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Intelligent Energy Europe

IGEIA

Integration of Geothermal Energy into Industrial Applications

Deliverable 7

Introduction to Underground Thermal Energy Storage and Market Potential in Sweden

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August 2007

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ra02e 2005-01-17

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1 Introduction

Ground source heat pumps using the underground as a source of energy have long been used for heating and cooling of residential buildings in Europe and the USA. To some extent, the systems have also been applied for commercial and institutional buildings and often in large scales.

At the end of 2004, the totally installed capacity of ground source systems for direct use (generation of electricity excluded) was in the order of 28 000 MW producing some 260 TWh of energy (Lund 2005)

Of this capacity, only a minor portion was applied for the industrial sector (1 300 MW) with the aqua- and agriculture sectors as dominating users (800 MW).

High temperature underground storage systems have not been more than sparsely realized. However, the potential for such systems using solar energy and industrial waste heat as a source of energy is high. In Europe a number of high temperature storage projects have been applied as experimental or demonstration plants.

In this project, the objective is to demonstrate all types of geothermal systems for industrial applications. Extraction of heat by shallow or deep wells are fairly well known, while systems for storage of heat and cold is still not very well adopted to market. For this reason an overview of options using the underground for seasonal or diurnal storage of thermal energy is given as a general introduction. The development of these storage technologies have preferably been performed within the frame of International Energy Agency, The Implementing Agreement "Energy Conservation through Energy Storage", ECES (homepage www.iea-eces.org)

2 Basic storage concepts for thermal use

2.1 Heat pump supported storage systems

2.1.1 Introduction

Storage of renewable energy in the underground will reduce the usage of fossil fuels and electricity. Hence, these systems will lead to CO_2 reduction as well as a reduction of other environmentally hazardous gas emissions, like SO_X and NO_X.

There are several schemes where the underground is used for UTES (Underground Thermal Energy Storage) depending on factors such as geological and hydrogeological site conditions. In figure 2.1, some different options for using the underground for efficient energy production are schematically illustrated.

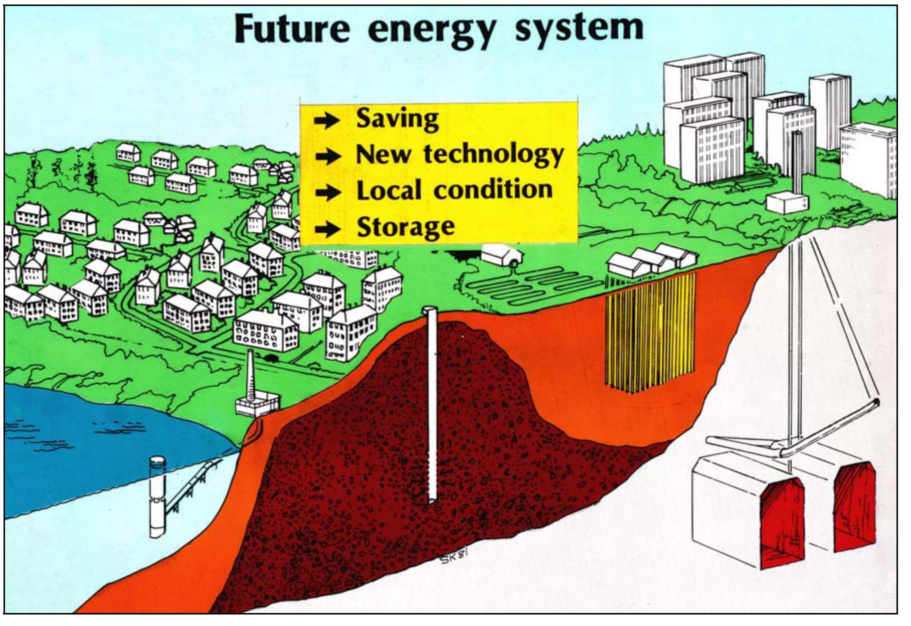

Figure 2.1 Different options of using the underground for efficient energy production with natural heat and cold.

The two most promising options are storage of energy in aquifers (ATES) and through borehole heat exchangers in a soil or rock mass (BTES). These concepts have already been introduced as commercial systems on the energy market in several countries. Another option is to use underground cavities, like abandoned mines, but these concepts (CTES) are so far rarely applied commercially.

2.1.2 Low temperature storage in aquifers (ATES)

In ATES (Aquifer Thermal Energy Storage) systems, groundwater carries the thermal energy into and out of an aquifer. Water wells are used for the connection to the aquifer. However, these wells are normally designed with double functions, both as production and infiltration wells.

The energy is partly stored in the ground water itself but to a larger extent in the grains (or porous rock mass) that form the aquifer. Heat is transferred from the ground water to the grains as it flows by. This results in the development of a thermal front between different parts of an aquifer that have different temperatures. This front will move in a radial direction from the well during charging of the energy storage and then turn back while discharging, see figure 2.2.

