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GEOTHERMAL RESOURCES AND USE FOR HEATING IN EUROPE

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ABSTRACT

Europe is the world top leader in geothermal direct uses. Geothermal energy is implemented in 32 European countries. Climate, market demand, reservoir conditions, and ecological reasons favour geothermal uses mainly for space heating, bathing and balneotherapy, than for heating greenhouses, aquacultures, or industrial uses. In a number of countries the development is based on waters exploited from wells up to ca. 3 km deep (e.g. Iceland, Turkey, Hungary, Italy, Germany, and France). Some countries (Sweden, Switzerland, Austria, and Germany) have been dynamically developing shallow geothermal use based on heat pumps.

Except for Iceland, geothermal is not a main player among renewable energy sources in Europe, although many regions possess prospective geothermal resources (mostly waters) which can be implemented on a wide scale especially for heating – a main factor contributing to the environmental pollutions and GHG emissions.

There is no doubt that in many aspects related to the geothermal heating sector, Europe has collected a lot of experience, achieved significant positive results, and owns modern and reliable technologies. They are reliable and economically viable. All these elements make this continent a good example for others to follow.

The wider development of RES (including geothermal) in space heating, as well as power generation, and biofuels is foreseen in Europe. This is an indispensable element of the EU energy strategy, i.e. to decrease the dependency of energy imports, to ensure the security of supply and competitive energy prizes. The EU and its member states are also the signatories of the Kyoto Protocol; the EU is committed to reduce greenhouse gas emissions by 8% below the 1990 level in 2008 – 2012, to introduce the emissions trading scheme, energy efficiency (a 20% energy consumption cut by 2020), and a 20% reduction in CO_2 emissions by 2020.

The proposal of a new EU-Directive addressing all sectors of renewables shall ease its development; the Directive aims to establish an overall binding target of a 20% share of RES in energy consumption (electricity generation, heating and cooling) to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%.

1. INTRODUCTION

Europe is one of the world leaders in geothermal direct use. It occupies the first place ahead of Asia, the Americas, Oceania and Africa. According to the data presented at the World Geothermal Congress 2005 in Turkey (Lund et al., 2005) geothermal energy is directly used in 32 European countries (for a total of over 70 countries reporting this type of use). Geothermal resources in Europe represent primarily waters (low-enthalpy resources) being mainly connected with sedimentary formations.

In Europe, climate, market demand, reservoir conditions, and ecological reasons favour applications of geothermal energy mainly for space heating; heating greenhouses; aquaculture; industrial uses; and bathing and balneotherapy. In a number of European countries, development is based on hydrothermal resources exploited from wells up to ca. 3 km deep. Some of them started to dynamically develop shallow geothermal energy use in the past few years, based on heat pumps – an innovative and very prospective geothermal line. Some of these cases across Europe are presented in this lecture.

2. GEOTHERMAL CONDITIONS AND POTENTIAL

The European continent is composed of three main geostructural units (Figure 1):

- Precambrian structures (including the Precambrian platform of North-western Europe occupying over half the total area of the continent);
- Palaeozoic folded structures of Central and Western Europe, partly covered by the Permian-Mesozoic sediments (maximum thickness amounts to 7-12 km in the territory of Poland);
- Alpine system of Southern Europe, running from the Iberian Peninsula to the Caucasus Mts.

Europe is characterized by low-to-moderate heat flow values. This parameter ranges from 30-40 mW/m^2 within the oldest part of the continent (the Precambrian platform) to 60-80 mW/m^2 within the Alpine system. Relatively high values of 80-100 mW/m^2 occur within seismically and tectonically active southern areas of Europe. Similar values are reported from some other regions, i.e. the Pannonian Basin and the Upper Rhein Graben (Hurter and Haenel [eds.], 2002).

Thermal and geological conditions result in the fact that Europe possesses mostly low-enthalpy resources. They are predominantly found in sedimentary formations. However, at attainable depths in several regions, high-enthalpy resources are also found, as in Iceland, Italy, Turkey, Greece, Portugal (Azores), Russia (Kamchatka) and at some other islands and overseas territories of France (Guadeloupe), and Spain (the Canary Islands). The main European geothermal fields under exploitation are in the Larderello region (Italy); the Paris Basin (France); the Pannonian Basin (Hungary, Serbia, Slovakia, Slovenia, Romania); several sectors of the European Lowland (Germany, Poland); the Palaeogene systems of the Carpathians (Poland, Slovakia); and other Alpine and older structures of Southern Europe (Bulgaria, Romania, Turkey).

The geothermal conditions and potential of Europe have been presented in the ‘Atlas of geothermal resources in Europe’ (Hurter and Haenel [eds.] 2002), a comprehensive work prepared thanks to the contribution of authors from over 30 states. It serves as a useful tool while planning projects of practical geothermal use. A sketch illustrating the general distribution of main basins and geothermal resources in Europe is shown on Figure 2. It reflects the thermal and geostructural features of the continent.

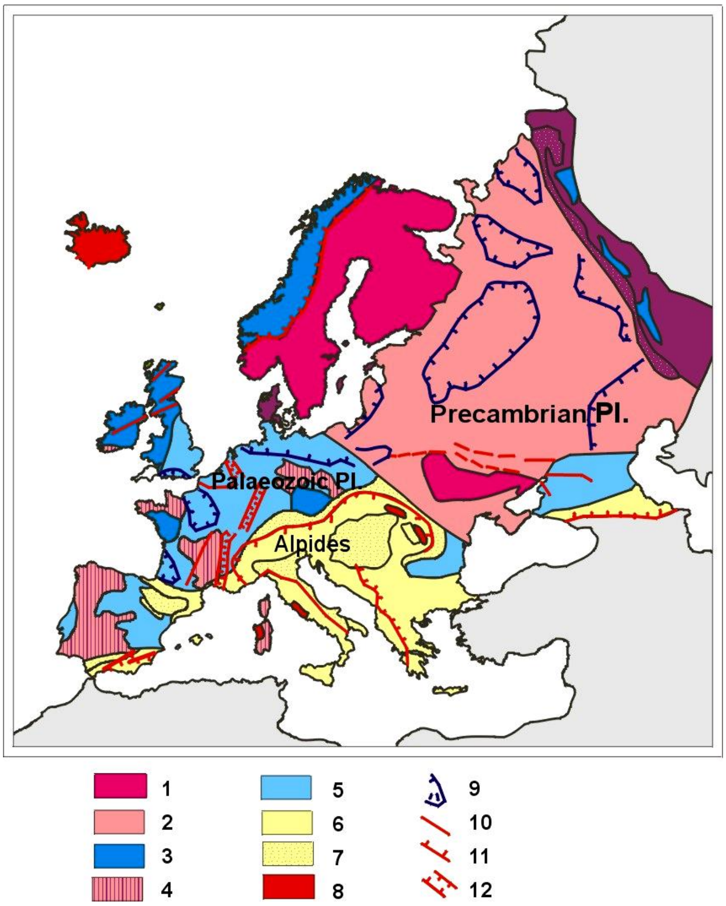

FIGURE 1: Geological setting of Europe (acc. to Stupnicka 1989 - simplified) Precambrian platform: 1. shields; 2. platform cover. Palaeozoic platform: 3. Caledonides; 4. Variscides; 5. platform cover. 6. Alpides; 7. Alpine basins and grabens; 8. Cainozoic volcanic rocks; 9. Contours of troughs; 10. Faults; 11. Thrusts; 12. Rifts

