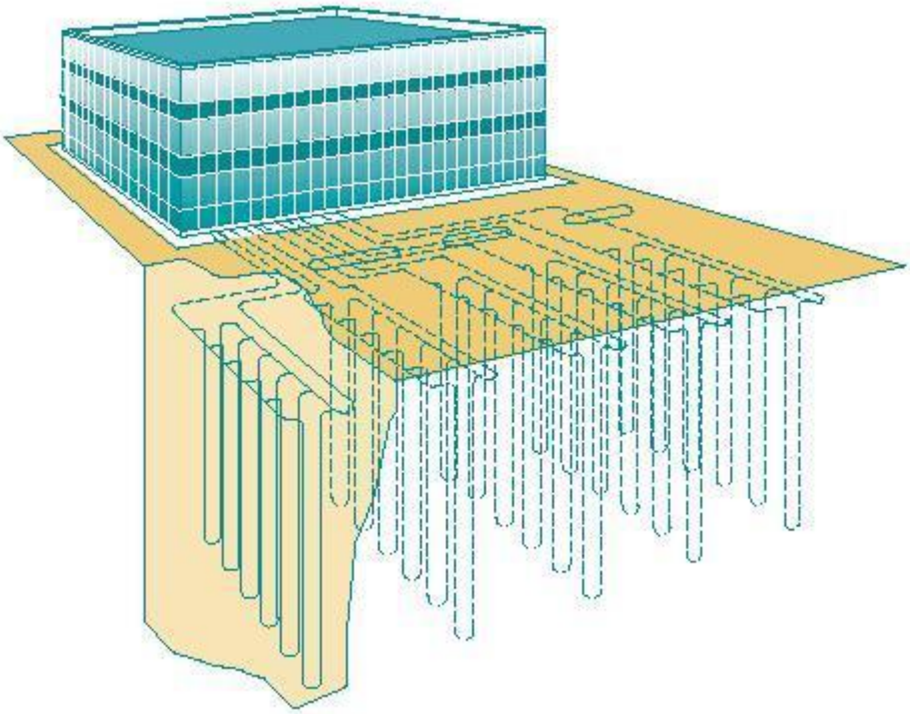
Software within building physics and ground heat storage

EED v3.2

Earth Energy Designer



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1. Introduction

1.1 Overview

Earth Energy Design (EED) is a PC-program for borehole heat exchanger design. Its ease 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 borehole 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 0. Algorithms have been derived from modelling and parameter studies with a numerical simulation model (SBM) resulting in analytical solutions of the heat flow with several combinations for the borehole pattern and geometry (g-functions). Those g-functions depend on the spacing between the boreholes at the ground surface and the borehole depth. In case of graded boreholes 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 borehole thermal resistance is calculated in the program, using the borehole geometry, grouting material, pipe material and geometry. The borehole pattern may be chosen at will from a database of 798 basic configurations.

1.3 System requirements and installation

EED v3 is a software package running on Microsoft Vista/Windows 7 and 8. Program and databases require approximately 7 MB hard disk space. EED is delivered as a self-extracting file that installs the program and databases in a folder the user can choose. 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)
gfunc3	eed	g-functions
Databases:		
borediam	txt	Borehole 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
Language files	txt	See folder Languages

Project data files have the extension “.dat”. Output files have the extension “.out”. 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!).

1.5 Important program features

Number of configurations	EED version 3: 798 EED version 2: 308
Number of g-functions	EED version 3: 6385 EED version 2: 2465
Types of borehole heat exchangers	Coaxial pipes U-pipes (single, double, triple)
Borehole depth	20 - 200 m
Ratio borehole spacing / borehole depth	$0.02 \le \frac{B}{H} \le 0.5$
Time interval t' = dimensionless time a = thermal diffusivity (m²/s)	$-8.5 \le \ln(t') \le 3$ 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 0.

1.6 New features in version 3.0

The main news of EED 3.0 are as follows:

- Optimization that gives a list of best solutions for various parameters within specified ranges. Results may be exported to Excel file.
- Simple cost calculation.
- English units added. Easy conversion between SI and English units.
- Pc-program multilingual. New languages can be added. Currently: English, German, Swedish, French, Dutch, Italian, Hungarian. See www.buildingphysics.com for more languages.

- More configurations with large systems (798 as compared with 308 in EED 2.0).
- More G-functions (6385 as compared with 2465 in EED 2.0).
- Improved accuracy (multipoles 1->10). Improved convergence on borehole length.
- Hot water treated separately.
- Flow rate can be given for whole system.
- A default input file can be created.
- List of most recent input files.
- A lot of smaller improvements.

Important notice for users of EED 2.0:

G-function numbers larger than 241 has new numbers in EED 3 due to new configurations. The numbers are not the same as in EED 2. When an old (EED 2.0) input file is read, the old G-func number will be remapped to the new definition. **Note however that EED 3.0 input files should not be used by EED 2.0 or EED 1.0.**

1.7 Update EED v3.2

Please see chapter 11 for more info about this upgrade.

Update info for new versions can also be found at
http://www.buildingphysics.com/index-filer/Page1139.htm

1.8 Documentation and frequently asked questions (FAQ:s)

Please see this page for more info :
http://www.buildingphysics.com/index-filer/Page1139.htm

2. EED main menu

2.1 Introduction

Figure 2.1 shows the main menu:

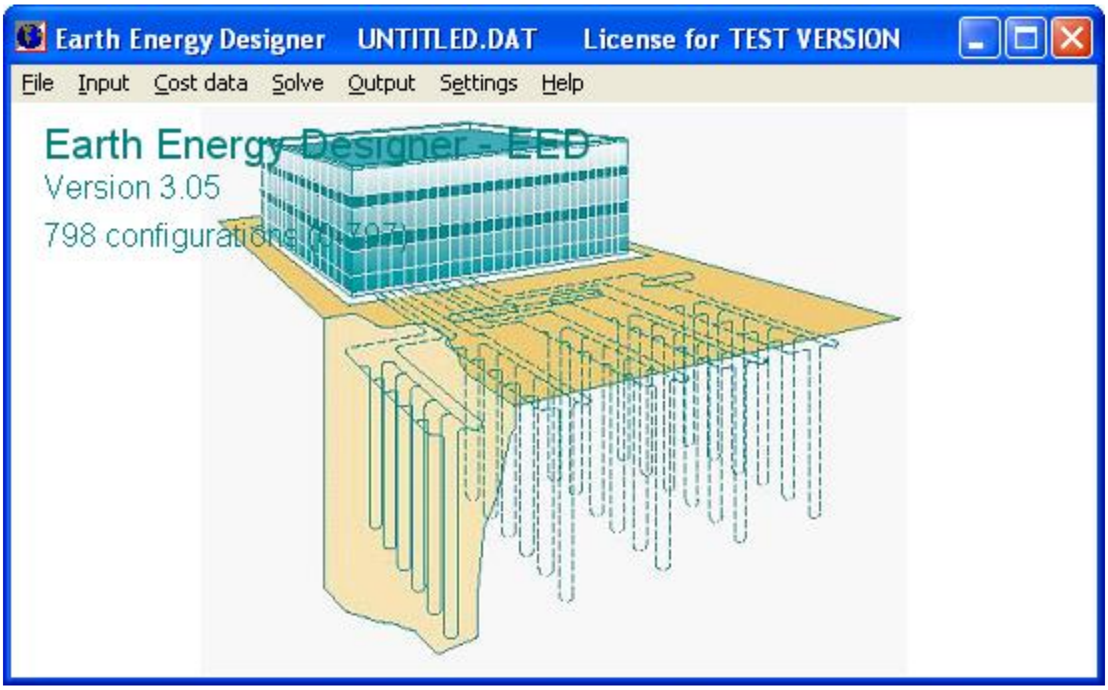


Figure 2.1: Main menu of EED.

File: Operations with files. 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.

Input: Input of data for ground, borehole, heat exchanger, heat carrier, building, loads, simulation time, etc.

Cost data: Simple cost data can be given here.

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 borehole length for a given min/max temperature

Optimization module

Output: Display of the results as text and graphs

Settings: Settings for language, units, and default input data.

About: Display of program version and authors. Update information.

2.2 Creating default input

EED is started with a default set of input data. The user may change this by creating the file ”Default_input.dat” which will be read every time EED starts. This file contains default values and may be changed to a default file for local conditions. To create this file use menu item **Settings/Use current input as default input**. To delete it, use **Settings/Clear default input.**

2.3 Output files

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.

3. Data input

The pull-down menu ”**Input**“, see Figure 3.1, comprises all functions for input or change of the data required for the calculation.

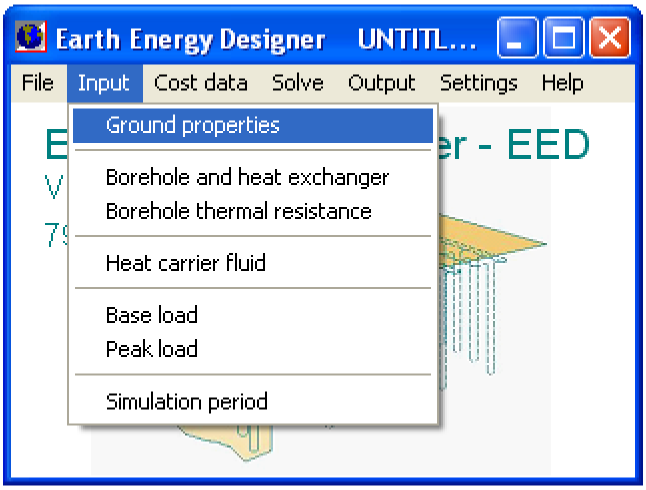


Figure 3.1: The input menu.

There are further sub-menus for specific input of data. These are data for underground parameters (”**Ground properties**“), boreholes and heat exchangers (”**Borehole and heat exchanger**“), method of calculation of the borehole thermal resistance (”**Borehole 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.

3.1 Ground Properties

Figure 3.2 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.

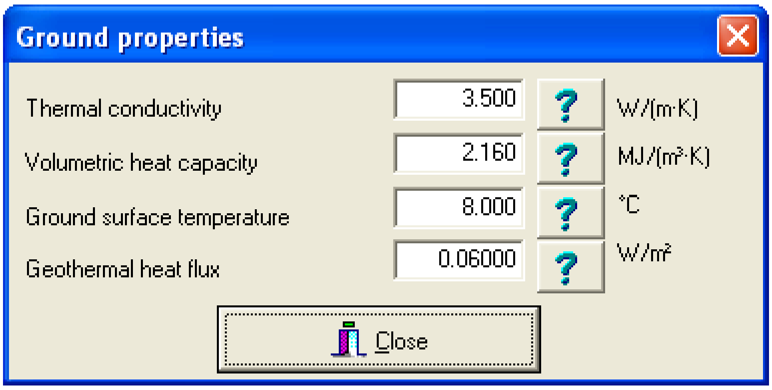


Figure 3.2: The ground properties menu.

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 3.3.

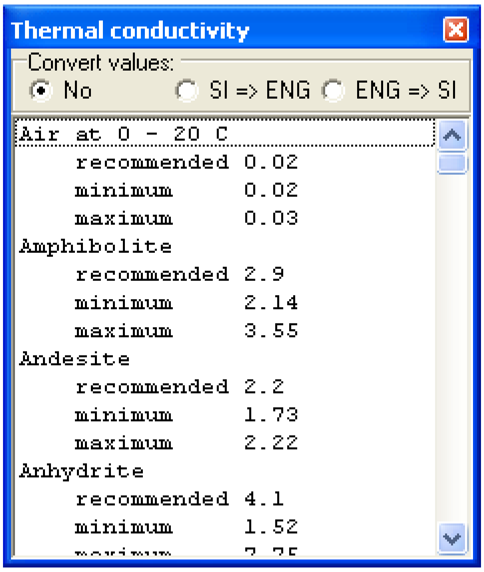


Figure 3.3: Database of thermal conductivities.

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 3.4. 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. The geothermal heat flux is found in the same way.

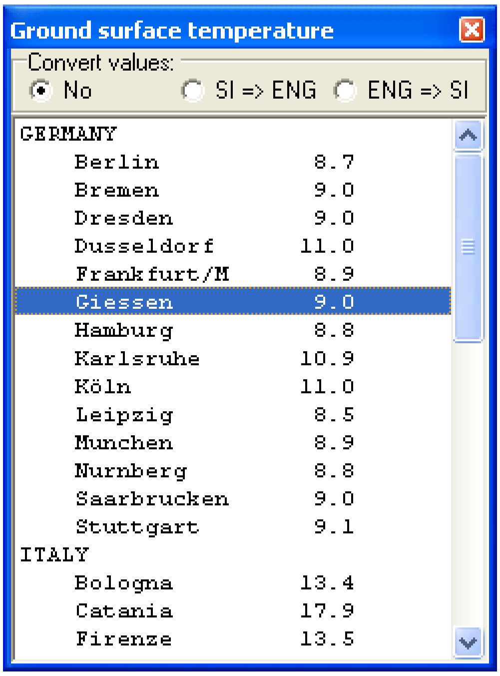


Figure 3.4: Database of ground surface temperatures.

With ground surface temperature, geothermal heat flux, and thermal conductivity of the ground the undisturbed ground temperature for half of the borehole 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.

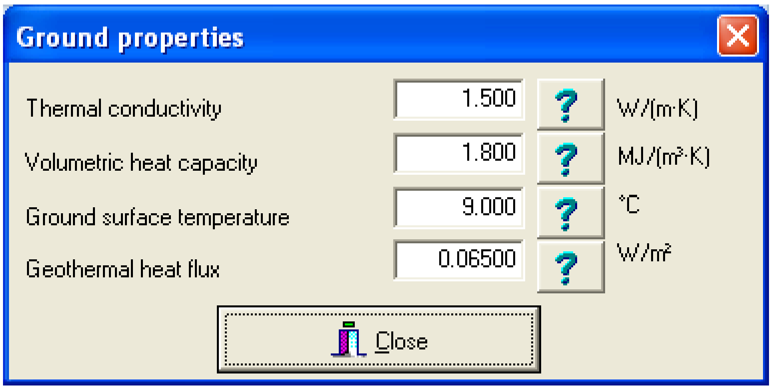


Figure 3.5: Data for our example.

3.2 Borehole and Heat Exchanger

Figure 3.6 shows the menu ”**Borehole and heat exchanger**” that deals with borehole 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.

