

# **EED - Frequently Asked Questions**

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<https://buildingphysics.com/download/eedfaq.pdf>

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# EED - Frequently Asked Questions

A collection of frequently asked questions has been assembled in this document. They are organized according to the most fitting submenu heading in the program.

The following documents may also be of some assistance:

- [Notes from Geotrainet Course in 2016 showing some test cases with comparisons to measured data](#)
- [Explanation to SPF in EED](#)
- [A “textbook”-file from the international summer school in 2001](#)
- [One of the papers cited in the manual from 1997 with conclusions of EED](#)
- [A general paper on GSHP from 2003, with reference to EED](#)
- [Paper that presents the first version of EED 1994](#)
- [Eskilson Ph.D.Thesis \(1987\).pdf](#)
- [Hellström Ph.D. Thesis \(1991\).pdf](#)

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## 1 General questions

**Q.**

I have downloaded the EED User Manual and after some study of it I have some questions to which I would be most pleased to receive your replies and observations. I should explain that I have developed an interest in applying BHES to UK conditions where the technology to date is largely ignored (GeoScience excepted). I would like to understand the mathematical basis for the so-called g-functions, and how they are calculated and incorporated into EED. I understand that they were originally formulated by P Eskilson in his Doctoral Thesis at The University of Lund (1987), and subsequently incorporated into the EED simulation model, apparently in a more simplified form. Most of the references are to internal reports published by Lund University by Eskilson and later workers. Is it possible for you to send me any papers explaining these functions in detail and how they feature now in EED?

**A.**

The g-functions are implemented in the EED program as they were formulated by Per Eskilson. Per Eskilson calculated g-functions for about 40 different configurations and for each configuration several different values of the dimensionless ratio between borehole spacing and borehole depth were used. All g-functions have since been recalculated to include shorter time-scales for 797 different configurations where the ratio between spacing and depth can be varied between 0,02 and 0,5. The theory of the g-functions is explained in Eskilson's doctoral thesis that can be downloaded from [www.buildingphysics.com](http://www.buildingphysics.com). The borehole thermal resistance is explained in more detail in the thesis by Hellström. Thus thesis can be found at the same site.

**Q.**

In the example design in the EED Manual it seems that equal rates of extraction/injection are applied to each borehole, obtained by dividing the monthly and peak net totals by the total number of boreholes (4 in the example). Is this a correct interpretation of EED and if so is an equal rate of heat extraction/injection applied to all boreholes in any selected configuration?

**A.**

No, that is not how the g-functions in EED have been calculated. The simplification assumed in the g-function formulation is that all boreholes have the same fluid temperature, so the heat transfer rates will vary between (and along) the boreholes. The fluid temperature used is the mean value of inlet and outlet fluid temperature. We have found this to be a good approximation and certainly better than assuming equal rates from all boreholes.

The g-functions have been calculated using a simulation model called Superposition Borehole Model that allows for various different loading conditions:

1. borehole wall temperatures the same for all boreholes – heat transfer rates calculated

2. heat transfer rate per meter borehole (heat flux) the same for all boreholes – borehole wall temperature calculated
3. total heat transfer rate (for all boreholes) given – common borehole wall temperature calculated (g-functions)
4. given inlet fluid temperature and fluid flow rate (boreholes may be coupled in series or parallel or combination of these, there may also be different hydraulic systems with different loading conditions) – outlet temperatures and heat transfer rates calculated
5. as number 4, but total heat transfer rate and flow rate are given – (required) inlet fluid (and resulting outlet) fluid temperatures are calculated. In this model the boreholes can be placed arbitrarily and also non-vertical. Load conditions can be varied (and mixed) with any time-step. (The SBM model is currently an old-fashioned FORTRAN program running in batch mode). Running EED and SBM for the same configuration and load conditions give the same results.

**Q.**

Does EED account for tilted (with an angle) boreholes?

**A.**

No, EED only allows for vertical boreholes. You can however use the mid-point of the effective length of the borehole as an approximation. The “mid-point” is at half of the depth of the borehole. In this case we consider that all boreholes are at least straight, when angled (not in a curve like in oil or deep geothermal). So if you draw a plan of the borehole field with the location on surface and extrapolate the relative position of the boreholes at final depth, the “mid-point” is just in the middle from the top to the bottom point, seen either from top or from the side. For the distance of boreholes at this mid-point, the boreholes in the upper half are closer to each other (I reckon only outward angles make a sense anyway), and in the lower half have more distance. So giving the mid-point as “spacing”, you have the average distance. As written, this is not exact, but a good approximation. We have however an inhouse model (SBM) that accounts for tilted boreholes. Let us know if you need help with calculations.

**Q.**

Wir arbeiten für die Auslegung von Erdwärmefeldern mit dem EED-Programm. Hierzu stellt sich folgende Frage:

Kann eine räumliche Temperatursausdehnung für ein Erdsondenfeld (ohne Grundwasser) mit dem o.a. Programm simuliert bzw. dargestellt werden. Es geht um die Beeinflussung eines benachbarten Sondenfeldes durch ein geplantes Sondenfeld in einem Genehmigungsverfahren. Hier wird ein entsprechender Nachweis verlangt.

**A.**

EED ist ein gegenüber numerischen Simulationsmodellen vereinfachtes Verfahren, in das Ergebnisse aus solchen Simulationen über die g-Functions eingehen. Daher kann nur die Temperatur in den Sonden, nicht die Ausbreitung berechnet werden. Entsprechend schnell ist die Berechnung.

Fuer die Temperaturlausbreitung eignet sich als Abschaetzung z.B. die Formel nach Guernsey, die in VDI 4640 Bl. 2 abgedruckt ist. Ansonsten muss mit numerischen Modellen wie FEFLOW gearbeitet werden.

**Q.**

EED does not account for the convective heat transfer with regional groundwater flow in the surrounding ground. To some extent, this limitation may be counted as the worst case scenario, because the convective heat transfer heat/cold withdrawal will alleviate heating/cooling peaks. However, we may overestimate the number of wells and increasing the cost because of this limitation. In this case, the use of models accounting for groundwater heat transfer (FEFLOW, TOUGH, other) may be beneficial. What, in your opinion, is the criterion which allows to judge if the groundwater flow should be taken into account? What do you think of the EED applicability for cases with intensive groundwater flow?

**A.**

EED uses a purely conductive approach, because the inclusion of groundwater flow requires much more input parameters and a much more complex calculation. EED is intended as a fast and easy method for the typical ground source system. If you suspect there might be a high influence of moving groundwater, a full hydrogeological model is required to get precise answers (and the hydrogeological investigations to determine the exact input parameters, too). To my experience, consistent with field observations, the way to use EED in areas with regional groundwater flow is the following:

For the short-term behavior ("peak load"), the influence of groundwater flow is negligible. Only with extreme Darcy-flow, there is a slight impact (the Darcy-flow is the only interesting value, as it includes the amount of water that passes the BHE, not just the velocity). I had a student do a thesis with a comparison of EED-results to results from a groundwater model (TRADIKON-3D, only used internally at the university), and the results showed just that: no or negligible short-term impact. For the long term, there is a substantial impact, as groundwater carries heat to and from the BHE. For single BHE or small numbers, I use the temperature values of the 2nd year as a reference; because of the groundwater, these temperatures will not be exceeded over the years. For large BHE fields, there is only a shift of the temperatures inside the field, so the impact is much smaller, and I calculate like in the purely conductive mode. NB: This are hints to use EED in cases it is not exactly intended for. There might occur misjudgments by the user, for which the developers cannot be held responsible. EED does a purely conductive calculation, for exact determination of groundwater impact, use other relevant software.

**Q.**

We work with geothermal activation of concrete energy piles. Recently I bought a license of EED3, but the available manual gave no hint how to set parameters in EED 3 to calculate these cases. Do you have some information with which parameter sets it is possible to work with energy piles of e.g. 1,20 m diameter, 10 m depth, a distance of 1,50 m center to center and different U-pipe variations to optimize output. One line of piles can contain up to 100 single piles. I would

appreciate very much to know how to set the EED-parameter, since in different reports people report to have used EED to solve these questions.

