Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

The Bulgarian Experience in the Thermal Response Tests

A. Georgiev *, S. Tabakova and R. Popov

* Department of Mechanics, TU of Sofia, Branch Plovdiv, Bulgaria

* AGeorgiev@gmx.de

Keywords: Borehole Thermal Energy Storage; Bulgarian experience; Thermal Response Test; TRNSYS simulations.

ABSTRACT

The heat source part of a Ground Source Heat Pump (GSHP) system, the ground heat exchanger, can be developed as an Aquifer Thermal Energy Storage (ATES) or as a Borehole Thermal Energy Storage (BTES). The hydro-geological restrictions are less for the BTES system, thus it has a bigger potential for application. There are built already some installations of this type in Bulgaria. Unfortunately the owners do not know exactly the values of the ground characteristics. That could bring to big inaccuracies during the project calculations and the construction of the geothermal systems. The knowledge of the underground characteristics is very important to design an installation using BTES. The most effective method to determine the ground thermal characteristics is the Thermal Response Test (TRT), which gives an opportunity for their determination in-situ.

The work presents a review of the experiments carried out by a research team of the Technical University of Sofia, branch Plovdiv. A mobile installation for implementing of Thermal Response Test has been designed and constructed in 2007. A test borehole heat exchanger (BHE) with a depth of 41 m has been constructed in the courtyard of the Technical University of Sofia, branch Plovdiv. Three tests have been performed in 2009 using the constructed mobile installation (namely in January, March and April). The ground thermal conductivity and the borehole thermal resistance have been determined experimentally. The results, obtained by the different tests, are compared and mathematical simulations by use of the TRNSYS 16.1 commercial program are also performed. The tests are the first ones of this type in Bulgaria. The mentioned team believes to have the leading position when a cadastre of the ground thermal properties is created in Bulgaria. The team will support the Balkan Peninsula projects connected with construction of Ground Source Heat Pumps.

1. INTRODUCTION

Thermal response test (TRT) is an internationally approved technique to identify geothermal underground parameters like effective ground thermal conductivity and borehole thermal resistance. It is considered to be the method which gives the highest accuracy of evaluation. Generally, these tests are performed with heat injection, using the same assumed power level as the one planned by the BHE system. The TRT was first implemented by Mogensen (1983) with an immobile installation. Later, TRT was developed as a mobile measurement installation appeared in Sweden (Eklöf and Gehlin, 1996) and at the Oklahoma State University (USA) by Austin (1998). Now, this type of measurement is used also in Germany (Sanner et al., 2000), Canada, Norway, Netherlands, England, Turkey (Paksoy et al., 2002) and Chile (Georgiev et al., 2002; Roth et al., 2004; Georgiev et al., 2006a).

Several TRTs are done in Bulgaria, too. Some activities in Bulgaria preceded the first official TRT (Georgiev et al., 2006b). The description of the Thermal Response Tests (experiment and simulation), which have been done with a mobile installation at Technical University of Sofia, branch Plovdiv is presented below.

2. TEST INSTALLATION

An original construction of a Thermal Response Test rig has been built recently at the Technical University of Sofia, branch Plovdiv (Georgiev et al., 2007). The scheme of the installation is shown in Figure 1. It consists of the following parts: electrical boiler 1, calorimeter 2, pressure watch 3, expansion tank 4, thermo–manometer 5, filter 6, circulation pump 7, de-aeration pipe 8, quick couplings 9, valves 10 and electrical unit 11.

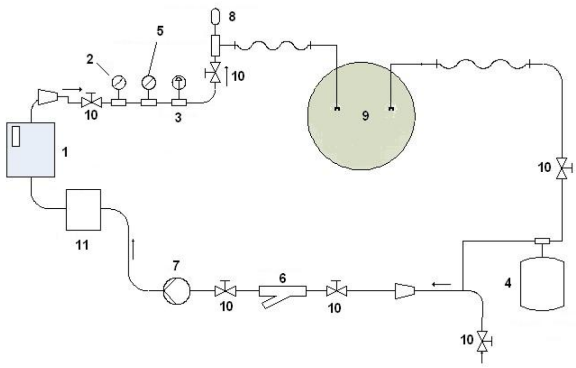

Figure 1: Installation scheme.

