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GEOTHERMAL ENERGY IN FINLAND

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ABSTRACT

The use of geothermal energy in Finland is restricted to the utilization of ground heat with heat pumps. This is due to the geological conditions as Finland is a part of the Fennoscandian (or Baltic) Shield. The bedrock is Precambrian covered with a thin (<5 m) cover of Quaternary sediments. Topography is subdued and does not easily produce advective re-distribution of geothermal heat by groundwater circulation systems. Due to crystalline character of the bedrock, rock porosity and its water content are low. This practically excludes geothermal systems utilizing hot wet rock.

The lithosphere is very thick in Finland (150-200 km), and heat flow is mostly below continental average (< 65 mW m^{-2}). Measured heat flow density values in the uppermost 1 km of bedrock range from very low (<15 mW m^{-2}) values to 69 mW m^{-2}, whereas an average value of 46 sites (53 boreholes) is 37 mW m^{-2}. Geothermal gradient is typically 8-15 K km^{-1}, and the annual average ground temperature at the surface ranges from about +5ºC in the southern part to about +2ºC in the northern parts of the country. Temperatures at 500 m below surface are usually between 8 and 14ºC. At 1000 m the temperature ranges from 14 to 22ºC. Values either extrapolated from geotherms or calculated with thermal models suggest that temperatures exceeding 40ºC should be encountered at 1-1.5 km depth. However, in order to reach 100ºC, depths from 6 to 8 km are required. These numbers suggest that Finland is not a good candidate for either wet or dry hot rock systems, although some formations with either anomalously high heat production rate or thermal blanketing effects due to low thermal conductivity should be investigated in more detail. Nevertheless, promising applications can be found for small-scale use of ground-stored heat in all parts of the country.

About 10,000 heat pumps have been installed in boreholes, lakes or Quaternary deposits since the early 1980's. About 70 % of them are horizontal ground coupled systems, 20 % are using lake water and 10 % are vertical ground coupled systems. Typical vertical installations are in small family houses using a shallow 100-200 m deep borehole. The order of magnitude of energy extraction from such holes is 50 W/m^3. The use of ground-heat with heat pumps is currently increasing in Finland.

1. INTRODUCTION

Finland is situated between latitudes 60 and 70 N and has a climate with average annual air temperatures varying from 5ºC in the southern part to –2ºC in the northern part of Finland. Because of the climatic conditions, space heating is usually needed from September to May. The current population of the country is about 5 million people.

The total annual consumption of energy in Finland in 1998 was 1.29 million TJ, which is divided according to various energy sources as follows: oil 28.0 %, coal 11.0%, natural gas 10.7 %, nuclear power 17.7%, hydropower 4.1 %, peat 6.2 %, wood and black liquors 19.2 %, imported electricity 2.6 % and other sources of energy 0.7 %. About half of the energy (49 %) is consumed by the industry, 22 % is used in space heating, 18 % in traffic and 11 % in households, agriculture, etc. (Energy Review, 1999).

Geothermal energy is not used in Finland for electricity production and there are no direct applications of geothermal energy either. This situation is due to the Precambrian geology with thick crust and lithosphere resulting in low geothermal gradient values. However, there are about 10000 heat pumps utilizing the ground-stored heat either in bedrock, Quaternary sediments or water-sources (lakes). Heat pumps seem to provide a feasible alternative for space heating in small family houses or country farms. In the official energy statistics (Statistics Finland, 1998) the consumption of ground heat is combined with other 'ambient sources' of space heating energy. This number accounts for a total of 1240 TJ in 1997 and it is about 1.2 % of the total energy consumed in space heating in Finland. The value has more than doubled since 1995 (510 TJ).

This paper reviews the present status and potential of geothermal energy in Finland, presents basic geothermal data with temperature and heat flow maps, and reports the history and development of heat pump applications in Finland.

