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State of the Art of the Geothermal Resources in Croatia in the Year 2004

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ABSTRACT

In general, there are two different regions in the Republic of Croatia both in geological and geothermal respect. The Dinaric area occupies the southeastern part of the country with predominantly Mesozoic carbonate rocks characterized by the temperature gradients ranging from 0.01 to 0.03°C/m. The northeast part of the country lies mostly in the area known as the Panon. It is dominated by clastic sedimentary rocks of Quaternary and Tertiary age that overly the crystalline bedrock and, occasionally, the Mesozoic sedimentary rocks. The temperature gradient in the latter area ranges from 0.03 to 0.07°C/m with considerable geothermal energy potential.

Altogether there are 28 reservoirs in Croatia. Only 18 of them have been utilized, although the percentage of usage of their available power is still very small. Installed capacities have a thermal power of 113 MW_t, with annual energy production of 680 TJ/yr. Improvement of such a condition can be significant for the future economic development of certain regions in Croatia. Increase of direct geothermal energy usage in the past five years was about 20%, while the plans for construction of a geothermal electric power plant are postponed to year 2010.

1. INTRODUCTION

The average temperature gradient in the north of Croatia, belonging to the Panonian sedimentary basin, is considerably above the world average, while in the southern, Dinarides area its value is below that level, e. g. Jelić, Kevrić and Krasić (1995). In spite of the huge geothermal potential accumulated in the reservoirs of the Panonian area, the stage of utilization of geothermal energy is very low, e. g. Košćak-Kolin (2000). Low temperature thermal water is widely used for bathing, swimming and medical purposes in traditional spas, some of which are also equipped with geothermal space heating systems.

Geothermal potential accumulated in the reservoirs of the northern part of Croatia can be a significant renewable energy source, substantially contributing to the overall energy efficiency and the environmentally acceptable energy policy, (Bošnjak et al 1998).

2. GEOLOGICAL BACKGROUND AND GEOTHERMAL RESOURCES

The Republic of Croatia can be divided generally into two geologically different regions: the Pannonian Basin and the Dinarides belt. Different opinions prevail with regards to the location of the boundary line between the two regions. The boundary on the fig. 1 is based on lithological characteristics and tectonics. Southwest of the boundary is the Dinarides area where the Mesozoic carbonate rocks prevail. The northeast area of the boundary belongs to the Pannonian Basin. In this area the Quaternary and Tertiary sedimentary rocks dominate which overly the crystalline bedrock and occasional Mesozoic sedimentary rocks. Locality of the stratigraphic unit and description of the rocks are represented on the geological map (Fig. 1). The main characteristics of the tectonic pattern are tangential structures (folds, thrusts, nappes) of the northwest-southeast strike, mostly originated in Paleogene, disturbed by younger normal faults from Neogene to Quaternary (Velić, I. & Velić, J., 1993).

These two geologically different regions have different geothermal characteristics. In the Dinarides area the temperature gradient ranges from 0.01 to 0.03 °C/m and the terrestrial heat-flow density from 20 to 60 m Wm^{-2} (Jelić et al., 1995). There are three prominent locations of geothermal wellsprings: Sveti Stjepan - Istria spa (28-31,1 °C), Lešće (33,4°C) and Topusko (64-65 °C).

Main geothermal potential in Croatia is in the Pannonian area (Kovačić, 2000, 2001 a). The temperature gradient in this region ranges from 0,03 to 0,07 ^{0}C/m, which is more than the world mean value. The terrestrial heat-flow density is also high, ranging from 60 to 100 m Wm^{-2} (Jelić et al., 1995) and occasionally up to 120 m Wm^{-2} (Kovačić, 1995). On some locations the heat-flow density across impermeable formation is even greater (Kovačić, 2001 b). Prominent locations of geothermal wellsprings in Pannonian area are: Geothermal area Hrvatsko zagorje - Jezerčica (38 °C), Krapinske Toplice (Spa) (40,7 °C), Stubičke Toplice (Spa) (57-58,2 °C), Sutinska Spa, (35,7 °C), Šemnica (32,6 °C), Gotalovac (25,7 °C), Tuheljske toplice (Spa) (32,9 °C); Geothermal area Zagreb - Sveta Jana (24,8 °C), Sveta Helena – Šmithen (27,3) and Sveti Ivan Zelina (22,2 °C); Geothermal area West Slavonia - Daruvarske toplice (Spa) (46,9 °C), Lipik (58,2 – 60 and Velika (Spa) (28,9 °C); Geothermal area Međimurje & Podravina - Varaždinske Toplice (Spa) (57,6 °C) (Kovačić & Perica, 1998).

