Geothermal Response Tests: the Design and Engineering of Geothermal Energy Systems

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1. 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. Often the application of a geothermal energy system is considered for use in prestigious buildings, hence the demand for professional services and quality in the field of groundsource design and implementation.

Figure 1. Some project impressions, drilling at St. Lukes (top left), trenching at Natures World (top right), Auger drilling in the Netherlands (bottom left) and completed wellfield at Croydon (bottom right).

Groenholland BV feels that the use of closed loop geothermal groundsource systems for both heating/cooling has a strong perspective in commercial applications, provided that testing, design and final quality are of a professional level. Furthermore it is essential that the groundsource systems are applied to suitable projects, where sustainability and the amenities of groundsource are fully exploited. Matching up groundsource and ideal projects will emphasise the groundsource benefits and will pave the way for successful future projects.

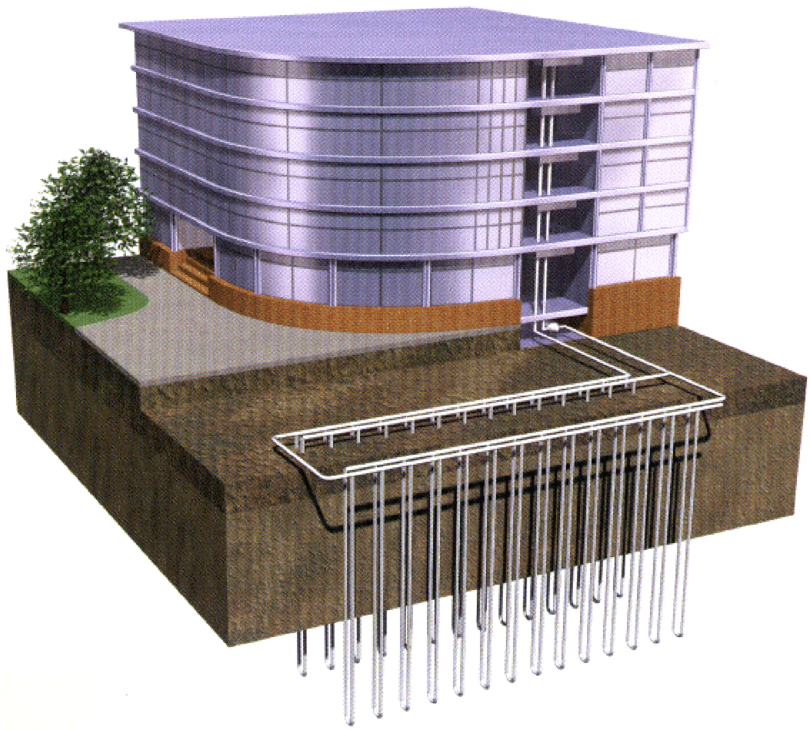
2. MARKET REQUIREMENTS

In building projects responsibilities of the involved parties are well defined in contracts: the client, the architect, structural engineers, building services engineers, contractors, sub-contractors, suppliers etc.

Not only is the scope of the work defined, but also the financial consequences, personal qualifications, time planning, health & safety issues, insurance requirements, warranties, taxation etc.

Groundsource has the potential to fit in with a large number of projects, providing the involved consultants and engineers can deliver a product that is recognised as being reliable and professional. This implies that the quality of design and implementation are a basic requirement for most jobs. If the groundsource community does not develop the required skills, the product will remain in the realms of hobby'ism and at best an academic pursuit. Consequentially groundsource will then be viewed as a potential liability to a project and the project funders will not regard it as a serious alternative to traditional heating and cooling.

Figure 2. Artist impression of groudsource aplication.

