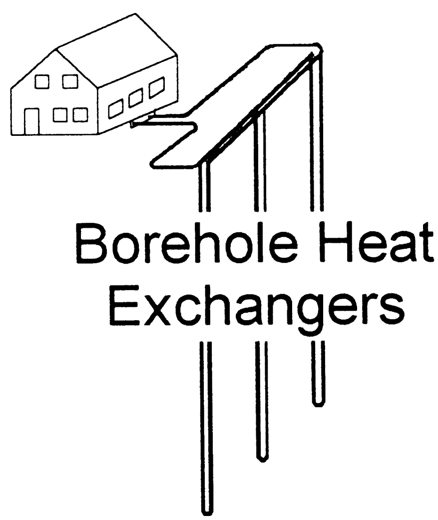
EED

Earth Energy Designer

User manual

Version 2.0



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1. Introduction

1.1 Overview

Earth Energy Design (EED) is a PC-program for bore hole heat exchanger design. Its easy of use, short learning curve, quick calculation times and inherent databases make it a useful tool in everyday engineering work for design of ground source heat pump system (GSHP) and bore hole thermal storage. In very large and complex tasks EED allows for retrieving the approximate required size and layout before initiating more detailed analyses. Even for very small plants EED values the effort to do a calculation instead of using rules of thumb is worthwhile. In ground source heat pump system, heat is extracted from the fluid in the ground connection by a geothermal heat pump and distributed to the building. The fluid is then re-warmed as it flows through the ground. In cooling mode, the process is reversed. This makes it a renewable, environmentally friendly energy source.

1.2 Background of EED

PC-programs for quick and reasonably sound dimensioning of ground heat systems with vertical earth heat exchangers have been presented by Claesson, Eskilson and Hellström, see list of literature in Section 6 . Algorithms have been derived from modeling and parameter studies with a numerical simulation model (SBM) resulting in analytical solutions of the heat flow with several combinations for the bore hole pattern and geometry (g-functions). Those g-functions depend on the spacing between the bore holes at the ground surface and the bore hole depth. In case of graded bore holes there is also a dependency on the tilt angle. The g-function values obtained from the numerical simulations have been stored in a data file, which is accessed for rapid retrieval of data by EED.

Calculation of brine temperatures is done for monthly heat/cool loads. Databases provide the key ground parameters (thermal conductivity and specific heat) as well as properties of pipe materials and heat carrier fluids. The monthly average heating and cooling loads are the input data. In addition, an extra pulse for peak heat/cool loads over several hours can be considered at the end of each month. The user can choose between different methods of establishing a monthly load profile. A printed output report and output graphical processing are provided. The program has an easy-to-use interface. The bore hole thermal resistance is calculated in the program, using the bore hole geometry, grouting material, pipe material and geometry. The bore hole pattern may be chosen at will from a database of more than 300 basic configurations

1.3 System requirements and installation

EED is a software package for running on Microsoft Windows 95/98/NT or to one of these compatible operating system. Program and databases require approximately 3 MB hard disk space. EED is delivered as a self-extracting file „self.exe“ that installs the program and databases in a folder the user can choose (default folder is C:\EED). It will install the following files and a subdirectory named „Projects“ where project data files may be stored. It may be a good idea to make further sub-folders for each major project. Also, the EED-icon will be added to the start menu of Windows.

1.4 Description of files

Name	Extension	Content
Programs and system files:		
eed	exe	Program file EED (executable)
gfunc	eed	g-functions
default	dat	Default project data file
e1	bmp	Background image (the user can store any other bitmap under this name to be displayed as background in EED)
Databases:		
borediam	txt	Bore hole diameter
cond	txt	Ground thermal conductivity
fillcond	txt	Filling thermal conductivity
gfunc	txt	List of g-functions
hcdat	txt	Heat carrier fluids
heatcap	txt	Ground specific heat
heatflux	txt	Geothermal heat flow
pipe	txt	Pipe material
surftemp	txt	Ground surface temperature

Project data files have the extension ".dat". Output files have the extension ".out". The standard project data file "default.dat" is read first with every program start. This file contains default values and may be changed to a default file for local conditions. Project data files can be saved under the "File" menu with the „Save“ or „Save as“ command:

Output files are generated by EED with the name of the project data file, adding the extension „.out“. These files are written in ASCII-code and can be loaded by common text editors (correct display of columns is only achieved with rigid fonts like Courier, not with proportional fonts). The monthly temperatures in the output files are listed in columns and can, after preparation with a text editor, be loaded into graphic software.

The databases are ASCII-text files with the extension ".txt" and can be completed with additional data the user may have, or changed to meet user requirements (sufficient experience is vital!).

1.2. Important program features

Number of configurations	308
Number of g-functions	2465
Types of bore hole heat exchangers	Coaxial pipes U-pipes (single, double, triple)
Bore hole depth	20 - 200 m
Ratio bore hole spacing / bore hole depth	$0.02 \le \frac{B}{H} \le 0.5$

Time interval t' = dimensionless time a = thermal diffusivity (m²/s)	$-8.5 \leq \ln(t') \leq 3$ with: $t' = \frac{t}{t_s}$ and $t_s = \frac{H^2}{9a}$
Short-time criterion E_1 = exponential integral	$0.5 \cdot E_1 \frac{r_b^2}{4at}$

Further details concerning the basic mathematical procedures used for the program can be found in the literature listed at the end of this manual, see Section 6.

1.5 EED main menu

1.5.1 Introduction

The main menu items, see Figure 1.1, are as follows:

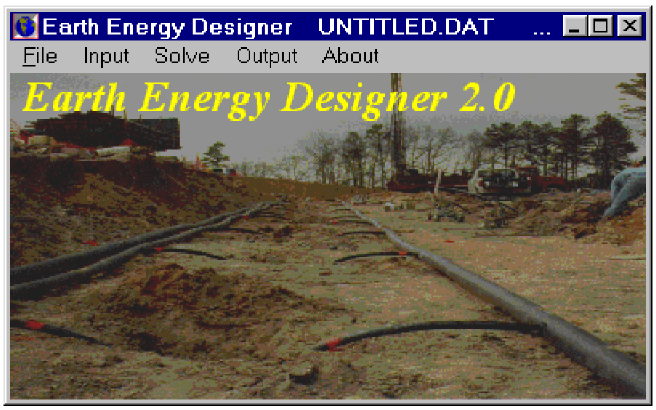


Figure 1.1: Main menu of EED.

- **File**: Operations with files (open, save, addition of memory notes to a project data file, exit)
- **Input**: Input of data for ground, bore hole, heat exchanger, heat carrier, building, loads, simulation time, etc.
- **Solve**: The calculation may be started in two different ways:
  - Calculation of the mean fluid temperature with the given load and layout
  - Calculation of the required bore hole length for a given min/max temperature
- **Output**: Display of the results as text and graphs
- **About**: Display of program version and authors

The background image may be changed by the user. Any Windows bitmap (.bmp) may be displayed. To do that, simply copy the file containing the bitmap into the directory where „eed.exe“ resides, and rename it into „e1.bmp“. If you like to save the image provided with EED, you should rename it to any other name before creating a new „e1.bmp“. EED automatically loads the file „e1.bmp“ as background image when the program is started.

1.5.2 The file menu

The file menu is shown in Figure 1.2. An existing project data file may be loaded by clicking on „**File**“ and „**Open**“.

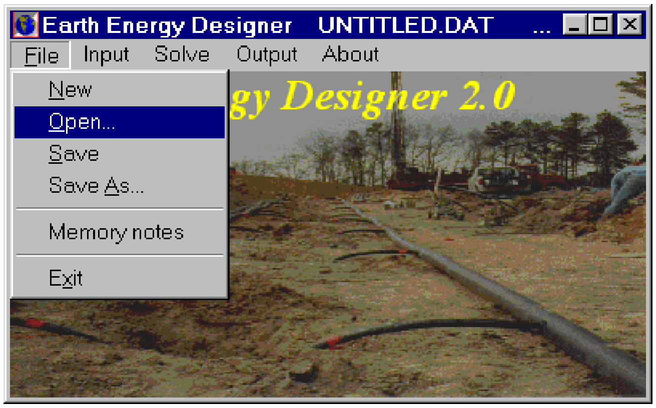


Figure 1.2: The file menu.

With the item „**Memory notes**“ in the File menu, a text (maximum five rows) can be typed that will be added to the header of the current project data file. This helps to identify the project and to distinguish different variations in the layout.

1.5.3 Closing the Program

After finishing calculations with EED, the program can be ended either by clicking on „Exit“ in the menu „File“, or by clicking on the „**X**“ in the upper right corner of the program window. The user is prompted, if the project data file should be saved (again). To start a new project without leaving EED first, „New“ in the „File“-menu is selected, or the default project data file „default.dat“ is opened.

The output files („*.out“) can be further edited. These are ASCII files and may be loaded into common text editors. The databases („*.txt“) are also ASCII-format and can be changed or further improved by experienced users.

2. Data input

The pull-down menu „**Input**“, see Figure 2.1, comprises all functions for input or change of the data required for the calculation.

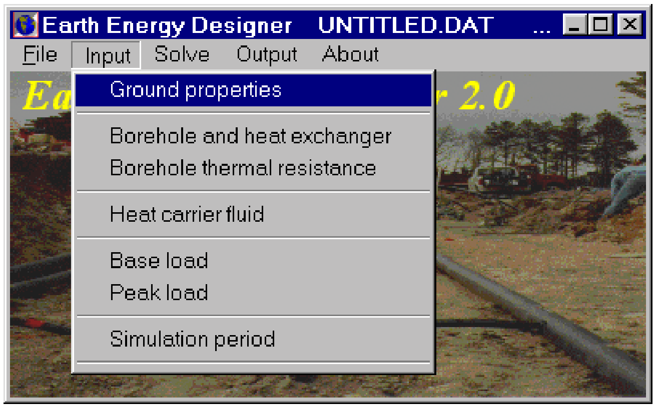


Figure 2.1: The input menu.

There are further sub-menus for specific input of data. These are data for underground parameters („**Ground properties**“), bore holes and heat exchangers („**Bore hole and heat exchanger**“), method of calculation of the bore hole thermal resistance („**Bore hole thermal resistance**“), properties of the heat carrier fluid („**Heat carrier fluid“**), base load and peak load data („**Base load“** and „**Peak load“**, respectively) and the desired simulation period („**Simulation period“**).

The following paragraphs show the input option by using a sample project. As example for the calculation of project „Manual_e“, data from a plant in the German city of Linden are used.

2.1 Ground Properties

Figure 2.2 shows the menu „**Ground properties“.** The input values can either be typed in directly (double-clicking in a field will highlight the contents, and with any new input the old content will be erased), or can be obtained from a database. For any field followed by a question mark, a database can be accessed.

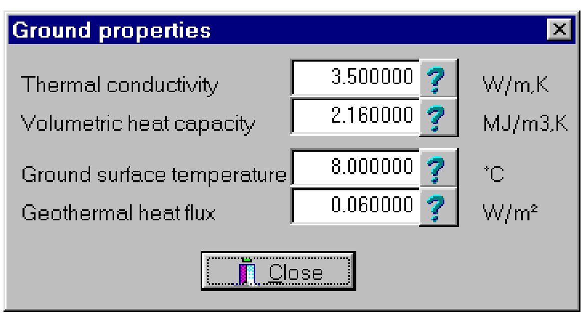


Figure 2.2: The ground properties menu.

