EXPERIENCES WITH THE BOREHOLE HEAT EXCHANGER SOFTWARE EED

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

B. Sanner, M. Klugescheid, T. Gonka, S. Mårtensson
Institute of Applied Geosciences, Justus-Liebig-University, Diezstrasse 15,
D-35390 Giessen, Germany

ABSTRACT

EED, the "Earth Energy Designer", has been tested and used since summer 1995. Validation runs against measured data from existing plants show a rather good prediction of fluid temperatures. At a workshop in early 1996 the test users could present their experiences with EED. EED proved to be a useful tool for design of borehole heat exchangers for UTES and GSHP.

One example shown here is a cold storage plant in Wetzlar, where EED was tested against measured data and simulations with the FD-model TRADIKON-3D.

1. INTRODUCTION

The program "Earth Energy Designer" (EED) for calculation of borehole heat exchangers (BHE) first has been presented at CALORSTOCK 94 in Helsinki (Hellström & Sanner, 1994a). Meanwhile various improvements have been made (Sanner & Hellström, 1996). A ß-version of the code was distributed to a small number of research groups and design engineers for testing. On Feb. 1/2, 1996 a workshop was held in Schloss Rauischholzhausen (convention centre of Giessen University) to discuss the experiences. In general, the program, user interface and databases in particular, was highly appreciated, and comparison of EED-calculations with experiences of existing plants and numerical simulations showed sufficiently accurate predictions. However, two major problems were encountered:

- For very shallow BHE (<15 m), the program gives unreliable results and even may terminate suddenly. This has been detected by J. Müller, who used the program as one of several tools for evaluating underground storage of solar thermal energy in shallow depth (see e.g. Beck et al., 1993). The final version of EED now can cope with such shallow BHE.
- J. Poppei used the program for design of deep borehole heat exchangers (>1000 m, e.g. Rybach & Hopkirk, 1995) and compared the results to numerical simulation runs made

earlier (Poppei, 1994). He did find substantial discrepancies (temperatures predicted by EED to low). The reason for this is EED taking the temperature at half the depth of the BHE as reference, while in the coaxial, insulated inner return pipe of a deep BHE the bottom hole temperature is closely represented. It was decided not to change EED to cover this aspect also, but to limit the use to BHE not deeper than 200 m.

The concept of the user interface and the databases was welcomed by all workshop participants. The program now is ready for practical use.

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 (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). Those *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, DIM and INOUT. The programs are extremely fast and thus allow to try a variety of possible layouts. The simple spreadsheet input mask enabled 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 was this input mask, which required good knowledge of values for input parameters and urged the user to do some calculation in advance.

After first discussions in summer 1991, co-operative work on the programme began in June 1992, and was presented at Calorstock 1994 (Hellström & Sanner, 1994 a). A preliminary version of EED was then shown in the second Rauischholzhausen Symposium in fall 1994 (Hellström & Sanner, 1994b), and the ß-version distributed in summer 1995. The new program EED combines features of TFSTEP and DIM. The calculation of brine temperatures is done for monthly heat/cool loads. Databases provide the key ground parameters (thermal conductivity, specific heat) as well as properties of pipe materials and heat carrier fluids. 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 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 files containing data for graphical processing are provided.

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. The borehole thermal resistance r_b is calculated in the program, using borehole geometry, grouting material and pipe material and geometry. The *g*-functions for borehole pattern can be browsed in a window, and the adequate function for the given layout is choosen directly. In TFSTEP and the early EED-versions, borehole distance was introduced through B/H-values, thus coupling it to borehole depth. This was a result of the geometrical nature of the *g*-functions. In the recent version, the borehole distance is typed in directly, and the program interpolates between suitable *g*-functions, keeping the borehole distance constant with changing borehole depth. The number of *g*-functions had to be increased considerably to allow this feature, and *g*-functions for smaller distances had to be added. An example of the current screen is shown in fig. 1.

