Prospects for wider energetic utilization of subgeothermal water resources - eastern Serbia case study

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Abstract. Extensive worldwide usage of fossil energy sources causes high pollution and contributes to global warming. Hence, achieving energy independence by stimulating efficient use of energy and environmentally friendly exploitation of renewable sources is a main orientation of European countries.

Geothermal energy is generally treated as a renewable and inexhaustible energy source. Nonetheless, direct use of low enthalpy subgeothermal resources, i.e. groundwater of 30º C or lower, for heating is commonly viewed as economically unjustified. To enable its usage, large panel surfaces or a high-temperature heat pump with excellent efficiency is required. The development of a cascade type heat pump and its wide application would enable more efficient utilization of widely available and easy replenished groundwater sources with temperatures of 10–30º C.

The hydrogeological conditions in eastern Serbia are particularly favourable for exploitation of subgeothermal resources due to rich aquifer systems and notable terrestrial heat flow formed into the main geo-structures of the region (Carpathian-Balkan arch and Dachian basin). More intensive exploitation of subgeothermal sources additionally justifies the existence of a number of urbanized small and medium-size cities with a heating infrastructure already developed and centralized. Sustainable use of groundwater resources should be followed by thermal reconstruction of the previously constructed buildings as well as new legislation which supports and encourages development of renewable energy sources. It is estimated that the total potential thermal power which can be generated from subgeothermal waters in the study area is around 33 MWt, which corresponds to some 16 % of the total heat requirements.

Key words: subgeothermal source, groundwater, heat pump, energy efficiency, eastern Serbia.

Апстракт. Интензивно коришћење фосилних горива широм света узрок је озбиљних загађења природе и утиче на глобално загревање. Отуда је један од главних циљева енергетске политике европских земаља коришћење ефикасније "зелене" енергије из обновљивих и сопствених извора.

Генерално, геотермална енергија представља вид обновљивих извора енергије. Ипак, и даље се сматра да коришћење субгеотермалне енергије ниске енталпије (температуре подземних вода од 30° C и ниже) за потребе грејања није у потпуности економски оправдано. Стандардна технологија за примену овог вида енергије захтева велике површине под панелима са цевима које проводе топлу воду и/или употребу топлотних пумпи са високим степеном искоришћења. Развој каскадне топлотне пумпе и њена шира примена омогућила би далеко ефикаснију употребу "лако" доступних подземних водних ресурса температуре између 10–30° C и стога је у више пројеката реализованих последњих година анализирана и развијана ова технологија.

Хидрогеолошки услови у теренима источне Србије, су веома повољни са аспекта експлоатације субгеотермалних ресурса. Подручје се одликује значајним количинама подземних вода и терестичним топлотним током у оквиру геолошких формација у основним гео-структурним јединицама овог

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региона (Карпато-Балканиди и Дакијски басен). Близина урбанизованих насеља и мањих градова и постојање развијеног и централизованог грејања су чињенице које повољно утичу на могућност експлоатације субгеотермалних водних ресурса. Одрживо коришћење подземних водних ресурса подразумевало би и потребну термалну реконструкцију и бољу изолацију постојећих грађевинских објеката, као и доношење нових законских прописа у Србији у циљу подстицаја коришћења обновљивих извора енергије. У подручју источне Србије, процењене количине енергије које се могу добити из субгеотермалних вода износе око 33 MWt, што би представљало око 16% укупних енергетских потреба неколико одабраних већих насеља за које је ова анализа вршена. И поред чињенице да се не очекује потпуно искоришћење овог потенцијала, евидентно је да је он далеко већи од 4 % колико је у плановима енергетског развоја предвиђено да би могло износити учешће геотермалних водних ресурса на нивоу целе Србије.

Кључне речи: субгеотермални извори, подземне воде, топлотне пумпе, енергетска ефикасност, источна Србија.

Introduction

The utilisation of low-enthalpy ground source heat for space-heating (or cooling) is widespread in the USA and in Canada, with recent growing interest throughout Europe (Banks 2008). The heat pump technology which supports low-enthalpy sources would help to achieve the objectives of the Kyoto protocols on "greenhouse" gas emissions. The thermal input for those pumps can be provided either directly by groundwater extracted from wells or tapped springs, or indirectly by water injected into the ground and then pumped out (rock and soil heat release) afterwards. Ground source heat pumps (GSHP) can be regarded as complementary technology inasmuch as they require a "driving" mechanical or thermal power input (commonly, electrical power to a compressor) that is used to extract renewable heat from the ground.

The heat effect delivered by a GSHP is typically 3–4 times the electrical power input. This means that it delivers heat 3–4 times more cheaply, with up to 75 % less CO_2 emission, than direct use of electrical resistance elements. This, in turn, allows GSHPs to deliver more CO_2-efficient space-heating than even the most efficient combustion of fossil fuels. Fossil energy sources are especially limited in European countries, and their dependence on import will be even more critical in the near future. Moreover, ground source heat can also compete effectively in terms of marginal costs with coal or gas (Younger *et al.* 2007). The energy of the geothermal water could be exploited to the maximum before it is returned to the ground through a reinjection well (as already required by legislation of the European Union). With reinjection an ecological problem is also minimized, as utilized geothermal water must not be released into local water courses.