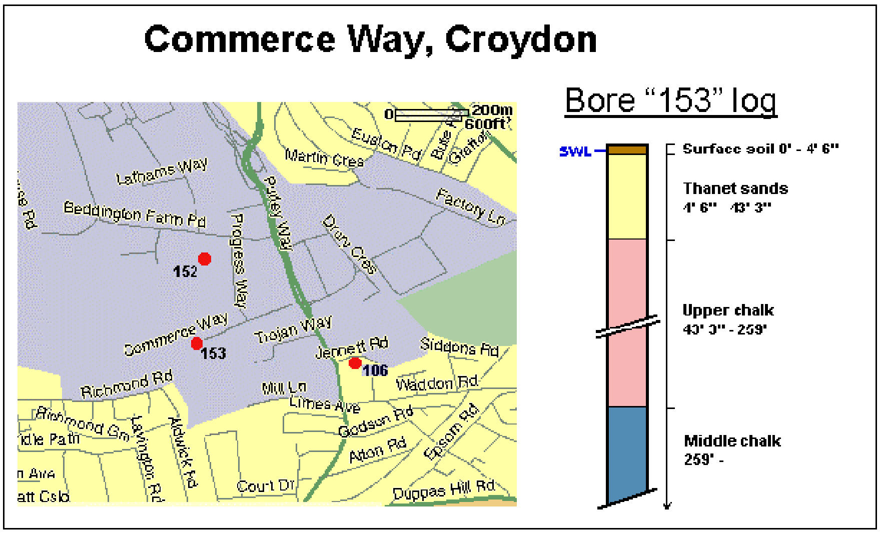


3. BASIS REQUIREMENTS FOR DESIGN

Provided a good quality energy profile (annual heating/cooling loads and peak heating and cooling demands) of the building is available through the building services consultant, a basic design of the geothermal groundsource system can be made using models like EED or GLHEWIN if the following information is available:

- Location and size of building site, area for groundsource application;
- Indication of local geology;
- Maximum (cooling) and minimum (heating) operating temperature requirements from the perspective of installed (heatpump) equipment; Antifreeze requirement.
- U-loop installation time, borehole obstructions;
- Tap water/ground water quality (EC, pH, etc.);
- Geothermal temperature profile (pre- and post-testing);
- Geothermal parameters (thermal conductivity, heat capacity, borehole resistance);
- Maximum or minimum medium temperature development under testing;
- Antifreeze parameters (type, concentration, heat capacity etc.);

Figure 4. Example of a site map and geological profile.



It is obvious that the quality of the initial design depends on the ability to provide reasonable estimates for geothermal parameters such as thermal conductivity, heatcapacity and borehole resistance. The results of the initial design, including a first cost approximation, will indicate whether the use of groundsource is a realistic venture for the specific project.
If, after this stage, the project is regarded as feasible and it is of sufficient size (> 25-40 kW peakload), a full site investigation, including a geothermal response test, should be considered. For smaller projects the cost of an extensive site investigation do not weigh up against the cost of a responsible "over design".

Figure 5. Example of a building load profile: monthly heating and cooling loads.

