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IEA HPP Annex 29 - Ground-Source Heat Pumps Overcoming Technical and Market Barriers
Status Report NORWAY

Jørn Stene

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RESULT (summary)

Norway is a member of Annex 29, "Ground-Source Heat Pump Systems Overcoming Technical and Market Barriers" (2004-2006), organized under the umbrella of the International Energy Agency (IEA) and the IEA Heat Pump Programme (HPP). The 7 participating countries are Austria (Operating Agent), Canada, Japan, Norway, Spain, Sweden and the USA. The Norwegian participation is financed by ENOVA SF, and SINTEF Energy Research is responsible for planning and carrying out the Norwegian activities.

This report provides a status for ground-source heat pump (GSHP) systems in Norway with regard to state-of-the-art technology, installation examples, geological data, costs and market opportunities. A Norwegian Internet homepage for ground-source heat pump systems (*www.energy.sintef.no/prosjekt/Annex29*) is also presented.

GSHP systems in Norway are classified as direct systems (groundwater and soil/ground) and indirect closed-loop systems (vertical-rock and horizontal-soil/ground). The vast majority of the installations are indirect closed-loop systems utilizing vertical boreholes in rock as a heat source, heat sink and thermal energy storage. GSHP systems are relatively capital intensive installations, but they achieve high energy efficiency due to the relatively high and stable heat source temperature and the fact that a considerable share of the cooling demand in non-residential buildings can be covered by means of free cooling.

In order to obtain energy efficient and reliable GSHP installations, it is important to implement a total quality concept where focus is on quality and system integration during all stages of the project. A life cycle analysis (LCA) will be an important tool in such a concept, since both the investment costs as well as the lifetime operational and maintenance costs are included.

KEYWORDS

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	IEA Heat Pump Programme Annex 29	Heating and cooling of buildings
	Ground-source heat pump systems	Norwegian status report

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1 SUMMARY

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This report provides a status for ground-source heat pump (GSHP) systems in Norway with regard to state-of-the-art technology, installation examples, geological data, costs and market opportunities. A newly established Norwegian Internet homepage for ground-source heat pump systems is also presented (*http://www.energy.sintef.no/prosjekt/Annex29*).

GSHP systems in Norway are classified as direct systems (groundwater or soil/ground) and indirect closed-loop systems (vertical-rock or horizontal-soil/ground). The vast majority of the installations are indirect closed-loop systems utilizing vertical boreholes in rock as a heat source, heat sink and thermal energy storage. GSHP systems are relatively capital intensive installations, but they achieve high energy efficiency due to the relatively high and stable heat source temperature and the fact that a considerable share of the cooling demand in non-residential buildings can be covered by means of free cooling.

In order to obtain profitable, energy efficient and reliable GSHP installations, it is important to implement a total quality concept where it is focused on quality and system integration during all stages of the project – design, installation, commissioning, operation and maintenance. A life cycle analysis (LCA) is a useful tool in such a concept, since both the investment costs as well as the lifetime operational and maintenance costs are included. Generally, heat pump installations with low capital costs achieve lower energy efficiency and have more operational problems than high-quality systems with higher capital costs.

The report has been quality assured by the Geological Survey of Norway (Midttømme, 2004), Båsum Boring AS (Skarphagen, 2004) and Geoenergi AS (Hellström, 2004).

2 PRESENTATION OF IEA HPP ANNEX 29

Organized under the umbrella of the International Energy Agency (IEA), the IEA Heat Pump Programme (*HPP*) is a non-profit organization under which participants in different countries cooperate in projects in the field of heat pumps and related heat pumping technologies such as air conditioning, refrigeration and working fluids (refrigerants). Under the management of an Executive Committee representing the member countries, the Programme carries out a strategy to accelerate the use of heat pumps in all applications where they can reduce energy consumption for the benefit of the environment. The 12 participating countries are Austria, Canada, France, Germany, Japan, the Netherlands, *Norway*, Spain, Sweden, Switzerland, the UK and the USA.

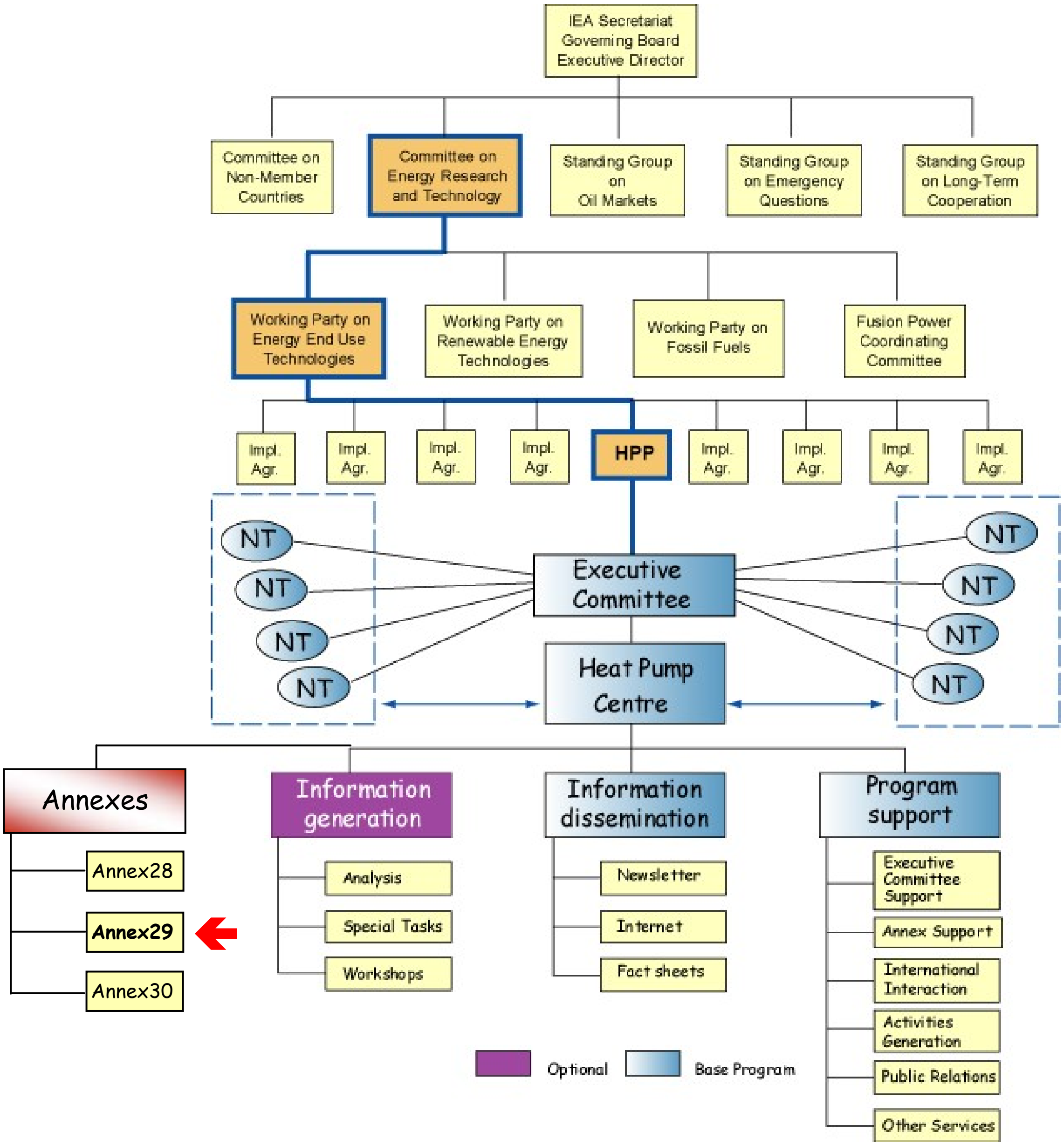

Figure 2.1 The Heat Pump Programme (HPP) and the Heat Pump Centre (HPC) are organized under the umbrella of the International Energy Agency (IEA).

The collaborative IEA Heat Pump Programme projects are known as *Annexes*, and are conducted on either a cost-sharing and/or a task-sharing basis by the participating countries.

IEA HPP Annex 29, Ground-Source Heat Pumps Overcoming Technical and Market Barriers will investigate ideas and identify systems that could improve the performance and market attractiveness of ground-source heat pump (*GSHP*) systems. Demonstration of the environmental benefits of GSHP systems is also an important objective.

Annex 29 will be operative from *March 2004* to *October 2006*, and the participating countries are:

- Austria
- Canada
- Japan
- Norway
- Spain
- Sweden
- USA

Austria is designated as the Operating Agent. The Norwegian participation in the Annex is financed by ENOVA SF, and SINTEF Energy Research, department of Energy Processes is responsible for planning and carrying out the Norwegian project activities.

The following activities will take place during the Annex period:

1) Technological development for increased performance and reduced cost of GSHPs.

- Heating-only versus heating and cooling systems
- Open versus closed loop systems
- Horizontal versus different vertical systems
- Direct expansion and secondary loop systems
- Use of different secondary fluids, including CO_2 in vertical probes (heat pipes)
- Direct and indirect cooling
- Recharging and moisture migration in the ground
- Extraction of heat from large surface areas, e.g. parking lots, runways etc.

2) Identification of market barriers and innovative approaches to increase system acceptance:

- Quality assurance measures
- Ground-coil system guarantees
- Contracting models for reduced initial cost
- Regulations, tariff structures etc.

3 THE NORWEGIAN HEAT PUMP MARKET

3.1 General

Figure 3.1 shows the annual installation rate for heat pumps in Norway during the period 1992 to 2003, whereas Figure 3.2 displays the accumulated heat production and energy saving for the installations in GWh per year. The data are based on information from the Norwegian heat pump association, NOVAP (*http://www.novap.no*) and SINTEF Energy Research.

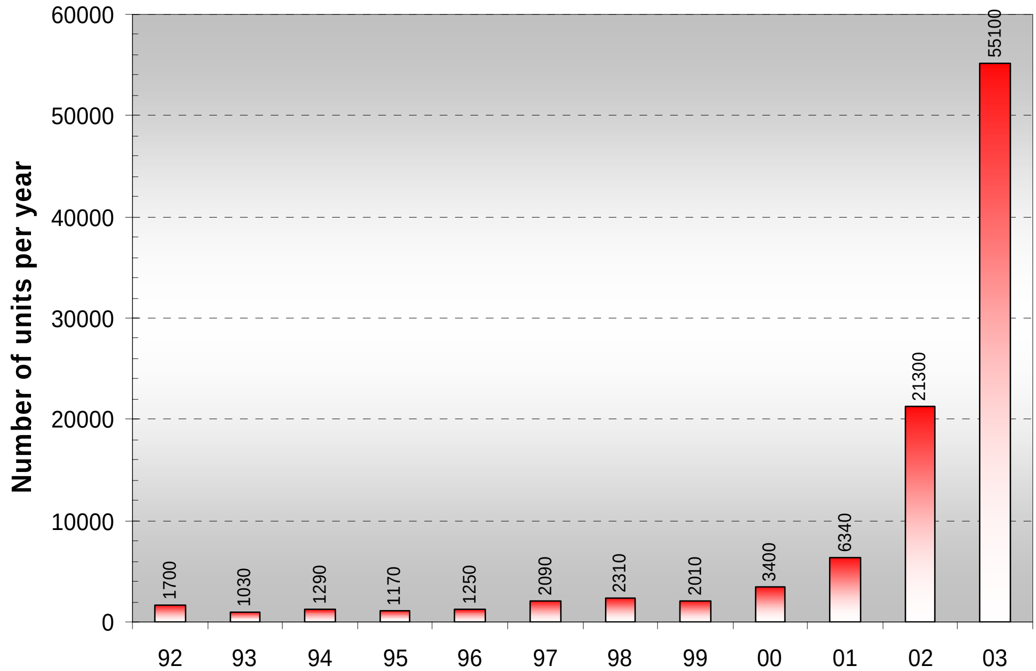

Figure 3.1 Annual installation rate for Norwegian heat pumps during the period 1992-2003.

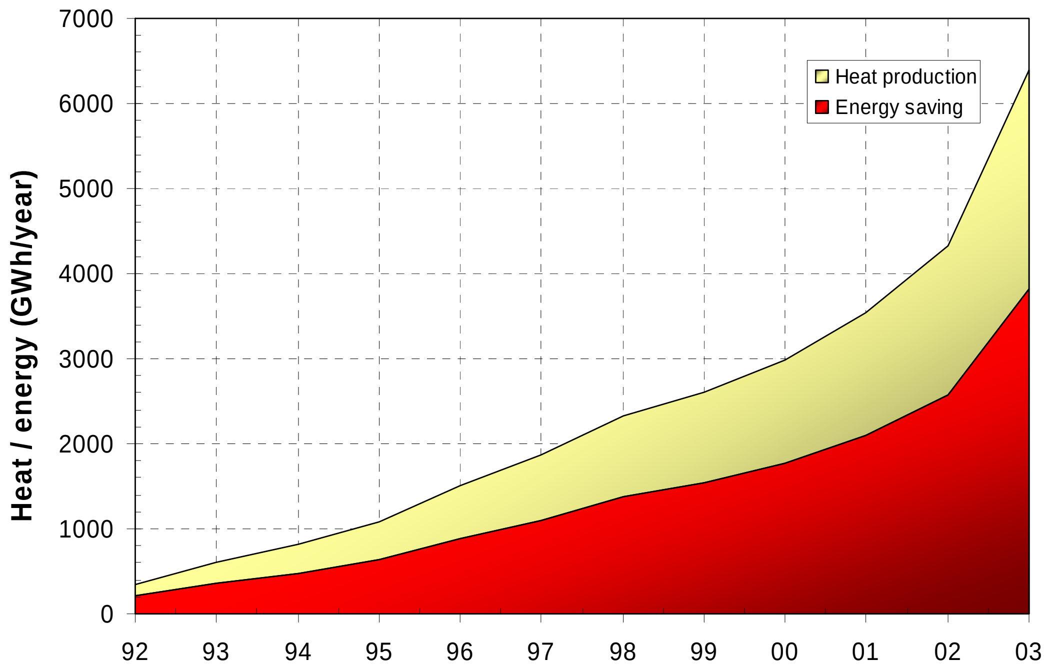

Figure 3.2 Accumulated heat production and energy saving during the period 1992-2003.

Figure 3.3 shows the annual installation rate for heat pumps in Norway sorted by heat sink and/or heat source (air-to-air, ventilation air, air-to-water, *water/brine-to-water*).

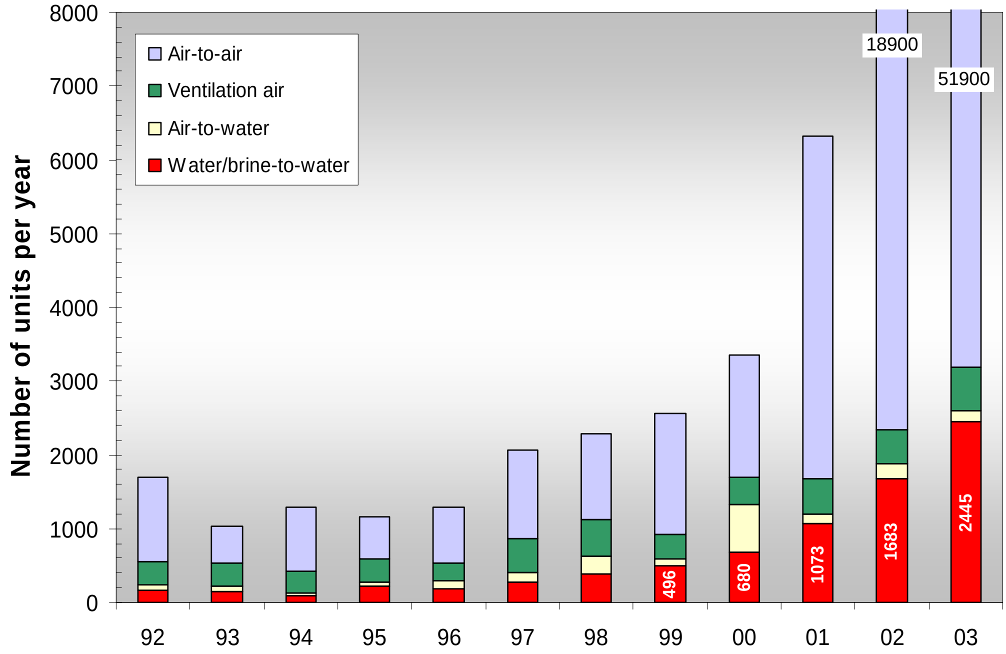

Figure 3.3 Annual installation rate for heat pumps in Norway during the period 1992-2003 sorted by heat sink and/or heat source.