Although the initial high capital cost of GSHP schemes is a potential weakness, within the European Union the uptake of ground source heat technology has dramatically increased (Allen *et al.* 2003). In Sweden, for example, which has few native fossil fuel resources and an energy economy that is founded on nuclear/hydroelectric electricity, there has been a strong political motivation to develop technologies that utilise electrical energy as efficiently as possible. Moreover, the strong environmental and centralist traditions of the Swedish government have stimulated the uptake of technology since the early 1990s by a generous subsidy programme. In 2007, it was assumed that 185,000 GSHPs were installed in Sweden, providing some 1700 MW of power (Bouma 2002; Younger *et al.* 2007; Banks 2008).

In central and SE Europe there is also growing interest in introducing, widely applying and promoting this kind of "green energy". In 2000, fewer than 1000 GSHP were functional within Czech Republic or Poland, while just five years later the number of procured and installed systems had increased tenfold. Rapidly growing interest in GSHPs is also noticed in Italy and in Slovenia, but the less powerful economies of the Balkan countries are still waiting for the encouraged legislation and the deduction of fees for their wider application. However, concerning groundwater resources and availability most of the countries that belong to the Balkan region are strong prospects. The efficient use of thermal potential of existing fluids would thus prevail over the possible alternative i.e. exploitation of rock and soil petrothermal resources.

Subgeothermal water sources

In most relevant references the geothermal fluids with a temperature lower than 100º C are classified as "low enthalpy": only the direct generation of electrical energy from water heat at a temperature higher than 100º C is considered to be fully feasible (Nicholson 1993; Lund & Freeston 2001; Huttrer 2001).

Due primarily to the "young Alpine geology" of the Balkan countries, there are insufficient geothermal fields to generate electrical power under existing technologies. However, the number of thermal occurrences is very large. For example, in Serbia alone over 230 springs or wells with thermal or mineral waters

are registered, 2/3 of them with water temperatures over 20º C. Most of the thermal waters are used for balneology and just a few for heating purposes. In contrast, in neighboring Hungary thermal flows are tapped for heating purposes in many locations. A good example is Hodmezovasarhely where 50000 inhabitants get their heat from the thermal waters at 80º C, tapped at a depth of 2000 m (75 % of utilized waters are reinjected into the ground).

Recently conducted studies aiming to assess the thermal potential of lower temperature ground sources in Serbia introduced the term "subgeothermal resources" (STEVANOVIĆ *et al.* 2008). It has been proposed that waters with a temperature of 30º C or lower are to be classified in this group whereas those with a temperature of 30–100º C belong to "geothermal resources". One of the explanations is very practical: although GSHP is necessary for water with lower temperatures, the panel radiator systems allow direct use of water with a temperature of 30º C or more without GSHP. However, as temperatures are lower, heating panels with larger surfaces are required.

Subgeothermal fluids in the territory of Serbia are typical of complex geology as well as of a moderate continental climate. They are classified as follows (Table 1):

Table 1. Energetic potential of subgeothermal sources.

Group	Temperature (°C)	Average depth (m)	Energetic potential
1	>10	0–20	None
2	10–16	20–75	Small
3	16–22	75–135	Moderate
4	22–30	135–200	High

Brief physio geography, geology and hydrogeology of the study area

There were several reasons to choose the Carpathian region in eastern Serbia (Fig. 1) as a study area: abundant groundwater reserves, considerable subgeothermal flow, a good number of small industrial towns with developed centralized heating infrstructure, and moderate continental climate. The northern boundary is the Danube River, the eastern/northeastern boundary is the state border with Bulgaria (toward which the Carpathian-Balkan mountain range continues), and its western border runs along the edges of the Velika Morava and Južna Morava valleys (Fig. 2). The main settlements are (from north to south): Donji Milanovac, Kladovo, Negotin, Majdanpek, Bor, Zaječar, Sokobanja, Knjaževac, Pirot (all with between 10000–60000 citizens). Further west in an adjacent area of central Serbia (Velika Morava valley) there are

several large cities such as Niš, Paraćin, Ćuprija, Požarevac and others that are also envisaged as possible consumers of geothermal energy produced either from local sources or from eastern Serbia (MILIVOJEVIĆ & MARTINOVIĆ 2005; MARTINOVIĆ *et al.* 2008).
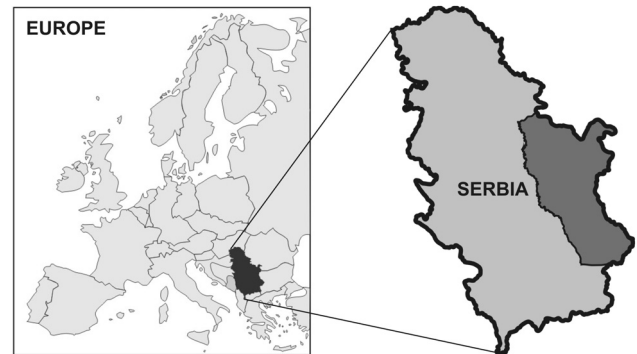

Fig. 1. Location maps of eastern Serbia.

