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Country Update for Sweden

Leif Bjelm, Per-Gunnar Alm and Olof Andersson

Engineering Geology, Lund University, PO Box 118, S-221 00 Lund, Sweden

leif.bjelm@tg.lth.se, Per-Gunnar.Alm@tg.lth.se, Olof.Andersson@sweco.se

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ABSTRACT

A summary of ongoing geothermal projects and heat production from heat pumps is presented. The Lund project is still the largest geothermal plant in Sweden producing about 250 GWh/year and has been doing so for 25 years, Bjelm and Alm (2010). Utilization of heat pumps is by far the most common way of using geothermal energy in Sweden, Figure 1. With bedrock-soil- water source heat pumps about 12 TWh heat energy is extracted or about 15 % of the national heat demand is covered this way making Sweden a leading nation in heat pump based geothermal utilisation. The majority of the heat pumps are small and typically used in single houses, Nowacki (2007) and Lund, Bjelm and Bloomquist (2008).

1. BACKGROUND

Geothermal energy in Sweden is thanks to the use of heat pumps an important national energy resource, Bjelm (2005). The latest couple of decades have been extraordinary regarding the amount of heat pumps put into operation in Sweden. The estimates today reveals that there are some 700 000 heat pumps of all kinds in operation and of those 310 000 are geothermal. Per capita most heat pumps in the world.

The oil crises around 1970 triggered nationwide ambitions to find useful replacement technologies for oil combustion and heating. Fortunately Sweden has had a power production strategy built on nuclear and hydroelectric power thereby providing the society with power at a reasonable price favourable for large-scale introduction of for example heat pumps. As time has passed by the technical development has improved Coefficient Of Performance (COP) for the heat pumps and today a Seasonal Performance Factor (SPF) of 4-5 is common, especially if the houses are adopted for low temperature heating

Figure 1: Sweden and major cities.

2. SHALLOW GEOTHERMAL IN SWEDEN

2.1 Utilization of extraction systems

Extraction systems mean that low temperature energy is extracted from the soil or upper parts of the bedrock either for space heating or cooling purposes. For utilization of heat an electrical driven heat pump is normally used. These systems sometimes referred to as Ground-Source Heat Pump systems (GSHP) encounter mainly three different commercial systems. These are by order of magnitude in application, ”rock heat”, ”top soil heat” and ”ground-water heat” (freely translated to English). However, in some cases, the rock heat system is also used for ”free” comfort cooling. For industrial purposes single boreholes are also used for dumping of heat in the underground, especially in the telecom sector. It is then referred to as ”rock cold”. Also ground water is often used for cooling, especially in the industrial sector, and then called ”ground water cooling”.

The rock heat system is principally illustrated in Figure 2. The system contains a borehole in which a Borehole Heat Exchanger (BHE) is inserted. The BHE consists of a single or double plastic U-pipe in which a heat carrier fluid is circulated. The fluid is transferring heat from the rock to an electrically driven heat pump that increases the temperature so it can be used for space heating and preparation of hot tap water.

Based on selling statistics derived from the Swedish Heat Pump Association there are currently around 230 000 of these installations. The rate of installation is about 25 000 units annually. This makes Sweden the world leading country for this type system, counted as per capita.

The second common GSHP system is the ”top soil heat”. As shown in Figure 3, this system is applied in gardens or other larger surface areas by ploughing down a plastic tube at depth of approx. 1 meter. As in the case of rock heat, a fluid is circulated through the tube, extracting heat from the soil. The difference is that the top soil system is based on freezing the moisture in the ground as energy released when water turns into ice (phase change energy). Hence, these systems works best in fine grained soil with a high porosity.