The laboratory is installed on a mobile trailer, where the equipment for implementing of TRT is situated. The platform sizes are 4.25 x 1.96 m, which is enough as a space for the equipment installation, as well as for the work inside the trailer during the experiments. The trailer consists of two parts. The first one contains the working installation. The second part is formed as a living room, foreseen for the investigators who will implement the in-situ tests. The living part consists of a gas stove for heating, a gas cooker, refrigerator, sink, table and 2 beds. The constructed trailer combines both options: an investigation installation and lodging. It is foreseen as completed outfit delivering the corresponding comfortable living conditions to the researchers during the tests (the tests are normally carried out on places outside the settlements). The investigation installation contains two types of facilities: one mechanical and one for control and measurement.

2.1 Mechanical Facilities

The calorimeter MEGATRON2 (Figure 2) of the company SIEMENS is situated in the system. It is an independent electronic apparatus for tracking and reporting of the consumed heat at automatic heating and cooling installations. The calorimeter has a memory and a display, which reports the consumed and measured energy values of the chosen day.

"AEROFLEX" insulation is used in the mobile system to avoid errors during the measurement and has the following thickness: the tube insulation is 1.5 mm and the insulations at the input and output of the borehole are 3 mm.

Figure 2: View of the calorimeter MEGATRON2.

The Electrical boiler consists of a body and a control unit. Two tubular electrical heaters are situated in the well insulated steel body of the boiler. The heaters have some heating degrees. A three phase circulation pump with 3 speeds ensures the movement of the heating medium through the boiler. The boiler thermostat regulates automatically the water temperature in the boiler body and the damage thermostat avoids the boiler overheating.

A pump with a wet rotor of the German company "WILO" has been chosen. This pump gives an opportunity for flow rate regulation on frequency. This option allows easy revolution and power regulation of an induction motor by means of the change of the pressure frequency. The borehole depth should be between 40 and 120 m, that means the full length will be between 80 and 240 m.

A system filter is used to eliminate all rigid parts, which enter the system during the filling up with the heating medium. The filter is of the net type and lets a pass only in the direction of the working fluid flow.

A thermo-manometer is needed in the setup to measure the pressure and the temperature of the heating medium after it leaves the electrical boiler and before it enters the borehole.

A pressure watch must protect the pump and the installation from a given high pressure or from overheating of the fluid in the boiler. The protection is fulfilled through the automatic current switching of the pump motor and the boiler heaters. The used pressure watch is produced by the company "WATTS", Italy - PM/5 model.

The expansion tank of the system is needed to equilibrate the small variations of the heating medium. The used expansion tank is of the membrane type and has a capacity of 8 l.

The pipeline used in the installation is a production of the German company "AQUATHERM". The main advantages of the pipes are the following: absolute corrosion stability, chemical stability, high impact stability, low tube roughness, very good welding characteristics and high thermal stability.

2.2 Control and Measurement Facilities

A fully automated system for data archiving of the company "SIGMATECH" EOOD (logger for collecting of the temperature data) Plovdiv has been selected. The multiprocessor system SH700 automates the measuring process of the ground thermal conductivity and processes the obtained data (Figure 3). It collects the data of the measured inlet and outlet borehole temperatures, of the five temperatures in the borehole depth and of the ambient temperature. The maximum number of measured temperatures is 20. The controller has a memory, where the measuring process is recorded. If a computer is used, it is possible to show the process in real time and to represent it after its finish.

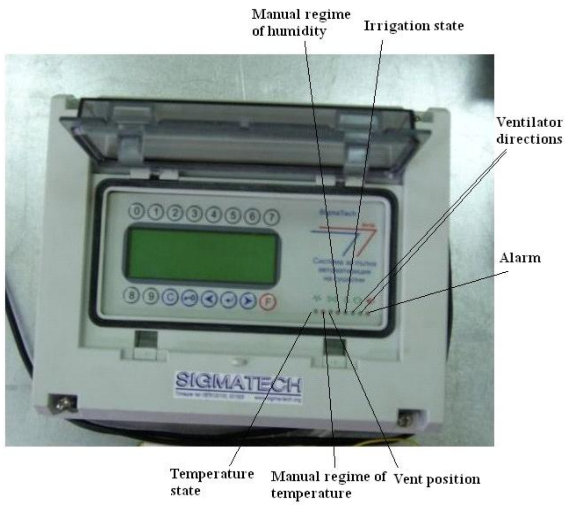

Figure 3: Data logger SH700 view.