During the research activities concerning the oil and gas resources in the Pannonian area some 3.500 boreholes were drilled, many of them have been drilled through the geothermal aquifers. Zone with the best conditions for exploitation of geothermal water from the drilled aquifers are: Geothermal area Zagreb (31 - 82 °C); Geothermal area Ivanić Grad (50 - 60 °C); Geothermal area East Slavonia - Bizovac (86 - 98 °C), Ernestinovo, Madarinci, Babina greda (74 - 125 °C); Geothermal area Međimurje & Podravina – Vučkovec (40 °C), Lunjkovec (125 °C) Velika Ciglena (150 - 170 °C) and Geothermal area Lešće & Karlovac (95 - 130 °C).

The most important area and locations where geothermal water is exploited are sketched on the map (Fig. 2).

3. GEOTHERMAL POTENTIAL

Total direct heat potential of 28 geothermal resources is about 1000 MW_t. This value follows from thermal power of each existing well, based on the energy usage down to the temperature of 25°C. Maximum annual thermal energy production from all geothermal reservoirs, calculated on the basis of the capacity factor of 50%, could reach full 18441,63 TJ/yr. According the calculations, the electric power of five suitable geothermal resources is about 50 MW_t maximally while the annual production of electrical energy amounts to 377,33 GWh/yr, calculated on the basis of the capacity factor of 90% (Jelić, K., Pavičić, H., et al, 2000).

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In Croatia there are 18 locations where geothermal energy is used mostly for the balneology, recreation and space heating (table 1). Still, it is only about one half of totally 28 geothermal reservoirs, situated in northen part of Croatia (Čubrić and Jelić, 1995). However, 5 locations with the highest geothermal potential, having geothermal water above 100^{o}C, are not used inspite of the allready existing wells, which require the greatest part of the investment costs.

Feasibility study on combined electricity and heat production were performed for 2 from 5 high-temperature reservoirs. It gave positive results in both technical feasibility and financial viability for the Velika Ciglena cogeneration plant, while the Lunjkovec-Kutnjak project was declared questionable in terms of financial viability. Since other 3 potential locations still have not been seriously considered, installing of the majority of geothermal capacities available for electricity production is not presumable in the near future.

Total production of electricity in Croatia yearly grows with a rate of 3%, expected to be 16700 GWh in 2004, as presented in **Table 1** (Energy Institute, 2003). One part of electricity is produced from hydro power plants with installed capacities of 2000 MW_e, while the remaining power is obtained from fossil fuels. Installed capacities of thermal power plants are 2000 MW_e. It is planned in the next five-six years that the gross production of electricity would reach a 20000 GWh/yr, including usage of energy transformation from geothermal reservoirs, as well as energy of other renewables (wind, biomass).

4. GEOTHERMAL UTILIZATION

All the localities where geothermal energy is used with the quantitative characteristics of the energetic installations are listed in the **Table 3**. The majority of the listed localities are spas, usually including hospitals and hotel capacities, equipped with swimming pools and other therapeutic and recreational facilities.

Except from natural springs, some of which have been used for centuries, geothermal water supply to those facilities is also drawn from shallow wells, drilled during the last few decades. While on some of the localities thermal water is used only for balneological and recreational purposes, others are heated by geothermal energy, due to water temperatures that make possible a useful amount of energy to be extracted by means of heat exchangers and heat pumps. There are also public recreational centers where geothermal water is used only in open-air swimming pools during the summer season. Obviously, the contribution of those facilities to the overall geothermal energy utilization is small.