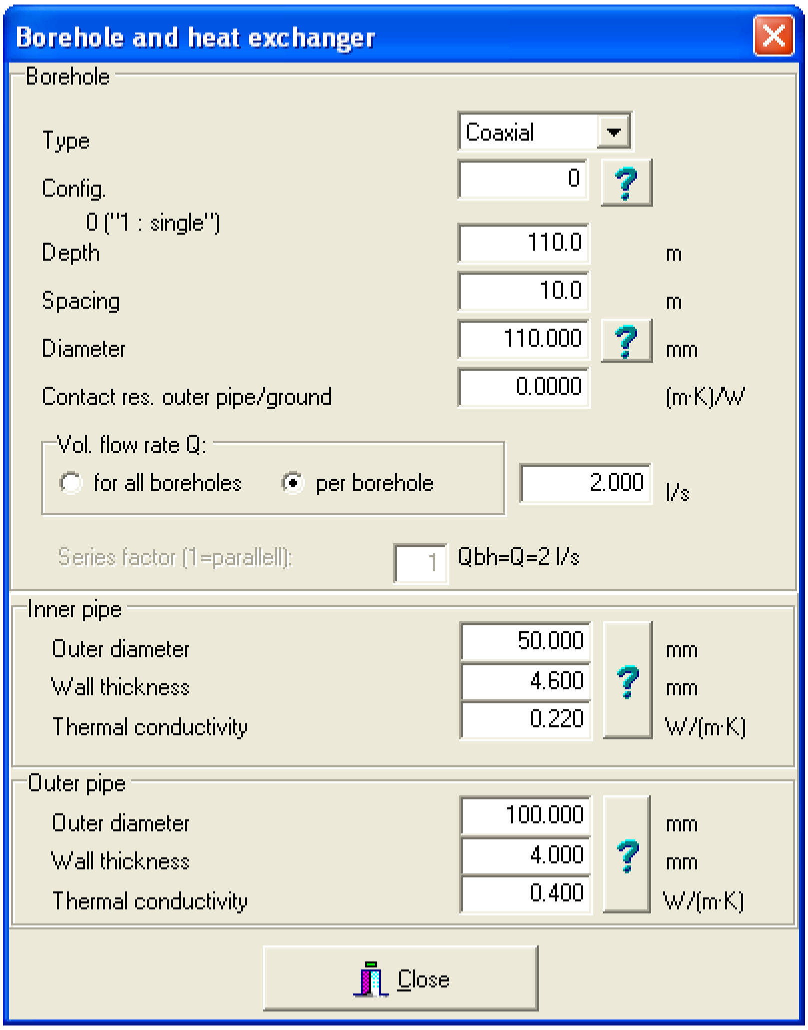


Figure 3.6: Input menu for borehole and heat exchanger.

When starting with the default data file, the heat exchanger type is set to ”Coaxial“. By clicking on the sign ”τ“ right of ”**Type**“, a small pull-down window offers four options as shown in Figure 3.7.

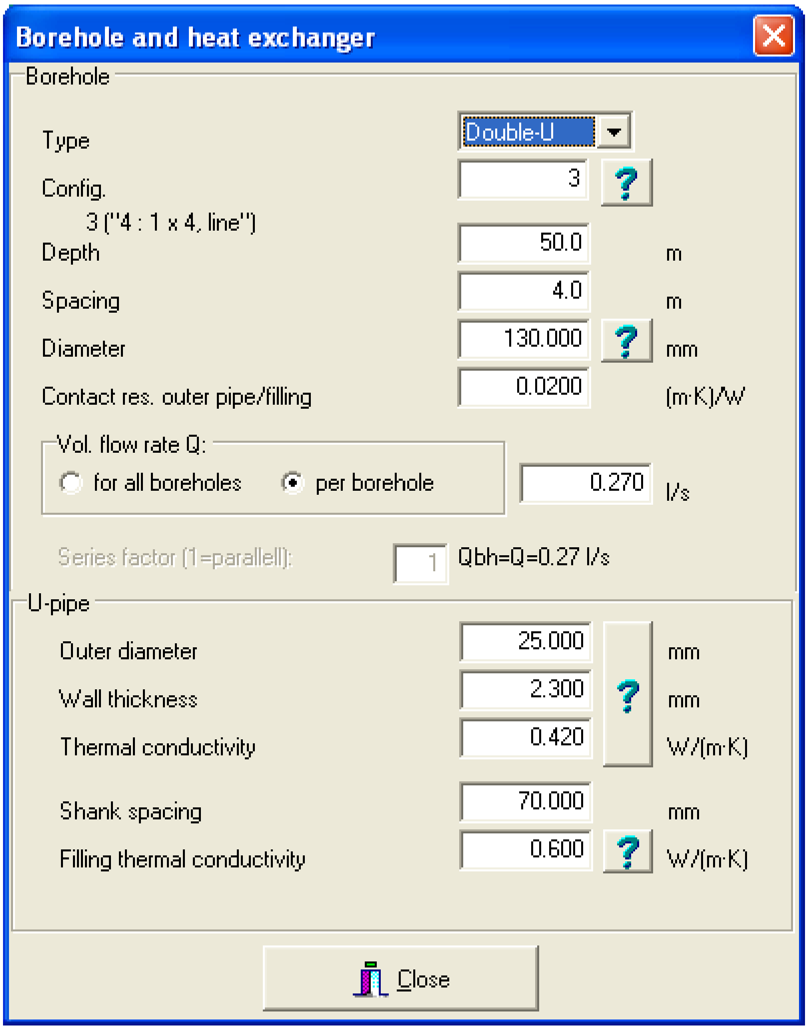


Figure 3.7: Options for heat exchanger type.

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

Next, the borehole geometry (”**Configuration**“) is asked for. This means selection of an adequate g-function.

The basic forms of borehole heat exchanger (BHE) geometry available 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 CONFIG.

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 3.8. The number in the first column shows the total number of boreholes in the configuration, followed by the exact geometry; the number in the last column is the number of the configuration (1-798). 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.

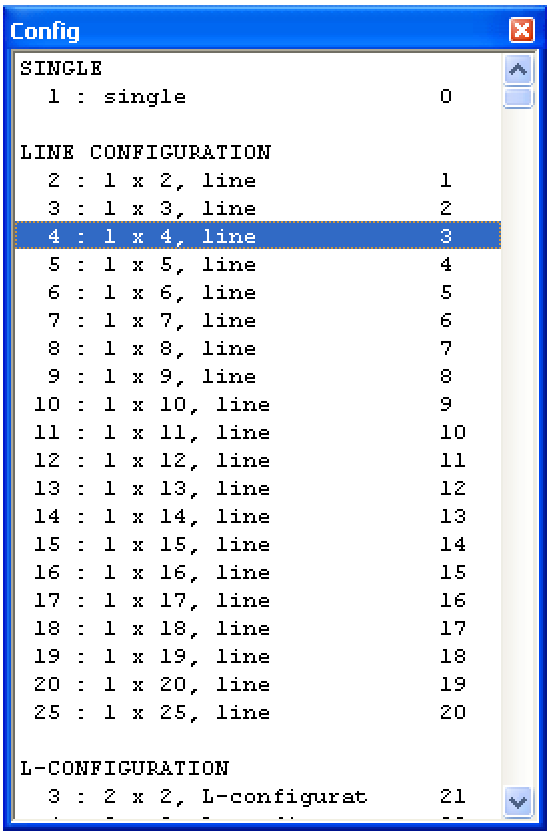


Figure 3.8: List of borehole configurations.

The function for Linden is four holes in a line, which has been selected. The borehole **depth** and borehole **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 borehole diameter is typed. A database, accessible by clicking on the question mark beside the field, suggests usual drilling diameters, including API-standards, see Figure 3.9. 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.

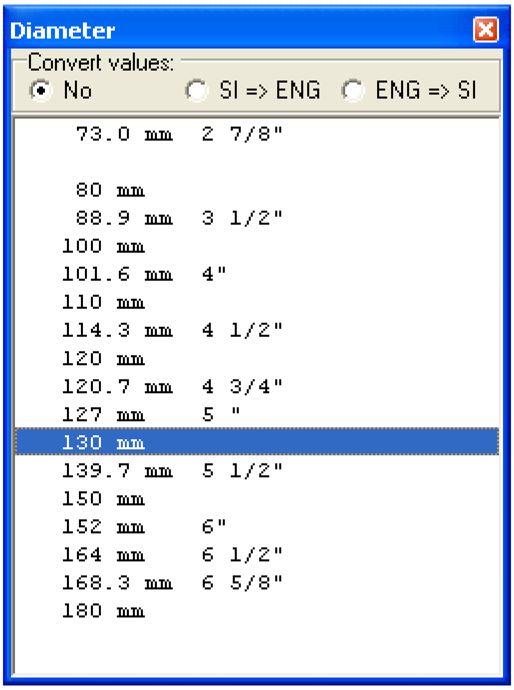


Figure 3.9: List of borehole diameter.

The next field in the sub-menu concerns ”**Volumetric Flow Rate“**. The flow through the pipes in one borehole is considered, in liter/s. EED needs this value to calculate the Reynolds number. In the Linden example approx. 4 m^3/h are circulated (0.0011 m^3/s), which are distributed to 4 boreholes. Thus the flow through one hole is 0.000275 m^3/s (and per pipe is 0.00014 m^3/s for a double-U-tube).

The **volume flow rate Q** can be given per borehole or for all boreholes. In the latter case (all boreholes), a “series factor” can be given. The flow rate per borehole then becomes the given value divided by number of boreholes divided by the factor:

$$Qbh=Q/(Nbh/factor))$$

If the factor is 1, all boreholes are parallel, i.e. the flow becomes Qbh=Qb/Nbh.

Consider another example with 6 boreholes. If these lies in a row (series) we have a series factor of 6:

Qbh=Q/(6/6)=Q (Q is the flow in each borehole)

If they are in series 3 and 3 (series factor 3)

```
      x x x
=>            =>                    (we have the flow Qbh=Q/(6/3)=Q/2 in each borehole)
      x x x
```

and for a factor of 2:

```
    => x x =>
=>  => x x => =>          (Qbh=Q/(6/2)=Q/3 in each borehole)
    => x x =>
```

Now the thermal contact resistance between pipe and borehole 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 $m^2 \cdot K/W$ is possible, otherwise 0.01 or, with poor fill, 0.02-0.03. In the Linden example, the filling of the borehole from the top does not allow good contact, and hence a value of 0.02 $m^2 \cdot K/W$ 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 borehole 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 3.10.

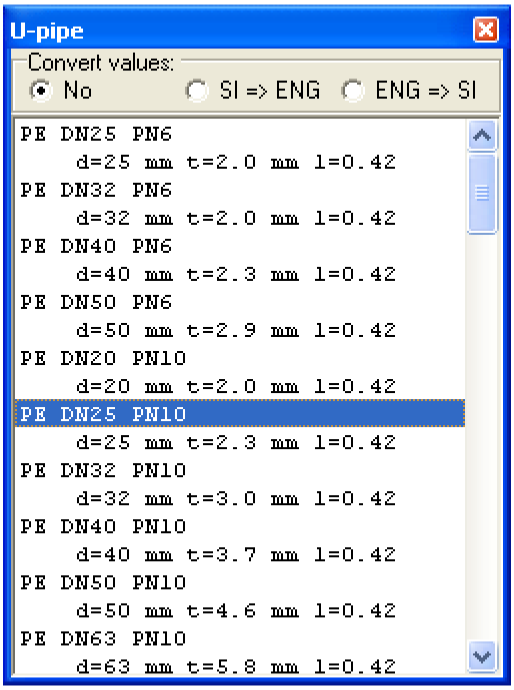


Figure 3.10: List of U-pipe measurements.

Now the field ”**Shank spacing**“ can be approached. This refers to the distance from centre to centre 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 too 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 borehole 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 3.11. 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.

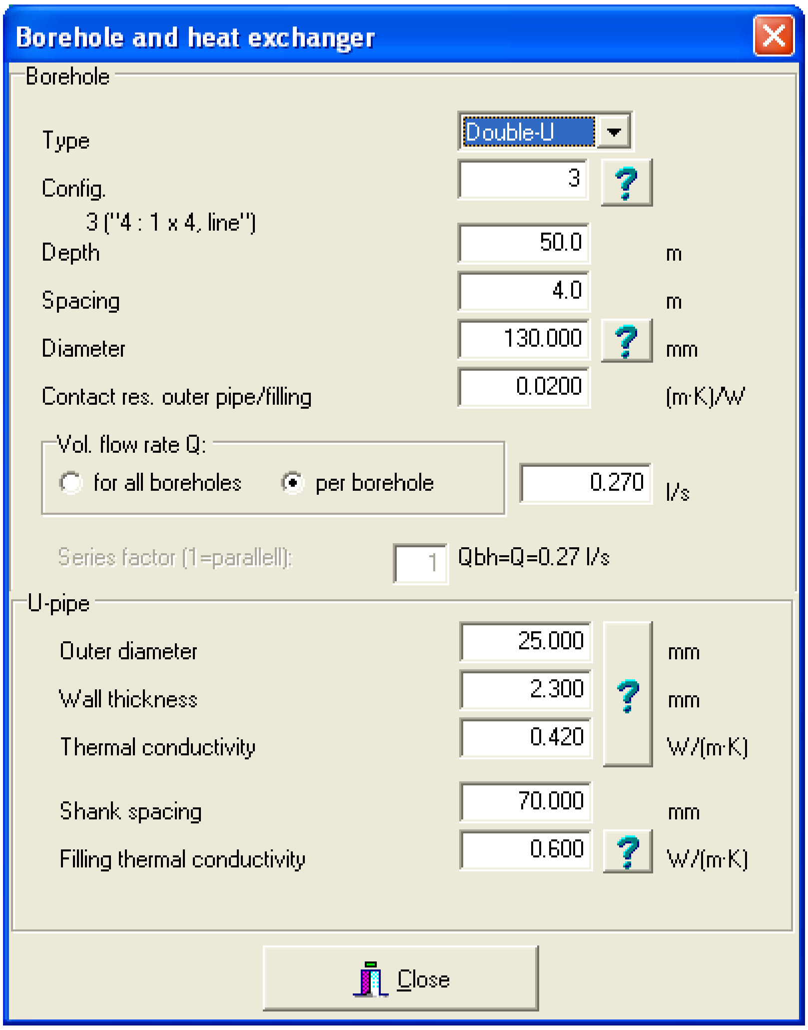


Figure 3.11: Data for our example.

The sub-menu ”**Borehole 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.

3.3 Borehole thermal resistance

The next sub-menu in the ”**Input“** menu concerns thermal resistances in the borehole (”**Borehole thermal resistance**“), see Figure 3.12. 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.

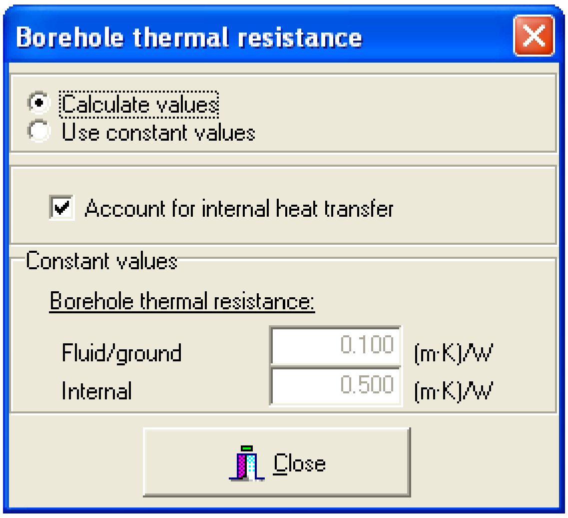


Figure 3.12: Input for Borehole thermal resistance.

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 borehole 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 boreholes 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 ”**5**“ in the upper right corner of the window.

3.4 *Heat Carrier Fluid*

Now the submenu ”**Heat carrier fluid**“ is opened by clicking on that item in the ”**Input**“-menu, see Figure 3.13. It contains input fields for thermal conductivity, specific heat capacity, density, viscosity and freezing point of the fluid.

