

COMPARISON OF DESIGN AND OPERATION OF A COMMERCIAL UK GROUND SOURCE HEAT PUMP PROJECT.

Dr. H.J.L. Witte, drs. A.J. van Gelder & drs. M. Serrão
Groenholland BV
Valschermkade 26, 1059 CD, Amsterdam, The Netherlands
E-mail: henk.witte@groenholland.nl; Website: www.groenholland.nl

ABSTRACT

In the autumn of 2000, the British Engineering Council awarded an Environmental Engineering award to the groundsource heatpump project at Commerce way, Croydon Surrey. This largest UK groundsource project is a speculative built industrial building of about 3000 m² with both offices and warehouse facilities. The building, that is occupied by Ascom Hassler Ltd. (a Swiss based IT company), is expected to have an annual cooling load of 100 - 125 MWh and a heating load of 90 - 100 MWh. Peak loads under hot summer conditions are anticipated to reach up to 130 kW.

During the normal life span of a building (25 years) the surplus of heat would lead to higher ground temperatures. This leads to less efficient heat pump operation and may result in insufficient capacity during cooling peak demands. As a solution a hybrid system, incorporating a dry-cooler, was developed. The principal idea was to use the dry-cooler to store cold in the wellfield during early spring, when the required summer peak load cool can be generated very efficiently and cheaply.

The operation and efficiency of the wellfield, the installed heat pump system and dry-cooler is controlled and monitored under a Building Management System (BMS). The results of the first year of operation of the system are presented. Using the monitoring data an evaluation of the original design can be made.

INTRODUCTION

During the period 1998-2001 we have found that closed loop, low temperature geothermal groundsource systems, used for both heating and cooling, are attractive for smaller and medium sized commercial and public buildings (25-500 kW peakloads) in the top-middle and higher market segments. The attractiveness of the groundsource system lies in the low running cost, low maintenance, emission reductions, small plant room and lack of external plant, absence of sound emissions and of course the marketable sustainable "green image". This potential of groundsource is recognised by high-end real estate developers and the more progressive architects and consultants.

The design of a robust and efficient geothermal energy system involves predicting the energy demands of the building and thermal response of a substantial ground volume over long periods in the future, usually on the order of 25 years. These predictions of thermal response involve many assumptions concerning design parameters. Although many important parameters can be measured or estimated with a high degree of confidence, for larger projects a monitoring programme is considered as an essential part of the final project quality.

In the Croydon project, the largest UK groundsource project to date, the client (AXA Sunlife) opted for a low temperature geothermal energy system as the capital cost were only slightly higher than for traditional HVAC systems (VRV, four pipe fan coils). Furthermore plantroom size is minimised and an unattractive and noisy outside plant is done away with. From the tenants perspective the system is an obvious choice because of the very long life expectancy and minimal maintenance, the lower running cost and the flexibility of water based system.

The groundsource heatexchanger is made up of 30 boreholes drilled to a depth of 100 meters into the underlying chalk formations. The wellfield area, of about 1000 m², is utilised as a parking facility. The operation and efficiency of the wellfield and the installed heat pump system is controlled and monitored under a Building Management System (BMS). The data collected with this system includes, amongst others, the outside air temperature, ground-heatexchanger flow and return temperatures and ground-temperatures at two

locations in the wellfield at depths of about 15 meters below surface.

With the information of the first year of operation we will present a preliminary evaluation of the operation of the system, with special attention to a comparison with the original design of the system.

GEOHERMAL ENERGY

A geothermal energy system uses the ground as a heat-source or heat-sink, depending on whether the system is used in heating or cooling mode. The ground is principally suited for low temperature energy exchange: the usual operating temperature bandwidth is between $-5\text{ }^{\circ}\text{C}$ and $40\text{ }^{\circ}\text{C}$ (not taking into account high temperature energy stores). Different systems for exchanging energy with the ground are in use, such as direct use of groundwater, closed-loop ground heatexchangers or direct expansion. Here, only closed-loop heatexchangers are considered.

A heatpump transfers this low thermal energy to high thermal energy, with a high efficiency. For every kilowatt of electrical energy used to drive the compressor (and pumps) a number of kilowatts of heat or cool are generated. The efficiency of a heatpump is expressed as its COP, the ratio between the electrical power consumption and thermal energy generated. Modern heatpumps have COP's between 4 – 5 in heating mode and between 3.5 and 4 in cooling mode.