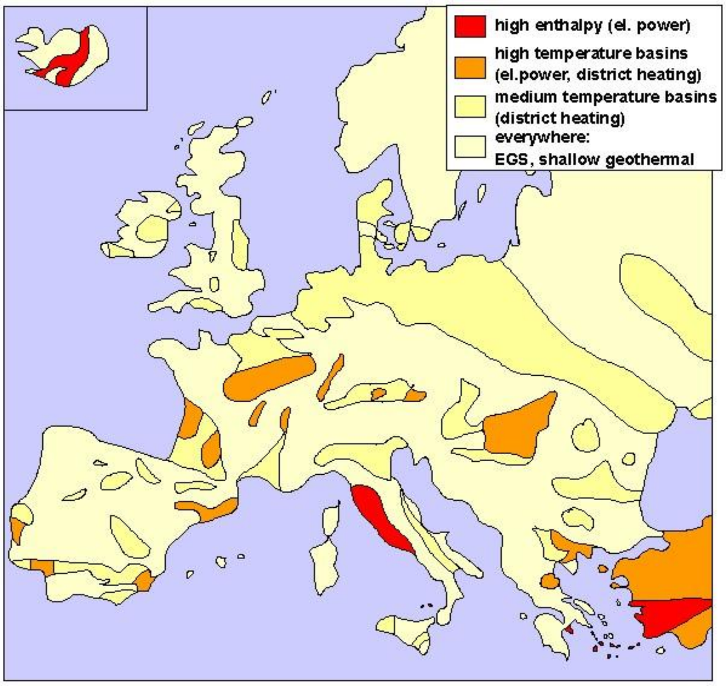

FIGURE 2: A sketch illustrating the general distribution of main basins and geothermal resources in Europe (Antics and Sanner, 2007; courtesy of authors)

3. GEOTHERMAL DIRECT USES – STATE-OF-THE-ART

According to the data presented at the World Geothermal Congress 2005 in Turkey, direct geothermal uses take place in 32 European countries (Lund et al. 2005). Data from 2004, partly updated in 2007, indicated that the total installed thermal capacity was 13 628 MW_t, while heat production amounted to 140 398.9 TJ (42916 GWh/a, i.e. 56% of the world total) (Lund et al. 2005; Table 1). These figures had almost doubled as compared with the data presented five years earlier at the World Geothermal Congress 2000 (Lund and Freeston 2001).

The trend of constant increase in direct use is continuing – the relevant partly updated figures presented at the European Geothermal Congress in Germany in 2007 are 14114.1 MWt and 158743.5 TJ/a, respectively (Antics and Sanner 2007).

It is worth noting that, with the exception of China, industrial scale of direct geothermal energy usage is primarily found in Europe. As shown in Table 2, Sweden, Iceland and Turkey have the largest share; followed by Hungary, Italy, Georgia, Russia, Germany, Switzerland and France (each of them produce over 5,000 TJ/y).

It is worth noting that high geothermal heat generation in Sweden, Switzerland, Germany, and Austria was achieved mostly by rapid heat pumps' development. The list of the top world countries is dominated by the European ones: Sweden (2), Turkey (4), Iceland (5), Hungary (7), and Italy (8) (Lund et al. 2005; Fridleifsson, this volume).

TABLE 1: Summary of geothermal energy uses by continent in 2004, showing the contribution of Europe (data from Bertani, 2005 and Lund et al., 2005)

Continent	**Direct uses**			**Electricity generation**		
	Installed capacity (MW_t)	**Total production**		**Installed capacity (MW_e)**	**Total production**	
		(GWh/a)	**(%)**		**(GWh/a)**	**(%)**
Africa	190	763	1	136	1088	2
America	8988	12119	16	3941	26794	47
Asia	5044	17352	23	3290	18903	33
Europe	**13628**	**42916**	**56**	**1124**	**5745**	**12**
Oceania	418	2793	4	441	2791	5
TOTAL	28268	75943	100	7974	56786	100

In Europe, geothermal energy is primarily used for heating and for bathing/swimming. Each of these two types consumes around 36 – 37% of the heat. A significant share is also bound with horticulture (greenhouses and soil heating) – ca. 18% (Antics and Sanner, 2007). Figure 3 shows the distribution of geothermal energy for direct use in Europe as in 2007.

TABLE 2: Europe – geothermal energy use, 2004 (based on Lund et al., 2005, Bertani, 2005) partly updated by Antics and Sanner, 2007)

Country	**Direct use**			**Electricity generation**	
	Installed capacity (MW_t)	**Total production**		**Installed capacity (MW_e)**	**Total production (GWh/a)**
		[TJ/a]	**[GWh/a]**		
Albania[1]	9.6	8.5	2.4		
Austria	352.0	2 229.9	619,4	1.2[2]	3.2
Belgium	63.9	431.2	119,8	-	-
Belarus	1.0	13.3	3,7	-	-
Bulgaria	109.6	1 671.5	464,3	-	-
Croatia	114.0	681.7	189,4	-	-
Czech Republik	204.5	1 220.0	338,9	-	-
Denmark	821.2	4 360.0	1 211,2	-	-
Finland	260.0	1 950.0	541,7	-	-
France	308.0	5 195.7	1 443,4	15.0	102.0
Georgia	250.0	6307.0	1 752,0	-	-
Greece	74.8	567.2	157,6	-	-
Spain	22.3	347.2	96,5	-	-
Netherlands	253.5	685.0	190,3	-	-
Ireland[1]	20.0	104.1	28,9	-	-
Iceland	1 791.0	23 813.0	6 615,3	202	1 406.0
Lithuania	21.3	458.0	127,2	-	-
Macedonia[1]	62.3	598.6	166,3	-	-
Germany*	504.6	2 909.8	808,3	2.01[2]	1.5
Norwey	450.0	2 314.0	642,8	-	-
Poland[1]	170.9	838.3	232,9	-	-
Portugal	30.6	385.3	107,0	16	90
Russia[1]	308.2	6 143.5	1 706,7	79	85
Romania	145.1	2 841.0	787,2	-	-
Serbia	88.8	2 375.0	659,8	-	-
Slovakia	187.7	3 034.0	842,8	-	-
Slovenia	48.6	712.5	197,9	-	-
Switzerland[1]	581.6	4 229.3	1 174,9	-	-
Sweden	3 840.0	36 000.0	10 000,8	-	-
Turkey[1]	1 177.0	19 623.1	5 451,3	20.0	105.0
Ukraine	10.9	118.8	33,0	-	-
Hungary	694.2	7 939.8	2 205,7	-	-
Great Britain	10.2	45.6	12,7	-	-
Italy	606.6	7 554.0	2 098,5	790	5 340.0
Total	**13 644.0**	**140 398.9**	**39 278,0**	**1 125**	**7132.7**

[1] – Data updated in 2007 (Antics and Sanner, 2007)

[2] - pilot binary power generation plants using 97 – 110˚C waters as a working fluid

Power generation using geothermal steam takes place in only a few European states, i.e. Iceland, Italy, Russia (Kamchatka), Turkey, Portugal (Azores) and in the overseas territories of France (Guadeloupe). In 2004, geothermal electricity in Europe contributed only 12% of the world total (Table 1). Recently, the list of European geothermal power producers has been extended by Austria and Germany (Organic Rankine Cycle, ORC, or Kalina systems). In Austria two binary installations based on 97 – 110˚C waters have been on-line since 2001 (Pernecker, 2002; Legmann, 2003). Since 2003 the first small plants (0.2 – 3 MWe) using a 97 – 155˚C water have been launched in Germany (some are in the initial stage of working and not listed in Table 2). Also in some other countries there are being conducted works aimed at power generation using geothermal waters in binary schemes (e.g. Jung et al., 2003; Krajl, 2003). This is a prospective line of electricity generation on a local scale but needs further work, i.e. improving the low efficiency. Such installations operate as co-generation ones supplying both heat and power.