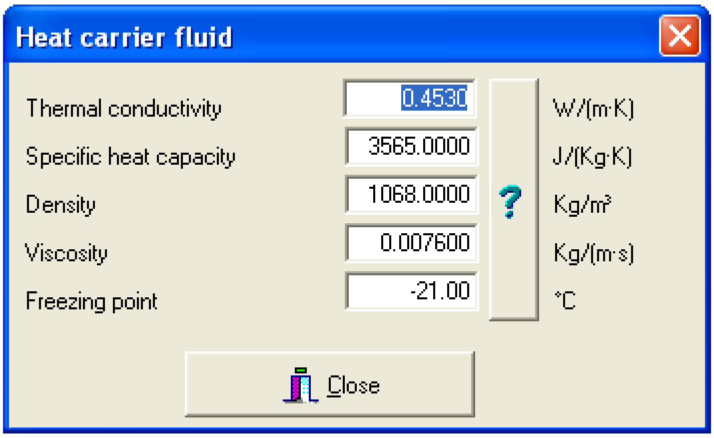
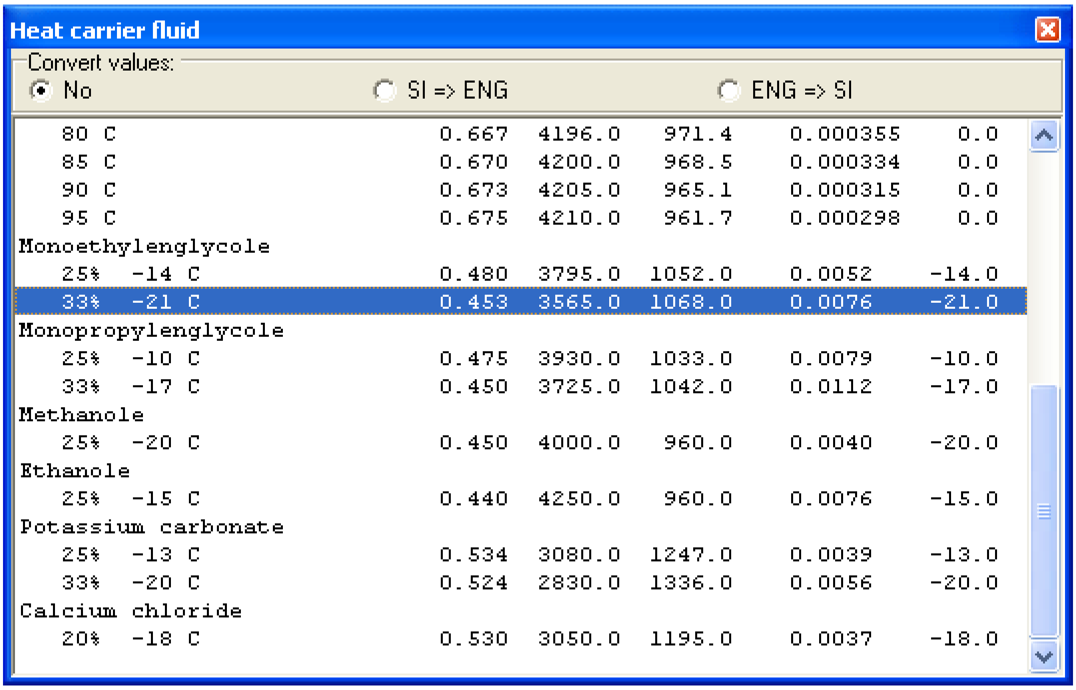


Figure 3.13: Input for Heat carrier fluid.

Data for common heat carrier fluids can again be picked from a database, see Figure 3.14, 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 ”5“ in the upper right corner of the database window.



80 C	0.667	4196.0	971.4	0.000355	0.0
85 C	0.670	4200.0	968.5	0.000334	0.0
90 C	0.673	4205.0	965.1	0.000315	0.0
95 C	0.675	4210.0	961.7	0.000298	0.0
Monoethylenglycole					
25% -14 C	0.480	3795.0	1052.0	0.0052	-14.0
33% -21 C	0.453	3565.0	1068.0	0.0076	-21.0
Monopropylenglycole					
25% -10 C	0.475	3930.0	1033.0	0.0079	-10.0
33% -17 C	0.450	3725.0	1042.0	0.0112	-17.0
Methanole					
25% -20 C	0.450	4000.0	960.0	0.0040	-20.0
Ethanole					
25% -15 C	0.440	4250.0	960.0	0.0076	-15.0
Potassium carbonate					
25% -13 C	0.534	3080.0	1247.0	0.0039	-13.0
33% -20 C	0.524	2830.0	1336.0	0.0056	-20.0
Calcium chloride					
20% -18 C	0.530	3050.0	1195.0	0.0037	-18.0

Figure 3.14: 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.

3.5 Input of Base Load Data

Figure 3.15 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 modelling of a specific load profile including loads independent of seasons, like domestic hot water (EED version 3 also allows a separate annual value for hot water that is spread out equally for the whole the year).

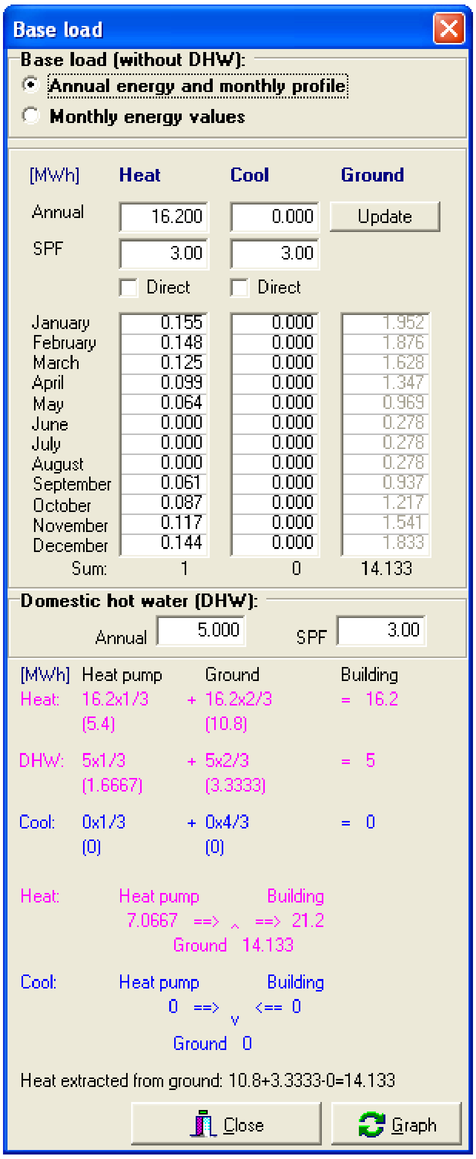


Figure 3.15: Input for base load.

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 a large SPF (99999 is shown here).

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 cannot be accessed directly. The Linden example now looks like shown below:

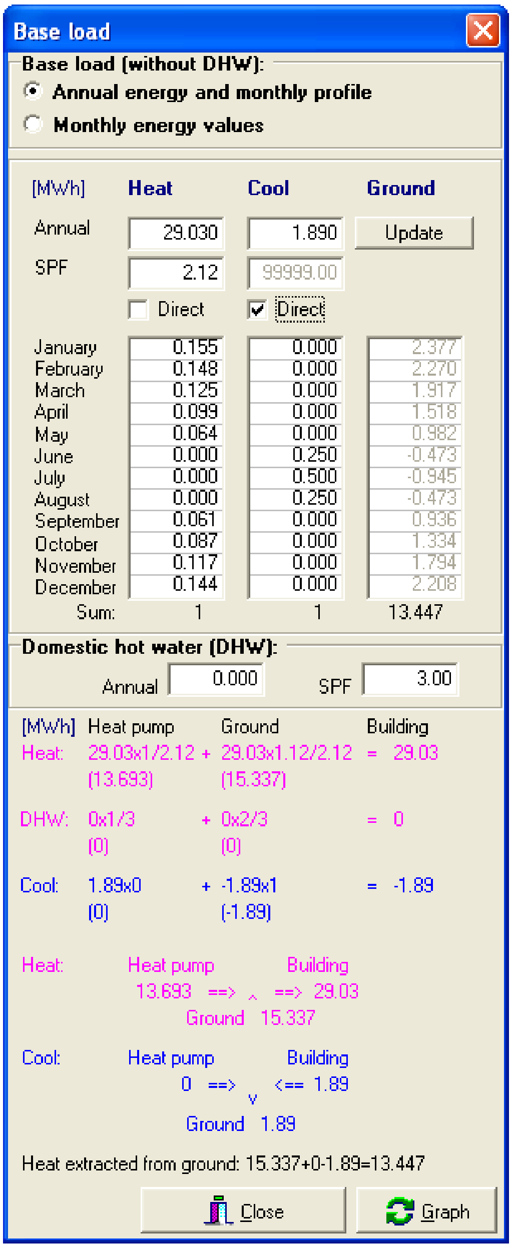


Figure 3.16: Data for our example.

When no more changes are desired, the sub-menu ”**Base Load**“ can be closed by either clicking on ”**Close**“ or on the ”**5**“ 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.

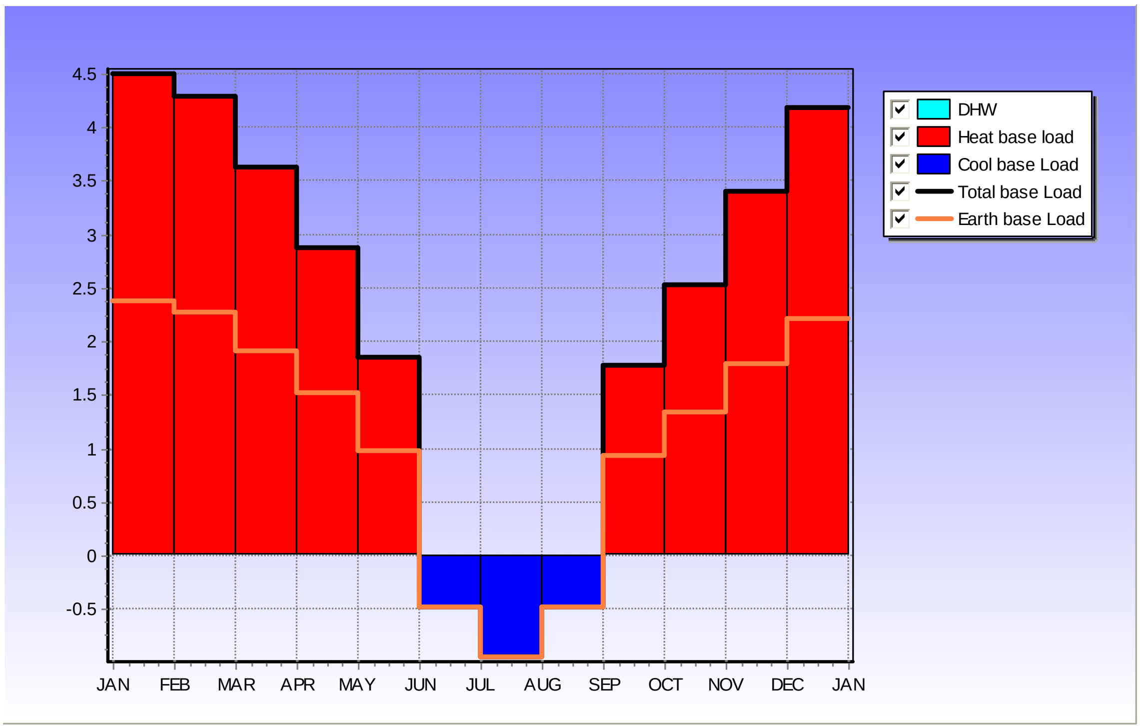


Figure 3.17: Menu button “Graph” draws a chart.

3.6 Input of Peak Load Data

Figure 3.18 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.

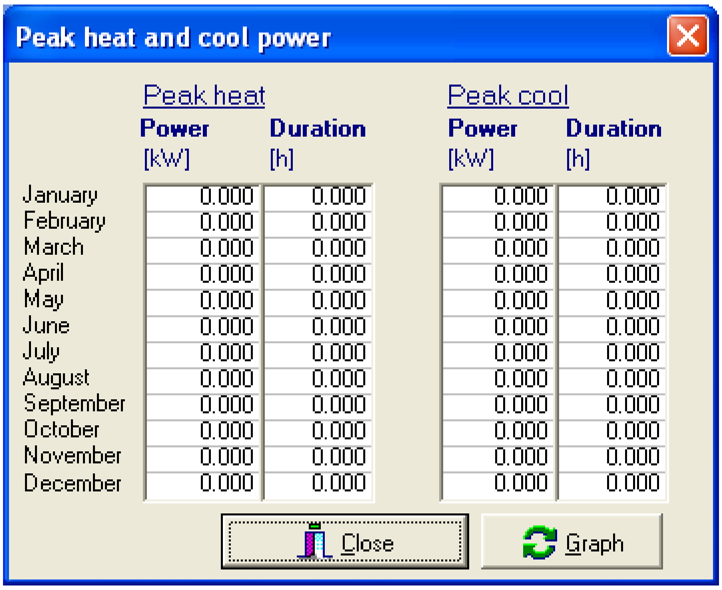


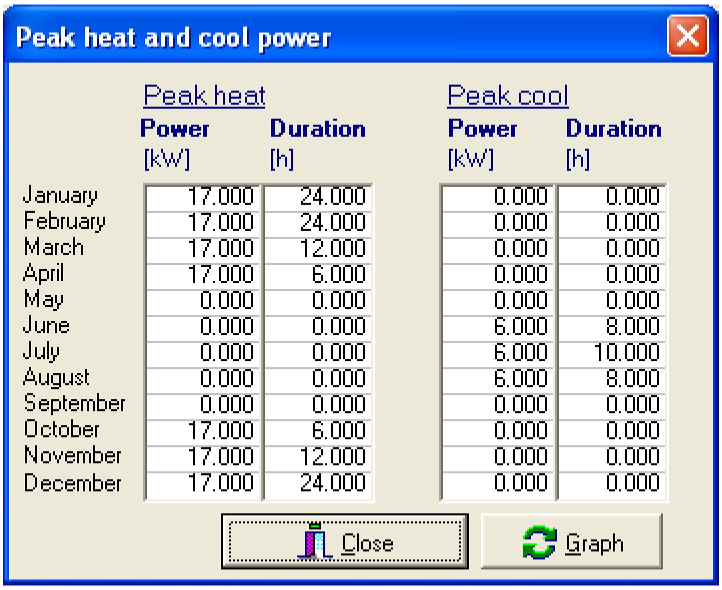
Figure 3.18: Input for peak heat and cooling power.

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 behaviour.