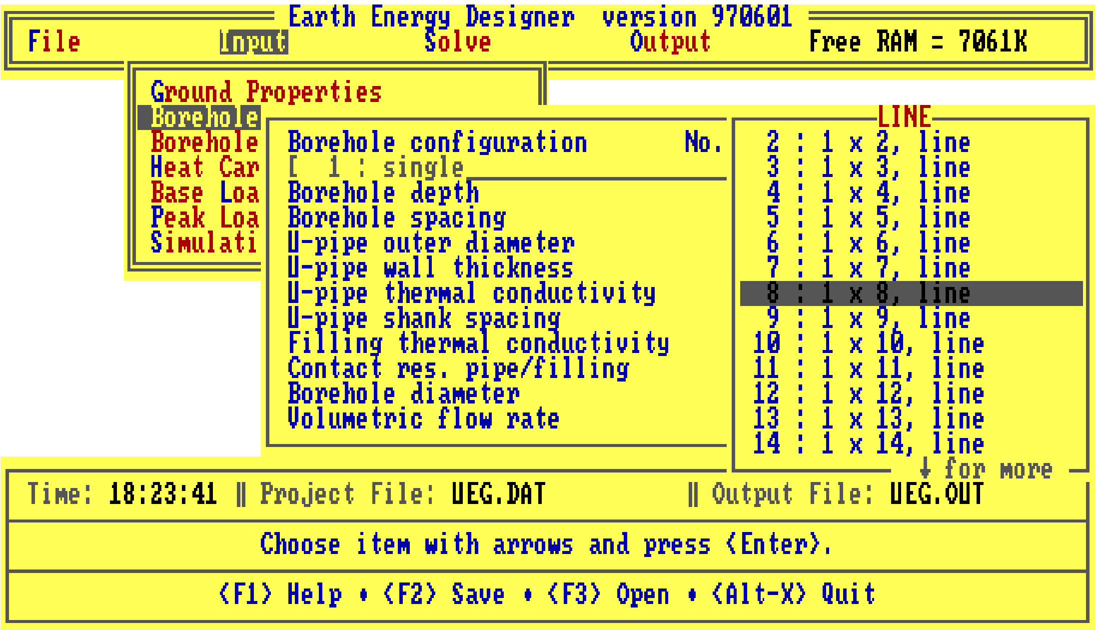

Fig. 1. EED borehole and heat exchanger menu with selection of *g*-function (Example UEG, see below) ***layout obsolete, version 1.0!***

3. EXAMPLES

Calculations with EED were compared to numerical simulation, e.g. using the FD-code TRADIKON-3D (Brehm, 1988). For a feasibility study for seasonal cold storage at the Reichstag building in Berlin, detailed modelling for borehole as well as aquifer storage was made (Sanner et al., 1994). Even if the ground in Berlin is better suited for aquifer storage (Knoblich et al., 1994), the borehole version had to be investigated also. For this purpose EED was used in a first phase, to get an idea of the required size of the store. In a second phase, individual "modules" consisting of 20 borehole heat exchangers (BHE) each 100 m deep in a 4 x 5 array have been modelled exactly using TRADIKON-3D. Fig. 2 shows the result of this simulation compared to an EED-calculation.

With TRADIKON-3D, BHE in the centre ("Zentralsonde"), at the outside ("Rand-sonde") and at the edge ("Ecksonde") of the array could be distinguished. EED gave as result only the mean brine temperature of the field. Load was given as monthly average, and thus the temperature development in the TRADIKON-3D-simulation (hourly time steps) shows a steep rise or fall at the beginning of each month, with subsequent approaching to a steady state. EED can not handle this short-term behaviour, but gives a good approximation of the mean values from the simulation.

Nevertheless, the aquifer solution proved much more economic than BHE in the Berlin site conditions, and the plant will be realized in 1998-2000 as aquifer cold storage in a shallow aquifer and high temperature heat storage in a deep, saline aquifer (Brandt et al., 1996).