The mountains of the Carpathian-Balkan arch are mostly unpopulated and used by the local villagers for specific crop cultivation or grassland during the summer months. Most of the hills are covered by forests or pastures. The demographic trend in the region is negative: the younger population is gravitating towards nearby industrial centers such as Bor or Zaječar.

The area is a prospect for the development of tourism. It is unpolluted and accessible by many roads, is rich in clean waters, and boasts beautiful landscapes and features such as caves, waterfalls and springs, including several spa and medical centers.

Annual average rainfall ranges from 600 mm to 750 mm for most of the cities, while the annual average air temperature for the entire region is around + 9º C.

The complex geology of eastern Serbia comprises two main geo-structures: the Carpathian-Balkan arch and the Dachian basin, both characterized by hydrogeological heterogeneity and a variety in aquifer systems and groundwater distribution. Thus, the region is characterized by the presence of formations with small groundwater reserves but also Mesozoic carbonate rocks, Tertiary or Quaternary alluvial and terrace deposits that could be very rich in groundwater (STEVANOVIĆ 1994).

The study area consists of several mountain massifs, the majority of which are built from carbonate rocks (Fig. 2). Precambrian rocks are not often exposed to the surface and can be found in anticline cores, often corresponding with mountain central parts and peaks. They are commonly overlaid by Paleozoic rocks (Ordovician, Silurian and Devonian age). Paleozoic formations, magmatic and metamorphic rocks are mostly aquitards or aquifuges.

The major part of the study area was invaded by the Middle Jurassic marine transgression, and the sedimentation cycle continued until the end of the Lower
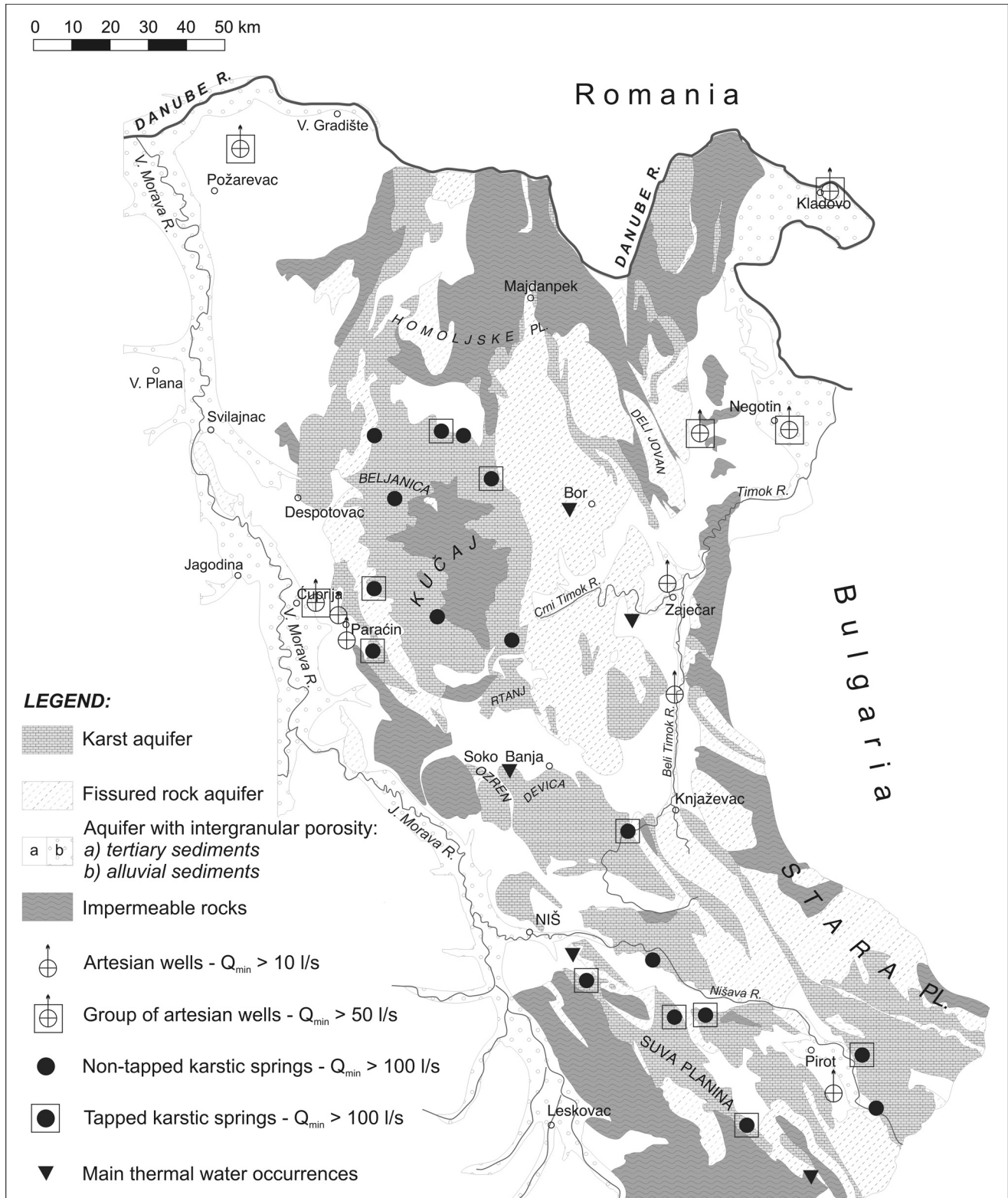
Fig. 2. Hydrogeological sketch map of eastern Serbia and main groundwater sources (based on Hydrogeological digital map of Serbia, Stevanovic & Jemcov 1995).

