SOFTWARE FOR DIMENSIONING OF DEEP BOREHOLES FOR HEAT EXTRACTION

G. Hellström
Lund Institute of Technology, Dept. Math. Phys.
P.O.Box 118, S-221 00 Lund, Sweden
Fax +46-46-104416

B. Sanner
Justus-Liebig-University, Inst. Appl. Geosciences
Diezstrasse 15, D-35390 Giessen, Germany
Fax +49-641-7028244

ABSTRACT

The PC-programs for dimensioning of heat extraction by deep boreholes developed at the department of Mathematical Physics at Lund University have proved to be fast and reliable tools. The program calculates the minimum fluid temperature at a user-specified time for the case of multiple, thermally interacting boreholes. The heat extraction is given by 12 consecutive heat extraction (or injection) steps. The thermal response function due to a step change in heat extraction/injection rate is given by a so-called *g*-function. The *g*-functions have been calculated for a large number of borehole configurations by use of a detailed three-dimensional simulation model. The current version of the program is a very fast and accurate computational algorithm with data input given interactively in a simple spreadsheet manner.

The Department of Mathematical Physics, Lund University, Sweden, and the Institute of Applied Geoscienes, Justus-Liebig-University, Giessen, Germany, are currently working on a new version of this program, called "Earth Energy Designer" (EED). Improvements to the program include a database for ground thermal properties and facilities to estimate the borehole thermal resistance from pipe material databases for different borehole heat exchanger installations. The influence of the flow velocity in the borehole will also be taken into account. A new user interface will allow comfortable control of input and computing.

1. INTRODUCTION

The PC-program "Earth Energy Designer" (EED) has been developed to enable engineers to dimension ground heat systems with vertical earth heat exchangers in the day-today-businees. The experience, in the European market as well as on the North American marketplace, has shown a considerable need to get rid of "rules of thumb" for design and layout of ground heat systems.

PC-programs for quick and reasonably sound dimensioning of ground heat systems with vertical earth heat exchangers have been presented by Claesson & Eskilson (1988), Claesson et al. (1990), Claesson (1991) and Hellström (1991). The algorithms have been derived from modelling and parameter studies with a numerical simulation model SBM

(Eskilson, 1986a; Eskilson & Claesson, 1988), evolving to an analytical solution of the heat flow with several functions for the borehole pattern and geometry (*g*-functions, see Eskilson, 1986b). This *g*-functions depend on the spacing between the boreholes at the ground surface and the borehole depth. In the case of graded boreholes there is also a dependence 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 the PC-programs.

Several PC-programs have been established to cover different aspects of vertical earth heat exchangers. The most important programs are:

TFSTEP	Calculation of brine temperature for stepwise heat extraction
DIM	Calculation of the borehole length required for specific heat extraction
INOUT	Calculation of brine inlet and outlet temperature from given mean brine temperature

The programs are extremely fast and thus allow to try a variety of possible layouts. The simple spreadsheet input mask enables experienced users to operate the programs easily for calculations with changing parameters. A major drawback in the use of the programs in the engineering praxis is this input mask, which requires good knowledge of values for input parameters and urges the user to do some calculation (e.g. average heat extraction w_n or borehole thermal resistance r_b) in advance.

Following first discussions in summer 1991, a co-operative work between Lund Institute of Technology in Sweden and Giessen University in Germany was begun to improve the versatility of the programs for the practical use in engineering. The general layout and structure of the new program was agreed upon during a meeting in June 1992.

The program should combine the features of TFSTEP, DIM and INOUT and provide databases for the key ground parameters (thermal conductivity, specific heat) as well as for pipe materials and heat carrier fluids. A printed output report and output files containing data for graphical processing should be provided.