Since 1998 the growth rate for the water-to-water and brine-to-water heat pump market (incl. GSHPs) has varied between 25 to 55%, and in 2003 growth rate was about 45%. Most of the installations are *residential systems* for combined space heating and hot water heating installed in new residences, and the main heat source is vertical boreholes in bedrock (ref. Chapter 4.3).

3.2 Market Opportunities for GSHP Systems in Norway

The Norwegian market for ground-source heat pump (*GSHP*) systems in residential and non-residential buildings is expected to grow the coming years as a result of:

- *Relatively high energy prices* – strengthens the competitive power of heat pumps vs. conventional heating and cooling systems (direct electric heating systems and oil-/gas-fired boilers, possibly in combination with separate cooling systems in non-residential buildings).
- *Relatively low interest rates* – favourable for capital intensive installations such as GSHPs.
- *Establishment of* ENOVA SF, which is owned by the Norwegian Ministry of Petroleum and Energy. The main mission of Enova SF is to contribute to environmentally sound and rational use and production of energy, relying on *financial instruments* and incentives to stimulate market actors and mechanisms to achieve national energy policy goals. The main objectives are improved energy efficiency, more flexibility in the energy supply (decreased dependence on direct electricity for heating), and an increased share of renewable energy sources. – e.g. more focus on hydronic heat distribution systems in buildings, small- and large-scale district heating systems and heat pumps. Enova SF administers an Energy Fund of *650 million €* over a ten-year period (2002-2012).

- *New national buildings codes* – will lead to a reduction in the space heating demand, but the demand for reheating of ventilation air and the space cooling demand will most likely increase in many types of non-residential buildings. The load profiles for heating and cooling matches the operating characteristics of GSHP systems utilizing underground thermal energy storage, leading to profitable and energy efficient installations. The new building codes will come into effect from January 2006.

- *New EU directive* (2002/91/EC), "Energy Performance of Buildings". The directive focuses on reducing the total energy use in buildings – i.e. heating, cooling and electricity demands. The directive will include new requirements for energy use in new and renovated buildings, energy inspections of heating/cooling systems as well as implementation of Energy Certificates for new buildings, buildings larger than 1000 m^2 that are being rehabilitated, public buildings larger than 1000 m^2 and buildings that are sold or leased. The directive, which will come into effect in Norway from January 2006, is believed to increase the attractiveness of GSHP systems for energy efficient heating and cooling of non-residential buildings.

- *Hydronic floor heating systems* were installed in 45% of new homes in 2003 – this trend facilitate the installation of GSHP systems (Varmeinfo - statistikk).

- Hydronic heat distribution systems is compulsory in new and renovated governmental buildings with a floor space above 1000 m^2, and hydronic heat distribution systems are also becoming more popular in new non-residential buildings. There is also increasing interest in small-scale and large-scale district heating (and cooling) systems. These factors facilitate the installation of GSHP systems.

- *Increasing awareness* of the economical, technical and environmental benefits of GSHP systems among end-users in general, the Norwegian public authorities, municipalities, building owners, energy utilities, development companies and consultant engineers.

Examples of current market impediments for GSHPs are:

- The total capital costs for residential GSHP systems including the hydronic heat distribution system are relatively high compared to conventional heating systems such as electric baseboard heaters, electric water heaters, wood-fired stoves, oil/kerosene stoves and gas/oil-fired boilers. As a consequence, GSHPs systems are mainly regarded a viable option in new or renovated residences with a floor space above 150 to 200 m^2.

- Non-residential building owners that lease their buildings are mainly interested in minimizing the capital costs. This hampers the use of capital intensive but energy efficient installations with low operating costs, such as GSHPs in combination with hydronic heat distribution systems.

4 SYSTEM DESIGN IN NORWAY – TECHNOLOGICAL STATUS

4.1 Introduction

Figure 4.1 shows a classification of typical ground-source heat pump (*GSHP*) systems in Norway.

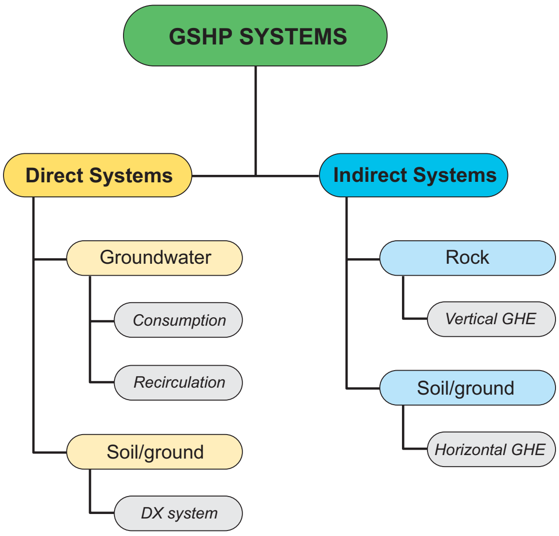

Figure 4.1 Classification of GSHP systems in Norway.

In *direct GSHP systems*, the heat pump evaporator is in direct contact with the heat source. In direct *groundwater* systems, the water can be used as a heat source, a heat sink or as a seasonal thermal energy storage – aquifer thermal energy storage (*ATES*). In direct systems utilizing *ground/soil* as the heat source, the evaporator is normally buried horizontally in the ground. These heat pumps are normally referred to as direct expansion systems (*DX systems*).

In *indirect GSHP systems*, an extra closed-loop ground heat exchanger (*GHE*) is installed between the heat source and the heat pump evaporator, and heat is transferred to and from the heat pump system be means of a secondary fluid (anti-freeze solution). The closed-loop heat exchanger (polyethylene tube) is either installed in deep vertical boreholes in bedrock or buried horizontally in the ground. Indirect GSHP systems can provide both heating and cooling (including free cooling), and the bedrock can also be utilized as an underground thermal energy storage (*UTES*).

4.2 Direct Systems – Groundwater

4.2.1 Consumption and Recirculation Systems

In open (direct) groundwater systems, groundwater is pumped to the heat pump evaporator from wells drilled in fluvial/glasiofluvial sand, gravel deposits close to watercourses (rivers, lakes) or fractured bedrock. Typical specifications for Norwegian groundwater systems are (NGU, 2004):

- Well – diameter: ID 150 to 200 mm
- Well – depth: 10 to 40 m (groundwater level at –1 to –10 m) – occasionally deeper
- Water flow rate: 0.15 to 25 l/sec

The largest groundwater inflow is found in sand and gravel deposits close to watercourses.

Groundwater systems are designed as consumption or recirculation systems according to the available groundwater flow rate from the well(s). In *consumption systems*, groundwater is pumped from one or several production wells, cooled by the heat pump evaporator and drained to separate injection wells, Figure 4.2. In *recirculation systems* the groundwater flow is limited, and the groundwater is returned to the production well(s) after being cooled by the heat pump. For the latter system, the temperature in the well(s) will drop during the heating season, and the heating capacity of the heat pump must be controlled in order to avoid freezing of the groundwater.

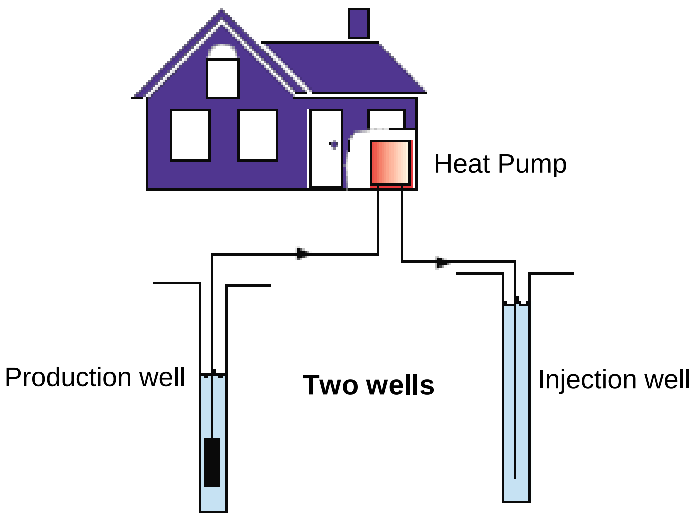

Figure 4.2 Principle of a groundwater system with two wells (consumption system).

Figure 4.3 shows an example of a groundwater well that has been drilled in gravel (Båsum, 2004).

Figure 4.3 Groundwater well drilled in gravel (Båsum, 2004).

It is of crucial importance to analyse the *groundwater quality*, since a high content of humus, iron, manganese or carbonates will lead to fouling and clogging of heat exchangers and pumps which in turn will reduce the COP of the heat pump and cause operational problems. According to NGU (2004), 25 to 30% of the groundwater systems have had operational problems due to fouling. It is also important to analyse the risk of setting of the ground and consequent damage to buildings.

In Norway, direct groundwater heat pump systems are mainly installed in *non-residential buildings* and in district heating/cooling systems, since problem-free operation requires thorough water analysis as well as competent design, installation and maintenance of the systems.

Reference is made to Chapter 5, *Groundwater and Bedrock Data – Digital Maps*, regarding information on groundwater temperatures in Norway.

4.2.2 Aquifer Thermal Energy Storage

In rare cases aquifers with negligible groundwater flow can be used as a seasonal thermal energy storage – aquifer thermal energy storage (*ATES*). By using a *cyclic regime* or flow, a hot and a cold reservoir will be created around each well or group of wells. In periods with a predominant heating demand, groundwater from the warm wells is cooled by the heat pump evaporator and returned to the cold wells. In periods with a predominant cooling demand, groundwater from the cold wells is used for cooling purposes, and the heated water is returned to the warm wells. Figure 4.4 sketches the principle of an ATES with a cyclic regime (IEA, 2002).

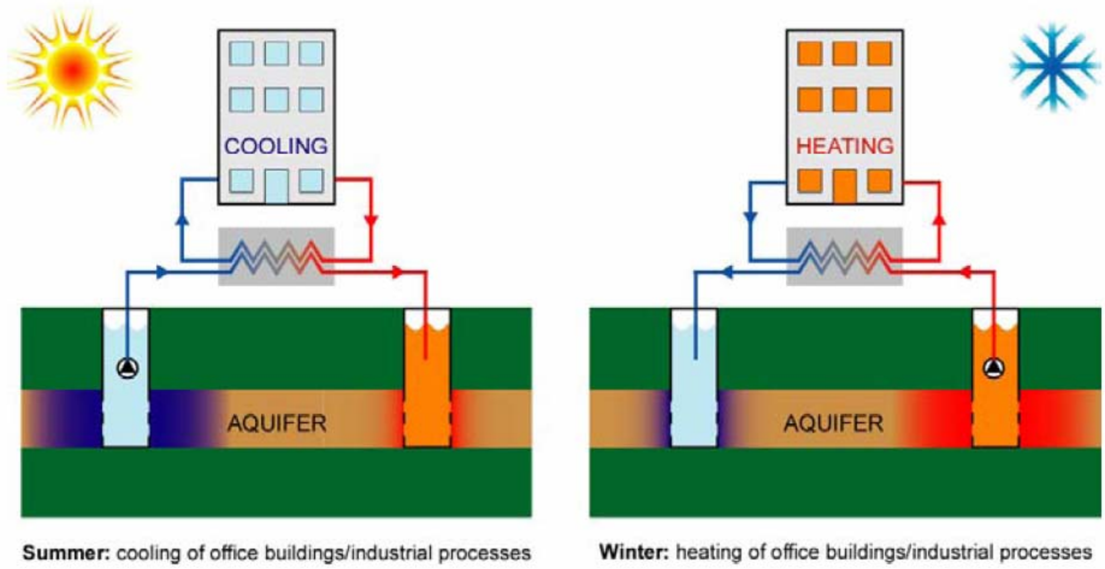

Figure 4.4 Principle of an aquifer thermal energy storage, ATES (IEA, 2002).

4.3 Direct Systems – Soil/Ground

4.3.1 Direct Expansion Systems

In direct expansion (DX) ground-source systems, which are rarely used in Norway, the evaporator consists of (plastic coated) copper tubes that are buried horizontally in the ground at a depth of 80 to 150 cm. The main advantages of these small-capacity systems are the simple installation and the higher evaporation temperature compared to indirect systems using a closed-loop ground heat exchanger (ref. Chapter 4.5). However, due to the relatively large working fluid charge and the risk of leakage, only systems with natural working fluids (propane, CO_2) are regarded as environmentally acceptable alternatives. It is of crucial importance that the systems are designed for proper oil return to the compressor at all operating conditions. Figure 4.5 sketches a residential direct expansion heat pump system.

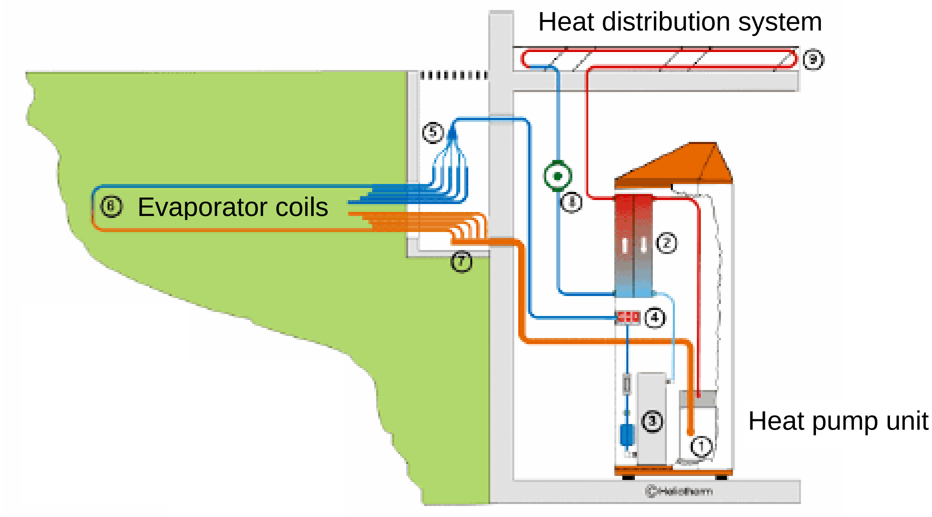

Figure 4.5 Principle of a direct expansion heat pump system (DX system).

4.4 Indirect Closed-Loop Systems – Rock

4.4.1 Design and Main Characteristics

In indirect closed-loop GSHP systems utilizing rock as a heat source, heat sink or thermal energy storage (*UTES*), energy wells are drilled vertically in the bedrock by means of pneumatically operated drilling rigs. In unfixed masses such as soil, sand, gravel and clay, well casing (steel tubes) is required in order to stabilize the boreholes. Heat is transferred between the energy wells and the heat pump evaporator by means of a secondary fluid (anti-freeze, brine) that circulates in a closed-loop made from high-density polyethylene (PEM) tubes. The part of the plastic tubes that are located in the energy wells is denoted the *ground heat exchanger (GHE)*. In order to ease the installation of the GHE and to avoid buoyancy caused by possible ice formation on the tubes, the GHE is equipped with a bottom weight (approx. 10 to 15 kg). Figure 4.6 sketches the principle of an indirect closed-loop GSHP system.

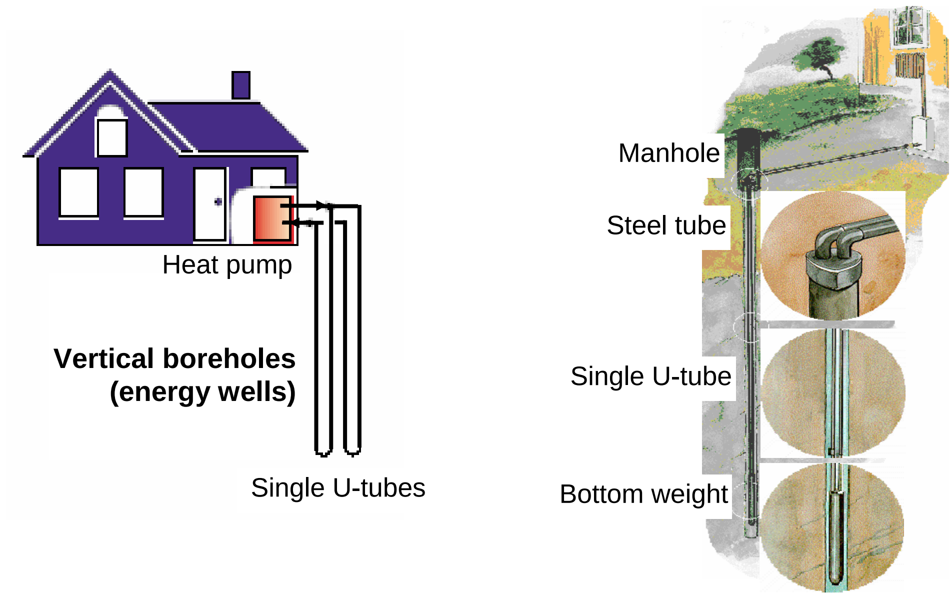

Figure 4.6 Principle and main components of a closed-loop GSHP system.