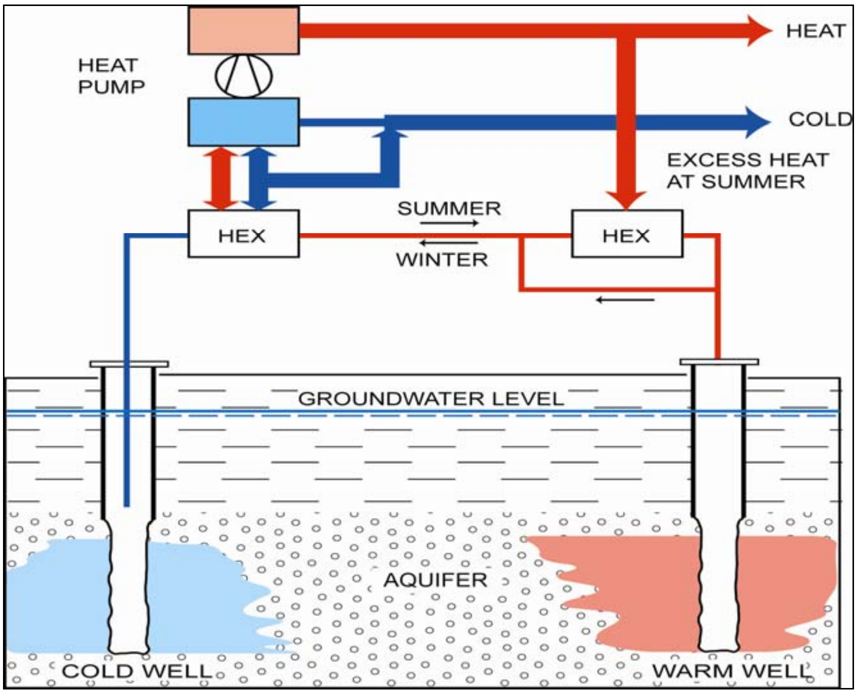

Figure 2.2 The most common ATES configuration.

Worldwide there are several hundreds of these systems in operation, with the Netherlands (more than 200 plants) and Sweden (some 60 plants) as the dominating countries of implementation. Practically all systems are designed for low temperature applications where both heat and cold are seasonally stored. Normally the cold side of the aquifer can be directly used for “free cooling”, while the warm side will act as an excellent source of energy for the heat pump. Typically the cold side of these systems will work at a temperature level of 4-8 ^{0}C, while the warm side will reflect the return temperature from the cooling loop, normally in the range of 12-14 ^{0}C.

2.1.3 Low temperature storage in boreholes (BTES)

BTES (Borehole Thermal Energy Storage) systems consist of a larger number of closely spaced boreholes, normally 50 – 200 m deep. These are serving as heat exchangers to the underground. For this reason they are equipped with Borehole Heat Exchangers (BHE), typically a single U-pipe.

There are several configuration options, but the system normally used in Sweden and Europe is principally illustrated in figure 2.3.

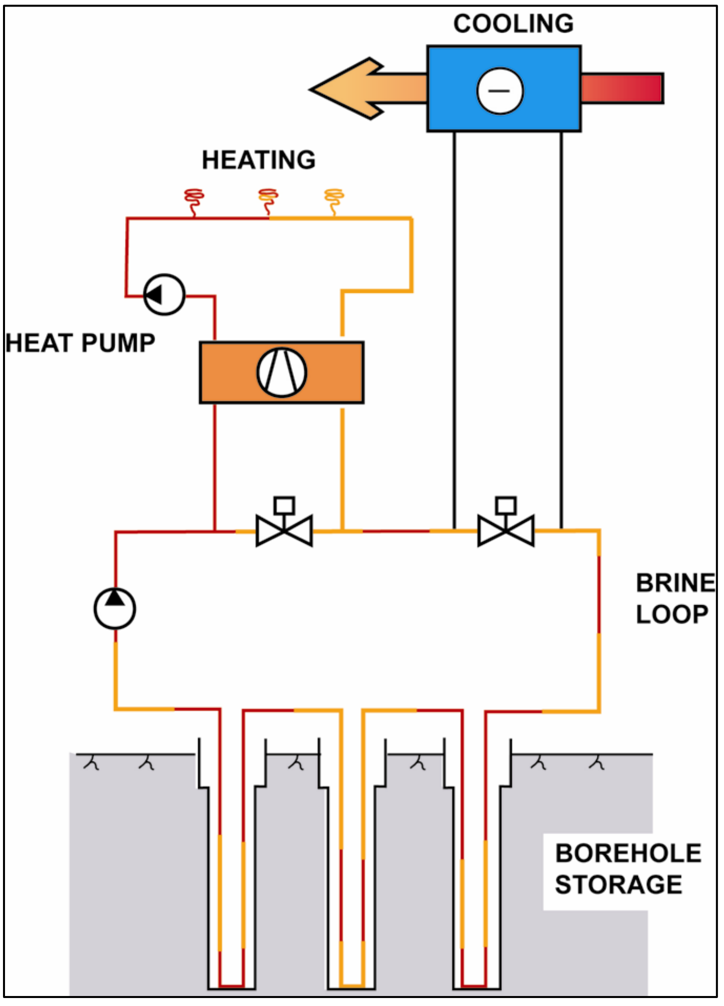

Figure 2.3.The most common BTES configuration in Europe.

In some countries the boreholes are backfilled with a sealing grout after the BHE installation. In Sweden, it is common practice to leave the boreholes without grout. Instead the boreholes are naturally filled with groundwater. Grout normally results in a decreased thermal efficiency of the boreholes, but on the other hand, it protects the groundwater from contamination.

In the U-pipe, a heat (or cold) carrier fluid is circulated to store or discharge thermal energy into or out of the underground. The storing process is mainly conductive and the temperature change of the rock will be restricted to only a few meters around each of the boreholes. Typically, these systems work with temperatures from 0 up to +10 ^{o}C in rock mass. However, the fluid normally varies between -4 and +12^{o}C.

There is also an “American” concept where the heat pump is used both for the heat and cold production. In the cooling mode, the condenser side is chilled by the boreholes and hence the temperature in the underground at the end of summer is at a higher level compared to the “European” system, typically around some + 20^{o}C. On the other hand, the winter mode will start with a higher quality of the heat source than the European system.

The BTES systems have been implemented in many countries with thousands of systems in operation. The number of plants is steadily growing and new countries are gradually starting to use these systems. They are typically applied for combined heating and cooling, always supported with heat pumps for a better usage of the low temperature heat from the storage. The users are dominated by commercial and institutional buildings.