Some measuring elements and sensors are mounted in the mobile station. The flow rate through the borehole is measured on the base of the calorimeter sensor and on the base of the electronic transformer of frequency to pressure. An inductive sensor with a code disc is used for measuring the motor revolutions of the electrical generator. The temperature of the generator motor oil is measured with another sensor. A controller for parameter measurement and control of the system motor–generator is mounted, too. The data logging system (SIGMATECH production) is used for measuring and archiving of the installation parameter values. A computer (supplied with processing software) analyzes the collected information. There are 8 temperature elements for PT100, which are used to measure the fluid temperature difference of the borehole (input and output), the temperature in the borehole at different depth and the ambient temperature. All the elements have a sensibility of about ± 0.050K in the temperature range 0°C–120°C.

The mobile station is normally used in different places (sometimes outside towns, without electricity). That is why an electrical generator is included in the system, too. It will deliver electricity in the mentioned regions or in urgent cases. An electrical generator of the company "SUBARU", model EH36B (Figure 4) has been chosen. It is connected to the electrical net of the installation. If the electricity turns off in urgent cases, the generator switches on automatically.

The induction motor of the circulation pump is regulated by the help of frequency regulator (MOELLER" DF51-322 company production), which is situated in the electrical unit. The frequency regulator can be used to manage the speed, torque, direction, start and stop of the pump motor.

Figure 4: Electrical power generator SUBARU.

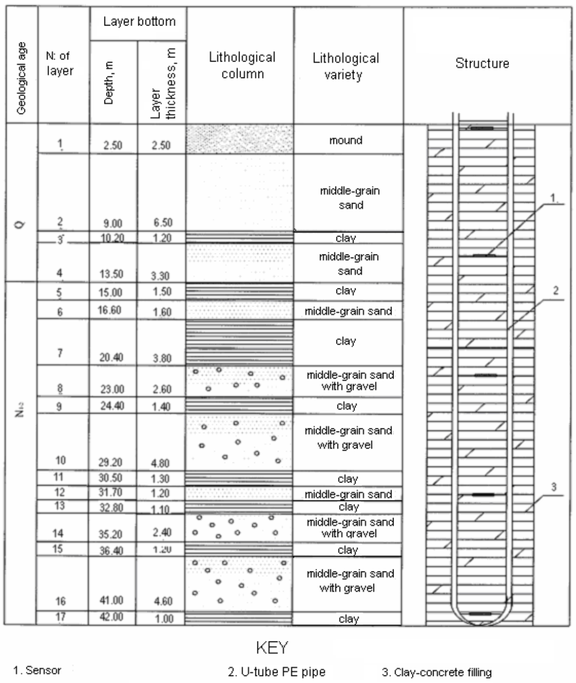

Figure 5: Lithological structure of the perforation.

A power regulator is situated in the electrical unit, too. It is used to manage the power of the electrical heater. Some energy is saved using the regulator and a precise regulation of the measuring process is ensured.

2.3 Geological Research Works during Drilling Works

Electrocarotage measurements were made during the performed drilling operations on the territory of the Technical University – Sofia, branch Plovdiv. These measurements were made with the carotage station KFE-2-12 and the potential drill B 4.5 A 0,4M. It consists of three electrodes, which are going down into the drilling hole and a fourth one is grounded. A 40 Hz electricity is fed and the potential difference between the electrodes, which are in the hole, is measured. The received data is recorded by means of the electrocarotage equipment. The formation of the geological cut is a result from the measurements done. A general lithological structure is worked out on its base (Figure 5).

2.4 The Borehole

In the borehole, deep 41.10 m, a single U-tube heat exchanger constructed of PN10 HDPE pipe, 25 mm diameter, has been installed. The borehole has a diameter of 0.18 m and has been backfilled with 11% bentonite and 2% cement solution. Cement has been added because of the specific soil type: sand soil with high water content. The entire external connecting pipe length has been thermally insulated to reduce the heat loss to the surroundings. There are two temperature sensors Pt 100 for measuring the inlet and outlet borehole temperatures, which are placed as near as possible to the pipe input and output. There are five other temperature sensors placed in different depths inside the borehole (Figure 6).

