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Geothermal energy into District Heating Systems in Zagreb, Croatia

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Abstract

So far, fossils are the main source of thermal energy. Because of the new environmental regulations and future requirements, thermal energy should be produced from sustainable, renewable and emission-free energy sources. In this context, geothermal power meets these requirements but it must be integrated into the existing systems. It is difficult to build new geothermal power plants and feed heat to existing network because the existing district heating systems are located in densely populated and built-up areas. This paper examines the possibilities of using geothermal resources in Zagreb city based on the available technologies, for district heating.

1. Introduction

Around the globe there is a growing need for the enhanced use of renewable energies due to the increasing energy demand worldwide, to the restricted reserves of fossil fuels raising concerns on the security of energy supply, and to considerations related to anthropogenic emissions of CO_2 affecting the Earth's climate. The current level of energy consumption is unsustainable, therefore action is urgently needed. This is addressed by several international and EU policies and strategies, such as, for example the Kyoto Protocol, or the European Union's headline targets of reducing greenhouse gas (GHG) emissions by 20%, to increase energy efficiency by 20%, and to increase the share of energy produced from renewable energy sources (RES) by 20% in 2020.

Among the renewable resources, since decades the geothermal energy is used around the world for heating houses [1]. Obviously, Earth's interior heat is most easily and successfully applicable for heating. For the Republic of Croatia, this energy can play a key role to achieve the energetic goals [2]. The country has many centuries of tradition of geothermal energy usage from natural springs for medical purposes and bathing. Geothermal energy is the basis of the economic success of numerous spas in Croatia. There are a total of 28 geothermal fields, out of which 18 are in usage. For the needs of space heating a total of 36.7 MW of heating power has been installed with annual usage of heating energy of 189.6 TJ/year. For bathing 77.3 MW of heating power is used, i.e. 492.1 TJ/year (Table1). [3].

Table1: Geothermal energy capacity in Croatia [3]

	Potential	Being used	Reserves
Total thermal capacity:	740 MWt	*36.7 MWt + **77.3 MWt	626 MWt
Total electricity capacity	45.8 MWe	0	45.8 MWe
*Individual space heating ** Bathing (balneology			

Until now, geothermal energy has not been used for the production of electricity. Along with the research activities regarding oil and gas, Croatia has also developed the technique and technology for obtaining geothermal energy from deep geothermal layers. At the same time, abandoned oil wells could be considered for geothermal energy utilization. This paper examines the possibilities of using geothermal resources for district heating in Zagreb city based on the available technologies.

2. District Heating System

District heating – DH – is a system which distributes heat from a centralized generation plant to end users (residential, tertiary, commercial, recreational facilities…) connected via a heating network and substations (Figure 1). DH has replaced, in most instances, traditional central heating systems where each building is heated by an individual boiler.

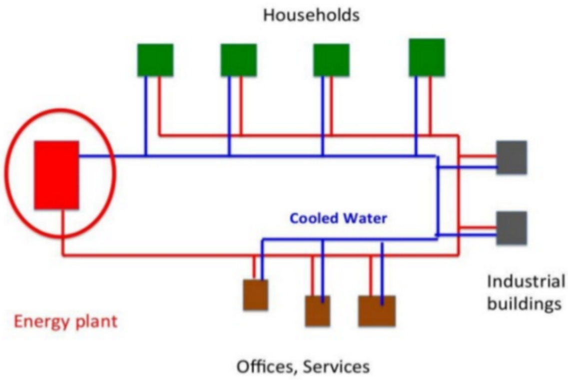

Figure 1. District Heating System

Clearly, DH achieves higher energy, economic and environmental performance. The main point of district heating is to create and maintain a pleasant indoor climate, so the outdoor temperature is the most important factor that determines the daily heat demand, and yearly variations in space heat demand. Despite its "modernity" DH is nothing new. As a matter of fact, it dates back to Roman ages as witnessed by remnants evidencing city homes and baths heated via natural hot water catchments and piping. At Chaudes Aigues, in Central France, a city DH system, pioneered in year 1330, fed by the Par hot spring at 82°C, is still operating to date. Heated homes were charged, in those times, a tax by the local landlord in exchange of maintenance duties, as reported in the city annals.