2.2 Underground storage of cold only

2.2.1 ATES systems

Another way to use the underground is to store natural cold from the winter to the summer season. The most effective cooling source for such an application is surface water, but also the out door air can sometimes be used, in that case through cooling towers or dry coolers.

These types of free cooling systems are designed for direct free cooling during the winter season, with excess cold stored in the underground to be recovered during the main cooling season in the summer.

So far this technology has only been applied as ATES projects with a principal system configuration according to option D in figure 2.4.

Since there are no heat pumps involved, these types of systems are highly energy effective with a SPF (Seasonal Performance Factor) in the order of 40-50. For comparison, the heat pump supported system B, described in chapter 2.1.2, has an experienced SPF in the range of 6-8, while the BTES systems, described in section 2.1.2, typically has a SPF somewhat lower (5-6).

For industrial usage, ground water with its natural temperature (normally 5-10oC in Sweden), is sometime directly used for process cooling. These systems are highly effective and profitable.

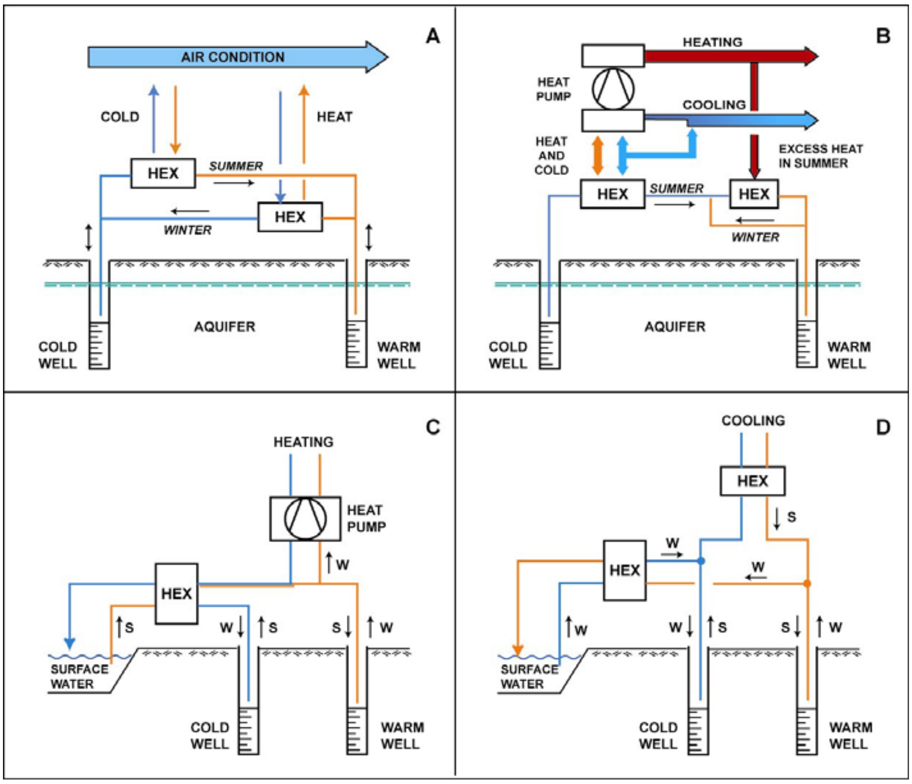

Figure 2.4 Optional ATES configurations where system D in some cases has been used for district cooling in Sweden.

In Sweden, the largest ATES system is designed for 25 MW cooling load and attached to the Stockholm city DC system. However, this system is diurnal and works as a “peak shaver” during hot summer days. The cold source is deep surface water from Lake Värtan. The system was taken into operation 1998 and has been operating at a reduced load capacity (approx 14 MW) ever since. The reason for the capacity reduction is mainly due to well capacity problems and a lower delta T in the DC (District Cooling) system than expected.

Another example is an ATES system (approx. 6 MW) just taken into operation in the city of Malmö. In this case harbour water from a shallow depth is used as source of cold to be seasonally stored in a limestone aquifer. The cold is to be directly used in local DC network close to the harbour.

2.2.2 BTES systems

In theory BTES may be used for storage of cold only, but at present the low thermal efficiency of especially single U-pipes will reduce the potential for such applications. Using double U-pipes in such applications will increase the potential but is still not optimal.

However, there is a development going on worldwide to increase the BHE (Borehole Heat Exchanger) efficiency using other technologies for the heat exchange between the rock mass and the boreholes. For instance there is a project in Halifax, Canada, that aims to store cold from the harbour by using a single insulated pipe in the boreholes and let the heat carrier flow against the borehole wall. Such a solution is optimal, but requires that the boreholes are artificially sealed to prevent leakages and potential contamination problems.

Another BHE development is ongoing in Sweden. In this case a coaxial type of exchanger with a tight thin mantle towards the borehole wall has been developed. This solution is still only on the prototype level and is not yet available on the commercial market.

With a more effective BHE, also BTES systems will be of interest for seasonal storage of cold only.

2.3 Underground storage of heat only

2.3.1 ATES Systems

In theory deep situated aquifers is a promising option for seasonal storage of high temperature sources such as solar or waste energy.

The principal system is similar to low temperature applications, but in this case hot and warm wells are used, see example figure 2.5.

To reduce storage losses, these systems should preferably be large scaled in size and placed in deep situated aquifers.

In principal the hot side is charged with a temperature up to 95 ^{o}C and then recovered at a considerable lower temperature due to losses.

Experiences from demonstration plants in other countries have shown that storage of temperatures above 95^{o}C may lead to advanced chemical problems such as scaling. However, to some extent these problems can be prevented by different forms of chemical treatment.