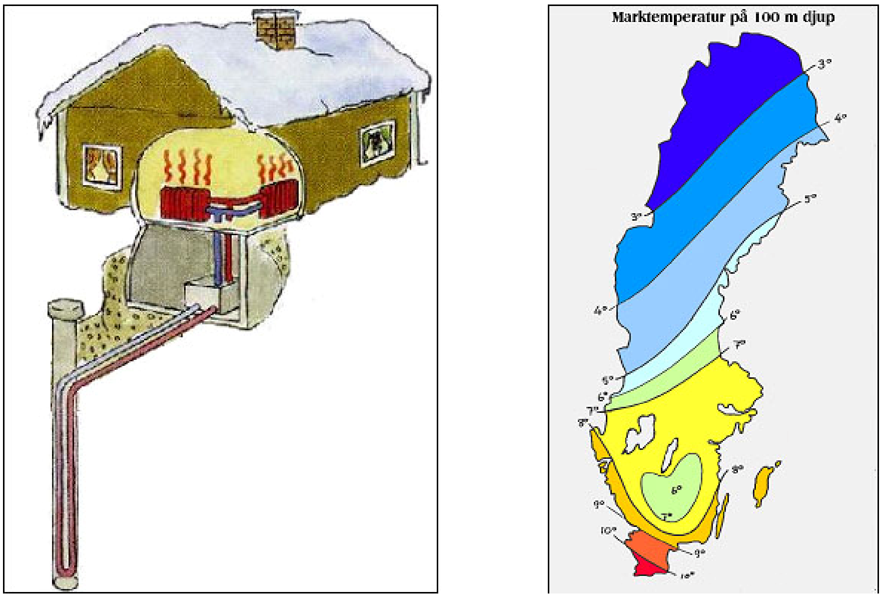

Figure 2: Rock heat is typically used for single residences. Heat is extracted from a closed loop entering a 100-200 m deep borehole. In Sweden the rock temperature varies between 10 and 3 °C.

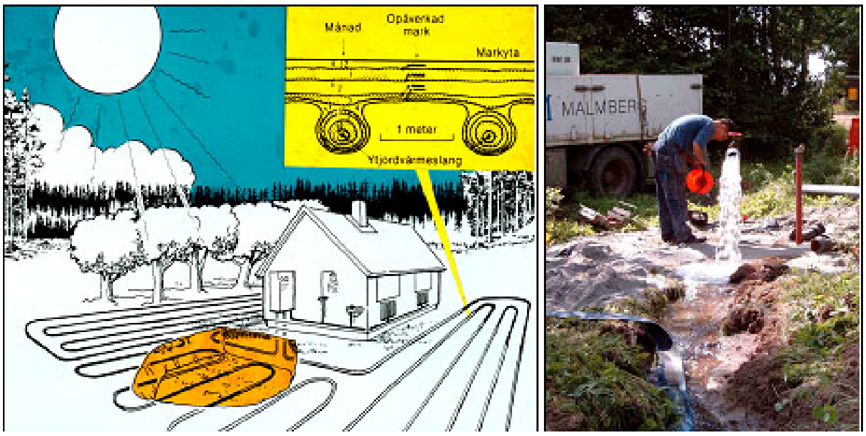

Figure 3: Top soil heat, often for a single house on the country side extract energy from the soil. Ground water heat is more effective, but is normally used in larger scales.

The temperature of ground water is constant all over the year. In general the temperature reflects the average temperature in the atmosphere. Expected temperature at 100 m depth is shown in Figure 2. This makes ground water heat to be the most efficient system of all GSHP systems. Another advantage is that that the ground water also can be used directly for cooling, both for comfort and process cooling. However, using ground water for technical purposes is limited. In Sweden only 10 % of the land area has aquifers and on top of that using ground water is heavily regulated. There are also potential chemical problems involved, mainly with corrosion and clogging by iron precipitation. For these reasons there are not so many plants realised (approx. a couple of thousands in total). Still, the ones existing are often large with capacities around 1 MW.

In Table 1 the experienced working temperature of the geothermal source, the efficiency expressed as seasonal performance factor (SPF) and the profitability expressed as straight pay-back time is given.