Typical specifications for Norwegian closed-loop GSHP systems are as follows (NGU, 2004):

- Borehole – diameter: 130 to 165 mm
- Borehole – depth: 80 to 200 m (300 m)
- GHE – type/design: PEM, PN 6.3, OD/ID 40/35 mm, single U-tubes (standard). Some systems use distance brackets to keep the tubes apart. Double U-tubes are used occasionally.

In order to attain good heat transfer conditions for the GHE, it is important to ensure *turbulent flow* for the secondary fluid at all operating temperatures. For systems with more than one GHE, the GHEs are either connected in parallel or two and two loops are connected in series. When selecting the configuration, there is a trade-off between the total pressure loss for the GHE loops and the pressure loss for the evaporator(s), since the configuration affects the temperature rise/-drop for the secondary fluid and with that the flow rates. Figure 4.7 shows the principle of serial and serial/parallel configuration for closed-loop vertical GHEs (single U-tubes) in bedrock.

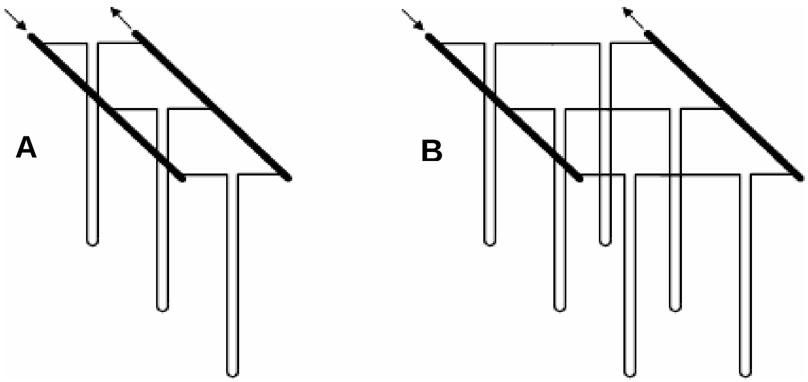

Figure 4.7 Principle of parallel (A) and parallel/serial (B) configuration for vertical GHE.

Figure 4.8 shows pneumatically operated rigs for drilling of energy wells (Båsum, 2004).

Figure 4.8 Drilling of energy wells by pneumatically driven rigs (Båsum, 2004).

The heat extraction rate from vertical boreholes in bedrock in Norway typically ranges from *20 to 60 W/m*. The lower value reflects a “dry well” without groundwater drilled in insulated rocks, whereas the high level presupposes permeable bedrock with high thermal conductivity and a large groundwater pressure gradient.

The heat extraction rate and with that the *required borehole depth*, is mainly dependent on the properties of the bedrock (rock types, permeability etc.), the amount of groundwater flowing in the bedrock, the groundwater level, the temperature of the ground and the borehole configuration (ref. Chaper 4.4.3). The groundwater level in Norway is normally 1 to 10 metres below the surface. In wells with low groundwater level or in dry wells, the boreholes are backfilled with water (requires non-permeable rock – normally not recommended), cuttings from the drilling process, concrete or a mixture of bentonite and quartz sand in order to improve the heat transfer between the bedrock and the GHE. Special distance brackets can be used to separate the downward and upward tubes, in order to minimize the heat transfer between the tubes.

Reference is made to Chapter 5, *Groundwater and Bedrock Data – Digital Maps*, regarding information on bedrock data and groundwater temperatures in Norway.

Figure 4.9 shows, as an example, the development of the wall temperature for a standard-sized residential GHE in Norway. The temperature was measured by means of thermocouples mounted at the wall of the plastic tube (PEM, OD/ID 40/35 mm), and the uncertainty was ±0.2 K. The heating capacity of the heat pump was about 6 kW, the energy well was 150 m deep, and the groundwater level was at approximately –20 m.

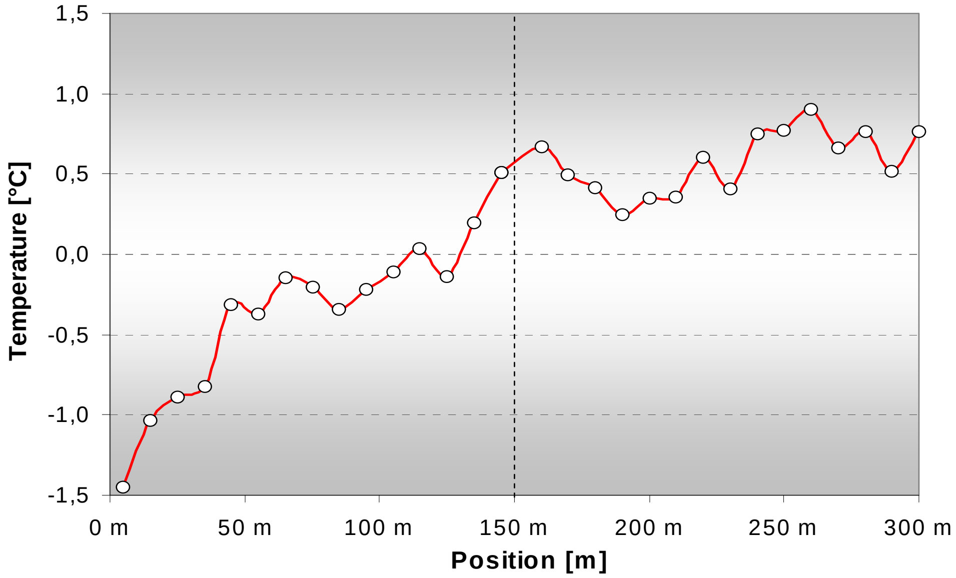

Figure 4.9 Measured wall temperatures for a standard-sized residential GHE (PEM, OD/ID 40/35 mm) installed in a 150 m deep energy well.

In this particular case, the wall temperature rises about 2 K between the inlet and outlet of the downward tube, whereas the wall temperature at the inlet and outlet of the upward tube are almost identical. The latter indicates that most of the “useful” heat transfer between the bedrock/groundwater and the secondary fluid takes place in the downward tube. Generally, the temperature development of the secondary fluid will depend on the design of the GHE and the flow rates.

4.4.2 Recharging and Thermal Energy Storage

For *residential GSHP systems* using a single energy well, the annual average temperature in the borehole will normally remain constant from year to year due to sufficient heat transfer from the surrounding rock and from groundwater. However, in cases with insignificant groundwater flow, the temperature of the bedrock will gradually drop as long as the energy wells are not recharged with external heat. Recharging can be accomplished by connecting a passive solar heating system to the GHE loop, or even better – utilizing heat from the exhaust air in the ventilation system in the house (Fahlén, 2004). Thermal recharging of residential systems is rarely used in Norway.

In Norwegian *non-residential GSHP systems*, the number of energy wells typically range from 5 to 50 (ref. Table 4.1, Chapter 4.4.7). The temperature development in the boreholes from year to year is, among other things, depending on the heat extraction rate for each well, the properties of the bedrock, the groundwater flow, the borehole configuration (I-shape, L-shape, rectangular shape) and the distance between the wells. When the groundwater flow is insufficient to recharge the wells after the heating season, the temperature will drop, and this will in turn reduce both the heating capacity and the COP of the heat pump. However, excess heat from the cooling system in the building or heat from the exhaust air in the ventilation system can be used to increase the temperature level in the energy wells. For larger buildings with both heating and cooling demands, the rock volume around the boreholes is often utilized as a *thermal energy storage* ("closed" energy system). The mutual distance between the 150 to 200 metre deep boreholes typically ranges from 5 to 10 metres (NGU, 2004). When designing thermal energy storages it is important to ensure a long-term energy balance, which means that the annual heat flow into and out of the storage should be in the same order of magnitude. Figure 4.10 shows the principle of a thermal energy storage, whereas Figure 4.11 shows an example of a monthly energy account.

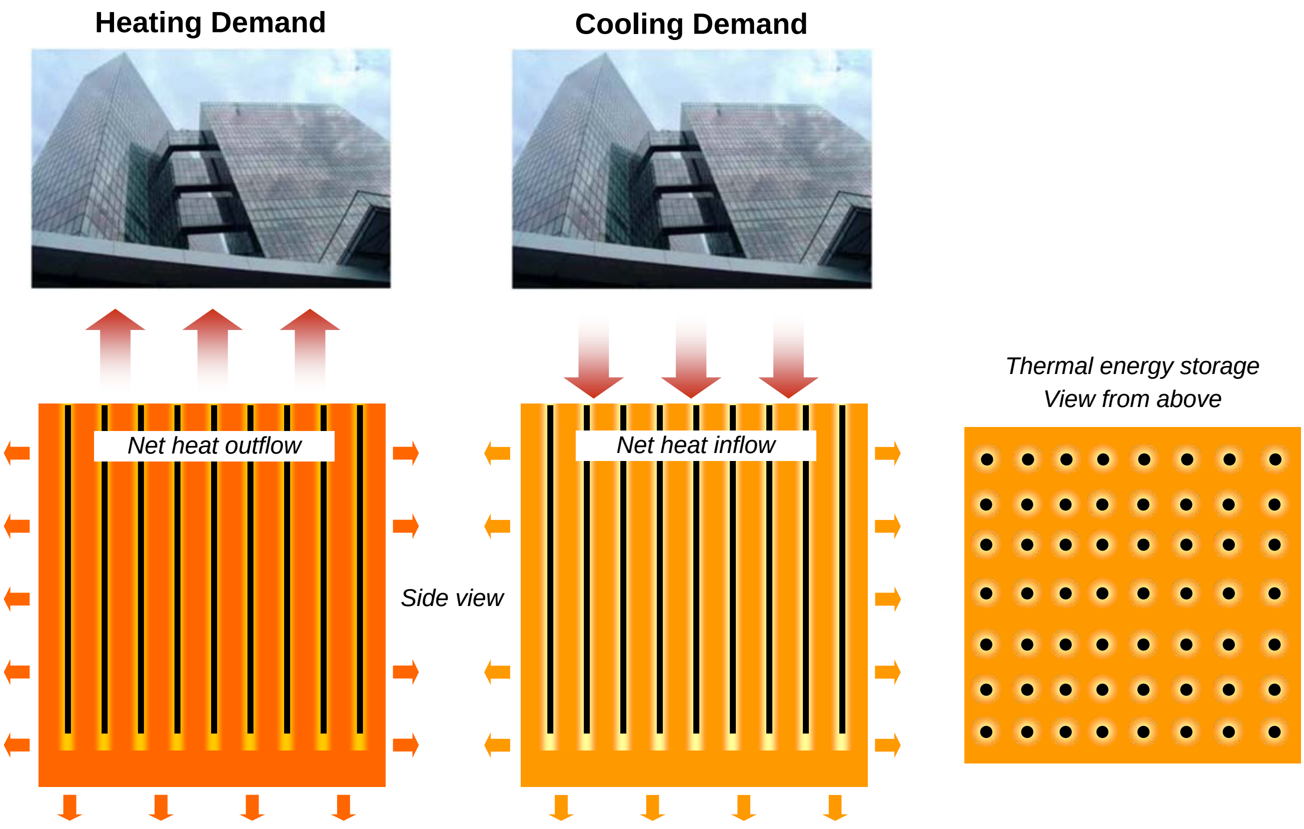

Figure 4.10 Principle of a thermal energy storage with energy wells in bedrock.

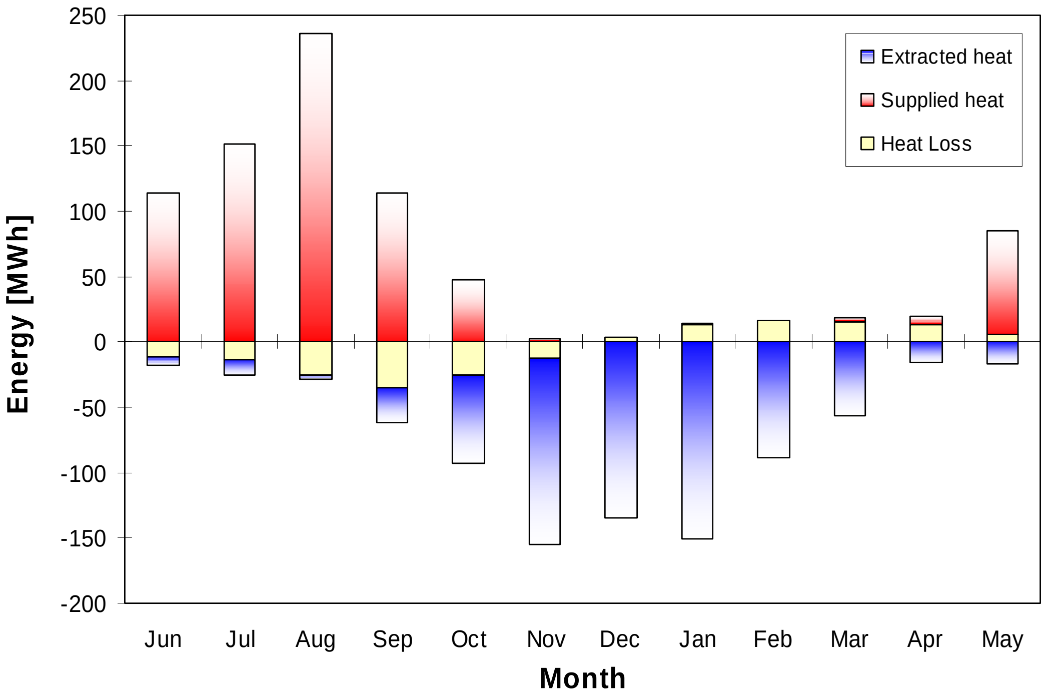

Figure 4.11 Example of a monthly energy account for a thermal energy storage.

In Figure 4.11, the sum of the extracted heat (*blue*), supplied heat (*red*) and heat loss (*yellow*) during a "normal" year is more or less zero (thermal energy balance). As a consequence, the average annual temperature of the storage will remain relatively constant from year to year.

Figure 4.12 shows, as an example, a possible principle for a GSHP system for space heating, reheating of ventilation air and space cooling of a non-residential building.

In periods with a *dominant heating demand*, the heat pump extracts heat from the energy wells, and the heat pump evaporator have sufficient capacity to cover the space cooling demand in the building (free cooling[1]). In these periods there will be a net extraction of thermal energy from the storage, and the temperature will drop gradually.

In periods with a *dominant cooling demand*, the cooling demand is covered by means of free cooling from the energy wells. If this is not sufficient, the heat pump is operated as a chiller, and the surplus heat is rejected to the energy wells. In these periods there will be a net input of thermal energy to the storage, and the temperature will rise gradually. During the year, the well temperature may typically fluctuate between 5 and 20ºC.

GSHP systems in Norway utilizing energy wells in bedrock as a heat source/sink or thermal energy storage, achieve *high overall energy efficiency*. The reason is that 80 to 90% of the annual heating demand for the building is covered by the heat pump units (bivalent system) operating at a relatively high evaporation temperature, and a considerable share of the annual cooling demand is covered by means of free cooling from the heat pump evaporator and the energy wells.

