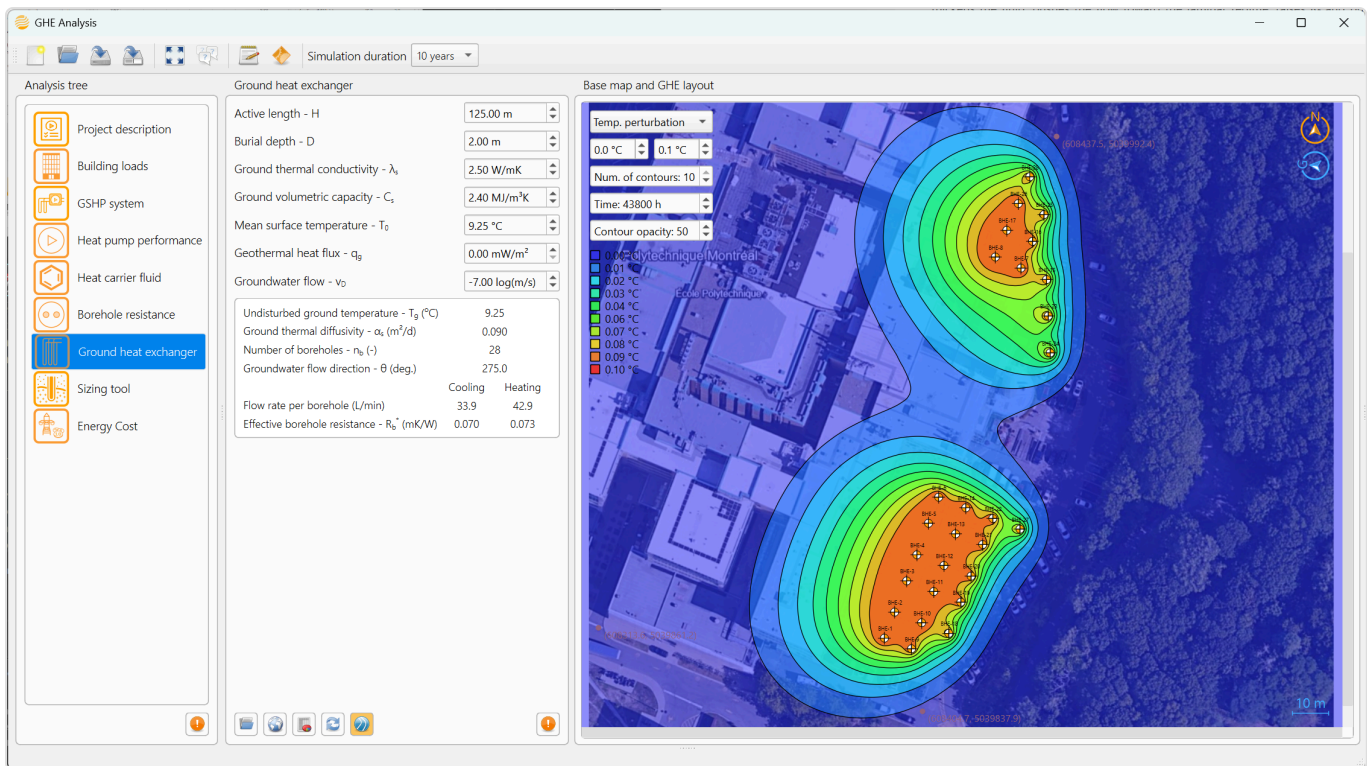


Figure 13 — Thermal plume viewer — isothermal contours of ground temperature change overlaid on the borehole layout at a user-selected simulation time

Note that the thermal plume is calculated based on the average ground thermal load from time zero up to the user-selected simulation time. This ensures an accurate representation of the cumulative thermal effects around the boreholes over time in a reasonable simulation time. By double-clicking a location on the map, the corresponding temperature at that coordinate will be displayed in the console under the field $T(x,y)$. To re-enable interactive mode, the thermal plume viewer must first be deactivated.

Active length (H) - The active length of each borehole is the distance from the top of the vertical pipes to the U-loop at the base of the well. This distance does not necessarily correspond to the length drilled on site. For Standing Column Wells, H corresponds to the saturated thickness along the SCW, that is, the groundwater static level minus the elevation of the base of the SCW.

Burial depth (D) - The burial depth is the depth to which the top of the vertical pipes will be installed below the final ground surface.

Ground thermal conductivity (λ_g) - This value is the average thermal conductivity along the well. For large projects, this value should be derived from a thermal response test conducted on site; the methodology for estimating thermal resistance and conductivity from TRT data.