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 and cool power

	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

Close Graph

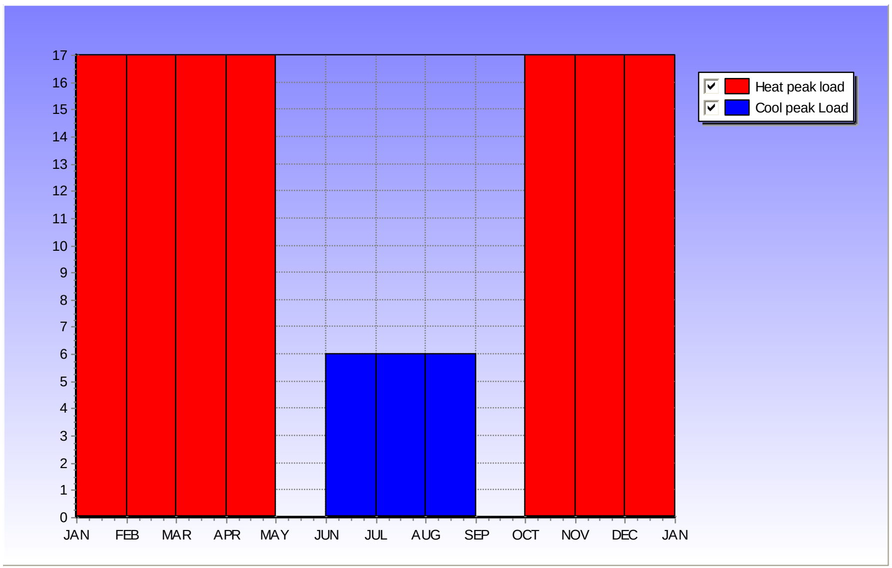


Figure 3.19: Data for our example.

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 the

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 the minimum fluid temperature

3. peak cooling power in the summer - most critical time is usually August (-September). This gives the maximum fluid temperature

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

See also questions/answers at
http://www.buildingphysics.com/index-filer/Page1440.htm

3.7 Simulation Period

Figure 3.20 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.

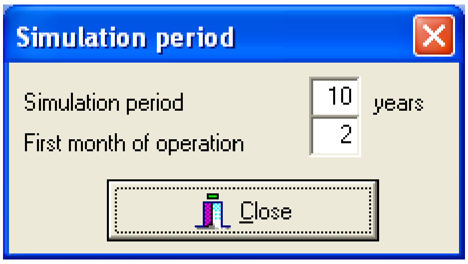


Figure 3.20: Input for simulation period.

4. Calculation of mean fluid temperature

The calculations can be done in the pull-down menu ”**Solve**“, see Figure 4.1. Two alternatives are offered in the ”**Solve**“ menu:

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

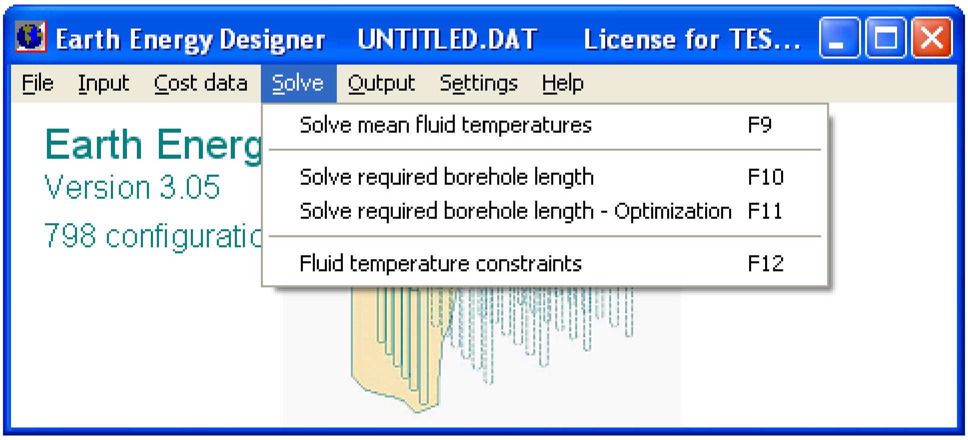


Figure 4.1: The solve menu.

In the Linden example, now a warning concerning the Reynolds number appears, see Figure 4.2.

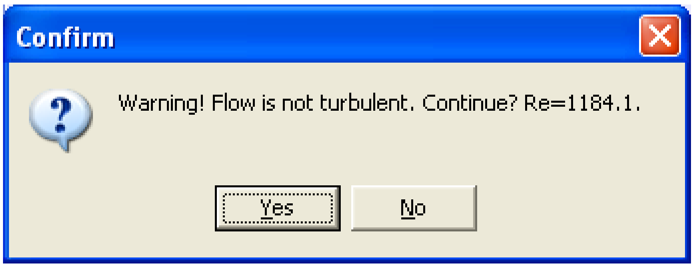


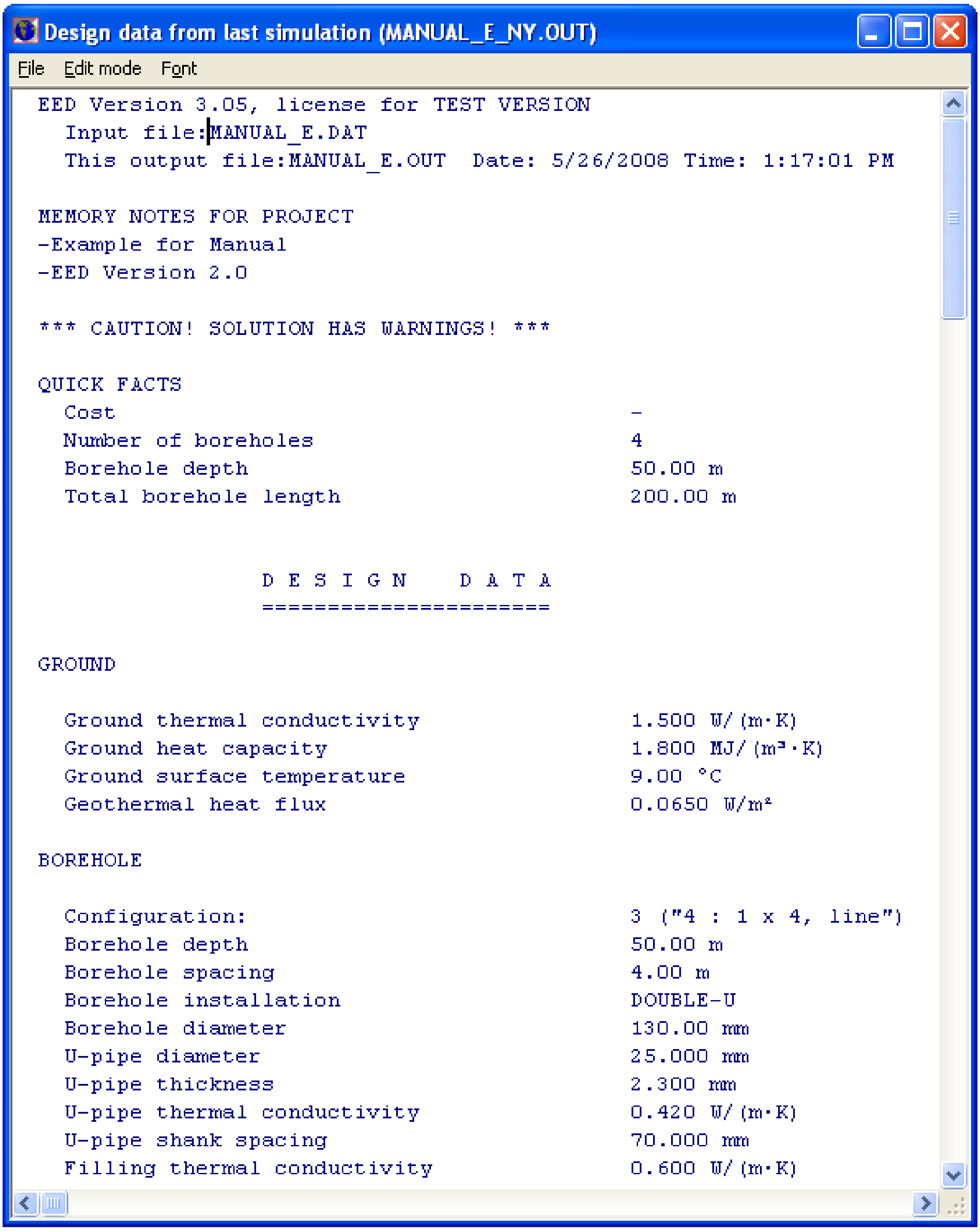
Figure 4.2: Warning for non-turbulent flow.

The flow within the heat exchanger pipes is not turbulent, exhibiting a Reynolds number of 1184. Thus, the heat transfer from pipe wall to fluid is poor. A Reynolds 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.

5. Output of results

5.1 Introduction

After completion of the calculation, a window showing the input data and the results is displayed, see Figure 5.1.



Design data from last simulation (MANUAL_E_NY.OUT)

File Edit mode Font

```
EED Version 3.05, license for TEST VERSION
  Input file:MANUAL_E.DAT
  This output file:MANUAL_E.OUT  Date: 5/26/2008 Time: 1:17:01 PM

MEMORY NOTES FOR PROJECT
-Example for Manual
-EED Version 2.0

*** CAUTION! SOLUTION HAS WARNINGS! ***

QUICK FACTS
  Cost                                        -
  Number of boreholes                         4
  Borehole depth                              50.00 m
  Total borehole length                       200.00 m


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

GROUND

  Ground thermal conductivity                 1.500 W/(m·K)
  Ground heat capacity                        1.800 MJ/(m³·K)
  Ground surface temperature                  9.00 °C
  Geothermal heat flux                        0.0650 W/m²

BOREHOLE

  Configuration:                              3 ("4 : 1 x 4, line")
  Borehole depth                              50.00 m
  Borehole spacing                            4.00 m
  Borehole installation                       DOUBLE-U
  Borehole diameter                           130.00 mm
  U-pipe diameter                             25.000 mm
  U-pipe thickness                            2.300 mm
  U-pipe thermal conductivity                 0.420 W/(m·K)
  U-pipe shank spacing                        70.000 mm
  Filling thermal conductivity                0.600 W/(m·K)
```

Figure 5.1: 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 5.2), 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 5.3).

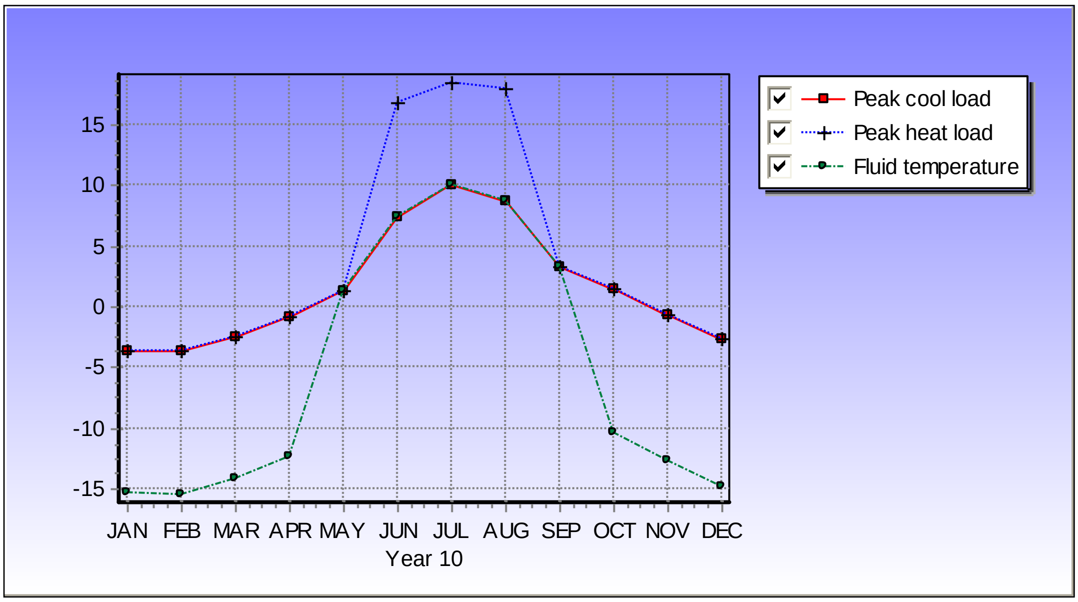


Figure 5.2: Fluid temperature chart.

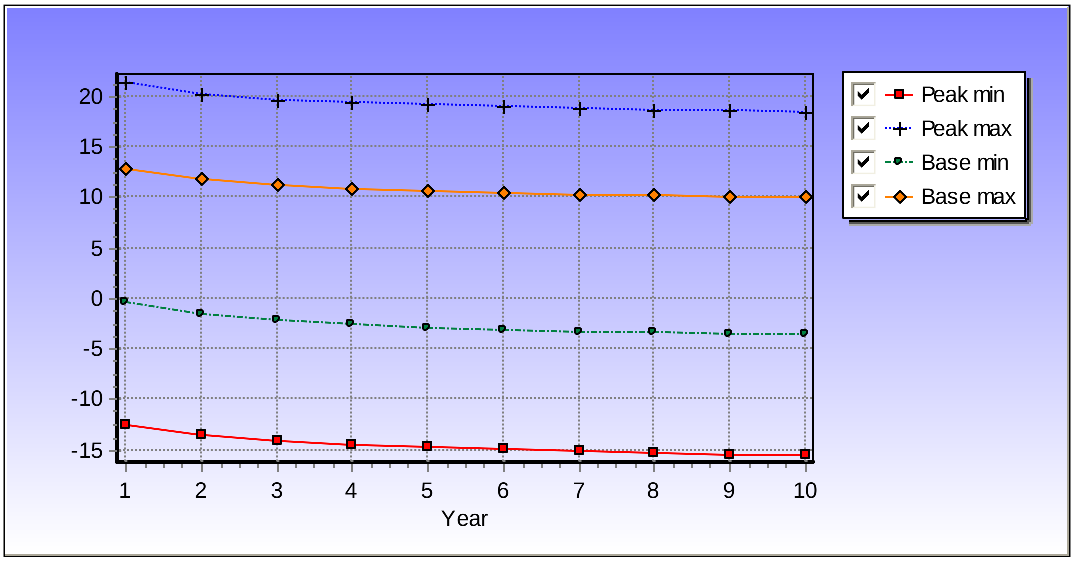


Figure 5.3: Minimum and maximum temperatures.

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 5.4, the following operations can be made:

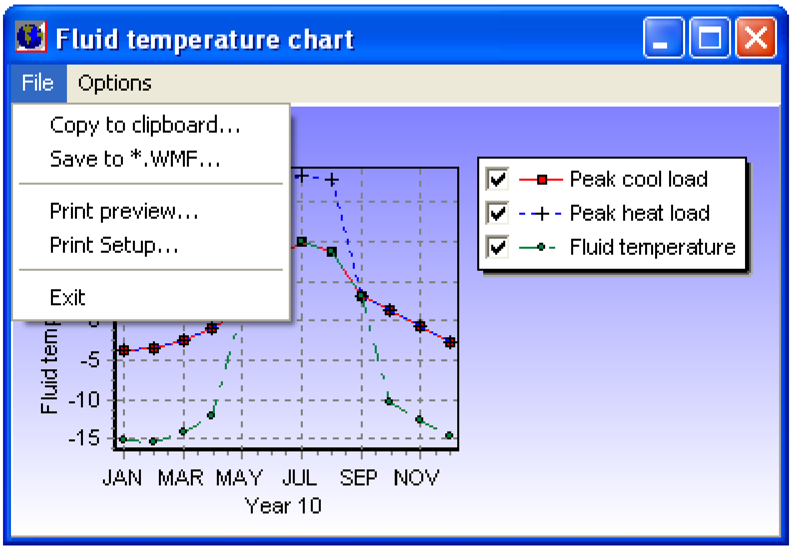


Figure 5.4 The file menu.

