# WATER TEMPERATURE ADJUSTMENT IN SPAS BY THE AID OF HEAT PUMPS

by

***Dejan T. RIZNIĆ*** [a*] ***and Bojan J. KOVAČIĆ*** [b]

[a] Technical Faculty Bor, University of Belgrade, Bor, Serbia
[b] Serbian Energy Efficiency Agency, Belgrade, Serbia

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*Mineral spas are considered an important national resource, used mainly for therapeutical and recreational purposes. However, raw mineral waters are often at temperatures different from the required ones and need to be cooled or heated to be adjusted to the level adequate for a specified purpose. For such an adjustment, energy is either released (when cooling down the mineral water) or consumed (for heating up the mineral water). Heat pumps may be used to multiply the gain of energy when released, or reduce the energy needed for heating the water. The report deals with technical possibilities and economic benefits of the use of heat pumps in such case studies in two spas of Serbia, Mataruska spa near Kraljevo, and Bukovicka spa in Arandjelovac.*

Key words: *mineral spa, geothermal energy, heat pump, coefficient of performance*

## Introduction

Mineral spas are developed around naturally occurring mineral water springs. In many cases, they are located in mountainous locales and show healthful benefits owing to both their mineral contents and often higher temperatures. This and other forms of geothermal energy is an important national wealth. Feasibility of its use is dependent on annual savings achieved when replacing part or the whole of conventional energy (coal, oil, gas) by it. Projects with direct use of this energy require larger initial investments and lower running costs afterwards. However, economic benefits is influenced by the locations of user and the source, efficiency of heat withdrawal, annual load factor, as well as of costs of financing, amortisation period and the rate of inflation. There are possibilities to choose between shallow wells with lower temperature and deep well with higher temperature, as well as to use or not the sophisticated devices such as heat pumps. These system have a long life time, which is beneficial for their economy. The economy from the point of view of the available geothermal mineral waters is dependent on a timely start of exploitation of this resource so to minimise the integral losses, which can be expressed as follows:

$$W = \mathrm{e}^{-rt}[W(\mathrm{id}) - W(t)]\mathrm{d}t \qquad (1)$$

* Corresponding author; e-mail: riznic.dejan@open.telekom.rs

where $W$ is the ideal status of the thermo-mineral water resources with minimum integral loss, $W$(id) – the ideal level of satisfying the need for this resource in the condition of stable social and economic development, $W(t)$ – the permanent level of satisfying the need for this resource in all time periods, and $r$ – the rate of discounting over time $t$. Economic effectiveness of costs to preserve thermo-mineral waters may be lower than the overall socio-economic effectiveness, in which case the cost necessary to preserve this national wealth is dependent on economic rules of valuation.

Evaluation of environmental parameters of thermo-mineral waters, as an important national resource of Serbia, begins with the general function of use: $f(e) = a^n$, which tells us that the value assessment of environmental and economic parameters of these resources is dependent on the way and manner the other resources are used (pollution dynamics, constituents of the resource, parameters of non-disturbed quality, as well as general effects of environment and the overall system). In this connection, dynamics of impact of environmental factors is faster and economically adaptable because the structure of the use of thermo-mineral sources must be faster and more diverse. Effectiveness of using these resources ($E$) at different levels of development in particular activities may be represented by the ratio of effectiveness of preparation, maximal exploitation ($V_{\text{max.}}$), minimum exploitation without losses ($V_{\text{min.}}$), optimum exploitation ($V_{\text{op}}$), and planned exploitation ($V_{\text{no}}$). It is expressed by:

$$E = \frac{(V_{\text{max.}} - V_{\text{op}})V_{\text{no}}}{(V_{\text{max.}} - V_{\text{min.}})V_{\text{op}}} \tag{2}$$

Alternatives are selected with reference to the money value of the resources invested. Current trends in energy highlight significant challenges of geothermal energy. The first of these is the need to reverse the energy consumption and emissions trends. Devising strategies to cost-effectively meet these challenges requires rational use of local renewable energy resources, [1].

Energy can exist in the form of heat, light, mechanical, electrical or chemical energy, and although energy can neither be created nor destroyed, it can be changed from one form to another and moved from place to place. Effectiveness of the use of thermo-mineral waters in spas may to a large extent be increased by the adjustment of their temperatures to the purpose by the use of heat pumps, a kind of sophisticated technical devices that are used to move heat from the source at lower to the sink at higher temperatures, opposite from the normal thermodynamical laws, on the account of mechanical work delivered by a compressor driven by electric motor or otherwise. The energy delivered by the heat pump is several times larger than the mechanical work at the input. In this paper the application of heat pumps in two of notable spas in Serbia, Bukovicka spa and Mataruska spa, with different needs for temperature adjustments, is presented.

