GEOENERGY RESEARCH AND ITS UTILIZATION
IN FINLAND

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Geoenergy is energy that is stored in the ground or water and used to heat and cool buildings. Most shallow geoenergy originates from solar radiation, and in Finland it is utilized via heat pumps. Geoenergy from the bedrock is utilized by means of borehole heat exchangers (BHE). The thermal properties of a BHE and the bedrock can be determined using a thermal response test (TRT). The Geological Survey of Finland (GTK) has its own TRT rig built in 2008. TRT results are used for case-specific modelling of BHE systems, which includes optimizing the number, depth and location of the BHEs. Careful modelling ensures that a BHE system is sustainable and the possible temperature changes in the geoenergy source are moderate. BHE systems can be observed in situ using the distributed temperature sensing (DTS) method. A DTS device measures temperatures via a fibre optic cable and is used, for instance, to determine the temperature profile of the bedrock.

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GEOENERGY IN FINLAND

Geoenergy is energy that is stored in soil, bedrock, groundwater, sediment layers or lake, river or sea water. Geoenergy in Finnish conditions is mostly shallow geoenergy stored in the first hundred metres of the Earth’s surface. Most of this shallow geoenergy originates from solar radiation and a smaller proportion consists of geothermal energy from the inner parts of the Earth’s crust. Geoenergy is used to heat and cool buildings and utilized by means of heat pumps in areas of low enthalpy (cool crust), such as in Finland. The seasonal performance factor (SPF) of a heat pump is usually about 3, which means that 2/3 of the energy comes from the Earth, free of charge. The rest comes from electricity required to run the pump. Geoenergy is a renewable, sustainable and environmentally friendly energy form.

The Geological Survey of Finland (GTK) aims at increasing the utilization and general awareness of geoenergy and its application in Finland. GTK has strongly invested in R&D and technology transfer activities, the development of its own methodology and practices and the promotion of geoenergy together with commercial actors and end-users. The focus is on large-scale commercial projects such as shopping centres, office buildings and logistics centres in cooperation with companies and other leading domestic and international research institutes. Most of the projects are commercial, and the obtained data are therefore confidential.

The total number of ground-source heat pumps (GSHP) and also the number of GSHPs installed per year have rapidly increased in the 2000s, as Figure 1 illustrates. Finland is one of the countries with fastest growing number of heat pumps. The total number of GSHPs installed in Finland by 2008 was approximately 46 000, and about 7 500 new heat pumps were installed in 2008. The annual increase in this sector is approximately 30%. (Suomen Lämpöpumppuyhdistys Sulpu ry., Finnish Heat Pump Association 2009)

Figure 1. Total number of ground source heat pumps in Finland in 2000–2008. (Suomen Lämpöpumppuyhdistys Sulpu ry., Finnish Heat Pump Association 2009)
GEOLOGICAL SETTINGS IN FINLAND REGARDING GEOENERGY

The average heat flow in Finland is 0.037 W/m², which is below the continental average of 0.065 W/m². The geothermal gradient is usually 8–15 K/km. The low gradient is due to the Precambrian geology, with a very thick lithosphere (150–200 km). The climatically controlled annual average ground temperatures range from over 6 °C in southern Finland to less than 2 °C in Northern Lapland (Figure 2). (Kukkonen 2000)

The average thermal conductivity of Finnish rocks is 3.24 W/(m*K) (Peltoniemi 1996). In most rock types, the mean thermal conductivity is 2–4 W/(m*K). Thermal conductivity is controlled by the mineral composition, texture and porosity of the rock and pore filling fluids (Clauser & Huenges 1995).

GTK will compile a national map of the geoenergy potential in Finland, which is affected by factors such as the lithology, depth of soil, groundwater conditions and the thermal conductivity of the bedrock. A national borehole register is also in progress.

THERMAL RESPONSE TEST (TRT)

TRT measurement

The idea of a thermal response test (TRT) is to measure the thermal properties of a borehole in situ. A TRT simulates the behaviour of a borehole heat exchanger (BHE). The TRT equipment heats up the heat carrier fluid at constant power and circulates it through the BHE. When the fluid temperatures in the ingoing and outgoing pipes are measured, the effective thermal conductivity and thermal resistance of the borehole can be determined. These parameters are needed in modelling a BHE system. (Eklöf & Gehlin 1996)

TRT measurements have become increasingly popular since the late 1990s. Nowadays, it is a routine procedure in many countries for designing a large BHE system (Sanner et al. 2005). TRT measurement has become a necessity for modelling a large BHE system with several BHEs, enabling scaling of the BHE system based on reliable underground data.