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 5.5, allows to change the style and to edit the graph:

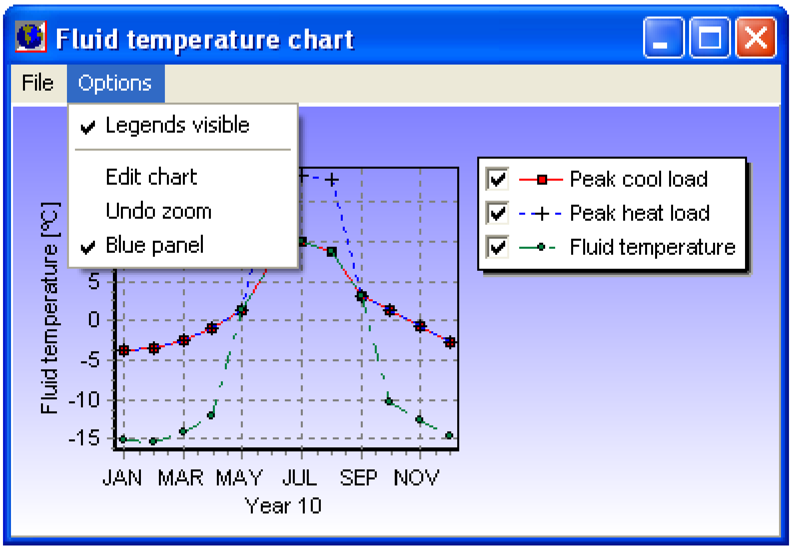


Figure 5.5: The options menu

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 colours, adjusting axes and scales, editing the legend, etc.).

5.2 Changing chart properties

5.2.1 Introduction

The properties of a chart may be changed by the chart editor (**Options/Edit chart**), see Figure 5.6.

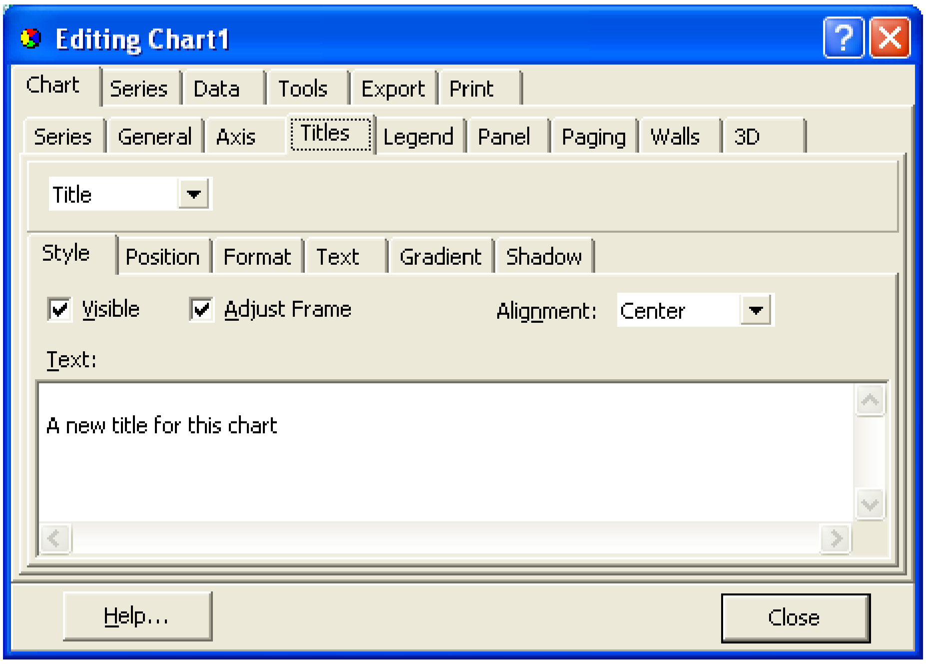


Figure 5.6: Chart settings may be changed in menu item **Options/Edit chart**.

5.2.2 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.

Chart pages

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. Colours, bevels, back images, colour gradient and border.

Paging Page - Definition of number of points per chart page

Walls Page - Left, bottom and back wall size and colour 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 colour and positioning

6. Calculation of required borehole 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 6.1, an easy way to calculate the required borehole length to fulfil this conditions is offered:

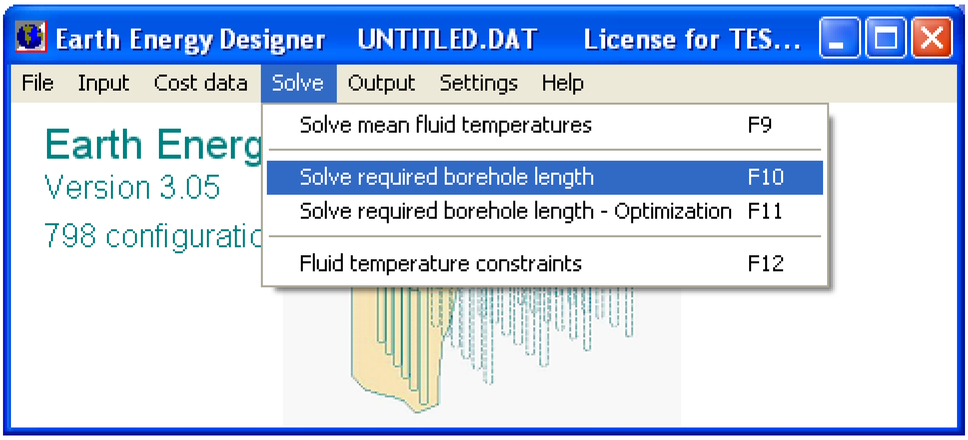
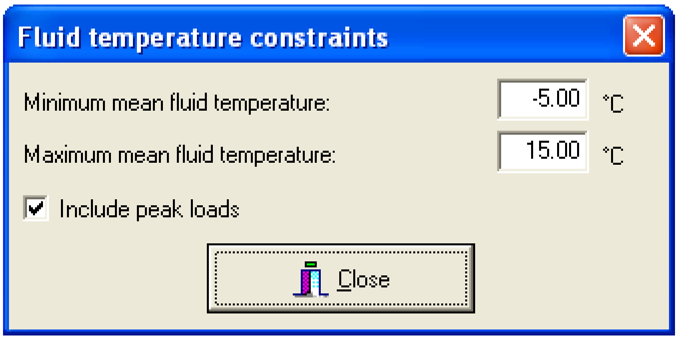


Figure 6.1: Item solve required borehole length.

To calculate the required borehole length for a given plant under certain fluid temperature constraints, the sub-menu ”Fluid temperature constraints“ in the ”**Solve**“-menu is opened, see Figure 6.2. The desired maximum and minimum fluid temperatures not be exceeded can be typed in. By activating ”4“ for ”Include peak loads“ the peak load temperature will be the criterion, with the field deactivated the base load temperature.



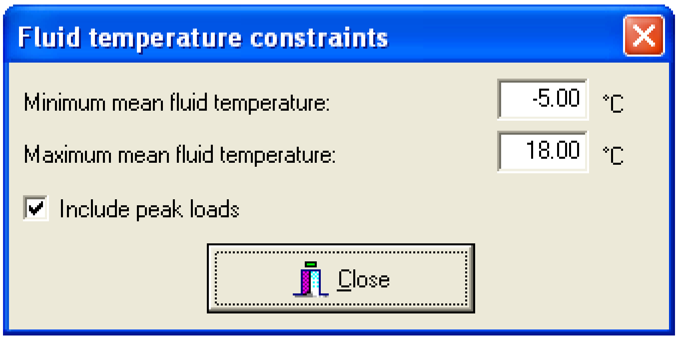


Figure 6.2: Input for fluid temperature constraints changed ("manual_x.dat").

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 ”**5**“ 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 borehole configuration as stated in the sub-menu ”**Borehole and Heat Exchanger**“ in the ”**Input**“-Menu, is started by clicking on ”Solve required borehole length“. The borehole length is increased, which can be seen in the output window. The graphics (see below) now show a very satisfying temperature development.

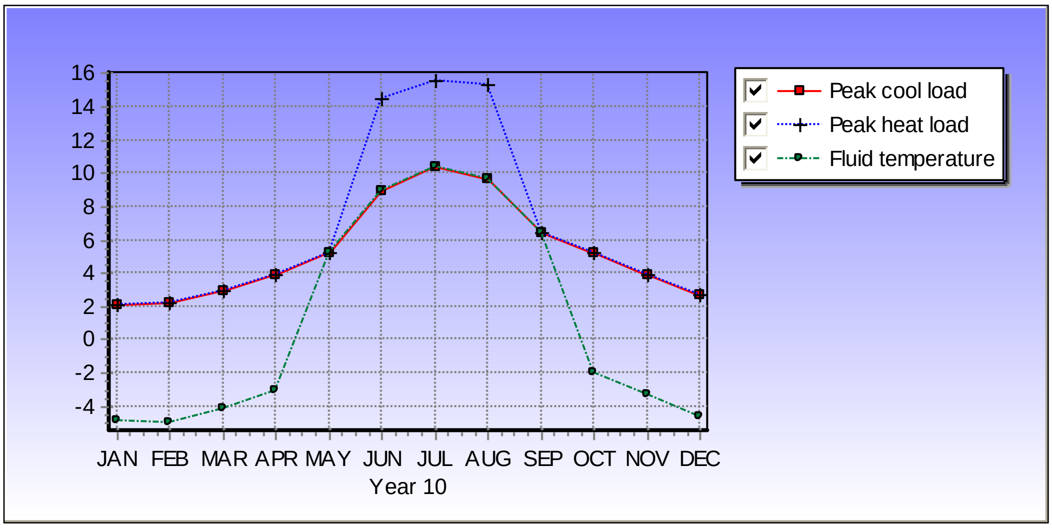


Figure 6.3: Fluid temperature chart.

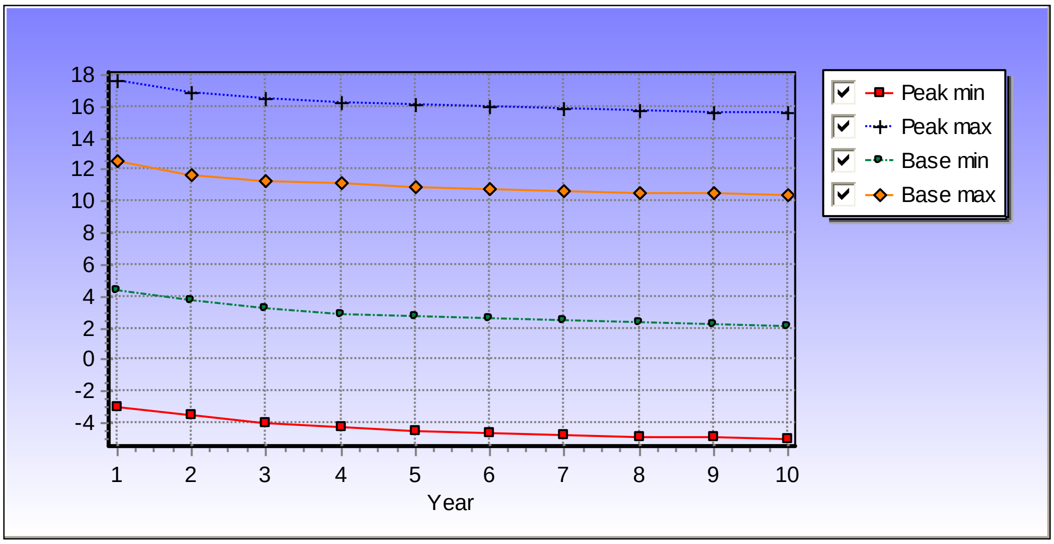


Figure 6.4: Minimum and maximum temperatures.

The content of the output file ”manual_x.out“ for the optimized Linden example is listed in 0. It is obvious, that the borehole 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 boreholes and the borehole 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 borehole 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 boreholes. 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 borehole 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.

7. Optimization of borehole length and cost

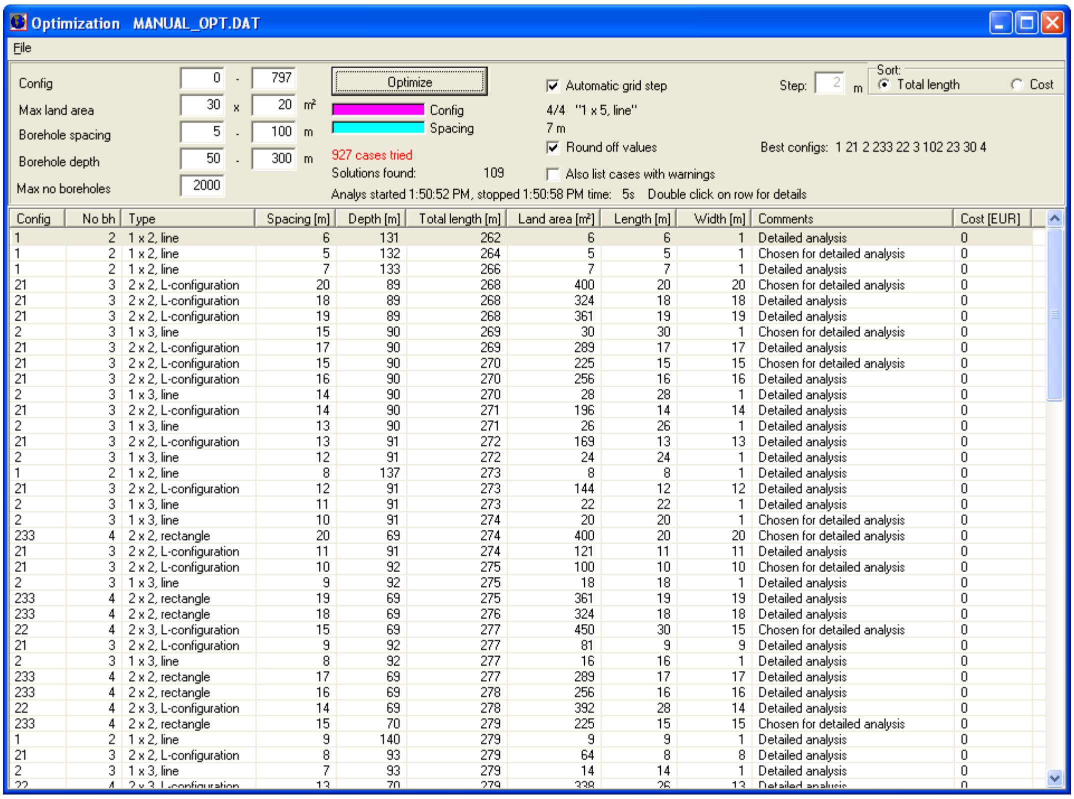
The optimization option gives the minimum total borehole length (or cost) for a given set of parameters (range of configuration numbers, land area, borehole spacing and depth, and number of boreholes), see Figure 7.1. Each configuration will be analysed for different values of the borehole spacing. If a configuration fits within the land area (length *x* width), a required borehole length calculation will be made and the result will be listed.

If option **Automatic grid step** is checked the borehole spacing value will start with 5 m and increase by 5 (5, 10, 15 m and so on) until the configuration does not fit within the specified land area. When all possible configurations have been analysed, the ten best configurations (i.e. with the minimum total borehole length or cost) will be marked "*Chosen for detailed analysis*". A new detailed analysis will then be started, this time with a borehole spacing grid step of 1 m. The time for the whole optimization might be a few seconds for a smaller systems (small load and small land area) up to several minutes for larger systems (large loads and large land areas). The grid step may be chosen at will if option **Automatic grid step** is unchecked.