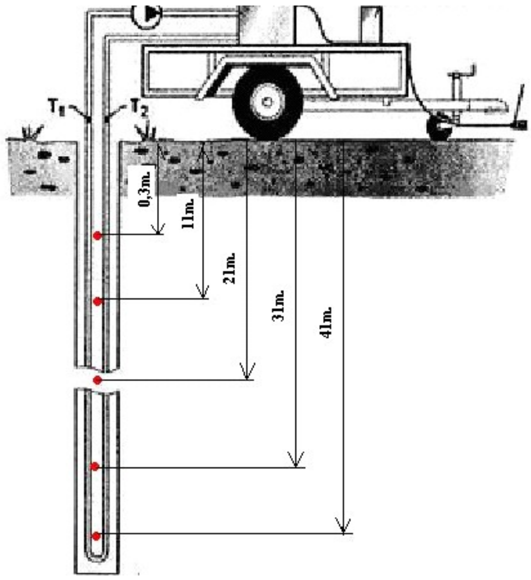

Figure 6: Situation of the temperature sensors in the borehole.

On the ground surface, 10 cm above the BHE, insulation plates have been placed in order to protect the borehole from the external climate influence. Then the plates have been covered with 0.5 mm aluminum foil to minimize the influence of sun radiation. A penthouse construction with 4.5 m² area and 0.9 m height has been built around the laboratory borehole for it's rain protection (Figure 7).

Figure 7: Connection of the borehole with the mobile installation.

3. EXPERIMENT

Since TRT is a relatively slow process, highly dependent on geothermal characteristics, grouting material of the borehole and ambient climate condition, it is recommended it's duration to be at least 4 days (Zervantonakis et al., 2006). The presented three TRTs with the above described installation have been carried out during 4 to 10 days in 2009. The time periods have been established in January, March and April. The measured temperatures are: the ambient temperature, the inlet and outlet temperatures of the borehole and the temperatures of the BHE at different depths. The measuring time step has been fixed at 60 s.

The average undisturbed ground temperature $T_{0,m}$ is a key parameter in Eq. (1) and should be measured prior to the test beginning when the electrical heaters are still switched off. Then the borehole is at thermal equilibrium with its surroundings. $T_{0,m}$ is determined by pumping the heat carrier fluid out of the borehole pipes and measuring its outlet temperature over a time of 10s. $T_{0,m}$ is then calculated as the average of the measurement data. In the presented experiments, $T_{0,m}$ has been established to be about 16.3°C. As soon as $T_{0,m}$ is measured, the electric heaters are switched on and a constant heat starts to be injected in the BHE.

The flow rate has been fixed at a constant value during the tests. The electrical heater power and the electrical power of the circulating pump have been maintained constant automatically. For the experiment purpose the installation has been filled with water and a pressure of 2.2 bars has been established. Most of the main characteristics of the Bulgarian made TRTs in 2009 are shown in Table 1.

Table 1: Main characteristics of the Bulgarian made TRTs in 2009.

	January	March	April
Date	11-21	16-24	13-17
Duration, days	10	8	4.3
Flow rate, l/ min	4.06	3.83	4.6
Electrical heater power, W	1500	2000	1500
Circulating pump power, W	100	100	100
Water pressure, bar	2.2	2.2	2.2
Undisturbed ground temperature, °C	16.3	16.3	16.35
Measuring time step, s	60	60	60

The control of the test rig is the most challenging part of the system. All data are automatically controlled by a specially designed system for the laboratory trailer needs, installed on the control board. The system is fully automatic and writes down all measured data in text files. If appropriate software is available, the data collecting process could be visualized in real time or after finishing the experiment. In the experiments the aim of a constant heat flow was realized by a constant frequency control of the circulation pump and boiler.