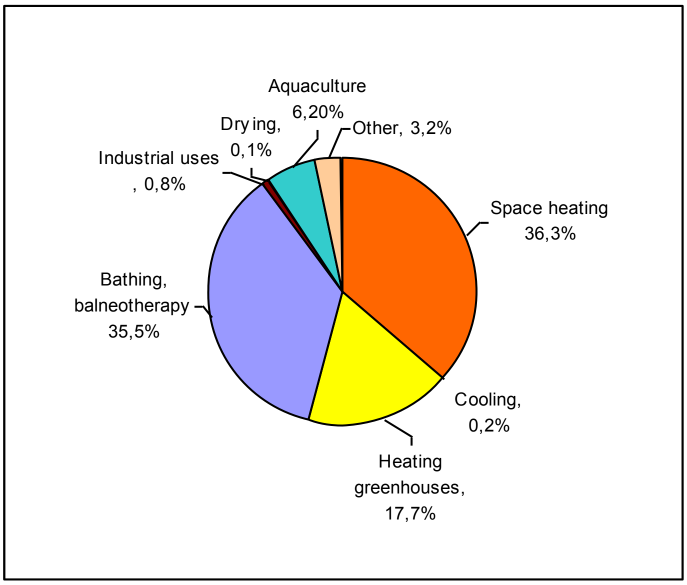

FIGURE 3: Distribution of geothermal energy for direct uses in Europe (% of TJ), 2007 (based on data from Antics and Sanner, 2007)

4. GEOTHERMAL IN ENERGY POLICIES AND STRATEGIES

Europe is the largest energy importer in the world. The import covers around 50% of its energy needs. The forecasts show that this figure may increase up to 70% in the coming 20 -30 years (Antics and Sanner, 2007). They urge to increase the share of energy from local, renewable energy sources, including geothermal energy. The growing interest in RES development results also from the fact that the European Union (EU) and its member states are the signatories of the Kyoto Protocol to the UN Framework Convention on Climate Change. The EU is committed to reducing greenhouse gas emissions by 8% below the 1990 level in 2008 – 2012. There are several key measures here, including the emissions trading scheme, energy efficiency which means a 20% energy consumption cut by 2020, and a 20% reduction in CO_2 emissions by 2020.

The EU energy strategy has three main imperatives – to ensure the security of supply, to ensure competitive energy prices and to reduce the climate change impacts of energy use. Hence, the need to significantly increase the share of the RES energy balance is becoming obvious.

So far, Europe has developed mostly wind, solar energy and biomass. Except for Iceland, geothermal has not been a main player although the continent poses prospective geothermal resources (mostly waters) which can be applied on a wide scale especially for heating – a main factor contributing to the environmental pollutions and GHG emissions. Fossil fuels (plus nuclear in some cases) will still play the main role. In 2006, the average share of all renewables in the heating sector in the EU was ca. 5% while the share of renewables in power generation was ca. 6%.

Currently there are two EU–Directives in the field of renewable energy: for electricity and for biofuels. The Renewables Directive (2001) aims to double the share of electricity production from RES to 21% by 2010 (however, this target will not be reached). For biofuels (Directive 2003) the relevant target is 5.75 (ca.1% in 2006). The third sector – heating and cooling – has not been legislated in the form of an EU–Directive so far. To change this situation, the proposal of a new Directive addressing all three RES sectors was announced in January 2008. It aims to establish an overall binding target of a 20% share of RES in energy consumption (electricity generation, heating and cooling) and a 10% binding minimum target for biofuels in transport to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%. Following the Directive, each EU-Member State shall set out the national action plan in order to reach the targets in 2020 taking into account the availability of various types of RES in their territories. Geothermal is a perspective type in several countries. The proposed overall national targets for the share of energy from renewable sources in final energy consumption in 2020 vary from 10% – 14% (e.g. Malta, Luxemburg, Czech Republic) to 34 – 49% (Austria, Sweden). In comparison – in 2005, the share of RES in the EU-countries varied from 0.0 – 0.9% (Malta and Luxemburg, respectively) to 39.8% (Sweden).

Among the initiatives dedicated especially to the promotion of wider geothermal development for heating one should mention The Kistelek Declaration (www.egec.org) adopted in 2005. It points out good geothermal resources (mainly waters) in many regions, which can provide a considerable share in the heating sector. The Declaration indicates that to achieve such a goal the EU shall foster its Member States to adopt a coherent legislation and economic system to ease geothermal use. Following the Kistelek Declaration an EU-funded project GTR–H (Geothermal Regulation – Heat) is being carried out. It aims to elaborate the legal framework that would facilitate the development of the geothermal heating sector.

In the European countries geothermal research, R&D, and investment projects are supported by donations or subventions provided by the public sources (national budget or specialized funds) devoted for the sector of renewable energy sources, environmental protection, etc. Some countries have special Guarantee Funds to limit the risks connected with drilling the first geothermal wells or limit the results of worsening exploitation parameters with time. Such economic incentives successfully work e.g. in France and Germany. Support for development comes also from the EU-budget in the frame of various funds and programs oriented at renewables and other sectors. As an example one can give the 7th EU Framework Program for 2007 – 2012 dedicated for R&D in many fields of science and economics. The Program involves energy and its renewable part (including geothermal).

5. METHODS AND TRENDS OF GEOTHERMAL EXPLOITATION

Geothermal resources are exploited and implemented in several ways. They mainly depend on:

- Depth of geothermal reservoir;
- Lithology of reservoir formation;
- Main reservoir and exploitation features and parameters.

It is crucial to preserve the renewability or sustainability of a geothermal reservoir. Besides, legal and environmental regulations established in the specific countries are of concern. Generally, there are three production and maintenance options for geothermal reservoirs and systems: (1) Exploitation of deep reservoirs; (2) Exploitation of shallow resources; (3) Enhanced Geothermal Systems (EGS; former name Hot Dry Rock Technology - R&D stage).

Some selected issues related with the production of deep and shallow geothermal resources for heating purposes in various European countries follow further in the text.

5.1 Exploitation of deep reservoirs

Water temperatures at outflows are from about 30 to a maximum of ca. 90-130ºC; TDS varies in a wide range from 1 to 150 g/dm^3. Waters are produced through a spontaneous artesian outflow or are pumped. Aquifers are connected mostly with sedimentary formations, such as limestones, dolomites, or sandstones. Some systems are connected with crystalline or metamorphic rocks.

In the majority of cases, exploitation is carried out in:

- Closed well systems, i.e. *doublets* or *triplets* of production and injection wells. Geothermal heat is extracted through heat exchangers;
- Open well systems, when only production wells (‘singlets’) are working. In some cases, when the injection is not necessary, the cooled geothermal water after passing through heat exchangers (or at least a part of it) is disposed into surface waters (i.e. rivers, ponds) or it is used for other practical purposes, for instance as drinking water or for swimming pools.

Water production from sedimentary rocks is related with some specific phenomena and problems. They have an influence on obtaining satisfactory reservoir and production parameters, and maintenance of long-term water production. Some of them are typical of all geothermal systems, some mainly depend on the lithological type of reservoir rocks. These are, e.g. change of production and injective properties; plugging of the near-hole zone; scaling; corrosion; etc. Suitable methods for a successive treatment and maintenance of such reservoirs and wells have been worked out and implemented in a number of countries, e.g. France with its carbonate reservoirs and Germany with sandstones (see detailed paper by Seibt, this volume). Depending on the temperature of the geothermal water at the outlet, the installations work as geothermal only, but sometimes they are used along with traditional fuels (integrated systems).

5.2 Exploitation of shallow resources

In this case, the heat of water, soil or rock formation is extracted through borehole heat exchangers/heat pump systems or heat pumps (different layouts and schemes). These installations are frequently part of integrated heating systems. Significant developments of this method were started at the beginning of the 1990s in several European countries (Switzerland, Germany, Austria, Sweden), similar to the USA, Canada or Japan. It opened a new line in geothermal use, creating prospects for other countries, e.g. because of the lack of limitations in the installation and economical profitability. Several aspects of the geothermal heat pumps’ development in Europe are treated in details by Rybach (this volume).

Roughly speaking, two types of recovery (current and potential) can be distinguished:

- Natural (i.e. created by nature);
- Structures or reservoirs formed as a by-product of man’s activity, oriented to other purposes than geothermal. Here one should mention old mine workings filled with warm water or air; road and railway tunnels drilled in rock masses which open up warm waters from the dewatering processes.

5.3 Enhanced Geothermal Systems

This method allows for the recovery of heat from the rock formations devoid of reservoir properties and waters. Usually such formations occur deeper than 3 – 5 km and reveal relatively high temperatures (over 150˚C) due to the depth and to high heat generation by radioactive elements contained in some minerals. Such formations can be artificially fractured and water can be injected into the fractures through the wells. After heating to about 100˚C (and more) such water (usually as a mixture of water and steam) can be pumped out to the surface and used for power generation and/or for heating. Instead of injecting water a bore-hole heat exchanger can be installed to extract formation heat. The technology is still in a stage of development.

International R&D projects on EGS (formerly named Hot Dry Rock) have been carried out in France (Soulz-sous-Forets), Germany and Switzerland. New ones are expected (e.g. Jung et al., 2003; Krajl, 2003). They are mostly oriented to power generation. In Soulz-sous-Forets commercial electricity production is expected to start soon.