For demonstration, we now start with „**Thermal conductivity**“. If no measured data from the site are available (e.g. from a thermal response test), the value has to be assessed from the database (according to the type of rock or soil). By clicking on the question mark beside the value for thermal conductivity, the database is opened in a new window, see Figure 2.3.

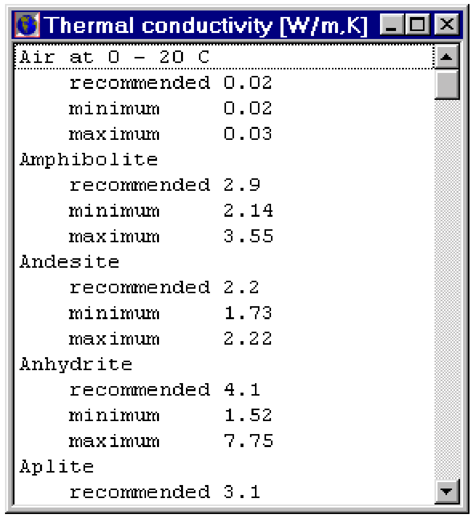


Figure 2.3: Database of thermal conductivities.

The values are sorted alphabetically by the type of rock. Some additional materials like air and water are also included. For each material, a recommended value is given (to use if no further info exists), and the minimum and maximum values found in literature or measurements. The value will be transferred to the data input box when clicked on. Double-clicking will do the same but also close the database window.

Data for the Linden site are used in our example. The underground consists of tertiary sand, clay, and in greater depth Paleozoic sediments. A plausible average for this subsoil has to be found. Moist sand is well representing the major part of the column, and hence "Sand, moist" is selected in the database. The value can be changed later in the sub-menu, as is done in the example (to 1.5 W/m/K), to represent better the thermal conductivity of the Paleozoic part of the profile.

Specific heat is selected in the same way, and then the annual average temperature at the earth's surface can be chosen („**Ground surface temperature**“). The database is opened by clicking on the question mark, and after selecting one of the countries for which data are available, a list with names of cities is displayed, see Figure 2.4. The temperatures are a hint for the ground surface temperature of the region. If necessary, interpolation has to be made, or the value for annual average air temperature has to be used. For the example of Linden the value of Giessen is selected, which is in only few kilometers distance. The geothermal heat flux is found in the same way.

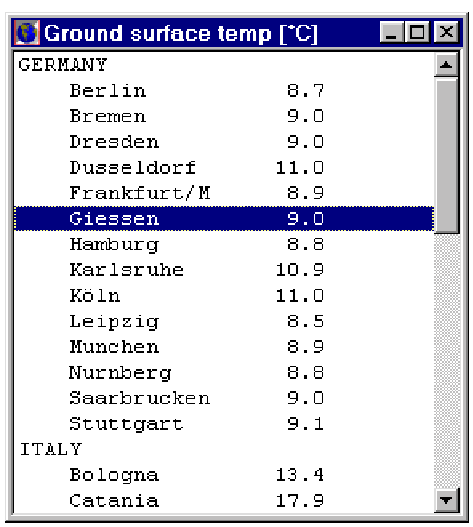


Figure 2.4: Database of ground surface temperatures.

With ground surface temperature, geothermal heat flux, and thermal conductivity of the ground the undisturbed ground temperature for half of the bore hole depth is calculated. Intentionally the geothermal heat flux and not the geothermal gradient is used for calculation to take into account the impact of thermal conductivity. The data for our example that follows are shown below.

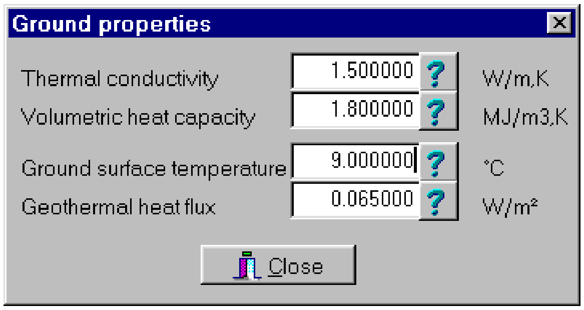


Figure 2.5: Data for our example.

2.2 Bore hole and Heat Exchanger

Figure 2.6 shows the menu "**Bore hole and heat exchanger**" that deals with bore hole data (number, geometry, depth, diameter) and with heat exchanger data. There are two different variations of the sub-menu, depending upon the type of heat exchanger selected; one for the coaxial type, and one for all U-pipe types. Again, for any field followed by a question mark, a database can be accessed.

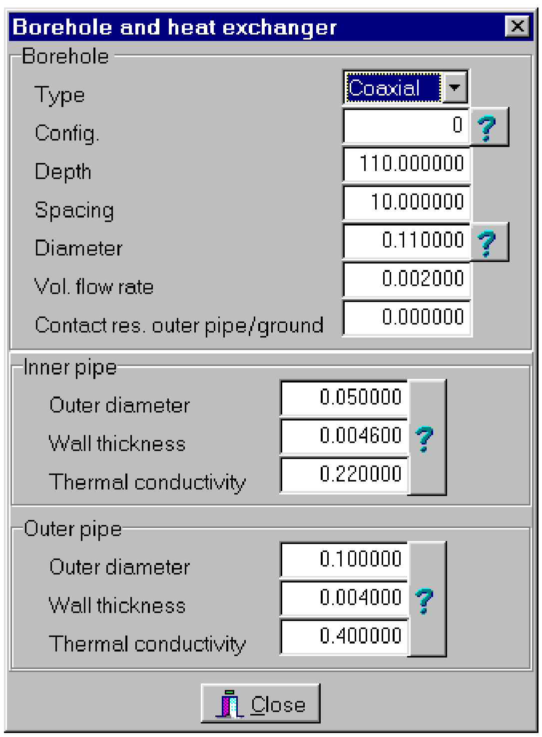


Figure 2.6: Input menu for bore hole and heat exchanger.

When starting with the default data file, the heat exchanger type is set to „Coaxial“. By clicking on the sign „▼“ right of „**Type**“, a small pull-down window offers four options as shown in Figure 2.7.

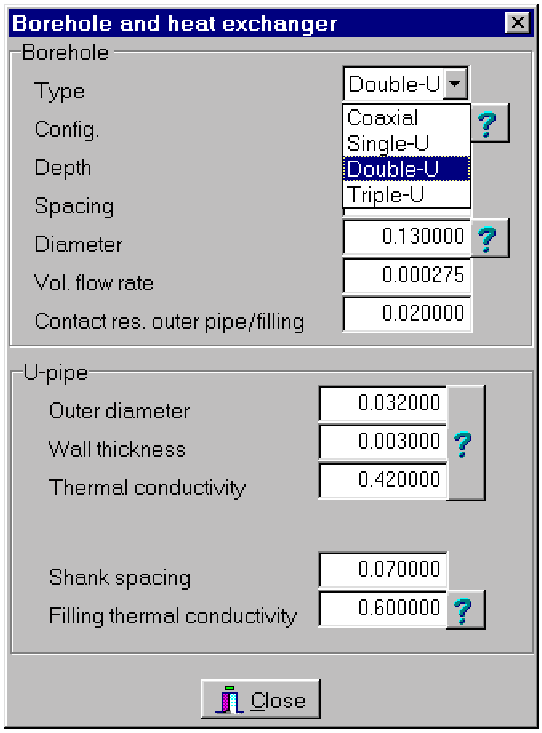


Figure 2.7: Options for heat exchanger type.

The most frequent type in mid Europe, also used in the Linden example, is double-U-pipes:

Next, the bore hole geometry („**Configuration**") is asked for. This means selection of an adequate g-function.

The basic forms of bore hole heat exchanger (BHE) geometry available in Version 2.0 are as follows:

Geometry	**Name**
Single BHE	SINGLE
BHE-Layout in a straight line	LINE
BHE-Layout in a line in L-shape	L-CONFIGURATION
BHE-Layout in two parallel L-shaped lines	L2-CONFIGURATION
BHE-Layout in a line in U-shape	U-CONFIGURATION
BHE-Layout in a line forming an open rectangle	OPEN RECTANGULAR CONFIG.
BHE-Layout in form of a rectangular field	RECTANGULAR CONFIGURAT.

Clicking on the question mark to the right of „**Config.**" opens a new window with a list of g-functions to choose from, see Figure 2.8. The number in the first column shows the total number of bore holes in the configuration, followed by the exact geometry; the number in the last column is the number of the configuration (1 to 307). A list of possible configurations and explanations of the geometry is given in the Appendix D of this manual. Only a certain number of g-functions can be displayed in the window, so it may be necessary to scroll down.

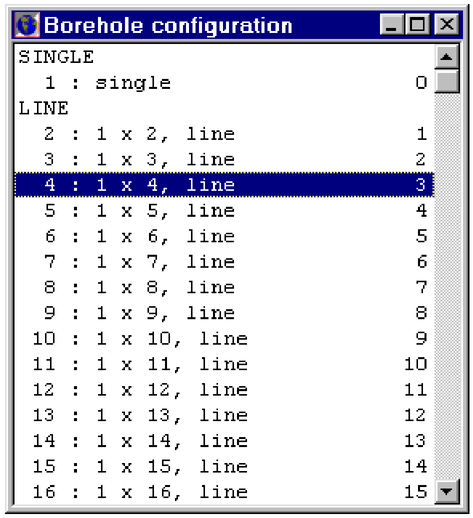


Figure 2.8: List of bore hole configurations.

The function for Linden is four holes in a line, which has been selected. The bore hole **depth** and bore hole **spacing** can now be typed in (50 m and 4 m, respectively, for Linden). No database values fit these parameters so it is given directly instead. In the field „**Diameter“** the bore hole diameter is typed. A database, accessible by clicking on the question mark beside the field, suggests usual drilling diameters, including API-standards, see Figure 2.9. In Linden, a 130-mm-diameter-hole has been drilled. A check is made, if the diameter is large enough to house the pipes, and sub-menu cannot be closed if not.

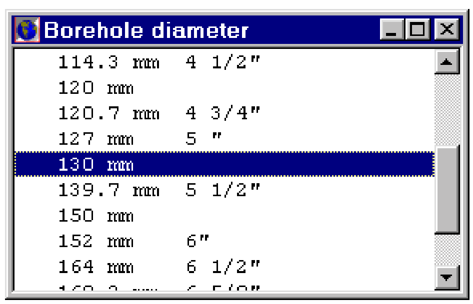


Figure 2.9: List of bore hole diameter.

The next field in the sub-menu concerns „**Volumetric Flow Rate“**. The flow through the pipes in one bore hole is considered, in m³/s. EED needs this value to calculate the Reynolds number. In the Linden example approx. 4 m³/h are circulated (0.0011 m³/s), which are distributed to 4 bore holes. Thus the flow through one hole is 0.000275 m³/s (and per pipe is 0.00014 m³/s for a double-U-tube).

Now the thermal contact resistance between pipe and bore hole fill is asked for („Contact res. outer pipe/filling“). This value depends on the quality of the grouting operation. When pumping grout into the hole from bottom to top very diligently, a value of 0.0 m²·K/W is possible, otherwise 0.01 or, with poor fill, 0.02-0.03. In the Linden example, the filling of the bore hole from the top does not allow good contact, and hence a value of 0.02 m²·K/W is typed in.