Cretaceous (Albian). Throughout this period, thick deposits, primarily of carbonate rocks, were formed to a total thickness of about 1300 metres. Carbonate rocks are characterized by the non-uniformity of the facies with prevalent limestone but also by "impure" varieties in lower sections, such as sandy limestones of the Dogger, or Oxfordian-Kimeridgian chert limestones. The carbonate complex was formed mostly

during the Tithonian, Valanginian, Hauterivian, Barremian and Aptian and it contains predominantly pure carbonates or magnesium carbonates.

The karst aquifer formed in carbonate rocks is rich in groundwater, and is recharged mainly from rainfall and from sinking flows which gravitate from impermeable rocks at higher altitudes. Carbonate rocks are well-karstified and contain very large groundwater reserves (STEVANOVIĆ 1994, 2009).

The karstic groundwater is used mostly for drinking purposes or for small industry supply; almost all the cities in the region are consumers. Although the total dynamic reserves in karst often surpass by far the exploitation capacities, most of the tapping structures are constructed simply to tap the natural discharge of the springs and thus depend solely on the natural flow regime. Aiming to overcome this problem, during the last three decades several successful aquifer control projects have been completed (STEVANOVIĆ *et al.* 2007). Karstic groundwater is extracted in a very small amount for irrigation purposes.

In the Timok tectonic trough on the eastern part of Carpathian arch, a volcanogenic-sedimentary series over 2000 meters thick (andesites, pyroclastics, tuffa) was formed during the Senonian and the Paleogene (Fig. 2). Fissured aquifer of this complex contains several important thermal and thermomineral occurrences with the water temperature ranging from 30–40º C (Brestovačka spa, Gamzigradska spa, Sokobanja, Nikoličevo, Šarbanovac).

Clastic sediments, marls, clays, and sands were deposited in a number of the intermountain depressions filled with lake waters during the Neogene (e.g. Žagubica, Bogovina, Sokobanja, Babušnica, Pirot). The sandy water-bearing layers could have an artesian pressure (confined aquifers) and are tapped in several locations (e.g. Negotin, Zaječar).

Most recent are alluvial sediments which follow major streams in the region (Nišava, Timok, Resava etc.) and are used mostly to supply local villages. The exception is Niš where a large amount of alluvial water is tapped (Mediana source) for Niš itself, the third largest city in the country.

Utilizing geothermics by cascade heat pump - Discussion

For heating purposes three basic types of heat pumps are used (GORIČANEC *et al.* 2008):
– a single stage heat pump,
– a two stage heat pump with a flash vessel,
– a two stage heat pump with a heat transmitter.
Using a single stage heat pump for heating buildings, the temperature of the secondary carrier can reach 55° C maximum, which is quite a bit too low for the heating of buildings with a "classical" radiator heating system. Therefore, single stage heat pumps

are primarily used for low-temperature heating systems, with the temperature of the secondary carrier up to 45° C. In high temperature heating systems, the temperature of the secondary carrier must be even higher than 60° C. With an appropriate refrigerant, a two stage heat pump with a flash vessel could be used for high temperature heating systems. But it is difficult to find a refrigerant which allows the exploitation of the temperature of geothermal water by cooling it to 10° C and at the same time reach a high temperature in the condenser of the second stage in the heat pump (GORIČANEC *et al.* 2009).

This problem has initiated research for a two stage heat pump with a heat transmitter (heat exchanger), schematically shown in Figure 3. The heat pump in fact consists of the two single stage heat pumps which are connected by a heat transmitter. The advantage of such a cascade heat pump is that, according to their physical-chemical characteristics, different refrigerants can be used at each stage. In choosing the refrigerant considerable attention must be paid to its physical-chemical characteristics, ecological acceptability, and use of recognized brands.
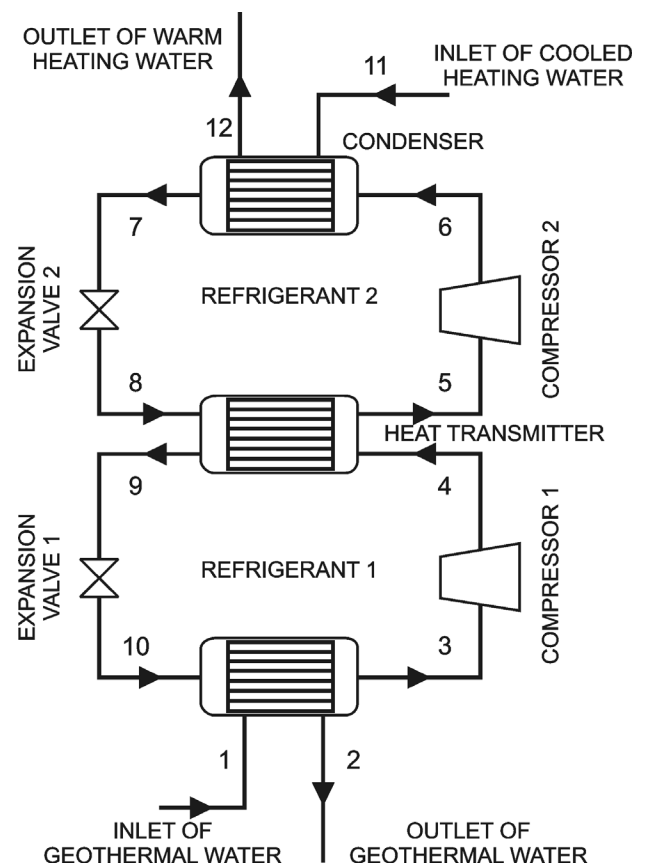
Fig. 3. Scheme of two stage heat pump with a heat transmitter (Goričanec *et al.* 2009)