## Heat pumps

### *Principle of operation*

Heat pumps operate in a similar way to a refrigerator – but in reverse. A compressor, condenser, expansion valve and evaporator are used to change the state of refrigerant from a liquid to hot gas and from a gas to cold liquid. The liquid refrigerant passes through the outdoor evaporator coils at a low temperature, where liquid from the ground enters and heat is transferred from this liquid to the refrigerant. As a result, the refrigerant boils and becomes vapour, which is then drawn into the compressor, where the temperature of the vapour is increased to over 100 °C. The vapour then enters the condenser and heat from the vapour is transferred across the coils. As the vapour cools it condenses back to a liquid, which releases latent heat to the fluid passing over the heat exchanger by which the heat is transferred to the heating, cooling or hot water systems. The refrigerant, now a very cold liquid at high pressure, passes through an expansion valve, which reduces the pressure so that the cold liquid can re-enter the evaporator and begin the cycle again, fig. 1.

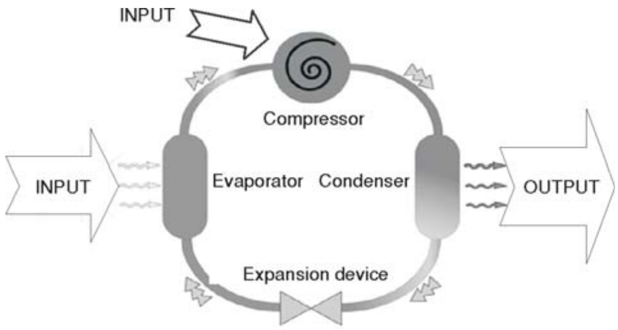


**Figure 1. Principle of the heat pump**

If geothermal reservoirs are close enough to the surface, they can be reached by drilling wells, sometimes several thousand meters deep. There are a number of ways in which heat can be extracted. These include open loop or closed loop systems, with the option of extracting heat from either the ground or a water source. Hot water from the wells (driven naturally or pumped) reaches the surface at different temperatures. Those waters at temperatures between 150 °C and 370 °C are used to generate electricity in geothermal power plants, while those (from shallower reservoirs) at lower temperatures between 20 °C and 150 °C are used directly in health spas, greenhouses, and industry and in space heating systems.

Besides from the geothermal waters, the heat pump can use the heat from the ground, which, at the depth of several meters, remains at a fairly constant temperature, between 11 and 12 °C, all the year round. Ground source heat pumps systems which extract heat energy from the ground or groundwater offer exceptionally high levels of efficiency, achieving also a significant reductions in $CO_2$ emissions. The pipes, filled with water and anti-freeze mixture, can be buried in the ground, either horizontally in trenches, or vertically in boreholes, and the heat pump extracts heat from the that water. This lowers the temperature of the water by two or three degrees, and such colder water is pumped round the underground pipes where it warms up again to about ten degrees. In either way, the heat pump does not produce energy but only transfers the "free" energy from the environment and electricity to the consumers.

### *Theoretical background*

Buki [2] describes in detail the operating parameters characterising the energy balance of the heat pump. Energy delivered by the heat pump to the consumers $Q_f$ is the sum of the "free" energy $Q_a$ taken from the surroundings and electrical energy $P$ taken from the grid, reduced for the losses from the evaporator $Q_{vA}$, compressor $P_v$, and condenser $Q_{vF}$, as shown eq. 3 and in fig. 2:

$$Q_f = Q_a + P - (Q_{vA} + P_v + Q_{vF}) \tag{3}$$

Simply stated, a heat pump is an electrically driven mechanical device which absorbs heat energy $Q_a$ at one location and transfers it to another. Although the heat pumps require electricity to operate, the generated output $Q_f$ is around up to four, five or even more times the power input *P*. The efficiency of the heat pump, known as the COP (coefficient of performance) is thus calculated from the following expression:

$$\text{COP} = \frac{Q_\text{a} + P - (Q_\text{vA} + Q_\text{P} + Q_\text{vF})}{P} \tag{4}$$

To calculate the energy gain through the COP, one has to calculate the losses for each particular case, making use of the parameters indicated in fig. 2. These refer to the state at identified points of the three different fluids circulating through the three loops: geothermal water or liquid mixture in pipes buried underground, refrigerant that changes phases within the heat pump loop, and water or other working fluid used to transfer heat from the condenser to the space being heated or cooled. The losses $Q_\text{vA}$, $P_\text{v}$, and $Q_\text{vF}$ are calculated for particular cases where applied.