[1] *Space cooling provided by means of heat exchange with cool ambient air, groundwater or rock & space cooling provided by the evaporator when the heat pump is operated in heating mode.*

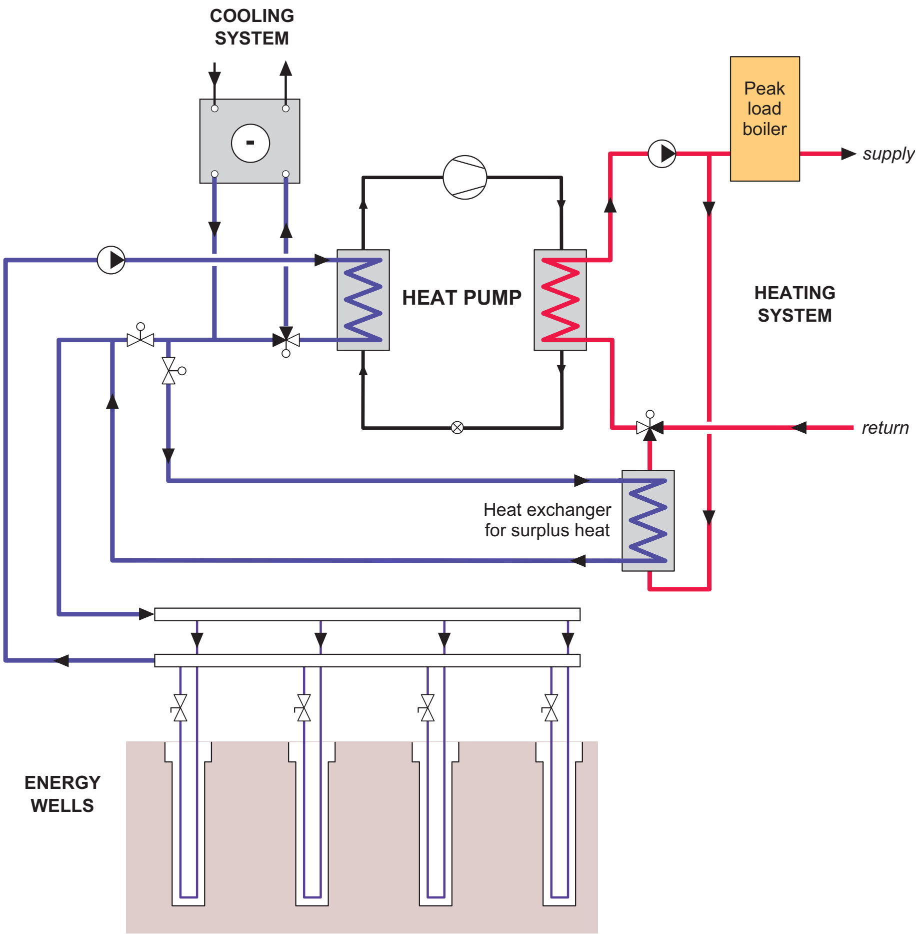

Figure 4.12 Principle of a GSHP system for space conditioning of a non-residential building.

4.4.3 Secondary Fluids

Ethylene glycol, $(CH_2OH)_2$, has been the most commonly used secondary fluid (anti-freeze/brine) in indirect closed-loop GSHP system in Norway. However, due to the risk of groundwater contamination, it is now being replaced by more environmentally friendly fluids like denatured ethanol (C_2H_5OH), potassium carbonate (K_2CO_2), potassium formate ($K[HCO_2]$) and potassium acetate ($KC_2H_3O_2$) (Stene, 1998).

4.4.4 Thermal Response Testing

Thermal response testing (*TRT*) is a method for measuring the thermal properties of the rock and the thermal resistance of a borehole, and with that the possible heat extraction rate from an energy well (Gehlin, 2002; Geoenergi AS). The TRT unit, which is connected to the ground heat exchanger (GHE), consists of a pump, an electric heater, a control unit and a data logger. Figure 4.13 shows the principle of the thermal response test unit (Gehlin, 2002).

During testing, the thermal output from the electric heater to the GHE is constant, and the supply and return temperature of the brine (i.e. T1 and T2) are measured by the data acquisition system. During testing it is important that the thermal power input to the brine circuit is more or less the same as the expected heating/cooling load for the borehole during normal operation. In order to achieve reliable results, the test period is normally 60 to 70 hours. Figure 4.14 shows a typical temperature curve for the brine during thermal response testing of a borehole (Gehlin, 2002).

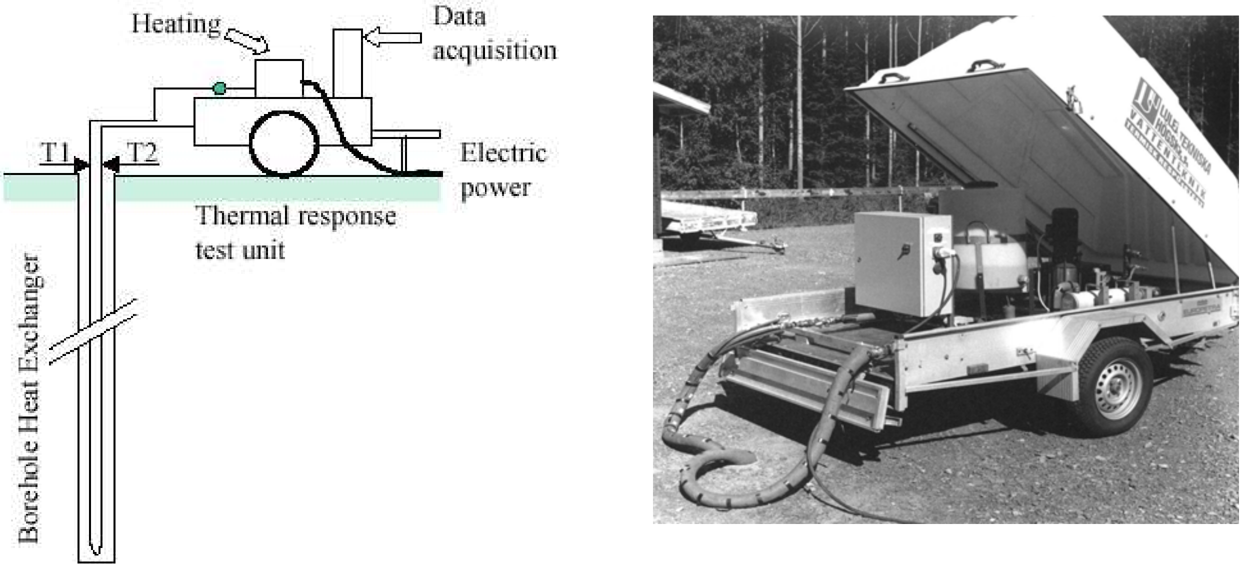

Figure 4.13 Principle of the thermal response test unit (Gehlin, 2002).

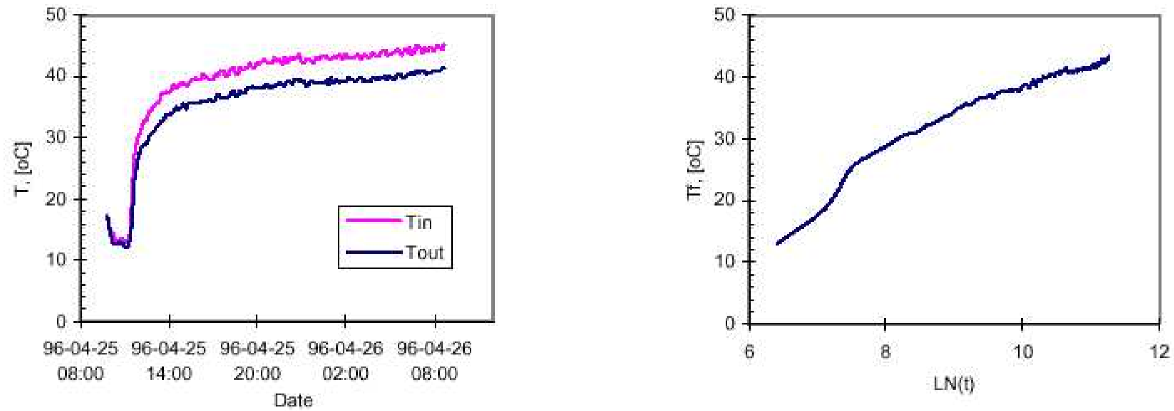

Figure 4.14 Temperature curves for the brine during thermal response testing (Gehlin, 2002).

The curve on the left hand shows the supply and return temperatures of the brine, while the curve on the right hand shows the average temperature in a logarithmic time axis (LN t). The angle of inclination and the absolute position for the latter curve determines the thermal conductivity and the thermal resistance in the borehole, respectively. A relatively flat curve located close to the time axis indicates efficient transportation of thermal energy from the brine to the surrounding bedrock. By means of especially developed software, the temperature measurements can be utilized for accurate design of borehole systems and thermal energy storages (Gehlin, 2002).

The costs[2] for a TRT measurement (~4900 €, 2004) is about the same as the total costs for a 150 m deep energy well (~4300 €, 2004). The TRT is mainly used to improve the accuracy during the design process of larger GSHP system with more than 15 to 20 boreholes. In some cases, TRT measurements can lead to a reduction in the total borehole depth. Geoenergi AS has carried out TRT measurements for more than 80 heat pump installations in Norway.

[2] *VAT not included. Exchange rate: 100 NOK = approx. 8.2 €*

4.4.5 *Improved Thermal Performance by Means of Hydraulic Fracturing*

In low-permeability bedrock the groundwater flow is very low or non-existent, and the thermal capacity of energy wells will be limited. One method to increase the permeability of the bedrock is to perform hydraulic fracturing. A part of the borehole is then sectioned by two special seals and pressurized until micro fissures are formed in the formation around the borehole. Injection of rounded sand grains in a high viscosity carrier fluid keeps the artificially created fissures around the borehole open after the pressure relief. Figure 4.15 shows the principle of hydraulic fracturing, whereas Figure 4.16 shows typical equipment used for the operation (groundwater wells).

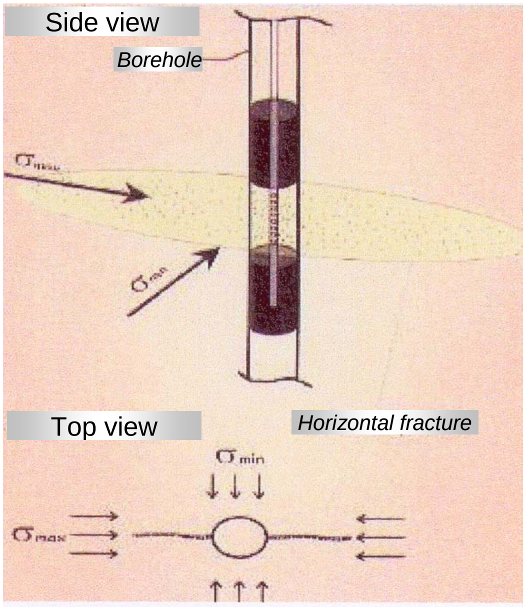

Figure 4.15 Principle of hydraulic fracturing.

Figure 4.16 Equipment used for hydraulic fracturing of groundwater wells (Vestnorsk Brunnboring AS).

Hydraulic fracturing is beneficial for GSHP systems where the main purpose is to extract heat from the ground/groundwater or to reject excess heat from the building or industrial process. Hydraulic fracturing is regarded a promising technology in Norway, but in order to become a viable technology the total costs of the operation must be lower than that of drilling deeper wells or extra wells. It is referred to NGU (2004) for more information on hydraulic fracturing.

4.4.6 Costs for Energy Wells

Typical costs[3] for rigging up, drilling of boreholes, installation of the GHE etc. in the Oslo area are as follows (Skarphagen, 2004):

• Rigging up:	270 €	*non-recurrent cost*
• Drilling:	18 €/m	*drilling in bedrock*
• Casing:	68 €/m	*drilling and installation of steel pipes in unfixed masses*
• GHE:	6 €/m	*OD 40 mm PEM twin tubes, charged with anti-freeze*
• Bottom weight:	160 €	*U-tube*
• External tubing:	22 €/m	*OD 40 PEM twin tubes*

Cutting of steel pipes, tight well cover, elbows, drilling through basement walls and ditching bring additional costs. A complete 150 deep energy well including the GHE and connecting tubing costs about *4290 Euro (~29 Euro/m)*[3] in the Oslo area. For larger thermal energy storages, which are being drilled during the winter, the price will be somewhat lower.

The total costs for the energy wells typically range *from 20 to 40%* of the total costs for the heat pump installation (Helgesen et al., 2001). For energy wells the specific capital costs (Euro/kW), remains relatively constant, whereas the specific capital costs for the heat pump units drops when the heating capacity of the plant increases. Consequently, *the larger the heating capacity of the heat pump system, the higher the relative costs for the energy wells.*

4.4.7 Installation Examples

Table 4.1 on the following page shows examples of Norwegian GSHP installations in non-residential buildings including block of flats, undetached houses, student homes, assembly buildings, schools, office buildings, nursing homes, hospitals and factory buildings. The heating capacity of the heat pump systems ranges from 40 kW to 8 MW. It is referred to the Norwegian IEA Annex 29 website (www.energy.sintef.no/prosjekt/Annex29/) for more information regarding Norwegian GSHP installations.

Examples of Norwegian GSHP heat pumps installed in a nursing home, block of flats, office buildings and district heating/cooling systems are provided on pages 22 through 29.

[3] *VAT not included. Exchange rate: 100 NOK = approx. 8.2 €*

Table 4.1 Examples of GSHP installations in Norway in non-residential buildings (NGU, 2004). HP and GW are short for heat pump and groundwater, respectively.

Installation	Type of Building	HP Capacity [kW]	No. of Wells x Depth	Year of Installation
Holmin Gartneri, Drammen	Greenhouses	250	GW	1983
4 blokker Varden, Fyllingsdalen	Block of flats	*	12 x 155	1984
Jens Sagen AS, Kristiansand	Engineering workshop	50	6 x 115	1985
Gudmund Grønvold, Målselv	Flats	52	GW	1985
Hotell Alexandra, Loen	Hotel	*	GW + DA	1988
Fjellanlegg, Sarpsborg kommune	*	*	19 x 100	1989
Kalnes landbruksskole, Sarpsborg	Agricultural school	*	27 x 100	1993
Bølerskogen borettslag, Oslo	Housing cooperative	*	6 x 125	1993
Skårsetlia kirke, Lillehammer	Church	40	*	1994
Mailundveien 21, Oslo	*	60	8 x 150	1995
Drammensveien 119, Oslo	*	45	6 x 160	1996
Drammensveien 50C, Oslo	*	50	6 x 140	1996
Ingar Nilsens vei 1, Oslo	*	40	5 x 150	1996
Melhus bo-/omsorgssenter	Nursing home	200	GW	1997
Underhugsveien 21, Oslo	Oslo	75	8 x 150	1997
Hegdehaugsveien 17, Oslo	Oslo	60	7 x 150	1997
Hegdehaugsveien 21, Oslo	Oslo	60	7 x 155	1997
Gardermoen flyplass, Ullensaker	Airport	8000	18 x 45	1998
Markaporten borettslag, Oslo	Housing cooperative	*	16 x 150	1998
Fossnes senter, Stokke	*	*	GW	1998
Blindern studenterhjem, Oslo	Student homes	150	16 x 160	1999
Lutvann borettslag, Oslo	Housing cooperative	*	21 x 150	1999
Lierbyen Skole, Lier	School	*	30 x 155	1999
Vestfold sentralsykehus, Tønsberg	Hospital	*	GW	1999
Filadelfia forsamlingshus, Arendal	Assembly building	*	5 x 140	1999
Lillo Sykehjem, Oslo	Nursing home	188	16 x 150	1999
Norcontrol, Horten	Office building	*	10 x 150	1999
Rana Sykehus, Mo i Rana	Hospital	*	GW	1999
Apaløkka Skole, Oslo	School	150	25 x 185	2000
Høyås Bo og rehab.senter, Kolbotn	Rehabilitation centre	130	*	2000
Sentermenigheten, Asker	Assembly building	100	13 x 130	2000
Gausebakken nord, Sandnes	*	*	10 x 150	2000
Brødrene Dahl, Sandnes	Industry	*	10 x 150	2000
Langhus Skole, Ski	School	150	20 x 185	2000
Norske ventiler, Ågotnes	Factory building	*	5 x 150	2000
Granvin sjukeheim, Granvin	Nursing home	*	10 x 100	2000
Deliskog Ind. Området, Ski	Factory building	180	20 x 185	2000
Kjeldås Skole, Sande	School	40	5 x 130	2000
Maridalsveien 3, Oslo	Office building	*	24 x 150	2000
Ulsrud Skole, Oslo	School	300	20 x 185	2000
Nøstehagen Bo-/omsorgssenter, Lier	Nursing home	120	14 x 160	2000
Vålerenga Skole, Oslo	School	*	16 x 160	2000
Sofienberggata 69, Oslo	*	45	6 150	2001
Kautokeino helsesenter	Heath centre	150	16 x 145	2000
Stabburveien 1, Fredrikstad	*	*	12 x 120	2001
Ericsson-bygget, Asker	Office building	750	60 x 200	2001
Bjølsen studentby, Oslo	Student home	700	48 x 160	2001
Bjøråsen skole, Oslo	School	150	20 x 185	2001
Lena Terasse, Melhus	Block of flats	150	GW	2001
Ringgata 1, Oslo	*	*	10 x 170	2001
Vetleflaten Sykehjem, Voss	Nursing home	200	17 x 175	2001
Ringstad gård, Halden	*	*	15 x 150	2001
Bergen rørhandel, Åsane	Industry	*	5 x 160	2001
Rødtvet skole, Oslo	School	250	12 x 160	2002
Sinsenveien 7-13, Oslo	*	*	13 x 160	2002
Kvernhuset Skole, Fredrikstad	School	300	28 x 165	2002
Stavsjøtunet, Malvik	Block of flats	45	4 x 180	2002
Mysen skole, Eidsberg	School	150	16 x 160	2002
Rosenvilde skole, Bærum	School	200	22 x 180	2002
Gipe bo og behandlingshjem, Nøtterøy	Nursing home	*	20 x 150	2002
Mysen skole, Eidsberg	School	150	15 x 150	2002
Gratangen sykehjem	Nursing home	*	8 x 190	2002
Bankbygget, Gol	Office building	*	7 x 180	2002
Rove gård sykehjem, Holmestrand	Nursing home	300	18 x 300	2003
Nadderud Vdr. Skole, Bærum	School	*	40 x 170	2003
Greverud omsorgsb./sykehjem, Oppegård	Nursing home	*	29 x 200	2003
Stav Skole, Skjetten	School	*	15 x 145	2003
Alnafossen kontorpark, Oslo	Office building	1200	54 x 180	2003
Sandetun bo og servicesenter, Sande	Nursing home	180	GW	2003
Galleberg skole, Sande	School	100	11 x 180	2003
Avantor - Nydalen syd, Oslo	Various buildings	6000	180 x 200	2004
Rutebilplata, Hønefoss, Ringerike	Various buildings	650	49 x 160	2004
Brønnøysund sykehjem, Brønnøy	Nursing home	*	40 x *	2004