Ground volumetric capacity (C_s) - This property is the product of the density (ρ in kg/m³) and the specific heat capacity (c_p in J/kg/K) expressed in millions (M) of J/m³/K. It is possible, but rather difficult, to deduce this value from a thermal response test. The use of a value taken from the literature is then recommended. The value of C_s is generally between 2.2 and 2.8 MJ/m³/K for most rocks (Waples and Waples, 2004).

Mean surface temperature (T_0) - The mean surface temperature is the average annual temperature observed at ground level. Together with the geothermal heat flux and ground thermal conductivity, this value is used to establish the undisturbed ground temperature between the surface and the base of the boreholes. To easily set the undisturbed ground temperature T_g , set the geothermal flux to 0.0; T_0 and T_g will then be equal.

Geothermal heat flux (q_g) - The geothermal heat flux, measured in milliwatts per square meter, is used to determine the undisturbed ground temperature T_g between the surface and the bottom of boreholes. The resulting undisturbed ground temperature T_g is shown below the input boxes.

Groundwater flow (v_D) - This value corresponds to the groundwater flux (Darcy flux), not the actual groundwater velocity. The input field accepts the base-10 logarithm of the flux in m/s, not the flux itself. Note that using a value of -12 allows the case of zero water flux ($v_D = 0$ m/s) to be numerically represented. The direction of water flow is illustrated on the map using the blue arrow (G).



Summary & charts: total field length, drilled depth and groundwater flow indicators

The page contains a summary showing the total length of the GHE, the total length drilled assuming that the wellhead starts at a depth D , as well as various values useful for the design of the GHE. Note that the direction of groundwater flow presented in the summary is calculated clockwise relative to the geographic north of the base map.



GSHP in practice: ground property accuracy, thermal response tests and field layout strategy

Beyond the ground properties, the field geometry itself is a design lever the a designer controls directly. Wider spacing reduces the long-term thermal interference between boreholes — decisive for strongly unbalanced loads — but demands more land; tighter grids save area at the cost of a field that drifts warmer or cooler over the years if the ground loads are unbalanced. The layout should be coordinated early with the rest of the site (foundations, parking, services and any future construction), since a borehole field is effectively permanent once drilled.

TRT Measurements. Under certain conditions, a 10% error in the undisturbed temperature (T_g) or thermal conductivity (λ_s) can lead to a 10% oversizing of the GHE. For large-scale projects, these values should therefore be derived from a thermal response test carried out on a test well. It should be noted that the test well should be located so that it can be integrated into the final geothermal field.

Groundwater flow. Where groundwater flow has been measured or estimated, it should always be incorporated into the design. The thermal advection from flowing groundwater can substantially reduce the required total borehole field length: the moving water continuously replenishes the thermal energy drawn from or rejected to the ground, attenuating the long-term temperature drift around the field and allowing a more compact layout. If the groundwater flow is uncertain at the design stage, the conservative choice is to ignore it; any flow present in reality will only improve performance beyond the design prediction. Characterising groundwater flow in the field is costly — it generally requires installing piezometers and running pumping tests — so the investigation is seldom justified on small projects. On the other hand, for large geothermal projects where significant groundwater flow is suspected, early characterisation of groundwater flow can be highly cost-effective. Accurate quantification of groundwater flow may substantially reduce the required borehole field size, with drilling cost savings often far exceeding the cost of the investigation.

g-function. The g-function is the dimensionless thermal response function of the borehole field. It quantifies the temperature rise (or drop) at the borehole wall per unit of normalised heat flux applied uniformly to all boreholes, as a function of dimensionless time. Because the g-function is computed from the complete field geometry — borehole positions, active depth, burial depth, spacing — together with the geological and hydrogeological properties of the formation, it fully encodes the long-term thermal behaviour of a specific design. GHE Analysis

recalculates the g-function automatically each time a borehole is added, moved, or removed, giving the designer immediate feedback on the thermal consequences of each layout decision. The maximum value reached by the g-function at the end of the design horizon is the single most informative performance indicator for the borehole field. A low maximum g-value means that the field can exchange heat with a smaller average temperature penalty at the borehole wall, which translates directly into a wider EFT margin from the temperature limits, a better seasonal heat pump COP, or a shorter total field length for the same performance target. Designers should therefore aim to minimise the maximum g-function value: wider borehole spacing, distributed or non-rectangular arrangements that reduce long-range thermal interference, and field configurations that exploit the local geology all contribute to flattening the g-function at long times. When groundwater flow is present, advective heat transfer further attenuates the long-term plateau, reinforcing the value of characterising the site hydrogeology early in the design process.



Sizing tool

Sizing tools have historically been widely used to determine the number and active length of the boreholes of a GSHP system. GHE Analysis allows you to easily size the GHE using ASHRAE's alternative method. The approach is particularly useful because it allows to easily determine the elements influencing the total length of the GHE and to modify them in order to reduce the size of the field. The active length H provided by the tool is therefore not used to simulate the GSHP system and calculate the values presented in the console.