2. USER-FRIENDLY PC-PROGRAM AND DATABASE "EED"

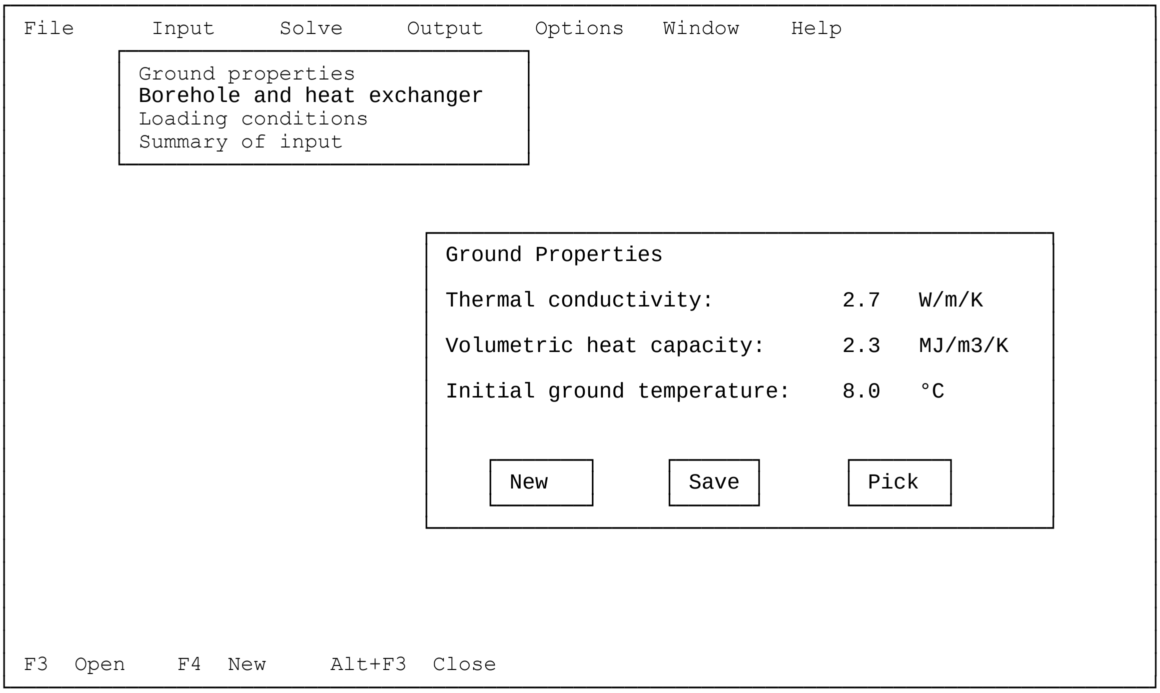
The program is written in Borland PASCAL. The user surface shows an up-to-date menu technique with pull-down menus for input parameters, control of calculation and output. Fig. 1 shows the screen for ground properties. With the "Pick"-option, the user can search for input parameter values interactively in databases. He can choose and pick values or type in own numbers. An example is given under 3.1.

The borehole thermal resistance r_b is calculated in the program, using borehole geometry, grouting material and pipe material and geometry. The material parameters can also be typed in directly or picked from a database. The *g*-functions for borehole pattern can be browsed in a window, and the adequate function for the given layout is choosen directly.

The calculation is done using 12 separate extraction steps as in TFSTEP. The steps now are considered as 12 month, and the monthly average heat extraction/injection are the input data. In addition, an extra pulse for maximum heat extraction/injection can be considered in the month of highest heating/cooling load. The user can choose between different methods of establishing such a monthly load profile.

Fig. 1: Example of EED menu screen, showing ground properties input summary

Layout obsolete, preliminary version to version 1.0



Target of the computing is either the brine temperature profile over the year with given borehole layout (former program TFSTEP), or the calculation of required borehole length for given minimum/maximum temperatures (former program DIM). Data for the monthly temperature profile can be stored in ASCII-Format on a file. This allows further graphical processing of the data with most graphic packages.

With known fluid flow volume the inlet and outlet temperatures of the earth heat exchangers can be calculated. Data for heat carrier fluids (water or various water/antifreeze-mixtures) can be picked from a database. The temperatures are calculated using the pipe geometry, according to program INOUT. The integration of the programs and the addition of databases to find plausible input data is hoped to result in a versatile tool for the hands of engineers.

