TRBOVLJE - HRASTNIK MINE AFTER CLOSURE - UTILISATION OF GEOTHERMAL ENERGY

Review
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Abstract: *Underground mines, which are often located close to urban settlements, or settlements located above the mines, which were created during the development of the mine, can already serve as a useful energy source in terms of the utilisation of geothermal energy during operation and especially after the end of operation.*

This paper presents the possibility of utilising geothermal energy from water and ground sources from the rehabilitated underground spaces of the Trbovlje – Hrastnik (RTH) mine. In the RTH area, there is great energy potential in the utilisation of underground water and heat from the ground. The utilisation of geothermal energy with heat pumps from groundwater (water/water system) and from ground collectors and wells up to a depth of 150 m (rock/water system) is shown. With the water/water system, an average of 2.7 MW of thermal energy is available; with the rock/water system, 7.5 kW of thermal energy is available from a 150 m deep well. With the rock/water system in particular, the development of the industrial zone in the RTH area can also cover a higher demand for thermal energy by increasing the number of collection points. The thermal energy obtained in this way is utilised via heat pumps to heat/cool commercial, residential and industrial buildings. This type of utilisation of geothermal energy contributes to carbon neutrality, as the use of geothermal energy has no negative impact on the environment and does not cause any greenhouse gas emissions.

The advantages of this type of utilisation of an abandoned mine lie primarily in the location of the energy plant, which is relatively close to the consumers and does not pollute the environment through its operation, but at the same time, due to the need to maintain certain mining facilities, it offers regular monitoring of the condition of abandoned underground facilities.

Key words: GEOTHERMAL ENERGY, MINE CLOSING, HEAT PUMP, CLOSED MINE ENERGY POTENTIAL

INTRODUCTION

Geothermal energy is renewable energy such as sunlight, wind, waves, rivers, tides and biomass, to name but a few. The use of fossil fuels to heat buildings is ecologically problematic and should be replaced by the use of renewable energy sources. The main advantage of using renewable energy sources is that we do not release CO_2 into the environment and therefore do not put additional burden on the climate [1,2,3]. By utilising the groundwater of the coal mine in the RTH area for the production of thermal energy, we replace approximately 2.1×10^6 units of natural gas in the production of 2.7 MW of thermal energy. This means that we provide 22.680 MWht/year of thermal energy. Geothermal energy can be utilised indirectly with the help of geothermal heat pumps or directly without the use of heat pumps. This makes it possible to utilise the heat for heating systems with high temperatures (up to 70 °C) or for cooling systems with temperatures below 12°C. The utilisation of geothermal energy is combined with structures that serve as heat exchangers, i.e. energy geostructures installed in piles, foundation slabs and linings of tunnels or underground excavations. The carrier of geothermal energy from the depths of the earth to the earth's surface is usually thermal water [4]:

- flows from underground deposits through natural faults to the earth's surface "natural thermal springs";
- flows from underground deposits to the earth's surface through the artificially created connecting openings of the geothermal well;
- flows to the earth's surface through an artificially created circuit of hot, dry rock.

In order to define the individual possibilities of utilising geothermal energy, we have presented the systems that can be used on abandoned mining sites in more detail. Geothermal energy sources are shown in Figure 1, following different principles from left to right depending on the depth of the geothermal source.

Figure 1, Geothermal energy sources [5]

The aim of the paper is to show the method of heat recovery in the aquifers of abandoned and rehabilitated coal mines, the representation of these reservoirs in RTH and the possibility of utilising geothermal energy in abandoned mines in the world [6,7].

Figure 2 shows the entrance to the underground collection gallery in the Trbovlje–Hrastnik mine (RTH).

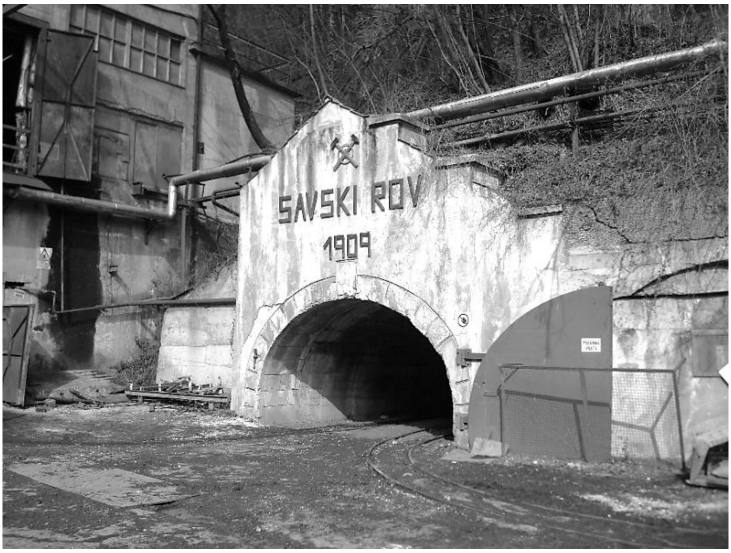

Figure 2, Underground water collection gallery (water/water system)