3.1 Test Evaluation

The line-source theory (Gehlin, 2002; Kavanaugh et al., 1997) is the most common and easiest approach applied for experimental data evaluation purposes, i.e., modeling the borehole heat exchanger as an infinite line-source in a homogeneous medium. Effects of borehole geometry and thermal properties are modeled implicitly by introducing a thermal resistance, known as borehole resistance R_B. The temporal evolution of the mean fluid temperature T_{Fm} (arithmetic mean of inlet and outlet fluid temperatures), can be calculated according to the line source theory as:

$$T_{Fm}(t) = \frac{Q}{4\pi\lambda H}\ln(t) + \frac{Q}{4\pi\lambda H}\left(\ln(4a/r_B^2) - \gamma\right) + \frac{QR_B}{H} + T_{0,m} \qquad (1)$$

where t, s is the time; λ,W/m.K the ground thermal conductivity; Q, W the imposed heating power; H, m the borehole depth; $T_{0,m}$, K the average undisturbed ground temperature; a, m²/s the ground thermal diffusivity; r_B, m the borehole radius and γ=0.5772 the Euler constant. Application of equation (1) to the real problem is connected with a systematic error, which diminishes with time and increases with borehole radius. Eq. (1) can be rewritten for evaluation purposes in the form of:

$$T_{Fm}(t) = c_1 \ln(t) + c_2 \qquad (2)$$

Further, the test evaluation will be based on Eq. (2), which will be fitted to the experimental data, and the curve constants c_1 and c_2 will be determined. The thermal ground conductivity λ and the borehole resistance R_B can be adequately calculated, by comparing Eqs. (1) and (2) when the curve parameters c_1 and c_2 are known.

3.2 Test Results

The mean fluid temperature in the borehole (average temperature of the inlet and outlet fluid temperatures of the borehole) and the ambient temperatures are shown for the different tests in Figures. 8, 9 and 10. The figures show that the experimental fluid temperatures rise slowly with small oscillations.

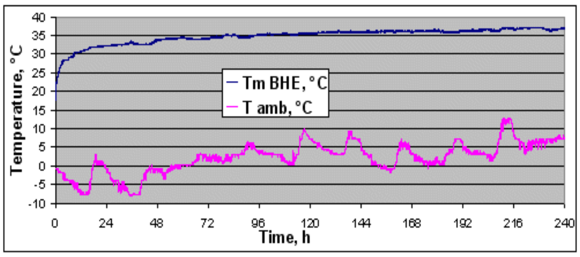

Figure 8: Profile of the mean fluid temperature in the borehole and the ambient temperature in January 2009.

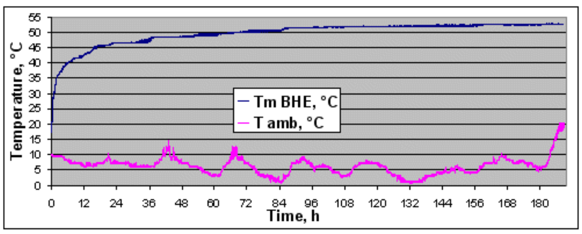

Figure 9: Profile of the mean fluid temperature in the borehole and the ambient temperature in March 2009.

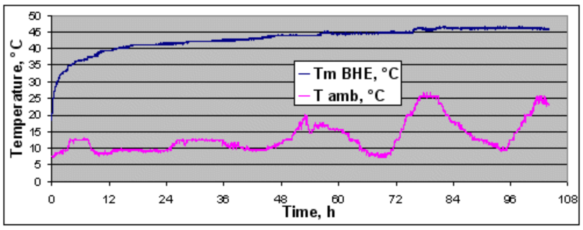

Figure 10: Profile of the mean fluid temperature in the borehole and the ambient temperature in April 2009.

The line source method gives more exact temperature estimations for longer terms of time. It takes some hours of the real BHE to behave as an ideal line source. Therefore, usually the data correspondent to the first 7 to 30 hours of experiment are not taken into account in the analysis. In the present work, this period is accepted to be 20 hours, as it depends on the estimated data. Figs. 11, 12 and 13 show the logarithmic time dependence of the temperature and the slope of the associated regression line. As stated previously, the thermal conductivity λ is related to the slope of the resulting line, given by Eq. (2). The resulting values received during the tests for λ vary between 0.85 and 0.92 W/mK and for R_B vary between 0.47 and 0.60 mK/W. The values of the ground thermal conductivity λ and borehole thermal resistance R_B for the different tests are presented in Table 2.

