

Experimental Measurement and Energy Evaluation of the Geothermal Water Energy Utilization in a Thermal Swimming Pool

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Abstract

This work focuses on the experimental measurement of the temperature and flow of cold, geothermal, pool and waste pool water of a thermal swimming pool in southern Slovakia. The measured quantities are necessary for the energy evaluation of geothermal water energy utilization. It is clear from experience that the geothermal energy utilization rate often does not even reach 40%. The remaining energy is considered waste, and in the form of waste pool water with too high temperature, it is most often discharged into surface streams. The results of the study showed that by applying appropriate measures to recover heat from waste pool water, it is possible to increase the energy utilization rate of thermal water from 40% to 85%, which is the ideal energy utilization rate according to energy point of view. At the end of the article, methods will be presented, thanks to which it would be possible to reduce the temperature of waste pool water to the value required by law and at the same time increase the rate of thermal water energy use.

Keywords

energy evaluation, geothermal energy, experimental measurement, thermal swimming pool

1 Introduction

Geothermal energy is the oldest renewable energy source. Its biggest advantage is that it does not depend on the weather or the alternation of day and night. Slovakia is small country with big geothermal energy potential. In Slovakia we can find 174 wells which provides thermal water with temperature from 30 °C to 130 °C. Thermal water with 130 °C can be used for electricity production, but in Slovakia we don't have any geothermal plant. Geothermal energy in Slovakia is used for direct utilization for centralized heating systems, greenhouses heating, or fish farms. Mainly is geothermal energy used in recreational facilities like thermal swimming pools, thermal baths or balneological sanatoriums [1–3].

The geological subsoil of Slovakia hides the potential of 5500 MW_t of thermal power. Currently, approximately 215 MW_t is used, while up to 60% is used in recreational facilities [1]. Depending on the type of recreational facility, thermal water is used either to fill the pools or to heat

the cold water used to fill the pools. In both cases, it is very common for recreational facilities to produce waste pool water that is too hot to be discharged into rivers.

Regulation of the Government of the Slovak Republic No. 269/2010 [4] and Act No. 364/2004 Coll. on water [5] prescribed the maximum temperature of waste pool water which can be discharged into the recipient without environmental pollution to the value of 26 °C [4, 5]. In most cases this requirement is not met, which is why recreational facilities are facing the sanction for environmental pollution.

Recuperation systems, or heat recovery systems, are known mainly in air conditioning systems. However, heat recovery systems from sewage systems from buildings are increasingly coming to the fore. The heat recovery system can also be applied in the technological room of the pools. Thanks to this system, it would be possible to ensure the maximum required temperature of the waste pool water and at the same time usefully use its energy

potential. In Sections 2 and 3, the recreational facility will be described in which the experimental measurement and subsequent energy analysis of the selected pool system took place. The article will also be devoted to the application of the heat recovery system and other possibilities of using the energy potential of waste pool water.

2 Solved pool system

Experimental measurements took place in the engine room of the swimming pool. The pool system is circulating. A tubular heat exchanger (Fig. 1) is used in the engine room of the pool, through which cold and thermal water flows. The cold water is heated using the heat of the thermal water and is released into the pool.

Thermal water with temperature of 68 °C enters the tubular heat exchanger. In case the flow is not sufficient, the system is also connected to a second geothermal well. Used thermal water flows from the pool system, but it is only cooled to 50 °C.

It is obvious that the use of thermal water energy is not sufficient. The temperature difference between the thermal water supplied to the heat exchanger and discharged out of it is only 18 °C.

3 Experimental measurements

In the cooperation with thermal bath in southern Slovakia, experimental measurements were made. During 27 days, the temperature and flow of pool, cold and thermal water were monitored and recorded. The main aim of the measurement was to find out the mentioned values because the measurement and regulation components are completely absent in the engine room of the pool.

A portable ultrasonic flow meter Flexim Fluxus F60x [6] (Fig. 2) was used to measure the water flow, which was installed on the thermal water pipe. A stationary Flexim Fluxus ADM 5107 ultrasonic flow meter was installed on



Fig. 1 Tubular heat exchanger in the engine room of the swimming pool
 [Authors]



Fig. 2 Portable ultrasonic flow meter Flexim Fluxus F60x [6]

the pool water pipe. The water flow recording interval was set to every 10 minutes on both flow meters. The portable ultrasonic flow meter Flexim Fluxus F60x is among the high-quality devices for recording the flow of any liquid, regardless of its viscosity and temperature. Flow measurement is made without direct contact with the liquid. Mentioned measure device is able to measure volume and mass flow, and liquid flow rate in pipelines.