Working temperature address the maximum and minimum fluid temperature on the evaporator side of the heat pump. For validation of figures the temperature on the condenser side is +45 °C. The efficiency is calculated by dividing the production of heat from the condenser with the consumption of electricity for running the heat pump and some other minor pumps belonging to the production system.

Ground source cooling reflects the ambient temperature of the rock or the ground water that are being used for cooling. The ground water systems have in these cases the highest efficiency and the lowest pay-back time.

Table 1: Typical operational and economic data for different GSHP systems in Sweden.

Type of system	Working temp. (°C)	Efficiency (SPF)	Pay-back time (year)
Top soil heat	-5/+5	3.0-3.5	4-7
Rock heat	-3/+7	3.5-4.0	5-8
Ground water heat	+3/+10	4.0-5.0	2-4
Ground source cooling	+3/+10	30-60	0-6

It has been estimated that the GSHP systems contribute to Swedish space heating demand with some 18 TWh annually. Of this energy approx. 6 TWh is electricity for running the heat pumps, while 12 TWh is extracted from the underground. This will correspond to 15 % of the energy demand for space heating. Since the systems mainly are used to replace old oil burners the geothermal heat represents some 1.5 million m^3 of oil (9.5 million barrels). Hence, the systems greatly decrease the emission of carbon dioxide and other environmentally harmful flow gases.

2.2 Utilization of underground thermal energy storage systems (UTES)

The former described systems recover by its own in a passive way, mainly by energy exchange with the atmosphere but to a minor degree by the geothermal heat flow. In UTES systems thermal energy is actively stored in underground. In most cases the storage is seasonal. This means that heat is stored from the summer season to be utilised during the winter season. For cooling purposes, cold is stored during winter to be recovered during the summer. Most of Swedish applications combine these two modes of operation. The two commercial systems are Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). These are principally illustrated in Figure 4.

In **ATES** systems groundwater is used to carry the thermal energy into and out of an aquifer. For the connection to the aquifer water wells are used. However, these wells are normally designed with double functions, both as production- and injection wells. The energy is partly stored in the ground water itself but partly also in the grains (or rocks mass) that form the aquifer. There are two modes of operation. In winter with a dominating heat demand, the warm wells are delivering heat to the heat pump over a heat exchanger. The chilled ground water is injected through the cold wells and cold is stored around these wells. In summer the flow direction is reversed and the cold is recovered and directly used for cooling. The waste heat from the cooling loop is then stored in warm wells. For peak cutting of cold the heat pump may be used. In this case the condenser is chilled by the ground water and the heat is stored in the warm side of the aquifer for the coming winter. Typical temperatures are 12-16 °C on the warm side and 4-8 °C on the cold side of the aquifer, Andersson (2007).

Worldwide there are approx. a thousand of ATES systems in operation, with the Netherlands as the main user. In Sweden ATES was implemented in the mid 80-ties and currently there are approx. 100 plants realized. All Swedish systems are large scaled and the average of capacity is around 2.5 MW.

BTES systems consist of a 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 or double U-pipe. In some countries the boreholes have to be grouted after the BHE installation. In Sweden no backfill is demanded unless the systems are located to protected areas. Instead the boreholes are naturally filled with groundwater. It has been shown that water filled boreholes are more efficient than grouted ones. In the BHE heat carrier 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. The rock temperature will typically swing between +2 °C at end of winter and +8 °C at the end of summer. The numbers of BTES plants are steadily growing and in Sweden it is estimated to be some 300 plants with more than 20 boreholes. These are typically applied for combined heating and cooling of commercial and institutional buildings, Andersson (2005).