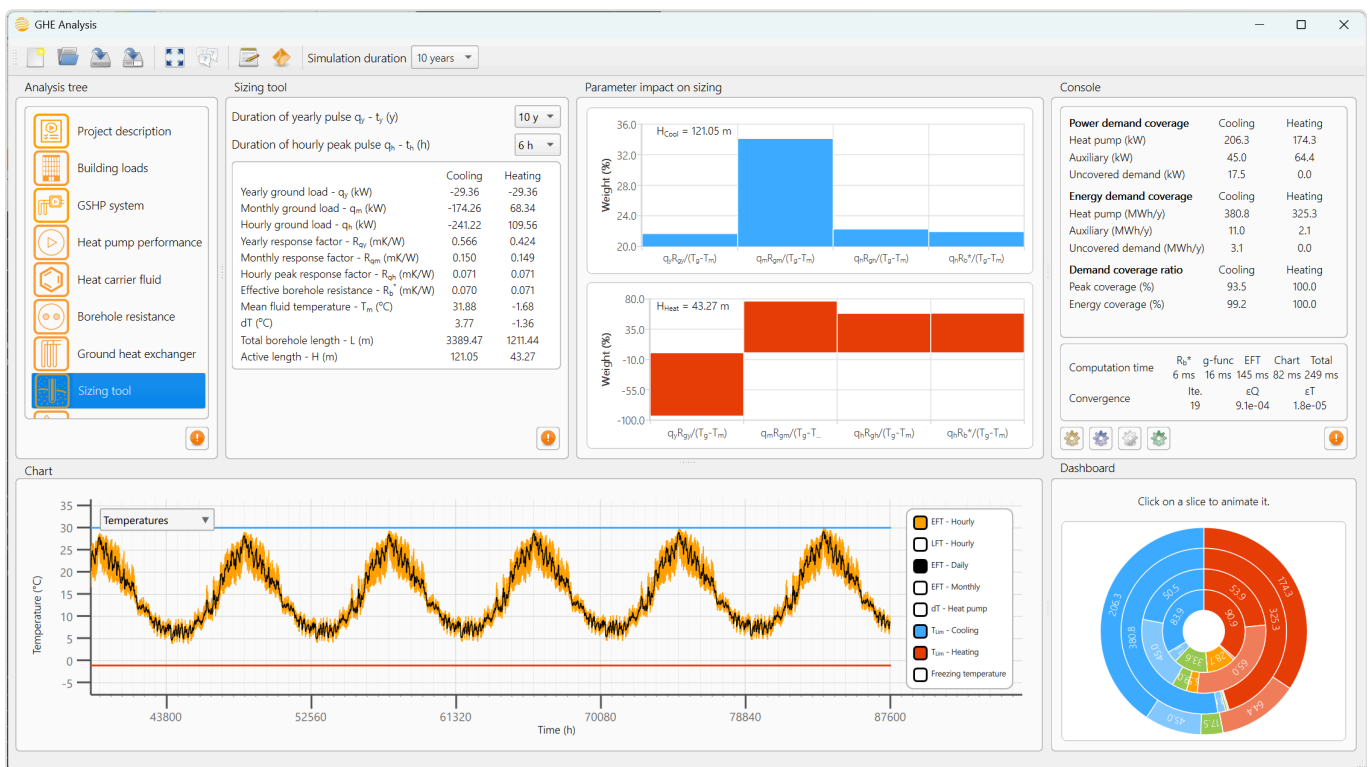


Figure 14 — Sizing tool panel — ASHRAE alternative method output showing required borehole active length broken down by pulse contribution

Duration of yearly pulse (t_y) - This is the period over which the average annual ground load is applied and should match the simulation duration. It captures the slow drift of the ground temperature caused by any imbalance between the heat injected and extracted over the years.

Duration of hourly pulse (t_h) - This is the duration of the peak-load block used to size for the worst case — typically a few hours (e.g. 4 to 6 h).



Summary & charts: ASHRAE three-pulse field length broken down by thermal contribution

The page contains a summary of the values useful for calculating the total length of the field by ASHRAE's alternative method. The charts represent the fraction of the total length as a function of the following four elements:

1. The first column is mainly associated with the annual pulse q_y . For balanced ground loads, this value is generally low. Otherwise, one should attempt to balance the ground loads or modify the geometry of the GHE.
2. The second column is a function of the monthly response factor (R_{gm}) and the average monthly load (q_m) of the month containing the thermal peak.
3. The third column is dictated by the hourly peak and by the hourly response factor (R_{gh}).
4. The last column is used to isolate the influence of R_b^* on the total length of the GHE.