The heat generation unit can be a thermal power plant, a waste incineration plant or an industrial process. It is important to stress that these DH systems can be completed thanks to local hot springs and shallow wells where surface evidence of geothermal heat is conveyed by water. Geothermal heating uses hot water or steam created below the Earth surface by extracting it and then using its heat, and usually returning the water back into the aquifer. These energy sources are sometimes at low temperature, and it is difficult to use it directly, but the additional use of heat pumps can be utilized to solve problem profitably.

3. Geothermal district heating potential

District heating systems combine heat sources and heat sinks. Many systems are usually fed with thermal energy from fossil fuels. New regulations and future requirements make it necessary, however, to consider alternative solutions. Thermal energy should be produced from sustainable, renewable and emission-free energy sources. Geothermal power meets these requirements [4,5,6].

Geothermal district heating is defined as the use of one or more production fields as sources of heat to supply thermal energy to a group of buildings (Figure 2). Services available from a district heating system are space heating, domestic water heating, space cooling, and industrial process heat [7]. District heating can be defined as central heat delivery to buildings owned by different parties for heating purposes and for warm-water delivery [8].

It is an ideal case for geothermal energy use when the geothermal reservoir can be reached at any point of the settlement with a minimal risk and a district heating network already provides heat for the buildings [9] . In this case, it is enough to conduct the geothermal water to the heating station of the district heating system and transmit its heat with a central heat exchanger. After that, only the water disposal has to be arranged. Consequently, the geothermal system consists of the production well, the water treatment and transmitting equipment, the heat exchanger and the water disposal unit (injection well, surface channel, cooling and storage ponds, etc.).

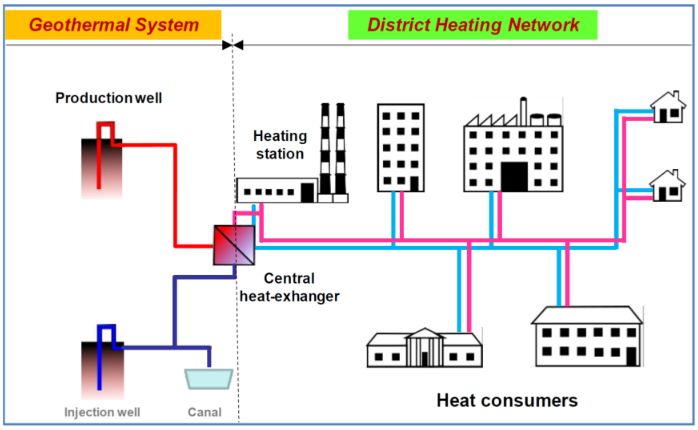

Figure 2. Scheme of geothermal based district heating

Even if district heating first-year costs are higher than those of a conventional system, a life-cycle cost analysis might still indicate economic feasibility of a district heating system. The 20-year annual average unit cost gives a rough comparison of the effect of fuel escalation and district heating system costs. Advantages of geothermal district heating include reduction of fossil fuel consumption, reduction of emission of greenhouse gases, reduced heating costs, reduced fire hazard in buildings, possibly cogeneration of electrical power.

Worldwide, the use of geothermal energy for space heating has increased to 44% in installed capacity and in annual energy use over last five years [9] (Figure 3). The installed capacity now totals 7,556 MWt and the annual energy use 88,222 TJ/yr. In comparison, 88% of the total installed capacity and 89% of the annual energy use is in district heating (28 countries). The leaders in district heating in terms of annual energy use are: China, Iceland, Turkey, France, and Germany, whereas Turkey, USA, Italy, Slovakia and Russia are the major users in the individual space heating sector (a total of 28 countries).