3. EXAMPLES FOR THE APPLICATION OF THE SOFTWARE

3.1. GSHP-Plant for 35 flats in Kochel am See, Bavaria, Germany

A ground source heat pump (GSHP) with vertical earth heat exchangers was designed for a housing project with 35 flats in Kochel am See, directly north of the Alpine front. Heat load is 210 kW with app. 1800 full-load hours, the plant is of the heating-only type. The ground belongs to the cretaceous "Flysch" series of the Northern Alps, in this particular geological situation consisting of marls, locally called "Zementmergel" (Sanner et al., 1992). The plant is in operation since summer 1993.

For the ground, a value is choosen from the database for heat conductivity. Because of the high carbonate content in the cretaceous marl in Kochel, the high value of 2.7 W/m/k seems to be adequate.

Name	min.	max.	suggested	Remarks
3 Dolomite	3.34	3.34	3.3	Ca-Mg-Carbonate
3 Limestone	0.52	3.05	2.4	Ca-Carbonate
3 Marl	2.04	2.70	2.2	Clayey limestone
3 Claystone/Siltstone	2.03	3.04	2.2	Grainsize < 0.063 mm
3 Sandstone	1.28	3.24	2.2	Porosity and moisture!

For specific heat capacity the suggested average value of 2.3 $MJ/m^3/K$ is selected.

Name	min.	max.	suggested	Remarks
3 Dolomite	2.42	2.63	2.5	Ca-Mg-Carbonate
3 Limestone	2.09	2.42	2.3	Ca-Carbonate
3 Marl	2.00	2.57	2.3	Clayey limestone
3 Claystone/Siltstone	2.13	2.42	2.3	Grainsize < 0.063 mm
3 Sandstone	1.56	2.78	2.0	Porosity and moisture!

The monthly heat load of the buildings is required as input. It can either be derived from the total annual heat load (378 MWh) by a given percentage of the total for each month, or by directly typing in the monthly loads. The heat extracted from the earth is calculated assuming a SPF of 3.

Month	Percentage	Monthly Load [MWh]	Heat from earth [MWh]
January	18	68.0	45.3
February	20	75.6	50.4
March	15	56.7	37.8
April	5	18.9	12.6
May	2	7.6	5.1
June	0	0	0
July	0	0	0
August	0	0	0
September	4	15.1	10.1
October	8	30.2	20.1
November	12	45.4	30.3
December	16	60.5	40.3
Sum	100	378.0	252.0

The German Federal Mining Law requires special permissions for boreholes deeper than 100 m. Hence a borehole length of 98 m is a good choice. Pipe diameter in a double-U-tube earth heat exchanger of this depth should be 32 mm, leading to a borehole diameter of 130 mm. Following rules of thumb, 20-24 boreholes would be required. The task is to calculate the brine temperature for a proposed layout of 21 holes. The holes are grouped in 3 lines (8, 9 and 4 holes) with a hole-to-hole-distance of 4 m.

The result of the calculation is shown in fig. 2. With 21 holes, the plant is a little undersized. Temperature in February is below -5 °C, and the SPF will not be superb. Nevertheless, the plant has been build with this layout due to restrictions of the area for drilling.

It is important to assess the result of a longer period of full-load operation. This will result in minimum brine temperatures in the heating mode and will restrict the plant's operation on a short-term basis. Fig. 3 shows the EED-calculation for the full heating load of 210 kW (140 kW extracted from the ground) over 24 hours. After one day of continuos operation with maximum load, the brine will cool down to a temperature below -6 °C. Together with a starting value much below 8 °C in wintertime the critical temperature of ca. -10 °C is very close.