The thermal water pipe is made of black steel threaded pipe with an outer diameter of 33.5 mm, an inner diameter of 27.0 mm and a wall thickness of 3.25 mm. The pool water pipe is made of PVC material with an outer diameter of 75.0 mm, an inner diameter of 67.8 mm and a wall thickness of 3.6 mm.

The parameters of the pipelines on which the experimental measurements were made are summarized in Table 1.

Sensors of ultrasonic flowmeters must be installed on a straight part of the pipeline, while it is advisable to maintain a calming part in from of and behind the sensors of approximately 15 to 20 cm. The placement of flow meter on the thermal water pipe is shown in Fig. 3.

To measure the temperature of the pool, cold and thermal water Comet temperature sensors were used, which

Table 1 Parameters of pipelines during the experimental measurements
 [Authors]

Pipeline	Material	Outer diameter (mm)	Inner diameter (mm)	Wall thickness (mm)
Pool water	PVC	75.0	67.8	3.6
Thermal water	Black steel	33.5	27.0	3.25

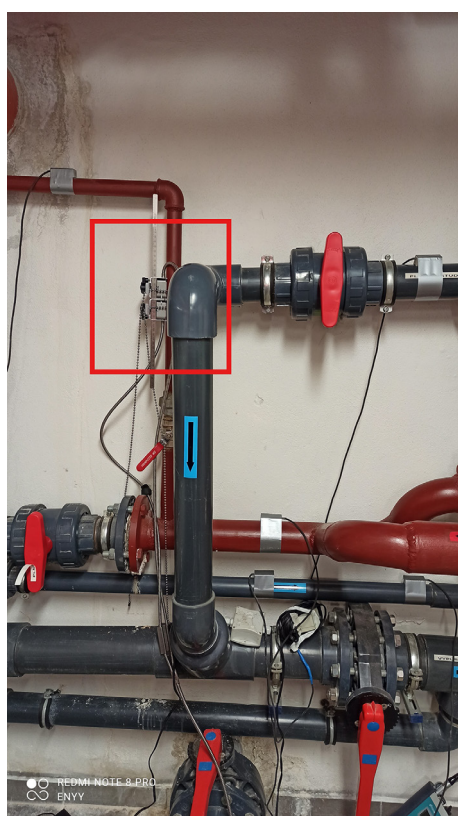


Fig. 3 Ultrasonic flowmeter sensors placement on the thermal water pipe [Authors]

were also connected to a unified data logger, in which the measured data was stored. Eight temperature sensors were installed so that two sensors were installed on each measured pipe in case one of them had failure. The location of the temperature sensors is summarized in the Table 2 and shown in the Fig. 4.

Thermal water temperature sensors (S7, S8) were installed on the supply pipe before and behind the sensors of the ultrasonic flowmeter, which can be seen in Fig. 4.

An important step in the measurements is according to measured flow rate, volume flow of water and the course

Table 2 Summarization of temperature sensors and its location [Authors]

Sensor	Location	Note
S1	Cold water	-
S2	pipeline	-
S3	Pool water	-
S4	pipeline	Pool water pipeline on which the ultrasonic flow meter sensors are located.
S5	Used thermal	-
S6	water	-
S7	Thermal water	Temperature sensor located before the ultrasonic flow meter sensors.
S8	supply	Temperature sensor located behind the ultrasonic flow meter sensors.

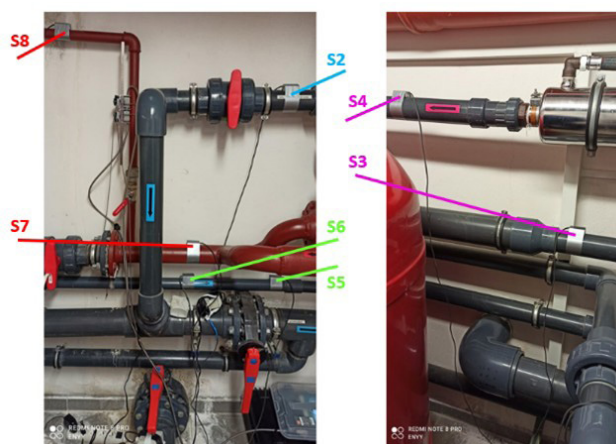


Fig. 4 Temperature sensor location [Authors]

of the sound speed. Based on research, there is a correlation among the temperature, pressure and sound speed of the measured fluid in the pipeline when using ultrasonic measurement methods.