**A.**

EED can be used for energy piles with up to 3 loops in one pile (triple-U), as long as some criteria are given:

1. Pile diameter not more than ca. 1/10th of pipe length, with a maximum of about 1,5 m.
2. Pile distance minimum 1/10th of pipe length (only for narrow piles!)

In your case, the pile diameter is a bit too large, and the remaining soil between adjacent piles (0,3 m!) tends to be much less than the pile diameter. I doubt that EED will give an accurate prediction of temperatures in this case.

In general, the input for an energy pile reads as follows (example):

- borehole heat exchanger type: triple-U
- borehole depth: 10 m
- borehole diameter: 800 mm
- contact resistance pipe/filling: 0 (m.K)/W
- (pipe as you wish)
- shank spacing: 500 mm (Diameter of iron re-inforcement cage!)
- filling thermal conductivity: Concrete (ca. 1,6 W/m/K)

If you want to model a single line with 100 piles, just use the g-function for a single line of 25 (maximum for line), and divide the bas- and peak-loads by 4. The difference in thermal response of a line of 25 to longer lines is negligible.

**Q.**

Do you provide training courses?

**A.**

Within academic co-operations, courses may be free (travel and accommodation will have to be provided); for commercial purposes, there are courses depending on time and topic (only EED, EED and GSHP design, and any other additions you might wish), and on the time needed for travel to the course venue.

**Q.**

I want to know if you have some files such as CD to demonstrate the process of using the software except user manual.

**A.**

In the user manual the process of design is shown using an example. The software is intended as a tool for GSHP designers, so a basic knowledge of the systems is of course required. This cannot be taught by using a CD-ROM. If you have specific questions concerning the use and operation of EED, please do not hesitate to contact us. If you need a basic teaching, a course might be required.

## 2 Ground Properties

The figure below illustrates how the initial ground temperature is used in the program. The program generates a linear temperature gradient  $\Delta T/\Delta z$  based on the input data of ground thermal conductivity  $\lambda$  and geothermal heat flux  $q_{geo}$  according to the relation:

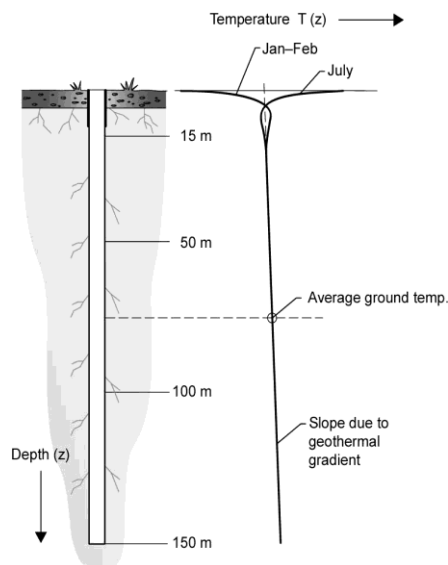
$$q_{geo} = \lambda \cdot \Delta T/\Delta z \quad \rightarrow \quad \Delta T/\Delta z = q_{geo} / \lambda$$

The ground temperature variation  $T(z)$  with depth  $z$  can now be written as:

$$T(z) = T_0 + (\Delta T/\Delta z) \cdot z$$

where  $T_0$  is the ground surface temperature.

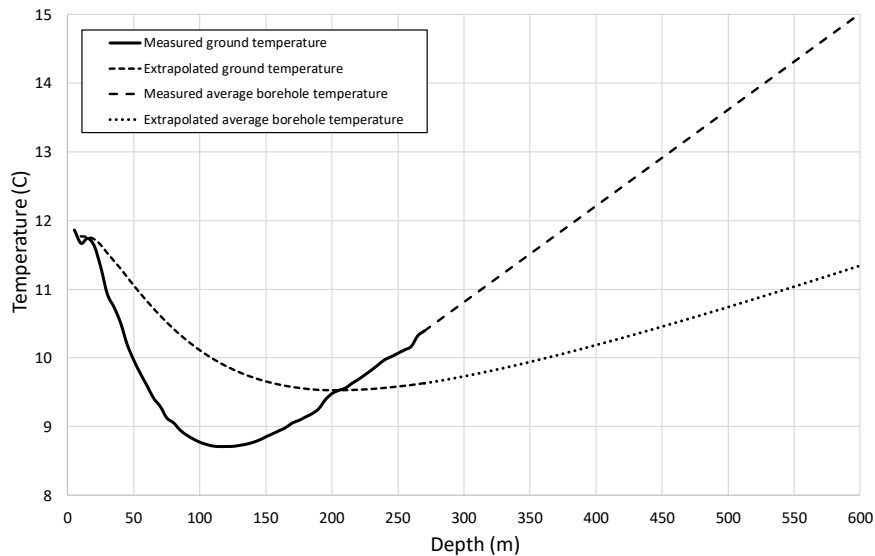
The program then uses the average value, the temperature at mid-point of the active borehole, as the initial ground temperature



Borehole with vertical temperature profile in the ground.

If a test borehole has been drilled at the proposed site for the geenergy project, it is possible to make a measurement of the vertical temperature profile after a certain time period allowing for the disturbances caused by the drilling operation to vanish.

The graph below provides an example of a measured and extrapolated vertical temperature profile in Central Stockholm. Here, the influence of heat losses from building foundations at the ground surface reaches a depth of about 150 m. Below this depth there is a fairly linear temperature increase with depth. The temperature profile below 265 m has been extrapolated based on a linear regression of measured temperatures in the interval 180-265 m. The corresponding average borehole temperature has been estimated based on these values.



Graph of measured and extrapolated vertical temperature profile in Central Stockholm. The corresponding average borehole temperature has been estimated based on these values

A thermal response test will also provide an average initial ground temperature along the active borehole.

In the case that the average initial ground temperature is known, this value should be written in place of the “Ground surface temperature” and the “Geothermal flux” value should be put to zero.

Property	Value	Unit
Thermal conductivity	3,500	W/(m·K)
Volumetric heat capacity	2,160	MJ/(m³·K)
Ground surface temperature	8,000	°C
Geothermal heat flux	0,00000	W/m²

**Q.**

I have a question about “ground properties”, you have listed many values of the ground. I want to know if these are average of all layers in the ground. The values are only sorted by the type of the rock in EED.



**A.**

If you know the ground profile with depth, you can take the weighed average between the relevant rock types. Let me give an example:

You may have a 120-m-borehole in (from top) 20 m of sand, then 50 m of limestone, and until final depth another 50 m of marl. The individual values are:

- sand, saturated	2.4 W/m/K
- limestone, massive	2.8 W/m/K
- marl	2.1 W/m/K

Now you do the weighed average:

20 m / 120 m x 2.4 W/m/K	= 0.40 W/m/K
50 m / 120 m x 2.8 W/m/K	= 1.17 W/m/K
50 m / 120 m x 2.1 W/m/K	= 0.87 W/m/K

And the sum of the values gives you the value over the borehole length with 2.4 W/m/K.

**Q.**

How can the “Geothermal heat flux” be obtained?

**A.**

The geothermal heat flux within Europe usually is obtained from an atlas issued by the European Commission containing a set of maps showing this value. It has to be calculated from measurements in boreholes, by taking a temperature profile with depth and measuring the thermal conductivity of the ground. For a GSHP project, you would not do that. If you do not have similar maps (check e.g. with the International Geothermal Association <http://iga.igg.cnr.it>), there are two ways to deal with it:

Take the default value (or a value between 0.06 W/m<sup>2</sup> and 0.07 W/m<sup>2</sup>). This is valid for most places on earth, outside geothermal anomalies.

If you have a measured average value over the borehole length (e.g. from the preparation of a Thermal Response Test), type in that value as ground surface temperature, and set the geothermal heat flux to 0.0. This is the most exact way, however, the final depth of the borehole should not differ much from the depth of the borehole the value was measured in. The value may vary in a region e.g. where deep faults and thermal waters occur (geothermal anomalies).