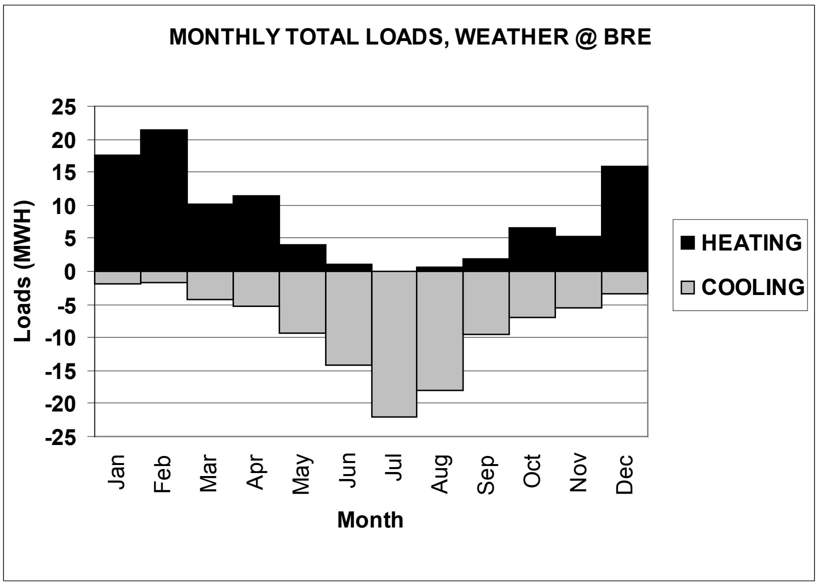
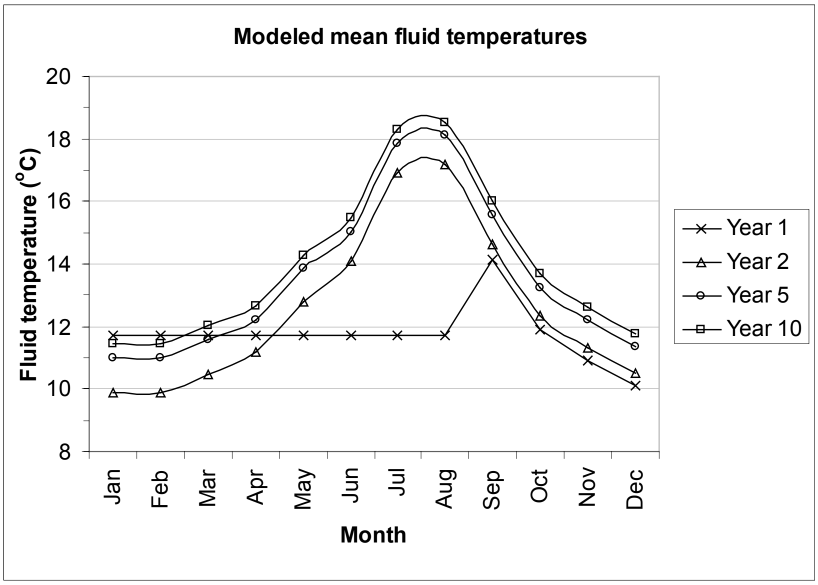


Figure 6. Example of basic design: seasonal fluid temperatures for a 10 year operation period.



4 SITE INVESTIGATION AND GEOTHERMAL TESTING

A site investigation and geothermal testing is a separate phase in the design of a geothermal wellfield. In this phase however it is relevant to acquire information relevant to design and implementation:

Site information

- Site location; address, postal code, altitude and X- and Y-coordinates;
- Area available (m^2) for heatexchanger and trenching;
- Entry point of pipework into building;
- Ground texture, ground/groundwater quality, soil contamination, mining etc.;
- Groundwater table (max/min);
- Underground infrastructure (telecom, gas, water, electricity);
- Available space for equipment, workwater, power, drilling spoils;
- Any other environmental concerns;

Project information

- Required permits for installation of heatexchanger and test drilling;
- Starting date, number of workable days;
- Health & safety regulations, required insurance coverage, CAR;
- 220V/110V, requirements for training and machinery certificates;
- Working hours, sound emissions;
- Method statement, responsibilities for sub-contractors;
- Available reports (environmental, geo-technical etc.)