The heat transmitter between the two stages represents a condenser for the first stage and an evaporator

for the second (GORIČANEC *et al.* 2008). The use of two stage heat pumps with a heat transmitter is suggested in the existing district heating system of buildings in the city of Lendava in Slovenia (TORHAČ *et al.* 2005). The heat source for the heat pumps is geothermal water of 42° C. The principle of exploiting heat from geothermal water in an individual facility is shown in Figure 4. With such a system it would be possible to exploit the heating of geothermal water to a temperature of even 10° C.
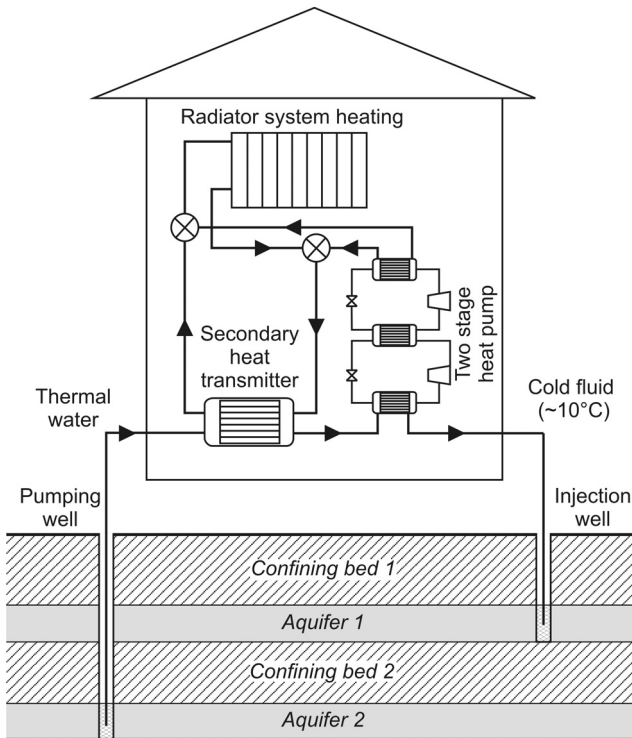

Fig. 4. Scheme of heating of building by a two stage heat pump and reinjection of utilized waters

The coefficient of profitability of a two stage heat pump and the period of time for the investment to be recovered show these to be good prospective solutions. In the case of the Lendava thermal source, the coefficient of profitability has been calculated on 1.19, and the investment will be returned in 3.2 years (KOZIĆ *et al.* 1994; TORHAČ *et al.* 2005). The coefficient of performance (COP) of a heat pump is between 3.5 and 4.4. Tests and calculations for water at lower temperatures, different refrigerants and equipment used resulted in a longer period for investment recovery, but still justifiable in terms of both economy and ecology.

At present, almost 50 % of total energy production in EU countries is spent in buildings. In Serbia even more, almost 2/3 of the energy is utilized for domestic heating, which is quite logical given that more than 50 % of buildings in Serbia were built before 1970. when application of thermal insulation was not obligatory. According to some estimates, the annual energy output is in the range of 150 to 250 kWh/m^2. This is 2–3 times more than optimal.

Moreover, the application of active and passive renewable energy for space and water heating is still not properly regulated in Serbia: it is only recommended in different state or local government strategies. However, central heating systems exist in numerous cities and can be used for conveying energy from alternative thermal sources.

Eastern Serbia - subgeothermal potential and prospect

Several conducted studies (STEVANOVIĆ 1994, 2009; MILIVOJEVIĆ & MARTINOVIĆ 2005, 2010; MARTINOVIĆ *et al.* 2008; STEVANOVIĆ et al. 2008) have concluded that eastern Serbia is one of the regions in the country with the greatest prospect for groundwater and subgeothermal energy extraction due to: richness of the aquifer, developed heating infrastructure within moderately populated cities, proximity of the sources to the end-users.