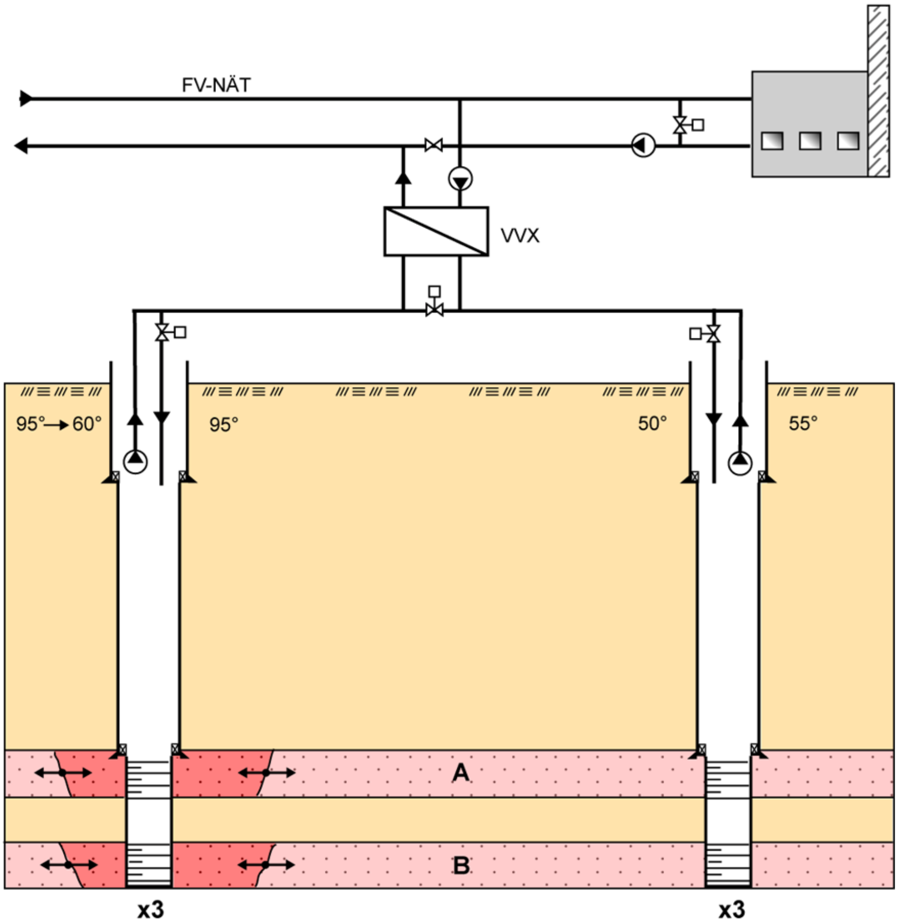

Figure 2.5 Principal configuration for high temperature aquifer storage, in this case connected to a district heating system (FV-nät).

In Sweden there have been a number of feasibility studies performed for such projects but up till now no plants have yet been realised.

In Europe a few experimental and demonstration plants exist in The Netherlands and Germany. The most known one is applied for the new Parliament Building in Berlin.

2.3.2 BTES systems

In an early stage of underground storage development a couple of cavern storage was demonstrated as technical feasible options for storage of hot water. However, the investment cost proved to be too high for a commercial application. Instead, a concept with borehole storage was introduced as a cheaper alternative.

The concept is similar to the BTES heat pump supported one, but the heat pump is replaced by solar collectors or a waste heat source, see figure 2.5

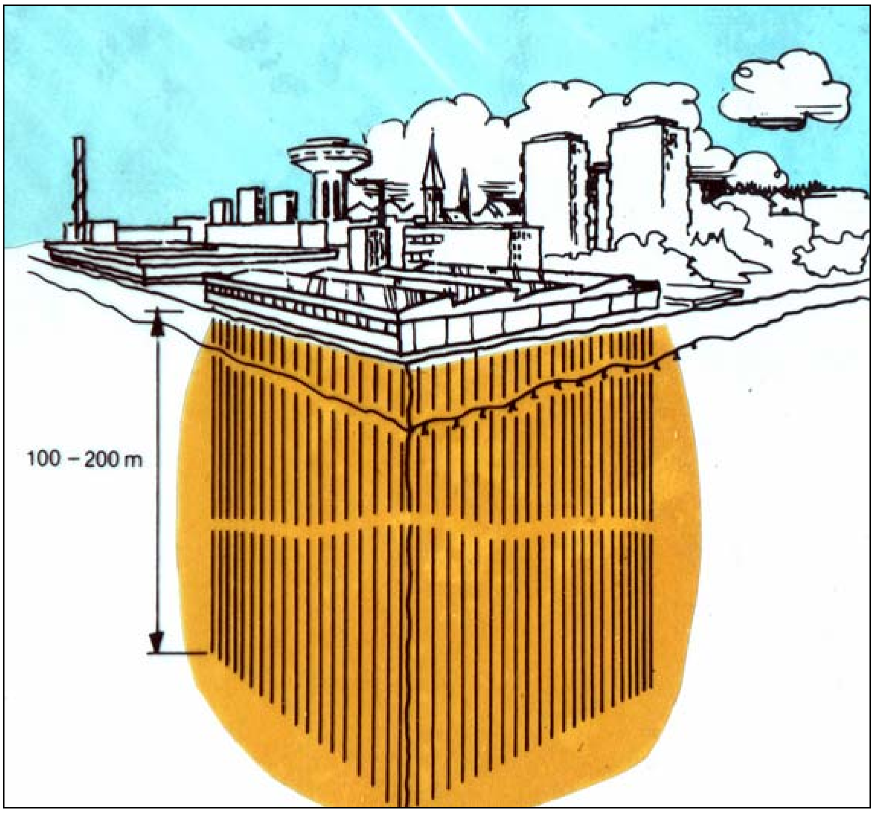

Figure 2.5 Principal for HT BTES systems, in this case with storage of solar energy.