In the RTH area there is a great opportunity to utilise geothermal energy from water and ground sources [11–13]. Therefore, we have identified all possibilities for the utilisation of geothermal energy in specific areas of the RTH. The possibilities are presented in Table 1 [14] and shown in Figure 3.

Table 1, Potential areas of utilisation of geothermal energy with different exploitation systems

System		Location	Potential User (kW)
TS-1	water/water	Talni audit, Trbovlje mine	The working premises of the Trbovlje mine (100 kW)
TS-2	water/water	Talni audit, Trbovlje mine	Plateau at k.+328 in the vicinity of the Gvido fan station (200 kW)
TS-3	water/water	Sava horizon—intersection Južna audit, Trbovlje mine	Plateau in front of the entrance to the Frančiška audit, plateau in front of the Frančiška fan station (200 kW)
TS-4	water/water	Sava horizon—water audit, separation plant Trbovlje	Premises of the separation plant (100 kW)
TS-5	soil/water	Vasle audit	Plate of the kennel society, building of the former Mechanics, Elementary School Alojz Hohkraut (50 kW)
HS-1	water/water	Zvezno horizon—Dol audit	Administrative building of Hrastnik mine (80 kW)
Tpi 1, 2, 3	soil/water	Surroundings of the AMDT hall	AMD Hall, Dinos Landfill (70 kW)

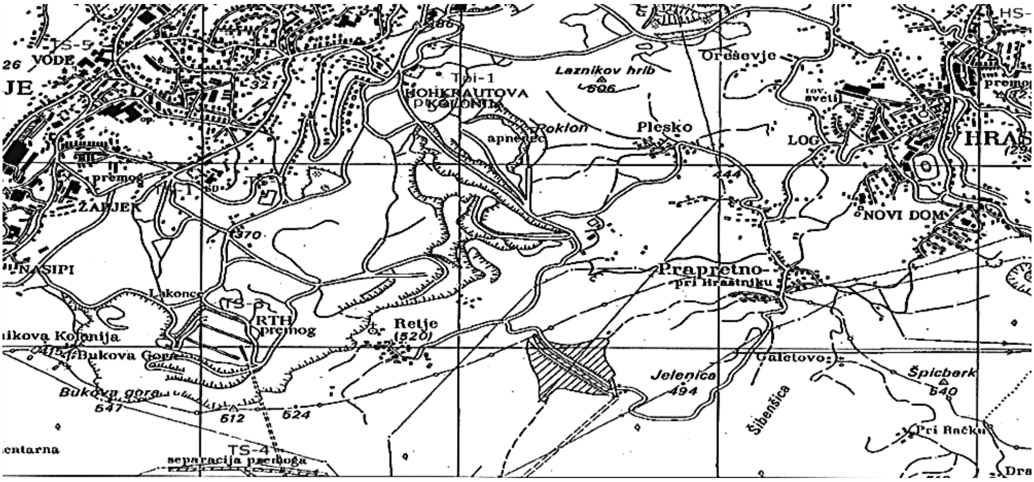

Figure 3, Locations of individual users for heating/cooling via heat pumps

In the RTH area, there is and will continue to be great energy potential in the utilisation of groundwater and geothermal energy. We have focussed on the use of geothermal energy from groundwater (water/water system) and from ground collectors and wells up to a depth of 200 m (rock/water system). The thermal energy obtained in this way is utilised via heat pumps to heat and cool commercial, residential and industrial buildings. We can receive financial incentives for the use of geothermal energy, as the use of geothermal energy has no negative impact on the environment and does not cause any greenhouse gas emissions.

In order to achieve the desired goals in terms of high-quality capture of geothermal energy from the aquifers in the underground spaces of the mine, the geological and hydrogeological conditions and the thermal conductivity of the rock in this area must be appropriate and researched.