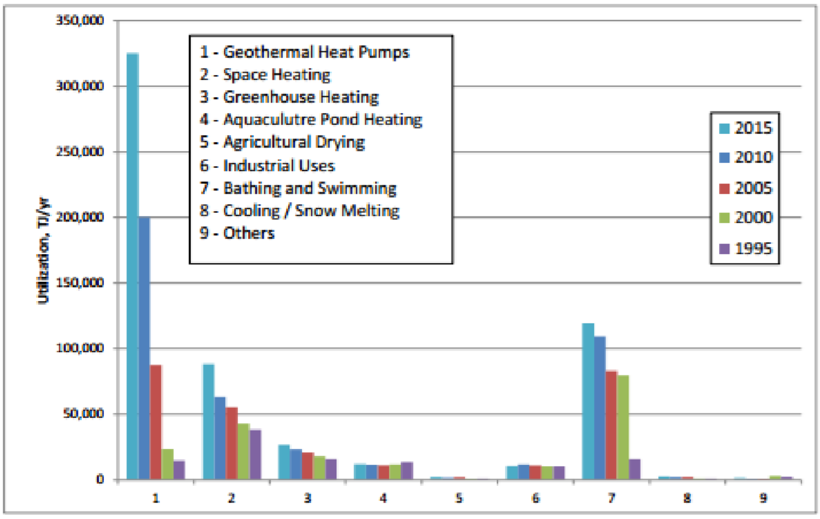

Figure 3. Comparison of worldwide direct-use geothermal energy in TJ/yr from 1995, 2000, 2005, 2010 and 2015

District heating nets are typically operated with hot water in a closed loop. On the side of the customer, heat is harvested using heat exchangers. Sometimes in the past even a direct connection without heat exchangers was used. Net temperatures are differently depending on the season and on the efficiency of the connected buildings. Influx temperatures are typically between 70 °C and 130 °C. However, 130 °C is the maximum temperature suitable for the pipes in long-term operation mode. In reality such a high temperature is only seldom needed in extremely cold days during the winter season. For domestic use the water minimum temperature is 60 °C; therefore the influx temperature has to be higher than 70 °C [10].

Lower process temperatures seem to be inacceptable due to arising problem with Legionella species. If so there will be a need for some kind of bacteriological treatment. Disadvantages of high temperature district heating systems are higher energy losses or higher insulation costs. Return flux temperatures depend on the energy efficiency of the respective buildings. For older buildings, a return flux temperature of 70 °C is typical. In state of the art buildings, a return flux temperature of 50 °C is sufficient. Lower temperatures are advantageous because they reduce energy losses.

4. Zagreb District Heating System

In Croatia, district heating (DH) companies serve about 11% of householders. The main towns where DH services are provided are: Zagreb, Osijek, Rijeka, Sisak, Vukovar, Karlovac, and Slavonski Brod. The DH services are provided by subsidiaries of a national company - Hrvatska Elektroprivreda (HEP) - and by municipal companies. In 2014, the generation of heat energy and process steam amounted to 2.2 TWh transported through networks that have a total length of around 300 kilometers (km). This represent 12.8% less than in 2013. It was affected by decreased consumption due to warm. [11]

In Zagreb, the heat to the network is provided by two CHP plants: TE-TO and EL-TO (Figure 4). Natural gas and coal are the main fuel in most of the plants in Croatia (Figure 5). Heavy fuel oil is used as a reserve and supplementary fuel. The heat generation capacity of the TE-TO-plant is about 950 MW and the electricity capacity about 177 MW. The total heat generation capacity in the EL-TO-plant is about 750 MW and the electricity generation capacity about 94 MW. The heat transmission from the CHP plants to the DH network is done by DH pumps which are operated in variable flow mode, which is a modern and efficient way to operate a DH system as heat is supplied on the basis of demand.