**Q.**

From where can I get values of geothermal heat flux of Toronto, Canada. I read FAQ in which you have mentioned that we can take default value of geothermal heat flux between 0.06 and 0.07. Please mention the units for these values. If I am using English units what will be values then.

A.

The EED databases by now yield only European values for site-specific parameters. There are some values for the rest of the world, of course, typically provided by geophysical institutes at universities and geological surveys. In case there is no further information, I suggest to use the average value of  $0.06 \text{ W/m}^2$  (ca.  $0.02 \text{ btu}/(\text{hr}\cdot\text{ft}^2)$ ). For areas in the Canadian shield (Northern Ontario), a lower number of ca.  $0.015 \text{ btu}/(\text{hr}\cdot\text{ft}^2)$  would be reasonable, for the Western regions a slightly higher value.

Q.

Concern # 1

I have obtained following parameters from In-Situ Thermal Conductivity Test:

$$\text{Calculated Thermal Conductivity} = k = 1.0 \text{ Btu}/\text{ft}\cdot\text{h}\cdot^\circ\text{F}$$

$$\text{Calculated Thermal Diffusivity} = 0.01625 \text{ ft}^2/\text{hr}$$

Based on above parameters, I have calculated Ground heat Capacity as follows:

$$\text{Calculated Thermal Diffusivity} = 1.000/0.01625 = 61.5 \text{ Btu}/\text{ft}^3\cdot^\circ\text{F}$$

(Please confirm whether I calculated correct or not?)

Concern # 2

I have soil temperatures at various locations of Canada at depth of 150 cm. Could I use those values of temperature at depth of 150 cm in EED 3.13 as Ground surface temperature?

Concern # 3

I am sure un-disturbed ground temperature is different from Ground Surface Temperature. Please mention formula or equation used by EED 3.13 to calculate it at various depths.

Concern # 4

We normally take services of a company to drill test borehole to find thermal conductivity as well as thermal diffusivity of ground. Would you please suggest us how could we calculate the Geothermal heat flux from test borehole?

Concern # 5

I have picked following values from In-Situ Thermal Conductivity Test:

$$\text{Power Input} = 4166 \text{ watts.}$$

$$\text{Borehole depth} = 185 \text{ feet.}$$

$$\text{Btu}/\text{hr}/\text{ft} = 4166 \times 3.41/185 = 76.8$$

Since, I don't have a Geothermal heat flux value, so I put 76.8 as ground surface temperature and set geothermal heat flux to 0.0. Did I do correct or not?

A.

Concern #1:

We do not need thermal diffusivity as input for EED. This value is calculated as

$$\text{thermal diffusivity} = \text{thermal conductivity} / (\text{density} \times \text{specific heat capacity})$$

Where the thermal conductivity and the volumetric heat capacity (=density x specific heat capacity) is given in EED.

Concern #2:

Temperature at 1-2 m depth is so close to mean surface temperature that you can use these values without further correction

Concern #3:

EED is calculating the temperature at half the depth of the borehole, as reference for the calculations. Temperature is rising slightly towards depth, according to the geothermal heat flux and thermal conductivity, and this increase is calculated starting from the ground surface temperature.

Concern #4:

To measure the geothermal heat flux, you need a vertical temperature log in the borehole, at a stable situation several weeks after drilling (the drilling process disturbs heavily the temperature distribution). With the known thermal conductivity and the temperature difference over the borehole depth, you can calculate the geothermal heat flux. Remark: This is normally not done for GSHP installations, there you use either estimated data, or in case you have a test, the procedure described in concern #5.

Concern #5:

There is no way to calculate the ground surface temperature from the heat input. I reckon that is a misunderstanding. As you have given the test result in the appendix, just use the value given there for the ground temperature: 10.9 °C or 51.6 °F, and set the geothermal heat flux to 0. Please be aware that that value only is valid for a depth in the range of that of the test borehole, i.e. some 180-190 ft !

### 3 Borehole and heat exchanger

**Q.**

Is the mass flow rate of the carrier fluid also a constant value for all boreholes in a multiple configuration: or is it only included as a parameter to calculate the Reynold's number and Borehole Resistance?

**A.**

It is only included to calculate the borehole thermal resistance. However, the flow rate for individual boreholes ought to be fairly similar in order for one borehole thermal resistance value to be representative for all boreholes.

**Q.**

I have seen in the presentation that we need to enter information about annual energy load variation, peak loads and flow rate in m<sup>3</sup>/s. I don't see anything about the temperature difference between entrance and exit in the borehole.

**A.**

The temperature curves given are the mean temperatures in the borehole heat exchangers (BHE), i.e. the mean value between inlet and outlet. This reflects the behavior of the BHE to the borehole and the outside ground, not the temperature development along the BHE axis. The value for flow rate ( $\text{m}^3/\text{s}$ ) is required for calculating the Reynold's number, which has an impact on heat transfer inside the pipes and thus on borehole thermal resistance. If hourly calculation is used, the flow rate value is used to calculate entering and exiting fluid temperatures.

#### 4 Borehole thermal resistance

**Q.**

What is the difference between “thermal resistance fluid/ground” and “effective borehole thermal resistance”? Which parameters do they depend on?

**A.**

“Fluid/ground” thermal resistance gives the thermal resistance between fluid and borehole wall perpendicular to the pipe axis (it does not include the effect of heat transfer between downwards and upwards flow channel)

“Effective borehole thermal resistance” includes the effect of heat transfer between downwards and upwards flow channel.

**Q.**

When I select “Use constant values” in the sub-menu concerning thermal resistances in the bore hole, how is the individual thermal conductivity (filling, pipe etc.) used?

**A.**

When “Use constant values” is selected, then properties of the borehole heat exchanger design, fluid, pipe and filling are not used.

**Q.**

What should the “internal” in the sub-menu concerning thermal resistances in the borehole be filled with?

**A.**

There are two ways of providing information about the heat transfer properties between the circulating heat transfer fluid and the borehole wall, either by specifying the design and the properties of the materials involved (heat carrier fluid, flow rate, pipe, filling material and contact resistance) or by giving a constant value for the borehole thermal resistance. The thermal short-circuiting between the downward and upward flow channel can cause substantial reduction of the thermal performance of the borehole heat exchanger. The thermal resistance between the upward and downward channel is called the internal thermal resistance. If you the option of calculating the borehole thermal resistance, you will get a reasonable value of the internal thermal resistance as a result. The value of the internal thermal resistance will influence the calculated fluid temperatures only if the box “Account for internal heat transfer” in the menu “Borehole thermal resistance” is checked.

**Q.**

I have question about the thermal resistances in your output file and I can't find an answer either in the manual or in the FAQs. In the output file various thermal resistances are listed:

**THERMAL RESISTANCES**

Borehole therm. res. internal	0.2248 K/(W/m)
Reynolds number	9907
Thermal resistance fluid/pipe	0.0053 K/(W/m)
Thermal resistance pipe material	0.0787 K/(W/m)
Contact resistance pipe/filling	0.0000 K/(W/m)
Borehole therm. res. fluid/ground	0.1026 K/(W/m)
Effective borehole thermal res.	0.1028 K/(W/m)

The meaning of some of them are clear, some not, so these are the questions:

Q1: How are “Borehole therm. res. internal” and “Effective borehole thermal res.” defined and what are the differences? Why is “Borehole therm. res. internal” larger than “Effective borehole thermal res.”?

Q2: Why does the sum of “Thermal resistance fluid/pipe” + “Thermal resistance pipe material” + “Contact resistance pipe/filling” + “Borehole therm. res. fluid/ground” not result into the “Effective borehole thermal res.”?

It would be very helpful to have a figure or a description explaining how these resistances are defined.

**A.**

A1: Let us for simplicity consider the case of a single U-pipe with the two shanks placed in a symmetric position. The local borehole resistance is calculated in a plane perpendicular to the borehole axis.

There is a filling material with a thermal conductivity  $\lambda_f$ . The surrounding ground has a thermal conductivity  $\lambda_g$ . The borehole radius is  $r_b$ .