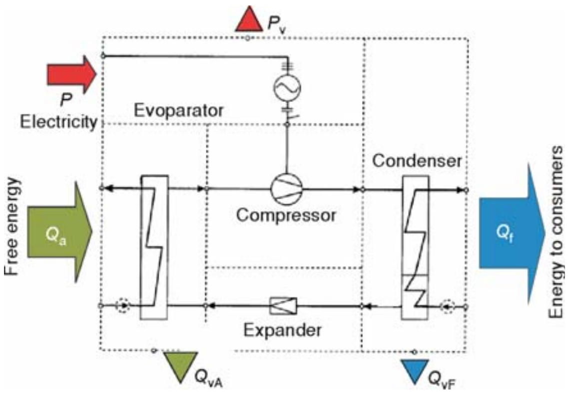


**Figure 2. Schematic of a heat pump operation**

Geothermal heat pumps can access the moderate temperatures just beneath the earth's surface and use it to heat and cool buildings. Within the upper 10 meters below the Earth's surface, a nearly constant temperature of 10 to 16 ºC is maintained. A geothermal heat pump (GHP) consists of a network of piping or tubing buried in the ground near the building, which can tap this free, year-round reservoir of constant temperature. Since the source of energy is found all over the world, this technology can be utilized virtually anywhere and is not dependent on accessing the hot water deeper inside the earth. However, the systems are higher priced than traditional air-source heat pumps and installation can be substantially higher in cost due to the length of pipes.

### *Economics of a heat pump*

In spite of the higher cost geothermal energy is becoming an economically attractive solution as the demand for clean, reliable, and renewable energy increases. A heat pump can help to achieve significant fuel cost savings compared to direct electric heating systems (*e. g.* storage heating), gas boilers, oil boilers, and some renewable energy systems, such as biomass boilers. This could translate into a considerable overall economic benefit, particularly so as possible subsidy will significantly shorten the "pay-back" time, making a heat pump an even more attractive option. The heat pumps are an environmentally friendly alternative to oil and gas. They do not require any fuel storage space, unlike oil which require large storage tanks, and biomass boilers which require wood/pellet storage. They do not require fueling as there are no harmful emissions.

A heat pump can move three to four times more heat to or from a building than the energy required to operate it. The energy efficiency of heating equipment can be compared by looking at the rated COP. The COP of an electric furnace is 1, since each watt of electricity put into it produces the equivalent of 1 W of heat energy out. The COP of a heat pump is three or greater so that each watt the heat pump used to run its transferring mechanism enables it to draw two or more watts from the Earth, giving a total of three or more units out for every one unit put in. Thus, the heat pump supplies more than 2/3 of the energy requirement from free energy stored in the earth and reduces the heating cost by more than 60%.

The efficiency of a heat pump depends upon the temperature at which it finds its heat (source temperature) and the temperature at which it discharges this heat (sink temperature). The greater the difference between the source temperature and sink temperature, the more work is done by the compressor in the heat pump, and consequently, the more cost. In other words, as the source temperature declines, so will the efficiency of the heat pump. In this article two different examples of possible use of heat pumps for adjustment of the thermo-mineral water in spas are presented, the first with ground water based open loop heat pump type, and second with ground source based closed loop heat pump type. In the first case, the heat of the underground hot water is used to supply heat to the district heating system of Mataruska spa, thus being cooled to the temperature needed for balneo-therapeutical purposes. In the second case, the ground based closed loop heat pump type is used to rise the temperature of the mineral water in Bukovicka spa for balneo-therapeutical purposes. The economy in both cases is primarily based on gains from the replacement of fossil fuels and electricity by the free geothermal energy.