2. GEOLOGICAL AND GEOTHERMAL CONDITIONS

Finland is a part of the Fennoscandian (also known as the Baltic) Shield. The bedrock is Archaean (3100 - 2500 Ma) and Proterozoic (2500 - 1300 Ma) in age, and it is covered by a thin, usually less than 5 m thick layer of Quaternary sediments. The crystalline bedrock is characterized by granitoids, gneisses and other metasedimentary or metavolcanic lithologies.

Heat flow and subsurface temperature data in Finland have been presented by Puranen et al. (1968), Järvimäki and Puranen (1979), Kukkonen and Järvimäki (1992) and Kukkonen (1988, 1989, 1993, 1999). The current geothermal data is based on the temperature logs on 46 sites and 53 boreholes shallower than 1100 m, as well as laboratory measurements of thermal conductivity of corresponding drill core samples. The measurements and the databases are from the Geological Survey of Finland.

Measured heat flow density (Fig. 1) correlates with the tectonic age, heat production and lithology of the sites (Kukkonen, 1989, 1993). The lowest values are encountered in the Archaean and Early Proterozoic areas in eastern and northern

Finland (13-30 mW m^{-2}), whereas the higher values are related to Early Proterozoic late-kinematic and anorogenic (rapakivi) granitoids in southern Finland (40-70 mW m^{-2}). Arithmetic mean of heat flow data is 37±11 mW m^{-2} (one standard deviation).

The climatically controlled average annual ground surface temperature varies from +6ºC in southern to +2ºC in the northernmost Finland. The ground temperature can also be estimated directly from meteorological annual air temperature in ºC averages as *T (ground) = 0.7, T (air) + 2.93* (Kukkonen, 1987).

Temperature maps are presented for 500 and 1000 m depths below surface (Fig. 2 and 3). The variation of temperatures reflects both climatic conditions as well as the crustal geothermal conditions. Temperature at 500 m is highest in southern Finland (12-14ºC) and lowest in northern Finland (6-9ºC). The values at 1000 m are 20-22ºC in the south, and 12-4ºC in the north, respectively. Extrapolation and calculation of temperatures at greater depths indicate that the 40ºC isotherm would be reached at 2-3 km, and the 100ºC isotherm at depths of 6-8 km (Kukkonen, 1999).

Topography in Finland is subdued and does not easily produce advective re-distribution of geothermal heat by the groundwater circulation systems. Due to low hydraulic permeability and low porosity of crystalline rocks the water content of bedrock is low (< 1 %), and thus the water content of the bedrock is low as well. These data indicate that the prospects for utilizing geothermal energy either in wet or dry rock systems are not very promising (Kukkonen, 1999). However, earlier interest in geothermal energy in Finland in 1970-80's was much concentrated in discussing the potential for such applications (e.g. Kivekäs, 1978, 1979, 1981; Risku-Norja, 1987, Risku-Norja et al., 1987).

Temperatures in the soil at 1 m depth vary annually between +2 to +12ºC in southern Finland, and -2 - +12 C in northern Finland. Temperature in the uppermost (< 200 m) bedrock below the penetration depth of annual variations is +2 to +8ºC. Such temperatures are favorable for heat pump systems in the scale of small family houses, country farms or sometimes in district heating systems of small communities.

3. USE OF GEOTHERMAL ENERGY: HEAT PUMPS

Due to the cool thermal regime of bedrock, the only type of geothermal energy used in Finland is ground heat with the aid of heat pumps installed either vertically in boreholes, or horizontally in Quaternary sediments as well as lakes and rivers. The ground heat is considered here as geothermal energy, although it is a combination of deep geothermal energy and solar energy stored in the near-surface layers of the earth. Interest towards such energy sources grew rapidly in the late 1970's after the increase of oil price. Several thousands of heat pumps were installed in soil, typically in farms in eastern Finland during 1980's. During the 1980's and 1990's the relatively low prices of oil and electricity reduced competitively the heat pump applications, and their popularity decreased. From 1985 to mid-1990 there were sold only about 100-200 heat pumps annually. However, there is currently an increasing interest in heat pumps. In 1998 about 800 heat pumps were sold.