Typically heat is seasonally stored at temperature levels up to around 70oC. Since there are storage losses the temperature will drop making the recovery temperature considerably lower. However, the heat losses will decrease with the size of the storage. Therefore the most efficient applications, with losses less than 30 %, are large scaled.

In Europe there are still only some 10 of these plants existing and the technology is still in an early commercial stage with a large market potential.

3 Natural sources of energy for storage

3.1 Outdoor air

Fluctuations in temperature during the day and over seasons make the ambient air an available cold source. Daily (diurnal) fluctuations between day and night is dependent on the adsorption of solar radiation by the earth's atmosphere and ground during the day and heat radiation balance between the sky and the ground at night.

The magnitude of change in temperature between day and night is affected by atmospheric and geographical conditions. The daily differences are small in hazy, humid climates at low elevations, whereas in regions with high elevation and less humidity the temperature fluctuations may be high.

In the Helsingborg area in southernmost Sweden, with a low elevation and a location close to the sea, the daily differences will be moderate. Also the seasonal temperature differences will be somewhat smaller than further away from the sea, but large enough for seasonal storage applications as shown in figure 3.1.

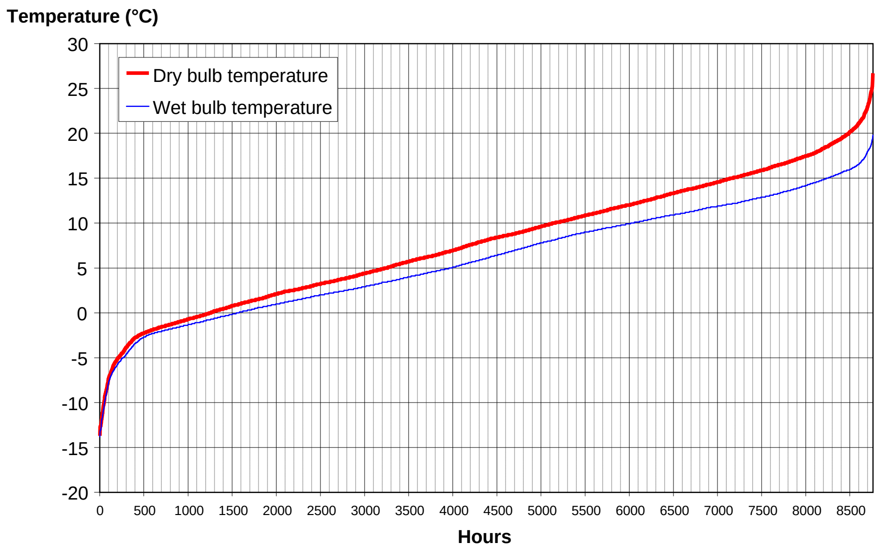

Figure 3.1 Temperature distribution curve for southern Sweden

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3.2 Surface water

Surface water (rivers, lakes, dams and sea water) provides a great potential as a cold source since cities and villages often are located close to such waters. The temperature of surface water is, with some delay, generally related to the air temperature. Sometimes however, it is also disturbed by heavy precipitation or melting snow and ice.

Typical for rivers and minor creeks are that there is no thermal stratification. Hence the temperature is independent of the depth. The water temperature rather reflects the air temperature variation, but with a slightly lower maximum value and a minimum at 0 ºC. In cold regions, there is a delay of the water's temperature rise in spring caused by melting of snow and ice.

Also, flowing water makes it quite easy to dispose waste heat while charging an underground cold storage (in applications where the heat is not used).

Lakes and larger dams are other cold sources for seasonal storage of cold. In southern Sweden, useful water temperatures at 0-5 ºC are normally available from December to April.

Lakes are normally thermally stratified. In summer, the temperature will be the highest at the surface and gradually become lower towards the bottom. In deep lakes, the bottom temperature may be as low as +4 ºC practically year around.

Seawater may be stratified due to differences in both temperature and salinity. This is the case in the archipelago of Stockholm where fresh water from the Lake Mälaren "floats" on top of brackish water. This situation causes the bottom water to stay cold also during the summer. In Stockholm such cold water is directly used for a district cooling system at a production temperature of 4-6 ºC with the highest value in September.

The same situation occurs in very deep lakes such as Lake Vättern, the second largest lake in Sweden, where the temperature swings between 4-8 ºC at 40 m depth. In this case the city of Jönköping is using that water for district cooling.

In Helsingborg, the sea close to the harbor does not seem deep enough to maintain a low temperature for free cooling during summer. Measurements covering a ten year period (1985-1996) indicate a great variation between years and generally a too high level over most of the cooling season (in average 7-11 ºC from June to September at a depth of 26 m).

Another option is to use the sea water in the same manner as is being planned for Malmö as described earlier in chapter 4.3.1.

The measurements in Öresund indicate that the temperature at shallow depths would be less than +5 ºC from early December up to late March/early April. This period would cover some 3 000 hours of free cold availability and indeed be an interesting source of cold for Helsingborg.

3.3 Solar energy

Without doubt solar energy will be the main source for any renewable energy system. Actually, solar is also the main component in shallow ground coupled systems, but by passive storage in the soil and rocks.

To have concentrated solar energy, solar collectors of different types and efficiency, is used to obtain a high temperature for seasonal storage in underground.