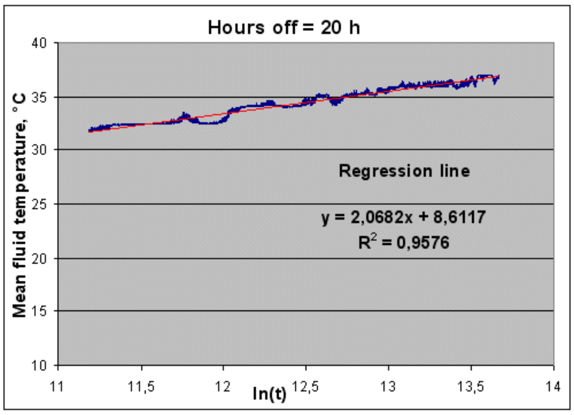

Figure 11: Logarithmic time plot of the mean temperature for the entire test length in January 2009 (excluding the first 20 hours).

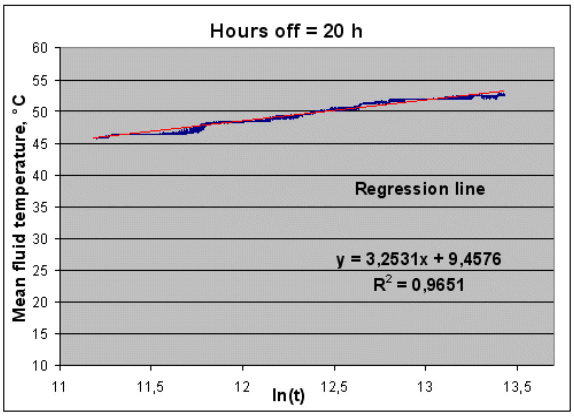

Figure 12: Logarithmic time plot of the mean temperature for the entire test length in March 2009 (excluding the first 20 hours).

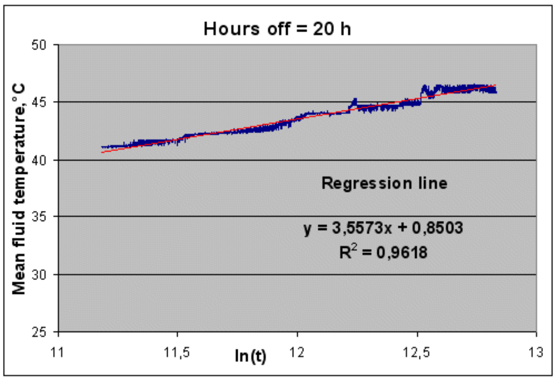

Figure 13: Logarithmic time plot of the mean temperature for the entire test length in April 2009 (excluding the first 20 hours).

Table 2: Values of λ and R_B during the made Bulgarian TRTs in 2009.

	January	March	April
Ground thermal conductivity λ, W/mK	0.85	0.92	0.87
Borehole thermal resistance R_B, mK/W	0.54	0.60	0.47

4. SIMULATION RESULTS

The Thermal Response Tests were studied by means of the TRNSYS TYPE 557 VERTICAL GROUND HEAT EXCHANGER (Hellström, 1989). This subroutine models a vertical heat exchanger that interacts thermally with the ground. This ground heat exchanger model is most commonly used in ground source heat pump applications. A heat carrier fluid is circulated through the ground heat exchanger and either rejects heat to, or absorbs heat from the ground depending on the temperatures of the heat carrier fluid and the ground. Figure 14 shows one U-tube per borehole; although this subroutine allows the user to have up to 10 U-tubes per borehole. The program assumes that the boreholes are placed uniformly within a cylindrical storage volume of ground. There is convective heat transfer within the pipes, and conductive heat transfer to the storage volume. The temperature in the ground is calculated from three parts: a global solution, a local solution, and a steady-flux solution. The global and local problems are solved with the use of an explicit finite difference method. The steady flux solution is obtained analytically. The temperature is then calculated using superposition methods. The subroutine at the heart of Type557 was written by the Department of Mathematical Physics at the University of Lund, Sweden and is considered to be the state-of-the-art in dynamic simulation of ground heat exchangers.

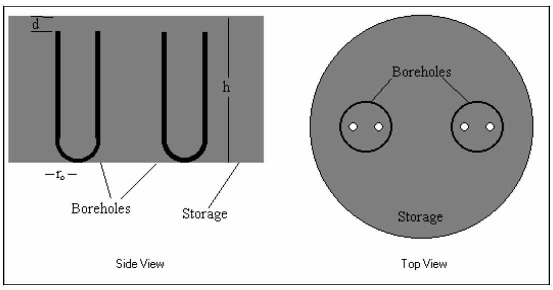

Figure 14: U-Tube Ground Heat Exchanger (taken from the TYPE 557 technical data sheet).