6. SPACE HEATING SYSTEMS BASED ON DEEP GEOTHERMAL SEDIMENTARY AQUIFERS – SELECTED EXAMPLES

6.1 France - carbonate reservoirs

France is among the leading European countries in geothermal direct use (Laplaige et al., 2000; Table 2.2). Geothermal waters are mostly connected with sedimentary basins. The main ones are the Paris Basin and the Aquitane Basin. The geothermal district heating systems operating in the Paris region are well known. The first geothermal district heating system was opened in 1969 there. The development is related to hydrothermal resources exploited in closed systems, i.e. through the doublets or triplets of wells (1.5-2.5 km deep). As a routine, the injection of cooled geothermal water back into reservoirs has been practised.

The Paris Basin (Figure 4) is a large regional structure filled with Mesozoic and Cainozoic series. They contain numerous aquifers, including geothermal. The geothermal gradient is about 4ºC/100 m. Most of geothermal space heating systems use warm water discharged by the Dogger (Middle Jurassic) limestones. Temperatures of the water produced vary between 60 and 80ºC (Ungemach, 2001). The waters have a relatively high TDS (from 5 to 35 g/dm^3), and amount of gases, while the prevailing water type is Cl-Na. Owing to the chemical composition and presence of hydrogen sulfide, these waters are corrosive and must be injected back.

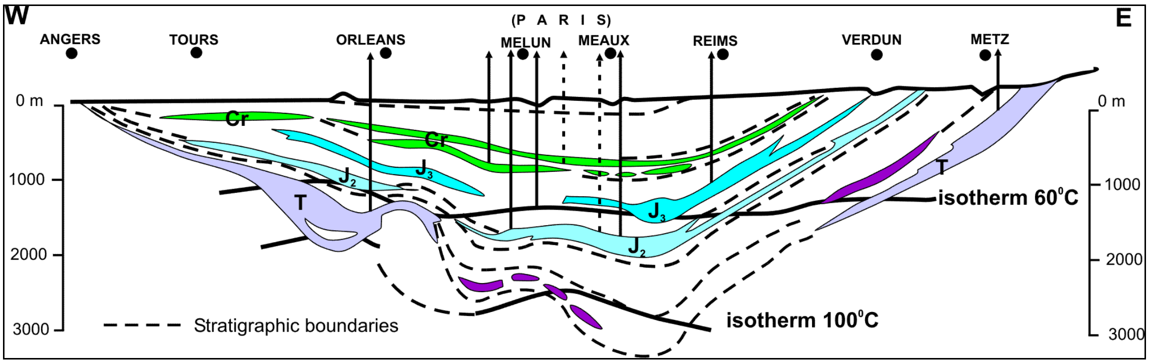

FIGURE 4: A sketch cross-section through the Paris Basin
T – Triassic, J_2 – Middle Jurassic (Dogger; geothermal aquifer), J_3 – Upper Jurassic (Malmian), Cr – Cretaceous

The peak period of geothermal space heating in France was in 1980-1986 (following the first oil crisis – see Fridleifsson, this volume). During those years, 74 plants were in operation: 54 in the Paris Basin, 15 in the Aquitaine and 5 in other regions (Laplaigne et al., 2000). A decrease in development occurred in 1986-1990. It was caused mostly by the drop in energy prices, and technical difficulties affecting geothermal installations. The latter was expressed by the scaling on the metal parts of geothermal loops due to the corrosiveness of the sulphide-rich geothermal water. Several initiatives and actions were undertaken to improve the economical situation of the plants, and to resolve the technical problems in the successive several years.

To solve technical problems – scaling, corrosion (and also blocking and damaging the reservoir by products of corrosion and scaling introduced to the reservoir with the injected water) – the technical projects embraced two priorities: (1) curative techniques for the elimination of scale and the reconditioning of the boreholes to restore the hydraulic well characteristics and; (2) the preventive methods for mitigating or avoiding corrosion and scaling processes. Special equipment was introduced to the wells (WBTT – well bottom treatment tubing) for performing the soft acidizing and continuous injection of inhibitors. The results were very positive. It is enough to say that a ten-fold decrease in casing corrosion was noted after the installation of that treatment. After the technical problems had been solved, several years were used for optimising geothermal heating networks and connecting new receivers (Laplaigne et. al., 2000).

Nowadays (2008), out of 74 plants operating in 1986, 61 are still on-line, the bulk of them (34) in the Paris Basin (Figure 5). Geothermal plants in this Basin are based on the well doublets drilled in years 1981-1987 (some new drillings were initiated in the last period). They supply space heating and domestic warm water (Laplaige et al., 2000; Ungemach, 2001). Both vertical and deviated wells are in use. They encounter geothermal aquifers at depths between 1430 and 2310 m. Maximum water flowrates are 90 – 350 m^3/h. In most cases, submersible pumps are installed. However, some of the wells are artesian. Wellhead water temperatures vary from 66 to 83ºC. Many geothermal plants work in combination with gas boilers. After passing heat exchangers, cooled geothermal water (40 – 60ºC) is injected back (Table 3). A sketch of the geothermal heating system based on water exploited in a closed loop of production and injection wells ("doublet") is shown in Figures 6 and 7.

TABLE 3: Geothermal doublets operating in the Paris Basin
(compiled from Ungemach, 2001)

Drilled years	**Number of doublets**		**Total depths of wells**		**Water flowrate (m^3/h)**	**Wellhead temperat. (ºC)**	**Method of product.**	**Remarks**
	Working	**Abandoned**	**Vertical (m)**	**Deviated (m)**				
1981-1987	34	20	1430-1790	1710-2310	90-350	66-83	Submersible pumps, Artesian	Gas cogeneration in some cases

Technically, the plants have reached a high level of performance. The average rate of availability, for all operations over the last three years, has been estimated as 94.7 %. This rate of availability reflects the significant progress which was made to ensure that installations are reliable. Finally, we can note that the average rate of geothermal energy coverage for the group of 29 networks is at approximately 60%, and up to 72% for those plants without cogeneration.

As mentioned before, the stability of the operation of geothermal systems in France was achieved thanks to elaboration and introduction of appropriate rehabilitation and preventive methods - tailored to carbonate and sandy reservoirs. They were aimed at mitigating or avoiding well damages, corrosion and scaling thus to maintain production and injectivity indices. One of the methods elaborated and successfully implemented is soft acidizing (Ungemach, 1997). It can also be applied in other sedimentary systems.

Mesozoic sedimentary basins cover extensive areas of many European countries. They are related with production of perspective geothermal systems e.g. in France, Germany, Poland, Denmark.

The case of the Paris Basin provides evidence that such basins are perspective for geothermal space-heating and other direct uses. There are many other such places across Europe (still waiting to be exploited) offering similar possibilities, e.g. Poland (Kepinska, 2004, Kepinska, 2005).

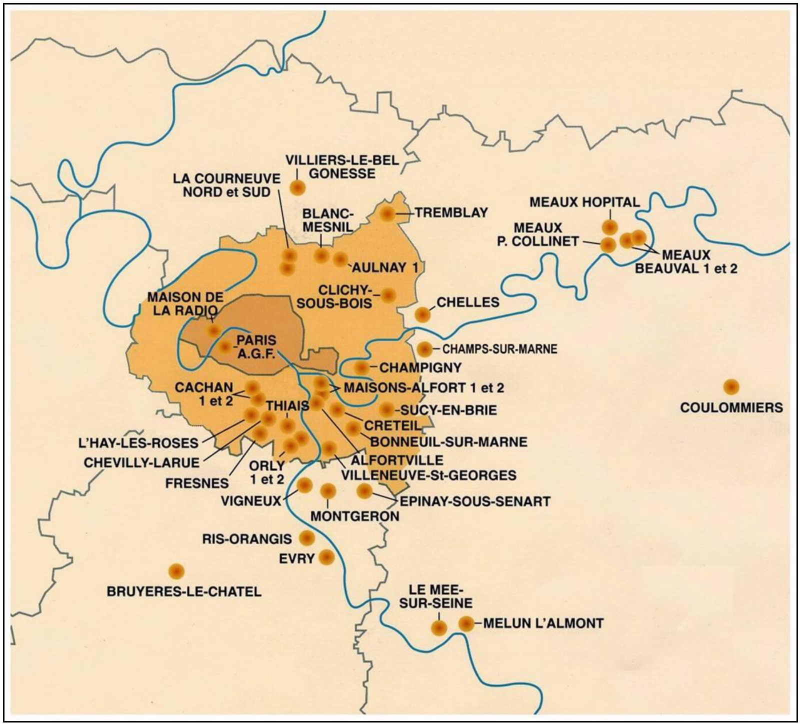

FIGURE 5: Geothermal heating plants operating in the Paris Basin, France
(source: BRGM)