Potentially the solar radiation is a huge energy source. In Sweden the radiation varies between 800 and 1 000 kWh/m^2 and year. This is some 10 times more than the heating need for the average residential building. This also means that the roof of any house, covered with solar collectors, in theory would collect much more heat than is needed for heating the same building.

The problem with solar collectors is the load density (in Sweden some 100 W/m^2) and the lack of balance between production and usage. The density problem results in large and expensive collector systems. A seasonal storage is the natural solution to solve the unbalance problem and among storage options UTES systems seem to be the most favorable one.

4 Waste energy as a source for storage

An obvious source of energy for storage is waste energy from different industrial processes. In practice almost all manufacturing industries are producing much more waste heat than they can use for heating.

In some cases the excess waste heat is used for district heating, but in other cases it is just let out to the air by cooling towers and/or ventilation and cooling with surface water.

ITT Flygt in Emmaboda is one example on such waste heat that can be better utilized by means of seasonal storage. In this case, and many other cases, some heat is already used internal at the factory. However, a seasonal storage will substantially increase the recovery factor. It may also open up the possibility for external use by the local district heating system.

Burning wastes of different kinds is a common source of heat for district heating, sometimes in combination with generation of electricity (cogeneration). However, in summer time the heat production is often much higher than the heat demand. Hence, that waste heat may be a subject for storage for recovery during winter.

Many countries have also cogeneration plants for electricity connected to district heating systems. Considering production of electricity also during summer at these plants, there are large quantities of heat that are wasted either by cooling towers or water chilling.

Industrial processes, especially in steel and paper manufacturing are real large consumers of electricity with a high waste heat potential. These plants are run all over the year and large amount of heat is disposed to the atmosphere at all times, even if some are recovered by being connected to district heating systems.

The temperature level of industrial heat varies largely from as low as 10-20^{o}C (i.e. plastic industries) up to 200^{o}C or more (i.e. steel manufacturing).

5 Swedish conditions for application

5.1 Climate

The Nordic countries are located in a zone of prevailing westerly winds where low-pressure systems move along zones that separate warm air from cold (primarily the polar front). The nearness to the northern Atlantic Ocean coupled with the prevailing wind direction generally create a, for the latitude, mild climate during the winter season. The low-pressure systems also bring frequent precipitation year round, although quite long periods with dry weather can occur in connection to so called blocking high pressure zones that direct low-pressures north and/or south of the region. Despite the moderating effect of the ocean, the Asian continental climate also extends to parts of the region at times, manifesting itself as severe cold in winter and extreme heat in summer.

As most of the low-pressures come in from the west, the western areas of the region receives the most precipitation. For Sweden, precipitation ranges from 1500-2000 mm/yr in the mountainous areas close to the border to Norway, while islands in the Baltic ocean get as little as 400 mm/yr. Generally, the precipitation rate in the Nordic region is 500-800 mm/yr.

According to the climate classification of *Köppen*, most of the region belongs to the type D climate (*cold*; average temperature of the warmest month > 10°C and that of the coldest month < -3°C). However, the south western part of the region is classified as type C (*temperate*; average temperature of the coldest month < 18°C and > -3°C, and average temperature of the warmest month >10°C) and the north western, mountainous region as type E (*polar*; average temperature of the warmest month < 10°C), see figure 4.1 and 4.2.

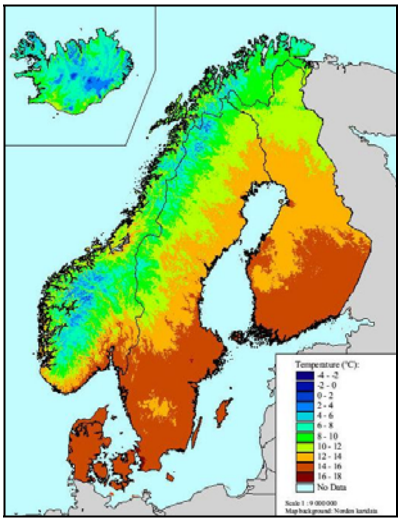

Figure 4.1 Scandinavian mean summer temperature 1961-1990

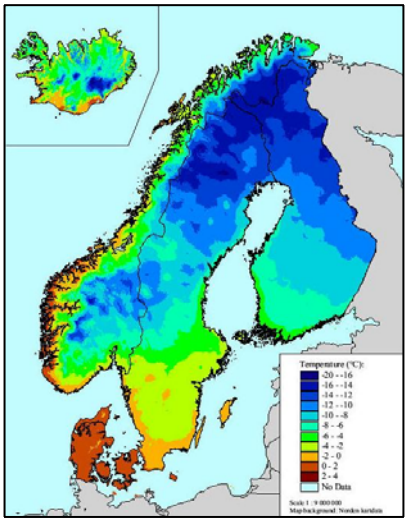

Figure 4.2 Scandinavian mean winter temperature 1961-1990

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5.2 Geology

The bedrock in Sweden and Finland is dominated by crystalline primary rock, mainly consisting of gneiss and granite. Locations in Sweden where the bedrock consists of sedimentary rocks are mainly the south western part of Skåne, the islands of Öland and Gotland and the Scandinavian mountain range, see figure 4.3.

Other important formations are glaciofluvial eskers and deltas. They are common along valleys in Sweden and Finland and represent excellent aquifers for ATES applications. Glaciofluvial deposits can also be found in Denmark, whose bedrock primarily consists of sedimentary rocks.

5.3 Legislations

Energy systems of the kind stated in this report are all a subject for permits according to the New Environmental Act from the year 2000.

In his act the portal paragraphs are pointing at the general principle that all human activity must be carefully designed and constructed not to cause any damages to the environment or human health.

Specific for systems that uses heat pumps there is a general role that they have to be announced to the local environmental authority (often the community department for health and environment). The authority may then reject the project if they find it can disturb the environment and or a third part.