"Mladost" Sport Centre, located in the south-western part of the Croatia's capital Zagreb, makes use of the geothermal water from the Zagreb geothermal reservoir. The whole complex, including open-air and indoor swimming pools with all the accompanying facilities, as well as two sport halls, is entirely heated by geothermal energy, including the peak consumption. Geothermal energy is extracted from the water flowing in a closed system, consisting of a production well, cascaded heat exchangers, injection pumps and an injection well. Pressure resulting from the density difference of water with different temperatures is used to establish so-called thermosiphon injection. Consequently, the injection system can operate without the support of the injection pumps for more than 7500 hours a year (Zelić et al, 1995).

Another locality where geothermal energy is used from deep production and injection wells is Bizovac, near the town of Osijek in the north-eastern part of the country. "Termia" Recreation Centre, consisting of a hotel equipped with a complex of open-air and indoor swimming pools, is heated by geothermal energy. The circulation of geothermal water is not closed like at "Mladost" Sport Centre.

In the **Table 3**, the outlet temperatures correspond to the average air temperatures during the year or the summer season, depending on the period of the year when a specific facility is in function. This methodology has been accepted taking into account equivalent fossil fuel energy that would be spent if water was heated from the ambient temperature. The authors have applied this approach of energy calculation, although the alternation of such a point of view can be the object of a discussion.

Installed thermal capacities in 2000 were 113 MW_t, which is not changed till today. In spite of that, annual energy usage was increased in last five years from 550 TJ/yr to 680 TJ/yr, as presented in Table 3.

As can be seen from the **Tables 5**, the total geothermal energy used for space heating in Croatia is almost 190 TJ per year. Adding the amount of energy of 490 TJ per year relating to the balneological and recreational use, gives the total of 680 TJ per year of geothermal energy used as direct heat. Relating those figures to the total installed geothermal capacity, which is 36.7 MW_t considering heating, and 77,3 MW_t taking into account balneology and recreation, gives capacity factor values of 0.16 and 0.23, respectively. Small capacity factor is a clear evidence of an inadequate use of the installed geothermal capacities. As in the most cases, quantities of available thermal water are much higher than those needed to satisfy the actual demand, even taking into account peak load situations that in reality rarely occur.

Figures regarding the number of geothermal wells drilled (**Table 6**), and the allocation of the professional personnel

(**Table 7**) during the last five years, as well as those relating to the total investments in geothermal during the last fifteen years (**Table 8**) indicate a certain stagnation of the geothermal energy sector development.

5. CONCLUSION

All the geothermal localities that have been used for decades for recreational and medical purposes belong to the group of the low temperature natural thermal springs. More recently some of those spas were equipped with space heating systems based on the utilization of geothermal energy by means of heat exchangers.

The geothermal reservoirs that are currently still not in use are located in agricultural areas. Another utilization of geothermal energy for greenhouse heating and the subsequent industrial processing of the produced fruits and vegetables would significantly increase the efficiency of the agricultural production. The foreseen development of the geothermal energy application in the agricultural sector strongly depends on the economic interest by private agricultural producers and food processing companies.

In accordance with the general orientation towards ecologically acceptable renewable energy resources proclaimed in the Strategy of the Energy Development of the Republic of Croatia, a significant growth of the geothermal energy usage is planned. In the first phase the growth will be based on the total exploitation of the existing geothermal wells and the increase of the capacity factors of the installed capacities. As the next step, the complete geothermal field development by means of newly drilled wells is planned.

Beside development in the direct heat segment, the planned construction of the geothermal power plant in Velika Ciglena by the year 2010 would bring Croatia into the group of countries producing electricity from geothermal sources. The initial power of 4.4 MW_e obtained from the existing well should be increased to the value of 13.1 MW_e by the construction of two additional production wells by the year 2015. As mentioned before, the pre-feasibility study on combined electricity and heat production in Velika Ciglena showed that such an energy generating plant could operate under economically acceptable conditions.