Technological research on the heat pump systems has also been carried out during the years. Pilot test plant projects and other studies were carried out in 1970-1980 by the Technical Research Center of Finland (e.g. Aittomäki and Wikstén, 1978), universities (e.g. Aittomäki, 1983) and by the governmentally owned electricity producer, Imatran Voima Company (e.g. Kankkunen, 1985; Tinell et al., 1986).

Unfortunately, there are no detailed statistics available on the existing heat pump installations, and this branch of business is divided into a number of small engineering and drilling companies that makes it difficult to compile such data. Therefore, the exact statistics of the numbers and properties of heat pump applications are not easy to obtain, and the present data are based on the estimates by the specialists working in the heat pump business. Further, the Finnish Heat Pump Association (Suomen Lämpöpumppuyhdistys) was established only in 1999 for promoting the use of heat pumps and distributing information on such energy systems.

It is estimated that at the end of 1999 there were a total of about 10,000 heat pumps in Finland, which were utilizing ground-stored heat in bedrock, soil, lakes or rivers (J. Hirvonen, The Heat Pump Association of Finland, pers. comm., 1999). Most of the early installations in 1980's were made in soil or lakes. About 70% of the heat pumps are horizontal soil installations, 20% in lakes and 10% in vertical boreholes (Table 1). Presently there seems to be a trend of shifting to the vertical ground coupled installations in boreholes.

A typical small-scale user of a heat pump is a family house (130-150 m^2) with an annual demand of heating energy of about 13,000 kWh/a (including the domestic hot water). This demand can be satisfied with either a vertical ground coupled (borehole) installation or horizontal (soil or lake water coupled) installation, depending on the type and size of property at use. It is common that the heat pumps work at about 60 % power of the required maximum heating power (about 8-9 kW). This is due to the fact that the duration of extremely cold periods, when the maximum heating power is required, is only few weeks annually. Thus, the heat pump satisfies about 90 % of the annual demand of heating energy, and the remaining heating energy is usually supplied by electricity.

The vertical ground coupled heat pumps are typically installed in boreholes 80-130 m deep. Deeper holes (150-200 m) were preferred in the 1980's. The coefficient of performance (COP), defined as the ratio of the energy produced to the energy used by the heat pump, has increased from the values of the early installations (COP = 2.5) to about 3.3 in the modern applications. Energy is extracted about 40-60 W/m of borehole. An ethanol-water solution is used as the heat exchange fluid and it is circulated in a U-shaped plastic installed in the borehole.

The horizontal ground coupled systems use pipes that are buried about 1.0-1.5 m below surface and separated horizontally by about 1.5 m. In the typical installation for a 130-150 m^2 family house the total length of the pipes is about 150 - 300 m. Horizontal coupled systems in lakes or rivers are usually dimensioned with slightly shorter pipes than those in sediments, but no detailed data on the properties of the existing horizontal installations can be given. Therefore, the data given in Table 1 are estimates and provide the orders of magnitude only.

Heat pump technology is utilized in a 0.5 MW district heating plant in Forssa, southern Finland (Tinell et al., 1986). The plant provides district heating for a small area with a few hundred family houses. The heat pump is extracting heat stored in a shallow (<50 m below surface) aquifer (7ºC) in a Quaternary esker formation. The water is returned to the aquifer at a temperature of 2–4ºC. The heat pump is connected to series with a boiler using heavy fuel oil. Contribution of the ground heat to the total energy production of the plant amounts to about 50 %, and the heat pump is operated with a COP value of 2.1.

Abandoned underground mines provide sometimes an easy access to utilizable heat sources. Hiiri (1985) investigated the possibility to use the closed Outokumpu mine in eastern Finland as a heat source for the district heating plant of the Outokumpu town. The calculations were based on a heat pump system with 7 MW heating power. In principle, Hiiri (1985) found the project technically and economically feasible, but the sensitivity involving economic and technical parameters was regarded as considerable. The application was not built, but the Outokumpu case indicated that the heat pump applications are worth investigating when a mine is closed.