For systems larger than 100 kW, the project is always regarded as potential environmental harmful and the announcement has to be more carefully described in an environmental assessment report.

In the case the underground is used as a source of energy the roles differs somewhat. In the case boreholes with a closed U-pipe system are attached to the heat pump, the same roles are applied. However, the possibility for a rejected project increases. For example may existing water wells, used for drinking water, close to such boreholes be a reason for deny.

In the case groundwater is used in the system the main role is that a permit has to be applied for. This application encounters a full technical description of the system together with an extensive environmental assessment report as well as a formal application written by a lawyer.

In order to describe the environmental effects extensive site investigations has to be performed, with test drillings, pumping tests and water chemistry analyses followed by modeling and operational simulations. The latter is done in order to establish an influence area.

The application is then submitted to the court for announcement to the public. Opposite interests within a defined influence area is then given the opportunity to react on the project. Finally there is a negotiation between the parties in the court before the verdict is given.

With a permit there will be terms for a controlling program that the permit taker has to follow for any number of years. The results of monitoring have to be reported to the regulatory authority once every year.

The process is often time consuming and expensive. For this reason it is looked upon as an obstacle for these types of systems.

Apart from the environmental act the local environmental authority as well as the regulatory authority may introduce site specific terms for using the underground as a source of energy.

One common such regulation applied in some communities is a restriction to install borehole energy wells inside water protected areas. The reason for this regulation is the risk for contamination of the ground water that is used as community drinking water.

6 Energy usage in Sweden

6.1 General needs

Most buildings in the region are heated for about 6-7 months each year. In Sweden alone, about 100 TWh annually is used for the heating of residential, institutional and commercial buildings. The average energy usage for heating is around150 kWh/m^2. (Energimyndigheten 2006)

Industries in general are in need of energy effective ways of cooling different processes rather than heating the workshops. However, there is often a need for heating of buildings and for tap water preparation, but this is in many cases covered by heat recovery from the processes.

The demand for comfort cooling during the warmer season is steadily increasing. Of interest is that also residential buildings, as well as schools, churches etc, starts to demand comfort cooling. Many buildings housing offices, shopping centres etc. want a complete regulatory system that can supply a comfortable indoor climate at any time of year. This means systems that supply heating and cooling, sometimes simultaneously.

6.2 Current energy use

Even if a lot of efforts has been made over the last decade, the dependence of fossil fuels is still at a high level, see figure 6.1.

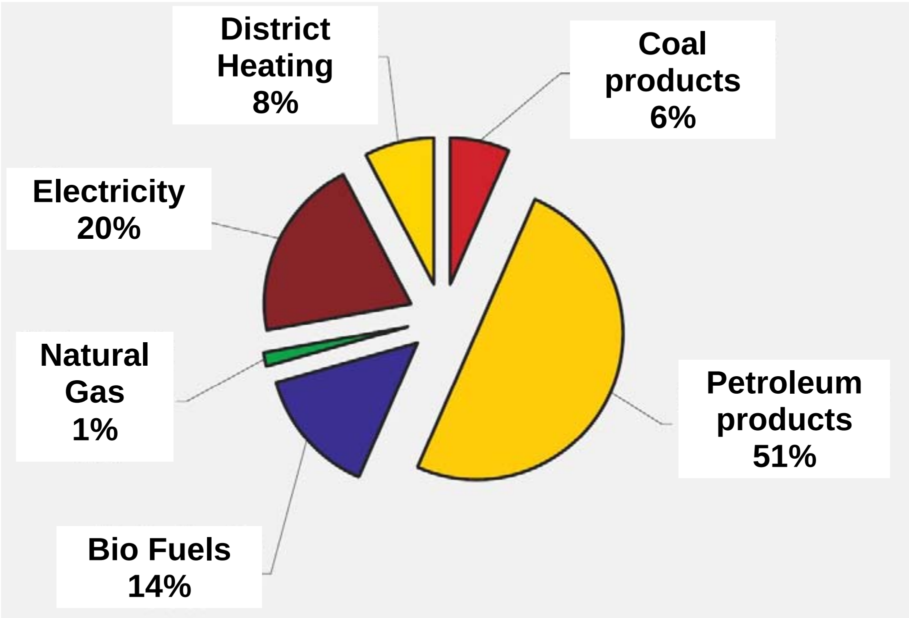

Figure 6.1 Gross usage of energy in Sweden divided into energy sources (Statistiska Centralbyrån 2005).

The total energy use is around 600 TWh yearly of which some 60 % is based on fossil fuels. The development of energy use the past 30 years is shown I figure 6.2. As can be seen the dependence of petroleum products (grey) has gradually decreased and to a large extent been replaced by nuclear power (red) and biomass (light blue).

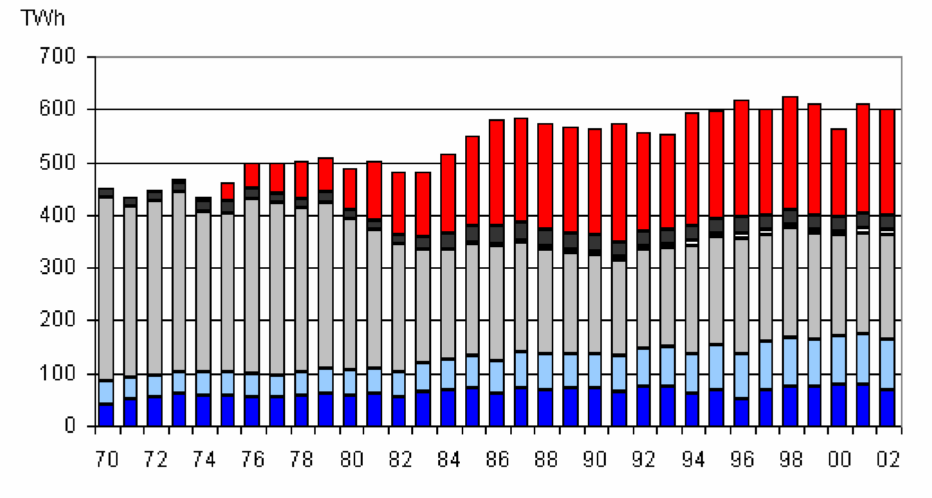

Figure 6.2 Development of energy use in Sweden. (Blue colour represents hydro power, light blue biomass, grey petroleum products, black coal and red nuclear power)

