GEOTHERMAL CONCEPT FOR ENERGY EFFICIENT IMPROVEMENT OF SPACE HEATING AND COOLING IN HIGHLY URBANIZED AREA

by

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New Belgrade is a highly urbanized commercial and residential district of Belgrade lying on the alluvial plane of the Sava and the Danube rivers. The groundwater of the area is a geothermal resource that is usable through geothermal heat pumps. The research has shown that the "heat island effect" affects part of the alluvial groundwater with the average groundwater temperature of about 15.5 °C, i. e. 2 °C higher than the one in less urbanized surroundings. Based on the measured groundwater temperatures as well as the appraisal of the sustainable aquifer yield, the available thermal power of the resource is estimated to about 29 MW_t.

The increasing urbanization trend of the New Belgrade district implies the growing energy demands that may partly be met by the available groundwater thermal power. Taking into consideration the average apartment consumption of 80 W/m^2*, it is possible to heat about 360,000* m^2 *and with the consumption efficiency of 50* W/m^2*, it would be possible to heat over 570,000* m^2*. Environmental and financial aspects were considered through the substitution of conventional fuels and the reduction of greenhouse gas emission as well as through the optimization of the resource use.*

Key words: *geothermal energy, geothermal heat pump, heat island effect, space heating and cooling, New Belgrade*

Introduction

The actual concept of the energy policy is imposed by the influence of climate changes and the unstable market of oil and gas. Its aim is to increase the use of renewable energy resources and energy efficiency, particularly in the building sector. The policy "20-20-20" of the European Parliament, which Directives are complied with the domestic legislative acts, requires the reduction of 20% in harmful gas emission, the increase of 20% in renewable energy resources, and the increase of 20% in energy efficiency by 2020 [1]. In the structure of the demands for energy consumption on the EU level, the building sector is far ahead of transportation, electrification, and industry sectors. Buildings are the greatest energy consumers, and statistics indicates that they share 40% in the consumed energy [2], with the increasing tendency of 0.6% annually for EU member states [3].The energy consumption structure in Serbia does not deviate from the above mentioned statistics, almost 50% of the consumed energy in Serbia is actually consumed by buildings, out of which 65% is used for space heating [4]. The greatest energy consumption is in the capital city, Belgrade, where the housing fund amounts more than a

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third of the whole housing fund in Serbia. As an illustration, for one heating season, the Public Utility Belgrade Heat Plant Service which covers about half of all the flats in the Belgrade area (about 300,000) via the district heating system, spends about 150-200 million Euros on fossil fuels. The remaining half of the residential units uses natural gas (9%), electricity (24%) and other fuels (5%) [5]. This energy-financial balance imposes a necessity for the increase of energy efficiency, not only within the building sector, but in using alternative/renewable energy resources, geothermal resources as well.

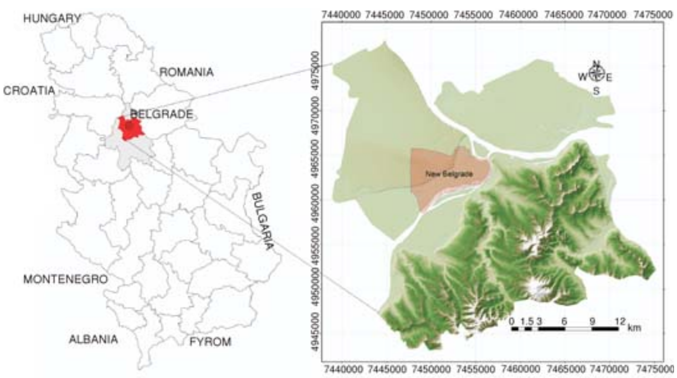

Figure 1. Geographical position of New Belgrade area

The New Belgrade district (fig. 1) is a good example of realising possibilities of efficient geothermal energy use for space cooling and heating. New Belgrade is the highest populated Belgrade municipality with about 215,000 people who mostly live in blocks of flats, while in the last 15 years the construction of office blocks has also been intensified, and this, exactly, defines the municipality as the main business area of Belgrade. The installed capacities of Belgrade heat plants for the New Belgrade area are about 950 MW, whereas those for the heating and cooling of remaining buildings are estimated at about 25 MW [6].