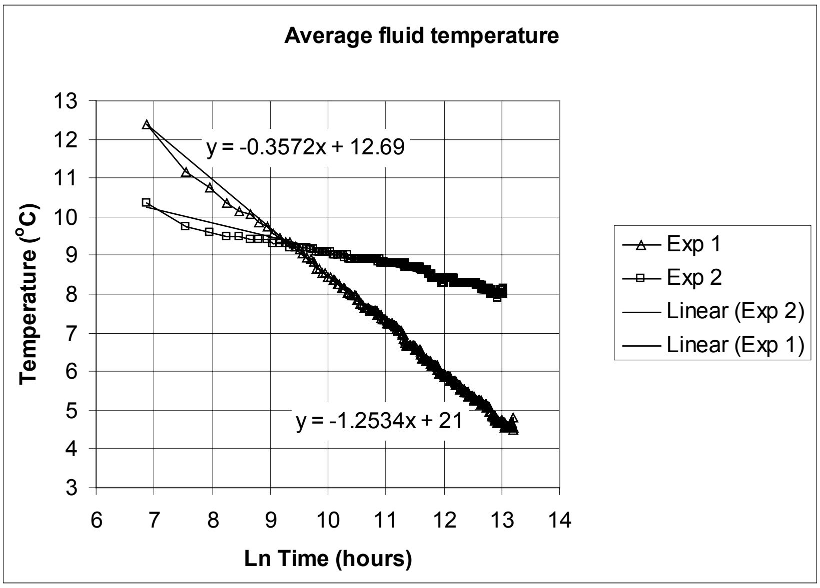
Geology, geohydrology, geochemistry

- Regional and local geology (National Geological Survey);
- Local borehole and well records/permits;
- Formation groundwater parameters (transmissivity, pore volume, pressure head etc.)
- Groundwater quality of aquifers (salt/sweet, methane, EC, pH);
- Geomorphology; stability of slopes, surface and subsurface drainage;

Test drilling and geothermal testing

- Site access, terrain quality, drainage;
- Borehole log, drilling technique (cased/uncased: water, air, mud, foam);
- Drilling time, wear on equipment (bits);
- Loss of circulation, volume and composition of grout;

Figure 7. Results from a geothermal respons test.



5. SITE INVESTIGATION REPORT

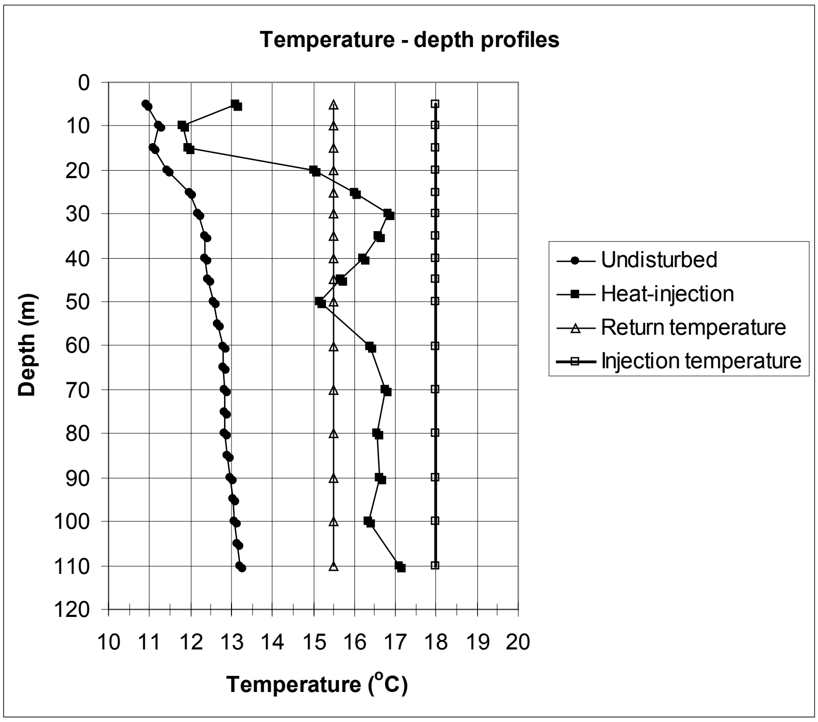
The report of the site investigation should contain all relevant information mentioned in the previous section "geothermal site investigation and testing" including maps and sections (to scale) of the site and geology. Soil and groundwater quality with regard to personal safety and health issues should be identified.

The geohydrological and geochemical chapter should at least give an indication of regional pressure heads (horizontal/vertical), Darcian and effective groundwaterflow (meter/year). The geochemistry of the groundwater should indicate whether any swelling problems with bentonite clays in the borehole grout should be anticipated and whether this can be remediated by additives. Geological/geohydrological information should be compared with the borehole log and other drilling information and should be evaluated. The borehole log and other drilling/grouting information should be presented fully.

For information on geothermal testing we refer to the presentation by Dr. H. Witte of Groenholland BV "Geothermal response test with heat extraction and heat injection". The choice between a heating (heat extraction) or a cooling experiment (heat injection) is project dependent and is made in consultation with the mechanical consultant. Methodology, experimental settings and data gathered from the experiments are presented and the reliability and quality of the data needs to be evaluated.