## Use of heat pumps in spas

### *Mataruska spa case study*

Mataruska spa is located in central Serbia, 7 km SW of the city of Kraljevo. Four of five geothermal wells (MB-1, MB-2, S-7, and S-10) are located in the spa park, while one well (MB-3) is located south of the city. The largest well (MB-2) produces 20 l/s of geothermal water at 52 °C outflow temperature, and when mixed with geothermal waters from other three close to it (MB-1, S-7, and S-10, with outflows 6.5 l/s, 4.9 l/s, and 8.4 l/s, and temperatures 32 °C, 42 °C, and 52 °C, respectively), the total production would be 39.8 l/s at average outflow temperature 47.5 °C. If the temperature for balneology is required to be not lower than 36 °C, the total free heat available for other uses is calculated to be $Q_a$ = 1.916 $MW_t$, and more if the temperature may be below 36 °C.

The district heating system (DHS) in Mataruska spa is based on fuel oil boilers which can produce up to 3.2 $MW_t$. Operating temperatures of district heating system are between 70 °C supply temperature and 50-55 °C return temperature for the houses. Some buildings are connected by heating pipelines to DHS, but some are heated by separate boiler houses. With current price of fuel oil, the cost price of heat is high (estimated 0.063 €/kWh), and the heat production in the last two heating seasons has amounted to 3.84 GWh (2010-2011) and 3.27 GWh (2011-2012) for the buildings that have been heated by the DHS, while the total heat demand was 6.97 GWh. Therefore, cheap electricity has been used for the additional heating, even of a pool in only hotel.

This serious problem could be easily solved by the use of available geothermal water and heat pumps without jeopardizing the use of water for balneology, [3]. By the extraction of heat from geothermal water in the evaporator and its transfer via condenser of the heat pump to the water in DHS, the temperature of the geothermal water will be lowered to suits the purposes of balneology without reducing its quality if cooled by some other possible means. The possibility and economic viability of use of the available geothermal heat to replace the existing heating is demonstrated on a smaller scale (to heat a single institution) and on the full scale (to replace the entire existing heating sources in the DHS in Mataruska spa).

### *Heating of an institution for rehabilitation*

The existing source of heat for the institution specialised for rehabilitation "Agens" in Mataruska spa is a boiler fired by light fuel oil. The heated area is 4410 $m^2$, and total volume of space is 13500 $m^3$. The installed consumer capacity of $Q_f$ = 673 kW is served from the boiler house 400 m away from the building. Heat losses are estimated to be $Q_{vF}$ = 66.5 kW, so that the total capacity of the boiler is $Q_k = Q_f + Q_{vF}$ = 739.5 kW. Sanitary hot water is produced in six electric heaters each of 6 kW installed capacity. The heating season lasts $n_s$ = 180 days with daily operation $n_d$ = 16 hours. The average outside temperature over the heating season is $t_o$ = 4.4 °C. Design ambient temperature is $t_u$ = 20 °C, and outdoor design temperature is $t_{sp}$ = –20 °C. Boiler efficiency is $\eta_b$ = 0.855. Lower heating value of the fuel oil is 41200 kJ/kg. The fuel consumption per season is calculated to be 84858 kg =101094 liters, assuming its density of $\rho$ = 839.4 kg/$m^3$. With fuel price of 38.6 RSD/liter, the fuel costs are RSD 4.26 million per season. With the costs for maintenance and electricity for sanitary hot water of RSD 1.11 million, the total costs of energy supply for the existing consumers in the institution specialised for rehabilitation "Agens" are RSD 5.37 million, equal to €67.1 thousand per season.

The current unfavorable situation could be drastically changed by the measures to insulate building envelope (1368 $m^2$ of outer walls) and to replace the windows (996 $m^2$) with more energy efficient ones. This is estimated to cost about €123 thousand, and might reduce the heat required by 57%, to roughly 290 kW. If the geothermal water is used as the heat source by the aid of a 96 kW heat pump to heat the space through the existing installation, additional cost of €35 thousand would be required for the heat substation and an increase of the surface of the radiators, so that the total cost would be €158 thousand. However, this investment would be easily paid back, since the estimated heating costs would be reduced to only €7500 to €8400 per season, several times less than at present, [4]. The use of a larger capacity (220 kW) heat pump would also make it possible for the total installation costs to be repaid if the above mentioned investment in insulation material and works could not be acquired, but within a much longer pay-back period.