The location of New Belgrade at the confluence of the two big rivers: the Sava and the Danube, has contributed immensely to the formation of the area on significant alluvial deposits of sand-gravel formations of high porosity and high hydrogeological parameter values. Simultaneously, the groundwater temperatures have increased values due to the existence of the heat island effect. These parameters, which will be analysed in greater details in this paper, have anticipated a high hydrogeothermal potential, thus this area has been selected as a representative case study. In this paper, a multidisciplinary approach has been applied together with the application of diverse hydrogeological, geothermal, and thermo-energy methods.

Research concept and methodology

New Belgrade is a highly urbanized area, with 91,000 flats, 800 high residential and office buildings, and about 160 km of roads [7]. The goal of the research is to consider the possibilities and effects of using the groundwater geothermal potential, with regards to the expected additional increase of construction and energy demands for heating and cooling of residential and office areas. Starting points for the research are:

- the data up to now on (hydro) geological characteristics indicate the existence of still unused groundwater resources within a shallow alluvial aquifer,
- geothermal energy of the alluvial groundwater can be used for building heating/cooling, via geothermal heat pump (GHP),
- the world experience with the GHP application for building heating/cooling so far has been positive with regards to (economic and ecological) viability, and
- the additional advantage with respect to the geothermal potential of the area is the heat island effect on the groundwater.

On the basis of the mentioned starting points the research has included:

- defining of hydrogeological characteristics of the area: horizontal and vertical distribution of aquifers, hydraulic conductivity, pumping well flow rates,
- measuring of the groundwater temperature and propagation of the heat island effect on the groundwater,
- evaluation of exploitable groundwater quantities,
- evaluation of groundwater thermo-energy potential,
- possibilities of the geothermal resource use for space cooling/heating, and
- environmental and economic aspects of the concept

Implemented research and results

Hydrogeological features of the area

A highly productive aquifer exists within the alluvial deposits (gravel, sand, and clay of different grain sizes) of the Sava and the Danube rivers (fig. 2). North-western part of the area consists of the deposits of low hydraulic conductivity ($K_f < 10^{-6}$ m/s), mostly loess, which made a low-yield aquifer. At the base of (Quaternary) alluvial and loess deposits, there is a thick complex of older (Neogene) sediments in which a low yield confined aquifer has been formed [8].

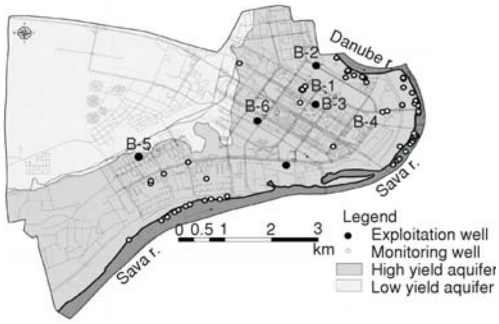

Figure 2. Simplified hydrogeological map of New Belgrade area

On the basis of the mentioned hydrogeological fratures of the area, as the immediate study matter of hydrogeological analyses, an alluvial aquifer has been defined, and it is characterized by the highest hydraulic conductivity, which also indicates the highest well flow rates. The extension of the alluvial aquifer is about 25 km^2 and the depths to the groundwater level range from 10.5 to 16 m [9]. The average thickness of the aquifer is about 14 m, the average well flow rate is about 7 l/s, and the hydraulic conductivity range is 10^{-3}-10^{-5} m/s (tab. 1). It should be emphasized that presented flow rates (tab. 1) are not the highest ones, but the operating flow rates of the wells, according to the consumers' demands.

Table 1. Main features of selected pumping wells in the alluvial aquifer, modified [9]

Well mark (marked on fig. 2)	Screen depth (m below surface)	Screen thickness [m]	Flow rate [ls^{-1}]	K_f [ms^{-1}]
B-1	10.5-20.5	10	5.5	$7.87 \cdot 10^{-3}$
B-2	15.0-25.0	10	6.0	$6.28 \cdot 10^{-5}$
B-3	20.00-29.00 31.00-40.00	9 9	4.0	$1.01 \cdot 10^{-4}$
B-4	18.0-30.0	12	10.0	$1.37 \cdot 10^{-4}$
B-5	18.5-22.0 26.0-34.0	3.5 8	10.0	–
B-6	16.00-22.00 24.00-27.00	6 3	10.0	–