The program was fed with measured data on borehole inlet and outlet fluid temperature as well as ambient temperature. The outlet fluid temperature was exclusively used for comparison with predicted outlet temperature in graphical presentation of results.

Figure 15, 16 and 17 present the results of the TRNSYS simulation. The agreement between experimental and TRNSYS simulated outlet temperature is remarkable.

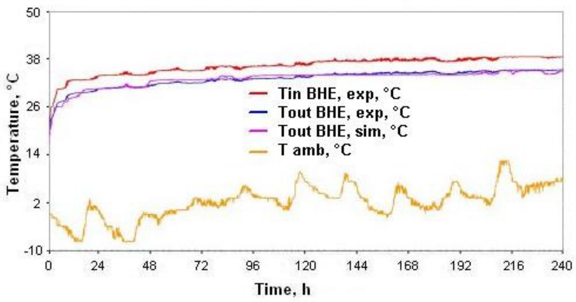

Figure 15: Simulation of the mean fluid temperature of the borehole using TRNSYS TYPE 557 (January 2009).

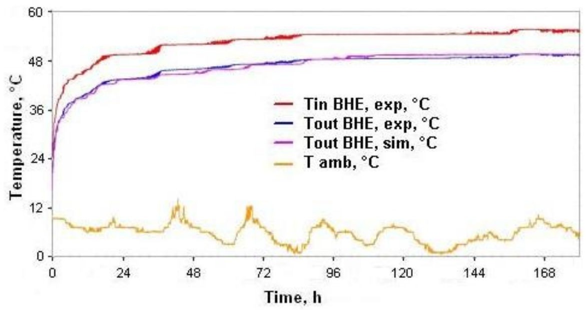

Figure 16: Simulation of the mean fluid temperature of the borehole using TRNSYS TYPE 557 (March 2009).

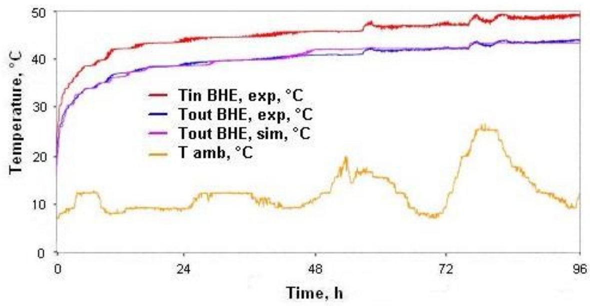

Figure 17: Simulation of the mean fluid temperature of the borehole using TRNSYS TYPE 557 (April 2009).

5. CONCLUSIONS

A mobile test rig to determine the ground thermal properties has been created at the Technical University of Sofia, branch Plovdiv. A borehole heat exchanger has been created in Plovdiv and several TRTs have been implemented in January, March and April 2009. Simulations using TRNSYS Type 557 has been applied as well, in order to understand better some of the features exhibited by thermal behavior of the system. The main conclusions drawn from all these studies are:

1. The designed mobile laboratory combines both options: an investigation installation and lodging. The working installation, which is incorporated in the laboratory, works fully automatically. Unfortunately not all of the parameters can be recorded – the fluid flow rate needs to be written down, too.

2. The pipeline between the borehole and the measuring installation is relatively long (about 7-8 m in total). That is the reason to have so high thermal losses and deviations of the measured temperatures. The pipeline has to be insulated additionally to avoid this disadvantage.

3. The delivered electrical power is unstable – it depends on the disturbances of the electrical net. The regulators have to be rearranged to ensure constant power during the whole time period.

4. The Line Source Model is used as a method for evaluation of the experimental results. It possesses some disadvantages. Several additional evaluation methods have to be used in the future with the purpose to determine more exactly the values of the thermal conductivity and the borehole thermal resistance.

5. The received values of the ground thermal conductivity are between 0.85 and 0.92 W/mK. This is caused by the soil structure (sand) and by the fact that there are many water carrier zones consisting of middle grainy sand and gravel with rubble.

6. The values of the borehole thermal resistance R_B are 0.54, 0.60 and 0.47 mK/W, respectively for the three discussed experiments. These values are more than 5 times higher than the normally used thermal resistance of the boreholes. These relatively high values are caused by the used materials – bentonite and cement. The next perforations, which will be performed in Bulgaria, must have a filling with higher thermal conductivity.