Now, the material and dimensions of the pipes are given („**Outer diameter**“, „**Wall thickness**“, „**Thermal conductivity**“). The values can either be typed into the relevant fields, or the database for pipe material can be opened (for all three parameters simultaneously) by clicking on the question mark to the right. In the Linden example a polyethylene pipe DN25 PN10 (German standard) is used. This and the slightly larger pipe DN32 PN10 are most frequent for bore hole heat exchangers in mid Europe. The database also contains data for pipes made from polyethylene, polypropylene, steel, copper and stainless steel. After selection of a pipe, the values (d = diameter, t

= wall thickness, l = thermal conductivity) are transferred to the sub-menu by double-clicking on the pipe designation, or by highlighting the pipe name, see Figure 2.10.

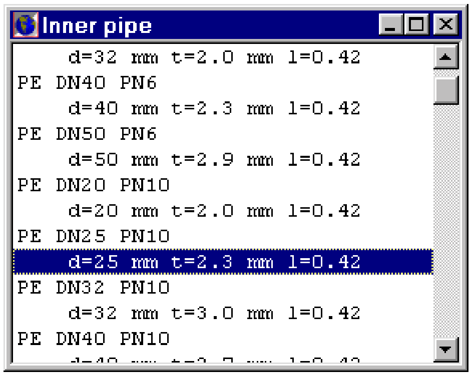


Figure 2.10: List of inner pipe measurements.

Now the field „**Shank spacing**“ can be approached. This refers to the distance from center to center of the up- and down-pipes in each “U”. No database is available here, and the value has to be typed in. With a real BHE in practice, the distance is not constant over the length, and an average has to be used. If spacers are used, the distance achieved by the spacers is relevant. EED checks if the distance is big enough to allow the pipes not to intersect each other, and does not allow closing of the sub-menu if the distance is to small. For pipes with 25 mm diameter, 0.07 m distance is sufficient. The next field („**Filling thermal conductivity**“) serves for input of thermal conductivity of the bore hole fill (grout). Again values can be picked from a database by clicking on the question mark beside the field. For the Linden example, a filling with drilling mud is used, and a value of 0.6 W/m·K is adequate for this.

Now the sub-menu is filled out completely and looks as shown in Figure 2.11. It can be closed by clicking on „**Close**“, if no more changes are desired. It is recommended to now and then save the project data file in the „**File**“-menu.

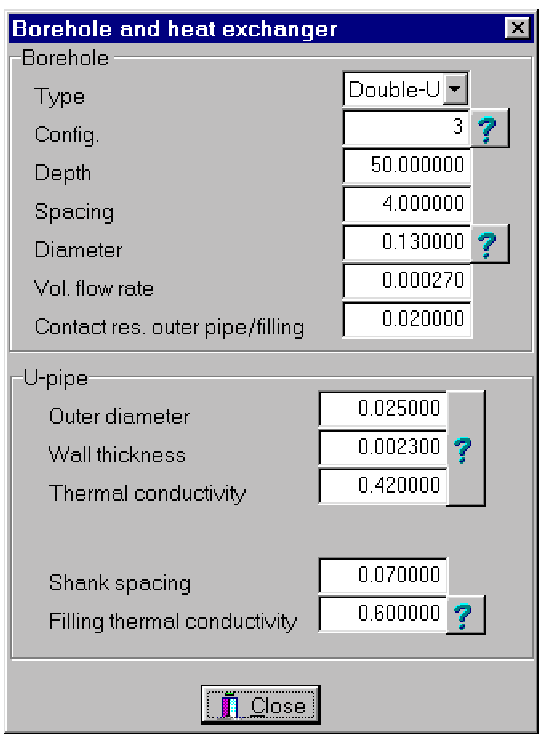


Figure 2.11: Data for our example.

The sub-menu „**Bore hole and heat exchanger“** is somewhat different, if **coaxial** heat exchangers are selected. A coaxial heat exchanger requires data for outer and inner pipe (typed or picked from the database). EED checks, if the inner pipe fits comfortably into the outer pipe, and does not allow closing of the sub-menu if not. The other parameters are identical with those in the U-pipe sub-menu.

2.3 Bore hole thermal resistance

The next sub-menu in the „**Input“** menu concerns thermal resistances in the bore hole („**Bore hole thermal resistance**“), see Figure 2.12. The values can either be stated, if they are known e.g. from a thermal response test, or can be calculated each time. By clicking on one of the circles in the top left corner of the window, a selection of one of the methods is made.

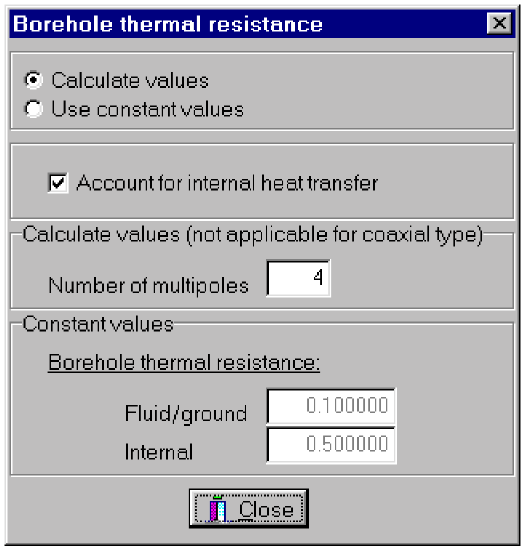


Figure 2.12: Input for Bore hole thermal resistance.

Usually the option for calculation will be used. The calculation uses an analytical solution that gives an exact solution of the two-dimensional heat conduction problem in a plane transverse to the bore hole axis. The solution consists of an infinite series of multipoles of rapidly decreasing strength (and importance). The accuracy of the solution depends on how many multipoles of the infinite series are evaluated. Four multipoles give a solution exact enough for most purposes, higher numbers will increase the computing time.

The user also choose whether or not to take account for heat transfer between the individual pipes with flow up or down ("Account for internal heat transfer"). The effect of natural convection in groundwater-filled bore holes with U-pipes is not accounted for. For the Linden example, the window will look as shown above. It can now be closed by either clicking on „**Close**“ or on the „**X**“ in the upper right corner of the window.

*2.4 **Heat Carrier Fluid***

Now the submenu „**Heat carrier fluid**“ is opened by clicking on that item in the „**Input**“-menu, see Figure 2.13. It contains input fields for thermal conductivity, specific heat capacity, density, viscosity and freezing point of the fluid.

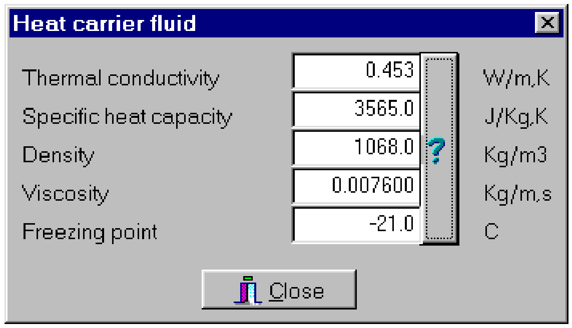


Figure 2.13: Input for Heat carrier fluid.

Data for common heat carrier fluids can again be picked from a database, see Figure 2.14, by clicking on the question mark to the right. The values in the database usually refer to a working temperature around 0 °C, which is typical for heat pump operation. Only in the case of pure water, a selection of working temperature levels is given. The database values are transferred simultaneously to the sub-menu by double-clicking on the required material and concentration, or by highlighting the line and clicking on the „**X**" in the upper right corner of the database window.

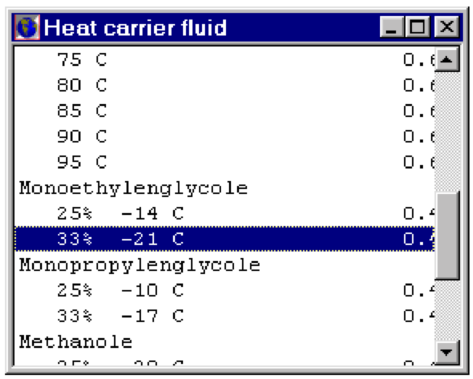


Figure 2.14: List of common heat carrier fluids.

In the Linden example monoethylen-glycole is used, and „Monoethylenglycole 33 %" is selected (the exact value in the plant is 29 %) by double-clicking on it.

2.5 Input of Base Load Data

Figure 2.15 shows the input for heating- and cooling-loads. EED offers two input methods. One method, „Annual energy & monthly profile", accepts the whole annual heating and cooling load in MWh and distributes it to the individual months using a given load profile (default values can be changed if necessary). The other method, „Monthly Energy Values", requires the heating and cooling load for each individual month. The first method is fast and is used for smaller plants, while the second allows modeling of a specific load profile including loads independent of seasons, like domestic hot water.

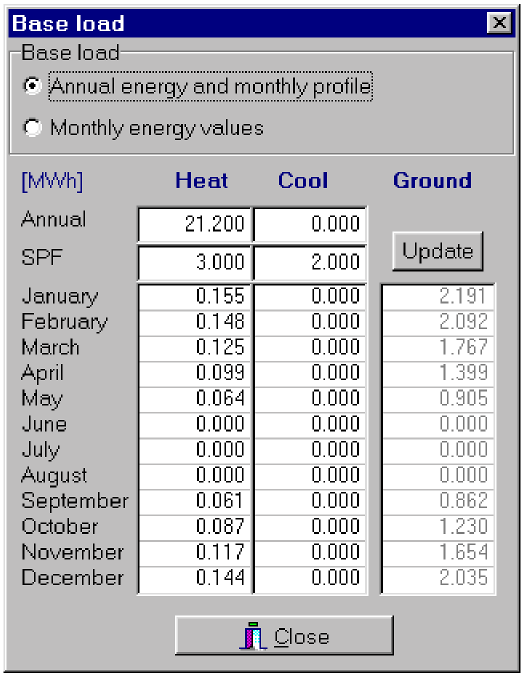


Figure 2.15: Input for base load.

The input field is divided in three columns, „Heat“, „Cool“ and „Ground“. In the first line under „Heat“ the annual heat load in MWh is typed, for Linden 29.03 MWh (winter 1993/94). Under „Cool“ the annual cooling load is stated, which was in Linden 1.89 MWh in summer 1994. The next line accommodates the seasonal performance factor (SPF); an annual average is required. For the Linden example it was SPF = 2.12 in winter 1993/94. In the cooling mode in Linden no heat pump is operated; this so-called „direct cooling“ can be simulated with SPF = 10000.

The factors in the following lines give the part of the heating and cooling load in each month, resp. 0.155 in January means 15.5 % of the heating load occurs in January. For the Linden example, the heating values are kept unchanged, while for cooling mode values in the months June-August are given. The last column displays the resulting heat extracted from or rejected to the earth for each month, as calculated using annual load, SPF, and monthly factors. Negative values mean heat flow into the earth. This column can not be accessed directly. The Linden example now looks like shown below:

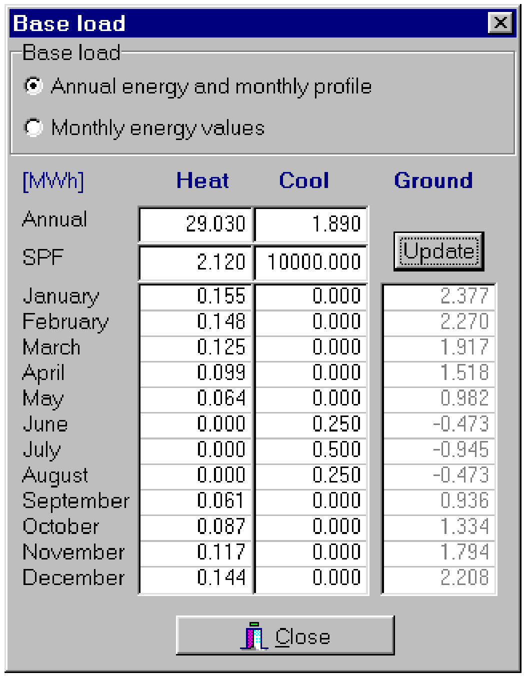


Figure 2.16: Data for our example.