4. DISCUSSION AND CONCLUSIONS

Geologically Finland represents an environment where the classical forms of utilizing geothermal energy (hot and dry rock or steam) are not economically feasible. The remaining alternative is ground-stored heat extracted with heat pumps from boreholes, surface sediments as well as lakes and rivers.

At the moment there are about 10,000 vertical or horizontal ground or lake coupled heat pumps in Finland used for space heating mainly in family houses and some small district heating systems in small communities. The majority of the heat pumps were installed in the 1980's as horizontal ground coupled systems. The numbers of delivered ground-heat systems decreased dramatically after 1985 and heat pumps almost vanished from the heating business. Currently about 800 heat pumps are sold annually, and there has been a slowly increasing volume of heat pumps sold since 1995. It is estimated that the total energy produced by heat pumps from ground heat sources is of the order of 500 TJ/a (Table 1). This is still less than 1 % of the total consumption of energy in space heating in Finland.

The major factor retarding the increase of using ground-heat systems in Finland has been the price of heat pump systems. In building a typical family house, the cost of installing a heat pump using ground-heat is about twice the price of installing systems based on oil or electricity, although the running costs of ground-heat systems are much lower. It should also be noted that the dispersed heat pump business may not be very good against major oil and electricity selling companies in the country. Additionally, we must also consider the lack of knowledge on heat pumps among the general audience. However, the present demand for environmentally better acceptable and sustainable technologies is constantly increasing the public interest in this field.

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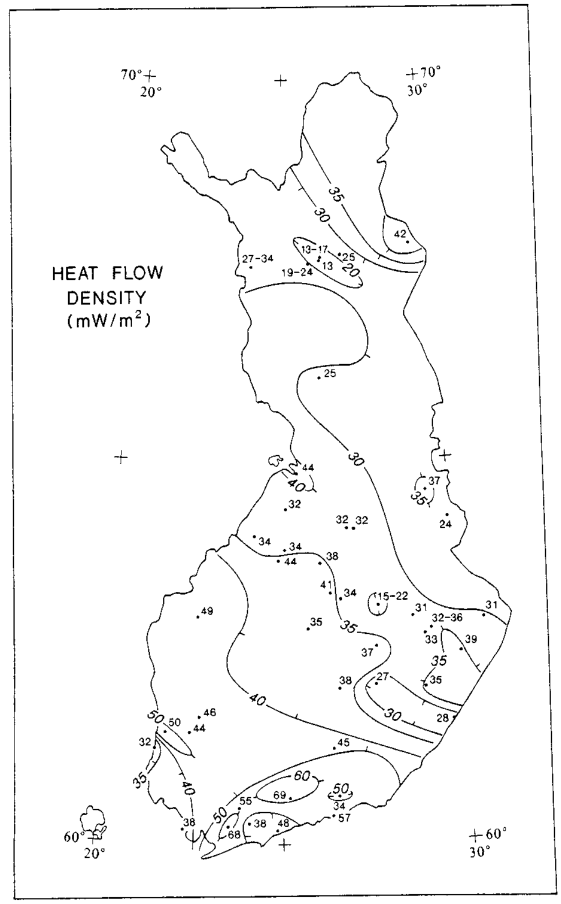