In practical terms, most important is the karstic type of aquifer in Jurassic and Cretaceous limestones, which covers about 30 % of this region. The region features a considerable number of karstic springs, of which 16 have a minimum yield of more than 0.1 m^3/s (STEVANOVIĆ 1995). All major cities use water from karstic aquifers; however, available reserves are several times higher than the water demand of this and neighboring regions, and will remain so for a long time to come. There is also good potential for groundwater utilization from alluvial sediments and Neogene formations in Intra-Carpathian basins. Regarding the total groundwater resources available there are some contradictions in their estimates. The Water Master Plan of Serbia from the year 2000 indicated dynamic groundwater reserves in the amount of 4.27 m^3/s, while some other studies found that even the reserves of karst aquifers are considerably higher, reaching 12.6 m^3/s. The karst and fissured aquifers are also rich in thermal water occurrences: there are 6 registered with temperatures over 30° C and some 20 with temperatures over 20°C. In addition, average water temperatures of artesian and subartesian waters from Neogene sediments are in the range of 10–18° C which also classifies those aquifers as ones with high potential for geothermics utilization (Table 2).

According to the preliminary assessment, some 1.7 m^3/s of groundwater in eastern Serbia can be extracted and sustainably used for heating/cooling systems (STEVANOVIĆ *et al.* 2008). This potential flow resulted from the calculation which took into consideration prioritized water utilization for drinking and industrial water supply, ecological flow for downstream water dependent eco-systems, and the average water temperature ranging from 10–30° C. The subthermal flow

Table 2. Available subgeothermal resources and calculated heat power in the Eastern Serbia.

Aquifer system	Total groundwater resources (l/s) *	Total heat potential capacity (Mwt)	Available subgeothermal water resources (l/s)			Available heat power (Mwt)
			Temperature 10–16° C	Temperature 16–22° C	Temperature 22–30° C	
Alluvial aquifer	1750	43.9	610	0	0	15.3
Neogene artesian aquifer	730	26.8	170	55	45	10.4
Karstic and fissured aquifer	5310	140.0	730	55	30	23.5
TOTAL	7790	210.8	1510	110	75	49.2

* temperature of groundwater resources: 10–30° C

$\Delta T =$ 6° C – temperature 10–16° C
$\Delta T = 12°$ C – temperature 16–22° C
$\Delta T = 18°$ C – temperature 22–30° C

can be separated into three categories as presented in Table 1. Total potential heat capacity is calculated by the formula:

$$Q = m * c * \Delta T$$

where,

Q – total potential heat capacity (MWt),
m – mass (kg),
c – specific water thermal capacity J/(kg°C) i.e. 0.004184,
ΔT – differential temperature (°C).

Differential temperatures are in the range of 6–18° C depending on geothermal categories (e.g. $\Delta T = 18°$ C for the waters with T 22–30° C). Available heat power is based on available water resources and tolerable COP, and is assumed to be around 49.20 MWt (Table 2).

The next step in the calculations considered the thermal heat power from sources which are located in the vicinity of the urban areas. Most of the water resources are at a viable distance from the consumers. The calculation is based on apartments with an average surface of 60 m^2 and required average heat of 100 kWh/m^2. The latter figure takes into consideration the implementation of some other energy efficiency measures to be implemented at the same time (thermal reconstruction and insulation of the buildings). Complete and systematic insulation would additionally improve the situation and reduce required heat, but at this stage just part of these activities are envisaged. Table 3 contains data concerning the total power required to heat the apartments in major towns, the potential subgeothermal flow available in their vicinity (for each of defined three categories), the potential thermal power which can be produced by heat pumps, and the percentage of heat demands that can be met by heat power generated in such a way.

The total potential thermal power which can be generated from subgeothermal waters for large settle-

Table 3. Potential of subgeothermal water resources and heat power in vicinity of urban areas of Eastern Serbia.

No	Main towns	Number of house holds in urban area	Total surface for heating (m^2)	Required heat power (Mwt)	Available subthermal flow (l/s)*	Potential thermal power supported by heat pumps (Mwt)	Cover of required heat (%)
1	Kladovo	5,016	300,900	30.1	110/20/10*	4.5	15
2	Negotin	2,739	164,300	16.4	120/20/10	4.7	29
3	Majdanpek	2,563	153,700	15.4	120/10/5	4.3	28
4	Zaječar	6,812	408,700	40.9	160/10/10	5.3	13
5	Bor	5,736	344,100	34.4	130/10/10	4.5	13
6	Knjaževac	4,015	240,800	24.1	150/10/10	5.0	21
7	Pirot	6,728	403,600	40.4	140/10/5	4.4	11
	TOTAL	33,600	2,016,100	201.7	930/90/60	32.7	