In the Table 3 and Fig. 5 this dependency is listed. It is clear from the data that as the temperature of the measured fluid increases, the speed of sound increases up to a temperature of 80 °C. As the temperature fluid increases further, the speed of sound decreases.

The average temperature of the thermal water flowing in the pipeline during the measurement was 66.6 °C and average sound speed was 1,552.18 m/s. Due to the dependence showed in the Table 3 and Fig. 5 it is possible to verify that the measured sound speed corresponds to the temperature of the liquid (in this case thermal water) that

Table 3 Sound speed dependence on the temperature and pressure of the fluid [6]

Temperature (°C)	Fluid pressure (bar)	Sound speed (m/s)	Density (kg/m ³)	Specific heat capacity (kJ/(kg K ⁻¹))
0.1	1.013	1,402.9	999.8	4.219
10	1.013	1,447.3	999.7	4.195
20	1.013	1,482.3	998.2	4.184
30	1.013	1,509.2	995.6	4.180
40	1.013	1,528.9	992.2	4.179
50	1.013	1,542.6	988.0	4.181
60	1.013	1,551.0	983.2	4.185
70	1.013	1,554.7	977.8	4.190
80	1.013	1,554.4	971.8	4.197
90	1.013	1,543.2	965.3	4.205
100	1.013	1,519.9	958.3	4.216
120	1.985	1,486.2	943.1	4.244
140	3.615	1,443.2	926.1	4.283
160	6.128	1,443.2	907.4	4.335

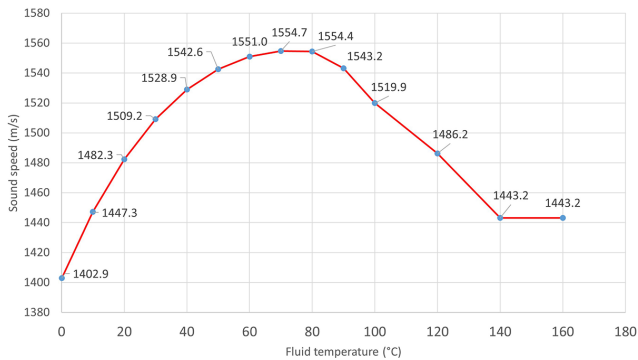


Fig. 5 Sound speed dependence on the temperature and pressure of the fluid [Authors]

flowed in the pipe. The course of sound speed during the measurement interval to verify is showed in the Fig. 6.

From the measurement of the thermal water flow speed in the pipeline, it is clear that the value fluctuated only minimally in the range from 0.67 m/s to 0.71 m/s. The average flow speed of thermal water in the pipe is 0.69 m/s. The flow rate of thermal water is shown in Fig. 7. The volume flow of thermal water pumped from the source varied from 1.37 m³/h to 1.49 m³/h. The average volume flow of thermal water from geothermal well is 1.43 m³/h. The volume flow of thermal water is shown in Fig. 8.

The average flow speed of the pool water in the pipe is 1.68 m/s. The volume flow of pool water varied from 21.98 m³/h to 22.25 m³/h. The average volume flow of pool water is 22.12 m³/h.

The curves have a similar course as the case with thermal water, so these graphs will not be presented. The measurement results are summarized in the Table 4, where the minimum, maximum and average value of the speed flow rate and volume flow of thermal and pool water are given.

The goal of recording temperatures during the operation of the reference pool was to verify the correctness of the information on the pool water temperature which was provided by the operator of thermal bath. It was also necessary to verify the cold water temperature which is heated using the heat of the thermal water and then is discharged into the pool. Finally, it was necessary to find out the thermal water temperature which is used to heat the cold water using a heat exchanger, and of course the temperature of the used or waste thermal water which flows directly into the sewer.