Groundwater temperature regime and heat island effect in study area

The heat island effect is a typical phenomenon for highly urbanized areas with characteristic microclimate changes [10] *i. e.* elevated air and ground temperatures which trigger the increase of groundwater temperature in shallow aquifers. In Basel (Switzerland), there is the elevation of 9 °C in the groundwater temperatures below densely urbanized parts of the city, compared to the groundwater temperatures in less urbanized surroundings [11], whereas in Istanbul (Turkey), the groundwater temperature difference between urban and rural areas is 3.5 °C [12]. Energy benefits of groundwater affected by the urban heat island effect could be significant. The survey results in Cologne (Germany) [13], have shown that by the temperature decrease of 2 °C of the 20 m thick urban aquifer, the amount of extractable geothermal energy beneath Cologne is 2.5 times higher than the residential heating demand of the whole city. In Ireland, the groundwater of 12 °C, drawn from a 1 m thick gravel aquifer carried through heat pumps, gives the energy saving of 2 GWh per annum, with a pay-back period achieved by savings in running costs of three separate buildings ranging from 1.5 to 4 years [14].

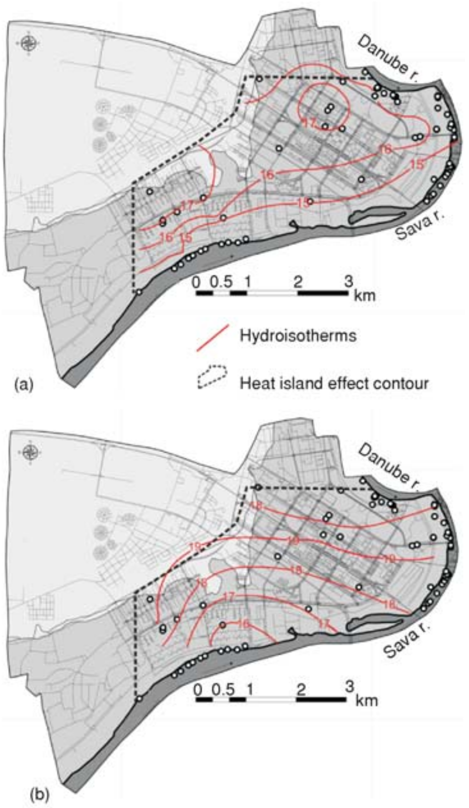

Figure 3. Simplified hydro-isotherm maps of New Belgrade area, (a) summer season, (b) winter season, modified [8]

The heat features of an alluvial aquifer in the New Belgrade area were studied for 12 months in the period of 2010-2011. The groundwater temperature monitoring was carried out in 65 wells [9]. The measurements were performed daily and the device was provided with a probe connected to a graduated measuring tape. The groundwater level and temperature were scanned on the display on the ground surface. On the basis of the gathered data the hydro-isotherm maps were made for typical time periods (fig. 3). The groundwater temperatures in the highly urbanized zone may reach 19 °C, whereas in the surrounding suburban area they range from 13 to 14 °C, which clearly indicates the existence of the heat island effect in part of the area, covering about 16 km^2 (fig. 3). The adopted average annual groundwater temperature within the zone of heat island effect is 15.5 °C, while the average groundwater temperature out of the zone is 13.5 °C.

Thermo-energy potential of resource

Thermal power (P) of the hydrogeothermal resource is calculated by the equation [15]:

$$\text{Therm. cap. [MW}_\text{t}] = \text{flow rate [kgs}^{-1}] \times (\text{inlet temp. [ºC]-outlet temp.[ºC]} \times \times 0.004184 \text{ MJ/kgºC} \quad (1)$$

Flow rate in kg/s is identical to the one in l/s, presented in tab. 2.