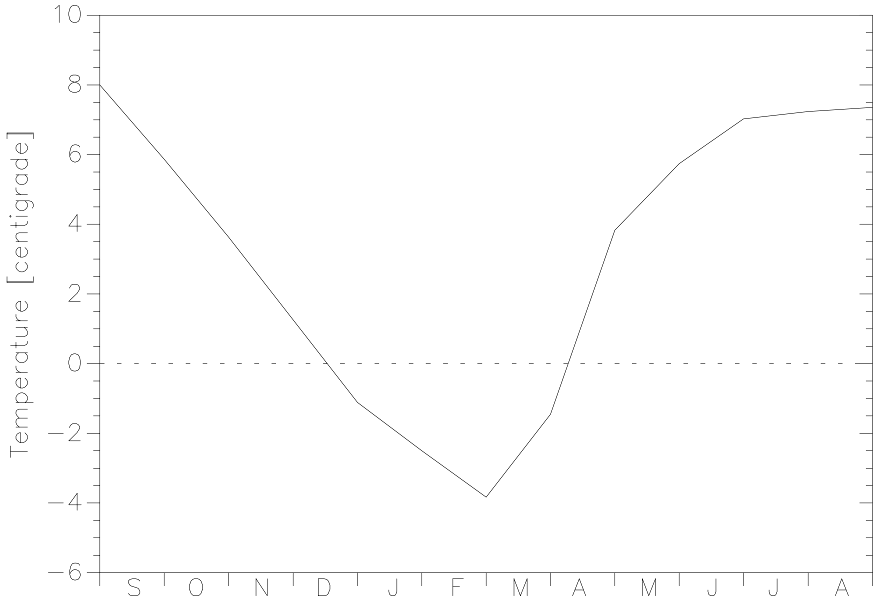


Fig. 2: Mean brine temperature over a year in Kochel plant, calculated with EED (start of operation in September assumed).

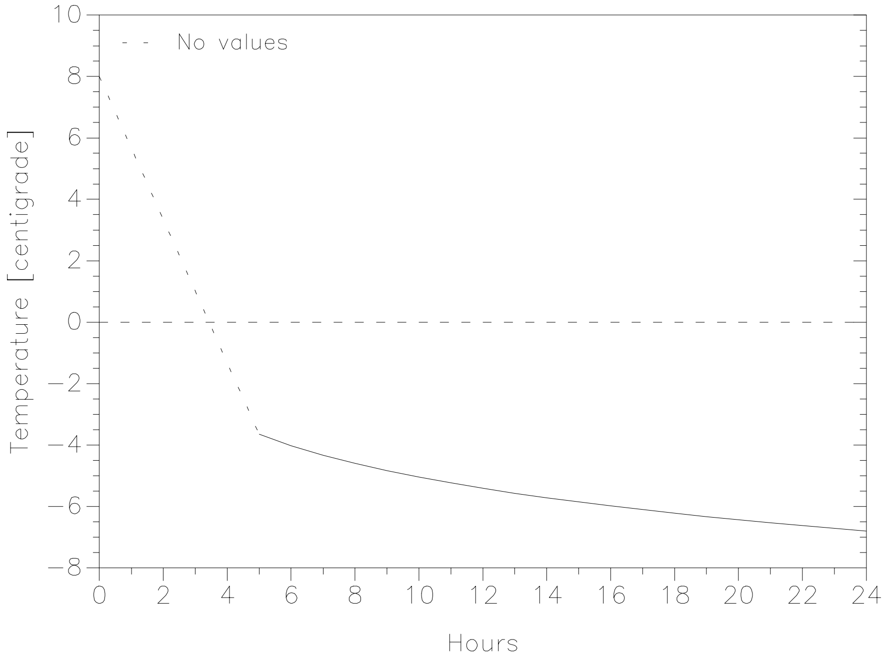


Fig. 3: Mean brine temperature for a maximum load operation in Kochel plant, calculated with EED.