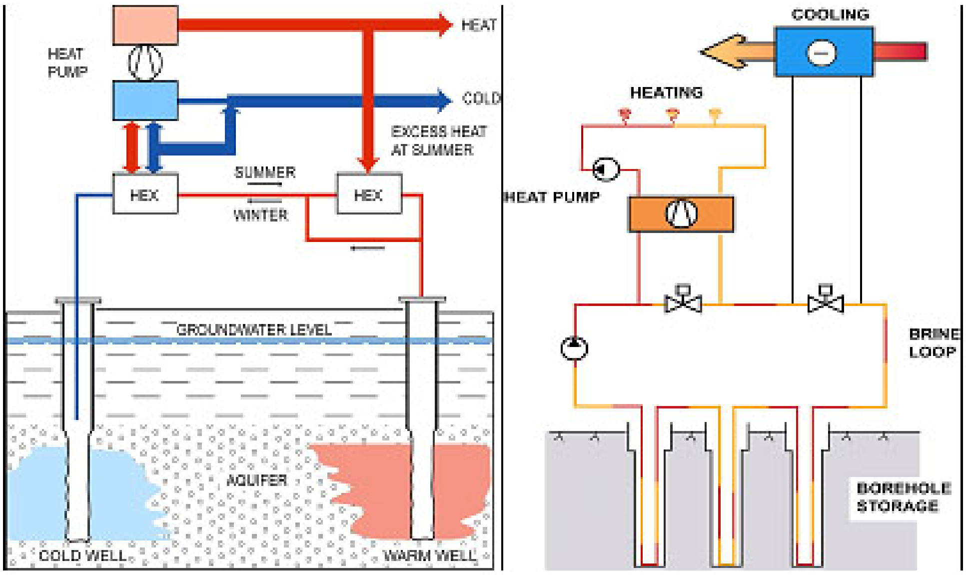

Figure 4: Principal configurations for the most common ATES (left) and BTES (right) systems

Table 2: Typical operational and economic data for different UTES systems in Sweden.

Type of system	***Fluid temp. (°C)***	***Efficiency (SPF)***	***Pay-back time (year)***
Aquifer storage (ATES)	+6/+14	6-7	1-3
Borehole storage (BTES)	-2/+9	4.5-5.5	4-6

At an experimental stage a couple of BTES installations are used for high temperature storage. The prospective is seasonal storage of solar energy and industrial waste energy. In general, BTES systems are regarded as having a huge market potential since it can be adopted practically anywhere, have a long lifetime (more than 50 years) and have a minimum of maintenance cost.

The experienced statistics on existing Swedish ATES and BTES systems used for combined heating and cooling are shown in Table 2.

3. THE LUND GEOTHERMAL HEAT PUMP PLANT

Compared to all other geothermal heat pump operations in Sweden the Lund facility is by far the largest with a double set up of pumps. The first unit came into operation late 1984 and the other about one year later and was first presented at the Geothermal conference in Portland USA 1983, Bjelm and Schärnell (1983). The dramatic increase in oil price 1973 and 1979 forced the communal energy facility in Lund to take actions getting rid of the oil dependency. Cost savings and environmental benefits were the main reasons.

Engineering Geology at Lund University and ASEA STAL a heat and power manufacturer in Sweden promoted the geothermal heat pump concept. The geothermal concept relies on a set of very porous sandstones belonging to Campanian of Upper Cretaceous sitting in the border zone between the Danish-Polish embayment and the Tornquist tectonic deformation zone crossing the province of Scania. The sandstone aquifer was explored and test pumped by means of two explorations wells drilled the year before the decision was taken to build the geothermal plant.

The tests confirmed a very permeable aquifer with a transmissivity of about 3 x 10^{-3} m^2/s. After final well completions it was confirmed that the wells were capable of delivering around 175 l/s. Production rates have since been around 125 l/s (450 m^3/h). Production temperature was initially around 22 °C and have today gone down to about 16-17 °C for some of the production wells. A certain stimulation procedure of the gravel packed well completion has been introduced through the years of operation. The injection pressure/resistance will go up after a while of injection probably due to settling of the gravel in the nearby vicinity of the screens. By means of stimulating the well by air-lifting the injection resistance drops markedly. The procedure is repeated once or several times per year or as needed. The action takes around a day/well. In realisation of the commercial project major contributions also came from VIAK AB and ASEA STAL Geoenergy

The two heat pumps can deliver 21 and 27 MW of heat energy respectively. Production data for 25 years of operation is shown by Figure 5.