GEOLOGICAL AND HYDROGEOLOGICAL SITUATION AND THERMAL CONDUCTIVITY OF ROCKS IN THE TRBOVLJE - HRASTNIK MINING AREA

GEOLOGICAL SITUATON OF THE TRBOVLJE – HRASTNIK MINING AREA

The Tertiary strata of the Zasavje coalfield stretch in an elongated strip running west to east. This band of Tertiary sediments is identified as the Laško-Zagorje Synclinorium, bordered by the Trojane Synclinorium to the north and the Litija Anticlinorium to the south. These are Tertiary rock formations that are geologically constrained by faults or fault systems.

Together with the Laško mine, the Hrastnik mine forms the easternmost Tertiary depression, followed by the Ojstro, Trbovlje and Zagorje mines in the west [8,9].

The oldest rock formations in the region include grey Permo-Carboniferous clastites and red and grey Gredenian clastites, found both north and south of the Tertiary depression.

The Triassic rocks of the Trojane anticline feature red siltstone, oolitic limestone, and sandy, micaceous dolomite from the Lower Scythian, alongside dark grey, flat micritic limestone from the Upper Scythian. These are succeeded by stratified, and sometimes laminated, anhydrite dolomite, which transitions upward into non-stratified sparitic dolomite with sizable lenticular conglomerate inclusions. Above the sparitic dolomite lies flat limestone with cherts, followed by tuffaceous rocks containing lenticular inclusions of limestone and sparitic dolomite. The tuff sequence is at times replaced by dark grey mudstone and chert. The upper part of this sequence is likely from the Lombard age, while the lower part might belong to the Fassano or possibly the Anisian. The boundary with the Anisian dolomite facies is not visible. Over the tuffogenic sequence, there is an unstratified dolomite layer from the Ridge facies, likely of Cordevolian age, overlain by dark grey clastics several hundred meters thick. The tuffaceous sequence and dark grey clastics with Cordevolian dolomite are attributed to the Pseudozyl Formation. In the Litija anticline, Carnian carbonates with tuffaceous rocks are found in the lower part, while the upper part contains sparitic dolomite, possibly from the Rhaetian age, and Norian limestone with megalodon shells.

During the Oligocene, Tertiary sediments began to accumulate transgressively over the Triassic base. The depositional environment changed frequently, resulting in varying facies forms, marking three sedimentation cycles. The first cycle consists of carbonaceous layers along with Oligocene marine clays. The second cycle starts with the deposition of Miocene Gova layers, while the third cycle is characterized by lighter sediments.

The Oligocene is divided into the bedrock (lower coal-bearing layers), the coal layer, the overburden (upper coal-bearing layers), and marine clay. The bedrock, primarily composed of clay, formed through material deposited in the depression from eroded surrounding areas. The bedrock thickness varies, reaching up to 80 meters in some places, and consists of clastic light grey clays (white bedrock), sometimes interspersed with sand and gravel. Towards the top, the bedrock darkens, merging into black bedrock and eventually the coal layer.

A swamp forest developed on the flat plain formed by the depression’s infill, providing the organic material for coal formation. The coal layer shows a distinction between the lower-quality bedrock and the higher-quality overburden. Bedrock coal contains more ash and has a lower calorific value, whereas overburden coal has less ash, lower density, and higher calorific value. Bedrock coal also contains clay admixtures and inclusions, while overburden coal is cleaner, though it occasionally contains kaolinite and tuffite. Pyrite and quartz concretions, pseudomorphs of plant remains, are also present.

The upper coal-bearing layers formed in a lake or lagoon environment, resulting in the formation of overburden marl, which differs significantly from the bedrock. The lower portion consists of black, thin-layered marl with organic admixtures, transitioning upwards into brown or grey hard limestone marl.

The grey marine clay was deposited during subsidence, when the sea flooded the lagoons. The transition from carbonaceous layers to marine clay is gradual, with no noticeable discontinuity. This subsidence continued until the area was completely submerged, transforming lagoons into sea bays. The grey marine clay, about 70 meters thick, is rich in foraminifera fossils and was no longer deposited after the middle Oligocene.

The final sedimentation cycle involves the Govec layers (lower Miocene), Laško layers (middle Miocene), and Sarmatian layers (upper Miocene). The Govec layers are absent from the surface at the Hrastnik, Ojstro, and Trbovlje mines due to erosion before the deposition of the Laško limestone, which is now exposed in these areas. However, Govec layers are found east of Hrastnik, in the Brezno area.