INSTALLATION EXAMPLE 1 – NURSING HOME

Name of building	Sandetun sykehjem og omsorgsboliger	
Location	Sande, Norway	
Year of construction	2004	
Heating and cooling demands	Space heating (floor heating system), reheating of ventilation air, hot water heating and space cooling	
Heat pump system	Heat pump units	2 x 90 kW
	Peak load units	Oil-fired boilers, 300 kW
Heat source and heat sink	Groundwater (consumption system) 2 production wells, 300 m deep (60 m with clay) 2 injection wells - 60 m away from the production wells Water flow rate approx. 36 m^3 per hour	
SPF for the heat pump unit	3.5 to 4.0	
Supplementary information	Prior to the project, the groundwater was analyzed and the capacities of the wells were tested. Due to high and stable groundwater temperature, the heat pump achieves a high seasonal performance factor (SPF). During summer, the groundwater is used directly for space cooling. If free cooling is not sufficient to cover the space cooling demand, the heat pump unit is run as a chiller, and the surplus heat is rejected to the groundwater. The operational experiences from the system are good.	
Contact	Company	Geoenergi AS
	Address	Sandakerveien 114 A, 0404 Oslo
	Contact person	Rune Helgesen
	E-mail	rh@geoenergi.no
	Internet	http://www.geoenergi.no

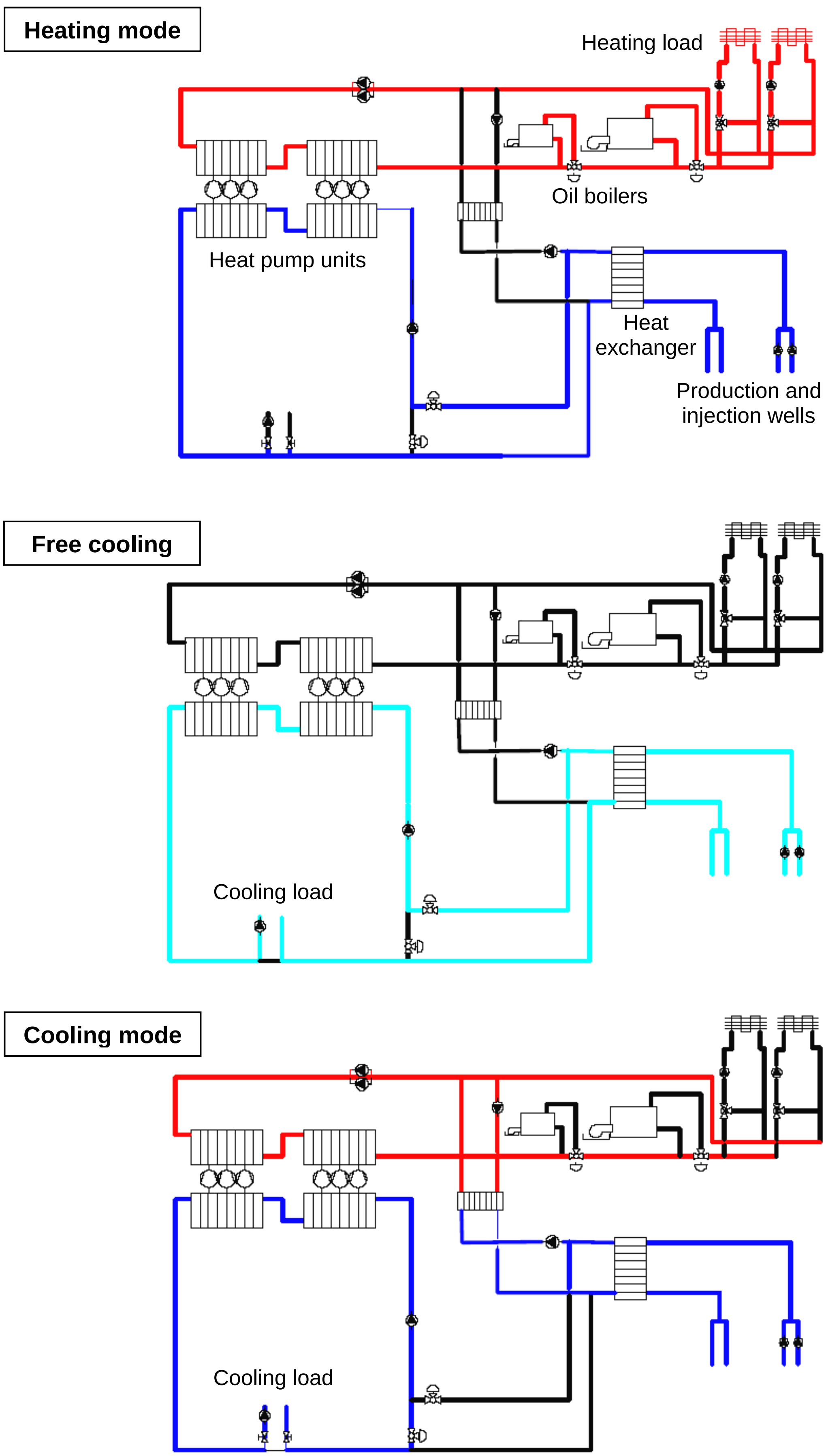

Figure 4.17 Operating modes for the 180 kW groundwater heat pump system (Geoenergi AS).

INSTALLATION EXAMPLE 2 – BLOCK OF FLATS

Name of building	Lena terrasse	
Location	Melhus, Norway	
Year of construction	2003	
Heating demands	118 flats, 8 500 m^2 – space heating (floor heating system), reheating of ventilation air and hot water heating	
Heat pump system	Heat pump units	2 x 130 kW
	Peak load units	Oil-fired boilers, 575 kW
Heat source	Groundwater (consumption system)	
	One production well, 34 m deep	
	One injection well 70 m away from the production well	
	Water flow rate approx. 54 m^3 per hour	
	Average groundwater temperature 6ºC	
SPF for the heat pump system	Approx. 3.0 (including peak load)	
Supplementary information	The heat pump unit has been designed to cover about 50% of the maximum space heating load (bivalent system), and covers about 80% of the annual space heating demand. The flats are equipped with low-temperature floor heating systems. More information about the heat pump system can be found at *http://www.caddet.org/infostore*	
Contact	Company	The Geological Survey of Norway
	Address	Leiv Erikssons vei 39, Trondheim
	Contact person	Kirsti Midttømme
	E-mail	kirsti.midttomme@ngu.no
	Internet	http://www.ngu.no

INSTALLATION EXAMPLE 3 – OFFICE BUILDING

Name of building	Alnafossen kontorpark	
Location	Brynseng, Norway	
Year of construction	2003	
Heating and cooling demands	35 000 m^2 – space heating, reheating of ventilation air, hot water heating, snow thawing and space/computer cooling	
Heat pump system	Heat pump units	2 x 600 kW
	Peak load units	Oil-fired boilers (bivalent system)
Heat source and heat sink	Vertical energy wells in bedrock 54 boreholes x 200 m Indirect system with single U-tubes (PEM, OD 40 mm)	
SPF - heat pump system	Not available	
Supplementary information	The energy wells are utilized as a thermal energy storage for the heat pump system. A considerable part of the space cooling demand is covered by free cooling from the heat pump evaporator (in heating mode) and from the relatively “cold” energy wells. The heat pump system was installed by the local energy utility, which is also responsible for operation and maintenance of the system.	
Contact 1	Company	Bærum Fjernvarme AS
	Address	Brynsveien 2, 1338 Sandvika
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	Internet	http://www.barum-fjernvarme.no
Contact 2	Company	Geoenergi AS
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	Contact person	Rune Helgesen
	E-mail	rh@geoenergi.no
	Internet	http://www.geoenergi.no

INSTALLATION EXAMPLE 4 – OFFICE BUILDING

Building type	Ericsson hovedkontor/main office	
Location	Asker, Norway	
Year of construction	2001	
Heating and cooling demands	Space heating, reheating of ventilation air, space cooling	
Heat pump system	Heat pump units	750 kW
	Peak load units	Oil-fired boilers (bivalent system)
Heat source	Vertical energy wells in bedrock 60 boreholes x 230 m – 10 m distance between the holes Indirect system with single U-tubes (PEM, OD 40 mm) Two and two energy wells connected in series	
SPF for the heat pump system	Not available	
Supplementary information	The energy wells are used as a thermal energy storage for the heat pump system. A considerable part of the space cooling demand is covered by free cooling from the heat pump evaporator (in heating mode) and from the relatively “cold” energy wells (free cooling).	
Contact 1	Company	Multiconsult AS
	Address	Hoffsveien 1, 0213 Oslo
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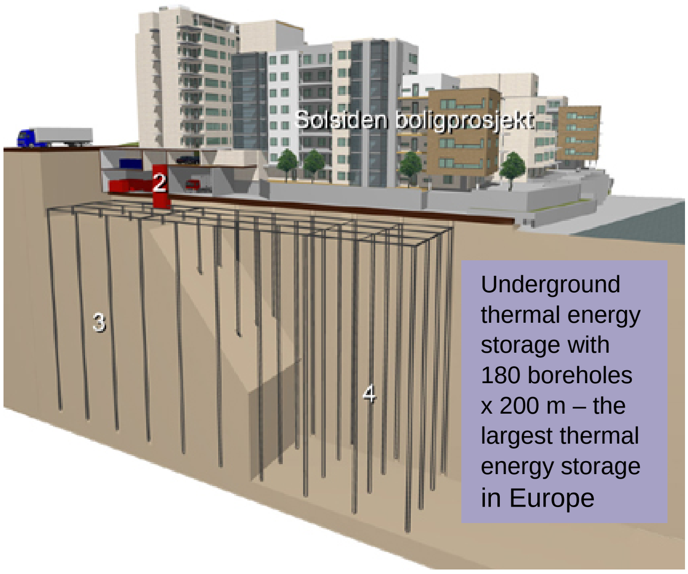
INSTALLATION EXAMPLE 5 – DISTRICT HEATING/COOLING SYSTEM



Name of building	Nydalen næringspark	
Location	Nydalen, Norway	
Year of construction	To be completed 2004	
Heating and cooling demands	180 000 m^2 - space heating, reheating of ventilation air, hot water heating and space cooling	
Heat pump system incl. peak load cooling with river water	Heat pump units Peak load units	6.0 MW heating, 9.5 MW cooling Oil-fired /electro boilers (bivalent syst.)
Heat source and heat sink	Vertical energy wells in bedrock 180 boreholes x 200 m – 7 m distance between the holes Indirect system with single U-tubes (PEM, OD 40 mm) Two and two wells connected in series	
SPF - heat pump system	Not available	
Supplementary information	Heat is supplied to a school building, a hotel, blocks of flats and a number of office buildings. The thermal energy storage (1.6 mill. m^3) is the largest of its kind in Europe. The peak load cooling load is covered by river water.	
Contact 1	Company Address Internet	Avantor ASA Nydalsveien 21, 0404 Oslo http://www.avantor.no
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INSTALLATION EXAMPLE 6 – DISTRICT HEATING/COOLING SYSTEM

Oslo Lufthavn, Gardermoen (photo Trond Isaksen).

Name of building	Oslo Lufthavn, OSL (Oslo Airport)	
Location	Gardermoen, Norway	
Year of construction	1998	
Heating and cooling demands	150 000 m^2 – space heating, reheating of ventilation air, hot water heating, snow thawing and space/computer cooling	
Heat pump system	Heat pump units	8 MW heating, 6 MW cooling capacity
	Peak load units	Biomass-fired boiler (20 MW)
		Oil-fired boilers (36 MW)
Heat source and heat sink	Groundwater (aquifer) 9 "warm" wells and 9 "cold" wells, 45 m deep 150 m between the hot and the cold wells The wells are equipped with special filter pipes Maximum water flow rate approx. 270 m^3 per hour	
SPF - heat pump system	Not available	
Supplementary information	The large aquifer under the airport is utilized as a thermal energy storage for the heat pump system. During the winter water is pumped from the warm wells, cooled by the heat pump and injected in the cold wells. During the summer, water from the cold wells is used for space cooling, and the heated water is injected in the warm wells. Additional cooling loads are covered by the heat pump units (chiller mode) and cooling towers.	
Contact	Company	Oslo Lufthavn AS (OSL)
	Address	Edwards Munchs vei, Gardermoen
	E-mail	Information manager
	Internet	firmapost@osl.no

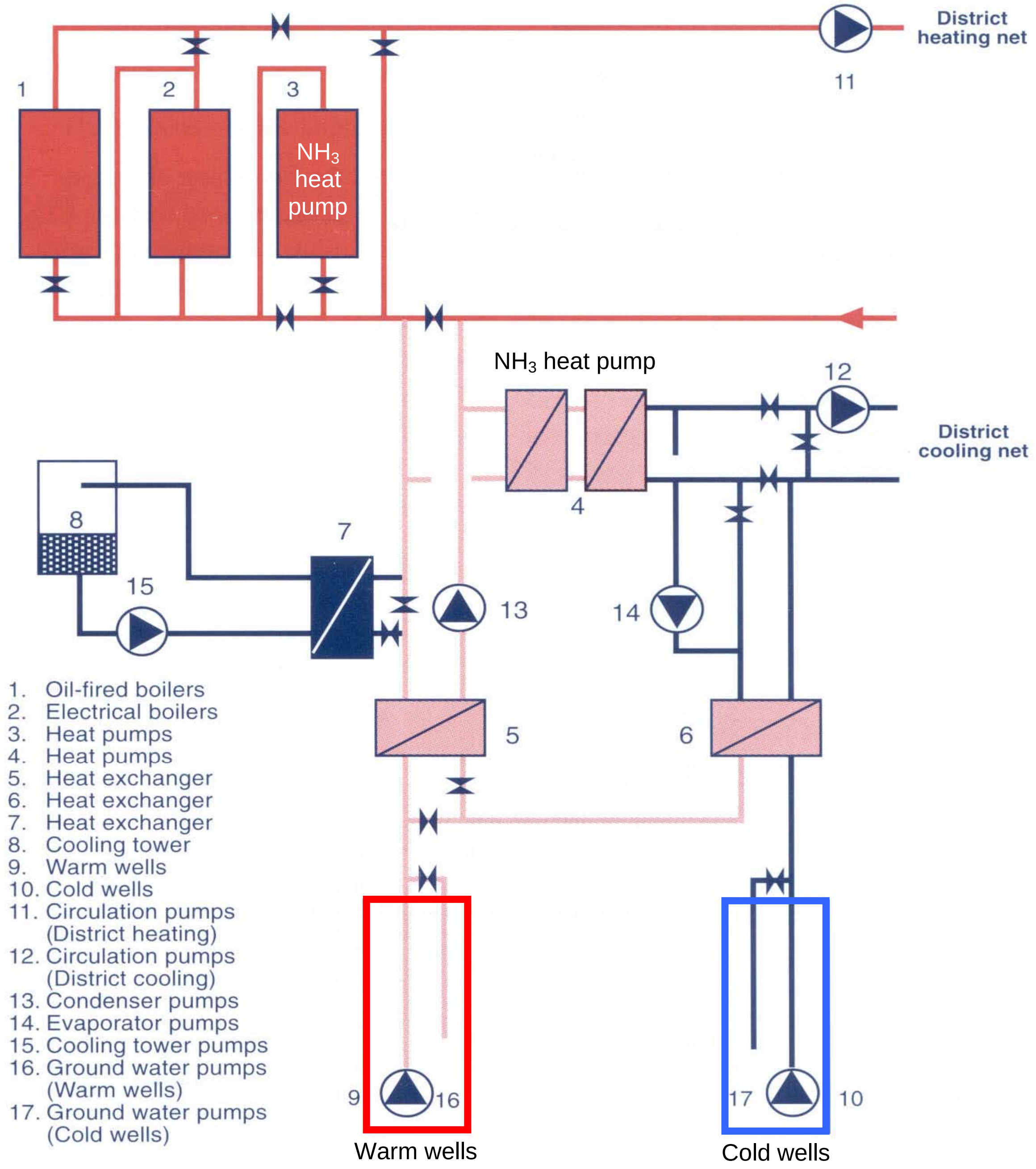


Figure 4.18 Principle of the energy plant at Oslo Airport (OSL), Gardermoen (Tokle, 1998).