Production from the Lund geothermal heat pump plant to the district heating net is today around 250 GWh of a total production of around 1000 GWh of heat from all sources and to all the demands in Lund, Bjelm and Alm (2010).

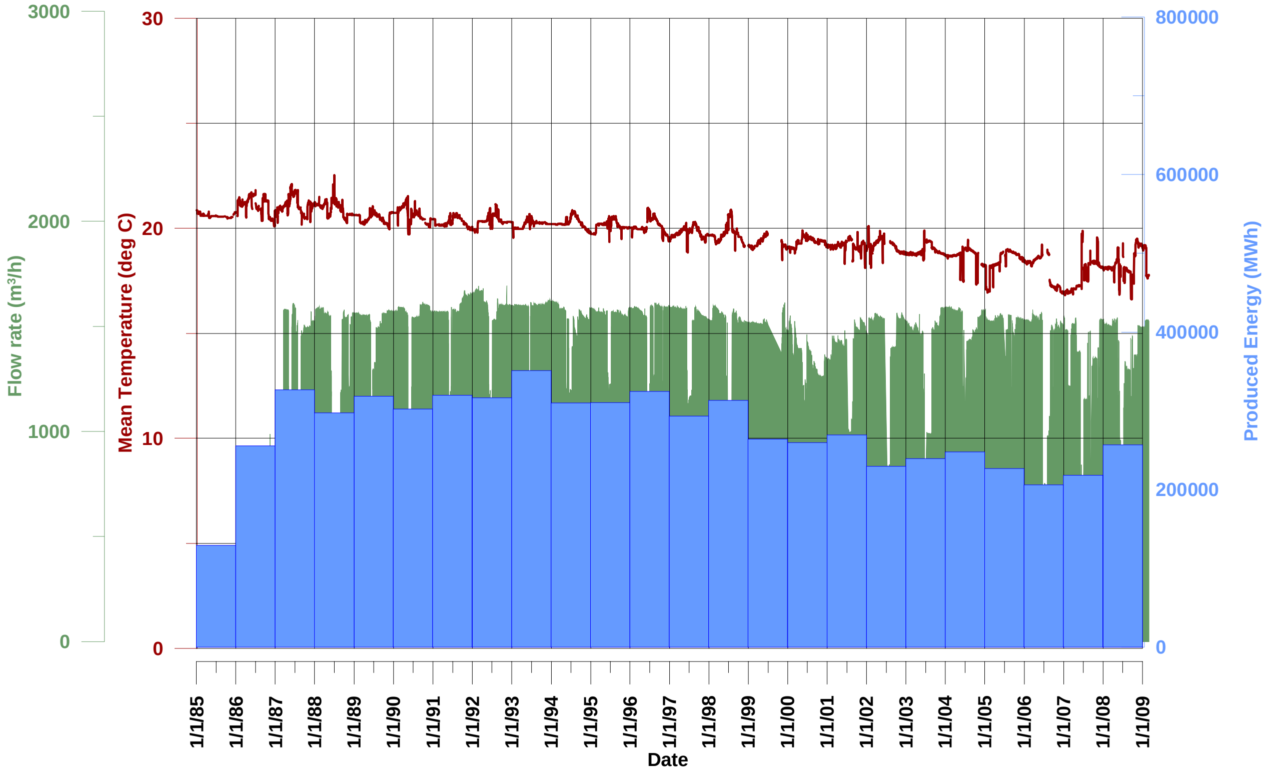

Figure 5: Relation between water production, mean water temperature and total energy production, Bjelm and Alm (2010).