The Laško layers, deposited after the Styrian orogenic phase, show a pronounced discordance, beginning with a thick basal conglomerate containing pebbles up to 30 cm in size, predominantly keratophyre. The conglomerate is cemented with a calcareous binder rich in calcareous algae (Lithothamnium). Higher up, the conglomerate transitions into Lithotamnian limestone, containing calcareous algae, fossils, and grains of quartz and keratophyre sand. Above the Lithotamnian limestone lies light grey, hard sandy marl (Laško marl).

The Sarmatian layers, the youngest in the region, appear in three separate areas between Trbovlje and Hrastnik. They form small patches northeast and southeast of Plesko and cover a larger area around Prapretno. In the Dol region, a significant unconformity exists between the Laško marl and Sarmatian clastics, where coarse clastics grade into silty clays higher up.

Figure 4 shows the map of Slovenia, on which the area of the Trbovlje–Hrastnik mine is marked with a frame.

Figure 4, Map of Slovenia (the RTH area is inside the rectangle)

HYDROGEOLOGICAL SITUATION OF THE TRBOVLJE - HRASTNIK MINING AREA

Due to the varied geological structure of the coal deposits in the Trbovlje–Hrastnik mine area and the many years of mining with various mining methods, the hydrological events in the rock are varied and sometimes unpredictable. The geological structure is fractured several times by fault zones, which significantly affects the hydrological conditions in the rock of the mine area. From a hydrological point of view, fault zones and an area destroyed by mining indicate water permeability even in areas that would be impermeable in their original state [10].

In coal mining, water ingress and collapses tend to occur more frequently in fault zones. Large fragments of rubble can come into contact with overlying materials, posing a risk of water or liquid masses penetrating the excavation site. These hazardous events are often concentrated in critical mining areas.

The rocks in the Trbovlje, Ojstro, and Hrastnik mining areas are classified into three hydrogeological categories: good aquifers, conditional insulators, and insulators. Good aquifers include Triassic dolomite, found beneath the coal seam. Additionally, the Lithuanian limestone in the overburden, which is mainly fed by meteoric water, plays a crucial role in the hydrogeological conditions. The ruggedness and fractures in the overburden make the Lithuanian limestone a significant water reservoir, classifying it as an aquifer.

Conditional insulators are rocks that, while impermeable in their original state, become highly permeable when subjected to mining damage. These include overburden marl and Laško marl. Lastly, swelling clays act as insulators as long as the destruction processes occur slowly. The swelling of the clay seals cracks caused by mining, preserving the rock's impermeability. This category includes bedrock clays, Oligocene marine clays, and Sarmatian clays.

TRBOVLJE MINE AREA

The syncline in the Trbovlje mine area is the shallowest, with the coal seam situated at around 170 meters above sea level. Beneath the Tertiary layers lies Triassic dolomite, which is highly fissured, unstratified, and water-permeable. This dolomite is widely exposed in the Sava Valley, meaning the water level within the dolomite aligns with the valley's bottom. The mining areas of the Trbovlje mine, where coal extraction took place, are located at higher elevations and are therefore unaffected by groundwater.

The water-bearing dolomite in the Trbovlje mine is indirectly drained into the neighboring Ojstro mine, where the water level is reduced to below 50 meters above sea level. Water enters the underground spaces primarily from the overburden layer and from older excavations. The key aquifer in the overburden is the Lithuanian limestone. After coal extraction, the overburden marl becomes permeable as a result of mining activities and does not swell sufficiently to seal the cracks. However, marine clay serves as a protective layer against water from higher up in the overburden, as it swells and quickly seals any cracks. Only in cases where cracks larger than the thickness of the

Oligocene marine clay form can this impermeable layer be compromised, allowing water or liquid masses to penetrate the underground spaces.

In the eastern part of the Trbovlje mine, there is no protective marine clay layer, as it was removed before the transgression of the Lithuanian limestone. This clay layer is also absent in a roughly 150-meter-wide strip parallel to the outcrops where the overburden marl reaches the surface. Consequently, water inflow into the Trbovlje mine is mainly influenced by precipitation, the consolidation of the overburden and old workings, and surface subsidence, which is ongoing due to mining activity. Since excavation at the Trbovlje mine ceased in recent years, a hydrogeological equilibrium has been established, resulting in decreased and stabilized water inflows.