Read together, the four columns tell you *why* a field is the size it is — and therefore where to act. A tall first column points to an unbalanced load that hybridisation or load-side measures could correct; a tall last column points to a borehole resistance worth improving before adding length.

GSHP in practice: using the sizing result as a starting point for full EFT simulation

It is important to keep in mind that the sizing tool assumes that EFT never exceeds T_{Lim} , which is not the case with the simulation model of GHE Analysis. Furthermore, two different lengths are calculated, one for the cooling mode and one for the heating mode. The longest value is usually a better guide of the length to use with GHE Analysis.

Treat the sizing tool as a fast, transparent starting point rather than the final word: it sizes for a temperature limit that is never exceeded, whereas the full simulation lets EFT move freely and reports what actually happens. A sound workflow is to size here, transfer the longer of the two lengths into the field layout, then confirm — and fine-tune — with the simulation, where load balancing, borehole resistance and field geometry can all be weighed against cost.



Console & Dashboard

GHE Analysis uses the console to present the main indicators useful for the design of a GSHP system and to provide information on the convergence of its simulation model. The console buttons give access to information related to demand coverage, energy use and energy efficiency of the system, as well as energy cost.

Results summary - The console is organised as four independent pages, accessed by clicking the , , , and  buttons at the top of the panel. All four pages share a common footer that shows computation times and convergence indicators.

- **Page 1 - Demand coverage.** Reports, for cooling and heating separately: the heat pump output at the system peak (kW), the auxiliary contribution at the system peak (kW), the uncovered peak demand (kW), the demand coverage ratio (%), the mean annual energy provided by the heat pump (MWh/y), the auxiliary annual energy (MWh/y), the annual uncovered energy (MWh/y), the peak coverage (%), and the overall annual energy coverage (%). This page answers the central sizing question: does the system meet the peak demand and cover the annual energy need?
- **Page 2 - Energy consumption.** Reports the total system peak power demand (kW) and the mean annual electricity consumption (MWh/y) for each component - heat pump, auxiliary equipment, and circulation pumps - together with the combined system total. Use this page to assess the electrical load profile and evaluate pump energy relative to compressor energy.
- **Page 3 - Ground performance and system efficiency.** Reports the seasonal COP of the complete system (sCOP), the average heat pump COP, the minimum or maximum EFT reached over the full simulation horizon, the mean annual energy exchanged with the ground (MWh/y), the long-term thermal balance of the ground (cooling energy minus heating energy, MWh/y), and the long-term EFT drift (ΔT , °C/y). A non-zero balance or a notable drift signals a thermally imbalanced field that may require corrective measures over its design life.
- **Page 4 - Annual energy cost.** Displays the mean annual energy cost attributed to the geothermal heat pump, auxiliary heating, auxiliary cooling, and the combined system total (currency/y), together with the effective mean energy rate (currency/kWh) for cooling and heating. This page is populated once the Energy Cost module contains at least one active tariff rule; dashes are shown otherwise.

Computation time and convergence - The console provides a summary of the time required to complete the calculation of the effective borehole resistance (R_b^*), the GHE transfer function (g-function), the entering fluid temperature (EFT) and the time required to display the results. Most of the time, the display of the graphs is the most time-consuming operation. To ensure the integration of the COP(EFT), CAP(EFT) and R_b^* (EFT) curves, GHE Analysis uses a robust iterative process to reduce the numerical error associated with the ground loads (ϵ_Q) and EFT (ϵ_T). The elements influencing convergence are a COP(EFT) and CAP(EFT) curve with abrupt changes in slope, a high R_b^* , and a circulation flow located in the transitional zone.

If the residuals (ϵ_Q , ϵ_T) fail to settle, the usual remedies are to smooth a heat-pump performance curve that changes slope too abruptly, to add boreholes or length where the fluid temperature swings are extreme, or to keep the circulation flow clear of the laminar-to-turbulent transition. A converged solution shown in green is the signal that the reported energy, efficiency and peak figures can be trusted.

Dashboard donut diagram - To allow an interactive design of the system, most of the numerical values displayed on the console are graphically illustrated on the donut diagram located in the dashboard. By clicking on a piece of the diagram, it is possible to highlight a particular indicator. Progressing from the outside to the inside of the diagram, the rings contain respectively the demand coverage, energy coverage, power demand and energy consumption. Starting from noon and moving counter-clockwise, the first three pieces of each ring correspond to cooling and the last three correspond to heating.



The Charts panel displays interactive time-series plots of all simulation outputs over the full design horizon. Select the variable to display from the first drop-down list at the top-left of the chart.