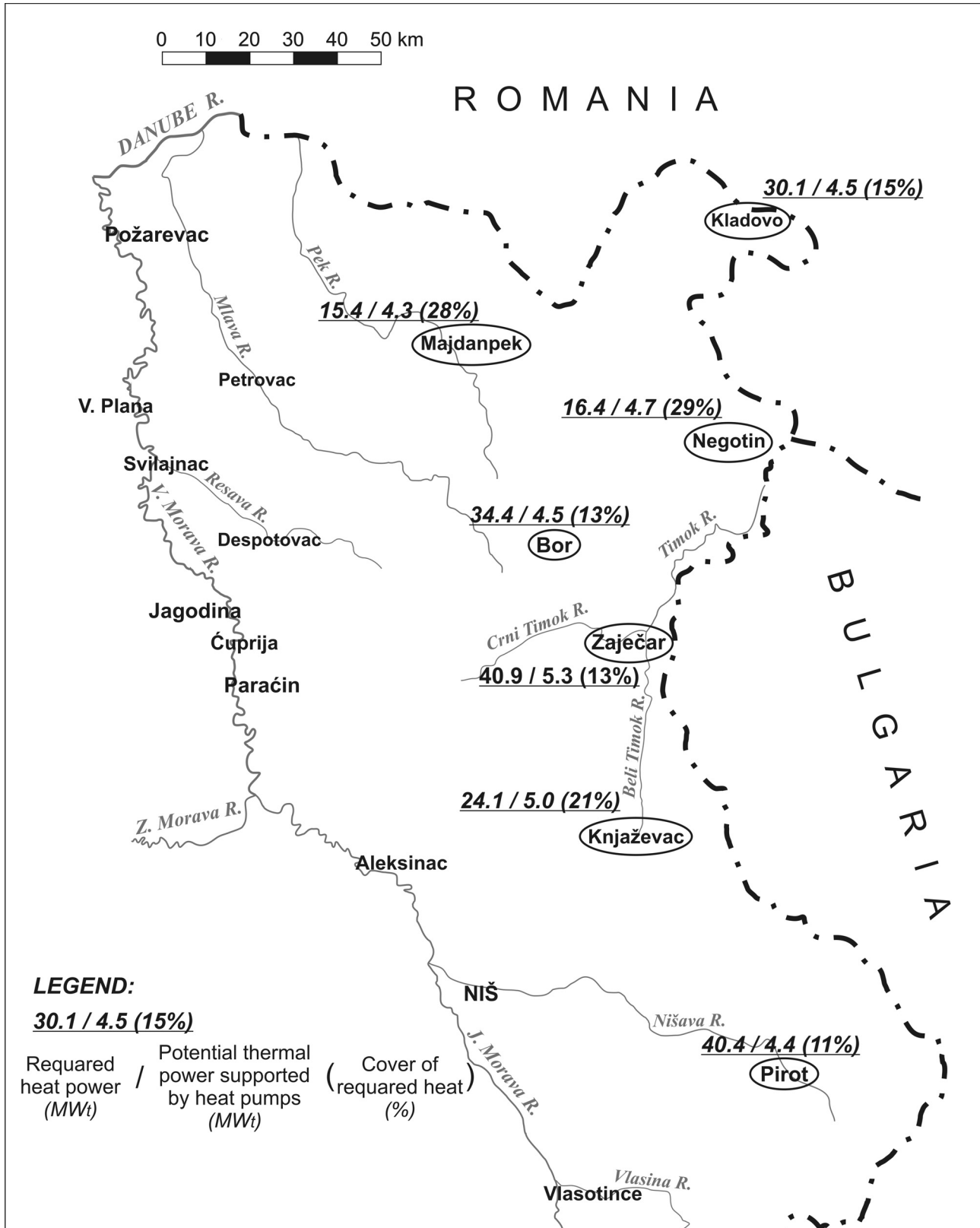* Flow of subgeothermal categories: 10–16 / 16–22 / 22–30° C

Fig. 5. The settlements - Main potential consumers of subgeothermal energy in eastern Serbia, their heat demands and possible cover

ments is assumed to be around 33 MWt, which corresponds to some 16 % of their total heat demands.

While it is clear that not all potential energy can be efficiently exploited, this figure indicates that the

potential of subgeothermal energy in this region is much higher than the 4 % contribution from that kind of energy source to the Serbian energy balance recently announced in the national energy plans.

Between 11 % and 29 % of heat demands of selected towns are covered (Fig. 5). The latter figure characterizes the town of Negotin where a relatively large groundwater resource is located near a small urban settlement.

Such promising geothermal potential requires further systematic research as well as the development of a new strategy and legislation. Therefore, greater governmental support for "green" energy production is expected. Sustainable groundwater extraction should also be followed by controlled extraction (by the provision of permits for exploitation rights) as well as permanent monitoring aiming to prevent over-exploitation and potential technogenic processes.

The implementation of new legislation similar to that of the European Union is also required particularly for utilized waters which have to be regularly reinjected into the ground. A sound practice applied in developed countries suggests that reinjection should take place in the layers regularly overlying the main aquifer (Fig. 4) in order not to cool the existing temperature of the tapped waters*. A new approach also requires intensive public promotion of energy efficiency demands and achievements. And last but not least, the reconstruction of old buildings and thermal insulation should systematically be undertaken.

Conclusions

Among the main advantages of subgeothermal energy extraction from groundwater (temperature 30°C or less) are:
- Easy tapping (once the groundwater resource is properly explored and defined);
- Renewable energy resource which is cheap to develop;
- Inexpensive heating pumps and equipment (will be even less costly with wider application and further commercialization);
- Conservation and guarding non-renewable energy sources for future generations (in accordance with sustainable development principles);
- Energy independence of the country;
- Lesser emission of CO_2, CO, along with numerous other ecological benefits;
- Prospect for alternative economic development including tourism, recreation and the development of spa centers.