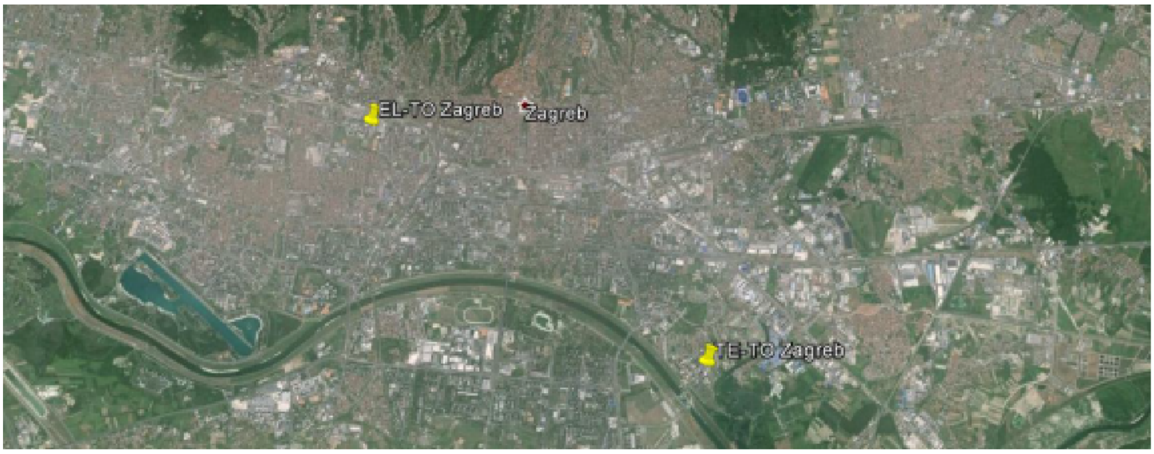

Figure 4. Location of TE-TO Zagreb and EL-TO Zagreb

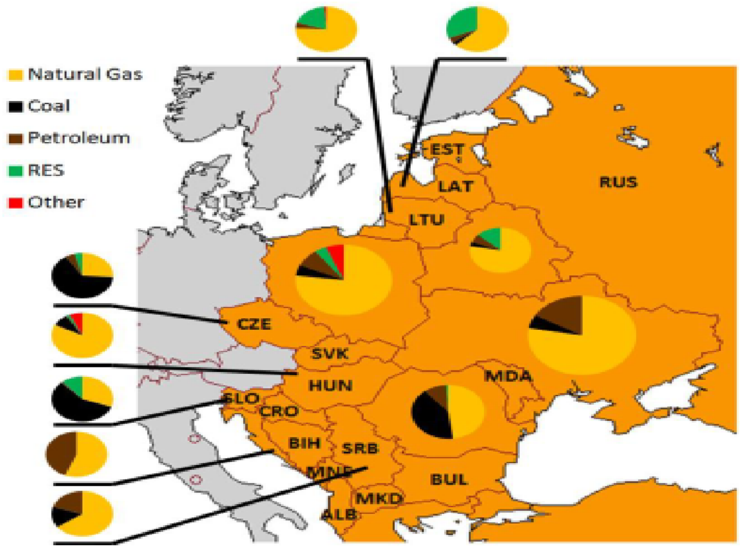

Figure 5. Share of different energy sources used in district heating systems in Eastern European countries

Concerning the heat demand, the number of customers in Zagreb DH has been rising in the past years, reaching 90,396 customers. Out of the total number of customers there are 86,358 households and 4038 businesses [12]. Business customers share of energy consumption is around 40%, while the remaining part, of 60%, is consumed by the households for space heating and domestic hot water preparation. In the Zagreb area, there are 8331,809 m^2 of connected area in DH systems out of which there is approximately 7165,356 m^2 of connected are within Zagreb DH. Total heat consumption, by all the households, is around 1018 GWh while the heat consumption of all the businesses is around 679 GWh. [13].

The city of Zagreb has a total population of 792,875 people living in 304,681 households. Share of the DH among the households is approximated as the ratio of the number of households supplied by DH and the total number of households, and it is around 28.3%. There are 2.6 people per household, which means that Zagreb DH supplies around 225000 people in those households [14].

5. Method for integrating geothermal energy for existing district heating

All over Europe, around 6,000 district heating networks exist [15]. 4,200 of them are displayed in the map in Figure 5. For historical reasons the East European countries have a high amount of district heating networks. In Western Europe, it is more common at high heat demand density areas. All over the world there were different reasons to build and use a district heating system. Most of those systems are fed by fossil fuels [16]. Geothermal district heating systems usually go along with a new designed district heating network because it is built in the best geothermal conditions in combination with thermal energy users located . Worldwide in a few cases geothermal plants were combined with existing district heating networks [17]. In those the existing infrastructure including the substations is fully usable for heat from renewable energy sources. If an existing district heating system is used the costs for the infrastructure can be reduced. (As an example, it costs around one million euros per kilometer for a geothermal district heating system). For this reason, it is highly attractive to integrate geothermal plants in existing district heating systems. But the most important is the feed temperature. This must meet the system requirements, otherwise it would not be useable. Too high temperatures are acceptable, too low temperatures are not. In those cases, the temperature level must be raised even if the enthalpy level stays the same.