4.5 Indirect closed-Loop Systems – Soil

Indirect closed-loop heat pumps that utilize soil as the heat source, are mainly regarded a viable option for residential installations. The ground heat exchanger (PEM, OD 40 mm) is buried horizontally in the ground at 60 to 150 cm depth and with 1 to 2 metres spacing. Due to the relatively large space requirement for the GHE, there are relatively few installations in Norway, and energy wells in bedrock represent a better alternative for houses will small yards. Figure 4.19 shows the principle of a residential indirect GSHP system extracting heat from soil/ground.

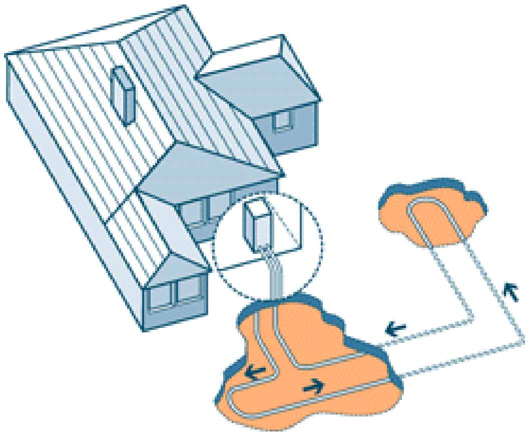


Figure 4.19 Principle of a residential GSHP utilizing a horizontal closed-loop GHE.

The heat capacity and thermal conductivity of the soil are mainly depending on the type of soil and the moisture content. Since most of the heat extracted from the ground comes from freezing of water, bog, garden mould, and clay are much better heat sources than gravel and dry sandy soil. The heat extraction rate for horizontal GHE in soil typically range from *15 to 20 W/m*.

Installations of horizontal closed-loop GHE are cheaper than vertical systems in bedrock, but the seasonal performance factor (SPF) will be inferior as a result of lower evaporation temperature. It is also more difficult to design the GHE correctly, and reduced growth for bushes and trees, settings of the ground and even permafrost have been reported.

4.6 Reported Problems for Norwegian GSHP Systems

In order to obtain profitable, energy efficient and reliable GSHP installations, it is important to implement a total quality concept where focus is on quality and system integration during all stages of the project – design, construction, installation, commissioning, operation and maintenance. A life cycle analysis (LCA) is a useful tool in such a concept, since both the investment costs as well as the lifetime operational and maintenance costs are included. *Generally, heat pump installations with low capital costs achieve lower energy efficiency and have more operational problems than high-quality systems with higher capital costs.*

Figure 4.20 illustrates the total quality concept.

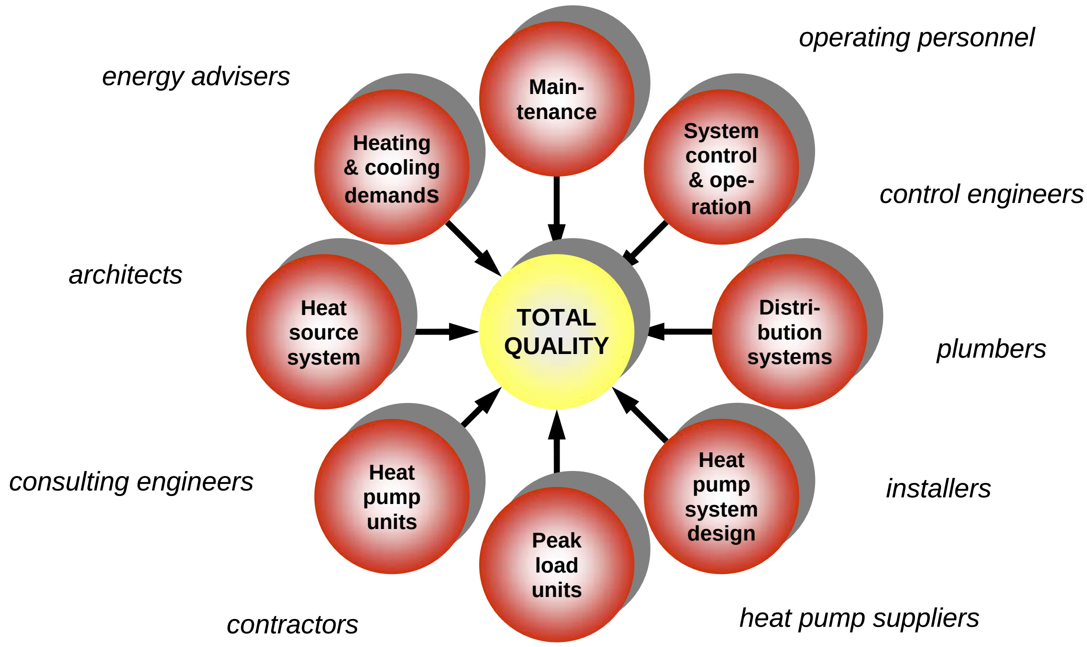


Figure 4.20 Illustration of the total quality concept for a GSHP system with regard to design, construction, installation, operation and maintenance.

Reported problems for Norwegian GSHP systems are summarized in Table 4.1:

Table 4.1 Reported problems for Norwegian GSHP systems.

Problem/Cause – Groundwater (Direct Systems)	**Consequences**
High content of humus, iron, manganese or carbonates in the groundwater	Fouling (oxidation of metal ionian) and clogging of heat exchangers and pumps – reduces the SPF for the heat pump, and may cause severe operational problems and possible shutdown of the system.
Short-term or long-term alternation of the groundwater level, e.g. due to mismatch in the flow rates between the consumption well(s) and the injection well(s).	May cause settings in the ground and possible damage to buildings and other installations.
Problem/Cause – Rock (Indirect Systems)	**Consequences**
Undersized energy wells, possibly in combination with insufficient or lack of recharging of the energy wells with external heat (e.g. excess heat from cooling systems, heat from exhaust ventilation air or solar heat).	Large temperature difference for the GHE and low evaporation temperature – reduces the heating capacity and the SPF for the heat pump, and may cause freezing of the boreholes and setting of the ground around the connecting pipelines to the energy central.
Mass flow rate (velocity) for the anti-freeze in the GHE below the critical Reynolds value (both temperature and fluid dependent).	Laminar flow in the GHE (Re < ~2300), low convective heat transfer coefficient and low evaporation temperature – reduces the heating capacity and SPF of the heat pump.
Problem/Cause – Soil (DX/Indirect Systems)	**Consequences**
Undersized horizontal GHE or insufficient ground area/volume for heat extraction etc.	Large temperature difference for the GHE and low evaporation temperature – reduces the heating capacity and SPF for the heat pump, and may cause settings of the ground around the pipelines and possible damage to buildings and other installations as well as permafrost.

SPF = Seasonal Performance Factor

Table 4.1 Reported problems for Norwegian GSHP systems - continued.

Problem/Cause – Components, System, Control	Consequences
Incorrect component selection, e.g. use of screw and scroll compressors instead of reciprocating compressor with better part load characteristics.	Reduces the SPF for the heat pump.
Incorrect or non-optimized system design.	Reduces the SPF for the heat pump, and may cause operational problems.
Oversized heat pump units.	Increases the first costs, reduces the SPF of the heat pump due to more part load operation and may cause operational problems.
Poor control system, e.g. imperfect coordination of the heat pump units and the peak load system (bivalent heating systems).	Reduces the SPF for the heat pump system.
Too high/low temperature level in the heat distribution and cooling distribution systems, respectively.	Reduces the SPF for the heat pump.
Compressor failure due to unfavourable operating conditions (low suction/high discharge temp.) etc.	Increases the first costs and reduces the SPF of the heat pump system due to lower operating hours.

SPF = Seasonal Performance Factor

5 GROUNDWATER AND BEDROCK DATA – DIGITAL MAPS

5.1 Groundwater

In Norway, the temperature in groundwater reservoirs 10 to 15 metres below ground level is typically 1 to 2 K higher than the average annual air temperature at the site, and the temperature is practically constant during the year. A rough overview of the groundwater temperatures in Norway, Sweden and Finland is shown in Figure 5.1. The map is based on data from the Nordic groundwater grid (NGU, 2004).

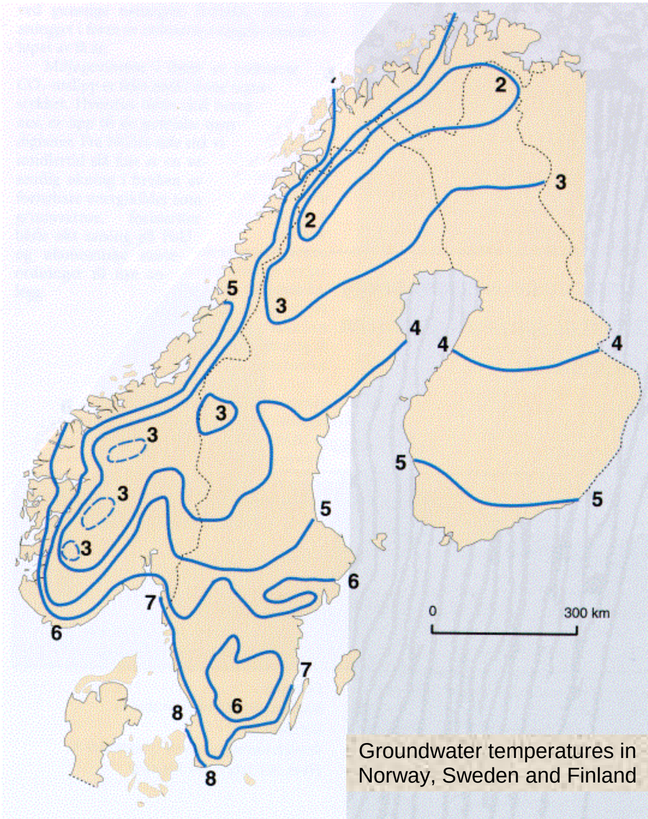


Figure 5.1 Groundwater temperature map for the Nordic countries (NGU, 2004).

Figure 5.2 presents, as an example, weekly temperature variations during one year (1983/84) for air, river water and groundwater at Elverum, Norway – inland climate (NGU, 2004). During the winter the air temperature fluctuates between -25ºC and +10ºC, the temperature of the river water is more or less at the freezing point, whereas the groundwater temperature remains more or less constant at 5ºC. This clearly demonstrates the great advantage of using groundwater as a heat source for heat pumps in Norway.

The Geological Survey of Norway (NGU) has developed *digital web-based groundwater maps*. The borehole database contains information from roughly 23,000 groundwater wells in bedrock, 2500 wells in sand/gravel and 1,500 energy wells (NGU, 2004), and the information includes location of the well (coordinates, municipality), well data (diameter, depth, application) and water flow rate. The borehole maps can be combined with detailed *digital bedrock maps* or *quaternary geological maps* (uncompacted material), see Chapter 5.2.

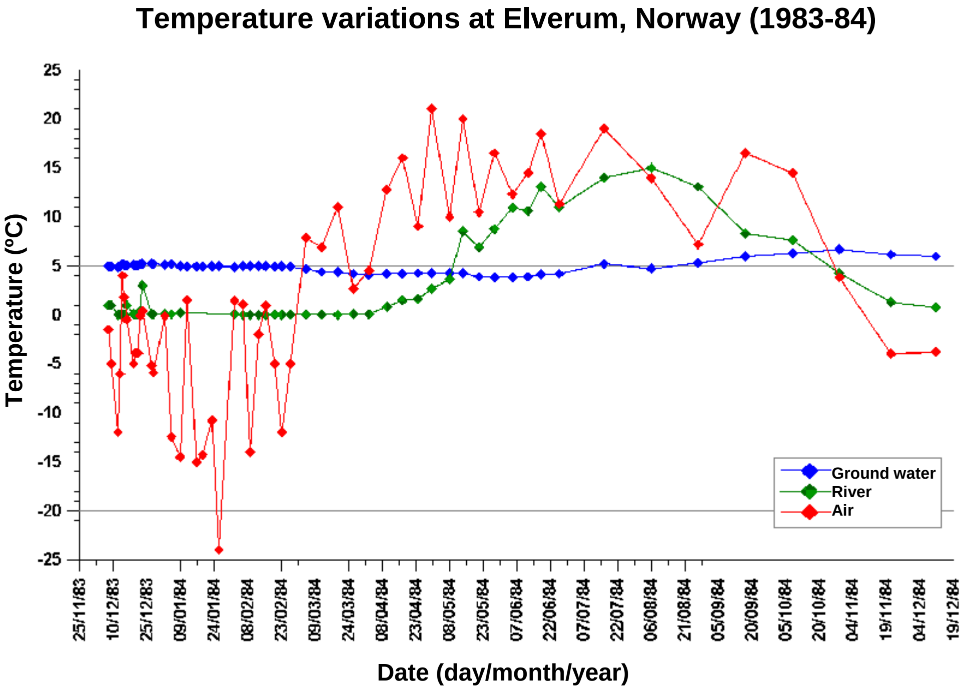


Figure 5.2 Weekly temperature variations during one year (1984/85) for air, river water and groundwater at Elverum, Norway – inland climate (NGU, 2004).

Figure 5.4 shows a printout example from the digital borehole database displaying the area around the city of Trondheim. The different well types are represented by coloured circles, and the topographical background map can be replaced by a bedrock map or a quaternary geological map.