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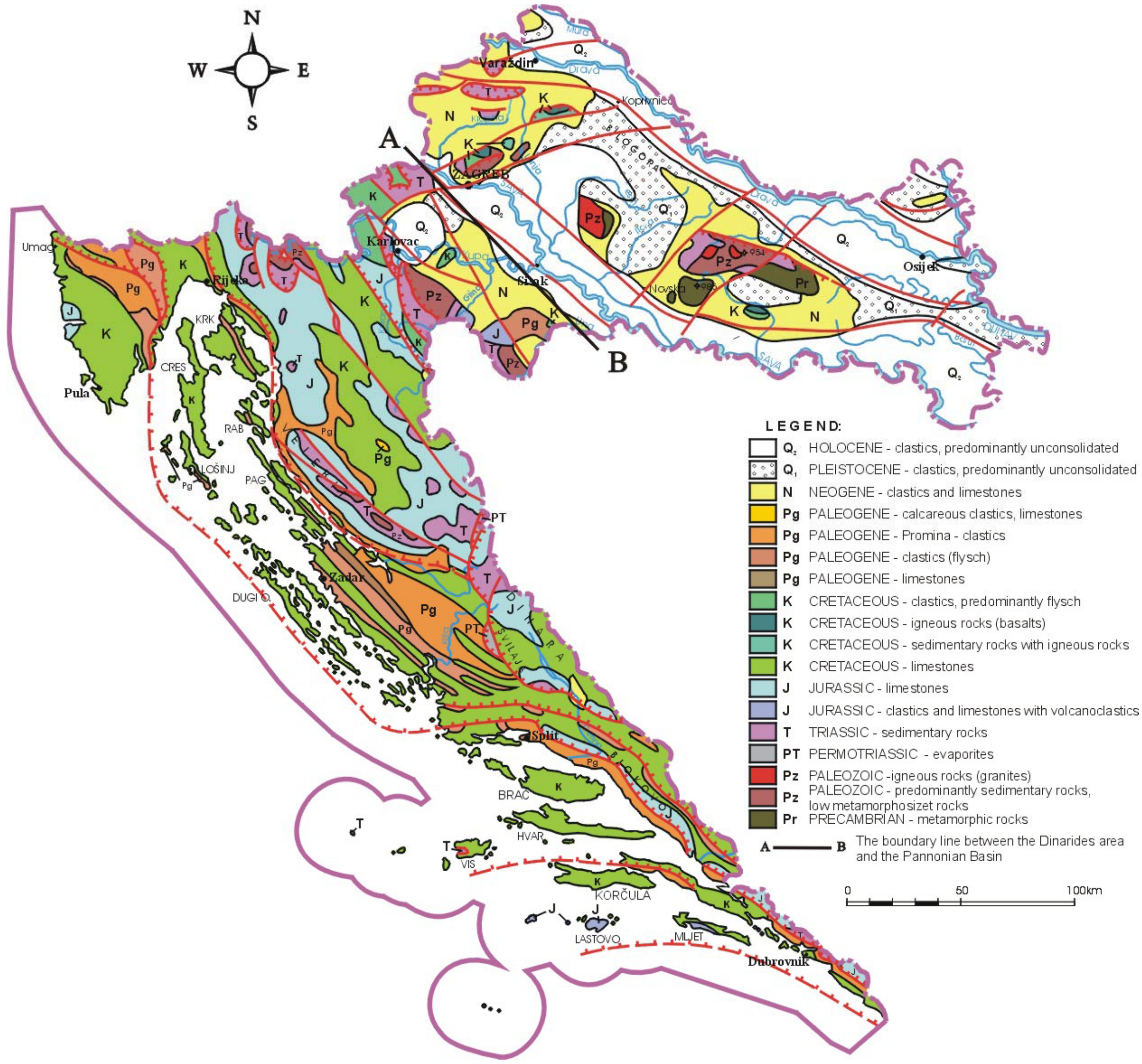

Fig. 1 Geological map of the Republic of Croatia (after Velić & Velić, 1993)