Table 2. Thermo-energy potential of the groundwater

Flow rate	Inlet temp.	Outlet temp.	Therm.capacity
Within heat island effect zone (16 km^2): 450 l/s	15.5 °C	5 °C	19.85 MW_t
Out of heat island effect zone (9 km^2): 250 l/s	13.5 °C	5 °C	8.93 MW_t
Σ 700 l/s			Σ 28.8 MW_t

On the basis of the shown parameters (tab. 1), as well as on the analogy and similarity with the adjacent area of the Belgrade municipal water supply source [9], the total well flow rate (total yield) of the alluvial aquifer is estimated at 700 l/s, *i. e*. 450 l/s within the heat island effect zone (16 km^2) and 250 l/s out of the zone (9 km^2). The adopted average (inlet) groundwater temperatures are 15.5 ºC (within the heat island effect zone) and 13.5 °C (out of the zone). The adopted outlet temperature of used water (5 ºC) represents the limit of water freezing. The total available thermal power of the geothermal resources is 28.8 MW_t.

Possible applications in space heating and cooling

The primary way of space heating in New Belgrade is district heating by means of conventional fuels and via high-temperature systems (radiators). The installed capacity of the New Belgrade heating plant is 920 MW. Towards the end of 2011, the heating plant delivered the heat energy for over 16 million m^2 of residential space and over 4 million m^2 of office space [6]. There has been the steady increase of both residential and office spaces, thus from December 2010 to December 2011, there was the total heat consumption increase of 1.8% [6]. It is estimated that the energy consumption for flat heating in the area of the Belgrade city will reach 6,300 GWh per year by 2030 [16].

In the coming years, the increase in thermal energy demands is expected, and part can be met at the expense of groundwater thermal power, for the heating of new buildings or through the substitution of fossil fuels for the existing buildings. With the average consumption of 80 W/m^2, it is possible to heat about 360,000 m^2 at the expense of available geothermal resources. With the increase in energy efficiency in construction, namely with the consumption decrease to 50 W/m^2, it would be possible to heat up about 570,000 m^2.

The efficiency of a heating system depends on: the consumption of the building, the type of heating system and the selection of interior installations. The highest degree of efficiency (COP = 3.0-5.0) is achieved in open loop GHP water-water systems [17]. Depending on the type of interior installations, system efficiency varies. The best energy efficiency is achieved when the secondary in the GHP heating system is represented by floor or wall panels. Thus, the installation of wall panels instead of high temperature radiators may achieve energy savings of 30% [17]. These savings are achieved due to the decreased temperature of the feeding fluid, better distribution of energy in the room (when it comes to the radiant heating) significant decrease of the difference between the temperatures of upper and lower zones in the room. The energy savings are also benefited by a significant accumulation of radiant heating unlike convective systems [17]. The GHP system efficiency is influenced by the well flow rate and the water temperature. COP increases with the flow rate increase and the inlet groundwater temperature. On the other hand, a flow rate depends on the well pump power performances (electric energy consumption), which, to a certain extent, affects the energy efficiency of the system.

In the New Belgrade district, there are a few buildings with their own (individual) space heating/cooling systems, based on hydrogeothermal energy. One of these is the building of the Republic Construction Department of Serbia (tab. 3).The energy source is provided via the construction of exploitation well B-3 (fig. 2, tab. 1).

The system consists of two GHP with parallel connection and the groundwater inflow of 0.9 l/s per a pump *i. e*. 1.8 l/s maximally. Wall panels are the internal heating installations, while the fancoils are used for the cooling mode.

Table 3. Individual low-temperature heating/cooling system of building of Republic Construction Department of Serbia [9]

Space size	1340 m^2
Projected climate conditions	Outdoor: winter T_{out} = –15 °C, summer T_{out} = +35 °C Indoor: winter T_{in} = 20 °C, summer T_{in} = 26 °C Fresh air inflow: 40 m^3/h per person
Resource (groundwater) parameters	Temperature: 14.0-16.0 °C Optimal flow rate of the well: up to 4 l/s
Heating mode energy parameters	Electr. input: 6.25 kW, Heating output: 40.15 kW COP = 6.42
Cooling mode energy parameters	Electr. input: 6.25 kW, Cooling output: 33.9 kW, EER = 5.42

Environmental and economy aspects

The use of geothermal energy contributes both to the financial savings and to the environment. The calculated heat power of 28.8 MW_t represents a financial saving potential, considering its equivalence to 21,000 t of crude oil, or 37,000 t of coal, or 30 106 m^3 of natural gas [18]. The most significant environmental benefit is the reduction of noxious gas emissions (tab. 4).