The goal of a design of a geothermal heat exchanger is to maintain a specified bandwidth of temperatures in the groundloop heatexchanger at which the heatpump may operate efficiently. The main issue with such a design is that we need to consider both the local process, occurring in and around the borehole, and the global process of the whole ground volume that is thermally influenced and its interaction with the boundaries. Especially for the local process, the earth is usually not capable of transporting the thermal energy rapidly enough to the heatexchanger. This means that the ground temperature around the heatexchanger tends to increase or decrease as long as the heatpump is in operation. For the global process, in a system utilising the ground for both cooling and heating there may either be a balance or imbalance in the total energy. In the first case the ground temperature will tend to show a yearly fluctuation around a mean value, in phase with the energy demand. In the latter case these fluctuations are also present, but the average ground temperature will tend to increase or decrease with time. The interactions with the boundaries include energy exchange due to conduction, groundwater flow, geothermal gradient and interactions at the surface.

In such a system there is a direct and dynamic coupling between the energy supplier (the ground) and the energy user (the building). Not only are the loads on the ground system determining the thermal response of the ground, the actual power generated will in turn depend on the source temperature. The design therefore needs to specify accurately the total seasonal loads, that determine the global response, as well as the peak load

demands and duration. These peakloads are superposed on the seasonal response of the system.

For a successful design detailed knowledge of the building loads as well as detailed geological and geohydrological knowledge are necessary. Moreover, the actual engineering of the boreholes and groundloop heatexchangers, material choice etc. all have to be considered carefully.

We will not consider the building load design in any detail. For the ground source design the principal input parameters are the seasonal loads and peak loads and duration. Several methods and models exist to calculate the energy requirements of a building (e.g. [1,2]). Main uncertainties are the climatic circumstances and the variations therein and the actual building use during its lifespan.

With respect to heat conduction in the ground the most important parameter is the thermal diffusivity of the ground, the ratio between the ground thermal conductivity and the volumetric heat capacity. Especially the thermal conductivity is difficult to establish with sufficient accuracy [3,4]. Although each soil type has a specific conductivity, the conductivity depends not only on the material itself but to a large extent on factors such as packing, pore volume and water content. Moreover, the sequence of soil types and presence of ground water or ground water flow in the different formations in the soil profile will affect the overall conductivity and relative contribution to the thermal forcing of the different depth intervals. As the soil conductivity is so important, several methods have been developed to directly measure the overall soil conductivity [5,6,7].

For the local process especially the borehole resistance is important. The borehole resistance [8] depends mainly on the loop type and material, loop dimensions, circulation fluid properties, temperature of the process, borehole engineering.

Furthermore the far field temperature in the ground and geothermal gradient needs to be measured.

THE CROYDON PROJECT

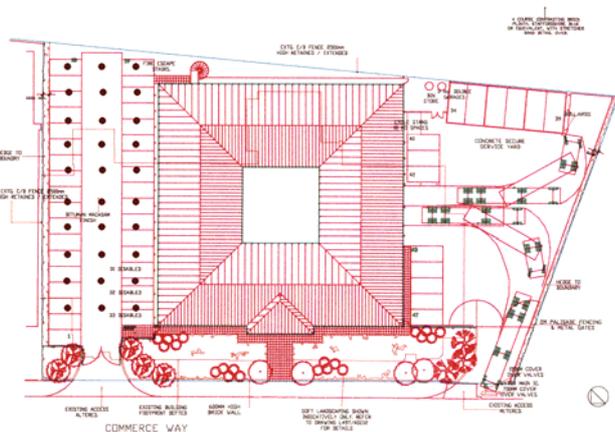
The Croydon building (figure 1) is a three story office building located at the Commerce way, Croydon Surrey (UK). Total surface area is about 3000 m^2 , with both offices and warehouse facilities. In the offices 85 Geothermic™ water-to-air heatpumps have been installed. The warehouse, of approximately 690 m^2 is heated or cooled using a low temperature underfloor heating, with to a water-to-water heatpump (26 kW). Total installed heating capacity is 225 kW, maximum cooling capacity installed is 285 kW.

Figure 1 – The Croydon building, Commerce way, Croydon Surrey (UK).



As all Geothermic™ heatpumps are connected in parallel to the pipework supplying the source and return water, therefore simultaneous cooling and heating loads are balanced in the building. During periods with a net cooling or net heating demand the ground heatexchanger (figure 2) supplies the additional heat or cool. The groundloop heatexchanger consists of thirty U-loops (40 mm. HDPE PN16) installed in 100 meter deep boreholes, with a distance between the boreholes of about 5 meters. Boreholes were fully grouted with a bentonite/cement mixture.