For the integration of geothermal energies into an existing district heating system many decisions have to be made. The most important include:

- the temperature levels
- the flow rate (and therefore the thermal power)
- the flexibility of the heating system in terms of being able to lower or increase the thermal energy output over a certain amount of time
- the yearly operation hours
- the controllability of the heating production.

Geothermal plants are predestined to cover the base load all year long with almost 8760 operating hours. The thermal energy demand on the hand of the users is changing frequently but in many times not rapidly. Since the entire pipeline system, which is running with water as transport medium, acts as a storage system itself, minor changes of the demand are manageable. More complex are longer periods of high temperature demand. For this scenario a district heating network must be designed. Customers should not be cold during harsher winter periods and industrial customers need access to the guaranteed amount of thermal energy for their processes.

For this case backup systems are necessary. Those can be either geothermal power plants which switch from electricity output to thermal energy output or any kind of combustion system like biomass or old integrated fossil fired heating plants. Since the operational hours are limited an alternating operation is advisable to run all components profitable. In areas with a high heat demand density district heating system are ideally used. Many customers with a high thermal energy demand are located within a small area. The distances between the consumers, the temperature loss due to transportation, and the electricity used for the circulation pumps are low.

6. Example from Zagreb Geothermal Area

Larger district heating networks are designed with several different diameters of pipelines. Usually the connection to the thermal energy generator has the widest diameter, the customer the narrowest. This depends on the layout of the network itself (tree, loop, or combination). To feed geothermal energy to a district heating system, supply points have to be found. This requires a close collaboration with the operator of the district heating network. Unproblematic are supply points which used to be connections for an existing fossil fuel heating or power plant. If similar power and flow rates are provided by one or several geothermal resources a connection to this supply point is easily manageable. In case of connecting a geothermal resource anywhere to the network some flow simulations of the network have to be made. This is not trivial.

The simulation of larger district heating networks is very time and computationally intensive and therefore in many cases not simulated dynamically but statically. If a right supply point within the right area is found, the connections can be prepared or constructed. Further research has to be made which analyses the economical reasonable distances between a geothermal power or heating plant and the existing district heating network. This mainly depends on the temperature difference between feed pipe and the surroundings, the isolation grade, the flow rate, sell price per kWh, and actual costs.

In Zagreb, the geothermal area is situated in the southwest part of the Panonian Basin and represents a part of the smaller Sava Basin, with the Mt Medvednica to the north and the river Sava to the south (Figure 6 and 7). The Mt Medvednica area is represented by a variety of chrono-stratigraphic units spanning in age from the Paleozoic to the Quaternary [18,19]. South of Mt Medvednica, the area is covered by Pliocene-Quaternary sediments. Exploration drilling show that underlying rocks are equivalent to those found at Mt Medvednica.