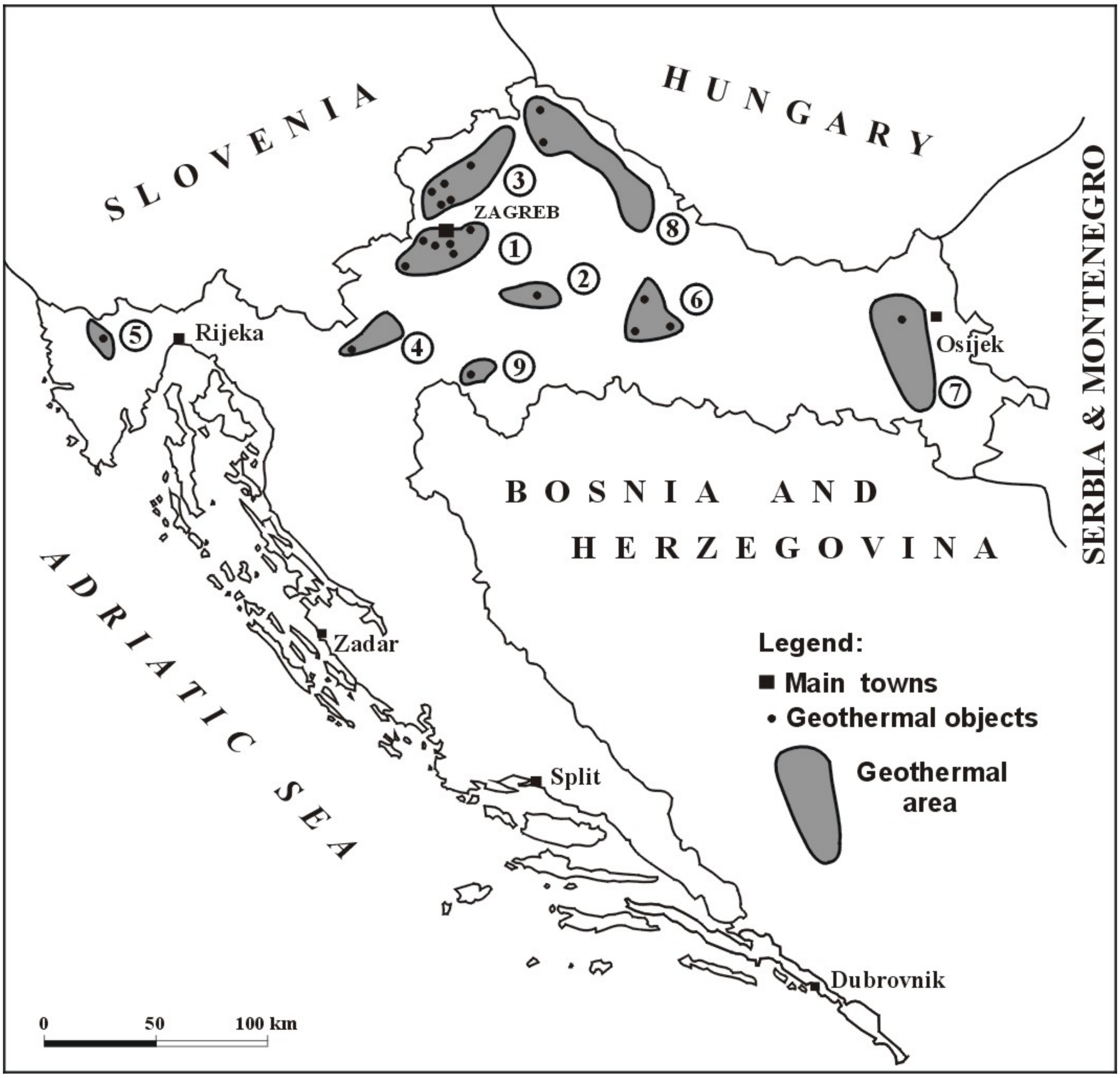

Fig. 2 Geothermal area and locations where geothermal water is exploited in Republic of Croatia

1. Geothermal area Zagreb (Mladost recreate-sport centre, University Hospital, Lučko-Factory, Sveta Helena - Šmithen, Sveta Jana, Sveti Ivan Zelina)

2. Geothermal area Ivanić Grad - Naftalan - Hospital

3. Geothermal area Hrvatsko zagorje (Jezerčica, Krapinske Toplice, Stubičke Toplice, Sutinske toplice, Tuheljske toplice)

4. Geothermal area Lešće - Karlovac (Lešće),

5. Geothermal area Istra (Sveti Stjepan - Istarske toplice),

6. Geothermal area West Slavonia (Daruvar, Lipik, Velika),

7, Geothermal area East Slavonia (Bizovac -recreactive centre),

8. Geothermal area Međimurje - Podravina (Varaždinske toplice, Vučkovec)

9. Geothermal area Topusko (Topusko - spa)

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	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 2004	0,0	0,0	2003,6	11411,9	2045,3	5357,8	0,0	0,0	0,0	0,0	4048,9	16769,7
Under construction in December 2004	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Funds committed, but not yet under construction in December 2004	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total projected use by 2010	4,4	34,3	2568,3	11947,8	2101,3	7965,2	0,0	0,0	26,0	53,0	4700,0	20000,0