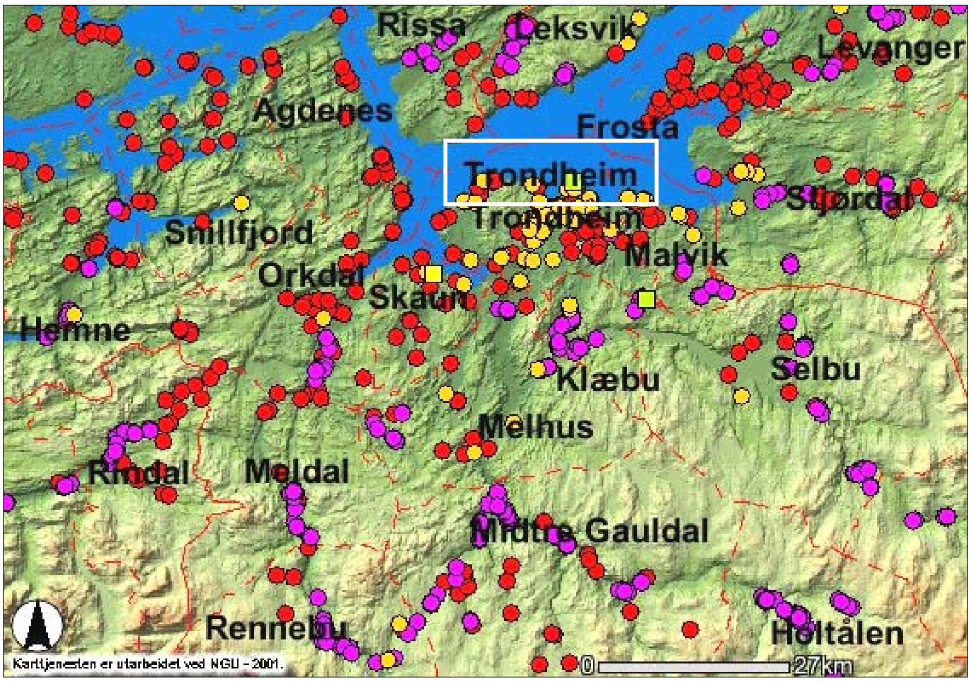


Figure 5.3 Printout example from the Norwegian borehole database. Red circles - groundwater wells in bedrock, violet circles - wells in sand/gravel, yellow circles - energy wells in bedrock (NGU, 2004).

5.2 Bedrock and Uncompacted Material

5.2.1 Thermal Conductivity of Bedrock

Figure 5.4 shows measured ranges for thermal conductivity of different rock types in Norway (NGU, 2004). For GSHP systems, fewer energy wells will be required in sandstone than in volcanic rock, limestone or syenite due to the considerably higher thermal conductivity.

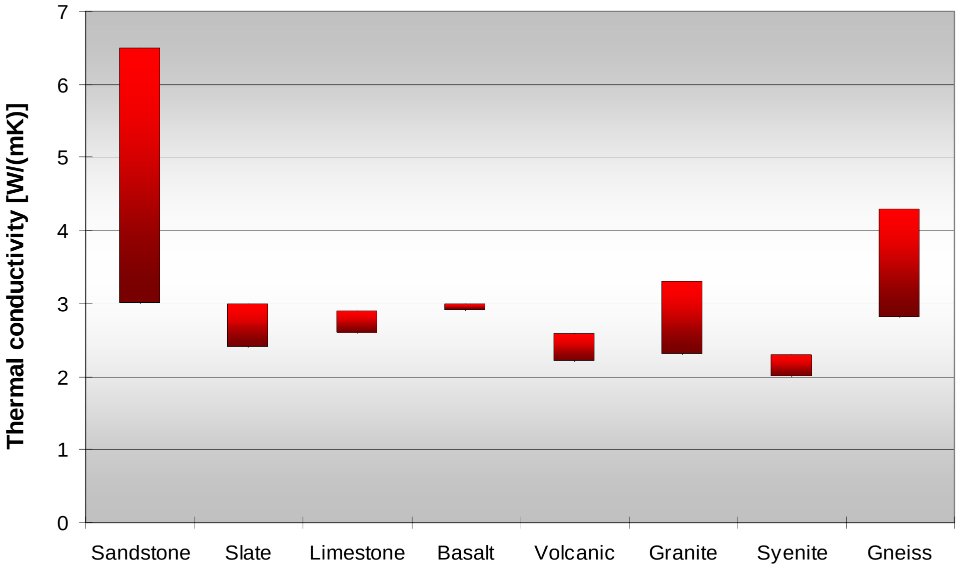


Figure 5.4 Measured thermal conductivity of different rock types in Norway (NGU, 2004).

Figure 5.5 shows, as an example, measured thermal conductivity of bedrock (average values) for the Asker/Bærum municipality south of Oslo (NGU, 2004).

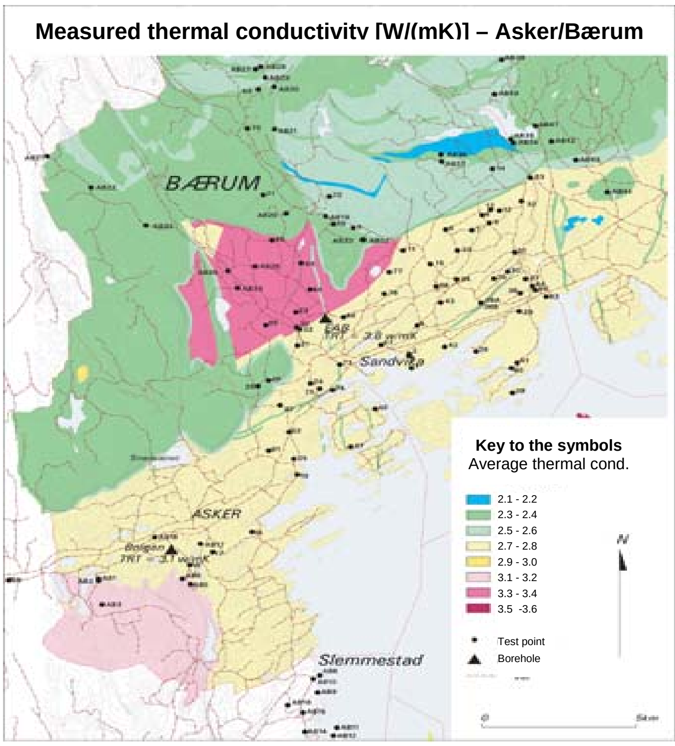


Figure 5.5 Measured thermal conductivity in bedrock for Asker/Bærum (NGU, 2004).

5.2.2 *Bedrock Data and Bedrock Maps*

Figure 5.6 shows examples of stratigraphy (rock type layers), geothermal gradients and groundwater levels for 475 m deep boreholes drilled at Arnestad and Gullhaug in Norway (NGU, 2004).

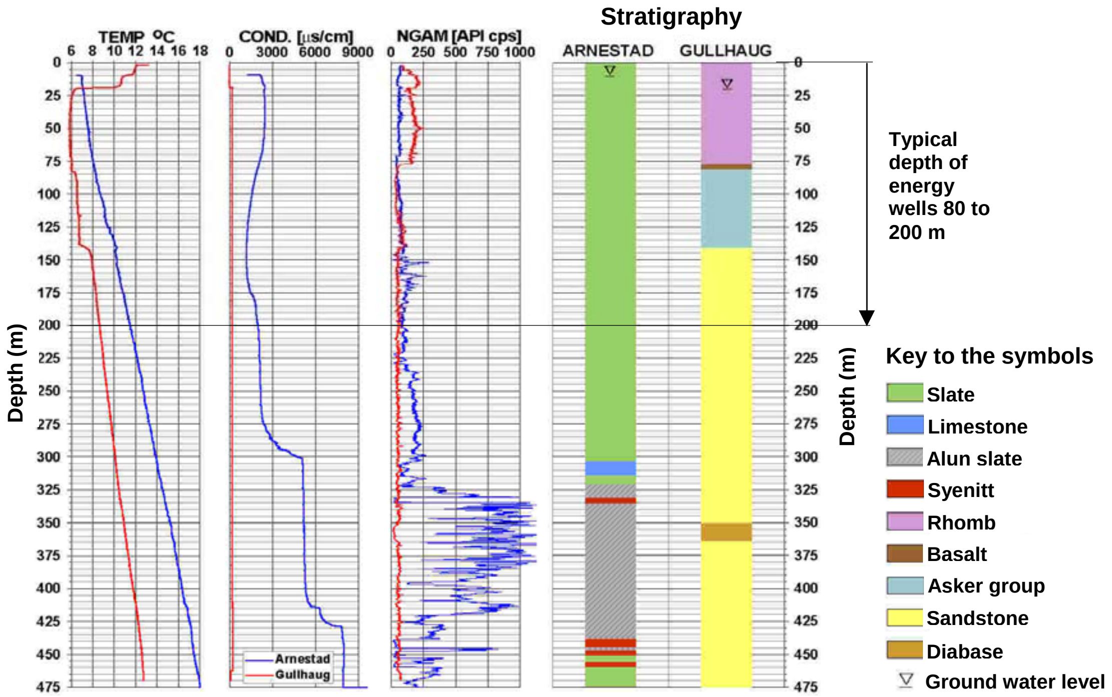


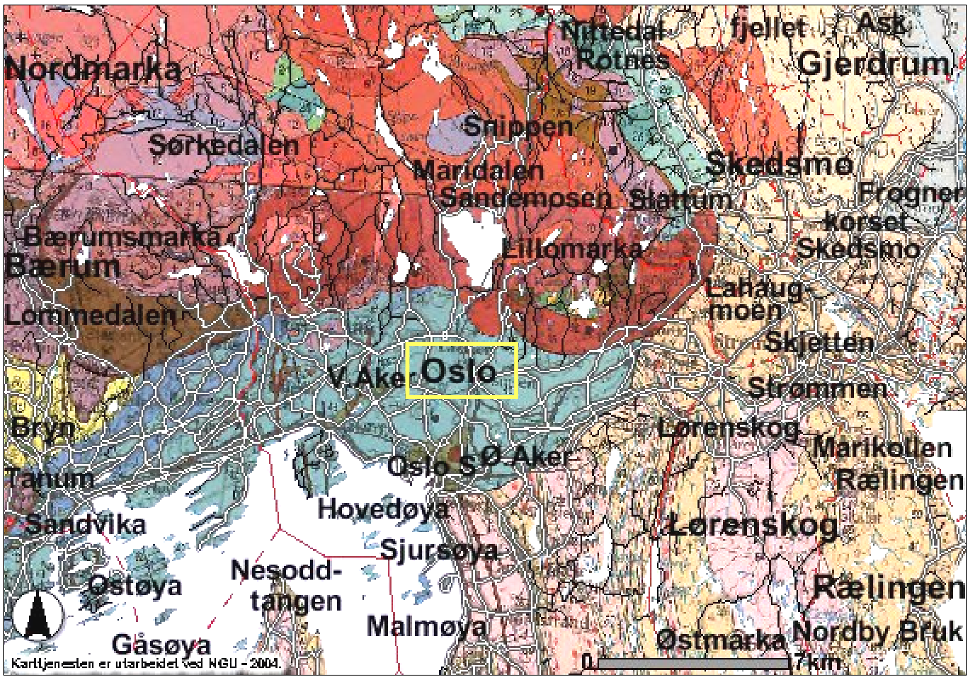
Figure 5.6 Example of stratigraphy, geothermal gradients and groundwater level for boreholes drilled at Arnestad and Gullhaug, Norway (NGU, 2004).

Figure 5.6 clearly demonstrates that there are considerable variations in the stratigraphy, geothermal gradient and groundwater levels for different boreholes, and that detailed information about the local conditions for the bedrock and the groundwater is required when dimensioning and drilling energy wells for GSHP systems.

The Geological Survey of Norway (NGU) has developed *digital bedrock maps* (1:250,000) and *quarternary geological maps* (1:1,000,000). The latter database includes information about uncompacted material such as sand, gravel and clay (NGU, 2004). As pointed out in the previous chapter, the maps can be combined with digital groundwater maps.

Figure 5.7 shows a printout example of digital bedrock maps displaying the areas around the two largest cities in Norway, Oslo and Bergen. Although the geological bedrock maps are essential tools when planning and designing GSHP installations, *geological expertise is always required* in order to obtain competent dimensioning and drilling of energy wells and thermal energy storages in bedrock. For larger installation with more than 15 to 20 energy wells, the utilization of thermal response testing (TRT) will lead to a more precise dimensioning and design of the borehole system (ref. Chapter 4.4.4).

An advanced high-resolution digital map system comprising e.g. bedrock maps (N250), quaternary geological maps (N1000) and groundwater wells is under development. A prototype version can be found at the Internet site: http://www.ngu.no/kart/arealis



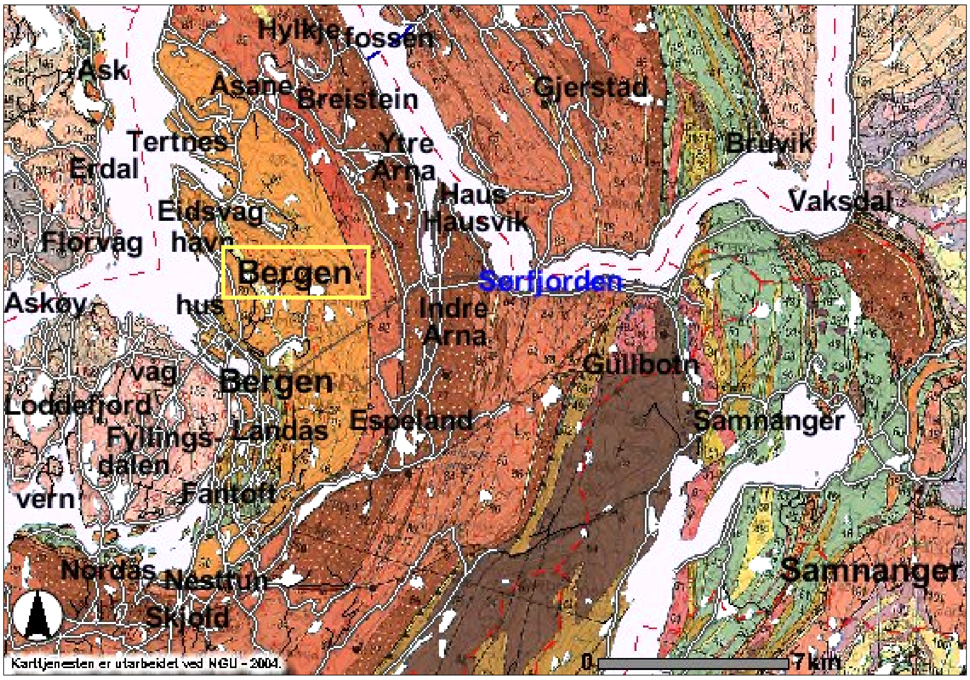


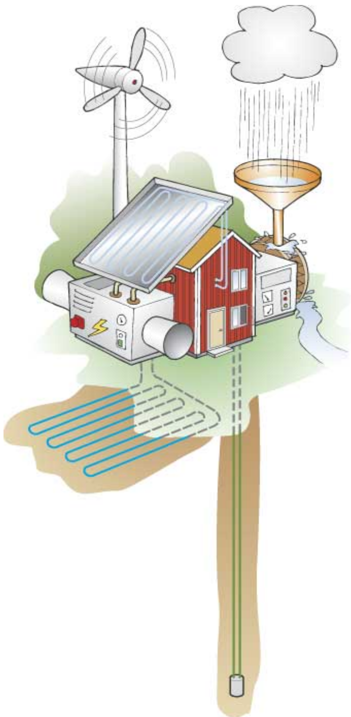
Figure 5.7 Printout examples from the Norwegian digital bedrock database (NGU, 2004).

6 NORWEGIAN INTERNET HOME PAGE

A Norwegian Internet homepage has been established under IEA HPP Annex 29, in order to disseminate relevant high-quality information on ground-source heat pump (GSHP) systems to different Norwegian target groups.

www.energy.sintef.no/prosjekt/Annex29/

The main structure of the homepage is as follows:



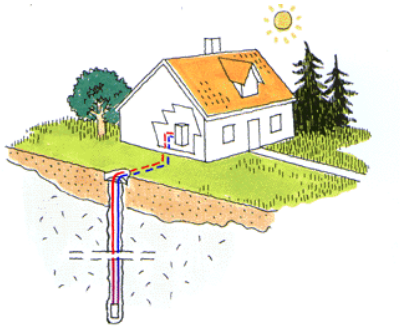
- **Hovedside** Main page
- **IEA Annex 29** Description of IEA HPP Annex 29
- **Grunnvarme** Classification and description of GSHP syst.
- **Eksempler** Presentation of different GSHP installations
- **Publikasjoner** Publications – reports, articles and brochures
- **Lenker** Internet links
- **Nyheter** News – technology, markets, policies etc.
- **Forskning** Research projects on GSHP systems

Although the Internet homepage has been tailor-made for different *Norwegian target groups*, there is plenty of updated and relevant information in English, including reports, articles, brochures, Internet links, news and presentations of new research and development projects. Some relevant information from the Norwegian website are presented on the following pages.

The Norwegian GSHP Internet homepage will be regularly updated and extended during the Annex period (2004-2006).