When no more changes are desired, the sub-menu „**Base Load**" can be closed by either clicking on „**Close**" or on the „**✕**" in the upper right corner of the window.

The method for monthly heating- and cooling-loads works very much alike, only the line for annual loads is not accessible and the monthly loads are typed in directly instead of the monthly load factors.

2.6 Input of Peak Load Data

Figure 2.17 shows the input for peak heat and cooling power. For each month the maximum heat load (which normally is the maximum heat pump heating output) and the continuous duration of this load can be given.

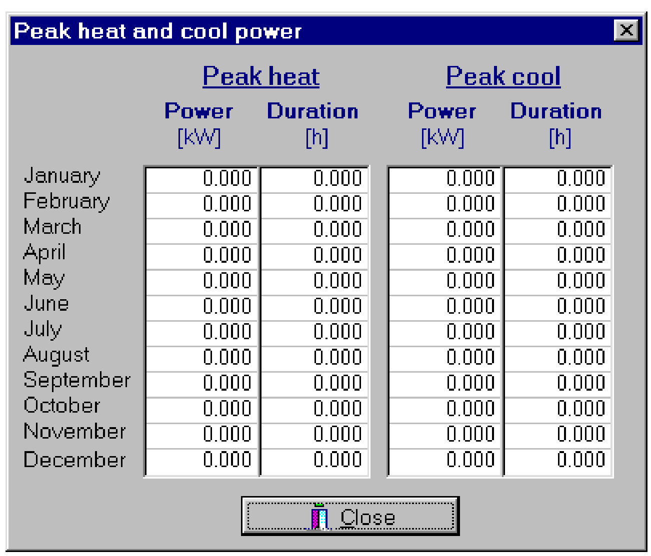


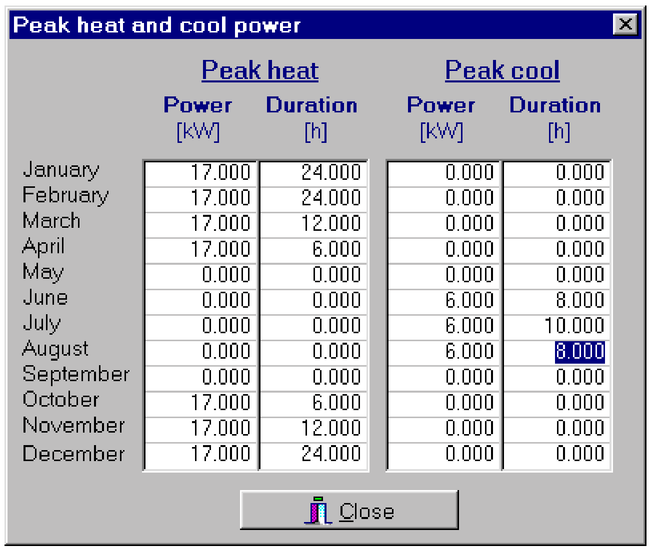
Figure 2.17: Input for peak heat and cooling power.

Peak loads are used to estimate the maximum possible temperature variations. The heat extraction or -rejection according to the peak load is added to the base load at the end of each month, and the resulting fluid temperatures are calculated. This values are stored separately in the output file and show the minimum respectively maximum temperatures which can occur.

Peak heat loads are given in kW. The program automatically calculates with the seasonal performance factor (SPF) given in the base load sub-menu. In cases where peak heat load may result in the same average heat extraction rate as given in base load, the curves will coincide. For the calculation it is supposed, that the *energy content* of the short peak load is negligible (i.e. included in the base load) and does not influence the long-term behavior.

In the Linden example the heat pump has a maximum heating output of 17 kW. In winter 24 hours of continuous maximum heating output are possible, the corresponding values are typed in the fields and are shown in the figure below:

In summer more than 10 hours maximum cooling load are not to be expected (early in the morning and during night normally no cooling is required). For the Linden example 6 kW maximum cooling load are given, which are supplied directly from the ground (SPF = 10000 is still valid from the base load sub-menu). The values are also shown in the figure below.



	Peak heat Power [kW]	Peak heat Duration [h]	Peak cool Power [kW]	Peak cool Duration [h]
January	17.000	24.000	0.000	0.000
February	17.000	24.000	0.000	0.000
March	17.000	12.000	0.000	0.000
April	17.000	6.000	0.000	0.000
May	0.000	0.000	0.000	0.000
June	0.000	0.000	6.000	8.000
July	0.000	0.000	6.000	10.000
August	0.000	0.000	6.000	8.000
September	0.000	0.000	0.000	0.000
October	17.000	6.000	0.000	0.000
November	17.000	12.000	0.000	0.000
December	17.000	24.000	0.000	0.000

Figure 2.18: Data for our example.

2.7 Simulation Period

Figure 2.19 shows the menu for simulation period. In „**Simulation Period**“ the number of years the simulation should comprise is stated (10 years in the sample case). Also the starting month is important, in particular in plants with heating and cooling. Those plants can have first a phase of heating the ground or first an extraction phase. The Linden plant was operational in February (very uncommon), the 2:nd month of the year.

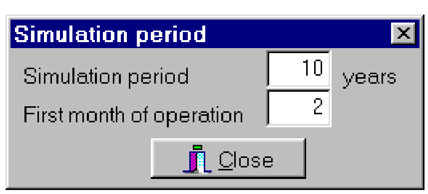


Figure 2.19: Input for simulation period.

3. Calculation of mean temperature of the heat carrier fluid

The calculations can be done in the pull-down menu „**Solve**“, see Figure 3.1. Two alternatives are offered in the „**Solve**“ menu:

- the calculation of the mean fluid temperature for a given plant (layout as given in the project data file),
- the calculation of the required bore hole length to keep the fluid temperature within given limits for that plant.

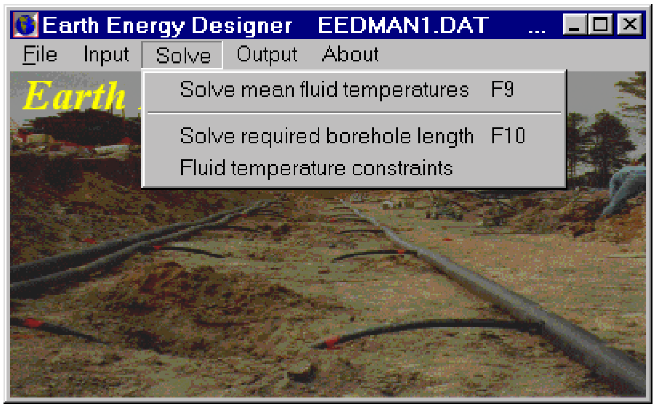


Figure 3.1: The solve menu.

In the Linden example, now a warning concerning the Reynold´s number appears, see Figure 3.2.

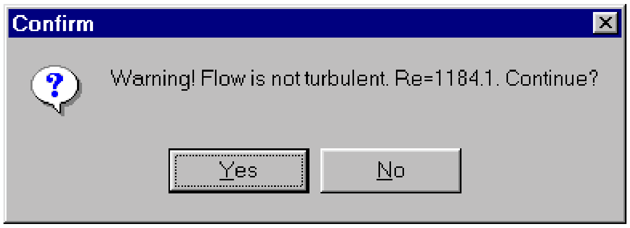


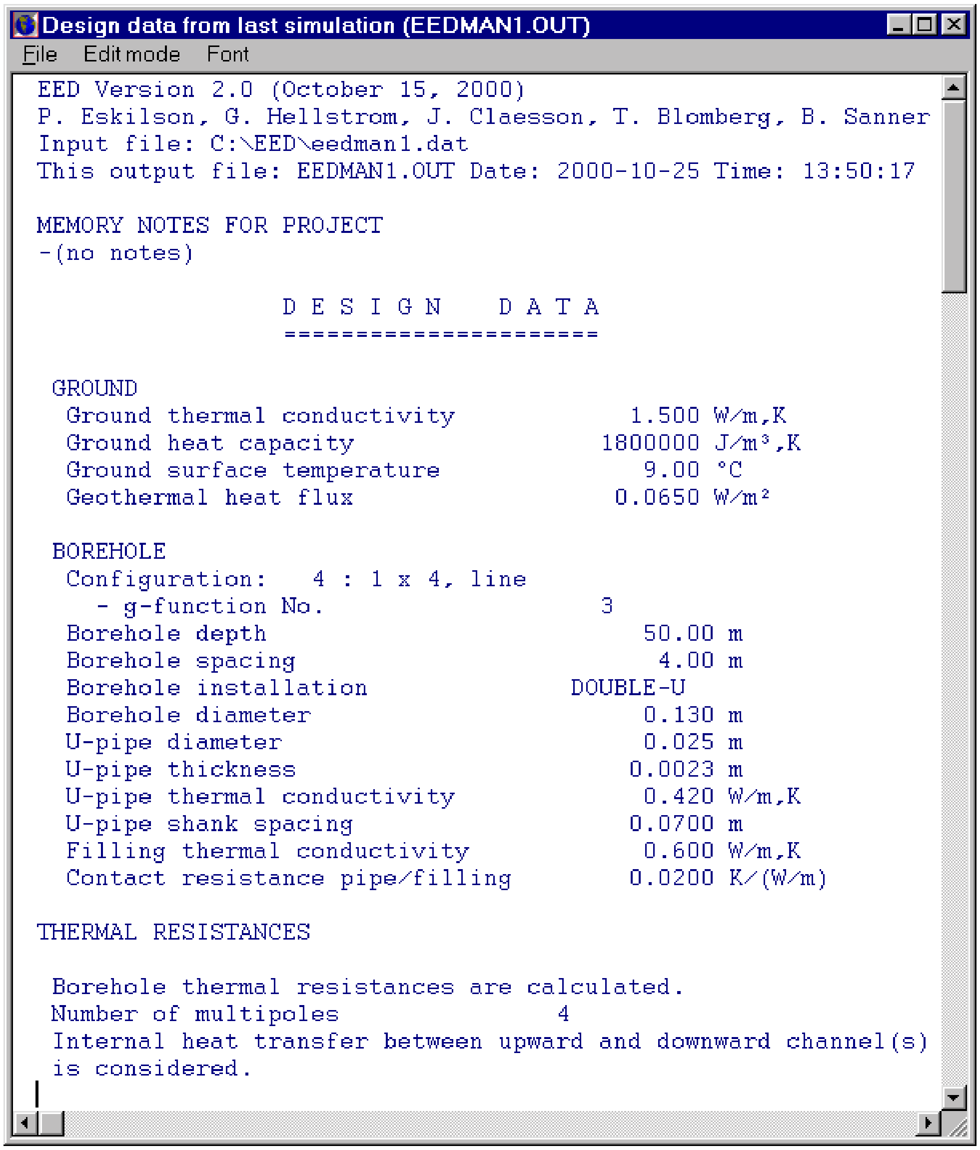
Figure 3.2: Warning for non-turbulent flow.