### *Use of geothermal energy for the entire DHS*

As mentioned, due to a high price of fuel oil and lack of finance, it has not been possible to meet heat demands for several last years, and additional heating (around half of the heat demand) has been produced by electricity. It is considered possible to utilise the heat from the existing wells to replace oil fired boilers in the entire DHS in Mataruska spa. The geothermal water from four wells, MB-1, MB- 2, S-7, and S-10, driven through a heat pump, where the water for the DHS will be heated, can produce up to 4.2 $MW_t$, more than needed for the entire existing DHS (2.85 $MW_t$). To achieve 4.2 $MW_t$ by the use of heat pump with COP ≥ 4, the average temperature of the geothermal water of 47.5 °C would lowered by ~20 °C, possibly below the levels suitable for some balneological and physio-therapeutical purposes. The cooling of the geothermal water from 4 wells by 11.5 °C to obtain 2.85 $MW_t$ needed by the existing DHS seems more reasonable, and is used for reference in technical and economic analysis done for this case.

A schematic presentation of a hybrid system in which the geothermal water is used both for balneological and physio-therapeutical purposes and for DHS in Mataruska spa is given in fig. 3. This system is based on the use of a heat pump which extracts (practically wasted) heat from the geothermal water for replacement of the existing fuel oil based DHS, which is then used for the balneological and physio-therapeutical purposes and re-injected to the well MB-3. The free heat $Q_a = 1.92$ MW$_t$ is extracted from the geothermal water by the heat pump for the existing DHS capacity $Q_f = 2.85$ MW$_t$ would need the compressor drive power $P = 932$ kW. Thus, the efficiency COP = 3.06 would be achieved. The above ideal heat balance neglects the heat losses $Q_{vA}$, $P_v$, and $Q_{vF}$ from the eqs. (3) and (4). In reality, however they need to be calculated by the use of parameters presented in fig. 2 determined for this particular case. On the other hand, the COP for water based heat pump is underestimated, so that these losses will be compensated.

The total cost of the conversion of the DHS in Mataruska spa to the geothermal water heating is estimated to be €2.5 million, where the largest cost factor of the heat plant is the heat pump system (€1.4 million). Other cost factors include restauration cost of the existing wells, heat transfer station expansions, pipeline and distribution system for connection to the existing local boiler houses, engineering, and contingency costs. Annual operating expenses are estimated to be €0.11 million needed to cover organisation and overhead costs, operation and maintenance expenditures, and to cover possible parasitic loads, [4].

For the cost/benefit analysis over a 30 years projected lifespan, annual discount rate of 5% as suggested in the EU guide [5], debt interest rate of 3% and debt fee of 0.5%, and payback period 20 years, the cost price of heat is approximately 0.034 €/kWh. The estimated energy efficiency of heavy fuel oil boiler, price for the heat at the exit of boiler house should be at least 0.063 €/kWh. The biggest economic benefit identified is the $CO_2$ savings which results from replacing the fuel oil for the heating plant by the emissions free geothermal energy.

An alternative was also considered for the case of a future increase of the DHS capacity, when