Series visibility via the legend - Each series entry in the chart legend can be clicked to toggle that series on or off. When several curves overlap - for example the hourly and daily EFT profiles - hiding the denser series clarifies the view without discarding any data. The legend entry re-enables the series with a second click.

Entering fluid temperature (EFT) - Plots the hourly EFT, the daily average EFT, and the monthly average EFT on the same time axis, together with horizontal lines marking the cooling and heating temperature limits ($T_{Lim,C}$, $T_{Lim,H}$) and, where applicable, the freezing threshold of the heat carrier fluid. This is the primary diagnostic chart: a EFT profile that consistently approaches T_{Lim} signals an undersized borehole field or insufficient flow rate. A pronounced sustained drift in the EFT profile over successive years reveals a thermally imbalanced field that may require a corrective strategy — beginning with measures on the building side, such as improving the building envelope (insulation upgrades, high-performance glazing, reduction of thermal bridges), adjusting solar gains (shading devices, solar heat-gain coefficient of glazing, overhangs), or reducing internal heat gains through more efficient equipment and controls — before adding mechanical supplements such as a solar supplement or a cooling tower.

ΔT displays the temperature difference between the entering and leaving fluid for each simulation hour, separated by heating and cooling mode. A ΔT that departs significantly from the design value indicates an off-design flow condition or an unusual building load pattern.

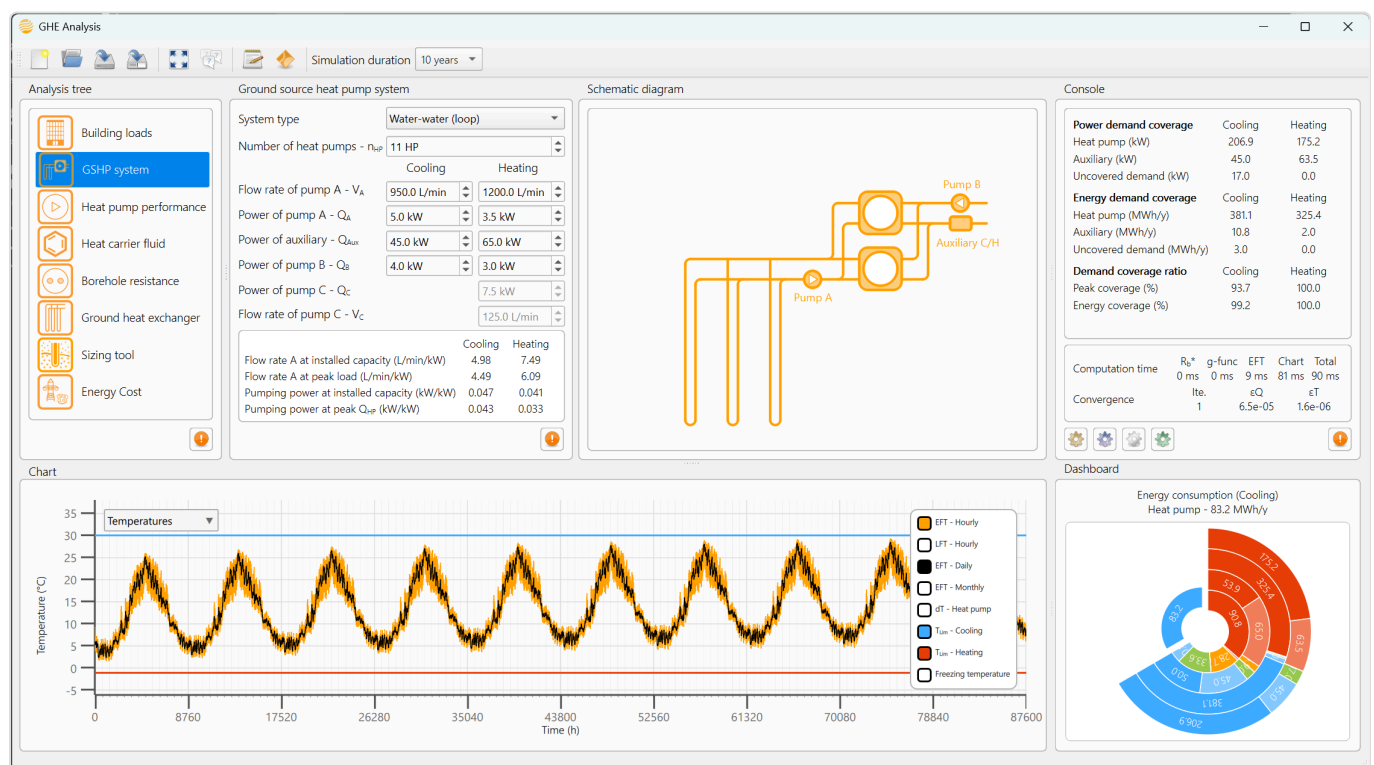


Figure 15 — Charts panel — entering fluid temperature (EFT) time series showing hourly, daily and monthly averages with cooling and heating temperature limit markers