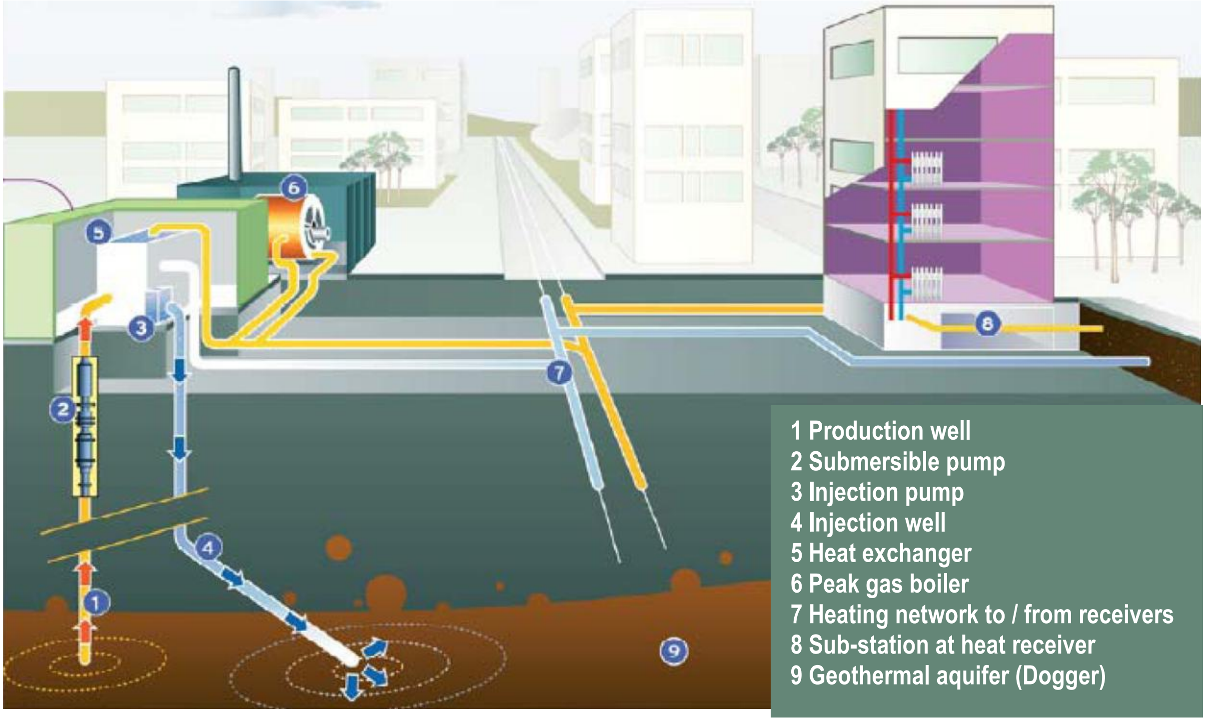

FIGURE 6: A sketch of geothermal heating system based on water exploited from Dogger sandstones in a closed loop of production and injection wells ("doublet"), the Paris Basin, France (source: BRGM)

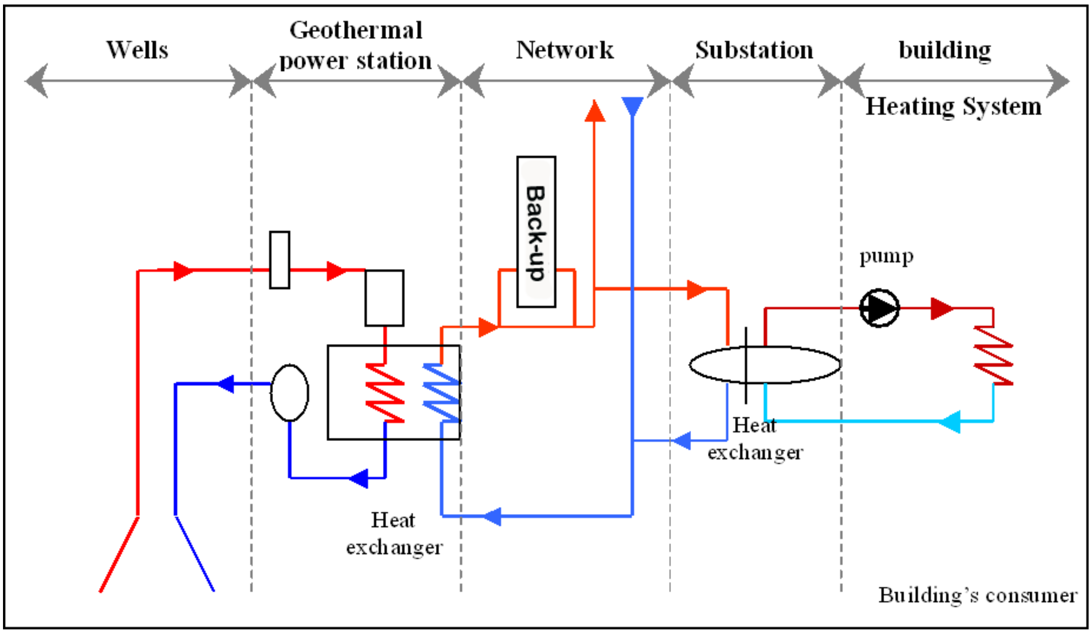

FIGURE 7: The main parts of a geothermal heating system, the Paris Basin, France

6.2 Sandstone reservoirs – Germany

In Germany, geothermal direct use development is based both on shallow and deep resources. This country is one of the European leaders in geothermal production (Table 2), having great dynamics of development. At present, 140 installations are operating with total installed capacity of 177 MW_t (Antics and Sanner, 2007). They mostly serve for district heating in some cases combined with greenhouses and thermal spas. During the last few years several new space heating plants have been launched. They are mostly located in the Munich area, S-Germany, which are characterised by very good reservoir and exploitation parameters: high temperatures (up to 120˚C), high water flowrates (100 – 300 m^3/h), low mineralization (usually ca. 1 – 2 g/dm^3). Such parameters made it possible to launch the first geothermal binary power installations (capacities 0.2 – 3 MWe) combined with heat production and supplying to the city networks. In the case of e.g. the Unterhaching co-generation plant the electric capacity is ca.3 MW_e while the thermal – ca.40 MW_t).

Among the geothermal space-heating plants exploiting water from deep sedimentary formations is the plant in Neustadt–Glewe, NE Germany. The plant has been in operation since 1995. The total installed thermal capacity is 16.4 MW_t, out of which 6 MW_t comes from geothermal while the rest from gas boilers **(**Menzel et al., 2000). In addition, a part for binary electricity generation (0.2 MW_e) was installed. The reservoir rocks are the Triassic sandstones situated at the depth of 2217-2274 m. They are exploited through the doublet of production and injection wells. Heat is extracted by heat exchangers (Figure 8). Production amounts to about 180 m^3/h of 95-97ºC water, while the TDS are high and reach 220 g/dm^3 (Table 4). The main ions are sodium and chloride, then calcium, magnesium, potassium, sulphate and some rare elements. The water contains about 10% of gas including carbon dioxide, nitrogen, and methane. The cooled geothermal water is injected back to maintain the pressure and also because of its high TDS.