Figure 2 – Location map showing the building and parkinglot with positions of the installed groundloop heatexchangers and observation wells.



Geology of the site has been described on the basis of three borelogs of the Geological Survey [9] in the vicinity and on the basis of the borelogs made during the drilling of a test borehole. Main geological sequence is: a surface layer (1.5 m), Thanet Sands (1.5 - 13 m), Upper Chalk (13 - 80 m) and Middle Chalk formation (80 m -).

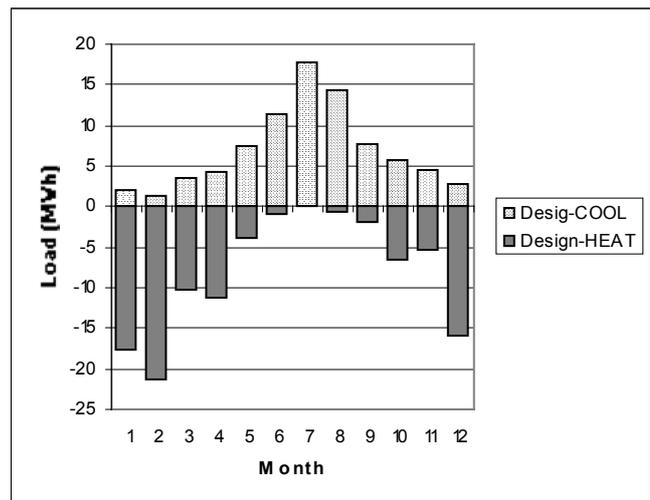
Groundwater levels are at about -2 m with respect to the surface level. Groundwater flow is in a north to northwesterly direction with an estimated darcy flow of 20 - 25 m/year in the chalk formations and of between 75 - 100 m/year in the Thanet sands.

DESIGN OF THE GROUNDLOOP HEAT-EXCHANGER

Critical design parameters are the ground thermal conductivity, far field temperature and energy loads. The thermal ground parameters were measured on site with an In Situ Thermal Response Test [4]. Results of this test showed a thermal conductivity of 2.2 W/mK, an average far field temperature of 11.6 °C and a geothermal gradient below 40 meters of approximately 0.009 °C/m.

Building loads were calculated by EDSL (Environmental Design Solutions, Milton Keynes, UK) using a three-dimensional dynamic model. Total yearly loads have been calculated as 100 MWh/year (average summer) up to 120 MWh/year (warm summer) cooling and about 95 MWh/year heating. Taking into account the average efficiency of the heatpumps, this translates to a load on the ground of 65 MWh heating and between 120 and 145 MWh cooling. Seasonal distribution of the average loads is depicted in figure 3.

Figure 3 – Design loads building, monthly heating and cooling loads.

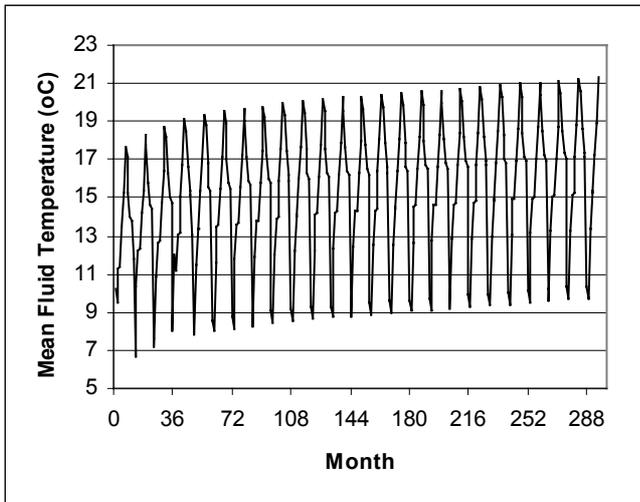


Evident from this figure is that even in winter some cooling occurs and that only in July no heating demand is present. The total net load on the ground during an average year is 55 MWh annual heat rejection.

Average monthly fluid temperatures (figure 4) in the groundloop heatexchanger were modelled using Earth Energy Designer (EED, [10]). Clearly average temperatures in the ground tend to increase, from about 13.5 °C in the first year to about 17 °C in the twenty-fifth year. The installed Geothermic™ heatpumps can operate efficiently within a temperature bandwidth of 0 °C - 30 °C, and design temperatures were selected accordingly. The limiting design temperature is the temperature during cooling peakloads, with a 30 °C limit.