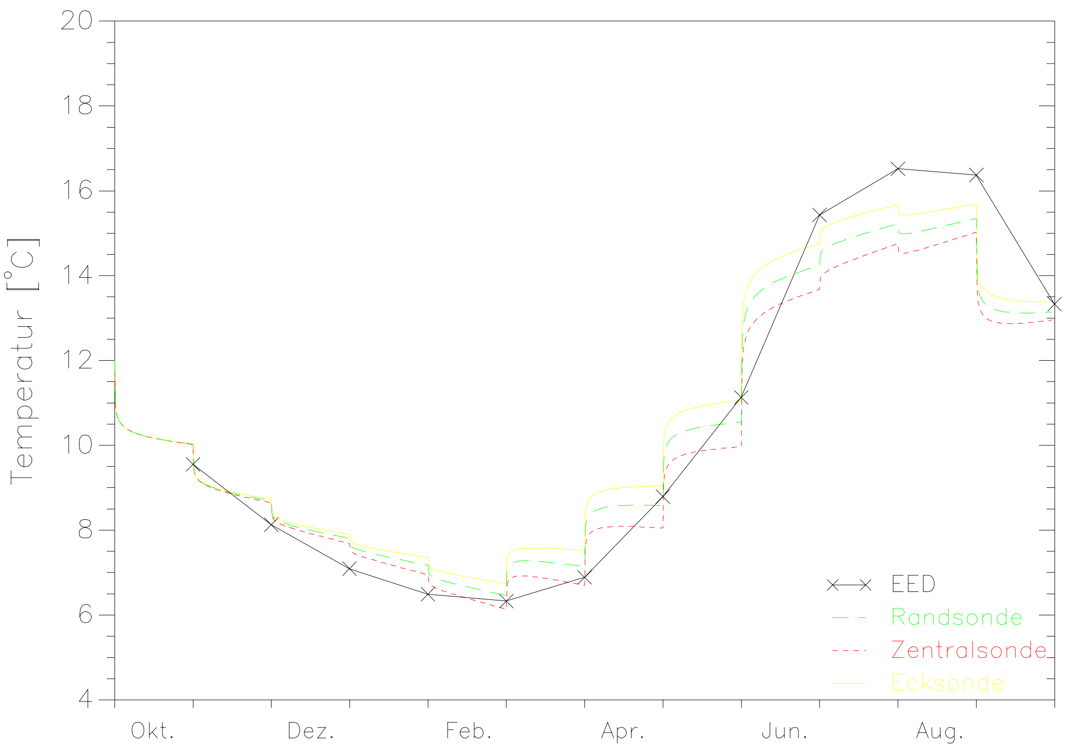

Fig. 2. Brine temperature in one module of a theoretical BHE cold storage plant for the Berlin Reichstag building, calculated with TRADIKON-3D and EED

An existing ground source heat pump (GSHP) plant with direct cooling was monitored from July 1995 on. The GSHP supplies heat to the chemical laboratory UEG, a building containing offices and labs. In summertime, cold brine from the BHE is used for direct cooling of the building (Sanner et al., 1996). The plant is operational since spring 1992, monitoring started in July 1995. The monitoring revealed a considerable cooling demand even in winter, caused by some heat-generating installations like atom absorption spectometry (AAS).

Fig. 3 shows the monitored mean brine temperature from July 1995 - July 1996 in UEG, Wetzlar, and the brine temperature calculated with EED. Monthly heat and cold demand was taken from measured data for EED calculation. Since the plant was operational over 3 years before monitoring started, temperature values for the fourth year were choosen for the graph in fig. 3. The exact load values for the three preceding years are not known, adding some possible error to the comparison. Also the exact distribution of simultaneous heat and cold generation in some months is unknown. However, the curves in fig. 3 do not match exactly due to the uncertainties, but EED gives a rather good prediction of the temperatures found in reality.

In 1997 it is planned to re-calculate several GSHP plants monitored in the 80's, to validate the EED predictions against these data. Also validation for new BHE versions like "energy piles" (see below) will be done.

4. CONCLUSIONS

It's easy use, short learning curve, quick calculation and inherent databases make EED a useful tool in everyday engineering work for design of GSHP or borehole thermal energy storage. Even for very small plants EED values the effort to do a calculation instead of using rules of thumb, and in very large and complex tasks EED allows to get an idea of the required size and layout before starting simulations.

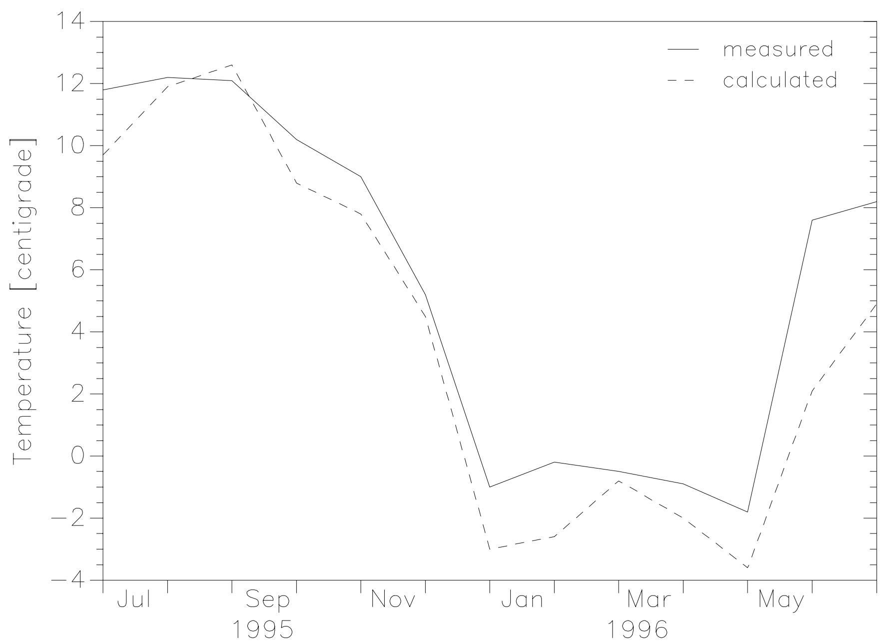

Fig. 3. Measured and calculated brine temperatures for UEG plant, Wetzlar

The number of *g*-functions will be further increased. It has e.g. been found, that a typical BHE layout for GSHP may be a U-shape or even a hollow rectangle. This is due to space constraints on building sites, where the remaining room between the building and the boundaries of the lot is used for BHE installation.