The results of water temperature measurements in the operation of solved pool are summarized in the Table 5 and Table 6, where is the minimum, maximum and average

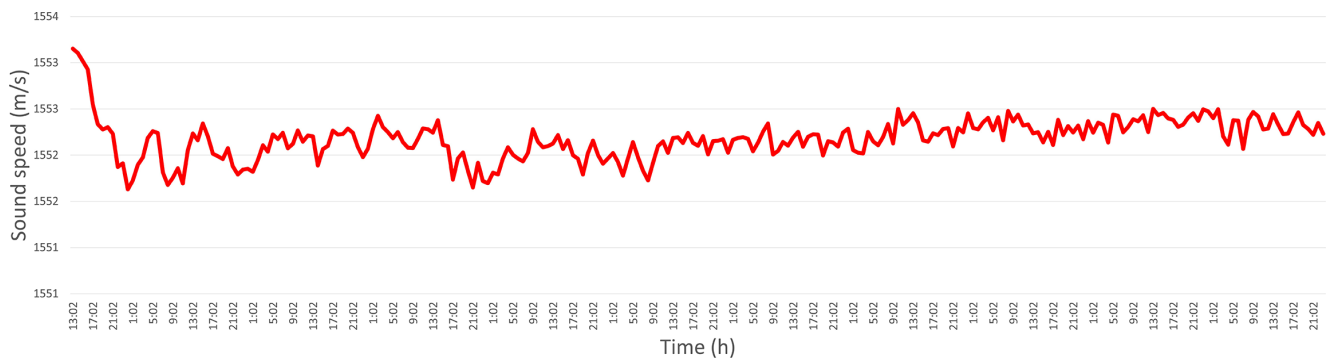


Fig. 6 Sound speed course during the measurement interval [Authors]

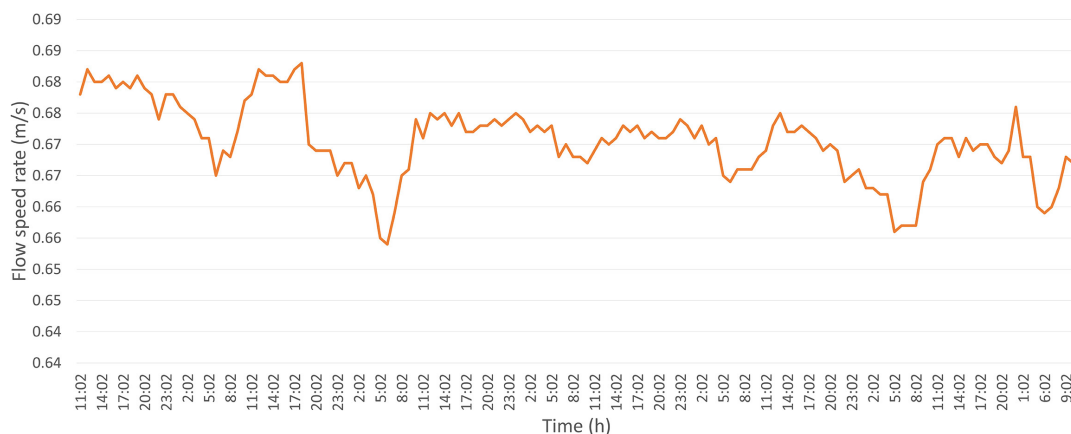


Fig. 7 The flow speed of thermal water during the measurement [Authors]