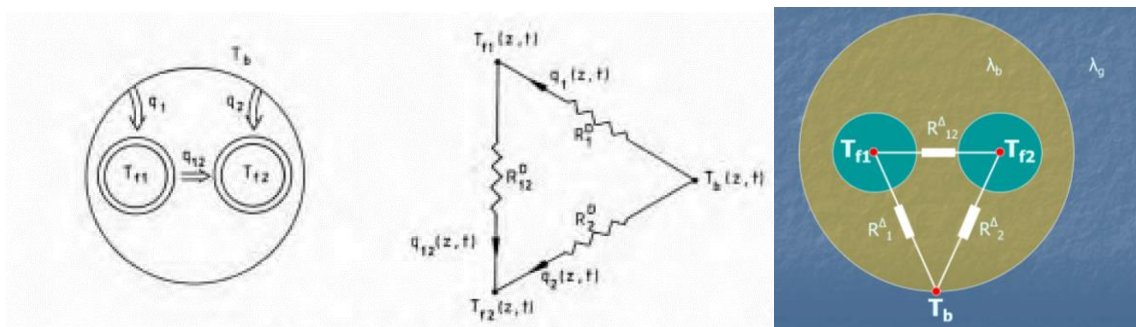
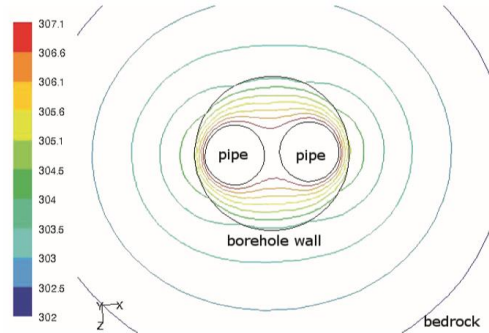


Figure shows the heat transfer circuit for a single borehole

There are two fundamental cases:

1. The fluid in both shanks have the same temperature  $T_f$  ( $T_{f1}=T_{f2}$ ). The temperature on the borehole wall will vary along depending on the proximity of pipes and the thermal conductivity of the surrounding ground. The average borehole wall temperature is  $T_b$ .



Ref: Anna-Maria Gustafsson, 2010.

An example of the isotherms around the borehole.

A steady-state heat transfer calculation using the so-called multipole method gives a heat flow  $q_p$  from each shank. The total heat flow from the two shanks becomes  $q=q_p+q_p$ . The total resistance between the fluid and the outer radius is defined by:

$$R_b = (T_f - T_b)/q$$

2. There is a temperature difference between the two shanks. In the fundamental antisymmetric solution the two shanks have the temperature  $+T_f$  and  $-T_f$  respectively. A steady-state heat transfer calculation gives a heat flow  $q_{12}$  between the two shanks. The internal thermal resistance  $R_a$  is defined by:

$$R_a = (T_f - (-T_f))/q_{12} = 2T_f/q_{12}$$

The effective borehole resistance  $R_{beff}$  is defined by the difference between the mean fluid temperature  $T_{fm} = (T_{fin} + T_{fout})/2$ , where  $T_{fin}$  and  $T_{fout}$  are the fluid temperatures in and out of the borehole, and the average borehole wall temperature  $T_b$ . The heat injection rate  $q = Q/H$  where  $Q$  is the total heat injection rate to the borehole and  $H$  is the active borehole length.

$$R_{beff} = (T_{fm} - T_b)/q$$

The  $R_{beff}$  takes into account the local borehole resistance  $R_b$  and the short-circuiting effect between the shanks due to the finite value of  $R_a$ .

A2: "Thermal resistance fluid/pipe", "Thermal resistance pipe material, and "Contact resistance pipe/filling" refers to the local heat transfer through one shank. They can be added to one "pipe" resistance  $R_p$ . The heat flow rate is then

$q_p$  and the resulting difference between fluid temperature  $T_f$  and the temperature  $T_p$  in the filling material adjacent to the pipe becomes:

$$T_f - T_p = q_p * R_p$$

The “local” borehole thermal resistance between fluid and ground includes the resistances from the pipes and the resistance through the filling material. The resulting borehole thermal resistance  $R_b$  is a function of the pipe resistance  $R_p$ , the pipe radius, the shank spacing, the filling thermal conductivity, the borehole radius and the ground thermal conductivity. The effective borehole heat transfer takes into account also the thermal short-circuiting effects due to the temperature difference between the shanks. The short-circuiting effects depend on the internal borehole resistance, the flow rate and active borehole length.

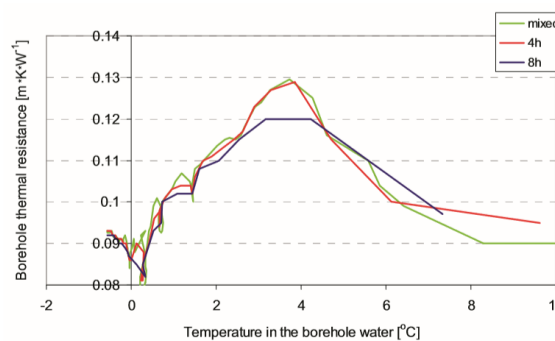
**Q.**

How is the influence of natural convection in groundwater-filled boreholes handled in EED?

**A.**

This topic has been studied for about 20 years and there no easy general solution to the problem has yet been found. The correlations to measured data that have been made are limited to specific geometric situation, such as a single U-pipe with 40 mm pipe diameter in a borehole with 140 mm diameter in a certain temperature range or time-consuming CFD-calculations of specific geometries.

The natural convection depends primarily on the temperature-dependent water properties, the specific heat transfer rate and the geometric layout of the borehole heat exchanger. The heat transfer results in a temperature difference between the outside of the pipes and the borehole wall. The ensuing density differences drive the natural convection and the flow resistance is due to the viscosity of the water. The figure below illustrates the general behaviour. Density differences are small around 4 °C where water exhibits a density maximum. At higher temperatures the viscosity is lower and offers less resistance. At lower temperatures the density differences increase and eventually the borehole water may freeze, which causes convection to cease but replaces water with ice (thermal conductivity 2,1 W/m,K).



Ref: Anna-Maria Gustafsson, 2010

## Example of computed borehole resistance at different borehole water temperatures

At the moment there are basically two approaches used to estimate the borehole thermal resistance in groundwater-filled boreholes. The first method assumes an annulus where the inner pipe has the equivalent diameter of the multiple pipe arrangement in the borehole. The heat transfer is then estimated based on published formulas for heat transfer in an annulus (Hellström and Kjellsson 1997, Gustafsson 2010, Schwencke 2013). The second approach is to use the conduction layer theory and fit the coefficient against field data (Spitler et al, 2016; Spitler et al, 2016).

The user is referred to the references below for more details.

### References:

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## 5 Energy loads – SPF, base and peak loads

### **Q.**

I am a registered user of the EED software. Over the last several months I have been through evaluation of EED modelling results performed by another consultant. In April I sent some questions to Burkhard and got very exhaustive answers. Thanks again for that. On a new spin of analysis I came across a parameter which proved to be very important: SPF. There is no explicit explanation of this parameter in the manual. I did a sensitivity test and found that altering SPF for Heating from 3 to 1 and for cooling from 4 to 1 impacts simulation results extremely.

I searched the Internet but was unsuccessful in finding the definition of “seasonal performance factor” in relation to ground heat pumps, looks like this is not a common term. Could you please provide an explanation of SPF and methodology of its calculation?

In my case I have monthly heating and cooling loads defined which, to my understanding is enough to set the energy transfer model. Why SPF play a role in this situation?

### **A.**

The seasonal performance factor SPF is quite common here in Europe, in German language under the name Jahresarbeitszahl and with the abbreviation JAZ in Switzerland and the sign beta in Germany (s.a. VDI 4640, the relevant German guideline). It is in fact an annual integrated COP.

The measurement of SPF is done by monitoring the electric power consumption of heat pump and ground-side circulation pump, and the heat / cold output of the heat pump towards the building. In the heating-only version we use mainly here in Germany, we do this over a full year; in heating/cooling you would do it over the respective season. In Germany, officially now another value has been introduced, the Jahresaufwandszahl, which is just:  $\text{Jahresaufwandszahl} = 1 / \text{Jahresarbeitszahl}$ .