Superposing a 136 kW cooling peakload on the modelled average medium temperatures a 7 hour peakload can be accommodated in year 5, in year 10 only 5 hours and in year 25 just 2 hours can be accommodated.

Figure 4 – Average modelled monthly fluid temperatures in the groundloop heatexchanger, for 25 years.



Instead of increasing the size of the groundloop-heatexchanger a drycooler was incorporated in the system. Depending on the operating temperatures (source and sink) a drycooler can very efficiently reject heat (COP of 50). The principal idea is therefore to use the drycooler to store cold in the ground during times when this can be done at high efficiency (spring and at night). Such a hybrid system allows more flexibility in building use (adding or removing heatpumps), and makes an active management of the ground temperatures possible. Also, a drycooler is a relatively cost effective way of rejecting heat.

MONITORING RESULTS

The building was commissioned in September 2000. The monitoring data from September 2000 up to November 2001 is now available. During this period the drycooler has not been used, energy demands presented therefore only refer to the building.

Outside air temperatures are presented in figure 5, together with the weather data (average minimum and maximum daily temperatures, climate station london Weather Centre - High Holborne) used in the building design. Temperatures have, until now, been on average with the exception of the summer period 2001, where higher maximum daily temperatures than average prevailed.

Design limits of 0 °C during heating and 30 °C during cooling have not been exceeded. Minimum heatpump source temperature (groundloop heatexchanger return temperature) recorded is 5.6 °C, maximum heatpump source temperature was 25.6 °C.

From the monitored ground-flow and return temperatures the actual building loads have been calculated (figure 6), taking into account the flowrates, medium properties and missing data. For the period September 2000 to October 2001 total energy extraction from the ground was 75 MWh, total energy rejection to the ground amounted to 160 MWh. The design loads on the ground were 65 MWh heating and 120 MWh cooling load. Heating loads are therefore quite close to

the design load, while cooling loads are 30% higher. Average peakloads during heating in December were 80 – 95 kW, in august cooling peakloads were on average between 70 – 100 kW. Highest peakloads recorded during the monitoring period were 135 kW cooling peakload (July) and 160 kW heating peakload (March).

Figure 5 – Average monthly day-minimum, day-maximum and day-average temperatures at Croydon and average temperature range of the climate station High Holborne london Weather Centre - (design temperatures).

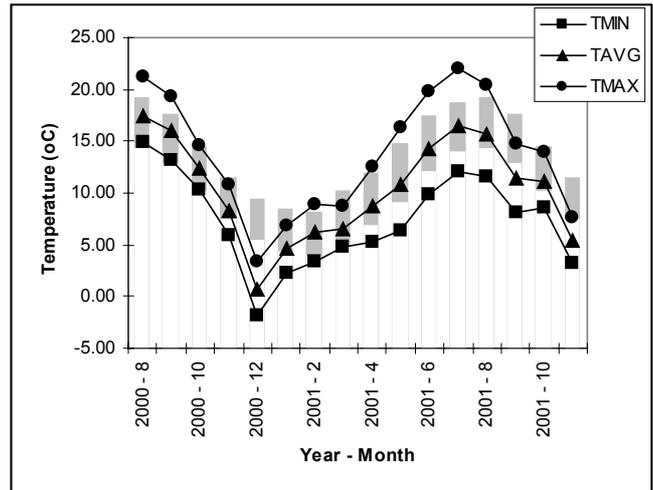
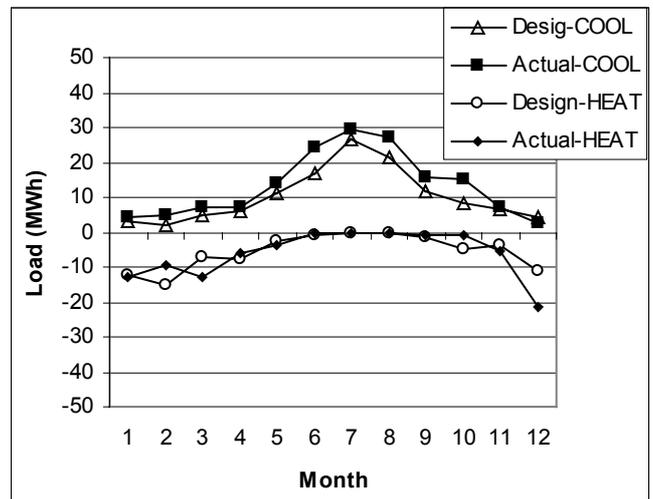