Currently, most of the water entering the Trbovlje mine comes from the Sava field. In the Plesko field, where the overburden marls and siliceous layers have eroded, the coal is in direct contact with the Lithuanian limestone, the primary aquifer in the Trbovlje–Ojstro syncline. In 2007, the average water inflow from this area was approximately 250 l/min. In contrast, water inflow from the former Lakonca and Frančiška fields has reduced due to consolidation, averaging around 10 l/min.

As of 2018, water from the III field zone flows at an average rate of 35 l/min, with additional water entering the mine from the surface through the collapsed roof marl at an average of 85 l/min. Within the Trbovlje mine, water is drained by gravity to the level of the Zvezno Horizon and then discharged into the Sava River. Currently, water pumping is only necessary from the Sava field, which lies below the Zvezno Horizon level. The total inflows of water in the Trbovlje mine in the five-year period are listed in Table 2.

Table 2, The total inflows of water in the Trbovlje mine in the five-year period

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**Average 2018–2022**
Average annual water inflow to the mine (l/min)	626	816	700	1287	764	838

OJSTRO MINE AREA

The hydrogeological conditions at the Ojstro mine are monitored using piezometers, manometers, and measurements of water inflow into the open mine spaces. The mine extends to a height of 56 meters above sea level (k.+56), where an auxiliary pumping station is situated. Currently, the total water inflow into the mine is approximately 6000 l/min, with the majority (about 5600 l/min) being directed to the pumping station at k.+56.

In the past, the dolomite aquifer at the Ojstro mine was drained through various drainage levels along the dolomite, initially at k.+130, then at k.+120, and later at k.+90. Presently, the drainage occurs at k.+43, where wells and drainage systems have been installed. These facilities required a substantial pumping capacity to manage the water flow and lower the water levels. Over time, continuous pumping caused a significant drop in the water level, and the drainage line at k.+90 has been dry for several years.

Observations indicate that the current water level around the exposed dolomite structures within the drainage funnel is below the k.+55 horizon.

Water levels are measured using piezometers in the dolomite at the Ojstro mine. In piezometer PJ-2, the water level is nearly 19 m below the drainage line, at k.+75.3, while in piezometer PJ-1, it is about 8 m below the top of the well, around k.+55. Manometers at horizontal wells M-3 and M-4 also assist in these measurements.

Water from the drainage systems and wells is directed to the pumping station at k.+43, the deepest open point in the Ojstro mine. The wells drilled from the pumping station, primarily in the direction of Terezija polje, account for most of the water flow, contributing about 2730 l/min. These wells are equipped with shut-off valves to allow temporary closure. Additionally, several shorter wells have been drilled in the dolomite aquifer area, though they are less extensive. The total inflow of water into the Ojstro mine over the five-year period is shown in Table 3.

Table 3, The total inflows of water in the Ojstro mine in the five-year period

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**Average 2018–2022**
Average annual water inflow to the mine (l/min)	6500	5700	5500	6200	6000	5980

HRASTNIK MINE AREA

In 2021, the Hrastnik mine was nearing the final stages of its closure, with the process of shutting down the RTH pits progressing from east to west. This began with the mostly closed Dol pits and moved toward the main pits of the Trbovlje mine, where coal extraction continued the longest. The Hrastnik 1 shaft was backfilled up to the level IV horizons. The installation of plugs and the shutdown of the main pumping station II in the Hrastnik mine resulted in a rise in the water level within the dolomite. After decommissioning pumping station II at k.+80, water filled audit GT-1 up to k.+200, where an auxiliary pumping station was constructed. A deep piezometer, PH-1b/04, was installed to monitor the water level in the dolomite. Water inflows into the Hrastnik mine over the past five years are summarized in Table 4.

Table 4, The total inflows of water in the Hrastnik mine in the five-year period

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**Average 2018–2022**
Average annual water inflow to the mine (l/min)	1856	1932	2125	1725	765	1680

This means that the total amount of water in the area of the closed RTH coal mine reaches a flow rate of around Q = 9000 l/min or 0.15 m^3/s. The average water temperature in winter is 11 °C.

The collection of groundwater and the total amount of water flowing from the Trbovlje–Hrastnik mine are shown in Figure 5.