Methods how to estimate these values for a given heating system and house are shown in a new guideline VDI 4650.

Now to the relevance of SPF: EED uses the heating and cooling load of the building as input. This was done because most contractors have to determine this values anyway. The load towards the ground, however, is different; it is higher in cooling mode, and lower in heating mode, because the heat pump evaporator always has lower thermal capacity than the condenser. This difference results in the SPF. To simplify this for standard applications, we allow the SPF to be stated as an annual average. We already some time ago started discussion on including a heat pump module and manufacturer’s performance charts, to calculate SPF/COP for each month.

For the experienced user, who knows the heat transferred to and from the ground, and who wants to state this explicitly, we have the option to click the box "Direct" in the "Base load" submenu. This is further described in the manual.

On Google, a simple search for "seasonal performance factor" returns plenty of relevant entries, with SPF or HSPF (Heating Seasonal Performance Factor, for the heating season only).

**Q.**

Ist mit der Jahresarbeitszahl wirklich die Jahresarbeitszahl des Gesamtsystems gemeint (die ja eigentlich erst im Feldversuch bestimmt wird, wenn es bereits zu spät ist) oder aber der COP der Wärmepumpe am für die Auslegung herangezogenen Betriebspunkt?

**A.**

Grundsätzlich ist die Jahresarbeitszahl gemeint. Sie muss hier im Vorfeld aber aus den zu erwartenden Betriebsdaten (bzw. den für die EED-Berechnung angestrebten Soletemperaturen) und den Herstellerangaben der Leistungszahl (kurve) angenommen werden. Falls Sie darin keine Erfahrung haben, bietet VDI 4650 eine Methode zur Berechnung.

**Q.**

I want to know how to obtain the value of "SPF", in the case of direct cooling, the SPF=10000 in summer, and SPF=2.12 in winter. The difference between summer and winter is so large, why?

**A.**

The value of 10000 can be used to indicate the heating/cooling loads are directly transferred to the ground side. This is the case e.g. in direct cooling, when no compressor is in operation. However, in the practice, there is a SPF of 20-40 in direct cooling, because circulation pumps have to be operated; this does not in the same way influence the ground, so we have used an SPF value of 10000 in earlier versions of EED. In later versions of EED you can achieve this in better way by clicking the "Direct" box.

In general, the SPF is calculated as the amount of heat or cold produced during a season divided by the amount of electricity required to run the heat pump over the same time. In direct cooling, there is no heat pump, so we use the method described above.

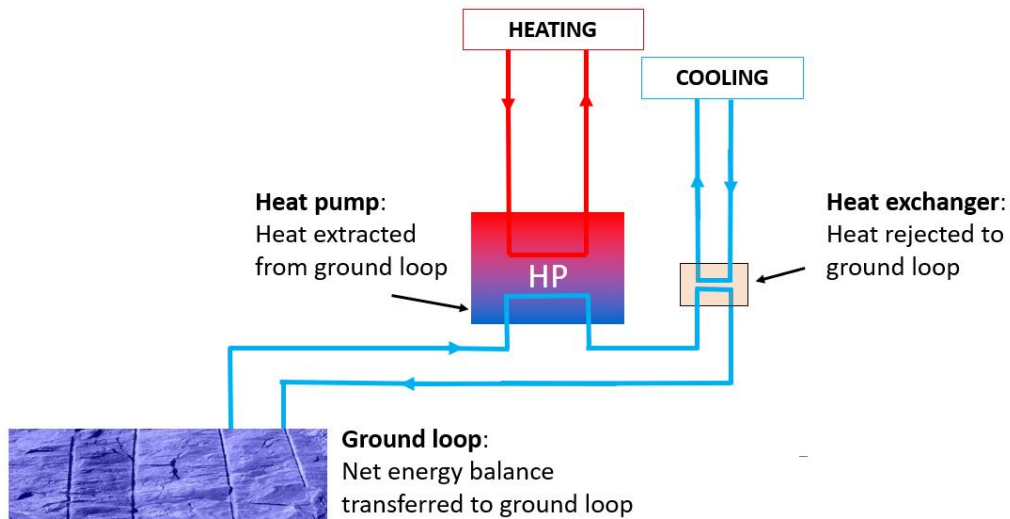
**Q.**

I've got for a review an EED case where the user (the HVAC company) has specified monthly heat and cool base loads, as well as peak heat and cool loads for each month of the year. In the program manual, you refer to the Linden sample case, where the system several months works for heating only and several months for cooling only, which make complete sense to me. However, in the files which I am sending to you, the engineer was inputting heat and cool loads simultaneously and getting outputs from the model (please take a look at the attached input and output files). My question is the following: the EED input allows simultaneous input heat and cool loads. However, the BTES hole cannot

simultaneously reject and extract heat (the BTES system cannot work in heating and cooling mode simultaneously). I would presume, that the algorithm adds monthly heat and cool loads with different signs and after that simulate the impact of the algebraic sum with one sign throughout the month (heat extraction if heating mode is prevailing and heat injection if cooling is prevailing). Am I right?

**A.**

Yes, you are perfectly right. And that is what in fact happens in reality, at least in a short distance from the pipe. Short-term variations from heating to cooling do not affect ground temperature, as the process is slow, and only the net impact over a longer time span will count. For larger plants, most of the short-term alternations between heating and cooling not even reach the ground, as they cancel each other out in the system loops.



The figure shows a simple system with simultaneous heating and cooling loads.

**Q.**

How does the program calculate peak heat loads and peak heat loads? Why are they added at the end of the month to calculate maximum and minimum temperatures?

**A.**

The base load tells the long-term story, i.e. the development of the ground temperature and thus fluid temperature in response to the heat extraction and injection. This is where real loads of heat are shifted in and out of the ground. The peak load is there to check if the maximum required load over a continuous operation time of some hours can be extracted or injected under the general long-term development. As we do monthly calculations, no temperatures are given for days other than the end of the months (or the beginning of the next, which is the same). Putting the peak load to the end of the month usually means

a worst-case scenario. The energy amount of the peak is not added to the monthly development, not to increase the base load by mistake.

The most critical loads for design are:

1. energy loads for heating and cooling. These loads determine the energy balance for the ground and the ground temperature evolution over time.
2. peak heating power in the winter – most critical time is usually january-march. This gives you the minimum fluid temperature.
3. peak cooling power in the summer – most critical time usually august (- september). This gives you the maximum fluid temperature.

The peak heat load occurs during the situation that results in the maximum value of the net heat extraction from the ground loop considering simultaneous heating and cooling loads during a month.

The peak cool load occurs during the situation that results in the maximum value of the net heat rejection from the ground loop considering simultaneous cooling and heating loads during a month.

The DHW (District Hot Water) energy load is important for the whole year, but DHW peak power is not important for the maximum fluid temperature in the summer.

**Q.**

In the third line of base load, you have a "Ground", and under that there is an "Update", I do not understand what is the meaning of this line?

**A.**

This column contains the balance of actual heat extracted from the ground loop due to heating and the actual heat rejected to the ground loop, as calculated from the load values and SPF values. You cannot access this column directly.

**Q.**

I have total heating as well as cooling load, water flow rate in boreholes, as well as inlet water temperature in boreholes. Please tell me how could I get the outlet temperature from borehole heat exchanger now? I want to know how the ground will behave in my case. This is very important because outlet temperature from ground will be the inlet temperature of HVAC equipment.

**A.**

In EED, the inlet water temperature is not considered as an input parameter. All the temperature calculations are done as a deviation from the undisturbed ground temperature that is calculated using values given in the "ground properties" submenu as input.

The resulting temperature is the mean fluid temperature, which is the average of the fluid temperature entering and exiting the borehole. Typically in heating mode the EWT (which is the temperature out of the borehole into the heat pump) is ca.

1.5-2.0 °C higher, the return temperature the same value lower than the mean temperature. In cooling mode, EWT is ca. 2 °C lower than the mean, return higher. As you wrote, this values depend upon flow rate, but also borehole depth, pipe diameter, filling, shank spacing, etc. In the old Lund PC DOS programs from the late 1980s, a program INOUT allowed for calculation of these temperatures, once the system design was done. In EED version 4 these temperatures can be displayed if hourly values are used. Note that you can convert monthly and peak loads to hourly values in the submenu "Hourly calculations". However, the flow rate specified in submenu "Borehole and heat exchanger" and does not vary with time.