Thermal loads (Q) - Overlays the building demand (Q_b), the heat pump output (Q_{HP}), and the auxiliary equipment contribution (Q_{Aux}). The ground loads series (Q_g) shows the hourly heat exchanged with the ground: positive values represent heat rejection to the ground (cooling mode) and negative values represent heat extraction (heating mode). When DHW loads are defined, the domestic hot water demand and the fraction actually covered appear as separate series. Heating loads are plotted as positive values; cooling loads as negative. This chart makes it easy to identify hours when the heat pump operates at full load, when auxiliary equipment engages, and when building demand is partially unmet.

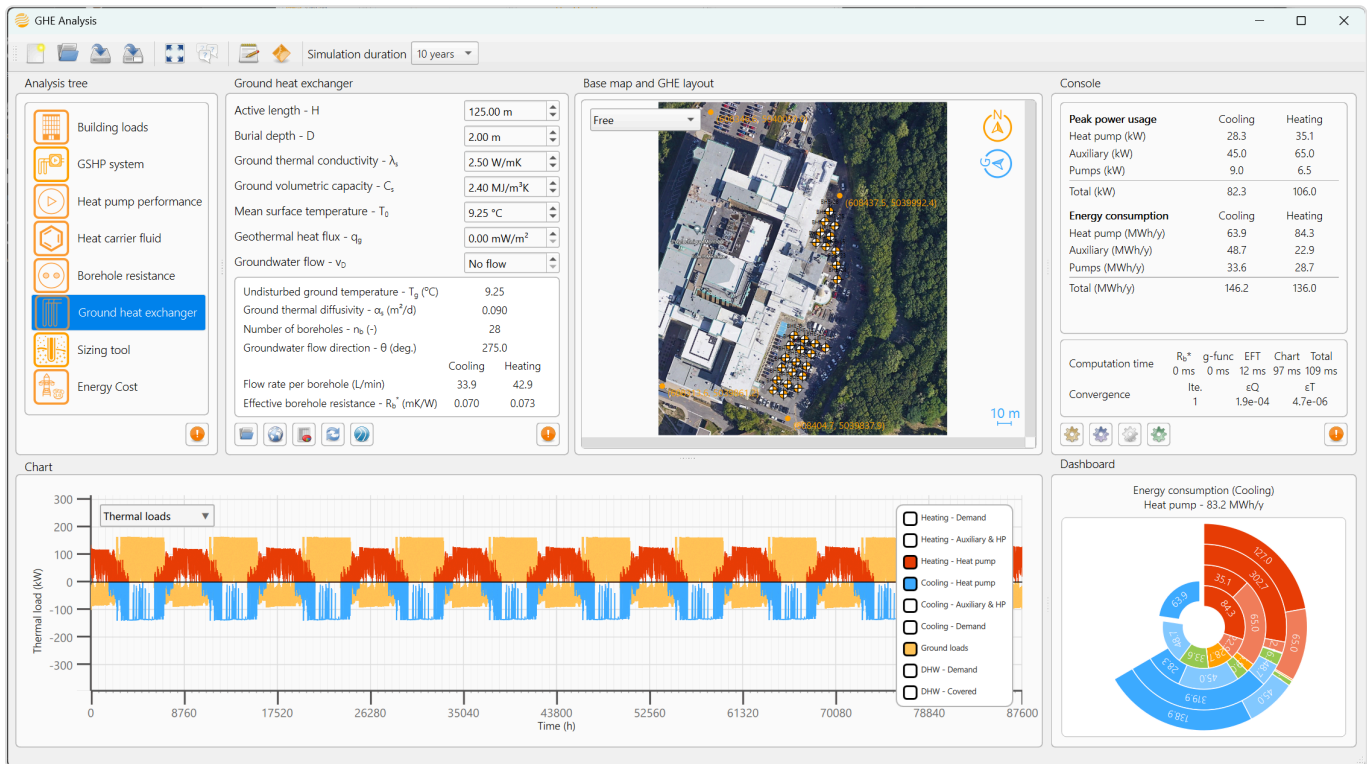


Figure 16 — Charts panel — thermal load time series overlaying building demand, heat pump output, ground loads and auxiliary contribution

Coefficient of performance (COP) - Plots the instantaneous COP and the mean COP corrected for part-load cycling, together with the number of active heat pumps and the number of installed heat pumps. The spread between the instantaneous and corrected COP curves quantifies the cycling degradation penalty governed by C_d . Low part-load ratios combined with a high C_d can significantly reduce the effective system COP relative to the manufacturer rating.