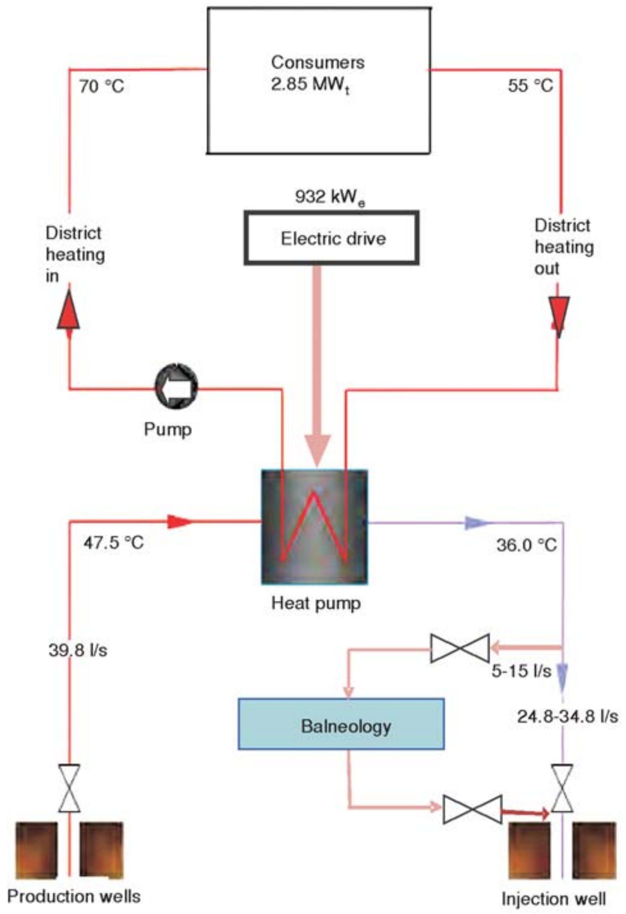


**Figure 3. Schematic of the hybrid process in Mataruska spa**

more consumers will be added and thus a new well would be required. The total cost for this alternative case is estimated to be €3.3 million. The main findings of the financial analysis are that the cost price is approximately 0.032 €/kWh, about a half of the present cost price of 0.063 €/kWh. This indicates that from the viewpoint of the financial analysis the alternative scenario with an increased load is more favourable than the case with the existing load.

### *Bukovicka spa case study*

In Bukovicka spa there are cold and hot springs of mineral water. Cold water from four wells "Talpara", "Djulara", "Pobeda", and "Knjaz Milos" are for drinking, and the hot water from one well "Topla voda", known as "Arkade", is used for balneo-therapeutical purposes (inhalation and bath). All wells are located in the park of Bukovicka Spa, and have the same characteristics, the only difference being in water temperatures. For balneo-therapeutical purposes, mineral water has to be heated up by some additional degrees (Celsius) by the use of natural gas and electricity.

In Special Rehabilitation Hospital "Bukovicka spa" 120 $m^3$ of mineral water per day is heated to temperatures ranging from 32 to 36 ºC. A monthly consumption at present is 22 MWh of electricity and 10000 $m^3$ of gas. Out of this, monthly consumption of gas for space (3608 $m^2$) heating is 6000 $m^3$ and 4000 $m^3$ for heating water (60 $m^3$/day) in the pool, while monthly consumption of electricity is 10 MWh for heating sanitary hot water and 12 MWh is used for other purposes. So, if only water in the pool and space are to be heated, the heat pump could be used to replace monthly all 10000 $m^3$ of gas and 10 MWh of electricity to heat sanitary hot water.

Unlike the open loop geothermal water based heat pump type used in Mataruksa spa, for the adjustment of the mineral water temperature in Bukovicka spa the closed loop ground based heat pump type is considered, fig. 4. Approximately about ten meters of pipe is needed for every kW of heat, so a considerable area is needed for closed loops to be buried horizontally in trenches, Vertical closed loops in boreholes take up less space, but they are much more expensive to install. Drilling equipment is used to bore small-diameter (~10 cm) holes, 50 m to 150 m deep.

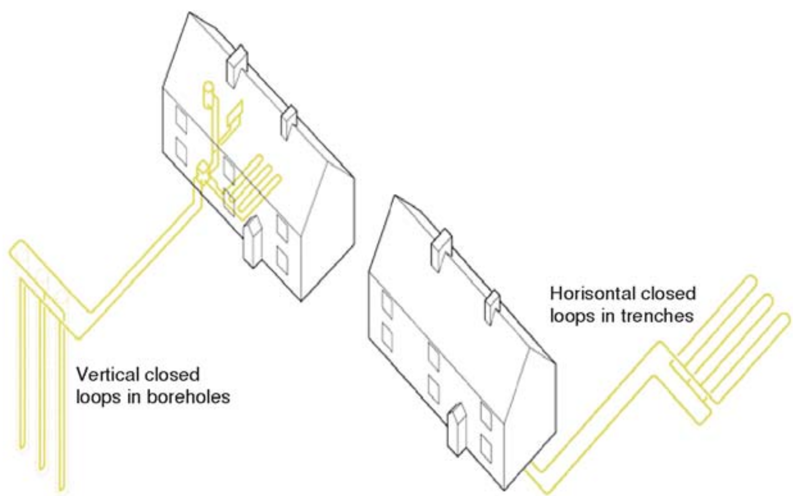


**Figure 4. Ground source based heat pumps with closed loops**

*Energy savings*

A standard cubic metre of natural gas at temperature under normal conditions (15 °C and 1013.25 mbar) has lower heating value of 33338 kJ/m$^3$, and when used for heating in a gas fired boiler, the total energy sent out is 93350 kWh/month. The overall efficiency of the gas fired heating system is $\eta_b = \eta_k \eta_c \eta_r$, where $\eta_k = 0.92$ is boiler efficiency, $\eta_c = 0.95$ efficiency of piping network and $\eta_r = 0.85$ control system efficiency, so that $\eta_b = 0.743$. On the other side, efficiency of the heat pump COP ≈ 3-4. So, when only gas used for heating is replaced by the use of heat pump with COP = 3, average electricity consumption would be 28626 kWh/month. In that case the energy saving on gas is 64720 kWh per month, but the overall saving is reduced by the consumption of pumps to pump from wells about 1000 kWh/month, so that the net calculated monthly energy saving on gas consumption would be 63720 kWh.