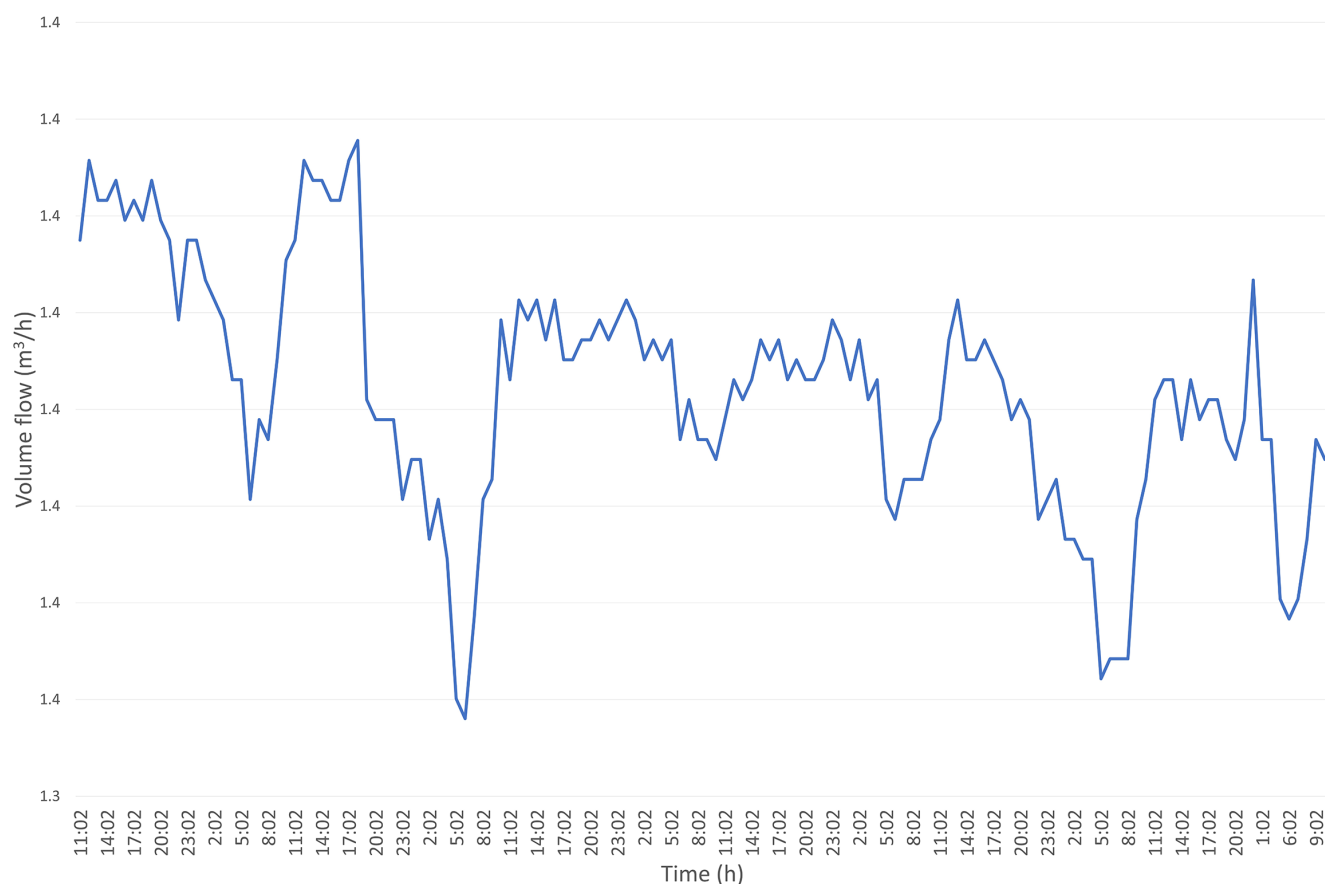


Fig. 8 The volume flow of the thermal water during the measurement [Authors]

Table 4 Measurement results of the speed flow rate and volume flow of thermal and pool water [Authors]

Water		Pool water	Thermal water
Flow speed (m/s)	Min	1.64	0.67
	Average	1.68	0.9
	Max	1.71	0.71
Volume flow (m³/h)	Min	21.98	1.37
	Average	22.12	1.43
	Max	22.25	1.49

Table 5 The results of cold and pool water measurement [Authors]

Sensor		S1	S2	S3	S4
Water		Cold water		Pool water	
Temperature (°C)	Min	-	19.47	22.88	26.43
	Average	-	22.65	27.84	28.54
	Max	-	24.53	39.66	40.07

Table 6 The temperature measurement results of thermal and wastewater measurement [Authors]

Sensor		S6	S7	S8	S9
Water		Waste water		Thermal water	
Temperature (°C)	Min	27.63	27.90	58.09	34.87
	Average	46.82	47.25	65.24	63.01
	Max	50.03	50.62	66.66	66.57

temperature by all eight sensors showed. The measured temperatures were further used in the calculation of the energy balance of the solved pool.

The temperature of the thermal water, with which the cold water is heated in the operation of the pool, reached an average of 63 °C. The temperature of the thermal water, which was measured at the overflow into the sewage system, reached a temperature of 47 °C. From environmental, but also an energy point of view, such a high temperature of wastewater is unacceptable.

The aim of the measurements was to determine the speed flow rate and volume flow of pool water, but especially of thermal water during operation of the solved pool. These values are included in the calculation of the energy balance. These quantities were not recorded in the pool system, so it was necessary to do experimental measurement during the operation of the pool.

4 Methodology

Section 4 describes the mathematical model of the geothermal source and the reference pool. To mathematically define the energy balance of a geothermal source, it is necessary to know the parameters that enter the

calculation – geothermal source copiousness, geothermal water temperature and the total volume of water required for filling and operating the reference pool.