Recently Groenholland BV have installed a separate observation well (closed PE pipe) in the borehole in which the geothermal test is conducted. This pipe is used for making a depth/temperature profile and it is used to check the active depth of the heatexchanger and the geothermal response from different sections of the borehole. In this way an indication of the relative contribution of different strata to the overall soil thermal conductivity can be evaluated.

Figure 8. Geothermal profile pre- and post-test. Indicating the natural geothermal profile, length of heatexchanger contribution and layer-specific contribution.



Apart from the factual data gathered during investigation, drilling and testing, the report should conclude with indications of energy extraction/injection rates achievable under realistic building operation. If required a site specific optimum drilling technique and depth can be advised.

6 GEOTHERMAL WELLFIELD DESIGN

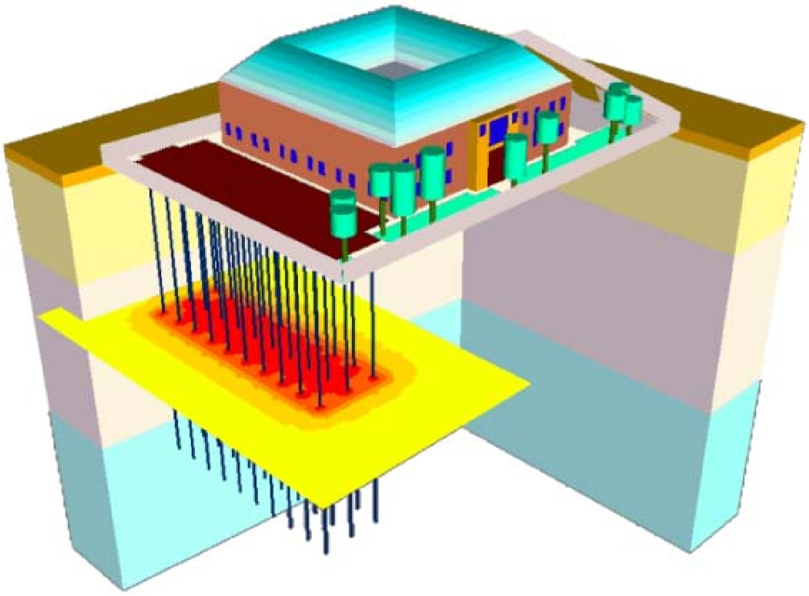
In the wellfield design the site information, the building energy profile and the control/operating strategy (operating temperatures, pumps, antifreeze concentration, running hours etc.) are integrated into a full design. Wellfield design is initially a compromise between funding cost of the wellfield and efficient operating temperatures.

The primary issue is to define an acceptable temperature bandwidth for 80-90% of the running hours of the system. In this way a basic efficiency (high COP) for the overall system is guaranteed. Coping with limited duration peak loads (heating & cooling) can be done under less then efficient running conditions, providing required building load specifications are met.

Fine tuning of the system, for instance establishing "free cooling" kWh in pre- and post-summer periods at very high COP's, or seasonal trimming of medium temperatures through an external heatexchanger, is part of further system optimisation.

Running cost of a system not only depend on the electrical input in compressors, but to a large extent on pumping cost. Like thermal design, the hydraulic design should in general be aimed at achieving low head losses under average and frequently occurring load (or part loads in multi-compressor heatpumps) conditions. Higher head losses under more extreme conditions (peak load) are likely to occur only a limited number of hours per year and are of less importance for the total electricity consumption. Turbulent flow and consequently better heat transfer, might even make sense under peak conditions. Do not forget however, that electrical input into the system benefits heat extraction, but is detrimental to cooling operation.

Figure 9. 3D impression of office building, heat exchanger wellfield and geology. Also shown is the average july ground temperature field, after 25 years of operation.



Wellfield design should not only consider the thermal and hydraulic properties, but should also address issues like the quality of used materials, environmental risk, preferred drilling technique, grout composition, positioning of headers, welding, flushing and pressure testing, trenching and backfilling. Furthermore it should be very clear were the demarcation between wellfield/installation is defined.