The two stages (cascade) heating pumps enable the exploitation of low enthalpy sources with temperatures over 10° C. However, every additional temperature degree makes this exploitation more feasible. Some regions such as eastern Serbia are a good example to demonstrate the feasibility and advantages of the development of subgeothermal resources and wider application of cascade heat pumps. One of the main advantages is the existence of a centralized heating infrastructure in most of the small or medium sized cities in the region.

Acknowledgements

References

Allen, A., Milenić, D., Sikora, P. 2003. Shallow groundwater aquifers and the urban 'Heat Island' effect: a source of low enthalpy geothermal energy. *Geothermics,* 32: 569–578

Banks, D. 2008. *An introduction to thermogeology: ground source heating and cooling.* 339 pp. Blackwell Scientific Publication, Oxford.

Bouma, J. 2002. Heat pumps – better by nature. *Newsletter*, Vol. 2, 20: 10–27

Goričanec, D., Saljnikov, A., Krope, J., Stevanović, Z., Rudonja, N. 2008. Economic and environmental sustainability of geothermal cascade heat pump. *In:* Proceedings of Conf. Sustainable development and climatic changes. 19-20 June, 2008, Niš (in Serbian, English summary).

Goričanec, D., Saljnikov, A., Antonijević, D., Krope, J., Komatina, M., 2009. Hydrogeothermal cascade heat pump – Economic and ecologic appropriacy. *In:* Proceedings of Intern. Conf. on Renewable Energies and Power Quality (ICREPQ'09), 15–17 April, 2009, Valencia.

Huttrer, G.W. 2001. Status of world geothermal power generation 1995-2000. *Geothermics*, 30: 7–27.

Kozić, D., Krope, J., Goričanec, D., 1994. Optimization of large heat pumps in long distance transit heat transportation. *International Journal of Power & Energy Systems*, 14, 1: 5–8.

Lund, J.W. & Freeston, D.H., 2001. Worldwide direct use of geothermal energy, *Geothermics*, 30: 29–68.

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* The heat pumps produce thermal energy by significantly decreasing initial water temperature (ΔT)

MARTINOVIĆ, M., STEVANOVIĆ, Z., SALJNIKOV A.,
    ANDREJEVIĆ S., 2008. Hydrogeothermal resources of
    Serbia – An energetic alternative. *In:* Proceedings of
    Conf. Sustainable development and climatic changes.
    19–20 June, 2008, Niš (in Serbian, English summary).

MILIVOJEVIĆ, M. & MARTINOVIĆ, M., 2005. Geothermal
    energy possibilities, exploration and future prospects in
    Serbia. *In:* Proceedings of the World Geothermal
    Congress 2005, April 24–29, 2005, Antalya.

MILIVOJEVIĆ, M. & MARTINOVIĆ, M., 2010. Serbia Country
    Update. *In:* Proceedings of the World Geothermal
    Congress 2010, April 25–29, 2010, Bali, Indonesia.

NICHOLSON, K. 1993. *Geothermal fluids: Chemistry and
    Exploration Techniques*. 268 pp. Springer-Verlag,
    Berlin.

STEVANOVIĆ, Z. 1994. Karst groundwater of Carpatho-
    Balkanides in Eastern Serbia. *In:* Stevanovic, Z. &
    Filipovic, B. (eds.), *Ground waters in carbonate rocks of
    the Carpathian - Balkan mountain range*, 203–237,
    Allston Hold. Jersey.

STEVANOVIĆ, Z. 1995. Karst ground waters of Serbia.
    Present and potential uses in regional water suplly. In:
    Lithospheric water mineral resources of Serbia. 77–119,
    Spec. ed. of Fac. Min. Geol. Belgrade

STEVANOVIĆ, Z., JEMCOV, I., MILANOVIĆ, S. 2007.
    Management of karst aquifers in Serbia for water supply.
    Environmental Geology, Vol. 51, 5: 743–748

STEVANOVIĆ, Z., SALJNIKOV, A., MILENIĆ, D., MARTINOVIĆ,
    M., ANTONIJEVIĆ, D., DOKMANOVIĆ, P., GOJAK, M., 2008.
    Optimization of energetic utilization of subgeothermal
    water resources (in Serbian). Report on technological
    development project no. 18008, Min. Sci & Techn.
    Devel. of Serbia, Archive of Fac. Min. Geol., Belgrade
    (in Serbian).

STEVANOVIĆ, Z., 2009. Karst groundwater use in the
    Carpathian-Balkan region, *In:* PALIWAL, B. (ed.), *Global
    Groundwater resources and management*, 26, 429–442,
    Scientific Publishers, Jodhpur

TORHAČ, E., CREPINSK ,L., KROPE, J., GORIČANEC, D.,
    SALJNIKOV, A., STIPIĆ, R., KOZIĆ, Dj. 2005. Profitability
    evaluation of the heating system using borehole heat
    exchanger and heat pump. *IASME Transactions*, Vol. 2,
    8: 1381–1388.

YOUNGER, P., 2007. THORA project proposal -
    Thermogeological outreach activity: Transfer of ground
    source heating and cooling technology beyond the
    European Union. Archive of University Newcastle upon
    Tyne, Newcastle.

Резиме

Потенцијал субгеотермалних водних ресурса за шире енергетско искоришћавање - пример источне Србије