7. It is expected some more perforations to be performed in Bulgaria and their corresponding TRTs to be executed. This will lead to the collection of bigger experimental data base, which can be used afterwards as a basis of a profound analysis of the ground thermal properties.

8. The precise preparation of the installation elements and the realized measurements during the Thermal Response Test lead to better final results.

9. The geological structure may be utterly different even within a very small perimeter – that is why it is necessary to carry out determination of the thermal properties for each single project where earth is treated as a source and/or storage of thermal energy.

10. The successful experiments based on the construction of the described BHE is a very good start for future detailed investigation and study of the soil thermal properties in other Bulgarian towns – it can result to a drawing up of a thermal conductivity cadastre.

11. Some simulations with TRNSYS 16.1 have been performed. The outlet fluid temperature has been compared with the experimentally measured outlet temperature. The comparison is graphically presented. A good coincidence is observed between both outlet temperatures.

ACKNOWLEDGEMENT

This work has been financially supported by the research project No BY-TH-212/ 2006 of the National Science Fund, Ministry of Education and Science, Bulgaria, which is gratefully acknowledged by the author.

REFERENCES

Mogensen P.: Fluid to Duct Wall Heat Transfer in Duct System Heat Storages, *Proceedings* Int. Conference on Subsurface Heat Storage in Theory and Practice, Stockholm, Sweden, (1983), 652-657.

Eklöf, C., and S. Gehlin, S.: TED – A Mobile Equipment for Thermal Response Test, *Master's Thesis* 1996:198E. Luleå University of Technology, Sweden, (1996).

Austin, W.A.: Development of an in-situ system for measuring ground thermal properties. *Master's thesis.* Oklahoma State University, Stillwater, Oklahoma, USA, (1998).

Sanner, B., Reuss, M., Mands, E., and Müller, J.: Thermal Response Test–Experiences in Germany. *Proceedings* of Terrastock 2000, 8th Int. Conference on Thermal Energy Storage, Stuttgart, V. 1, (2000), 177-182.

Paksoy, H., Gurbuz, Z., Turgut, B., Dikici, D. and Evliya, H.: Aquifer thermal storage (ATES) for air-conditioning of a supermarket in Turkey. *Proceedings* of World Renewable Energy Congress-VII 2002, Cologne, Germany, (2002), 10_n66.pdf.

Georgiev A, Ortiz A, Roth P.: Underground thermal energy storage Chilean experience, *Proceedings* of World Renewable Energy Congress-VII 2002, Cologne, Germany, (2002), 05_N39.pdf.

Roth, P., Georgiev, A., Busso, A., Barraza, E. First In-situ Determination of Ground and Borehole Thermal Properties in Latin America, *Renewable Energy*, **29**, (2004), 1947-1963.

Georgiev, A., Busso, A., Roth, P.: Shallow Borehole Heat Exchanger: Response test and Charging - Discharging test with solar collectors, *Renewable Energy,* **31**, (2006), 971-985.

Georgiev, A., Pekov, O., Angelov, A., Popov, R., Urchueguía, J. F., and Witte, H.: First steps of ground accumulation in Bulgaria. *Proceedings* of the World Renewable Energy Congress-IX, Italy, Florence, (2006).

Georgiev, A., S. Barzilova, S. and Kartelov, Y.: Construction of a mobile station for ground thermal properties measurement, *Thermo techniques for the mode of life*, **5/6**, (2007), 26 – 30. (in Bulgarian).

Zervantonakis, I., and Reuss, M.: Quality requirements of a Thermal Response Test. *Proceedings*, ECOSTOCK 06, 10th Int. Conference on Thermal Energy Storage, Stockton, USA, (2006), 435-441.

Gehlin, S.: Thermal Response Test. Method Development and Evaluation, *Doctoral Thesis* 2002:39. Luleå University of Technology, Sweden, (2002).

Kavanaugh, S. P., and Rafferty, K.: Ground-source heat pumps: design of geothermal systems for commercial and institutional buildings, *ASHRAE, Inc*, Atlanta, USA, (1997), 22-31.

Hellstrom G.: Duct ground heat storage model, *Manual for Computer Code*, Department of Mathematical Physics, University of Lund, Sweden (1989).