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2004

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Annual Energy Produced 2004[3)] GWh/yr	Total under Constr. or Planned MWe
Total						0,0	0,0	4,4

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2004 (other than heat pumps)

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating
2) 1F = Single Flash B = Binary (Rankine Cycle)

   2F = Double Flash H = Hybrid (explain)

   3F = Triple Flash O = Other (please specify)

   D = Dry Steam

3) Data for 2004 if available, otherwise for 2003. Please specify which

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Bizovac (Termia RC)	HB	26,0	90,7	11,0			8,670	5,1	53,613	0,196
Daruvar (Daruvar Spa)	B	18,0	47,0	10,8			2,726	5,5	26,261	0,305
Ivanić Grad (Naftalan Hospital)	B	2,7	62,0	10,8			0,578	1,3	8,779	0,481
Krapinske Toplice (Krapina Spa)	HB	70,0	41,0	9,8			9,138	5,4	22,223	0,077
Lipik (Lipik Spa)	HB	8,3	61,0	10,7			1,747	4,5	29,856	0,542
Livade (Istria Spa)	B	2,0	28,0	11,3			0,140	0,7	1,542	0,350
Samobor (Šmidhen SRC)	B	30,0	28,0	20,2			0,979	4,0	4,115	0,133
Stubičke Toplice (Stubica Spa)	HB	95,0	53,4	10,1			17,211	3,7	21,132	0,039
Sveta Jana (Sveta Jana)	B	53,0	26,0	19,0			1,552	5,1	4,709	0,096
Topusko (Topusko Spa)	HB	124,5	62,0	19,7			22,034	31,3	174,634	0,251
Tuhelj (Tuhelj Spa)	B	75,0	32,0	10,0			6,904	75,0	217,635	1,000
Varaždinske Toplice (Varaždin Spa)	HB	27,0	58,0	10,0			5,422	5,3	33,555	0,196
Velika (Toplice RC)	B	35,0	25,0	20,0			0,732	8,8	5,804	0,251
Zagreb (INA)	H	5,5	55,0	30,0			0,575	0,1	0,330	0,018
Zagreb (Mladost SC)	HB	50,0	80,0	10,5			14,539	6,6	60,503	0,132
Zagreb (University Hospital)	H	55,0	80,0	50,0			6,904	1,6	6,331	0,029
Zelina (Zelina RC)	B	30,0	40,0	20,2			2,485	3,0	7,835	0,100
Zlatar (Sutinske Spa)	B	220,0	32,0	19,4			11,598	1,7	2,825	0,008
TOTAL		**927,0**					**113,936**	**168,7**	**681,682**	**0,190**

TABLE 4. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

[1] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	36,660	189,600	0,164
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	77,276	492,082	0,236
Other Uses (specify)			
Subtotal	**113,936**	**681,682**	0,190
Geothermal Heat Pumps			
TOTAL	**113,936**	**681,682**	0,190

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}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. (^{o}C) - outlet temp. (^{o}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

[7] Includes balneology

TABLE 5. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

[1)]Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled: Electric Power	Direct Use	Combined	Other (specify)	Total Depth (km)
Exploration[1)]	(all)					
Production	>150° C					
	150-100° C					
	<100° C		1			0,9
Injection	(all)					
Total		0	1	0	0	0,9

TABLE 6. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	0	10	3	0	0	3
2001	0	12	3	0	0	3
2002	0	13	3	0	0	3
2003	0	15	3	0	0	3
2004	0	15	4	0	0	3
Total	0	65	16	0	0	15

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

TABLE 7. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004) 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$	%	%
1990-1994	2,0	0,0	1,7	0,0	1,8	98,2
1995-1999	0,0	0,0	1,9	0,0	20,6	79,4
2000-2004	0,0	1,0	2,0	0,0	40,0	60,0