3.2. STES-Plant for the glass-lens factory "Ophthalmica" in Rathenow, Germany

In Rathenow, some 60 km west of Berlin, a factory for glass-lenses has been build in a new commercial area (fig. 4). The single-storey building is heated by a ground source heat pump and cooled using seasonal thermal energy storage (STES). In summertime, some areas containing rooms with dust-free environment have to be cooled. Cold is provided by circulating brine through 10 earth heat exchangers each 60 m deep, and thus recovering cold produced by heat pump operation in winter. A heat pump with 64 kW heating output supplies 90 MWh of heat, resulting in 1400 full-load hours for heating. The plant is in operation since June 1992.

Fig. 4: "Ophthalmica"-plant, administration wing.

The ground consists of sand, the ground water level is some 2-3 m below ground surface. The databases suggest for saturated sand values for thermal conductivity of 2.4 W/m/k and for specific heat of 2.5 MJ/m3/K.

Month	Percentage	Monthly Load [MWh]	Heat from earth [MWh]
January	18	16.2	10.8
February	20	18.0	12.0
March	15	13.5	9.0
April	5	4.5	3.0
May	2	1.8	1.2
June	0	-3.0	-3.0
July	0	-3.5	-3.5
August	0	-3.5	-3.5
September	4	3.6	2.4
October	8	7.2	4.8
November	12	10.8	7.2
December	16	14.4	9.6
Sum	100	90.0/-10.0	60.0/-10.0

Fig. 5 and 6 show the results of a calculation using EED. The layout for heating is adequate. Low temperatures are achieved in January/February, but due to the cooling in June-August thermal recovery of the ground is fast. For the maximum case a particularily low temperature beneath -7 °C is found after about 20 hours, but for cooling the temperature does not exceed much the critical value of 16 °C.

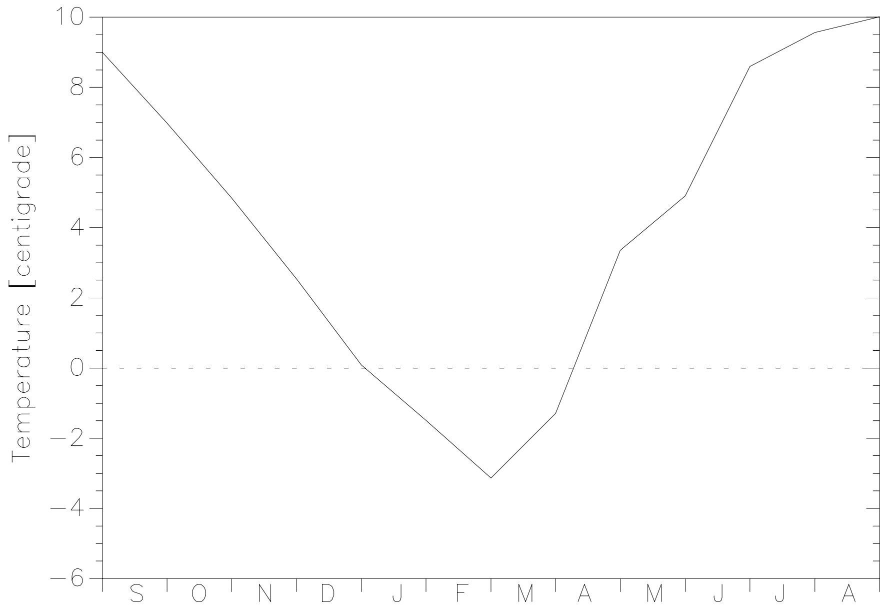


Fig. 5: Mean brine temperature over a year in Rathenow plant, calculated with EED (start of operation in September assumed).