The flow within the heat exchanger pipes is not turbulent, exhibiting a Reynold´s number of 1184. Thus, the heat transfer from pipe wall to fluid is poor. A Reynold´s number of >2300 is desirable. The calculation can be continued anyway, by clicking on „Yes“, and the warning vanishes. After few seconds the calculation is completed. In cases where fluid temperatures become lower than the fluid´s freezing point, a warning is given.

4. Output of results

4.1 Introduction

After completion of the calculation, a window showing the input data and the results is displayed, see Figure 4.1.




```
EED Version 2.0 (October 15, 2000)
P. Eskilson, G. Hellstrom, J. Claesson, T. Blomberg, B. Sanner
Input file: C:\EED\eedman1.dat
This output file: EEDMAN1.OUT Date: 2000-10-25 Time: 13:50:17

MEMORY NOTES FOR PROJECT
-(no notes)

                 D E S I G N   D A T A
                 =====================

 GROUND
  Ground thermal conductivity               1.500 W/m,K
  Ground heat capacity                    1800000 J/m³,K
  Ground surface temperature                 9.00 °C
  Geothermal heat flux                     0.0650 W/m²

 BOREHOLE
  Configuration:   4 : 1 x 4, line
    - g-function No.                      3
  Borehole depth                            50.00 m
  Borehole spacing                           4.00 m
  Borehole installation                 DOUBLE-U
  Borehole diameter                         0.130 m
  U-pipe diameter                           0.025 m
  U-pipe thickness                         0.0023 m
  U-pipe thermal conductivity               0.420 W/m,K
  U-pipe shank spacing                     0.0700 m
  Filling thermal conductivity              0.600 W/m,K
  Contact resistance pipe/filling          0.0200 K/(W/m)

THERMAL RESISTANCES

 Borehole thermal resistances are calculated.
 Number of multipoles                   4
 Internal heat transfer between upward and downward channel(s)
 is considered.
```

Figure 4.1: Input data and calculated results (menu item Output/View design data).

With the „File“ command of the new window, the output file can be printed or saved under another name. Editing and changing fonts and format is also possible. The output file is an ASCII-file and thus can be loaded into most text editors to be further edited. The complete file Manual_e.out is printed in Appendix A.

In the „**Output**“ menu of EED also graphs of the temperature development can be displayed. The temperature over the months of the last year of simulation can be seen with „Plot Fluid Temperatures“ (see Figure 4.2), and the evolution of the highest and lowest temperatures for each year of the simulation period can be seen with „Plot Min-Max Temperatures“ (see Figure 4.3).

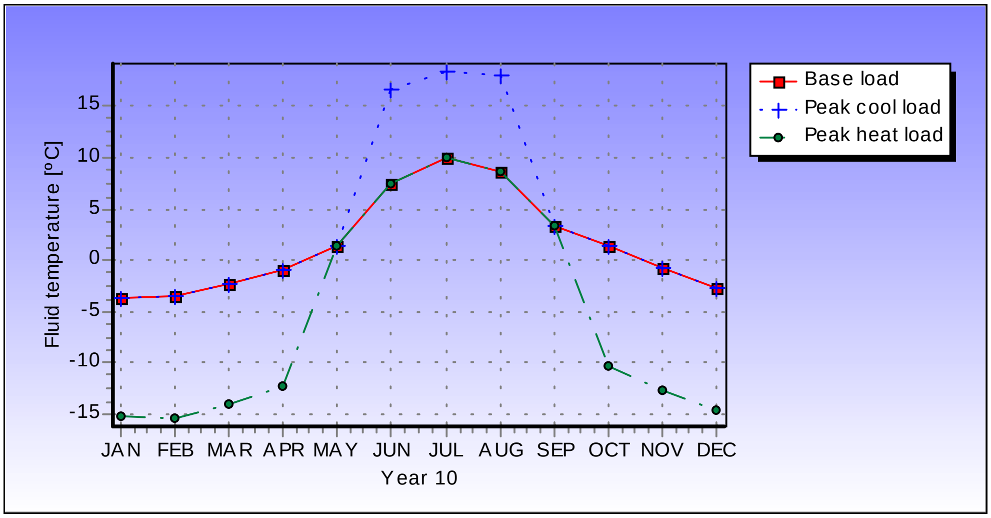


Figure 4.2: Fluid temperature chart.

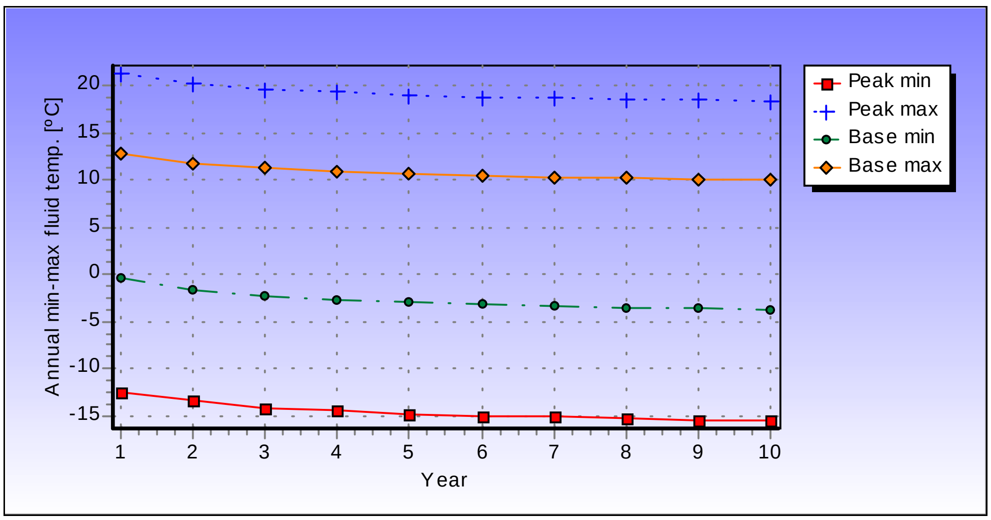


Figure 4.3: Minimum and maximum temperatures.

The graphs „Fluid temperature chart" and „Minimum and maximum temperatures" can be kept open on the screen, and they will be updated with every new „Solve"-action. When a new data file in menu „File" is opened, the windows with the graphs are closed automatically.

Each of the two graphic windows has the pull-down menus „File" and „Options". With the „File" menu for graphs, see Figure 4.4, the following operations can be made:

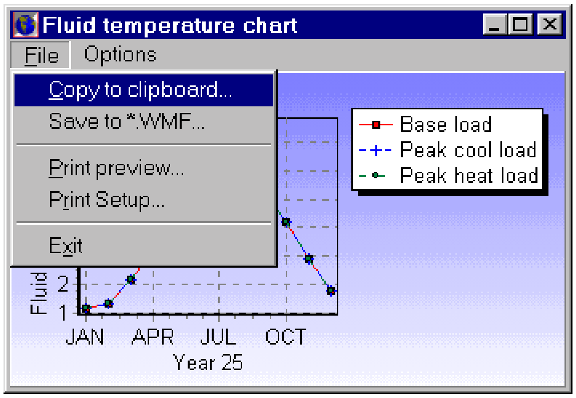


Figure 4.4 The file menu.

With „Copy to clipboard...", the figure can be transferred to other programs under Windows (e.g. MS-Word). The command „Save to *.WMF..." allows to save the graph as a Windows-Metafile, that can later be imported into other programs. „Print preview..." allows to check the printer output of the graph, to change and adjust it, and to send it to a printer; with „Print setup", the printer can be selected and configured.

The pull-down menu „Options", see Figure 4.5, allows to change the style and to edit the graph:

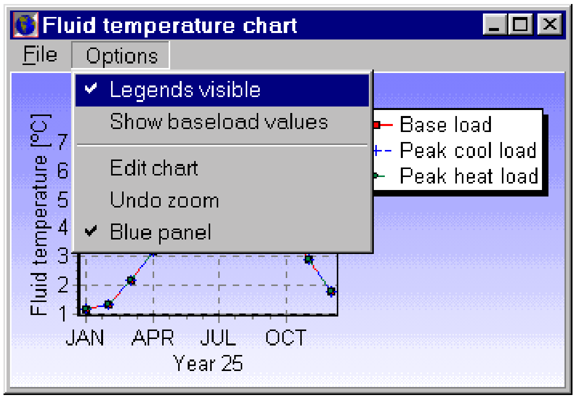


Figure 4.5: The options menu

To allow using different graphic packages, two data output files are created after each „**Solve**" operation. These files, called „tfluid.out" and „tfmin.out", contain the data points for the graphs in ASCII-format. An example is given in Appendix C.

The command „Edit chart" allows a more sophisticated editing of the figure (changing colors, adjusting axes and scales, editing the legend, etc.).

4.2 Changing chart properties

4.2.1 Introduction

The properties of a chart may be changed by the chart editor (**Options/Edit chart**), see Figure 4.5,

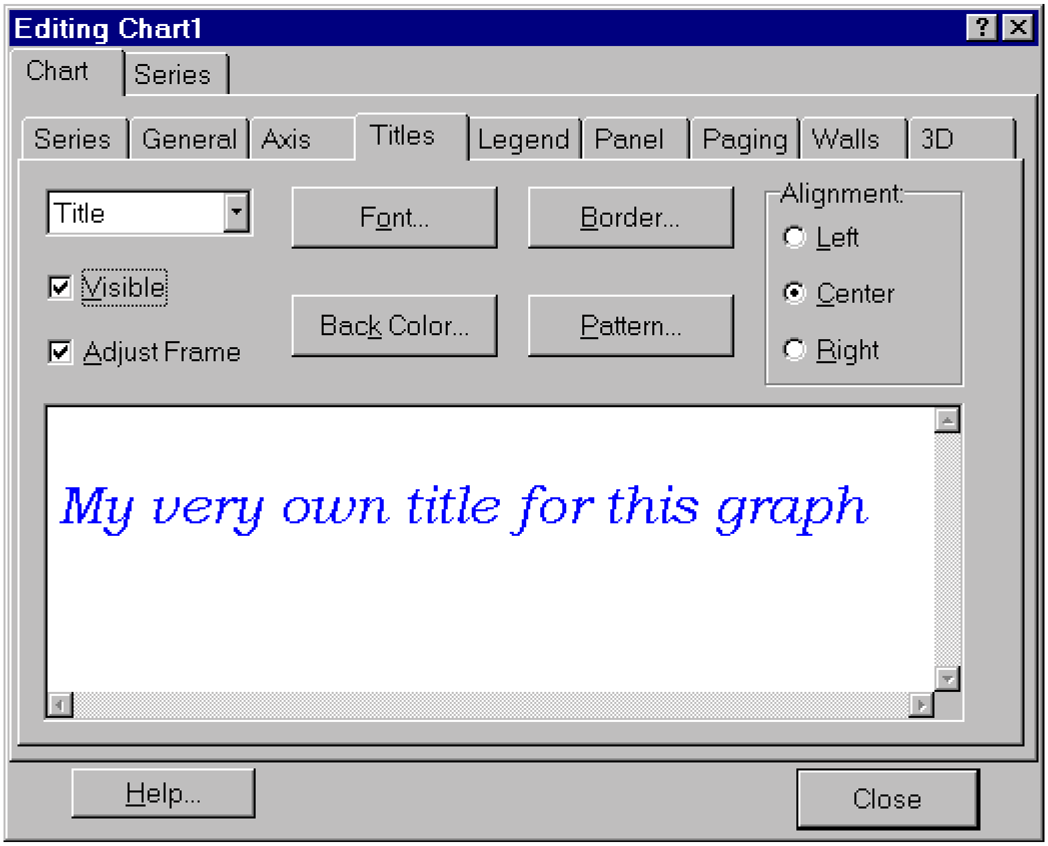


Figure 1: Chart settings may be changed in menu item **Options/Edit chart**.