The above parameters are used to calculate the energy balance of geothermal source. Before designing the thermal bath, it is necessary to know the theoretically usable energy provided by the geothermal well:

$$E_{theo} = \frac{M_{tot} \times c \times (\theta_0 - \theta_r)}{3600} \text{ (MWh)} \quad (1)$$

where:

- M_{tot} – is the total volume of water required for the operation and filling of the pool (m^3),
- c – specific heat capacity of water (kJ/kg K),
- θ_0 – thermal water temperature ($^{\circ}\text{C}$),
- θ_r – required temperature of cooled wastewater ($^{\circ}\text{C}$).

The calculation of the theoretically usable energy provided by a geothermal well is mainly based on the temperature difference. The calculation includes the thermal water temperature and the temperature of cooled wastewater which is set by standards at 24°C .

The next step in the calculation of the energy balance is the calculation of usefully used energy of thermal water:

$$E_u = \frac{M_{tot} \times c \times (\theta_0 - \theta_{waste})}{3600} \text{ (MWh)} \quad (2)$$

where:

- M_{tot} – is the total volume of water required for the operation and filling of the pool (m^3),
- c – specific heat capacity of water (kJ/kg K),
- θ_0 – thermal water temperature ($^{\circ}\text{C}$),
- θ_{waste} – wastewater temperature ($^{\circ}\text{C}$).

Changes in the listed formulas are only due to temperature differences. In the calculation of useful energy, it is necessary to consider the real temperature of wastewater which is in many cases different by required wastewater temperature.

By calculation of the degree of energy utilization of thermal water source, it is possible to determine the percentage of this energy that is used:

$$\eta = \frac{E_u}{E_{theo}} \times 100 \text{ (%) } \quad (3)$$

where:

- E_{theo} – is theoretically usable energy provided by the geothermal well (MWh),
- E_u – usefully used energy of thermal water (MWh).

In many thermal baths in Slovakia, we encounter the fact that the use of thermal water energy does not even reach 50%. Approximately 50% of the thermal energy that we pump from the geological sources is considered waste and has no use. The aim is to increase the thermal water energy rate of utilization, thereby extending the lifetime of the thermal water source and reducing sanctions for discharging wastewater with too high temperature.

The total volume of water required for the operation and filling of the pool is also included in the calculation of the energy balance. This value must be determined separately for each solved pool according to its input values:

- volume of the solved pool (m^3),
- pool water temperature ($^{\circ}\text{C}$),
- cold and thermal water temperature ($^{\circ}\text{C}$),
- filling time of the pool (hours, days),
- the number of operating days of the pool (days).

Mathematical calculations must be done separately for filling and operating the pool. During the filling of the pool, the quantity τ is considered in the calculation, which determines the time of filling the pool. When calculating the operation of the pool, the quantity τ is also considered in the calculation, which determines the number of days during the summer, winter or year-round operation of the pool.

The volume flow of pool water, which depends on the solved pool volume, can be calculated according to Eq. (4):

$$m_{PW} = \frac{V}{(\tau \times 3.6)} \text{ (l/s)} \quad (4)$$

where:

- V – volume of the solved pool (m^3),
- τ – filling time of the pool (hours), or operating days of the pool (days).

Most pools in Slovakia use a pool system in which it is necessary to mix thermal water with cold water in such a ratio that the required temperature of the pool water is reached. This means that the pool water is composed of thermal and cold water. Their mixing ratio depends on the desired pool water temperature.

The volume flow of thermal water required during filling or operation can be calculated according to Eq. (5):

$$m_{TW} = \frac{m_{PW} \times (\theta_{PW} - \theta_{CW}) \times P_{HS}}{(\theta_0 - \theta_{CW})} \text{ (l/s)} \quad (5)$$

where:

- m_{PW} – is the volume flow of pool water (l/s),
- θ_{PW} – pool water temperature ($^{\circ}\text{C}$),

- θ_{CW} – cold water temperature (°C),
- θ_0 – thermal water temperature (°C),
- P_{HS} – allowance for heat losses in distribution system (depends on the pipe length and location of distribution system) (-).

The volume flow of cold water, which is required for mixing with thermal water can be calculated using a simple equation:

$$m_{CW} = m_{PW} - m_{TW} \quad (\text{l/s}) \quad (6)$$

where:

- m_{PW} – is the volume flow of pool water (l/s),
- m_{TW} – thermal water volume flow (l/s).