6.3 Industrial sector

The industrial sector is a large consumer of electricity. In rough figures and according to statistics from 2006 the sector stands for some 100 TWh, while the households consume about 35 TWh, see table 6.1.

Table 6.1 Usage of electricity in Sweden (Statistiska Centralbyrån 2005)

SECTOR	**CONSUMPTION (TWh)**
Manufacturing industries	57
Service industry	40
Agriculture	3
Households	34
Total (losses excluded)	**136**

The service sector includes electricity for transports and commercial and institutional buildings.

It is of interest that a significant part of electricity (about 7 TWh) is used for heat pumps, mainly in the household sector.

By indoor area industrial buildings represent about 100 Mm^2. This is some 15% of all buildings in Sweden. For heating all buildings approx. 120 TWh is used. Of this heat some 10% (12 MWh) is used for heating of industrial buildings. The dominating source is still oil (4,5 TWh), followed by district heating (4 TWh) and electricity (2,5 TWh), while the rest is produced by biomass and other forms of sources (1,5 TWh).

There should be a large potential for much more heat recovery than today. The potential for recovery can be calculated to at least 10 TWh. To achieve a larger recovery, UTES technologies should be judged as an important tool.

There seem to be an equal large potential for geothermal systems when it comes to cooling industrial processes. How big this potential really is can not be calculated since proper statistics is missing concerning cooling. In theory, and taken into consideration that almost all electricity used for processing will turn out as waste heat, the potential for cooling can be roughly estimated to 40-50 TWh/year.

Geothermal systems may be able to reduce the electricity that currently is used to run chillers and cooling towers with approx. 5-10 TWh/year. This calculation is based on that the COP for “conventional cooling” is in the order of 5-8 and that the COP for geothermal cooling (commonly known as “free cooling”) is in the order of 30-50.

6.4 Current geothermal use

Extraction of geothermal heat is mainly known as “Soil heat” and “Rock heat”. According to recent reports these systems provide approx.15 % of the heating demand for buildings in Sweden (recently published by the Swedish Board for Energy,

The calculated extraction of natural heat, mainly geothermal, is shown in figure 6.3.

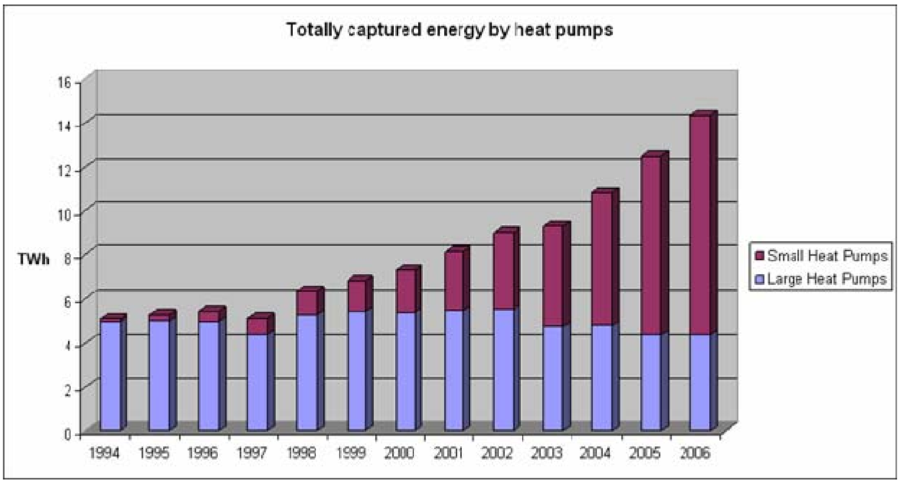

Figure 6.3 Growth of natural heat extraction in Sweden (Nowacki 2007)

It shall be remarked that the diagram only considers heat pumps that are 12 years or younger. In practice there is many more in production. The number of GSHP installed since 1980 and forward is estimated to in the range of 280 000 at the end of 2006 (according to unpublished information from The Swedish Heat Pump Association 2007).

The number of larger systems for commercial and constitutional buildings and enterprises are growing, but have not yet reached the same level of general awareness and acceptance as the smaller GSHP: s. However, the market is rapidly growing, especially for BTES applications.

7 Summery

Geothermal systems, especially shallow geothermal, has since long been applied for the residential sector in Sweden. Hence, some 15% of space heating within this sector is covered by heat extracted from the underground or from air.

The industrial sector, in general terms, has so far not shown much interest for the opportunities the underground represent when it comes to thermal energy supply. Despite large quantities of waste heat, around10 TWh/year, external heat is commonly bought for space heating. By using seasonal storage of waste heat this figure could be considerably lowered. This would be of benefit for the environment, but certainly also for the industry itself.

Another large potential is to use geothermal systems for cooling of industrial processes. This will save electricity for compressor cooling and water used in large cooling towers. Combined with air condition for workshops and offices, it will also significantly improve the working environment, making it easier to get working labors and to increase the productivity and maybe also the quality of products that are manufactured.

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