Note that the fitting of each configuration will be parallel to the length/width-axes (e.g. a line of 5 boreholes will not be analysed diagonally across the land area, instead the maximum of the width/length will be used to obtain the maximum spacing).

Also note that results will not be listed if there is an alert (warning) on the solution, unless "Also list cases with warnings" is checked.

Figure 7.1 shows results for "manual_x.dat" (the flow rate has here been increased from 0.27 l/s to 0.6 l/s to assure turbulent flow). The best solution found is two boreholes in a line with a spacing of 6 m. This gives a borehole depth of 131 m, and a total borehole length of 262 m.



Config	No bh	Type	Spacing [m]	Depth [m]	Total length [m]	Land area [m²]	Length [m]	Width [m]	Comments	Cost [EUR]
1	2	1 x 2, line	6	131	262	6	6	1	Detailed analysis	0
1	2	1 x 2, line	5	132	264	5	5	1	Chosen for detailed analysis	0
1	2	1 x 2, line	7	133	266	7	7	1	Detailed analysis	0
21	3	2 x 2, L-configuration	20	89	268	400	20	20	Chosen for detailed analysis	0
21	3	2 x 2, L-configuration	18	89	268	324	18	18	Detailed analysis	0
21	3	2 x 2, L-configuration	19	89	268	361	19	19	Detailed analysis	0
2	3	1 x 3, line	15	90	269	30	30	1	Chosen for detailed analysis	0
21	3	2 x 2, L-configuration	17	90	269	289	17	17	Detailed analysis	0
21	3	2 x 2, L-configuration	15	90	270	225	15	15	Chosen for detailed analysis	0
21	3	2 x 2, L-configuration	16	90	270	256	16	16	Detailed analysis	0
2	3	1 x 3, line	14	90	270	28	28	1	Detailed analysis	0
21	3	2 x 2, L-configuration	14	90	271	196	14	14	Detailed analysis	0
2	3	1 x 3, line	13	90	271	26	26	1	Detailed analysis	0
21	3	2 x 2, L-configuration	13	91	272	169	13	13	Detailed analysis	0
2	3	1 x 3, line	12	91	272	24	24	1	Detailed analysis	0
1	2	1 x 2, line	8	137	273	8	8	1	Detailed analysis	0
21	3	2 x 2, L-configuration	12	91	273	144	12	12	Detailed analysis	0
2	3	1 x 3, line	11	91	273	22	22	1	Detailed analysis	0
2	3	1 x 3, line	10	91	274	20	20	1	Chosen for detailed analysis	0
233	4	2 x 2, rectangle	20	69	274	400	20	20	Chosen for detailed analysis	0
21	3	2 x 2, L-configuration	11	91	274	121	11	11	Detailed analysis	0
21	3	2 x 2, L-configuration	10	92	275	100	10	10	Chosen for detailed analysis	0
2	3	1 x 3, line	9	92	275	18	18	1	Detailed analysis	0
233	4	2 x 2, rectangle	19	69	275	361	19	19	Detailed analysis	0
233	4	2 x 2, rectangle	18	69	276	324	18	18	Detailed analysis	0
22	4	2 x 3, L-configuration	15	69	277	450	30	15	Chosen for detailed analysis	0
21	3	2 x 2, L-configuration	9	92	277	81	9	9	Detailed analysis	0
2	3	1 x 3, line	8	92	277	16	16	1	Detailed analysis	0
233	4	2 x 2, rectangle	17	69	277	289	17	17	Detailed analysis	0
233	4	2 x 2, rectangle	16	69	278	256	16	16	Detailed analysis	0
22	4	2 x 3, L-configuration	14	69	278	392	28	14	Detailed analysis	0
233	4	2 x 2, rectangle	15	70	279	225	15	15	Chosen for detailed analysis	0
1	2	1 x 2, line	9	140	279	9	9	1	Detailed analysis	0
21	3	2 x 2, L-configuration	8	93	279	64	8	8	Detailed analysis	0
2	3	1 x 3, line	7	93	279	14	14	1	Detailed analysis	0
22	4	2 x 3, L-configuration	13	70	279	338	26	13	Detailed analysis	0

Figure 7.1: The optimization list can be sorted for any column by clicking on the header. Double click on the row for full details.

8. Cost data

There is an option to specify simple cost data for the analysis, see Figure 8.1. If cost data is given, the calculated cost will be shown in the output result file and in the optimization list. The parameters are as follows:

- Fix initial cost (fix cost for the whole system)
- Fix cost per borehole
- Cost per drilled unit length
- Fix cost per borehole for soil drilling
- Cost per drilled unit length in the soil (depth should be given)
- Cost per length for the ditches (the ditch length is assumed to be equal to the borehole spacing times (number of boreholes-1)

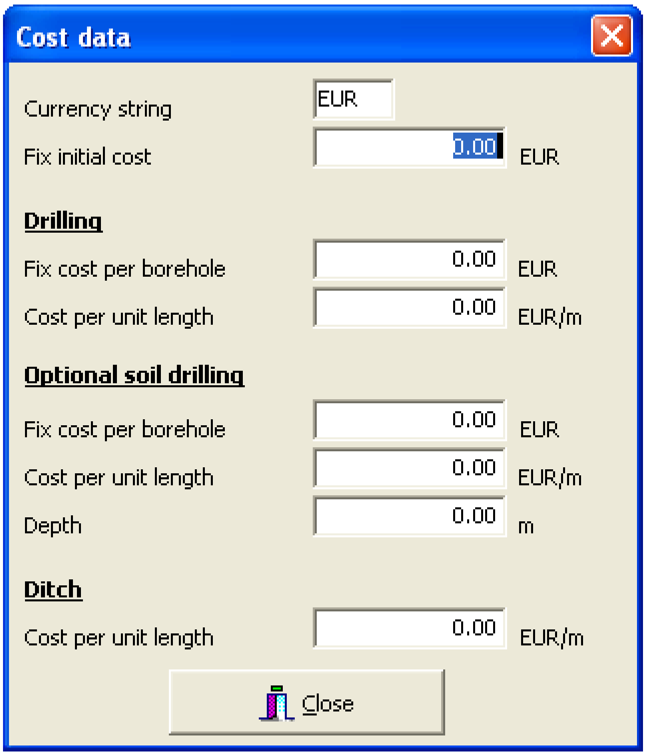


Figure 8.1: Cost data.

9. Change of units

English units are now supported. Input values can easily be converted back and forth between SI and English units, see Figure 9.1. There are two options: convert current input values and change units, or just change units (without conversion of current input).

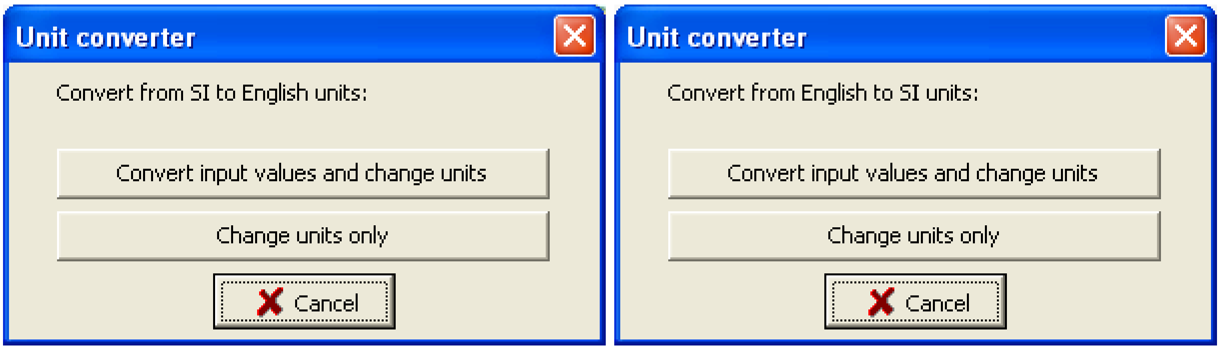


Figure 9.1: Conversion of input to new units.

Figure 9.2 shows an example with English input. Figure 9.3 shows an output example with English units.

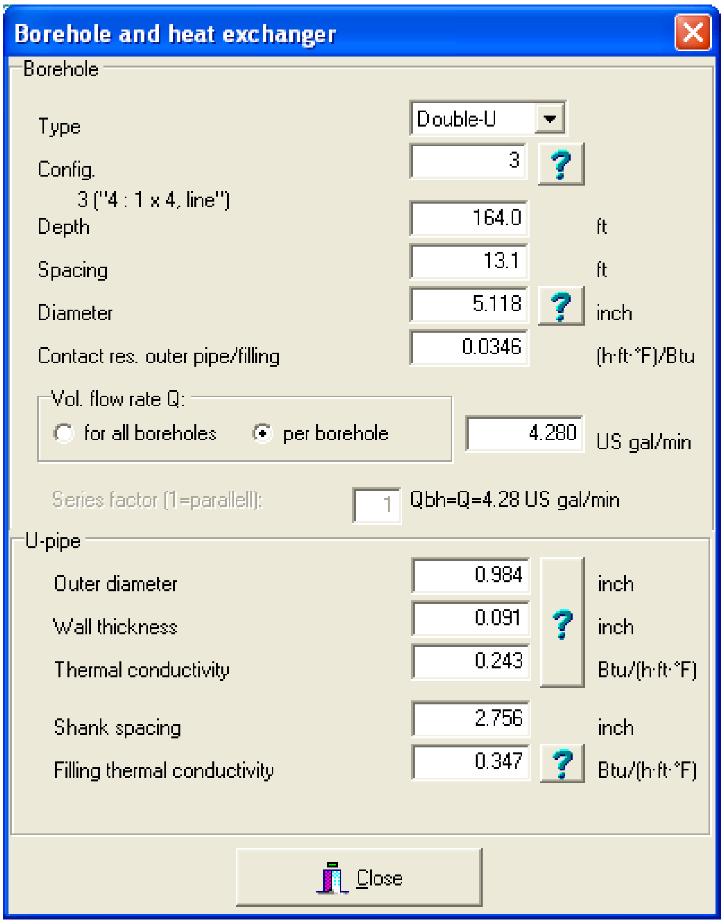
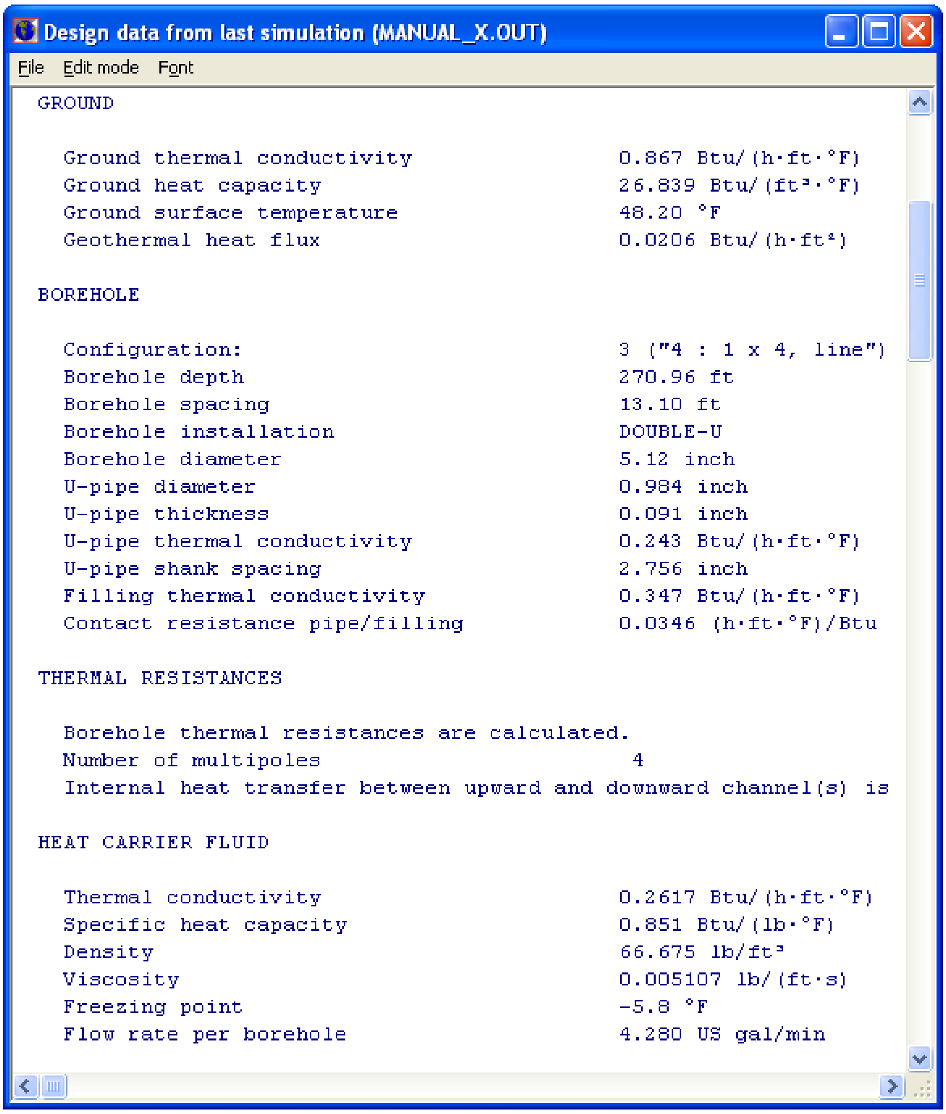


Figure 9.2: An input example with English units.

Note: The flow rate is given in US gallons (not Imperial gallons) which is 3.7854118 liter.




```
GROUND

  Ground thermal conductivity              0.867 Btu/(h·ft·°F)
  Ground heat capacity                     26.839 Btu/(ft³·°F)
  Ground surface temperature               48.20 °F
  Geothermal heat flux                     0.0206 Btu/(h·ft²)

BOREHOLE

  Configuration:                           3 ("4 : 1 x 4, line")
  Borehole depth                           270.96 ft
  Borehole spacing                         13.10 ft
  Borehole installation                    DOUBLE-U
  Borehole diameter                        5.12 inch
  U-pipe diameter                          0.984 inch
  U-pipe thickness                         0.091 inch
  U-pipe thermal conductivity              0.243 Btu/(h·ft·°F)
  U-pipe shank spacing                     2.756 inch
  Filling thermal conductivity             0.347 Btu/(h·ft·°F)
  Contact resistance pipe/filling          0.0346 (h·ft·°F)/Btu

THERMAL RESISTANCES

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

HEAT CARRIER FLUID

  Thermal conductivity                     0.2617 Btu/(h·ft·°F)
  Specific heat capacity                   0.851 Btu/(lb·°F)
  Density                                  66.675 lb/ft³
  Viscosity                                0.005107 lb/(ft·s)
  Freezing point                           -5.8 °F
  Flow rate per borehole                   4.280 US gal/min
```

Figure 9.3: An Output example with English units.

Note that the default data in the pick list windows are given in SI units, see Figure 9.4. If English units are preferred, you can either convert the SI data to English units, or edit the text files and give data in English units. It is recommended that you check input and output results.