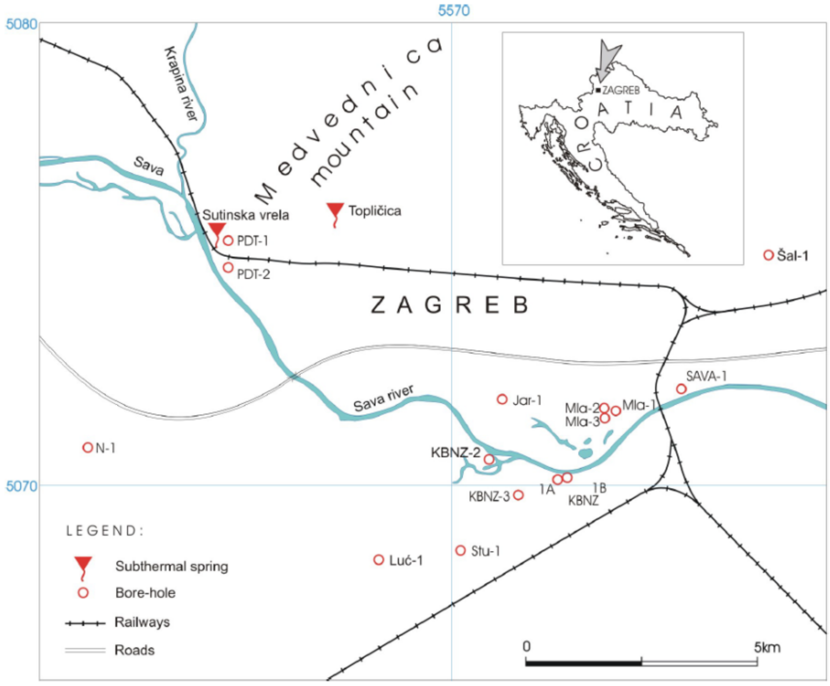

Figure 6. Map of the Zagreb geothermal area [20].

Geothermal aquifers were drilled in many cases. A few geothermal aquifers have been discovered at the depth of 300 to 1000 m with temperature of 30 to 80 °C. There are two types of aquifers. The main type is represented by the Triassic dolomite breccias, dolomite and dolomite limestone while the less important type includes the Miocene bioclastic limestone. At the depth of 500 m, the lowest temperature is 27 °C and the highest 52 °C. At the depth of 1000 m, the lowest temperature is 31 °C (the extrapolated values) and the highest is 80.7 °C. Terrestrial heat-flow density values on the well locations in the Zagreb geothermal area vary from 58 mW/m^2 while the highest amounts to 102 mW/m^2.

Geothermal water is currently exploited from only a few boreholes. No central, updated database on use of geothermal water in Zagreb geothermal area exists so far. At several locations water is used in different way, but everywhere with various intensity during the year. The University Hospital uses the geothermal resource for space heating and sanitary warm water; installed capacity is 6.90 MWt. Geothermal resource is used by several companies and for space heating, distric heating and spas.

Energy capacity of geothermal waters is calculated from the volume flow rate and inlet/outlet temperatures. Total available quantity of water is 114,5 l/s, but only 26,5 l/s is currently in use. Energy capacity is 23,7 MWt. Of this, only about 25 % is used. Since geothermal water from majority of boreholes is unused, the total energy potential of geothermal waters in Zagreb geothermal area is considerably greater than that in use.

Figure 7. Zagreb Geothermal wells

Conclusions

Geothermal heat is perfectly suited for heating buildings in Zagreb. However, the usage of this sustainable and environmentally friendly resource is limited due to the need of district heating systems. Investments in building of district heating are very costly. Besides the challenge to develop new district heating systems there is also a transformation of energy usage going on in several countries of Europe. Coal will no longer be used for power generation. As a side effect, the accompanied heat, traditionally delivered by district heating nets, will no longer be available in the future. Again, geothermal heat is perfectly suited for substitution.

For the integration of geothermal energy systems into district heating networks the right locations for newly constructed geothermal heating or power plants have to be found. The right location is defined by an area in which the geothermal and geological conditions meet the needs for the district heating system while the people living in the neighborhood are not disturbed and the surrounding environment is not affected in terms of sustainability. For this GIS programs can be used which allow a graphical solution to find locations in a region or an area with high density of population and building-sites as well as many regulations for the nature site. On variable plays the distance of geothermal plants to the existing district heating network. This has to be taken into account, too, but is more dependent on finances than on the technical side. This has to be investigated furthermore. But the same GIS method is useable and will be integrated into the research which will carry on for an example detail planning for the integration of geothermal energy systems into the district heating network of Zagreb area. This network has a length of 300 km.

As recommendations for developing geothermal district heating in Zagreb area, firstly, it is important to continue increasing awareness amongst decision-makers and investors with communication campaigns concerning the importance of the heating sector, the benefits of DH systems, and the potential and advantages of geothermal energy. Secondly, more financing is needed to develop geothermal systems and DH infrastructures all over Europe, and in particular in dense urban areas where it is a highly competitive option. Finally, responsive policy makers in focal countries have to establish a regulatory framework suitable for a sustainable development of geothermal DH systems.

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