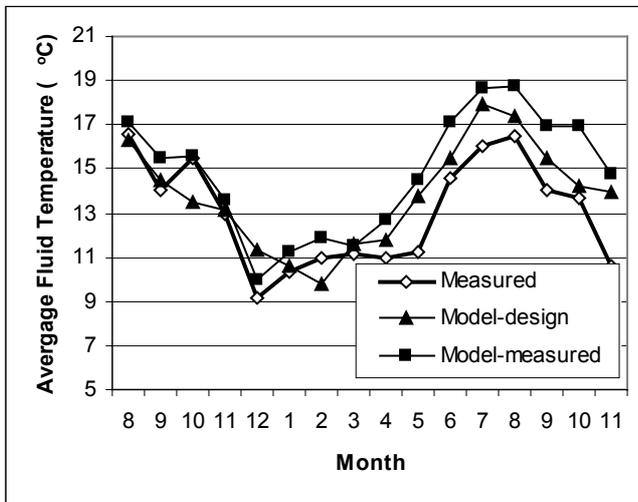
Figure 6 – Design heating and cooling loads and measured heating and cooling loads.



The measured energy demand is in reasonable agreement with the design demands for the winter period. The cooling load is much higher than anticipated, even when taking into account that the summer of 2001 was relatively warm (10% higher).

The original design of the ground heatexchanger temperatures has been re-calculated using the measured loads. Results of these calculations are presented in figure 7, together with the measured average fluid temperature.

Figure 7 – Measured average monthly fluid temperatures and modelled average monthly fluid temperatures (design load and measured load).



Both models, that is to say the model using the original design loads and the model with the actual measured loads, correspond rather well with the measured fluid temperatures during the heating season. As expected, the model with the measured loads fits closer than the original design due to differences in load distribution. Measured fluid temperatures during summer (heat rejection) are significantly lower however, up to almost 3 °C. This may be an indication of an effect of the horizontal shallow depth loops (not accounted for in the design software), or of groundwater flow providing additional cooling in the ground heatexchanger due to mass transport.

For a number of selected days in December and august a comparison has been made between measured and calculated peakload response. Calculated peakload responses (figure 8 & 9) fitted well after adjusting for the initial actual fluid temperature and the borehole thermal resistance (about 20% lower fluid-to-ground resistance than calculated). Differences in the calculated and measured curves are mainly due to the fact that during the actual peakloads the load is not constant but may vary quite considerably and rapidly.

The total system performance can be estimated with the monitoring data. At present only a rough estimate is possible, because the information concerning the underfloor heating has not been included yet. The first estimate of the actual system performance shows a COP of 3 in heating mode and of 3.4 in cooling mode.

CONCLUSIONS

The first analysis of the monitoring data from the closed loop groundsource project at Croydon (UK) show first of all that considerable savings have been made. A cumulative total of the first 15 months of operation are 80 MWh heating and 240 MWh of cooling that has been provided by the groundsource.

The original building design predicted accurately the heating loads observed so far. The cooling loads observed are about 10% higher than estimated. Partly this may be attributed to the fact that the summer of

2001 was relatively warm, with an additional effect of losses due to the employed pumping scheme.

Figure 8 – Peakload response during a number of winter days (average peakload in kW in brackets) and calculated peakload response.