The heat pumps work most efficiently with a small temperature difference, which means that the water sent to the consumers will not be very hot, [6]. As the water temperature in the pool should be 36 °C, the water in that case could be heated by the use of heat pump only. However, the ground based heat pump alone cannot rise water temperature above 55 °C, and therefore, in case when also the space heating with higher temperature is required, gas as an additional heat source is to be employed. In such a combined space heating system, with both gas fired boiler and heat pump employed, the heat pump would be used as long as the outside temperature does not require water temperature above 55 °C, [7]. For calculation, it can be assumed that in that case the heat pump would cover at least 65% of the heat demand, while the gas fired boiler would cover the rest 35%. The total energy needed for heating is 56000 kWh/month. Of that amount, electricity needed for heating by the use of heat pump is 11164 kWh, while the use of gas would be 19610 kWh. For water in the pool to be heated, energy needed is 37340 kWh. Electricity needed for heating the water in the pool via heat pump 11451 kWh. Total energy used would be 42230 kWh without 12 MWh of electricity used for other purposes. As in this case the heat pump is of a smaller capacity, consumption of electricity for pumping the water from wells would be less, say 750 kWh, so that the total energy saving would be 50370 kWh per month. This is expected to be on the safe side, because a greater share of the heat pump in space heating can be achieved. Also, the assumed COP = 3 may be considered conservative, because recent development demonstrate that much higher values can be achieved.

*Economic benefits*

The money value of the energy savings achieved by the use of the heat pumps will be calculated by the use of the tariffs without tax. Unit cost of natural gas excluding tax is assumed to be 0.43 €/m$^3$, and unit cost of electricity excluding tax 0.055 €/kWh if 20% of total consumption is at night and 80% at day. Current monthly bills for heat energy would be 4300 € for gas plus 550 € for electricity (12 MWh of electricity used for other purposes is not taken into account). If the low temperature heating would be possible, the gas could be replaced by electricity used to drive the heat pump and thus monthly bill would be reduced to 1574 € instead of 4300 €. If it is not possible, a portion of heat demand that heat pump is not capable to cover would be covered by gas at monthly cost of 903 € and the rest by the electricity used to drive compressor of the heat pump at monthly cost of 1230 €. In both cases the overall monthly bills would be practically the same (1574 2124 € in the case of low temperature heating, and 2133 €), and the monthly savings would be 2726 € (56.21%) and 2717 € (56.02%), respectively.

Obviously, to achieve so high energy and consequent financial savings, considerable capital investments would be needed to replace the existing heating system in Special Rehabilitation Hospital "Bukovicka spa" by the new heating system with the ground based heat pump. The pump capacity should be about 50 kW capacity with estimated cost of €97 thousand for the entire system to be replaced. For the cost/benefit analysis the lower monthly saving (2717 €) will be adopted, distributed at 100% during 6 months and 40% outside the heating season, so that the calculated annual saving would be €22.8 thousand, with no additional operating and maintenance expenses needed. The projected lifespan is assumed to be 25 years, and discount rate 7 %/year. With these assumptions, the simple pay-back period for investment would be 4.25 years, but with recommended discounting is 5.22 years, with positive net present value (NPV) = = €168.67 thousand, while the calculated internal rate of return (at NPV = 0) would be 23.8%.

## Concluding remarks

Geothermal energy can successfully be used in spas to adjust the water temperature for balneo- and physio-therapeutical purposes by the aid of heat pumps. This has been demonstrated to be energy efficient and economically viable solution both for the case when hot mineral water is available and thus needs to be cooled down and for the case when lower temperature mineral water needs to be heated up.

The heat pumps can also be used to heat the building environment. By the use of heat pumps the "free" geothermal energy can replace two thirds or more of the conventional heat energy, usually generated by fossil fuels. Besides cutting the energy bills by more than a half, economic and environmental benefits of the use of geothermal energy by the aid of the heat pumps are augmented by extending the season of balneo-therapy, as well as by reducing the $CO_2$ emissions.

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