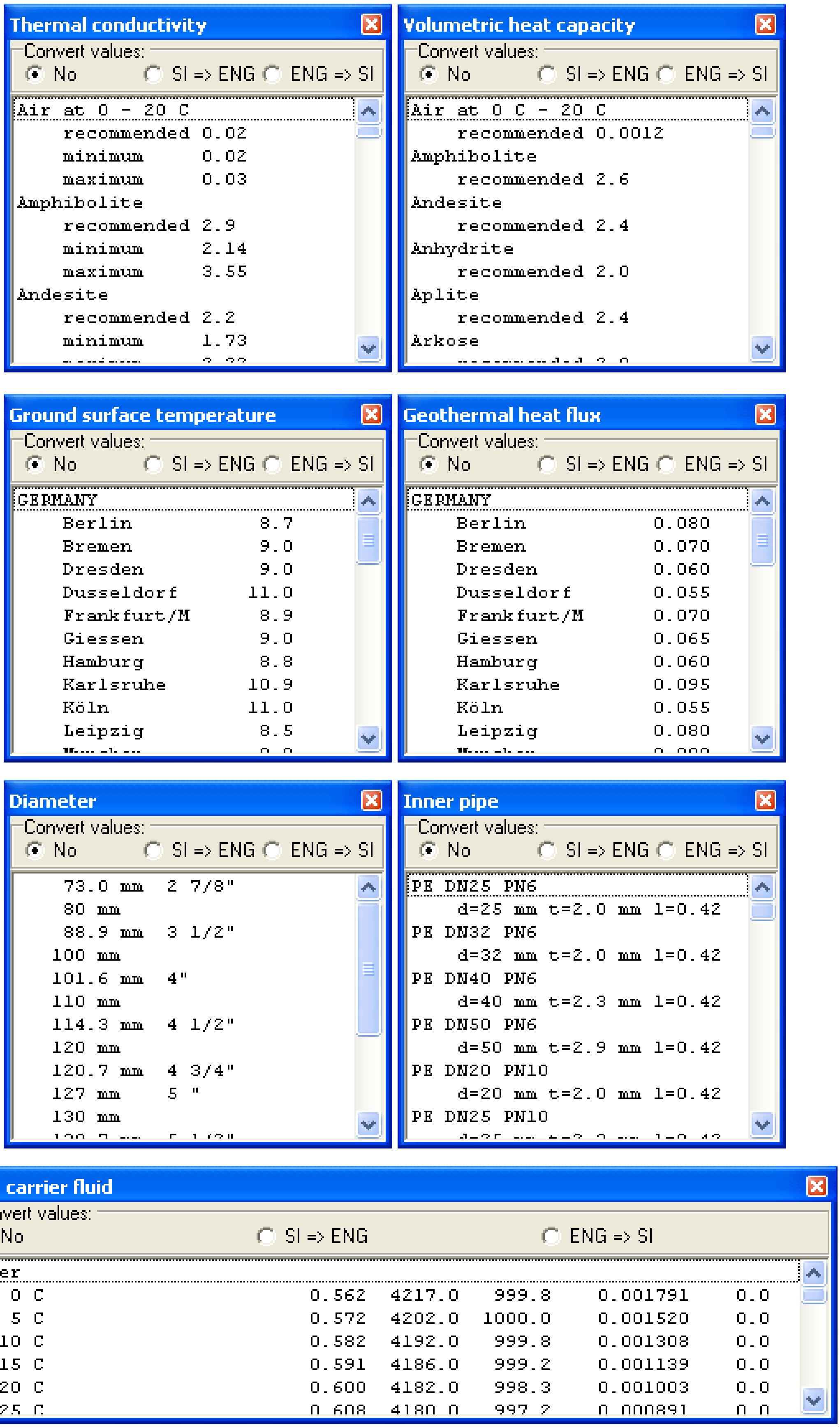


Figure 9.4: Data in the pick lists are provided in SI units.

10. Multilingual option

10.1 Introduction

Figure 10.1 shows the language option (menu item **Settings/language**). A click in the list will change the language for the menu, input data, and output results. The most current language files are listed at

http://www.buildingphysics.com/EED_languages.htm

Figure 10.1: Dialog for changing language (list is defined in file “Lang.txt”).

10.2 How to create files for a new language

New language files can easily be created and edited, see Figure 10.2. There are three files for the menu text, the input dialogue text, and the output text:

- Menu text: Lang_menu_***.txt
- Input text: Lang_in_***.txt
- Output text: Lang_out_***.txt

The string “***” should be replaced by the ISO 639-2 Code, see e.g.:

http://www.loc.gov/standards/iso639-2/php/code_list.php

E.g. the Swedish files should be named

- Lang_menu_swe.txt
- Lang_in_swe.txt
- Lang_out_swe.txt

If you create new language files please consider to email these to info@blocon.se and we will make these available to others. The files must be in “Ansi”-format (Windows-1252), see http://en.wikipedia.org/wiki/Windows-1252

Some languages might have most characters supported, but not all. An example is Hungarian (which has ű and ő that is not part of Windows-1252). It is however possible to replace these with other characters and still obtain readable text.

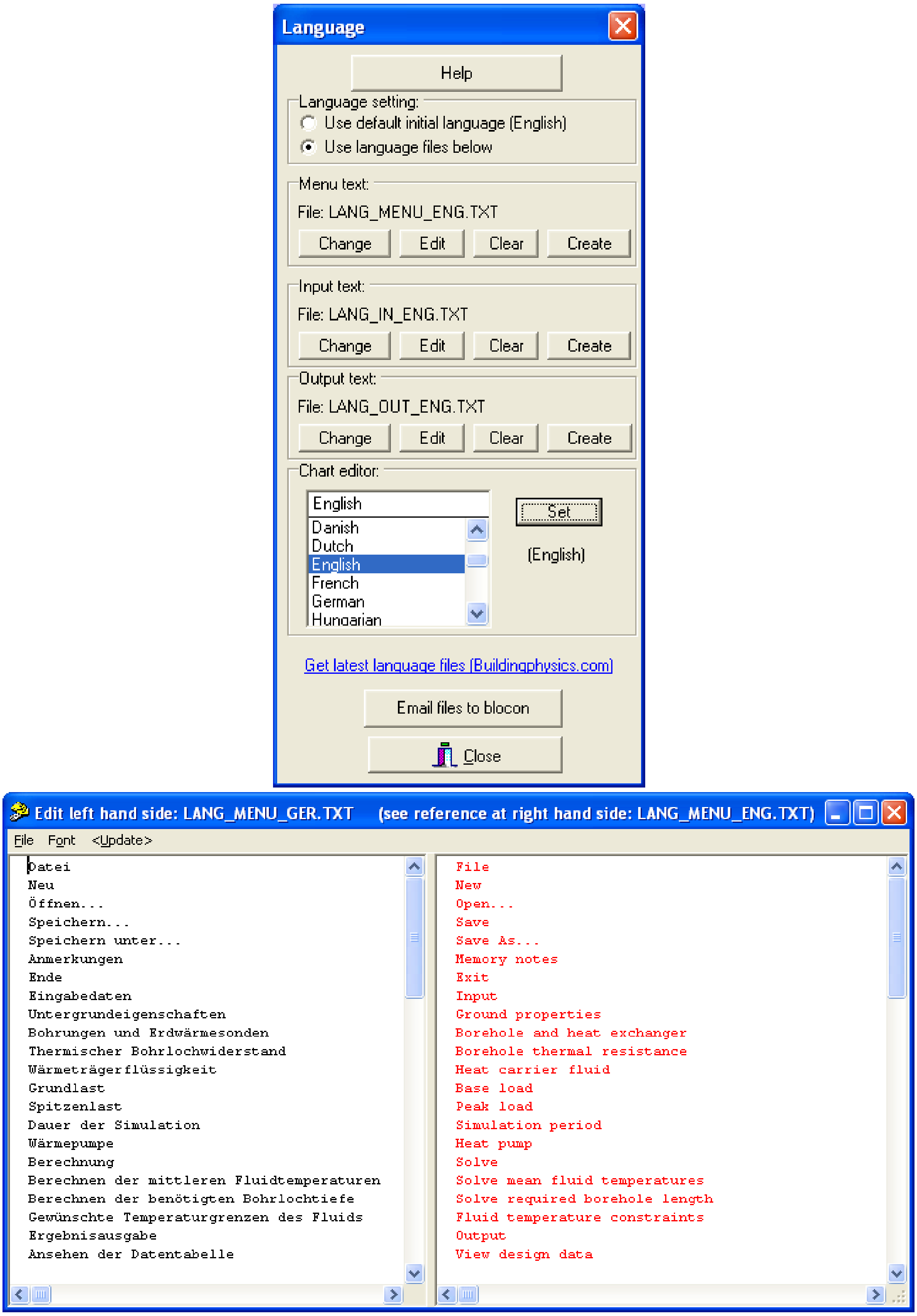


Figure 10.2: Creating/changing language files.

11. Update EED v3.2

11.1 Introduction

EED v3.2 is an important upgrade that is better adapted to Windows Vista, Windows 7 and Windows 8. The new features are described below.

11.2 New license management system

The license management system is improved with easier activation/deactivation using a new license server.

Important: If you have an old license key for v3.0 or v3.1 you need to convert it to a new product key for v3.2 before activation. This can be made in the "About"-box in EED v3.2, or by using the link at http://www.buildingphysics.com/index-filer/Page1139.htm

11.3 Installation to new folders

In Windows Vista, Windows 7 and Windows 8 the Program Files folder and the Program Files (x86) folder (and all subfolders beneath) are read-only folders for standard users (users that run programs with standard privileges). This means it is not possible for them to create files or update files in this location of the hard disk. The folders are write-protected.

Therefore, default project files, languages files and other input files required to run EED v3.2 will now be installed to

"...My Documents\Blocon\EED 3"

The exe-file (and necessary license files) is now installed to folder:

"C:\Program Files (x86)\BLOCON\EED_v3"

Note that EED 3.2 will have a new name on the start-menu: "**EED 3.2 Multi-lingual**" (not to be confused with the older versions 3.0-3.16 that had the name " EED 3 Multi-lingual".

11.4 Export to Excel improved

The export from the Design Data window (menu item Output/View Design data) to Excel has been improved with better formatting.

Note that a .csv file is created and opened by Excel. On American Windows versions, the comma is set as default for the "List Separator", which is ok for CSV files. On European Windows versions this character is reserved as the Decimal Symbol and the "List Separator" is set by default to the semicolon ";".

11.5 Updated language files

The setup file for v 3.2 will install the latest language files. For more info, see
http://www.buildingphysics.com/index-filer/Page1139.htm

12. Literature

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Appendix A. Output data file ”Manual_e.out“

”Manual_e.out“

```
EED Version 3.05, license for TEST VERSION

  Input file:C:\Documents and Settings\Thomas\My Documents\RAD
Studio\Projects\EED_3\Projects\MANUAL_E.DAT

  This output file:MANUAL_E.OUT  Date: 5/26/2008 Time: 1:39:14 PM


MEMORY NOTES FOR PROJECT

-Example for Manual

-EED Version 3.0


*** CAUTION! SOLUTION HAS WARNINGS! ***


QUICK FACTS

  Cost                                       -

  Number of boreholes                        4

  Borehole depth                             50.00 m

  Total borehole length                      200.00 m



                 D E S I G N   D A T A

                 ======================


GROUND


  Ground thermal conductivity                1.500 W/(m·K)

  Ground heat capacity                       1.800 MJ/(m³·K)

  Ground surface temperature                 9.00 °C

  Geothermal heat flux                       0.0650 W/m²
```

BOREHOLE

Configuration:	3 ("4 : 1 x 4, line")
Borehole depth	50.00 m
Borehole spacing	4.00 m
Borehole installation	DOUBLE-U
Borehole diameter	130.00 mm
U-pipe diameter	25.000 mm
U-pipe thickness	2.300 mm
U-pipe thermal conductivity	0.420 W/(m·K)
U-pipe shank spacing	70.000 mm
Filling thermal conductivity	0.600 W/(m·K)
Contact resistance pipe/filling	0.0200 (m·K)/W

THERMAL RESISTANCES

Borehole thermal resistances are calculated.

Number of multipoles 4

Internal heat transfer between upward and downward channel(s) is considered.

HEAT CARRIER FLUID

Thermal conductivity	0.4530 W/(m·K)
Specific heat capacity	3565.000 J/(Kg·K)
Density	1068.000 Kg/m³
Viscosity	0.007600 Kg/(m·s)
Freezing point	-21.0 °C
Flow rate per borehole	0.3 l/s

BASE LOAD

Annual DHW load	0.00 MWh
Annual heating load (DHW excluded)	29.03 MWh
Annual cooling load	1.89 MWh

Seasonal performance factor (DHW)	3.00
Seasonal performance factor (heating)	2.12
Seasonal performance factor (cooling)	99999.00

Monthly energy profile [MWh]

Month	Factor	Heat load	Factor	Cool load	Ground load
JAN	0.155	4.50	0.000	0.00	2.377
FEB	0.148	4.30	0.000	0.00	2.270
MAR	0.125	3.63	0.000	0.00	1.917
APR	0.099	2.87	0.000	0.00	1.518
MAY	0.064	1.86	0.000	0.00	0.982
JUN	0.000	0.00	0.250	0.47	-0.473
JUL	0.000	0.00	0.500	0.94	-0.945
AUG	0.000	0.00	0.250	0.47	-0.473
SEP	0.061	1.77	0.000	0.00	0.936
OCT	0.087	2.53	0.000	0.00	1.334
NOV	0.117	3.40	0.000	0.00	1.794
DEC	0.144	4.18	0.000	0.00	2.208
	-------	-------	-------	------	-------
Total	1.000	29.03	1.000	1.89	13.447

PEAK LOAD

Monthly peak powers [kW]

Month	Peak heat	Duration	Peak cool	Duration [h]
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 borehole length 200.00 m

THERMAL RESISTANCES

Borehole therm. res. internal 0.6625 (m·K)/W

Reynolds number 1184

Thermal resistance fluid/pipe	0.1757	(m·K)/W
Thermal resistance pipe material	0.0771	(m·K)/W
Contact resistance pipe/filling	0.0200	(m·K)/W
Borehole therm. res. fluid/ground	0.2088	(m·K)/W
Effective borehole thermal res.	0.2100	(m·K)/W

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) [°C]

Year	1	2	5	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) [°C]

Year	1	2	5	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) [°C]

Year	1	2	5	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

Appendix B. Output data file ”Manual_x.out“

”Manual_x.out“

```
EED Version 3.05, license for TEST VERSION
  Input file:C:MANUAL_X.DAT
  This output file:MANUAL_X.OUT  Date: 5/26/2008 Time: 1:40:45 PM

MEMORY NOTES FOR PROJECT
-Example for Manual
-EED Version 3.0

QUICK FACTS
  Cost                                    -
  Number of boreholes                     4
  Borehole depth                          82.58 m
  Total borehole length                   330.34 m


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

GROUND

  Ground thermal conductivity             1.500 W/(m·K)
  Ground heat capacity                    1.800 MJ/(m³·K)
  Ground surface temperature              9.00 °C
  Geothermal heat flux                    0.0650 W/m²

BOREHOLE

  Configuration:                          3 (”4 : 1 x 4, line”)
  Borehole depth                          82.58 m
  Borehole spacing                        4.00 m
  Borehole installation                   DOUBLE-U
  Borehole diameter                       130.00 mm
  U-pipe diameter                         25.000 mm
  U-pipe thickness                        2.300 mm
  U-pipe thermal conductivity             0.420 W/(m·K)
  U-pipe shank spacing                    70.000 mm
  Filling thermal conductivity            0.600 W/(m·K)
  Contact resistance pipe/filling         0.0200 (m·K)/W

THERMAL RESISTANCES
```