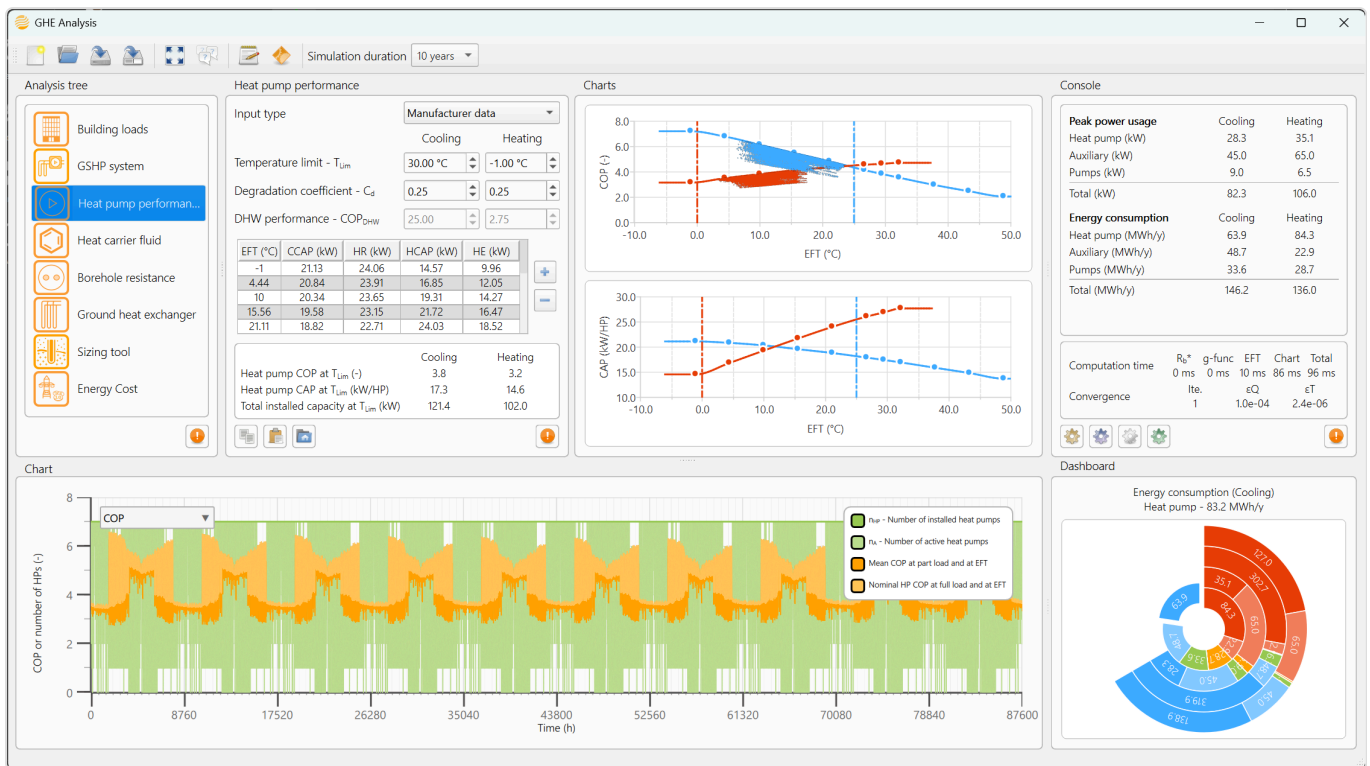


Figure 17 — Charts panel — instantaneous and part-load corrected COP over the simulation horizon with number of active and installed heat pumps

Effective borehole thermal resistance (R_b^*) - Plots R_b^* to reflect the variation of convective resistance with EFT. A spike in R_b^* at low flow rates corresponds to the laminar-to-turbulent transition. Use this chart to confirm that the design flow rate is keeping the circuit in the turbulent regime during peak periods.

g-function - Displays the thermal response function of the borehole field on a logarithmic time axis. The g-function is the core transfer function that converts ground loads into temperature changes at the borehole wall. Its shape encodes the geometry of the borehole field: a steeper rise at long times indicates stronger thermal interaction between boreholes, typical of dense rectangular fields. A well-designed borehole field targets the lowest possible maximum g-function value: a lower plateau means that the same ground load produces a smaller temperature penalty at the borehole wall, directly widening the EFT margin from the temperature limits and improving heat pump efficiency over the full design life. Use this chart together with the GHE Designer to compare layout alternatives and identify the configuration that minimises the long-term g-function.