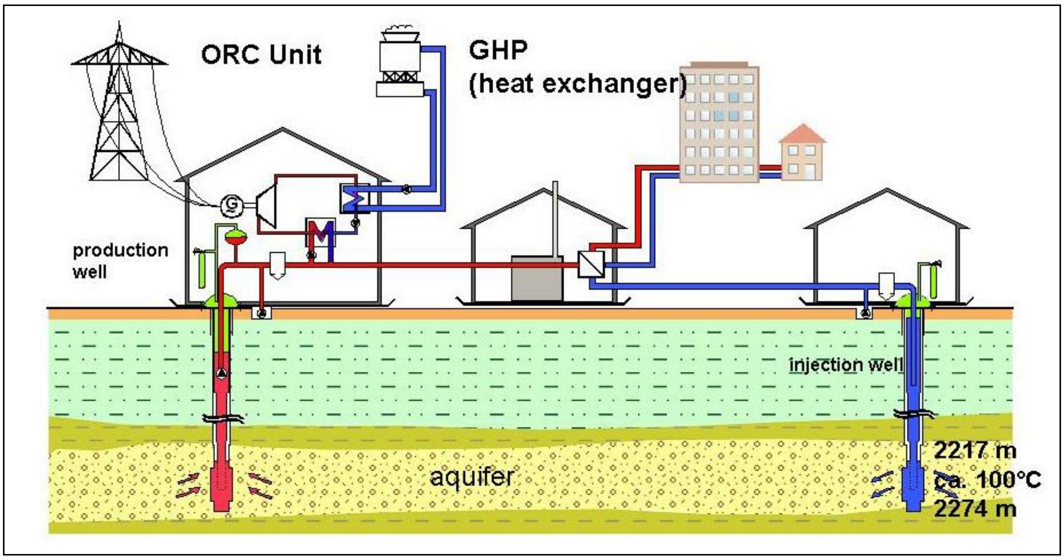

FIGURE 8: A scheme of the Neustadt-Glewe geothermal space heating plant, Germany
GHP – geothermal heating plant, ORC – Organic Rankine Cycle turbine for electricity generation
(Courtesy P. Seibt)

To avoid corrosion and scaling problems, specific materials were applied: glass-fibre tubes, resin-lined steel tube parts and measures such as inertisation by means of nitrogen loading. The materials and equipment stand up to the extreme temperatures, aggressive brine and pressure conditions.

However, the injection pressure has been increasing during the course of exploitation. This problem was caused by the sedimentation of solid particles on the filter section of the injection well. The solids consisted mostly of acid-soluble iron hydroxides and aragonite. The removal of these components was done by using the soft acidizing method – i.e. by adding highly-diluted HCl lowering the pH value of the injected cooled geothermal water (Menzel et al., 2000). As a result, the injectivity index of the injection well was considerably decreased. This method of geothermal well treatment is presented by Seibt (this volume).

TABLE 4: Main data on the sandstone geothermal reservoir in Neustadt–Glewe, Germany (Menzel et al., 2000)

Depth of the aquifer	2217-2274 m
Lithology	Sandstones
Stratigraphy	Triassic (Keuper/Rhetian)
Temperature gradient	4.06°C/100m
Effective porosity	22%
Permeability	0.5-0.8 x 10^{12} m^2
Reservoir temperature	98°C (2223 m)
Number of wells	2 (1 production and 1 injection)
Distance between wells	1,350 m
Productivity	183 $m^3(h \cdot MPa)$
Injectivity	265 $m^3(h \cdot MPa)$
Wellhead temperature	95 - 97°C
TDS	220 g/dm^3

The soft acidizing method gives good results in sedimentary geothermal environments, both for rehabilitation of well casings, and the reservoir rock formation itself. What is most important, however, is that it can be applied during the geothermal doublet exploitation (no breaks in their operation), and does not require using heavy equipment and rigs. The soft acidizing is carried out with the use of light equipment and coiled tubing. This economically profitable method gives more permanent results than other well and reservoir rehabilitation and maintenance methods.

The method of soft acidizing and related problems and technologies applied to carbonate and sandstone geothermal reservoirs and adequate study cases are described in details in specialist papers (e.g. Seibt and Kellner, 2003, Ungemach, 1997, Ungemach, 2001, Ungemach, 2003).

6.3 Ways of cooled geothermal water disposal

In a majority of space-heating systems, after heat extraction the geothermal water is injected back into the reservoir. Sometimes it is disposed to surface reservoirs (rivers). However, in some particular situations, spent water after passing through heat exchangers or heat pumps is not re-injected, but applied for some practical needs. In the operational European cascaded or multipurpose plants, the water is applied in pools or for balneotherapy purposes. In a smaller number of cases, such water may meet some standards and is used as tap water (i.e. TDS less than 1 g/dm^3 and appropriate chemical composition). Some examples are listed in Table 5. Presently, and in the coming years, closed geothermal exploitation systems will prevail. This is caused by the necessity to preserve the renewable features of reservoirs, mitigate corrosion and scaling, and meet the environmental requirements.

TABLE 5: Methods of disposal of cooled geothermal water from heating systems – examples

Type of reservoir rocks	Example	Method of exploitation	TDS, (g/dm^3)	Wellhead temperature (ºC)	Method of disposal of cooled geothermal water
Carbonates	Paris Basin France	Doublets	6.5-35	66-83	Injection
	Podhale region Poland	Doublet	2.5-2.7	82-87	Injection, part used for swimming pools, and disposed into river
Sandstones	Neustadt – Glewe, Germany	Doublet	220	95-97	Injection
	Mszczonow, Poland	Singlet	0.5	41	No injection, cooled water for drinking
	Slomniki, Poland	Singlet	0.4	17	No injection, cooled water for drinking

7. SPACE HEATING SYSTEMS BASED ON SHALLOW GEOTHERMAL RESOURCES – SELECTED EXAMPLES

7.1 Geothermal heat pumps – Switzerland

Switzerland belongs to the world’s leaders in shallow geothermal resource applications through heat pumps. It is among the world’s top countries along with the USA, Sweden, Germany and Austria (Lund, 2001). It is worth noting that in the 1970’s, this country did not carry out geothermal use (except for bathing and swimming in some spa resorts). Statistically, it was estimated that one shallow heat pump was installed within every two km^2 of country area (Rybach et al., 2000). Significant and rapid development of geothermal direct uses has been made in the last decade or so. Numerous promotions, economical incentives, research, and technology make Switzerland an example for others to follow.

Specifically for Switzerland – as an Alpine country – and prospective field of geothermal heat pump usage represents the implementation of thermal energy contained with drainage waters met during the tunnelling of new roads and railways through mountain massifs, or drained constantly out of already existing tunnels. The temperatures of such waters are in the range from 10-25ºC. About 1,200 tunnels with a total length of 1,600 km have been built in the country. Several new ones are being constructed, the longest of which will be over 50 km (Wilhelm and Rybach, 2003).

In several cases, the temperature and flowrate of tunnel water led to the use of their potential for small space-heating and domestic warm water preparation systems of residential buildings in sites located close to the tunnel portals. Because of economic reasons, the distance between portal and consumer should be shorter than 1–2 km.
A significant number of existing tunnels represents a total thermal potential of 30 MW_t, enough to provide several thousand people with thermal energy. Moreover, about 40 MW_t are estimated to be available from drainage water at the portals of two new tunnels under construction: with lengths of 35 km and 57 km. This theoretical potential is a subject of detailed modelling and evaluation, to give more realistic values which could be used for planning of the so-called portal-near heating systems (Wilhelm and Rybach, 2003).

The Swiss case of the geothermal heat pumps’ development forms a perfect example to follow by many countries. In a wider scope it is presented by Rybach in this volume.

7.2 Coal mines as potential geothermal energy reservoirs

In recent decades, coal mining has declined in many regions of the world, causing the abandonment of underground mines. There are many abandoned coal fields around Europe and the world, e.g. in France, Germany, Great Britain, the Netherlands, Poland, Spain, Slovakia and Ukraine. Abandoned, water-filled mine workings contain tens of millions of cubic meters of warm water. They constitute a significant, but little-studied, geothermal resource that can be used with the application of heat pumps for space-heating, recreation, agriculture, and industry. Several installations, based on geothermal heat pumps, are already working in Canada, Germany, and Scotland. These show that mines that have extracted fossil fuels in the past can produce clean and renewable geothermal energy.

Generally, coal fields are located in areas of a mean geothermal gradient varying from 17 to 45°C/km. These values give temperatures of 30-50°C at the deepest levels of the mines (1000 –1200 m).