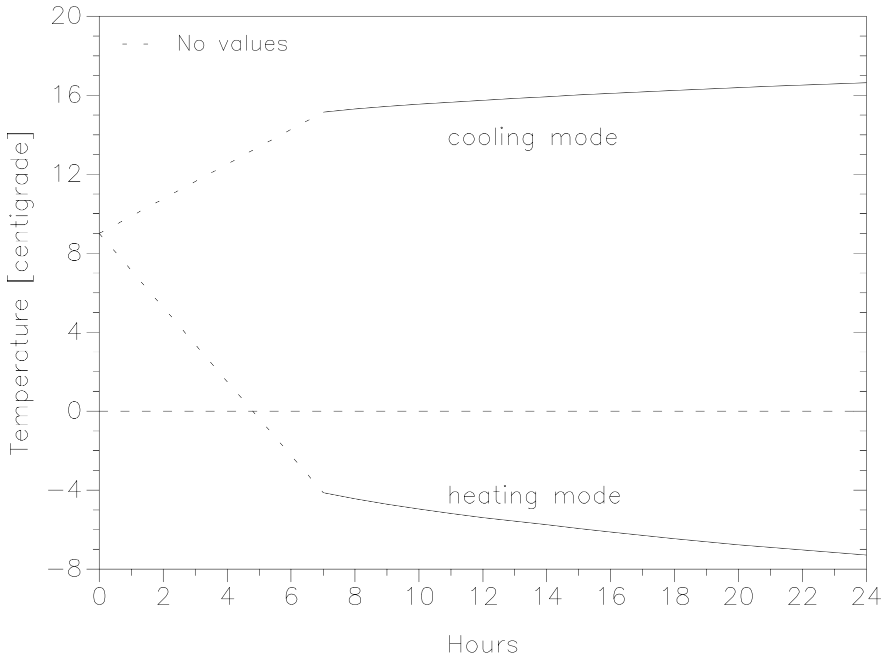


Fig. 6: Mean brine temperature for a maximum load operation in Rathenow plant, calculated with EED.

The plant required 34 MWh electricity for heating and cooling in the 92/93 season, supplying 90 MWh of heat and 10 MWh of cold.

4. CONCLUSIONS AND OUTLOOK

The performance of the PC-programs and the response to the announcement of the new version are encouraging. The authors are optimistic to achieve the goal to produce a tool for wide application.

A first version of EED should be presented end of summer 1994. In fall 1994, the program shall be distributed to some experienced engineers in the earth energy scene for a field test. Comments and suggestions from these users will be the basis for optimisation of the program. The authors hope to release the final program in summer 1995.

Additions to the program for economic assessment are considered. Versions in national languages are also planned, a German version hopefully will be available at the release of the final program.

REFERENCES

Claesson, J. and Eskilson, P. (1988). PC Design Model for Heat Extraction Boreholes. Proc. 4th int. Conf. Energy Storage JIGASTOCK 88, 135-137, Paris.

Claesson, J., Eskilson, P. and Hellström, G. (1990). PC Design Model for Heat Extraction Boreholes. Proc. 3rd WS on SAHPGCS Göteborg, CIT_ 1990:3 99-102, Göteborg.

Claesson, J. (1991). PC Design Model for Thermally Interacting Deep Ground Heat Exchangers. Proc. WS on GSHP Montreal, HPC-WR-8 95-104, Sittard.

Eskilson, P. (1986a). Superposition Borehole Model. University of Lund, Lund.

Eskilson, P. (1986b). Temperature Response Function g for 38 Borehole Configurations. University of Lund, Lund.

Eskilson, P. and Claesson, J. (1988). Simulation Model for thermally interacting heat extraction boreholes. Numerical Heat Transfer, 13 149-165

Hellström, G. (1991): PC-Modelle zur Erdsondenauslegung. Symp. Erdgekoppelte Wärmepumpen Rauischholzhausen, IZW 3/91 229-238, Karlsruhe

Sanner, B., Knoblich, K. and Euler, G. (1992). Nutzung oberflächennaher Geothermie in Kochel a.S., Geologie und Anlagenplanung. Z. Angew. Geowiss., 11 97-106, Giessen

Sanner, B. (1993). Economic and Environmental Analysis of Heat Pump Systems with Seasonal Cold Storage. Proc. WS Heat Pumps and Thermal Storage Fukuoka, HPC-WR-11 139-153, Sittard