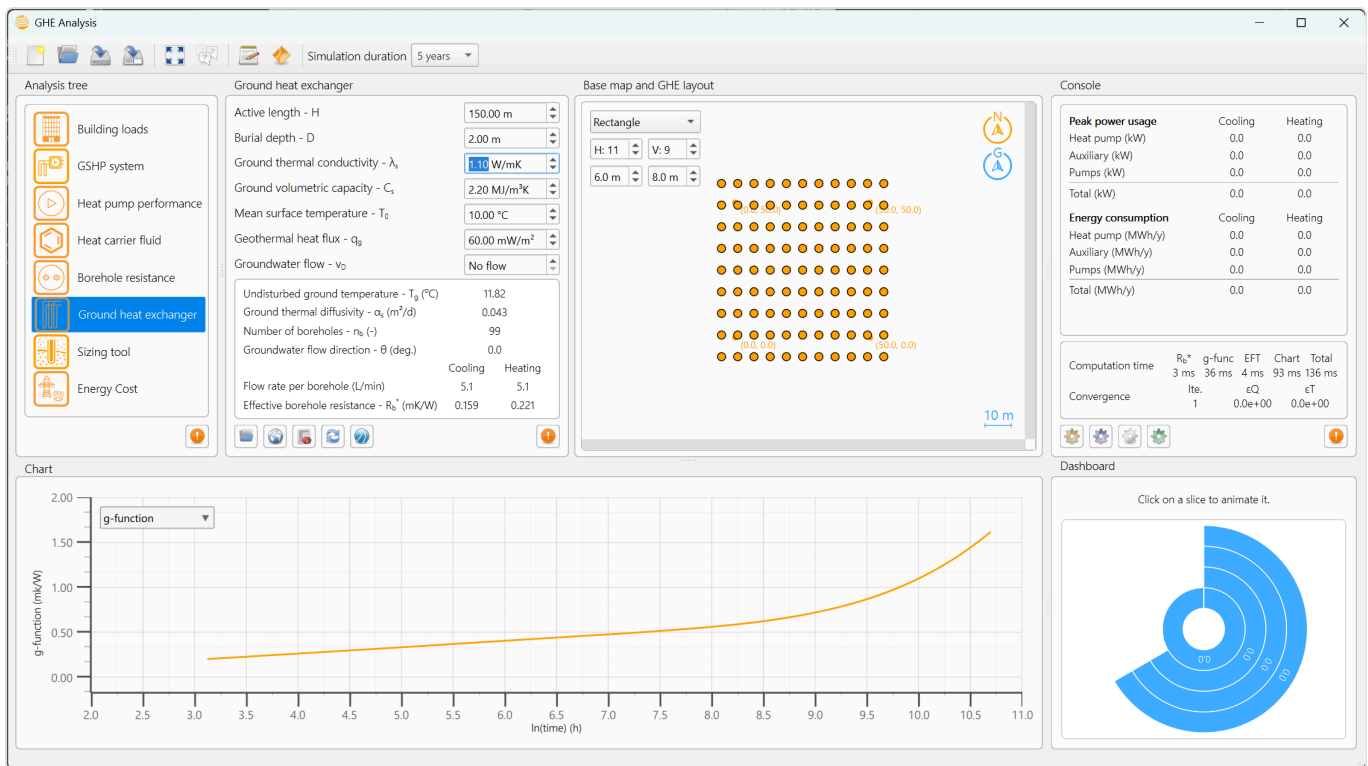


Figure 18 — Charts panel — g -function of the borehole field on a logarithmic time axis showing the thermal response and long-term inter-borehole thermal interaction

Energy cost - Shows the hourly operating cost - geothermal heat pump, auxiliary heating, auxiliary cooling, and system total - as time series, together with a stacked monthly bar chart decomposed by tariff rule. This chart is populated only when the Energy Cost module contains at least one active tariff rule; it remains empty otherwise. The monthly stacked bars reveal seasonal cost patterns and the relative weight of each tariff rule over the year.

Summary & charts: navigating the chart panel

Zoom options - Hold the left mouse button and drag to draw a rubber-band selection rectangle; the chart instantly zooms into the selected area. Scrolling the mouse wheel zooms along the time axis around the cursor position. Zooming is available on all chart types including the energy cost bars.

Restore-view button - The **Restore view** button in the main toolbar resets the zoom for all charts simultaneously, returning to the full simulation span and the auto-scaled Y axis. Use it after zooming in to quickly recover the overall picture of the simulation.

Value callout - The **callout** button in the main toolbar activates a floating tooltip. Once active, hovering over any point in the chart displays the exact time and value in a label that follows the cursor. Clicking a point pins the callout in place so the value can be read or copied; clicking elsewhere dismisses it. The callout is particularly useful for reading peak EFT values or identifying the exact hour of maximum ground load.

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The scientific publications listed below underpin the models implemented in GHE Analysis. For a broader list of publications associated with the software's development, visit gheanalysis.com/references.

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