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

HEAT CARRIER FLUID

Thermal conductivity	0.4530 W/(m·K)
Specific heat capacity	3565.000 J/(Kg·K)
Density	1068.000 Kg/m³
Viscosity	0.007600 Kg/(m·s)
Freezing point	-21.0 °C
Flow rate per borehole	0.270 l/s

BASE LOAD

Annual DHW load	0.00 MWh
Annual heating load (DHW excluded)	29.03 MWh
Annual cooling load	1.89 MWh

Seasonal performance factor (DHW)	3.00
Seasonal performance factor (heating)	2.12
Seasonal performance factor (cooling)	10000.00

Monthly energy profile [MWh]

Month	Factor	Heat load	Factor	Cool load	Ground load
JAN	0.155	4.50	0.000	0.00	2.377
FEB	0.148	4.30	0.000	0.00	2.270
MAR	0.125	3.63	0.000	0.00	1.917
APR	0.099	2.87	0.000	0.00	1.518
MAY	0.064	1.86	0.000	0.00	0.982
JUN	0.000	0.00	0.250	0.47	-0.473
JUL	0.000	0.00	0.500	0.94	-0.945
AUG	0.000	0.00	0.250	0.47	-0.473
SEP	0.061	1.77	0.000	0.00	0.936
OCT	0.087	2.53	0.000	0.00	1.334
NOV	0.117	3.40	0.000	0.00	1.794
DEC	0.144	4.18	0.000	0.00	2.208
	-------	-------	-------	------	-------
Total	1.000	29.03	1.000	1.89	13.446

PEAK LOAD

Monthly peak powers [kW]

Month	Peak heat	Duration	Peak cool	Duration [h]
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 borehole length 330.34 m

THERMAL RESISTANCES

Borehole therm. res. internal 0.6625 (m·K)/W

Reynolds number 1184
Thermal resistance fluid/pipe 0.1757 (m·K)/W
Thermal resistance pipe material 0.0771 (m·K)/W
Contact resistance pipe/filling 0.0200 (m·K)/W

Borehole therm. res. fluid/ground 0.2088 (m·K)/W

Effective borehole thermal res. 0.2121 (m·K)/W

SPECIFIC HEAT EXTRACTION RATE [W/m]

Month	Base load	Peak heat	Peak cool
JAN	9.86	27.19	-0.00
FEB	9.41	27.19	-0.00
MAR	7.95	27.19	-0.00
APR	6.30	27.19	-0.00

MAY	4.07	0.00	-0.00
JUN	-1.96	0.00	-18.17
JUL	-3.92	0.00	-18.17
AUG	-1.96	0.00	-18.17
SEP	3.88	0.00	-0.00
OCT	5.53	27.19	-0.00
NOV	7.44	27.19	-0.00
DEC	9.16	27.19	-0.00

BASE LOAD: MEAN FLUID TEMPERATURES (at end of month) [°C]

Year	1	2	5	10
JAN	10.79	3.69	2.68	2.14
FEB	5.20	3.71	2.74	2.21
MAR	5.58	4.39	3.46	2.93
APR	6.27	5.27	4.38	3.86
MAY	7.47	6.57	5.71	5.20
JUN	11.05	10.23	9.40	8.90
JUL	12.51	11.74	10.94	10.45
AUG	11.64	10.92	10.15	9.66
SEP	8.25	7.60	6.85	6.37
OCT	7.03	6.43	5.71	5.24
NOV	5.66	5.10	4.40	3.93
DEC	4.38	3.85	3.17	2.71

BASE LOAD: YEAR 10

Minimum mean fluid temperature 2.14 °C at end of JAN

Maximum mean fluid temperature 10.45 °C at end of JUL

PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month) [°C]

Year	1	2	5	10
JAN	10.79	-3.33	-4.34	-4.89
FEB	-2.01	-3.49	-4.46	-5.00
MAR	-1.52	-2.70	-3.63	-4.16
APR	-0.66	-1.66	-2.56	-3.07
MAY	7.47	6.57	5.71	5.20
JUN	11.05	10.23	9.40	8.90
JUL	12.51	11.74	10.94	10.45
AUG	11.64	10.92	10.15	9.66
SEP	8.25	7.60	6.85	6.37
OCT	-0.15	-0.75	-1.48	-1.95
NOV	-1.62	-2.18	-2.88	-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 10.45 °C at end of JUL

PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month) [°C]

Year	1	2	5	10
JAN	10.79	3.69	2.68	2.14
FEB	5.20	3.71	2.74	2.21
MAR	5.58	4.39	3.46	2.93
APR	6.27	5.27	4.38	3.86
MAY	7.47	6.57	5.71	5.20
JUN	16.68	15.85	15.02	14.52
JUL	17.62	16.85	16.05	15.56
AUG	17.26	16.55	15.78	15.29
SEP	8.25	7.60	6.85	6.37
OCT	7.03	6.43	5.71	5.24
NOV	5.66	5.10	4.40	3.93
DEC	4.38	3.85	3.17	2.71

PEAK COOL LOAD: YEAR 10

Minimum mean fluid temperature 2.14 °C at end of JAN

Maximum mean fluid temperature 15.56 °C at end of JUL

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       10.56454
     7       12.90950
     8       11.43602
     9        5.87740
    10       -7.85510
    11      -10.23755
    12      -12.40748
    13      -13.08966
    14      -13.37751
    15      -12.05969
    16      -10.32548
    17        3.21811
    18        9.27671
    19       11.74868
    20       10.36958
    21        4.90147
    22       -8.75341
    23      -11.07001
```

tfmin.out:

```
     1      -12.40748
     2      -13.37751
     3      -14.06348
     4      -14.45232
     5      -14.72429
     6      -14.93410
     7      -15.10569
     8      -15.24368
     9      -15.35282
    10      -15.44333
```

24	-13.18046
25	-13.81478
26	-14.06348
27	-12.71133
28	-10.94231
29	2.63565
30	8.72646
31	11.22884
32	9.87822
33	4.43218
34	-9.20399
35	-11.50335
36	-13.59785
37	-14.21738
38	-14.45232
39	-13.08735
40	-11.30582

(only first 40 of 120 values shown)

Appendix D. List of possible borehole configurations

SINGLE

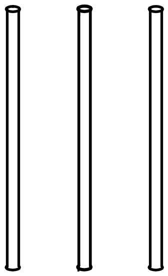
No. BHE	Name	No. of configuration
1	single	0

Example (configuration #0):

LINE CONFIGURATION

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):

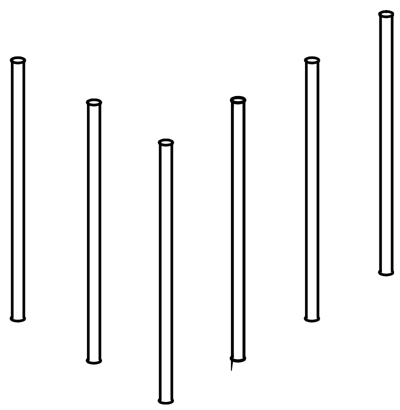


L-CONFIGURATION

No. BHE	Name		No. of configuration
3	2 x 2, L-config	21	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):

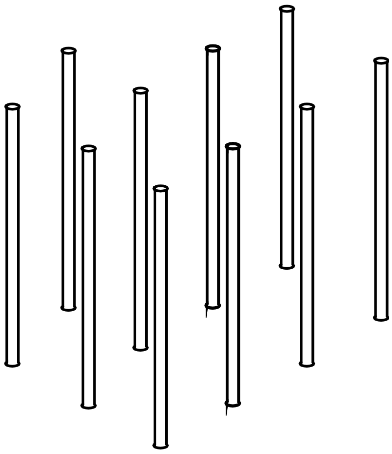


L-config., 3 x 4 boreholes, total 6 boreholes

L2-CONFIGURATION

No. BHE	Name	No. of configuration
8	3 x 3, L2-config 66	
10	3 x 4, L2-config 67	
:	:	:
22	3 x 10, L2-config	73
12	4 x 4, L2-config 74	
14	4 x 5, L2-config 75	
:	:	:
24	4 x 10, L2-config	80
16	5 x 5, L2-config 81	81
18	5 x 6, L2-config 82	
:	:	:
26	5 x 10, L2-config	86
20	6 x 6, L2-config 87	
22	6 x 7, L2-config 88	
:	:	:
28	6 x 10, L2-config	91
24	7 x 7, L2-config 92	
26	7 x 8, L2-config 93	
:	:	:
30	7 x 10, L2-config	95
28	8 x 8, L2-config 96	
30	8 x 9, L2-config 97	
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 boreholes, total 10 boreholes

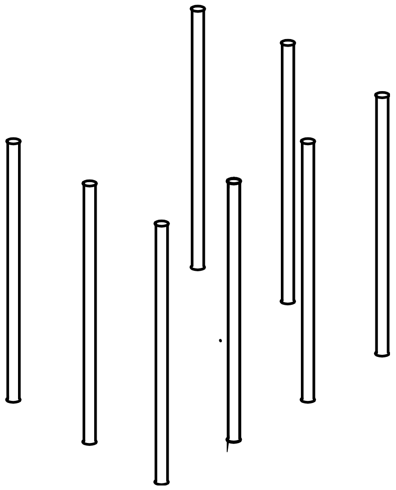
U-CONFIGURATION

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 boreholes, total 8 boreholes

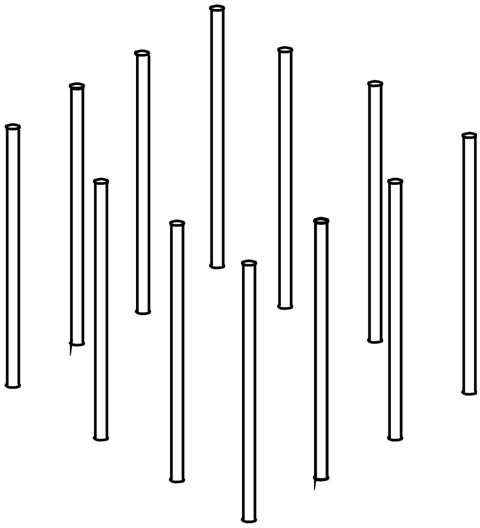
OPEN RECTANGULAR CONFIGURATION

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):

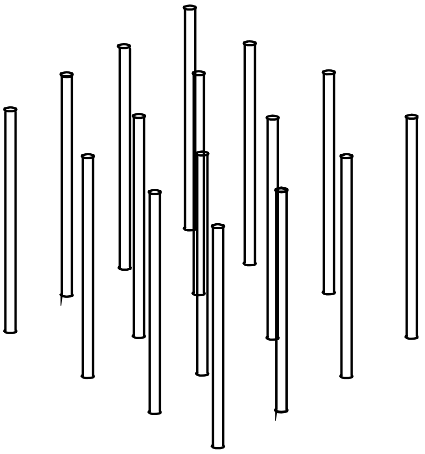


Open rectangular config., 4 x 4 boreholes, total 12 boreholes

No. BHE	Name	No. of configuration
4	2 x 2, rectangle	233
6	2 x 3, rectangle	234
:	:	
20	2 x 10, rectangle	241
22	2 x 11, rectangle	242 //comments EED 3.0 has new numbers from 242
:	:	
100	2 x 50, rectangle	281
9	3 x 3, rectangle	282
:	:	
150	3 x 50, rectangle	329
16	4 x 4, rectangle	330
:	:	
200	4 x 50, rectangle	376
25	5 x 5, rectangle	377
250	5 x 50, rectangle	422
36	6 x 6, rectangle	423
:	:	
300	6 x 50, rectangle	467
49	7 x 7, rectangle	468
:	:	
350	7 x 50, rectangle	511
64	8 x 8, rectangle	512
:	:	
400	8 x 50, rectangle	554
81	9 x 9, rectangle	555
:	:	

405	9 x 45, rectangle	591
100	10 x 10, rectangle	592
:	:	
400	10 x 40, rectangle	622
121	11 x 11, rectangle	623
:	:	
407	11 x 37, rectangle	649
144	12 x 12, rectangle	650
:	:	
403	13 x 31, rectangle	691
196	14 x 14, rectangle	692
:	:	
406	14 x 29, rectangle	707
225	15 x 15, rectangle	708
:	:	
405	15 x 27, rectangle	720
256	16 x 16, rectangle	721
:	:	
400	16 x 25, rectangle	730
289	17 x 17, rectangle	731
:	:	
408	17 x 24, rectangle	738
324	18 x 18, rectangle	739
396	18 x 22, rectangle	743
361	19 x 19, rectangle	744
380	19 x 20, rectangle	745
399	19 x 21, rectangle	746

400	20 x 20, rectangle	747



Example (configuration #330):

Filled rectangular config., 4 x 4 boreholes, total 16 boreholes

LARGE RECTANGULAR CONFIGURATION 1:1

441	21 x 21, rectangle	748
484	22 x 22, rectangle	749
529	23 x 23, rectangle	750
576	24 x 24, rectangle	751
625	25 x 25, rectangle	752
676	26 x 26, rectangle	753
729	27 x 27, rectangle	754
784	28 x 28, rectangle	755
841	29 x 29, rectangle	756
900	30 x 30, rectangle	757
961	31 x 31, rectangle	758
1024	32 x 32, rectangle	759
1089	33 x 33, rectangle	760
1156	34 x 34, rectangle	761

LARGE RECTANGULAR CONFIGURATION 1:2

450	15 x 30, rectangle	762
512	16 x 32, rectangle	763
578	17 x 34, rectangle	764
648	18 x 36, rectangle	765

722	19 x 38, rectangle	766
800	20 x 40, rectangle	767
882	21 x 42, rectangle	768
968	22 x 44, rectangle	769
1058	23 x 46, rectangle	770
1152	24 x 48, rectangle	771

LARGE RECTANGULAR CONFIGURATION 1:3

432	12 x 36, rectangle	772
507	13 x 39, rectangle	773
588	14 x 42, rectangle	774
675	15 x 45, rectangle	775
768	16 x 48, rectangle	776
867	17 x 51, rectangle	777
972 :	18 x 54, rectangle	778
1083	19 x 57, rectangle	779
1200	20 x 60, rectangle	780

LARGE RECTANGULAR CONFIGURATION 1:4

484	11 x 44, rectangle	781
576	12 x 48, rectangle	782
676	13 x 52, rectangle	783
784	14 x 56, rectangle	784
900	15 x 60, rectangle	785
1024	16 x 64, rectangle	786
1156	17 x 68, rectangle	787

LARGE RECTANGULAR CONFIGURATION 1:5

405	9 x 45, rectangle	788
500	10 x 50, rectangle	789
605	11 x 55, rectangle	790
720	12 x 60, rectangle	791
845	13 x 65, rectangle	792
980	14 x 70, rectangle	793

LARGE RECTANGULAR CONFIGURATION 3:4

432	18 x 24, rectangle	794
588	21 x 28, rectangle	795
720	24 x 30, rectangle	796
972	27 x 36, rectangle	797