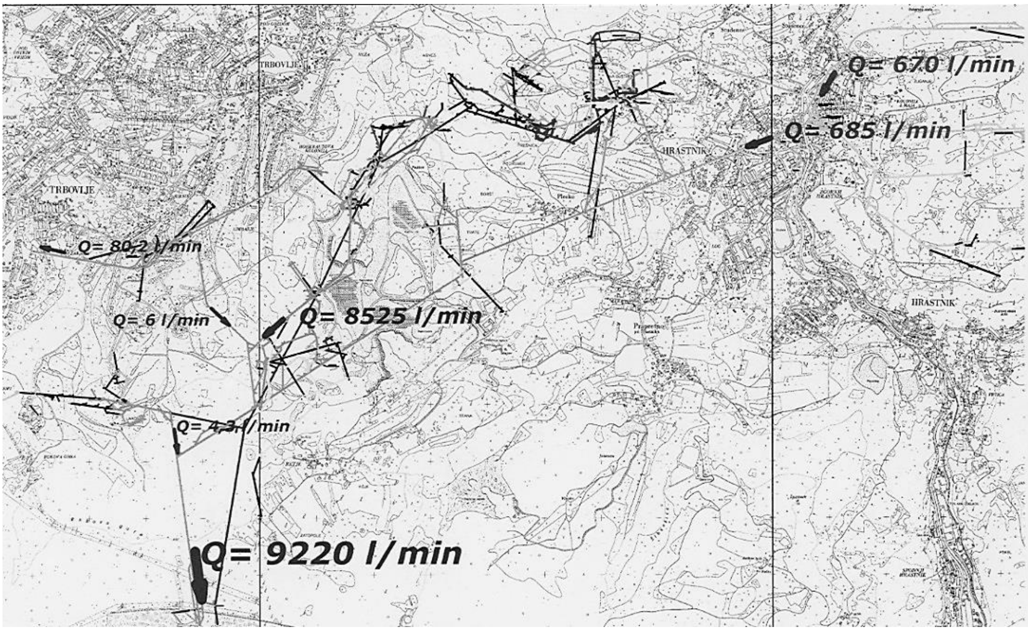

Figure 5, Total inflow of water from the underground areas of the Trbovlje–Hrastnik mine

THERMAL CONDUCTIVITY OF THE ROCK IN THE AREA AND HEAT FLOW

The most important factor for the provision of heat is the geological composition of the rocks, more precisely their thermal conductivity. The thermal conductivity λ of a material is given as the ability to conduct heat (the unit for heat is J) in a unit of time through a wall of a certain thickness at a certain temperature difference on different sides of the wall. The unit for this is therefore $Js^{-1}m^{-1}K^{-1}$ or $Wm^{-1}K^{-1}$. The amount of potential energy is proportional to the thermal conductivity of the rock. The thermal conductivity λ can be measured on rock samples using suitable measuring devices or determined using certain thermal phenomena in boreholes. The individual types of rock are differently sensitive to the transferred heat. The water content and porosity of the soil have a major influence on thermal conductivity. The thermal conductivity of the soil increases with the water content of the soil (dry soil is less conductive; the higher the water content, the greater the ability to accumulate heat)

Slovenia is characterised by an increase in temperature from the southwest to the northeast, with the highest temperatures measured in the Pannonian basin and in the eastern part of the Krško-Brežice region.

The thermal conductivity values for various rock types are listed in Table 5 (VDI 4640 German guidelines for ground coupled heat pumps, utes and direct thermal use of the underground).

Table 5, Thermal conductivity values for the individual rock types at 20°C

Rock type	Thermal conductivity λ (W/mK)	
	Range of values	Common values
Igneous rocks		
Basalt	1.3 – 2.3	1.7
Diorite	2.0 – 2.9	2.6
Gabbro	1.7 – 2.5	1.9
Granite	2.1 – 4.1	3.4
Peridotite	3.8 – 5.3	4.0
Rhyolite	3.1 – 3.4	3.3
Metamorphic rocks		
Gneiss	1.9 – 4.0	2.9
Marble	1.3 – 3.1	2.1
Metaquartzite	App. 5.8	5.8
Mica	1.5 – 3.1	2.0
Clay shale	1.5 – 2.6	2.1
Sedimentary rocks		
Limestone	2.5 – 4.0	2.8
Marl	1.5 – 3.5	2.1
Quartzite	3.6 – 6.6	6.0
Salt	5.3 – 6.4	5.4
Sandstone	1.3 – 5.1	2.3
Anthracite	0.3 – 0.6	0.3
Claystone/Siltstone	1.1 – 3.5	2.2
Unconsolidated soils/rocks		
Gravel - dry	0.4 – 0.5	0.4
Gravel - water saturated	App. 1.8	1.8
Morena	1.0 – 2.5	2.0
Sand - dry	0.3 – 0.8	0.4
Sand - water saturated	1.7 – 5.0	2.4
Clay/silt - dry	0.4 – 1.0	0.5
Clay/silt - water saturated	0.9 – 2.3	1.7
Peat	0.2 – 0.7	0.4

As a result of the temperature difference between the Earth's interior and the surface, a flow of heat is directed towards the surface. In the outermost shell of the Earth, the so-called crust, the heat flux density is on average about 0.05 W/m^2. The distribution of the heat flux density in the ground in Slovenia is shown in the heat flux density map (Figure 6).