4. GEOTHERMAL EXPLORATION PROJECTS

Traditional geothermal energy, extracting geothermal water from deep seated formations has been explored several times in southern Sweden but so far there is only one plant in commercial operation, the Lund geothermal heat pump plant further described above. Geothermal research is going on at Lund University, Engineering Geology, since 1977 and they are the main scientific organisation in Sweden for the exploration and utilisation of geothermal energy sources. All together Engineering Geology has been involved in more than 15 deep geothermal exploration and production well drillings.

The latest exploration wells were drilled 2002-2004 and one of the wells was drilled to 3700 m with the lower half in crystalline basement, partly as a drilling technology project, Bjelm (2006), Bjelm and Rosberg (2006). The wells have so far not been put into production because of too limited water production from the second well. On the other hand investigations are right now going on for drilling new geothermal production wells within the first geothermal production field in Lund. The cooling caused by re-injecting water has now reached a couple of the production wells, Bjelm and Alm (2010) and a slight depletion in the energy production has occurred. A seismic campaign was recently carried out for an enhanced geological and geophysical understanding of the production field and for final well site selections.

Around 2002 two geothermal exploration boreholes were drilled in Malmö by E.ON some 20 km west of Lund. The goal was heat extraction in combination with heat pumps. The wells were drilled to about 2 km depth into Triassic sandstones but only one of the wells could provide enough water production capability. The wells were abandoned but might in the future serve as test wells for geological CO_2 storage. Engineering Geology has also carried out geothermal exploration work for Landskrona and Ystad communities also situated in Scania. So far no actions have been realised for using geothermal energy in those cities but the exploration work has identified several promising prospects.

Recently the Royal Institute of Technology in Stockholm started exploration for geothermal energy related to impact craters. One at Birka not far from Stockholm and one in central Sweden, the so called Dellen prospect. At Birka, two wells were core drilled to about 1000 m, but the wells proved to be tight and were abandoned, Henkel et al. (2005). Fracturing the formation was planned but could not be realized. The Dellen project is still in an early planning stage and exploration drilling might be executed in a couple of years as part of the Swedish Deep Drilling Program (SDDP). Another local organisation, in the Siljan impact crater area, has recently started exploration activities. Abandoned very deep gas exploration wells in the area provide useful background information such as temperature measurements.

CONCLUSION

Sweden is one of the majors in the world regarding the utilisation of geothermal energy for heating. An extensive use of heat pumps has put Sweden at the top per capita speaking. Covering about 12 % of the national heat demand speaks for itself. The small heat pump market now show signs of being matured and drop a bit. However, it looks as if larger systems for both multifamily residences and commercial buildings are filling up the gap. Currently, especially ATES and BTES systems are steadily growing on the market.

APPENDIX – STANDARD TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009				5500		62500	9234	61500		2000 (w)		141
Under construction in December 2009												
Funds committed, but not yet under construction in December 2009												
Total projected use by 2011				5600		67200		68400		4100 (w)		156.6

(w) = Wind

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2009

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

Report the COP = (output thermal energy/input energy of compressor) for your climate

Report the equivalent full load operating hours per year, or = capacity factor x 8760

Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

Locality	Ground or water temp (^{o}C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Lund	19	4700	2	V	3.3	> 7000	900	
Sweden	5-20	5-7	>300000	V, H, W	3 - 5	> 5000	21600 - 30240	
TOTAL	5 - 20		>300000	V, H, W	3 - 5		>22500	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	140	828	0.188
District Heating [4]			
Air Conditioning (Cooling)	140	648	0.147
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]			
Other Uses (specify)			
Storage (Heating)	90	504	0.178
Storage (Cooling)	90	612	0.216
Subtotal	460	2592	
Geothermal Heat Pumps	30 4200	769 12000	0.81 0.091
TOTAL	4690	15361	0.104

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005		3	6			
2006		2	5			
2007		2	5			
2008		2	5			
2009		2	5			
Total		11	26			

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004	22.2					
2005-2009	0.07					

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