If a warranty on the thermal operation of the wellfield is required, this is preferably done on the basis of the original design specifications and the climatic conditions (both average and extreme climatic conditions) on which the design loads are based. Similar to the site test report a fault analyses should be included, giving both expected averages and variance.

7 IMPLEMENTATION AND COMMISSIONING

After a tender procedure the implementation phase is reached in which timing is often the key element, as the installation of the wellfield has to fit in with the builders time planning and activities. In pre-work meetings, dates will be set and a "method statement" dealing with health & safety, equipment specification, training certificates etc. will have to be provided.

Quality of used materials and techniques is important. MDPE heatexchangers and components are available from recognised sources and are fabricated to international standards. Minimum pressure class in our opinion is PN16 for vertical pipework and PN10 in horizontal sections. Welding machinery should be able to match outdoor conditions and perform high quality work.

Figure 10. Implementation: Drilling and trenching.

The role of the geothermal consultant/engineer is mainly to facilitate drilling and in conjunction with drillers come up with the most efficient drilling technique. Further there is need for an intermediate between the building contractors site management and the drillers. Most problems are very practical (need for water, removal of drill cuttings etc.), however the impression the drilling, which often is a messy business, makes is very important for the overall acceptance for groundsource. Apart from managing practical problems, the main issue for the consultant is surveillance of the quality as specified in the design. Key issues are:

- Drilling depth, borehole diameter, spacing;
- Installation of heatexchangers, grout composition/borehole filling;
- Compliance with actual health & safety issues;
- Work progress (time planning) and site cleanliness;
- Liasing with site management.

After drilling and heatexchanger installation the individual heatexchangers should be flushed with clean water and, if required, pressure tested. Following this, welding of the heatexchangers and the horizontal pipework takes place. We have found that the use of electrical welding sockets give good results even in very poor external operating conditions, providing pipework and sockets are well prepared and dry. If any stress occurs on joints, we advise the use of braces. Before any work takes place in trenches make sure safety regulations are met and that the trench bottom is covered in sand to avoid damage to pipework.

The role of the consultant and engineer in the phase of horizontal installation is quite critical in regard to the final quality of the product. All welds need to be visually inspected and extreme stresses on bends should be avoided. In installing pipework a decision should be made on flow/return sides of the system. If more heatexchangers are combined into one set, a parallel setup (reverse header) can be used.

After the completion of the heatexchanger wellfield (or separate components) it should be water flushed and purged of debris/air and pressure tested. While pressure testing the tested section should be visually inspected. A site plan with the exact positions of the individual boreholes and horizontal pipe runs should be made. It is advisable to place marker tape in the trenches over the horizontal pipework conduits after they have been halfway backfilled with sand. When the individual flow and return pipes are connected to the manifold the flows over the different ground heatexchanger sets have to be hydraulically balanced.

Commissioning of the system and handover to the client or their representative is essential for future liability. It is advised to supply the client with a short report regarding the implementation of the system and a site map with the positions of boreholes and trenching.

Figure 11. Comissioning (plantroom with heatpump and manifolds): demarcation of the groundsource at the manifold.

8 CONCLUDING REMARKS

From numerous presentations and discussions, we conclude that closed loop groundsource systems appeal as well to developers and professionals in the building industry as to their clients. Proof of this we find in the number of enquiries and actual projects.

Regarded as a sustainable energy system, groundsource not only projects an esteemed "green image", it also is a very practical two-sided system offering both heating and cooling operation. If well designed and implemented, it offers a very long life expectancy, is versatile in servicing different end use installations (heatpumps, chillers, cooled ceilings, fancoils), offers running cost savings and requires little or no maintenance.

Apart from the appreciation for groundsource, the majority of building consultants and engineers still consider it as a new and relatively unproven technology. If the market for groundsource projects is to grow it is necessary to provide quality services that fit in with the building industry requirements.

We suggest that, a site investigation, possibly geothermal testing and at a later stage the design and implementation of a geothermal wellfield are considered for all but the smallest projects. Not only will this improve the confidence in design and efficiency of groundsource systems, it will also bring the credibility to win future projects.

Figure 12. Site map with location individual heat exchangers.