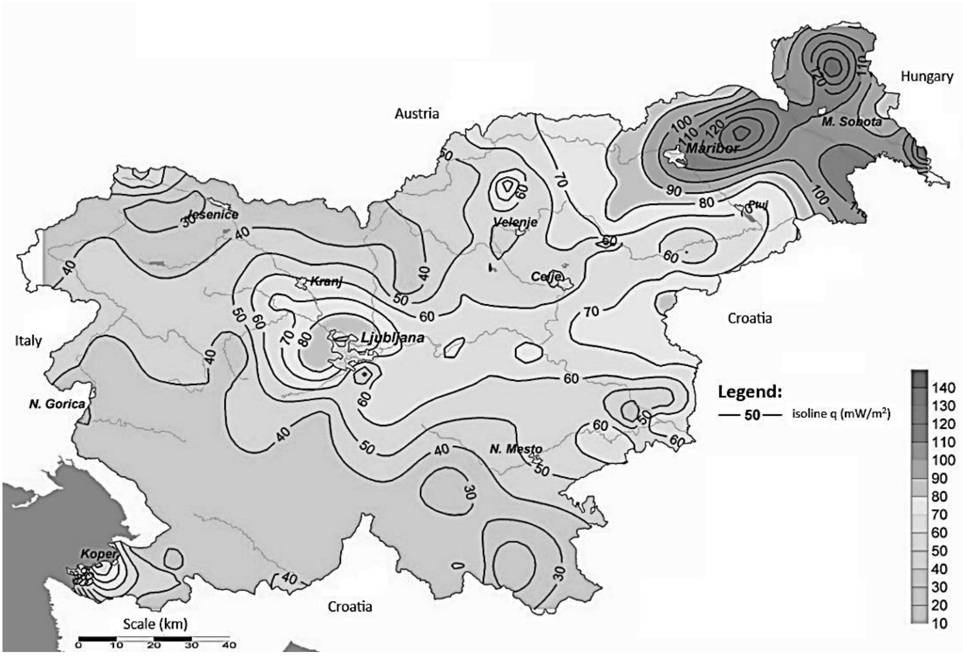

Figure 6, Heat flow density map of Slovenia according to the Geological Survey of Slovenia

GEOTHERMAL ENERGY POTENTIAL IN THE RTH AREA

There is considerable potential for the utilisation of geothermal energy from water and ground sources in the RTH area. We have therefore identified all opportunities for the utilisation of geothermal energy in specific areas of the RTH, which are listed in Table 1, reproduced in the preceding text.

THE ENERGY POTENTIAL OF SOIL AND WATER IN THE RTH FOR THERMAL ENERGY PRODUCTION

In the RTH area, it makes sense to utilise the thermal potential of water for the heating and cooling of commercial, industrial and residential buildings after the closure of the RTH underground spaces, as well as during coal mining in the Trbovlje mine. The water from the RTH mine can be used primarily as a water/water system (where the used water flows into the Sava River) and to a lesser extent as a rock/water system. In the case of the water/water system, we can calculate that approximately 2.7 MW of thermal energy (Q = 9000 l/min, ΔT = 4°C (guideline value that Q = 60 l/min is sufficient for approx. 18 kW)) is recovered via the heat pumps. When designing the heating/cooling systems themselves, however, other parameters such as the construction of the buildings etc. must be taken into account, so that the above values are only guidelines. For a rock/water system, it is assumed that around 5 kW of thermal energy can be extracted from a borehole approximately 100 metres deep. In the case of a soil/water ground collector system, it is assumed that around 2 kW of heat energy can be extracted from an area of approx. 100 m^2.