4.2.2 Chart and series properties

There are two principal sections to the Chart editor, Chart parameters and the Series parameters, which are separated as two tabs of the Chart Editor. To get help on any topic in the Chart Editor, select the help button (question mark) at the top right hand side of the Editor window and drag it onto the Topic in question.

<u>Chart pages</u>

You may define overall chart display parameters as follows:

Series page - You can change a series type to line, bar, area, point, etc. Select the series type of choice from the gallery.

General Page - Chart rectangle dimensions, margins, zoom and scroll, print preview and export

Axis Page - All axes definitions. Some parameters depend upon the series associated with the axis.

Titles Page - Title and Footer

Legend Page - Legend display. Formatted displays work in conjunction with the chart series. See also the 'General' page of the Series.

Panel Page - Chart Panel display properties. Colors, bevels, back images, color gradient and border.

Paging Page - Definition of number of points per chart page

Walls Page - Left, bottom and back wall size and color definitions

3D – 3D perspective options.

Series Pages

The series pages contain parameters dependant on the series type concerned. The most important options are as follows:

Format Page - Contains Series type specific parameters

Point – Visible points, margins

General Page - Series value format, axis association

Marks Page - Series mark format, text, frame and back color and positioning

5. Calculation of required bore hole length for given fluid temperature constraints

In the chosen example of Linden the plant is undersized, as also was detected in the monitoring data. Mean base load temperatures below 0 °C over several weeks should be avoided, and temperatures should preferably not drop below -5 °C in peak heat load conditions. With the second alternative in menu „**Solve**“, see Figure 5.1, an easy way to calculate the required bore hole length to fulfil this conditions is offered:

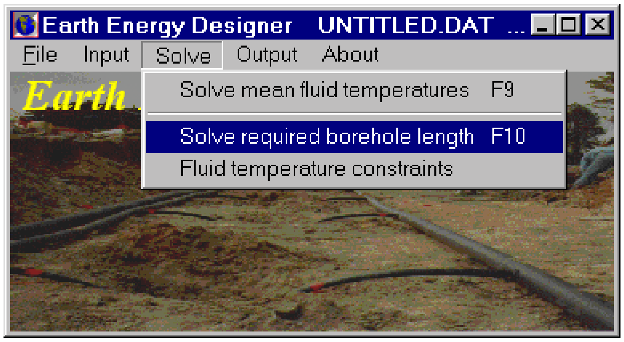


Figure 5.1: Item solve required bore hole length.

To calculate the required bore hole length for a given plant under certain fluid temperature constraints, the sub-menu „Fluid temperature constraints“ in the „**Solve**“-menu is opened, see Figure 5.2. The desired maximum and minimum fluid temperatures not be exceeded can be typed in. By activating „✔“ for „Include peak loads“ the peak load temperature will be the criterion, with the field deactivated the base load temperature.

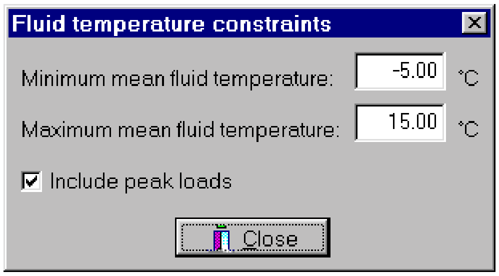


Figure 5.2: Input for fluid temperature constraints.

After stating the fluid temperature constraints (-5.0 °C and 18.0 °C, respectively, for the Linden example) the sub-menu can be closed by either clicking on „**Close**“ or on the „**X**“ in the upper right corner of the window. To keep the earlier calculations, a new project data file called „manual_x.dat“ is created in the menu „**File**“ with the command „Save as...“. Automatically the output will be written to a new output file „manual_x.out“.

The calculation, using the bore hole configuration as stated in the sub-menu „**Bore hole and Heat Exchanger**“ in the „**Input**“-Menu, is started by clicking on „Solve required bore hole length“. The bore hole length is increased, which can be seen in the output window. Also the parameter for bore hole depth in the sub-menu „**Bore hole and Heat Exchanger**“ in the „**Input**“-menu is automatically set to the new value of 82.87 m for the Linden example. The graphics (see below) now show a very satisfying temperature development.

<u>NB:</u> When calculating the required bore hole length, the value for bore hole length is changed in the sub-menu „**Bore hole and Heat Exchanger**". The program has some routines to avoid paradox

operation conditions (e.g. heat extraction with fluid temperatures higher than those of the surrounding ground), but nevertheless unrealistic bore hole length can be suggested in extreme cases. Hence it is recommended to check regularly fluid temperatures and bore hole length when using the option „**Solve required bore hole length**“.

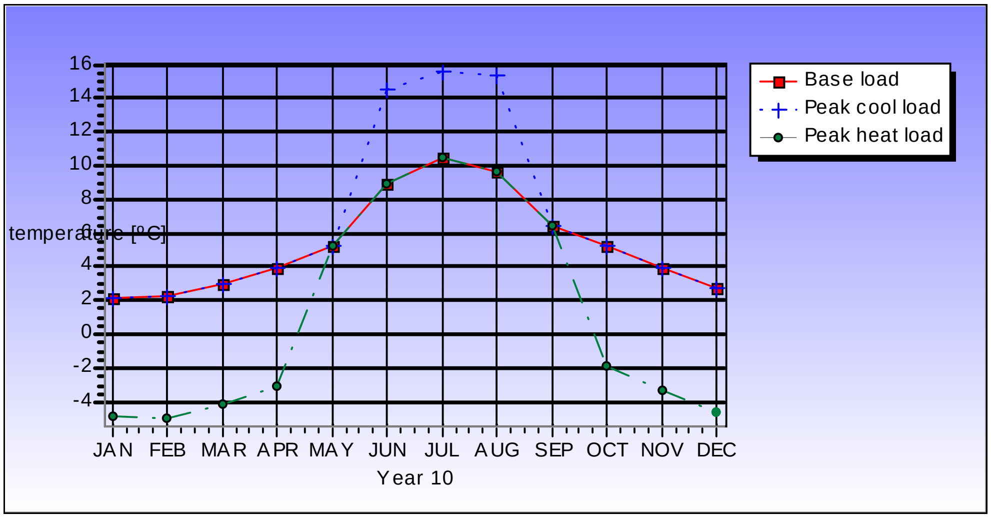


Figure 5.3: Fluid temperature chart.

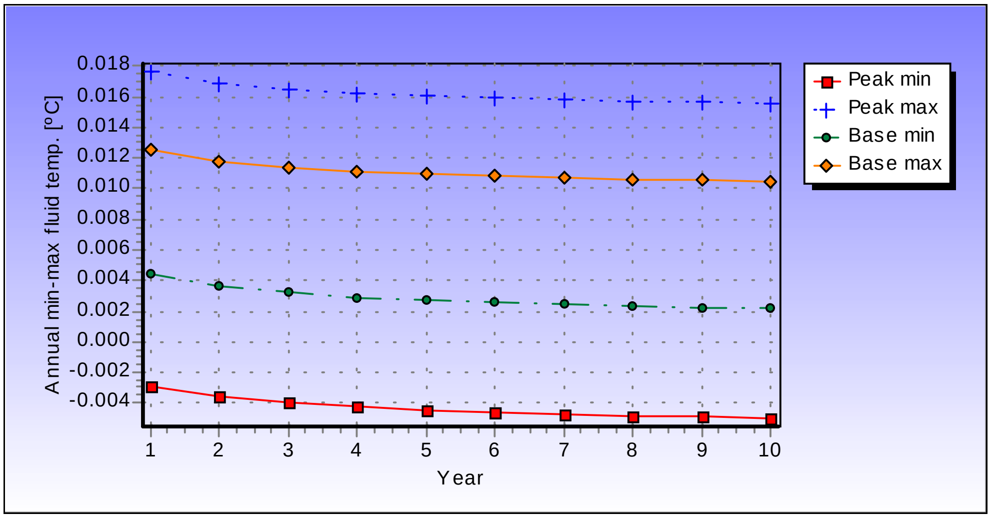


Figure 5.4: Minimum and maximum temperatures.

The content of the output file „manual_x.out“ for the optimized Linden example is listed in Appendix B. It is obvious, that the bore hole depth has to be increased by ca. 65 % to achieve an energetically optimum layout. Economic consideration can result in not following this design in a particular case; but in any case the layout has to guarantee the plant will work at least without thermal problems in the ground.

In the graph „Minimum and maximum temperatures“ the temperature curves will approach an almost horizontal line after some years. The time to attain such steady-state thermal conditions increases with the number of bore holes and the bore hole depth. For sites without groundwater flow the temperature development over simulation period has to be observed thoroughly. A totally horizontal line theoretically will only be found in plants with balanced heating-/cooling load, but an asymptotic closing in to a not too low temperature level is sufficient (not to high level in case of cooling).

The influence of groundwater flow through the bore hole field is not accounted for in the present version of EED. The effect of the groundwater flow is to move the thermal disturbance (caused by the injection or extraction of heat) away from the bore holes. This effect improves the performance of systems designed for dissipation of heat and cold into the ground. The improvement depends on the magnitude of the groundwater flow (given in terms of the so-called "Darcy flow") and on how much of the total bore hole length penetrates layers with groundwater flow. For systems intended for storage of heat and/or cold, the groundwater flow will increase heat losses and thereby reduce the efficiency of the store.