A relatively new approach to built BHE are "energy piles". This term refers to foundation piles equipped with plastic tubes to form a heat exchanger (Sanner, 1995). In areas, where foundation piles are required to carry the building weight, energy piles can be an economic form of BHE. The technique is used since ca. 1990 in Austria, later in Switzerland and Germany, and a first plant in USA (Albany, NY) has been built. Those energy piles can generally be calculated with EED, assuming larger borehole diameters and concrete as borehole fill. EED in the current version allows up to 3 U-pipes in a hole (triple-U); for some energy pile up to 5-6 U-pipes are used. Since energy piles are bound to gain a higher share of the BHE market, additions to EED in this direction and validation for energy piles makes sens.

ACKNOWLEDGEMENTS

The authors wish to thank all the test users of the ß-version of EED for their comments and contributions for improving the code. Special thanks to Prof. Dr. Ladislaus Rybach of ETH Zurich for allowing us to search his rock thermal database, and to Jens Müller, Landtechnik Weihenstephan, who produced the most intriguing fatal errors with EED and thus helped us to eliminate some bugs.

LITERATURE

Beck, M., Müller, J., Reuss, M., Schulz, H. & Wagner, B. (1993): Untersuchungen zur saisonalen Speicherung von Niedertemperaturwärme im Erdboden. - 429 pp., Landtechnik-Bericht 7, Landtechnik Weihenstephan, Freising

Brandt, W., Möllemann, G., Poppei, J. & Seibt, P. (1996): Kälte- und Wärmespeicherung im Zentrum Berlins. - Proc. 4. Fachtagung Geothermie Konstanz, GtV, Neubrandenburg, in press

Brehm, D.R. (1989): Entwicklung, Validierung und Anwendung eines dreidimensionalen, strömungsgekoppelten finite Differenzen Wärmetransportmodells. - Giessener Geologische Schriften 43, 120 pp., Giessen

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

Claesson, J., Eskilson, P. & Hellström, G. (1990): PC Design Model for Heat Extraction Boreholes. - Proc. 3rd WS on SAHPGCS Göteborg, CIT³ 1990:3, pp. 99-102, Göteborg

Claesson, J. (1991): PC Design Model for Thermally Interacting Deep Ground Heat Exchangers. - Proc. WS on GSHP Montreal, HPC-WR-8, pp. 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. & Claesson, J. (1988): Simulation Model for thermally interacting heat extraction boreholes. - Numerical Heat Transfer, 13, pp. 149-165

Hellström, G. (1991): PC-Modelle zur Erdsondenauslegung. - IZW Bericht 3/91, pp. 229-238, Karlsruhe

Hellström, G. & Sanner, B. (1994a): Software for dimensioning of deep boreholes for heat extraction. - Proc. CALORSTOCK 94, pp. 195-202, Espoo/Helsinki

Hellström, G. & Sanner, B. (1994b): PC-Programm zur Auslegung von Erdwärmesonden. - IZW-Bericht 1/94, pp. 341-350, Karlsruhe

Knoblich, K., Sanner, B. & Klugescheid, M. (1994): Thermische Eigenschaften weichselkaltzeitlicher Ablagerungen im Stadtgebiet von Berlin und Möglichkeiten der Wärme-/Kältespeicherung. - Giessener Geologische Schriften 51, pp. 135-148, Giessen

Rybach, L. & Hopkirk, R. (1995): Shallow and deep borehole heat exchangers, achievements and prospects. - Proc. World Geothermal Congress '95, pp. 2133-2138, IGA, Auckland

Poppei, J. (1994): Untersuchungen zur Weiterverwendung der Geothermiebohrung Bühl 1 als tiefe Erdwärmesonde. - IZW-Bericht 1/94, pp. 275-284, Karlsruhe

Sanner, B., Knoblich, K., Klugescheid, M. & Reichmann, J. (1994): Studie für einen saisonalen Wärme-/Kälte-Speicher am Reichstagsgebäude in Berlin. - Proc. 9. Int. Sonnenforum Stuttgart, pp. 783-790, DGS Verlag, Munich

Sanner, B. (1995): Energiepfähle. - Geothermische Energie 12/95, pp. 5-7, Neubrandenburg

Sanner, B., Klugescheid, M., Knoblich, K. & Gonka, T. (1996): Saisonale Kältespeicherung im Erdreich. - Giessener Geologische Schriften 59, Giessen, in press

Sanner, B. & Hellström, G. (1996): "Earth Energy Designer", eine Software zur Berechnung von Erdwärmesondenanlagen. - Proc. 4. Geothermische Fachtagung Konstanz, GtV, Neubrandenburg, in press