**Q.**

Can you give me some detailed information about the base load and peak load. Could you tell me the reason why you separated the base load and peak load. When we have calculated the total heating /cooling load, how can we confirm the values of the base load and the peak load?

**A.**

This question refers to the engineering practice, and not to the EED operation. Therefore I only can tell what you need for EED:

The base load is the total amount of heat/cold required in a month (in MWh), either given directly as a monthly value, or as a total over the year and a monthly percentage (see manual). This value controls the long-term behavior of the system over the year.

The peak load is the maximum heating or cooling output required during the coldest (or hottest) day of the month, given in kW, and the expected duration during this day, in hours.

If you want to know how to get these values for a given building, please consult your HVAC planners.

**Q.**

Ich habe mir die FAQs mal durchgelesen, weil ich ein Verständnisproblem mit den Peak-Loads habe. "The peak load is the maximum heating or cooling output required during the coldest (or hottest) day of the month, given in kW, and the expected duration during this day, in hours." Wenn ich also jetzt zB für Januar 10kW und 24h eingebe, dann bedeutet das nicht, dass in allen 31 Tagen 24h Maximalleistung erbracht wird, sondern EED nimmt diesen Peak nur als Hinweis für Minimaltemperaturen. Sehe ich das so richtig?

**A.**

Die peak load wird natuerlich nicht an allen 28-31 Tagen eines Monats angesetzt (dafuer gibt es ja die Base load), sondern nur an einem Tag. Dies ist rechnerisch immer der letzte Tag eines Monats, da dies bei fortschreitender Abkuehlung den worst case darstellt. An allen anderen Tagen wird die durchschnittlich Monatsleistung erbracht, die peak load am letzten Tag dann aber nicht zur monatlich entzogenen Waermemenge dazugerechnet (sonst waere diese ja um den Betrag dieses einen Tages hoeher).

**Q.**

Sind bei Eingabe der Dauer der Spitzenlasten tägliche Wärmepumpenlaufzeiten gemeint? Dann käme ich beim "Linden"-Beispiel aus dem Handbuch auf etwa 3360 Volllaststunden, während sich in der Grundlast bei 29030 kWh/a und einer Wärmepumpen-Heizleistung von 17 kW etwa 1700 Stunden ergeben. Für die Bestimmung der minimalen Fluidtemperaturen scheint mir das von entscheidender Bedeutung zu sein, denn die meisten Wärmepumpen schalten ja bei  $-5^{\circ}\text{C}$  Soleeingang ab – zumindest in der Voreinstellung. Bedeutet "mittlere minimale Soletemperatur  $-5^{\circ}\text{C}$ " eigentlich, dass bei  $3^{\circ}$  Spreizung die Sole im Vorlauf  $-6,5^{\circ}\text{C}$  und im Rücklauf  $-3,5^{\circ}\text{C}$  hat? Wenn ein Monatsmittel gemeint ist, könnte es also auch sein, dass die Temperaturen im WP-Eingang temporär  $-5^{\circ}$  unterschreiten und die Wärmepumpe dann abschaltet, bis die Sole sich wieder "beruhigt" hat?

**A.**

Spitzenlasten sind nicht die taeglichen, sondern die maximal an einem Tag vorkommenden Stunden (also am kaeltesten bzw. bei Kuehlung am waermsten Tag des jeweiligen Monats. Wichtig ist dabei eigentlich nur die maximale Leistung/Laufzeit im Monat mit der kaeltesten Soletemperatur aus Grundlast. Nur gelegentlich kommt es vor, dass das absolute Temperaturminimum im zweitkaeltesten Monat, aber bei groesserer Spitzenlast auftritt (analog auch fuer Kuehlung). Die restlichen Monate dienen letztlich nur noch dazu, eine schoene Kurve fuer die Grahik zu bekommen – auslegungsrelevant sind sie dann nicht mehr.

Die Betriebsstunden Linden stimmen dann wieder. Ihre Annahme zu mittlerer Fluidtemperatur und Eintritts-Austritts-Temperatur ist korrekt.

**Q.**

Müssten nicht bei einer WW-Bereitung über die Wärmepumpe auch im Sommer Spitzenlasten angesetzt werden? So, wie ich das bislang alles verstanden habe, kann die WP ja nur unter Volllast laufen oder eben gar nicht (abgesehen vielleicht von den neuen modulierenden Nibe-Pumpen).

Wie sie sehen, bin ich weder Thermodynamiker noch TGA-Planer. Leider bekommt man als Bohrbetrieb von den Auftraggebern (im EFH-Bereich zumeist Heizungsbauer) nur selten (bzw. nie) Lastprofile geliefert. Was Volllaststunden sind bzw. dass das eine Rolle spielt, wissen die meisten gar nicht. In der Regel bekommen wir den Wärmebedarf aus dem EnEV-Nachweis auf den Tisch oder auch nur eine Quadratmeterzahl und müssen bereits für die Angebotserstellung einer Sondenbohrung die Wärmepumpe selbst auslegen. Mit viel Glück ist bereits klar, welche WP es sein soll. Nun ist mir das Vorgehen vieler Bohrunternehmen (wir sind recht neu am Markt) nicht so ganz geheuer, grundsätzlich mit  $50\text{ W/m}$  zu rechnen. Deswegen haben wir EED gekauft, um auch im EFH-Bereich wenigstens mal nachrechnen zu können, zumal die Wärmeleitfähigkeiten in der VDI ja etwas differenzierter angegeben sind als die Entzugsleistungen. Die Diskrepanz zwischen EED und VDI ist nun allerdings recht frappierend (wie mir nach Lektüre Ihres diesbezüglichen Artikels jedoch bereits im Vorfeld des EED-Erwerbs klar war), ein Bohrmeterbedarf auf der sicheren Seite kaum am Markt durchzusetzen. Mal schauen, wie wir damit

umgehen werden. Zumindest wollen wir keine Wärmequellen errichten, die nach Ablauf der Gewährleistung den Geist aufgeben.

Noch einmal zurück zu meinen Fragen bzgl. der Lastverläufe: kennen Sie vielleicht eine Quelle, in der es so etwas wie Standardprofile für Wärmepumpen (Wohnhäuser, Neubau und Bestand) mit Spitzenlasten und Laufzeiten gibt, die vielleicht auf Erfahrungen bzw. Feldversuchen basieren und die als Eingabegrößen für EED dienen könnten?

**A.**

Auch im Sommer sind bei WW-Bereitung zumindest Grundlasten anzugeben. Da der Untergrund da aber insgesamt wärmer ist als im Winter (weniger Wärmeentzug), kann auch WP-Vollast fuer 1-2 Stunden da nichts mehr gross bewirken. S.o. zu den Kurven in der Graphik...

**Q.**

bei unserer Tagesarbeit mit EED ist uns eine Ungereimtheit aufgefallen, wofür wir keine Erklärung finden.

Die monatliche Verteilung der Heizlast wird in EED standardmäßig von November bis Januar mit 56,40% des Gesamt-Jahresbedarfs angegeben. Bei einer Gegenkontrolle haben wir diese Verteilung auch in vorliegenden geologischen Gutachten wiedergefunden. Entgegengesetzt dazu nimmt eine Berechnung lt. ENEV §3 von November bis Januar den Gesamt-Jahresbedarfs mit 81,00% an. Resultierend würden in einem aktuellem Fall lt. EED-Verteilung ~380 m abgeteuft. Wenn wir die Monatsverteilung der ENEV in EED übertragen, errechnet das Programm aber ~500m. Wir berechnen jede Anfrage (auch kleine Gebäude) mit EED. Die Frage ist nun, welche Verteilung wir annehmen sollen. Des Weiteren die Frage, was würde bei einer Bemessung lt. VDI 4640 passieren – das Problem würde überhaupt nicht sichtbar.