Table 4. Potential noxious gas savings for New Belgrade case example [18]

	Crude oil	Coal	Natural gas
CO_2 [t]	102,000	119,000	24,000
SO_X [t]	670	780	160
NO_X [t]	191	225	47

A well pumping rate should be in accordance with the natural aquifer recharge. Over-pumping leads to the over-lowering of groundwater level and rapid water-change, which could lower the groundwater temperature. Disposition of used groundwater may be into the open river flows or (de)watering channels, into the sewage system or back into the aquifer. Besides, (part of the) used water may be reused for a few different purposes: water-supply of facilities, technical, and anti-fire water, *etc*. Water disposition back into the aquifer may trigger "thermal response" phenomenon *i. e*. unwanted decrease/increase of groundwater temperature. Therefore, calculation of distance between pumping well and injection well is crucial and the following formula [19] is one of the recommended:

$$L > \frac{2Q}{T\pi i} \tag{2}$$

where L [m] is the distance between pumping and injection well, Q [ls^{-1}] – the well flow rate, T [m^2s^{-1}] – the aquifer transmissivity, and i – the groundwater hydraulic gradient.

The limiting factor for such a system in urban areas is the plots being occupied by facilities when it is not possible to respect the calculated distance of injection well(s).

In order to establish the economic viability of GHP systems in new buildings, it is necessary to compare them to conventional heating systems, regarding the initial investments, maintenance expenses, system durability and the price of heating resources. The experiences suggest that average initial investment into GHP systems ranges from 850 EUR per kWh for heating and 1 000 EUR per kWh for combined heating/cooling systems. The initial investments into conventional systems are generally lower: up to 40% for heating systems and 20% for combined heating/cooling systems. It should be emphasized that, in the past years, GHP system initial costs decrease and approach the conventional systems. Unlike initial costs, maintenance costs of GHP systems are lower up to 50% [20].

Discussion and conclusion

The New Belgrade city district is a living and business one where further increase of urbanization and energy demands is expected. The main hydrogeological feature of the area is a shallow alluvial highly productive aquifer. As a result of high urbanization, in some parts of New Belgrade the heat island effect has been identified and it is observed in the increased groundwater temperatures of 2 °C, on average, compared with the suburban surroundings. The total energy potential of the alluvial groundwater of the New Belgrade district has been calculated at about 29 MW_t and this enables heating of 360,000-570,000 m^2 of living or business space, depending on building energy efficiency.

According to the manner of exploitation and distribution of the heat energy, individual and centralized systems may be distinguished. In individual systems, one building has its own pumping well and GHP installation of kW capacity. A centralized system implies groundwater exploitation field with several wells and a centralized GHP system of the MW capacity. Those systems are usually connected to the existing heating plants which use conventional fuels, thus the heat energy could be distributed via the same pipeline.

The estimate is that individual systems represent a more efficient concept for the New Belgrade case example, for the following reasons.

- Technically simpler and more energy-efficient space cooling.
- Temperature and energy losses are lower due to the shorter groundwater transport.
- More flexible implementation from the aspect of urbanism and construction.
- More favourable conditions for controlled decrease of groundwater level because of "dispersed" well-pumping points.

The greatest financial viability of GHP system is in new buildings, whose design incorporates the installation of such a system. The presented example of the building of Republic Construction Department represents a good instance, with high energy performances of the building and a careful selection of interior installations – wall panels in combination with fancoils. Very low energy consumption is achieved as well as very low demands in terms of the pumping well flow rate.

The most common way of "energy used" groundwater disposal is via injection wells. It requires complex project design solutions with the aim of the system longevity and it is the result of the analyses of hydrodynamic and thermodynamic features of an aquifer, the possibility of an adequate location of the injection well (with regards to the approachability in highly urbanized areas), the price and possibility of water use for other purposes.

The general conclusion is that a wider application of individual GHP water-water systems for space heating and cooling in newly-designed buildings, within the urban area of New Belgrade, represents an energy efficient concept that is sustainable from both economic and environmental aspects.

Nomenclature

i – groundwater hydraulic gradient, [–]
K_f – hydraulic conductivity, [ms^{-1}]
L – length, [m]
P – thermal power, [MW_t]
Q – flow rate, [ls^{-1}]
T – aquifer transmissivity, [m^2s^{-1}]
t – temperature, [°C],

Greek letters

π – Ludolph's constant, [–]

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