Anleggseksempler (*Examples of GSHP Installations*)

I de senere år har det vært en betydelig økning i antall installasjoner av grunnvarmebaserte varmepumpeanlegg i blant annet Norge, Danmark, Sverige, Sveits, Tyskland, Østerrike, Frankrike, Canada og USA. Denne siden presenterer en del installasjoner i boliger, ulike typer yrkesbygg samt større fjernvarme- og fjernkjølesystemer.



- Norsk status (*NGU*)
- Internasjonal status (*Renewable Energy World*)

Norske anlegg (*Norwegian installations*)

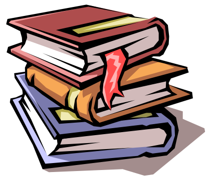
- Enebolig (Trondheim)
- Helsebygg - Sandetun sykehjem og omsorgsboliger (Sande)
- Terrasseleiligheter - Lena Terrasse (Melhus)
- Kontorbygg - Alnafossen kontorpark (Brynseng)
- Kontorbygg - Ericssons hovedkontor (Asker)
- Fjernvarme-/fjernkjøleanlegg - Nydalen Næringspark (Nydalen)
- Fjernvarme-/fjernkjøleanlegg - Oslo Lufthavn (Gardermoen)

Utenlandske anlegg (*European installations*)

- Lavenergibolig - Grafstal (Sveits)
- Enebolig - Avolsheim (Frankrike)
- Enebolig - West Grimstead (Storbritannia)
- Nærvarmeanlegg for boliger - Swifterbant (Nederland)
- Skole - Buntingsdale (Storbritannia)
- Kjøpesenter - Arninge (Sverige)
- Skole - Stockholm (Sverige)
- Hotell - Luleå (Sverige)
- Kontorbygg - Lyon (Frankrike)
- Kontorbygg - Delft (Nederland)
- Kontorbygg - Chesterfield (Storbritannia)
- Fjernvarmeanlegg (Tyskland)
- Større varmepumpeanlegg (Tyskland)

Bøker, rapporter, artikler og foredrag (*Books, reports, articles, lectures*)

Norske (*Norwegian*)



Rapport (2004) - Scope of Dynamic Thermal Storage (DTS)
Forstudie av dynamisk termisk lager fra NTNU-SINTEFs Smartbyggprogram (*2002-2006*)

Rapport (2004) - Større varmepumpeanlegg med grunnvarme som varmekilde
Beskrivelse av grunnvarmebaserte varmepumpesystemer for større bygninger (*SINTEF*)

Rapport (2004) - Temahefte, varmepumper i boliger
Boligvarmepumper med varmeopptak fra bl.a. fjell, grunnvann eller jord (*SINTEF*)

Rapport (2003) - Enviro-Cores: Thermal Storage Integrated with Heat Pumps
Analyse av ulike typer termiske energilagre integrert med varmepumpe (*Interconsult ASA)*

Rapport (2003) - Thermal Energy Storage, a State-of-the-Art Report
Statusrapport om termisk lagring fra NTNU-SINTEFs Smartbygg-program (*2002-2006*)

Foredrag (2003) - Grunnvarme
Innføring i varmepumpebaserte grunnvarmesystemer - anleggseksempler (*NGU*)

Rapport (2003) - Geotermisk energi fra fast fjell
Analyse av grunne og dype anlegg - diplomoppgave (*NTNU*)

Rapport (2003) - Energiuttak fra fjell
Et studium av data fra termisk responstesting - hovedoppgave (*NTNU*)

Rapport (2002) - Termisk Responstesting
Bruk av termisk responstesting ved dimensjonering av energibrønner - prosjektoppgave (*NTNU*)

Rapport (2002) - Bruk av grunnvarme til oppvarming av eneboliger og næringsbygg
Barrierer og muligheter med grunnvarme - oppgave utført av studenter i Eksperter i Team (*NTNU*)

Rapport (2002) - Grunnvarmebasert oppvarming av bolighus
Vurdering av hullengde på energibrønner - oppgave utført av studenter i Eksperter i Team (*NTNU*)

Utenlandske (*International*)

Artikkel (2004) - Geothermal (Ground-Source) Heat Pumps - A World Overview
Internasjonal status for grunnvarmebaserte varmepumpesystemer (*GHC Bulletin*)

Rapport (2004) - Smart Generation, Powering Ontario with Renewable Energy
Utdrag fra rapport om fornybare energikilder inkl. grunnvarmebaserte varmepumper (*Canada*)

Rapport (2004) - Solvärme i bosteder med analys av kombinationen solvärme og varmepumpe
Utdrag av lisensiatrapport som bl.a. omhandler lading av energibrønner med solvarme (*Sverige*)

Artikkel (2004) - Bergvärmepumpe med borrholsåterladning
Bruk av avtrekksluft fra ventilasjonsanlegg for lading av borehull for boliger (*Sverige*)

Artikkel (2004) - Energy Comparison of a Ground-Source R-1270 Heat Pump
Optimalisering av grunnvarmebasert varmepumpe med propylen (R-1270) som arbeidsmedium (*England*)

Artikkel (2004) - CO_2 Two-Phase Thermosyphon as Heat Source for Heat Pumps
Effektivt varmeopptakssystem for borehullsbaserte varmepumper (*Østerrike*)

Artikkel (2003) - Ground-Source Heat Pump - A World Overview
Internasjonal status for grunnvarmebaserte varmepumpesystemer (*Renewable Energy World*)

Artikkel (2003) - Current Status of Ground Source Heat Pump Systems i Europe
Europeisk status for grunnvarmebaserte varmepumpesystemer

Bøker (2003) - Ground-Source Heat Pump Systems
Henvisning til ulike håndbøker om grunnvarmebaserte varmepumpeanlegg (*ASHRAE*)

Artikkel (2003) - Energy and Exergy Analysis of Ground Source (Geothermal) Heat Pump Systems
Energi-/eksergianalyse av en 50 m dyp energibrønn med enkle U-rør (*Tyrkia*)

Artikkel (2003) - Heat Transfer Analysis of Boreholes in Vertical Ground Heat Exchangers
Analyse av varmetransport i vertikale borehull med enkle og doble U-rør (*Kina*)

Rapport (2002) - Ground-Source Heat Pump Systems Case Studies
Henvisning til rapport om case-studier av grunnvarmebaserte varmepumpeanlegg (*IEA HP Centre*)

Artikkel (2002) - CO_2 Heat Pipes for Heat Pumps
Beskrivelse av et nytt og mer effektivt varmeopptakssystem for grunnvarmeanlegg basert på CO_2 (*Østerrike*)

Brosjyre (2002) - Closed-Loop Ground-Coupled Heat Pumps
Direkte og indirekte grunnvarmebaserte systemer (*IEA Heat Pump Centre*)

Rapport (2002) - Solfångare och värmepump - Markedsöversikt og preliminära simuleringsresultat
Kombisystemer med varmepumper og solvarmelagring i grunnvarmebrønner (*Sverige*)

Artikkel (2001) - Ground Heat Sources for HPs - Classification, Characteristics and Advantages
Generell beskrivelse av grunnvarmebaserte varmepumpesystemer (*Tyskland*)

Rapport (2001) - System för värme och kyla ur mark - En nulägesbeskrivning
Teknisk, økonomisk og miljømessig vurdering av grunnvarmebaserte varmeopptakssystemer (*Sverige*)

Artikkel (2001) - Underground Thermal Energy Storage
Energilagring i fjell (borehull), grunnvannsreservoarer og bergrom (*Tyskland*)

Artikkel (2001) - PC Programs and Modelling for Borehole Heat Exchanger Design
Presentasjon av programvare for beregning av borehull for grunnvarmesystemer (*Sverige, Tyskland*)

Rapport (1999) - Ground-Source Heat Pumps - A Technology Review
Internasjonal status mht. teknologi, anvendelser, standarder, økonomi og marked (*BSRIA, England*)

Rapport (1999) - Global Warming Impacts of Ground-Source HPs Compared to Other Systems
Grunnvarmebaserte varmepumper kontra konvensjonelle systemer for oppvarming/kjøling (*Canada*)

Magasin (1999) - Ground-Source Heat Pump Systems
Newsletter med tema grunnvarmebaserte varmepumper (*IEA Heat Pump Centre*)

Magasin (1998) - Heat Pump Systems and Thermal Storage
Newsletter med tema varmepumper og termisk lagring (*IEA Heat Pump Centre*)

Lenker til Internettsider (*Links to Norwegian and international websites*)

Norsk grunnvarmekompetanse (*Norwegian Expertise*)

- Norges geologiske undersøkelse (*Trondheim*)
- Norsk brønnborerforening (*Horten*)
- Båsum Boring AS (*Børsa, Krøderen*)
- Geoenergi AS (*Oslo*)

Boring av energibrønner (*Norwegian Drilling Companies*)

- Agder Brønn- og Spesialboring AS (*Arendal*)
- Brustugun Brønnboring AS (*Skjåk*)
- Brødrene Myhre Brønnboring AS (*Hønefoss*)
- Båsum Boring AS (*Børsa, Krøderen*)
- Gudbrandsdal Brønnboring AS (*Kvam*)
- Hallingdal Bergboring AS (*Ål*)
- Holt Risa AS (*Holmestrand, Porsgrunn, Nærbø*)
- Nordenfjeldske Brønn- og Spesialboringer AS (*Åsnes, Finnskog*)
- Rejos Gruppen – Brønnboring (*Storslett*)
- Sør-Norsk Brønnboring AS (*Skien*)

- Universal Brønnboring AS (*Oslo*)
- Vann & Energiboring AS (*Froland*)
- Vestnorsk Brunnboring AS (*Eikangervåg*)
- W.B. Brønnboring AS (*Brevik*)

Internasjonale grunnvarmesider (*International Websites*)

- Den svenske brønnborerforeningen
- International Ground Source Heat Pump Association
- Geothermal Heat Pump Consortium (*USA*)
- International Geothermal Association
- Earth Energy Society of Canada
- Tysk grunnvarmeside med mange gode artikler (*Sanner*)
- PC-program for brønndimensjonering (*GCHPCalc*)
- PC-program for brønndimensjonering (*EED*)

Norske organisasjoner og aktører (*Norwegian Organisations*)

- SINTEF Energiforskning AS (*Trondheim*)
- Norsk varmepumpeforening, NOVAP (*Oslo*)
- Kulde-og varmepumpeentreprenørenes landsforening, KELF (*Oslo*)
- ENOVA SF (*Trondheim*)

Internasjonale organisasjoner og aktører (*International Organisations*)

- IEA Heat Pump Centre (*IEA HPC*)
- European Heat Pump Association (*EHPA*)
- Caddet Energy Efficiency and Renewable Energy

Nyheter om grunnvarme (*News*)

03.12.2004 - Grants and Tecnologies - Ground-Source Heat Pumps
Ny tilskuddsordning for grunnvarmebaserte varmepumper (*Storbritannia*)

29.10.2004 - Smart Generation - Powering Ontario with Renewable Energy
Ny rapport fra Ontario - Fornybare energiressurser inkl. grunnvarme (*Canada*)

01.09.2004 - Earth Energy Heat Pumps as a Component of Green Heat
Kampanje for å fremme bruken av grunnvarmebaserte varmepumper (*Canada*)

19.08.2004 - Earth Energy Systems Offer Greatest Greenhouse Gas Mitigation
Grunnvarmebaserte varmepumper kan redusere verdens CO_2-utslipp med 6%

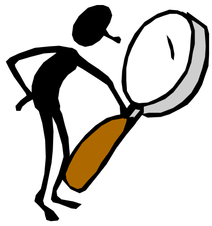
18.07.2004 - Global Warming Impact of Ground-Source Heat Pumps (Canada)
Grunnvarmebaserte varmepumper gir lavest miljøbelastning av oppvarmings-/kjølesystemer

26.05.2004 - EU Commission Report - The Share of Renewable Energy in the EU
EU-fokus på blant annet grunnvarmebaserte varmepumper - se side 30, 32 og 37

05.05.2004 - Storstilt satsing på grunnvarme
Planlagt installasjon av 25000 større grunnvarmebaserte varmepumper innen 2008 (*Canada*)

Forsknings- og utviklingsprosjekter *(R&D Projects)*

Norske (*Norwegian*)



Rapport (2004) - Scope of Dynamic Thermal Storage
Forstudie av dynamisk termisk lager fra NTNU-SINTEFs Smartbygg-program (2002-2006)

Rapport (2003) - Thermal Energy Storage - A State-of-the-Art Report
Statusrapport om termisk lagring fra NTNU-SINTEFs Smartbygg-program (2002-2006)

Utenlandske (*International*)

Artikkel (2004) - Heat Transfer in Ground Heat Exchangers with Groundwater Advection
Innvirkning av grunnvannsbevegelser på varmetransport i kollektorslanger (U-rør) i vertikale borehull (*Kina*)

Arikkel (2004) - Roof-Sized PV/Thermal Array Combined with a Ground-Coupled Heat Pump
Analyse av oppvarmingssystem for bolig med grunnvarmepumpe og PVT solenergipaneler (*Nederland*)

Artikkel (2004) - Improvement in Modelling of Heat Transfer in Vertical Ground Heat Exchangers
Modellering av varmetransport for kollektorslanger (U-rør) i vertikale borehull (*Kina*l

Artikkel (2004) - CO_2 Two-Phase Thermosyphon as Heat Source for Heat Pumps
Ny type varmeopptakssystem for borehullsbaserte varmepumpeanlegg (*Østerrike*)

Artikkel (2002) - CO_2 Heat Pipes for Heat Pumps
Et nytt og mer effektivt varmeopptakssystem for grunnvarmeanlegg (*Østerrike*)

7 REFERENCES

- Båsum Boring AS, 2004: Information from website: http://www.basum.no/
- Eggen, G., 2003: *Feasibility Study – ENVIRO CORES: Thermal Energy Storage Integrated with Heat Pumps*. Interconsult ASA, Trondheim, Norway.
- Fahlén, P., 2004: *Bergvärmepump med borrhålsåterladdning* (GSHP with recharging of the borehole). Energi/Milö 4/2004, pp. 59-62.
- Gehlin, S., 2002: *Thermal Response Test – Method Development and Evaluation*. Doctoral thesis (2002:39) at Luleå University of Technology, dept. of Environmental Engineering, Div. of Water Resources Engineering, Sweden. ISSN 1402-1544.
- Gether, H., Gether, J., Stang, J., 2003. *Scope of Dynamic Thermal Storage*. A systems and feasibility study within the research program "Smart Energy-Efficient Buildings" and NTNU and SINTEF, 2002-2006.
- Helgsen, R., Skarphagen, H., Gleditsch Borgnes, B., Bøhn, T.I., 2001. *Evalueringsrapport – Termisk responstesting av energibrønner (Thermal response testing of boreholes)*. E-Co Smart, NGU (Geology for the Society) and Geoenergi AS.
- Helgesen, R., 2004: *Oral communication*. Geoenergi AS, Norway (http://www.geoenergi.no).
- Hellström, G. *Oral communication*. Geoenergi AS, Norway.
- IEA, 2002: *Energy Conservation through Energy Storage Programme (ECES)*. Brochure from the International Energy Agency, version May 2002.
- Midttømme, K., 2004: *Oral communication*. Geological Survey of Norway (NGU).
- NGU (Geological Survey of Norway), 2004. Information from website: http://www.ngu.no/
- Nielsen, K., Gether, H., Gether, J., 2003: *Thermal Energy Storage.* A State-of-the-Art Report within the research programme "Smart Energy-Efficient Buildings" and NTNU and SINTEF, 2002-2006.
- Lund, J., Sanner, B., Rybach, L., Curtis, R., Hellström, G., 2003: *Ground- Source Heat Pumps – A World Overview*. Renewable Energy World, July-August 2003, pp. 218-227.
- Skarphagen, H., 2004: *Oral communication*. Båsum Boring AS, Norway.
- Stene, J., 1998: *Guidelines for Design and Operation of Compression Heat Pump, Air Conditioning and Refrigerating Systems with Natural Working Fluids*. IEA Heat Pump Programme Report no. HPP-AN22-4. ISBN 90-73741-31-9.
- Tokle, T., 1998: *Oslo Gardermoen Airport – Ammonia Heat Pump System Using Ground Water as Heat Source and Heat Sink*. Heat Pump Centre Newsletter, Vol. 16, no. 3/1998, pp. 20-22.

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