Water reservoirs can be found in almost all kinds of underground mines after termination of exploitation and abandonment of mine workings. In coal mines, extraction of laterally distributed coal seams forms large areas of horizontal or sub-horizontal zones of empty openings and voids which are defined, after flooding of the abandoned mine, as water reservoirs. The site-specific conditions of each coal field or coal-mining area impact on the potential utilization of reservoirs for geothermal purposes (Figure 9).

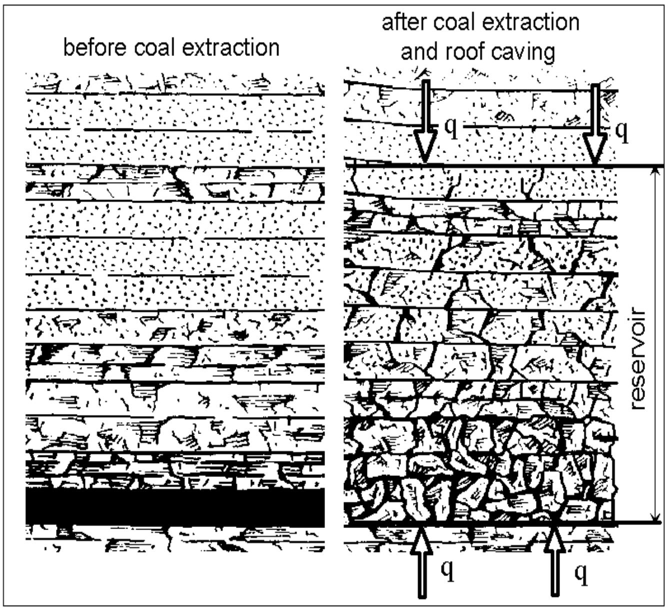

FIGURE 9: Sketch of water reservoir in the mine workings after extraction of coal seam (black layer) and caving in of the roof; arrows q mark heat inflow (Malolepszy 2003)

Geothermal heat contained in water and ventilation air pumped out from the underground mines can be used for space-heating based on heat pumps. In the case of Poland, R&D work has been conducted on this interesting subject, especially as far as the Upper Silesian Coal Basin is concerned. This is one of the biggest hard-coal basins in Europe, a basis for the development of a strong electro-energy branch. Since the 1990’s, this branch has been in the process of restructuring. One of the results was the closing of many mines. Basic theoretical studies and evaluation of the geothermal potential of coal mines have been made (Malolepszy, 2003).

On an international scale, the Minewater project oriented to geothermal heat extraction from closed underground mines is being carried out by a consortium of partners from the Netherlands, UK, France and Germany. The project focuses on a pilot station in the city of Heerlen (Netherlands) that will use water from the local abandoned coal mines for a space heating system in this town. It is estimated that the concept implemented in Heerlen will give a CO_2 reduction of 50% in comparison with conventional fuels (www. minewaterproject.info)

In the case of Poland, despite the great interest, the practical use of geothermal heat from the underground mines has not entered the application stage yet. Among the proposals are heating systems (based on heat pumps) and stenothermal fish farming. A technological project and economical analysis was done concerning the use of warm water pumped out from one selected coal mine for stenothermal fish farming (African catfish). The parameters of water pumped out of the mine are: a flowrate of ca. 180 m^3/h and a temperature of about 20ºC. The fish farm would be sited near the shaft, from which water is pumped out to the surface. The heat would be recovered through heat pumps. The yearly production could reach over 110 tons of fish. The results of the analyses indicate that the installation would be profitable. At the same time, it would be a solution to limit the unemployment problem for miners dismissed from the closing mines (Bujakowski, 2001).

7.3 Salt dome structures as potential geothermal energy sources

Salt domes and diapirs – specific tectonic structures formed of Permian (Palaeozoic) saline formations are found in some European countries (e.g. Germany, Poland).They reveal specific thermal features and may be treated as potential heat sources for local heating (Bujakowski [ed.] et al., 2003).

These salt structures were formed by the pushing of plastic saline formations upward to the surface owing to the pressure of a few kilometres thick layer of younger sedimentary rocks (from Triassic to Quaternary in the case of Poland). Such diapirs have their roots at 5 to 8 km b.s.l., whereas their roof parts are often some hundred to some tens of metres from the surface only (Figure 10). Sporadically, their top parts, the so-called gypsum caps, may manifest as outcrops.

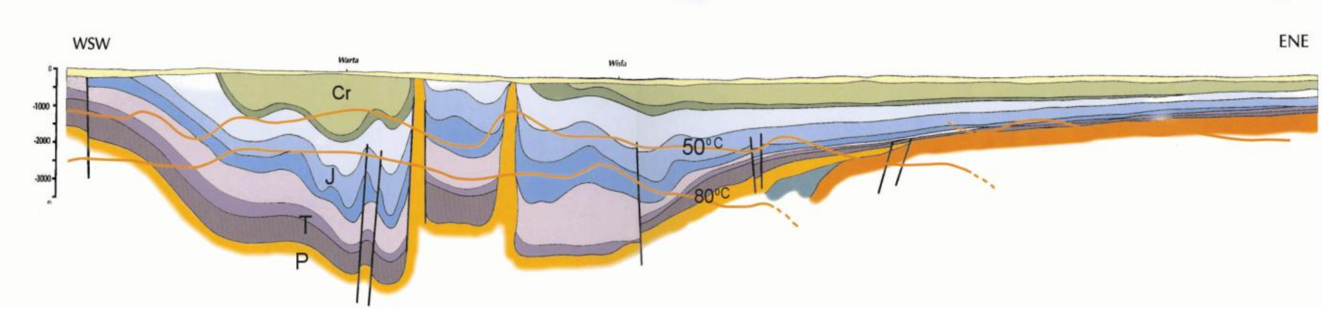

FIGURE 10: Geological cross-section through Polish Lowland, showing Permian (P) salt diapirs piercing younger rocks (in: Gorecki, 1995)
P- Permian, T – Triassic, J – Jurassic, Cr – Cretaceous

As compared to other rocks, salt has exceptionally good thermal properties, i.e. high thermal conductivity from 6 to 7 W/mK, exceeding 2-3 times the values for the neighbouring rocks (limestones, sandstones, siltstones). Heat is acumulated in the saline structures, causing a growth in temperature in the neighbouring rocks. Diapirs are migration paths (‘thermal bridges’) facilitating the Earth’s heat transport from greatest depths to the surface. Increased temperatures can be observed within the diapirs to about a depth of 4 km. A sketch of the heat transfer within the salt dome and its surrounding is shown in Figure 11.

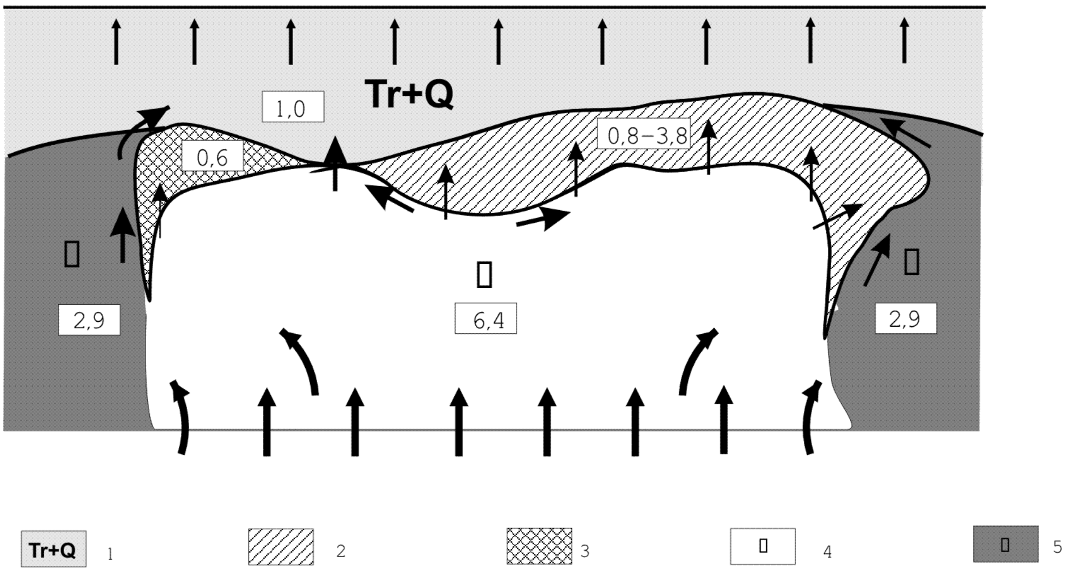

FIGURE 11: A sketch of the heat transfer within the salt dome and its surroundings, Poland
1. Tertiary and Quaternary sediments; 2. gypsum-anhydrite cap; 3. clay cap; 4. Permian (salt dome structure); 5. Jurassic. In rectangles - values of geothermal gradients, ºC/100 m
(Bujakowski [ed.] et al. 2003)