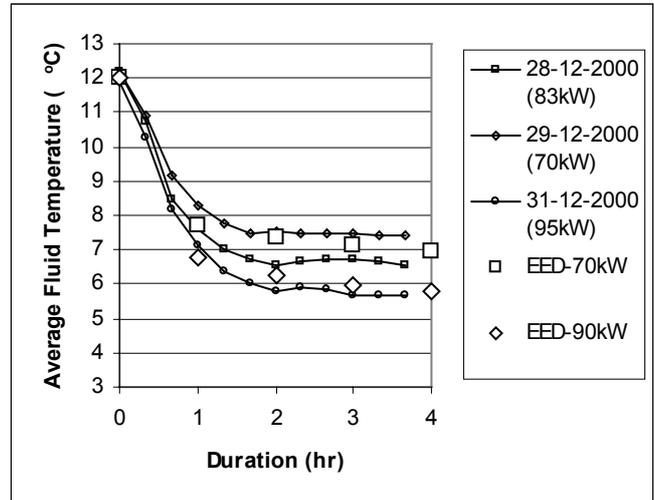
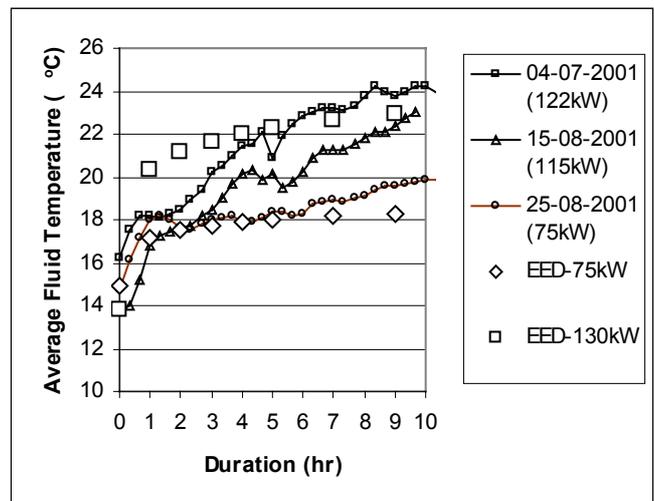


Figure 9 – Peakload response during a number of summer days (average peakload in kW in brackets) and calculated peakload response.



Modelled groundloop temperatures correspond well with observed temperatures during the heating season. Fluid temperatures during the summer season are significantly lower than expected. The most probable cause is the additional cooling provided by groundwater flow, not taken into account in the calculations. Also, peakload characteristics could only be reproduced by assuming a lower borehole thermal resistance. This may indicate, especially with cooling peakloads, an effect of forced convection around the borehole. Both phenomena have been observed in several In Situ Geothermal Response Tests and in a controlled experiment with artificially generated groundwaterflow [11].

A more detailed analysis of the monitoring data of Croydon is presently being carried out. This analysis will include an detailed evaluation of the pumping

scheme employed in the building, and will include a separate analysis of the warehouse (with a separate water-to-water heatpump and underfloor heating).

Proceedings Workshop "Geothermische Response Tests", Lausanne.

ACKNOWLEDGMENTS

The authors would like to thank Peter Heaton for his help with several practical matters. Ascom Hassler Ltd. is thanked for their permission to monitor the Croydon building and present the results.

REFERENCES

- [1] ASHRAE (1998). ASHRAE Handbook, Fundamentals. American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA.
- [2] BLAST (1986). Building loads and system thermodynamics. University of Illinois, Urbana-Champaign.
- [3] Austin, W.A. (2000). Development of an In-Situ System and Analysis Procedure for Measuring Ground Thermal Properties. ASHRAE Transactions 106.
- [4] Van Gelder, A.J., Witte, H.J.L., Kalma, S., Snijders, A. and R.G.A. Wennekes (1999). In-situ Messungen der thermische Eigenschaften des Untergrunds durch Wärmeentzug. IN: T. Hitziger (Ed): OPET Seminar "Erdgekoppelte Wärmepumpen zum heizen und Klimatisieren von Gebäuden. 109 pp.
- [5] Eklöf, C. and S. Gehlin (1996). TED – A mobile equipment for Thermal Response Tests. Master's Thesis 1996: 198E. Lulea University of Technology, Sweden.
- [6] Austin, W.A. (1998). Development of an In-Situ System for Measuring Ground Thermal Properties. MSc. Thesis, Oklahoma State University, USA. 164 pp.
- [7] Witte, H.J.L., A.J. van Gelder, J.D. Spitler. (2002). In Situ Measurement of Ground Thermal Conductivity: The Dutch Perspective. Accepted for publication in the ASHRAE Transactions, Vol. 108., No. 1.
- [8] Hellström, G. 1991. Ground heat storage, Thermal analysis of duct storage systems: Part I. University of Lund, Department of Mathematical Physics. Lund, Sweden.
- [9] British Geological Survey. (1997). The physical properties of major aquifers in England and Wales. Hydrogeology Group, Technical report WD/97/34.
- [10] Eskilson, P., Hellström, G., Claesson, J., Blomberg, T. & Sanner, B. (2000). Earth Energy Designer.
- [11] Witte, H.J.L. (2001). Geothermal Response Tests with Heat Extraction and Heat Injection: Examples of Application in Research and Design of Geothermal Ground Heat Exchangers.