6. Literature

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Appendix A. Output data file „Manual_e.out“

„Manual_e.out“

```
EED Version 2 (March 7, 2000)
P. Eskilson, G. Hellstrom, J. Claesson, T. Blomberg, B. Sanner
Input file: C:\EEDman\Projects\Manual_e.dat
This output file: MANUAL_E.OUT    Date: 07.09.00   Time: 22:33:13

MEMORY NOTES FOR PROJECT
- Example for Manual
- EED Version 2.0
- Solving method „Mean fluid temperatures“

                 D E S I G N    D A T A
                 ======================

 GROUND
  Ground thermal conductivity            1.500 W/m,K
  Ground heat capacity                 1800000 J/m³,K
  Ground surface temperature              9.00 °C
  Geothermal heat flux                  0.0650 W/m²

 BORE HOLE
  Configuration:   4 : 1 x 4, line
    - g-function No.                   3
  Bore hole depth                         50.00 m
  Bore hole spacing                        4.00 m
  Bore hole installation              DOUBLE-U
  Bore hole diameter                      0.130 m
  U-pipe diameter                        0.025 m
  U-pipe thickness                      0.0023 m
  U-pipe thermal conductivity            0.420 W/m,K
  U-pipe shank spacing                  0.0700 m
  Filling thermal conductivity           0.600 W/m,K
  Contact resistance pipe/filling       0.0200 K/(W/m)

THERMAL RESISTANCES

 Bore hole thermal resistances are calculated.
 Number of multipoles                 4
 Internal heat transfer between upward and downward channel(s) is
 considered.

 HEAT CARRIER FLUID

  Thermal conductivity                   0.453 W/m,K
  Specific heat capacity                  3565 J/kg,K
  Density                                 1068 kg/m³
  Viscosity                           0.007600 kg/m,s
  Freezing point                         -21.0 °C
  Flow rate per bore hole             0.000270 m³/s
```

BASE LOAD

Annual heating load	29.03 MWh
Annual cooling load	1.89 MWh
Seasonal performance factor (heating)	2.12
Seasonal performance factor (cooling)	10000.00

Monthly energy profile

Month	Heat load	Cool load	(MWh)
JAN	0.1550	0.0000	
FEB	0.1480	0.0000	
MAR	0.1250	0.0000	
APR	0.0990	0.0000	
MAY	0.0640	0.0000	
JUN	0.0000	0.2500	
JUL	0.0000	0.5000	
AUG	0.0000	0.2500	
SEP	0.0610	0.0000	
OCT	0.0870	0.0000	
NOV	0.1170	0.0000	
DEC	0.1440	0.0000	
	----------	----------	
Total	1.0000	1.0000	

PEAK LOAD

Monthly peak powers (kW)

Month	Peak heat	Duration	Peak cool	Duration
JAN	17.00	24.0	0.00	0.0
FEB	17.00	24.0	0.00	0.0
MAR	17.00	12.0	0.00	0.0
APR	17.00	6.0	0.00	0.0
MAY	0.00	0.0	0.00	0.0
JUN	0.00	0.0	6.00	8.0
JUL	0.00	0.0	6.00	10.0
AUG	0.00	0.0	6.00	8.0
SEP	0.00	0.0	0.00	0.0
OCT	17.00	6.0	0.00	0.0
NOV	17.00	12.0	0.00	0.0
DEC	17.00	24.0	0.00	0.0

Number of simulation years 10
First month of operation FEB

C A L C U L A T E D   V A L U E S
==================================

Total bore hole length 200.0 m

THERMAL RESISTANCES

Bore hole therm. res. internal	0.6625 K/(W/m)
Reynolds number	1184
Thermal resistance fluid/pipe	0.1757 K/(W/m)
Thermal resistance pipe material	0.0771 K/(W/m)
Contact resistance pipe/filling	0.0200 K/(W/m)
Bore hole therm. res. fluid/ground	0.2088 K/(W/m)
Effective bore hole thermal res.	0.2100 K/(W/m)

SPECIFIC HEAT EXTRACTION RATE (W/m)

Month	Base load	Peak heat	Peak cool
JAN	16.28	44.91	-0.00
FEB	15.55	44.91	-0.00
MAR	13.13	44.91	-0.00
APR	10.40	44.91	-0.00
MAY	6.72	0.00	-0.00
JUN	-3.24	0.00	-30.00
JUL	-6.47	0.00	-30.00
AUG	-3.24	0.00	-30.00
SEP	6.41	0.00	-0.00
OCT	9.14	44.91	-0.00
NOV	12.29	44.91	-0.00
DEC	15.13	44.91	-0.00

BASE LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.08	-1.54	-2.95	-3.68
FEB	0.82	-1.54	-2.88	-3.60
MAR	1.51	-0.41	-1.70	-2.41
APR	2.70	1.06	-0.18	-0.88
MAY	4.65	3.22	2.03	1.35
JUN	10.56	9.28	8.14	7.47
JUL	12.91	11.75	10.66	10.00
AUG	11.44	10.37	9.32	8.68
SEP	5.88	4.90	3.89	3.26
OCT	3.94	3.04	2.06	1.44
NOV	1.72	0.89	-0.06	-0.68
DEC	-0.40	-1.17	-2.09	-2.70

BASE LOAD: YEAR 10
Minimum mean fluid temperature -3.68 °C at end of JAN
Maximum mean fluid temperature 10.00 °C at end of JUL

PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.08	-13.09	-14.50	-15.23
FEB	-11.03	-13.38	-14.72	-15.44
MAR	-10.14	-12.06	-13.35	-14.06
APR	-8.68	-10.33	-11.56	-12.26
MAY	4.65	3.22	2.03	1.35
JUN	10.56	9.28	8.14	7.47
JUL	12.91	11.75	10.66	10.00
AUG	11.44	10.37	9.32	8.68
SEP	5.88	4.90	3.89	3.26
OCT	-7.86	-8.75	-9.73	-10.36
NOV	-10.24	-11.07	-12.02	-12.64
DEC	-12.41	-13.18	-14.10	-14.71

PEAK HEAT LOAD: YEAR 10
Minimum mean fluid temperature -15.44 °C at end of FEB
Maximum mean fluid temperature 10.00 °C at end of JUL

PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.08	-1.54	-2.95	-3.68
FEB	0.82	-1.54	-2.88	-3.60
MAR	1.51	-0.41	-1.70	-2.41
APR	2.70	1.06	-0.18	-0.88
MAY	4.65	3.22	2.03	1.35
JUN	19.80	18.51	17.38	16.71
JUL	21.31	20.15	19.06	18.40
AUG	20.67	19.61	18.56	17.91
SEP	5.88	4.90	3.89	3.26
OCT	3.94	3.04	2.06	1.44
NOV	1.72	0.89	-0.06	-0.68
DEC	-0.40	-1.17	-2.09	-2.70

PEAK COOL LOAD: YEAR 10
Minimum mean fluid temperature -3.68 °C at end of JAN
Maximum mean fluid temperature 18.40 °C at end of JUL

******** END OF FILE **********

Appendix B. Output data file „Manual_x.out“

„Manual_x.out“

```
EED Version 2 (March 7, 2000)
P. Eskilson, G. Hellstrom, J. Claesson, T. Blomberg, B. Sanner
Input file: C:\EEDman\Projects\Manual_x.dat
This output file: MANUAL_X.OUT    Date: 07.09.00   Time: 23:41:46

MEMORY NOTES FOR PROJECT
- Example for Manual
- EED Version 2.0
- Solving method „required bore hole length“

                 D E S I G N    D A T A
                 ======================

 GROUND
  Ground thermal conductivity            1.500 W/m,K
  Ground heat capacity                 1800000 J/m³,K
  Ground surface temperature              9.00 °C
  Geothermal heat flux                  0.0650 W/m²

 BORE HOLE
  Configuration:   4 : 1 x 4, line
    - g-function No.                   3
  Bore hole depth                          82.87 m
  Bore hole spacing                         4.00 m
  Bore hole installation               DOUBLE-U
  Bore hole diameter                       0.130 m
  U-pipe diameter                         0.025 m
  U-pipe thickness                       0.0023 m
  U-pipe thermal conductivity             0.420 W/m,K
  U-pipe shank spacing                   0.0700 m
  Filling thermal conductivity            0.600 W/m,K
  Contact resistance pipe/filling        0.0200 K/(W/m)

THERMAL RESISTANCES

 Bore hole thermal resistances are calculated.
 Number of multipoles               4
 Internal heat transfer between upward and downward channel(s) is
considered.

 HEAT CARRIER FLUID

  Thermal conductivity                    0.453 W/m,K
  Specific heat capacity                   3565 J/kg,K
  Density                                  1068 kg/m³
  Viscosity                            0.007600 kg/m,s
  Freezing point                          -21.0 °C
  Flow rate per bore hole               0.000270 m³/s
```

BASE LOAD

Annual heating load	29.03	MWh
Annual cooling load	1.89	MWh

Seasonal performance factor (heating)	2.12
Seasonal performance factor (cooling)	10000.00

Monthly energy profile

Month	Heat load	Cool load (MWh)
JAN	0.1550	0.0000
FEB	0.1480	0.0000
MAR	0.1250	0.0000
APR	0.0990	0.0000
MAY	0.0640	0.0000
JUN	0.0000	0.2500
JUL	0.0000	0.5000
AUG	0.0000	0.2500
SEP	0.0610	0.0000
OCT	0.0870	0.0000
NOV	0.1170	0.0000
DEC	0.1440	0.0000
Total	1.0000	1.0000

PEAK LOAD

Monthly peak powers (kW)

Month	Peak heat	Duration	Peak cool	Duration
JAN	17.00	24.0	0.00	0.0
FEB	17.00	24.0	0.00	0.0
MAR	17.00	12.0	0.00	0.0
APR	17.00	6.0	0.00	0.0
MAY	0.00	0.0	0.00	0.0
JUN	0.00	0.0	6.00	8.0
JUL	0.00	0.0	6.00	10.0
AUG	0.00	0.0	6.00	8.0
SEP	0.00	0.0	0.00	0.0
OCT	17.00	6.0	0.00	0.0
NOV	17.00	12.0	0.00	0.0
DEC	17.00	24.0	0.00	0.0

Number of simulation years 10
First month of operation FEB

C A L C U L A T E D   V A L U E S
=================================

Total bore hole length 331.5 m

THERMAL RESISTANCES

Bore hole therm. res. internal	0.6625 K/(W/m)
Reynolds number	1184
Thermal resistance fluid/pipe	0.1757 K/(W/m)
Thermal resistance pipe material	0.0771 K/(W/m)
Contact resistance pipe/filling	0.0200 K/(W/m)
Bore hole therm. res. fluid/ground	0.2088 K/(W/m)
Effective bore hole thermal res.	0.2141 K/(W/m)

SPECIFIC HEAT EXTRACTION RATE (W/m)

Month	Base load	Peak heat	Peak cool
JAN	9.82	27.09	-0.00
FEB	9.38	27.09	-0.00
MAR	7.92	27.09	-0.00
APR	6.27	27.09	-0.00
MAY	4.06	0.00	-0.00
JUN	-1.95	0.00	-18.10
JUL	-3.91	0.00	-18.10
AUG	-1.95	0.00	-18.10
SEP	3.87	0.00	-0.00
OCT	5.51	27.09	-0.00
NOV	7.42	27.09	-0.00
DEC	9.13	27.09	-0.00

BASE LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.80	3.70	2.70	2.15
FEB	5.20	3.72	2.75	2.22
MAR	5.58	4.40	3.47	2.95
APR	6.28	5.28	4.39	3.87
MAY	7.48	6.58	5.73	5.22
JUN	11.06	10.24	9.41	8.91
JUL	12.52	11.75	10.95	10.46
AUG	11.65	10.93	10.16	9.68
SEP	8.26	7.61	6.86	6.38
OCT	7.04	6.44	5.72	5.25
NOV	5.67	5.11	4.41	3.94
DEC	4.39	3.86	3.18	2.72

BASE LOAD: YEAR 10
Minimum mean fluid temperature 2.15 °C at end of JAN
Maximum mean fluid temperature 10.46 °C at end of JUL

PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.80	-3.34	-4.34	-4.89
FEB	-2.01	-3.50	-4.46	-5.00
MAR	-1.52	-2.71	-3.63	-4.16
APR	-0.67	-1.67	-2.56	-3.08
MAY	7.48	6.58	5.73	5.22
JUN	11.06	10.24	9.41	8.91
JUL	12.52	11.75	10.95	10.46
AUG	11.65	10.93	10.16	9.68
SEP	8.26	7.61	6.86	6.38
OCT	-0.16	-0.76	-1.48	-1.96
NOV	-1.63	-2.19	-2.89	-3.35
DEC	-2.93	-3.46	-4.14	-4.60