**A.**

EED ist ein internationales Programm, das in vielen Ländern eingesetzt wird. Die Verteilung der Heizlast auf die einzelnen Monate stammt aus praktischen Erfahrungen und Monitoringdaten aus den 1990er Jahren. Sie ist lediglich als Vorschlag gedacht, wenn man keine anderen Vorgaben oder Daten hat (Default).

Wenn Sie z.B. in Übereinstimmung mit EnEV (oder anderen nationale Regeln) rechnen wollen, dann müssen Sie natürlich die dort getroffenen Vorgaben einhalten, und die Default-Werte in EED ggf. entsprechend ändern.

Bei grösseren Anlagen empfiehlt es sich sowieso, nicht die monatliche Verteilung zu nehmen, sondern die jeweils auf den Monat entfallenden Wärmemengen direkt aus der Berechnung des Wärmebedarfs zu übernehmen.

Zur Frage VDI 4640: In der Version von 2001 sind sowieso nur recht grobe Richtwerte angegeben, Feinheiten wie die monatliche Verteilung der Heizlast kommen garnicht vor. VDI 4640-2:2001 garantiert auch keine optimalen Anlagen, die Richtwerte stellen lediglich sicher, das keine Anlagen gebaut werden, die

vollkommen unbrauchbar sind. Anders ist es mit dem Entwurf VDI 4640-2:2015, bei dem fuer kleinere Anlagen mit EED berechnete Werte verwendet werden, es also bei Einhaltung der Anwendungsgrenzen keine Diskrepanzen geben sollte (die endgueltige Version VDI 4640-2 neu wird fuer Anfang 2019 erwartet).

## 6 Solve

### Q.

In the 'Solve mean fluid temperatures' mode, the fluid temperature can get below freezing point of the carrying liquid or can go over the temperatures expected to come from the building while in cooling mode. In the attached output, the maximum temperature in cooling mode goes over 93 C, while the real maximum temperature coming from building will be 40 C (from condenser)? I presume, in this mode the algorithm has an imperative to extract/inject the specified temperature and have no constraints. For this, having the fluid specific heat capacity and flow speed through the pipe, the program iteratively finds the appropriate temperature which would provide prescribed heat extraction/injection still balanced with the thermal capacity and conductivity of the BTES system (using the linear source solution similar to the Theis solution for groundwater). Am I right?

### A.

Almost. In the 'Solve mean fluid temperatures' mode, the program calculates the temperature response to a given amount of heat injection/extraction variation, using the thermal parameters (specific heat, thermal conductivity) of the ground, pipes, etc., and the geometric influence of pipe grids as contained in dimensionless thermal response function called the g-function. There is no consideration of the maximum or minimum temperatures a system can cope with; this is for the user to check and to make the system accordingly. In the "Solve required borehole length" mode, these temperature limits can be stated explicitly.

For your case, of course the temperatures are far out off any reasonable limits. When you look at the specific heat extraction rate for peak cooling, it exceeds 150 W/m! Here values between 20-80 W/m are normal, in respect to the thermal conductivity in the underground on site. The system is just too small for a peak cooling load in excess of 1.5 MW.

Some other observations of your case:

1. The ground thermal conductivity of 1.9 W/m/K is low, this is a value e.g. for wet clay. When drilling in your area, you may have some clay, sand, till, etc., but with the borehole reaching down to 180 m depth, there ought to be a good deal of hard rock with higher thermal conductivity. So I would expect a higher value. Such a low value of course means higher extremes than with higher conductivity; please check.
2. For a drilling depth of 180 m, the distance between holes of 4.3 m is rather small. Considering usual deviations from the vertical, there is a very good chance for a driller to hit a BHE installed before.



The g-functions are based on fully three-dimensional numerical solutions of the heat conduction equation assuming the same borehole wall temperatures for all boreholes. The resulting heat transfer rate along the boreholes will vary according geometric conditions such as borehole diameter, depth, spacing and number and configuration of boreholes. The borehole wall temperature at every moment is matched so that the sum of each borehole heat flow equals the prescribed total heat flow. This means that the changing ground temperature may result in gradually less favorable ground temperatures in the vicinity of some boreholes. If a (infinite or finite) line source approach is used then all the heat flux on the borehole wall will not change with time.

One point usually is the most difficult to bring across: EED is a very fast tool to get sound layouts for borehole heat exchangers, or to play quickly with various alternatives in a pre-design phase. With this as a goal, it is not made to cover every aspect. The major limitation is the purely conductive approach. So for choosing EED for a specific task, you should know what you want to use it for (and I meanwhile use it much more often than any other tool).

**Q.**

Wenn ich EED die minimale Bohrlänge berechnen lasse und dabei als Grenze -14°C Soletemperatur(Quelltemperatur) – auch unter Berücksichtigung der Peaks – eingabe, erhalte ich dann ein technisch mögliches Ergebnis? Die Einsatzgrenzen einer WP liegen ja bei -5°C – 25°C, müssten aber meiner Meinung auch kurzzeitig tiefere Temperaturen “ertragen” können.

**A.**

Rechnen kann man natuerlich alles, selbst die Grenze von -273 °C waere hier kein Problem. Praktisch geht das natuerlich nicht. Fuer sinnvolle Temperaturgrenzen finden Sie in VDI 4640 oder bei den WP-Herstellern Angaben.

In einem Teststand habe ich 1985 bereits eine Erdwaermesonde bis auf -13 °C Austrittstemperatur heruntergefahren, um die Grenzen auszutesten. Die 22-kW-WP von Siemens hat das klaglos mitgemacht, tiefer kam sie nicht mehr. Leistungszahl in diesem Betriebszustand etwa 1,5. Sinnvoll ist das also nicht. Auch bei Direktverdampfern (z.B. mit Ammoniak) hat man vor einigen Jahren so tiefe Temperaturen propagiert, um Bohrmeter zu sparen. Neben den Umweltauswirkungen (grosser Gefrierradius) ist dabei auch die Arbeitszahl unbefriedigend, wie ich auf langes Nachbohren auf Tagungen herausfinden konnte.

**Q.**

zur Angabe der jährlichen min Temperaturen: sind damit die Temperaturen vor dem Wärmeentzug oder nach dem Wärmeentzug durch die Wärmepumpe gemeint ?

**A.**

Die Temperaturen sind grundsatzlich als mittlere Soletemperaturen angegeben, d.h. als Mitteltemperatur in der Erdwaermesonde. Die Temperaturen des jeweils zur Waermepumpe zurueck und dann wieder in die Erdwaermesonde

fließenden Wärmestroms liegen somit um je die halbe Temperaturspreizung im Solekreislauf über bzw. unter dieser Temperatur (die Spreizung in einer typischen Wärmepumpenanlage liegt bei 3-4 K). Die Spreizung ist von der Durchflussmenge, dem Solegemisch etc. abhängig und kann somit nicht immer angegeben werden. Wir haben übrigens dennoch vor, fuer einfache Faelle eine Berechnung der resultierenden Ein- und Austrittstemperaturen in das z.Z. in Bearbeitung befindlichen Update zu EED zu integrieren. Sie werden bei Verfüegbarkeit benachrichtigt.

**Q.**

Angabe der jährlichen max Temperaturen (free cooling): sind damit die Temperaturen im Vorlauf oder im Rücklauf der Erdwärmesonden gemeint? s.o.

– sind Angaben zur Temperaturspreizung (Heiz- bzw. Kühlbetrieb) möglich?

– Freikühlbetrieb: werden Eingangs-Temperatur hinterlegt, damit die maximale Temperatur berechnet werden kann oder spielt die Eingangstemperatur ab einer bestimmten Länge der Erdwärmesonden keine Rolle mehr?