Fig. 1. Geothermal heat flow density (mW m^{-2}) in Finland

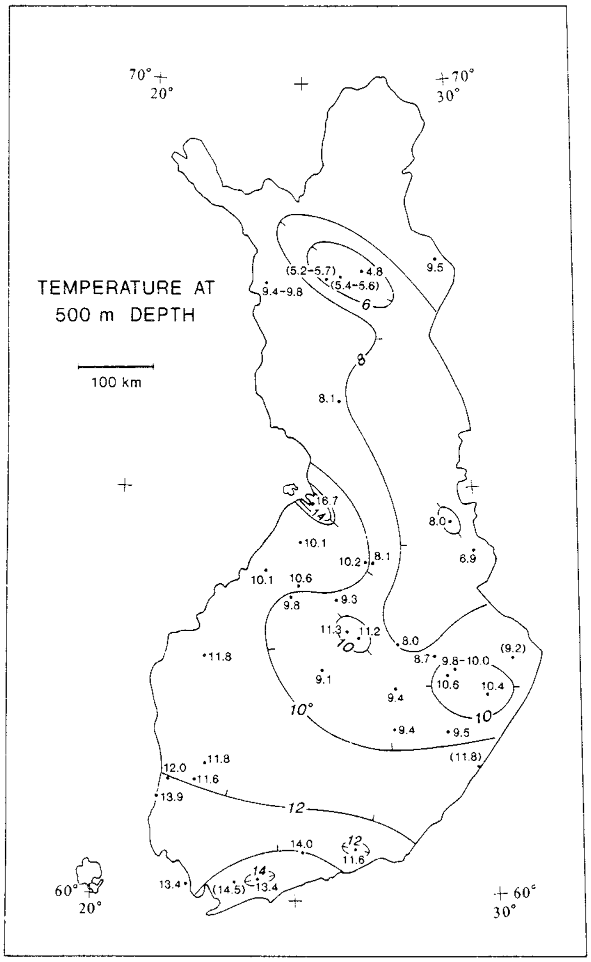

Fig. 2. Temperature (°C) at 500 m below surface.

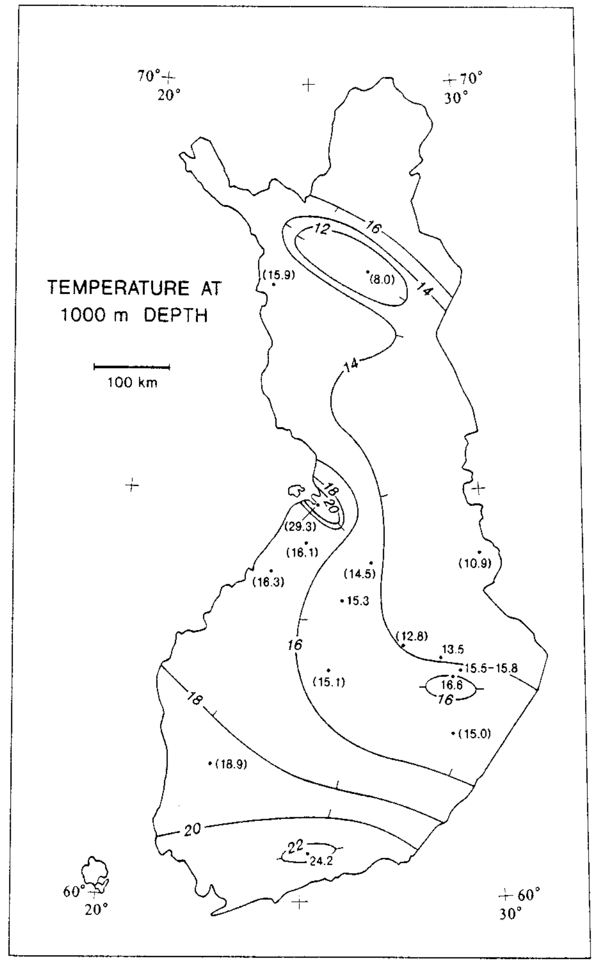

Fig. 3. Temperature (°C) at 1000 m below surface.

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Table 1. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF DECEMBER 1999.

Locality	Ground or water temp (°C)	Typical heat pump capacity (kW)	Number of units	Type	COP	Equivalent Full load Hr/year	Thermal energy Used (TJ/year)
Not spec.	+2 - +5	8	1000	V	2.5-3.3	4000	50
Not spec	-2 - +14	8	7000	H	2.5-3.3	4000	330
Not spec.	+1 - +5	8	2000	L	2.5-3.3	4000	95
Forssa S-Finland	+7	500	1	G	2.1	4900	9
			10000				484

Notes: V = Vertical ground coupled, H = Horizontal ground coupled, L = lake or river source, G = groundwater coupled district heating plant.