PEAK HEAT LOAD: YEAR 10
Minimum mean fluid temperature -5.00 °C at end of FEB
Maximum mean fluid temperature 10.46 °C at end of JUL

PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month)

Month	Year 1	Year 2	Year 5	Year 10
JAN	10.80	3.70	2.70	2.15
FEB	5.20	3.72	2.75	2.22
MAR	5.58	4.40	3.47	2.95
APR	6.28	5.28	4.39	3.87
MAY	7.48	6.58	5.73	5.22
JUN	16.70	15.88	15.05	14.55
JUL	17.64	16.88	16.08	15.59
AUG	17.29	16.57	15.80	15.32
SEP	8.26	7.61	6.86	6.38
OCT	7.04	6.44	5.72	5.25
NOV	5.67	5.11	4.41	3.94
DEC	4.39	3.86	3.18	2.72

PEAK COOL LOAD: YEAR 10

Minimum mean fluid temperature	2.15 °C	at end of JAN
Maximum mean fluid temperature	15.59 °C	at end of JUL

******** END OF FILE **********

Appendix C. Data output files

Data output files (for the first calculation in this manual)

tfluid.out:

1	-1.46234
2	-11.02517
3	-10.13564
4	-8.67796
5	4.64913
6	10.56472
7	12.90986
8	11.43624
9	5.87745
10	-7.85507
11	-10.23752
12	-12.40746
13	-13.08964
14	-13.37749
15	-12.05968
16	-10.32547
17	3.21812
18	9.27690
19	11.74905
20	10.36980
21	4.90152
22	-8.75336
23	-11.06998
24	-13.18043
25	-13.81475
26	-14.06345
27	-12.71131
28	-10.94229
29	2.63568
30	8.72666
31	11.22922
32	9.87844
33	4.43223
34	-9.20394
35	-11.50331
36	-13.59781
37	-14.21734
38	-14.45229
39	-13.08732
40	-11.30579

(only first 40 of 120 values shown)

tfmin.out:

1	-12.40746
2	-13.37749
3	-14.06345
4	-14.45229
5	-14.72426
6	-14.93406
7	-15.10565
8	-15.24364
9	-15.35278
10	-15.44329

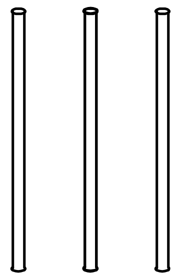
Appendix D. List of possible bore hole configurations

No. BHE	Name	No. of configuration
1	single	0

Example (configuration #0):

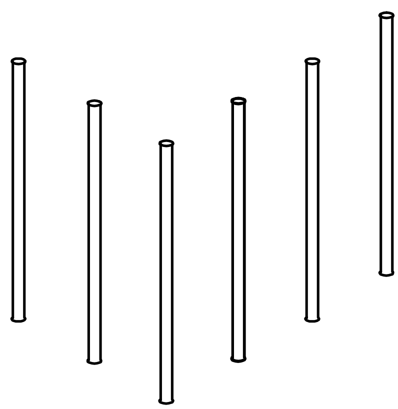
No. BHE	Name	No. of configuration
2	1 x 2, line	1
3	1 x 3, line	2
:	:	:
20	1 x 20, line	19
25	1 x 25, line	20

Example (configuration #2):



No. BHE	Name	No. of configuration
3	2 x 2, L-config	21
4	2 x 3, L-config	22
:	:	:
11	2 x 10, L-config	29
5	3 x 3, L-config	30
6	3 x 4, L-config	31
:	:	:
12	3 x 10, L-config	37
7	4 x 4, L-config	38
8	4 x 5, L-config	39
:	:	:
13	4 x 10, L-config	44
9	5 x 5, L-config	45
10	5 x 6, L-config	46
:	:	:
14	5 x 10, L-config	50
11	6 x 6, L-config	51
12	6 x 7, L-config	52
:	:	:
15	6 x 10, L-config	55
13	7 x 7, L-config	56
14	7 x 8, L-config	57
:	:	:
16	7 x 10, L-config	59
15	8 x 8, L-config	60
16	8 x 9, L-config	61
17	8 x 10, L-config	62
17	9 x 9, L-config	63
18	9 x 10, L-config	64
19	10 x 10, L-config	65

Example (configuration #31):

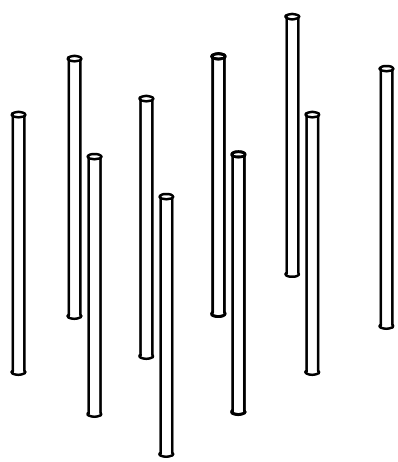


L-config., 3 x 4 bore holes, total 6 bore holes

No. BHE	Name	No. of configuration
8	3 x 3, L2-config	66
10	3 x 4, L2-config67	
:	:	:
22	3 x 10, L2-config	73
12	4 x 4, L2-config74	
14	4 x 5, L2-config75	
:	:	:
24	4 x 10, L2-config	80

No. BHE	Name	No. of configuration
16	5 x 5, L2-config81	
18	5 x 6, L2-config82	
:	:	:
26	5 x 10, L2-config	86
20	6 x 6, L2-config87	
22	6 x 7, L2-config88	
:	:	:
28	6 x 10, L2-config	91
24	7 x 7, L2-config	92
26	7 x 8, L2-config93	
:	:	:
30	7 x 10, L2-config	95
28	8 x 8, L2-config96	
30	8 x 9, L2-config97	
32	8 x 10, L2-config	98
32	9 x 9, L2-config	99
34	9 x 10, L2-config	100
36	10 x 10, L2-config	101

Example (configuration #67):

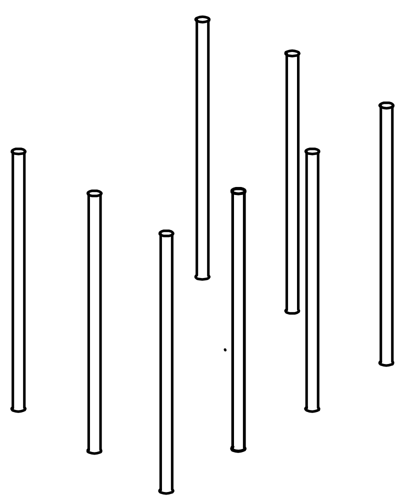


L2-config., 3 x 4 bore holes, total 10 bore holes

No. BHE	Name	No. of configuration
5	3 x 2, U-config 102	
7	3 x 3, U-config 103	
:	:	:
21	3 x 10, U-config	110
6	4 x 2, U-config 111	
8	4 x 3, U-config 112	
:	:	:
22	4 x 10, U-config	119

No. BHE	Name	No. of configuration
7	5 x 2, U-config 120	
9	5 x 3, U-config 121	
:	:	:
23	5 x 10, U-config	128
8	6 x 2, U-config 129	
10	6 x 3, U-config 130	
:	:	:
24	6 x 10, U-config	137
9	7 x 2, U-config 138	
11	7 x 3, U-config 139	
:	:	:
25	7 x 10, U-config	146
10	8 x 2, U-config 147	
12	8 x 3, U-config 148	
:	:	:
26	8 x 10, U-config	155
11	9 x 2, U-config 156	
13	9 x 3, U-config 157	
:	:	:
27	9 x 10, U-config	164
12	10 x 2, U-config	165
14	10 x 3, U-config	166
28	10 x 10, U-config	173

Example (configuration #112):

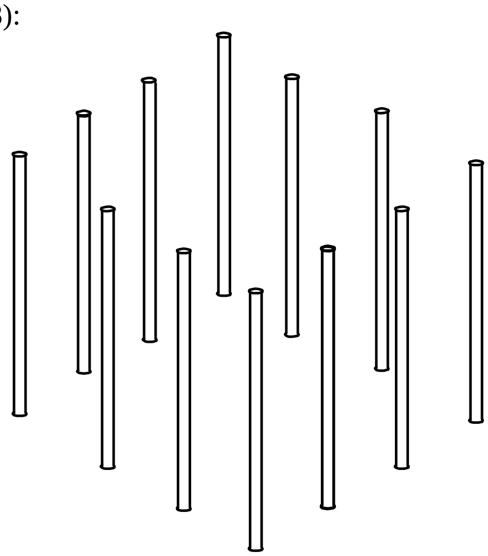


U-config., 3 x 4 bore holes, total 8 bore holes

No. BHE	Name	No. of configuration
8	3 x 3, open rect.	174
10	3 x 4, open rect.	175
:	:	:
52	3 x 25, open rect.	187

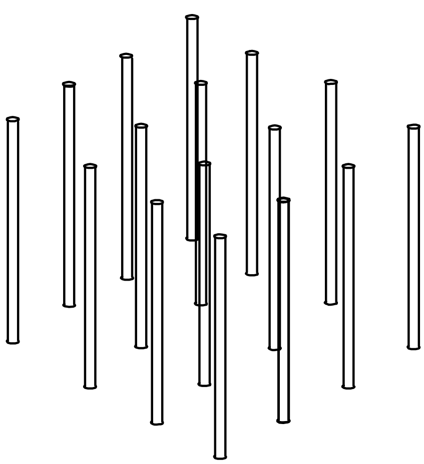
No. BHE	Name	No. of configuration
12	4 x 4, open rect.	188
14	4 x 5, open rect.	189
54	4 x 25, open rect.	200
16	5 x 5, open rect.	201
18	5 x 6, open rect.	202
:	:	:
46	5 x 20, open rect.	211
20	6 x 6, open rect.	212
22	6 x 7, open rect.	213
:	:	:
40	6 x 16, open rect.	219
24	7 x 7, open rect.	220
26	7 x 8, open rect.	221
:	:	:
38	7 x 14, open rect.	225
28	8 x 8, open rect.	226
30	8 x 9, open rect.	227
:	:	:
36	8 x 12, open rect.	229
32	9 x 9, open rect.	230
34	9 x 10, open rect.	231
36	10 x 10, open rect.	232

Example (configuration #188):



Open rectangular config., 4 x 4 bore holes, total 12 bore holes

No. BHE	Name	No. of configuration
4	2 x 2, rectangle	233
6	2 x 3, rectangle	234
:	:	:
50	2 x 25, rectangle	247
9	3 x 3, rectangle	248
12	3 x 4, rectangle	249
:	:	:
75	3 x 25, rectangle	261
16	4 x 4, rectangle	262
20	4 x 5, rectangle	263
:	:	:
100	4 x 25, rectangle	274
25	5 x 5, rectangle	275
30	5 x 6, rectangle	276
:	:	:
100	5 x 20, rectangle	285
36	6 x 6, rectangle	286
42	6 x 7, rectangle	287
:	:	:
96	6 x 16, rectangle	293
49	7 x 7, rectangle	294
56	7 x 8, rectangle	295
:	:	:
98	7 x 14, rectangle	299
64	8 x 8, rectangle	300
72	8 x 9, rectangle	301
:	:	:
96	8 x 12, rectangle	303
81	9 x 9, rectangle	304
90	9 x 10, rectangle	305
100	10 x 10, rectangle	306
120	10 x 12, rectangle	307



Example (configuration #262):

Filled rectangular config., 4 x 4 bore holes, total 16 bore holes