**A.**

Die absolute Eingangstemperatur wird nicht eingegeben, sie kann natuerlich im Einzelfall hoeher sein. Bei Temperaturen bis etwa 30 Grad Celsius spielt das keine Rolle. Bei Anlagen mit hoeheren Temperaturen, wie sie z.B. in Waermespeichern wie Neckarsulm-Amorbach vorkommen, ist EED sowieso nur begrenzt einsetzbar; dabei handelt es sich um Sonderanwendungen, die auch von oekologischer Seite ausfuehrlich geprueft werden muessen, eine numerische Modellierung ist dabei m.E. unerlaesslich. EED kann dabei nur als Vorplanungsinstrument dienen. In den ueblichen Faellen erdgekoppelter Wärmepumpen liegen die Eintrittstemperaturen in das Erdreich zwischen minimal etwa -5 °C im Winter und rund 20 °C (oder etwas darueber) im Sommer. Bei direkter Kuehlung sind 20 °C sowieso nicht zu ueberschreiten.

## 7 Output

**Q.**

Could you please send me calculation details for SPECIFIC HEAT EXTRACTION RATE [Btu/(h·ft)]?

**A.**

It is the heat rate extracted from the ground divided by the total length of borehole heat exchangers (in EED, the monthly value for peak heat load re-calculated for the ground side using the SPF, and then divided by total BHE length). An example in SI:

Peak Heating load in February	15 kW
SPF	4
Heat extraction rate on ground side	11.25 kW
Total BHE length	225 m

Specific heat extraction rate =  $11250 \text{ W} / 225 \text{ m} = 50 \text{ W/m}$

The same for English units, in BTU/hr and ft instead of W and m.

**Q.**

1) I have seen in the presentation that we need to enter information about peak loads, annual energy distribution and a flow in  $\text{m}^3/\text{h}$ . I don't see anything about the temperature difference between entrance and exit in the borehole. The graphs after calculation give an average temperature + maximum and minimum values that should correspond to the maximum and minimum average temperatures according to the peak kW. Can you help me with this?

2) We have a tricky calculation to do. We have a heat pump that will only produce cold and will release 70 kW in the ground ( $10 \text{ m}^3/\text{s}$ ). We might have a very exceptional use of a generator during 48 hours that will need to reject an overall (heat pump + generator) 210 kW to the ground with  $20 \text{ m}^3/\text{h}$ . How can we handle this in EED since the  $\text{m}^3/\text{h}$  will be very different when the generator is on? I was thinking of doing it in two steps with EED:

– First the heat pump alone during 20 years with 57 kW and  $10 \text{ m}^3/\text{h}$  to get the maximum temperature of the ground over the period.

**A.**

1) The temperature curves given are the mean temperatures in the borehole heat exchangers (BHE), i.e. the mean value between inlet and outlet. This reflects the behavior of the BHE to the borehole and the outside ground, not the temperature development along the BHE axis. The value for flow rate ( $\text{m}^3/\text{h}$ ) is required for calculating the Reynold's number, which has an impact on heat transfer inside the pipes and thus on borehole thermal resistance.

2) What you describe is exactly the way I would do it myself. In a case for only heat injection into the ground, you will see a temperature increase over the years, and probably you will need a very large installation to cope with this over a longer period. In such a case, it might be wise to use the winter cold for getting some of the heat out of the ground again, e.g. by just pumping the fluid through a dry air cooler. Such a "cold storage" system can reduce the required BHE length greatly, and often is more economic than a pure cooling option (heating up the ground only).

## 8 How to input data from a Thermal Response Test

**Q.**

Our company deals with "BTE problems" so we purchased your software EED 3.12 some months ago. It seems to be very useful and user-friendly. But there are some things connected to borehole thermal resistance which we do not understand to.

We found that thermal resistance of borehole depends on volumetric flow rate of brine (affecting the Reynolds number). Is it possible to use measured value of thermal resistance which we got from TRT to calculations in EED? During TRT there was totally different volumetric flow than it will be in borehole connected to

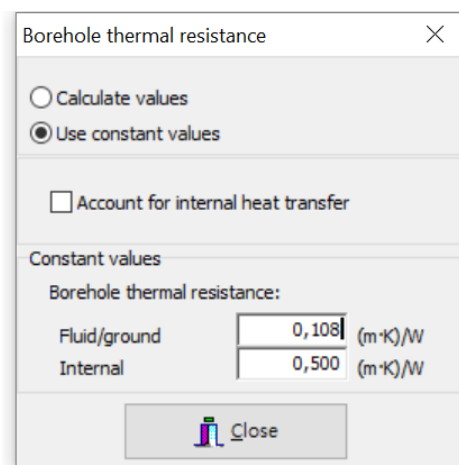
heat pump. How much is thermal resistance of borehole affected by volumetric flow of brine?

**A.**

The standard evaluation of a thermal response test gives the effective thermal conductivity of the ground and the effective borehole thermal resistance of the borehole heat exchanger. The value of the effective borehole resistance includes the effect of thermal short-circuiting and it depends on fluid thermal properties (temperature-dependent), flow rate and depth of borehole. In the case of groundwater-filled boreholes there is an additional dependence on specific heat transfer rate. Differences between the thermal response test and design conditions have to be taken into account.

To use the measured value of the effective borehole thermal resistance:

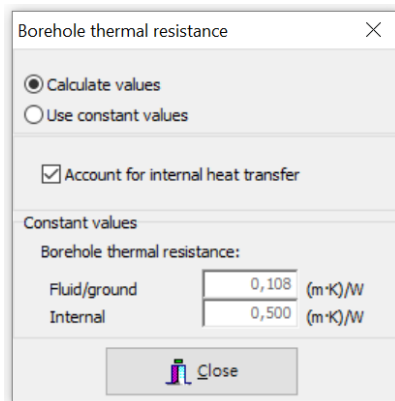
1. Go to menu “Borehole thermal resistance”
2. Check “Use constant values”
3. Uncheck “Account for internal heat transfer”
4. Insert your measured effective borehole thermal resistance value in the box “Fluid/ground”
5. The value for Internal is not used if “Account for internal heat transfer” is unchecked



Example of using measured effective borehole thermal resistance obtained from a thermal response test.

To study the effect of a change in fluid properties and flow rate it is recommended to use EED to obtain a reasonable match with measured data:

1. Go to menu “Borehole thermal resistance”
2. Check “Calculate values”
3. Check “Account for internal heat transfer”



4. Go to menu "Heat carrier fluid"
5. Give fluid properties at the fluid temperature used in the thermal response test
6. Go to menu "Borehole and heat exchanger"
7. Set the parameters for your borehole heat exchanger. Usually there are the same uncertainties with regards to actual shank spacing and/or filling thermal conductivity. Vary those values within reasonable limits (start with shank spacing) and match the calculated effective borehole thermal resistance (see the calculated data in the output window) with the measured borehole thermal resistance at the flow rate used in the thermal response test.
8. Go to menu "Heat carrier fluid"
9. Give properties at desired fluid temperature of design case
10. Go back to menu "Borehole and heat exchanger"
11. Vary "Volumetric flow rate"
12. Study the variation of "Effective borehole thermal resistance" in the "Design Data" output file

**Q.**

Unser Büro arbeitet seit einiger Zeit mit dem Programm EED. Zudem führen wir seit etwa 2 Jahren Thermal-Response-Tests durch. Nun habe ich bei der Umsetzung des aus dem Test berechneten thermischen Bohrlochwiderstandes in der EED Simulation das Problem, dass im EED unter „Borehole thermal resistance“ als „constant values“ zwei Parameter – „Fluid/ground“ und „Internal“ abgefordert werden, aus dem TRT jedoch nur ein Wert ( $R_b$ ) berechnet wird.

Ich würde mich sehr freuen, wenn Sie mir einen Hinweis geben könnten, wie ich den im Test berechneten thermischen Bohrlochwiderstand im EED umsetzen kann. Für Ihre Unterstützung bedanke ich mich im Voraus und verbleibe mit freundlichen Grüßen

**A.**

Der mit dem Responsetest gemessene und ueber die bekannte Formel ermittelte Wert entspricht etwa dem Wert "Fluid/Ground". Der Wert "Internal", der den Waermeaustausch zwischen den einzelnen Rohren beschreibt, ist grundsatzlich hoeher und kann bei dem Defaultwert von  $0,5 \text{ K}/(\text{W}/\text{m})$  belassen werden. Er geht in den Gesamtwert ("effective" im Ausgabefile \*.out) nur sehr gering ein.