In Poland salt from a few diapirs has been exploited on a great scale (table salt production and industrial applications) by the leaching method. It lies in the injection of water and undersaturated brine through the wells to a depth of some hundred to 1.2 km (at such depths, temperatures are higher by several degrees centigrade than in the neighbouring rocks). These fluids dissolve salt, and the produced brine is pumped to the surface. The brine on the surface reaches 28-30°C. It is a carrier both of the mineral substance (salt) for further processing, and for geothermal heat to the surface.

The results of studies (Pajak et al., 2003) have shown that a thermal capacity of 1 MW_t can be yielded from the saline rooms at about 30^oC of the carrier. Thermal energy enclosed in the brine can be directly used for floor heating, swimming pools, and heating of soil in vegetable cultures. This energy can also be used through the heat pumps for space heating and domestic warm water preparation. Before thermal energy production from a specific diapir, an economic analysis has to be made. The subject of geothermal energy evaluation and possible production from salt domes will be continued.
The described idea has not been implemented in practise so far but it remains as an interesting and site-specific proposal for future harnessing of geothermal energy for heating.

8. ECOLOGICAL EFFECTS

Geothermal shall gain a significant share in many local heating markets. Ecological benefits are among the main and the strongest arguments for introducing the geothermal space heating within any region. Such systems always brings measurable results in the elimination of a significant part of fossil fuels (often coal and coke) burnt for heating which results in essential decrease in related emissions of greenhouse gasses, dusts and solid particles.

As a good example one can give the Podhale geothermal heating project, Poland (Kepinska, 2004, Kepinska, 2005). Its realization brings measurable results in the elimination of a considerable part of over 200 000 tonnes of coal and coke burnt per year in that region. In 2007 the system supplied 600 individual (small) consumers, 170 multi-family buildings, 69 hotels and boarding houses, 27 schools and 165 other buildings. Geothermal heat production was 300 TJ (www.geotermia.podhalanska.pl).

Work to connect new consumers is underway. The project has been monitored as far as the limitation of emissions, such as CO, SO_2, and dust are concerned. In the case of Zakopane – the main city supplied by geothermal (population 30,000, over 3 million tourists/a) thanks to the successive introduction of geothermal heating in 1998-2007, annual average concentrations of particulate matter (PM_{10}) and SO_2 have dropped by about 50% in comparison to the situation before geothermal heating was started. Moreover, during the winter heating season of 2001/2002 the SO_2 concentration dropped by 67% as compared to the situation in 1994-1998 prior to geothermal heating initiation in Zakopane. Total CO_2 reduction in 2007 was over 29,000 tons. Figure 12 shows ecological effect expressed as a limitation in SO_2 emissions generated so far mostly by coal-fired heating systems while Figure 13 shows the limitations of CO_2 emissions achieved thanks to geothermal heating introduction in the city.

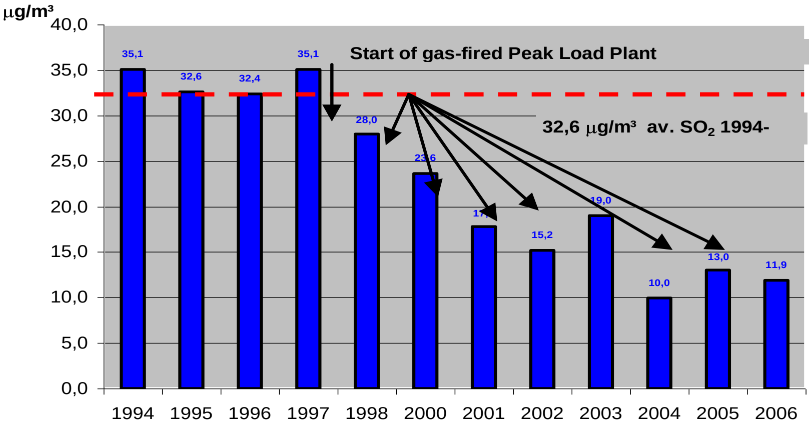

FIGURE 12: Limitation of average annual SO_2 emissions thanks to the introduction of geothermal space heating system in Zakopane, Poland (source: PEC Geotermia Podhalanska SA)
1994-1998: situation prior to geothermal project development - space heating based on hard coal and other fossil fuels, 1998-2000 – bulk of coal-based systems replaced by gas-fired Peak Load Plant, since 2001 – development of geothermal space heating system

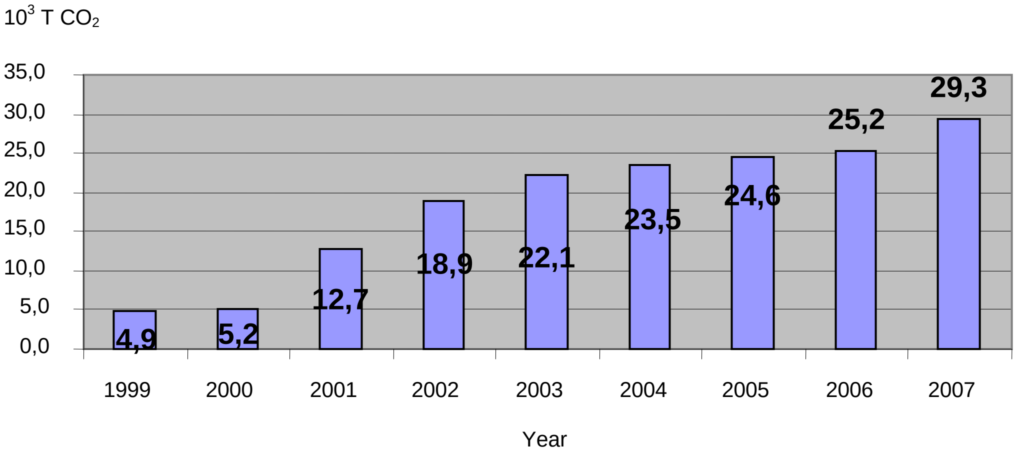

FIGURE 13: Limitation of CO_2 emissions thanks to geothermal heating introduction in Zakopane, Poland (source: PEC Geotermia Podhalanska SA)

9. CLOSING REMARKS

In Europe, space heating belongs to the most important types of geothermal energy use. Systems based on deep hydrothermal resources, as well as on shallow groundwater and rock formations, are successfully exploited. The variety of reservoir conditions and production methods proves the variety of possibilities in which geothermal energy can be used, adjusted to local conditions and needs. They are reliable and economically viable.

The future development of the geothermal heating sector will involve the progress in existing and in new technologies and types of use (Antics and Sanner, 2007): improved and innovative methods in exploration, technologies, materials; construction of new district heating networks, improvement of existing networks and plants; increased applications and innovative concepts for geothermal energy use in horticulture, aquaculture, industrial drying processes; further increase of efficiency and technologies in heat pumps (shallow geothermal); demonstration of new applications (de-icing and snow melting on roads, airport runways, sea water desalination).

Many experts point out that faster and wider geothermal development in Europe is possible thanks to international cooperation and the transfer of good practices and technologies. Such cooperation has been ongoing but there are many more opportunities to extend its scope.

The anticipated progress in geothermal development shall also be facilitated by adequate legal and economical measures both at the levels of the European Union and particular European countries.

The space heating sector will remain number one among direct geothermal use in Europe. In this particular field the continent has collected a lot of experience, achieved significant positive results, and owns modern and reliable technology. All these elements make Europe a good example for others to follow as far as geothermal heating is concerned.

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