To achieve the required pool water parameters, it is necessary to ensure the correct percentage of mixing cold and thermal water, which can be calculated according to the Eqs. (7) and (8):

$$\eta_{TW} = \frac{m_{TW}}{m_{PW}} \times 100 \quad (\%) \quad (7)$$

$$\eta_{CW} = \frac{m_{CW}}{m_{PW}} \times 100 \quad (\%) \quad (8)$$

where:

- m_{TW} – is thermal water volume flow (l/s),
- m_{PW} – pool water volume flow (l/s),
- m_{CW} – cold water volume flow (l/s).

In addition to volume flows, it is also necessary to calculate the volume of pool, cold and thermal water needed during filling and operation of the pool. The volume required to fill the pool during summer, winter, or year-round operation depends on its volume and the number of fillings during operating time of solved pool. The pool water volume for filling of the pool can be calculated by Eq. (9):

$$M_{PW} = V \times n_F \quad (\text{m}^3) \quad (9)$$

where:

- V – is volume of solved pool (m³),
- n_F – number of pool fills during operation (x/operation).

As already mentioned, the volume of pool water is made up of mixed thermal and cold water. To calculate the volume of thermal and cold water, it is possible to apply

the percentages calculated in Eqs. (7) and (8). Then is possible to calculate thermal and cold-water volume according to Eqs. (10) and (11):

$$M_{CW} = \frac{\eta_{CW}}{100} \times M_{PW} \quad (\text{m}^3) \quad (10)$$

$$M_{TW} = \frac{\eta_{TW}}{100} \times M_{PW} \quad (\text{m}^3) \quad (11)$$

where:

- η_{CW} – is percentage ratio of cold water in pool water mixture (%),
- η_{TW} – is percentage ratio of thermal water in pool water mixture (%),
- M_{PW} – the pool water volume (m³).

The above calculation must be done separately for filling and operating the solved pool. The change that significantly affects the calculation is in Eq. (4), where it is necessary to take into account the different time of filling and operation of the pool.

In the past, Štefanička [7] and Jurka [8] were mainly concerned with the calculation of the energy balance of the thermal bath in their dissertations, while the presented calculation is based on these works and mathematical-physical procedures.

5 Energy balance calculation

During the experimental measurements, it was found that there is a complete absence of measuring devices in the engine room of the pool. Therefore, it was necessary to find out the temperatures of cold, pool, thermal and wastewater as well as their volume flow. These values will be further used in the calculation of the energy balance, the procedure of which was described in Section 4.

The solved pool has a plan area of 212.5 m², volume of 297.5 m³, required pool water temperature of 28 °C. According to results of experimental measurements the thermal water temperature is 65.2 °C, wastewater temperature of 47.3 °C. The pool is in operation 362 days a year. During the remaining days it is drained, maintained and refilled.

The Table 7 summarizes the input data for calculating the energy balance of the solved swimming pool. The thermal water temperature of 65.3 °C and its volume flow rate of 1.43 l/s were considered in the calculation. During the experimental measurements, it was founded that the temperature of the wastewater greatly exceeds the legally specified maximum temperature of wastewater.

Table 7 The summarization of the input data for energy balance calculation of solved pool [Authors]

Thermal water temperature	Thermal water volume flow	Wastewater temperature	
		Required	Real
θ_0 (°C)	m_{TW} (l/s)	θ_r (°C)	
65.3	1.43	26.0	47.3

The Table 8 summarizes the results of thermal water energy utilization. From the results of energy balance calculation, the rate of use of thermal water energy is not sufficient. Only 43.2% of thermal water energy is usefully used. This phenomenon occurs because thermal water with a temperature of 65.3 °C is pumped from the geothermal source. This is brought to the heat exchanger in the engine room of the swimming pool. Here, it transfers its heat to cold water, which is then drained into the pool. The measurements showed that cooled thermal water with a temperature of up to 47.3 °C leaves the heat exchanger. The temperature difference between the pumped and waste thermal water is only 18 °C, which results in insufficient use of thermal water energy.

The aim of this work, which is very important for operators of recreational facilities, is to achieve the required temperature of cooled wastewater which is drained into the recipient. If all the original input data that entered the previous calculation of the energy balance will be kept and will be varied only with the required temperature of the cooled wastewater, it is possible to increase the rate of thermal water energy utilization as shown in Fig. 9.