THERMAL POTENTIAL OF THE WATER/WATER SYSTEM

Considering that the total water flow from the underground spaces of the RTH is approx Q = 9000 l/min and that not all potential geothermal energy production systems will be in operation at the same time, the effects of mixing different water temperatures and their possible drop in water temperature in the system must be examined. The following results from the equation for the temperature:

$$\frac{m_1 \cdot c_1 \cdot T_1 + m_2 \cdot c_2 \cdot T_2}{m_1 \cdot c_1 + m_2 \cdot c_2} = T$$

Where they mean:

m_1, m_2 – masses of water [kg]

c_1, c_2 – specific heat of the water [J/kgK] → $c_1 = c_2$

T_1, T_2 – temperature of the water [°K]

T – temperature of the mixture [°K]

A simple calculation shows that if:

- Water consumption 1000 l/min, T = 281°K approx. P = 300 kW heat extracted,
- Total water volume 9000 l/min, T = 285°K,
- The drop in water temperature is ΔT = 0.4°C.

As the water flows in this case and there is no constant 24-hour abstraction, the effects of the temperature difference are negligible for the consumers located one after the other in the groundwater abstraction system.

THERMAL POTENTIAL OF THE SOIL/WATER SYSTEM

The heat capacity of a borehole is determined using the following formula:

$$\frac{L_1 \cdot q_1 + L_1 \cdot q_1 + \cdots + L_n \cdot q_n}{\sum(L_1 \ldots L_n)} \cdot \eta = Q_{well}$$

Where they mean:

$L_1 \ldots L_n$ – length of the individual well sections in a particular rock [m]

$q_1 \ldots q_n$ – Thermal expenditure of the individual well sections [W/m]

η – well efficiency (approx. 90%)

Q_{well} – thermal output of the borehole [W/m]

Total depth of the wells:

$$\frac{Q_{min}}{Q_{well}} = N_m$$

Where they mean:

N_m – total depth of the wells [m]

Q_{min} – minimum heating capacity required for the building [W]

Q_{well} – thermal output of the borehole [W/m]

Table 6, Energy production (1800 and 2400 hours/year) taking into account an annual energy consumption between 100 and 150 kWh/m²year - determination of the q-value

Rock type	**Specific heat extraction**	
	for 1800 hours	**for 2400 hours**
General values	**W/m**	**W/m**
Poor composition (dry deposits) (λ<1.5)	25	20
Normal rocks and water-saturated sediments (λ<1.5 – 3.0 W/mK)	60	50
Hard rock with high thermal conductivity (λ>3.0 W/mK)	84	70
Individual rocks		
Dry gravel, sand	<25	<20
Water-permeable gravel, sand	65-8	55-65
Strong water currents through gravel and sand	80-100	80-100
Moist clay, loam	35-50	30-40
Massive limestone	55-70	45-60
Sandstone	65-80	55-65
Acid magmatite (e.g. granite)	65-85	55-70
Basic magmatite (e.g. basalt)	40-65	35-55
Gneiss	70-85	60-70

CONCLUSION

Based on the definition of geothermal energy utilisation systems in the RTH area, we can state the following:

1. Potential areas of geothermal energy utilisation with various geothermal energy utilisation systems are [14]:

System		**Location**	**Potential User (kW)**
TS-1	water/water	Talni audit, Trbovlje mine	The working premises of the Trbovlje mine (100 kW)
TS-2	water/water	Talni audit, Trbovlje mine	Plateau at k.+328 in the vicinity of the Gvido fan station (200 kW)
TS-3	water/water	Sava horizon—intersection Južna audit, Trbovlje mine	Plateau in front of the entrance to the Frančiška audit, plateau in front of the Frančiška fan station (200 kW)
TS-4	water/water	Sava horizon—water audit, separation plant Trbovlje	Premises of the separation plant (100 kW)
TS-5	soil/water	Vasle audit	Plate of the kennel society, building of the former Mechanics, Elementary School Alojz Hohkraut (50 kW)
HS-1	water/water	Zvezno horizon—Dol audit	Administrative building of Hrastnik mine (80 kW)
Tpi 1, 2, 3	soil/water	Surroundings of the AMDT hall	AMD Hall, Dinos Landfill (70 kW)

2. With the water/water system, a thermal energy of approx. 2.7 MW is to be expected via the heat pumps (Q approx. 9000 l/min., $\Delta T = 4°C$)
3. For the rock/water - Geosonde system, approx. 5 kW of thermal energy can be obtained from a well approx. 100 m deep.
4. For the soil/water - ground collector system, approx. 2 kW of thermal energy can be obtained from an area of approx. 100 m^2.

Optimum utilisation of the geothermal potential in the RTH area makes sense in any case if there are enough users.

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