In Finland, the first thermal response test (TRT) equipment was constructed in spring 2008. In 2009, GTK conducted a total of 17 thermal response tests at 8 sites. Most of the research areas were sites where a commercial building or a residential area will be constructed. The TRT results were used in modelling the BHE system. GTK’s TRT rig is especially designed for the cold climate and uses advanced technology in measurement control and data collection.

Figure 2. Annual average ground surface temperatures in Finland. (Leppähäri 2008)
Method development

The International Energy Agency (IEA) has several Implementing Agreements (IA) concerning renewable energy, among other topics. One of these IAs is Energy Conservation though Energy Storage (ECES). GTK is the representative of Finland in ECES and one of the subtask leaders in ECES Annex 21.

ECES Annex 21 is focused on the development and unification of the thermal response test, especially for underground energy storages. In Annex 21, experts from 15 countries are working together to compile TRT experiences worldwide, to develop the method further and disseminate the knowledge gained and the technology. Annex 21 will also initiate a worldwide TRT standard.

In connection to the cooperation in ECES, but also separate from it, GTK has started agreement-based cooperation with the Japanese Kyushu University and Professor Fujii’s team. This work is concentrating on top-quality development of borehole heat exchanger theory and modelling. GTK is also coordinating a national GEOENER project, which is aiming at the concept development of large-scale geoenergy systems. Several Finnish companies from different branches together with educational institutes are participating in GEOENER.

DISTRIBUTED TEMPERATURE SENSING

Distributed temperature sensing (DTS) involves the measurement of temperature with a fibre optic cable. The DTS device sends a laser pulse to the fibre, which works as a temperature sensor. The laser pulse of a particular wavelength scatters and some of it returns to the DTS device to be analyzed. The backscattered light contains information about the temperature at the scattering point, which is determined by the travel time of the incident light. The backscattering is caused by the Raman effect.
The Raman effect produces temperature-dependent Stokes and anti-Stokes signals, and their amplitude ratio is used to determine the temperature. The DTS device simultaneously measures the temperatures along the whole cable length. To obtain accurate temperature readings, every measurement must be calibrated. After good calibration the temperature accuracy is better than 0.1 C. (Tyler et al. 2009)

GTK uses DTS in geoenergy research to measure borehole temperatures and monitor BHE systems that are in use. The monitoring of active boreholes provides valuable information on how the system functions in situ and how the adjacent boreholes in a large BHE system affect each other. GTK recommends DTS monitoring for large BHE systems. GTK has also carried out some tests with simultaneous DTS and TRT measurements. One interesting aspect in the future would be to monitor the heat outflow from new buildings to the ground under them.

MODELLING OF THE BOREHOLE HEAT EXCHANGER SYSTEM

Modelling of the BHE system means optimizing the number, depth and location of the boreholes. The area reserved for the boreholes, thermal properties of the bedrock, monthly heating and cooling needs of the buildings and technical properties of the borehole and heat carrier fluid all affect the modelling results. It is necessary to conduct TRT measurement before modelling the BHE system so that the exact thermal conductivity of the bedrock and the thermal resistance of the boreholes are known. GTK optimizes every system case-specifically in close co-operation with HVAC (heating, ventilation, air-conditioning) engineers. GTK has mostly designed large BHE systems consisting of tens of boreholes.

In heating mode (winter), the heat pump extracts heat from the boreholes, which causes the system to cool down. In cooling mode (summer), some energy is returned to the boreholes. In Finland, buildings usually need more heating than cooling, so the geoenergy source tends to cool down. Careful
CASE STUDY: GEOENERGY STUDY FOR A LOGISTICS CENTRE IN SIPOO, SOUTHERN FINLAND

In autumn 2008, GTK carried out an extensive geoenergy study for the retail cooperative SOK in Sipoo, Southern Finland, at a site where a new SOK logistics centre will be built. The study included geological bedrock mapping, a fracture study, bore powder analysis and TRT measurements.

The geological bedrock mapping revealed a dihedral contact between two different rock types, diorite and granite gneiss, in the middle of the area. In addition, the granite gneiss was much more fractured than the diorite. Therefore, test boreholes were drilled on both sides of the contact and an additional borehole was placed near the contact. The TRT measurements showed that there is a significant difference in the effective thermal conductivity between the diorite and the gneiss sides of the contact.

The results were used in modelling a BHE system for the hall. The final BHE system will consist of 150 BHEs, each 300 metres deep. Optical cables for DTS measurements will be installed in some of the boreholes, and in the coming years GTK will monitor the temperature development of the BHE system. The modelling of the BHE systems makes sure that the annual temperature decrease in the system is low enough. In this way, the coefficient of performance (COP) of the heat pump remains continuously high and the whole BHE system is efficient and sustainable. It is also important to note that the boreholes affect each other.

Figure 5. A thermal response test in Sipoo. Photo: Ilkka Martinkauppi, GTK.
REFERENCES