It is clear from the Fig. 9 that when the wastewater temperature is reduced, the rate of thermal water energy usage

Table 8 The results of energy balance calculation of solved pool [Authors]

Theoretically usable energy provided by the geothermal well	Usefully used energy of thermal water	Thermal water energy rate of usage
E_{theo} (kWh)	E_u (kWh)	η (%)
61.2	26.5	43.2

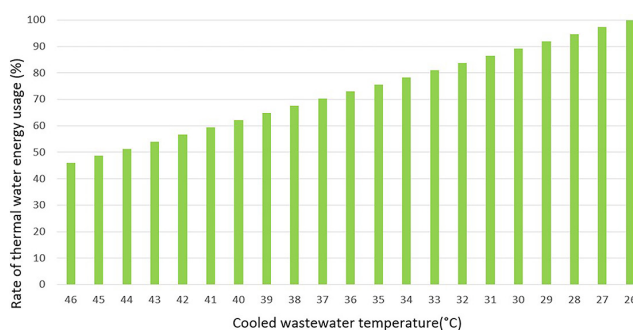


Fig. 9 Dependence of increasing the rate of thermal water energy utilization on reducing the temperature of wastewater cooling [Authors]

increases. In the original calculation of the energy balance of the solved pool, the thermal water energy utilization was 43.2% if the wastewater was cooled to a temperature of 47.3 °C. If sufficient use of thermal water energy was ensured in the operation of the solved pool, the temperature of the wastewater would reach a temperature of approximately 30 °C, or the prescribed 26 °C when the energy of the thermal water would be used to 100% which represents an ideal state.

6 Discussion

Thermal, as well as non-thermal recreational facilities are producers of a large volume of wastewater, which is most often discharged into surface streams. The laws prescribe a maximum wastewater temperature of 26 °C. At this temperature, the environment is not damaged. It is known fact from practice that swimming pools discharge wastewater with a significantly higher temperature, which was also proved by experimental measurements. The temperature of pool wastewater can be reduced and usefully used thanks to the heat recovery system. In the principle, the heat recovery system from waste pool water is based on the installation of a heat exchanger in the waste pool water circuit. Wastewater and cold water flow through the heat exchanger. In the ideal case, the heat exchanger is countercurrent, due to the greater rate of heat transfer between the flowing fluids [9]. Waste pool water transfer its heat to cold water, which is preheated to a higher temperature and then used in the operation of individual pools, or for other utilization:

- preheating for the preparation of hot water (when using the heat recovery system for this purpose, there would be savings in terms of the design of the storage heater, when its smaller volume and power would be sufficient),
- active thermal protection of buildings systems (the main function of this system is to reduce the heat loss of non-transparent building structures in the winter and at the same time reduce or eliminate the heat gain in the summer) [10],
- cooling production.

Another option to cool the waste pool water to a low temperature is to create a multi-stage cooling system. The first stage of cooling the waste pool water would be the heat exchanger, while the second stage would be the heat pump, thanks to which it would be possible to cool the waste pool water to a temperature of approximately 15 °C [11].

7 Conclusion

According to data from experts in the field of geothermal energy, Slovakia is a country with relatively large geothermal potential. The theoretically usable energy potential of geothermal energy in Slovakia is more than 5,000 MW_t, assuming that the thermal water will be returned to the geological subsoil through injection wells. To the greatest extent, up to 60% of the total installed heat output, geothermal energy is used in recreational facilities, the water used cannot be returned to the geological subsoil, because it came into contact with the surrounding air, but especially with human skin. Therefore, this water is considered waste and is discharged into the sewer or, more often, surface streams. These are polluted and degraded due to the influence of high-temperature wastewater.

Recreational facilities discharge wastewater with temperatures too high to be discharged into the surface

stream without polluting the environment. The maximum wastewater temperature is in Slovakia prescribed by Act No. 364/2004 Coll. on water [5] and Regulation of the Government of the Slovak Republic No. 269/2010 [4]. During experimental measurements that were carried out in the solved thermal bath, it was founded that the temperature of wastewater reaches up to 50 °C which is environmentally unacceptable. The operator of a thermal bath must spend a lot of money to pay penalties for environmental pollution.

Thanks to the heat recovery system that was briefly described, it would be possible to ensure a decrease in the temperature of the waste pool water, which is related to an increase in the rate of use of thermal water energy. As a result, the lifetime of the geothermal source will be extended.

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