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Energy Assessment of Thermal Water Utilization in Swimming Pools

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Abstract

In Slovakia, thermal water is used to the greatest extent in recreational facilities, which includes thermal swimming pools, medical sanatoriums or balneological facilities. Generally recreational facilities are the largest producers of waste pool water, which is discharged through a cooling pond or cooling canal most often into rivers. Wastewater temperature discharged from the recreational facility can be a maximum of 26 °C according to requirements of laws and regulations. The rate of energy use is closely related to the temperature thermal and wastewater which enter the swimming pool. The article is aimed at analysis of the energy balance and management of thermal water in the proposed swimming pool. Conclusion will be focused on increasing the rate of use of thermal water, where the pros and cons will be summarized.

Keywords: geothermal energy, thermal water, thermal baths, energy evaluation

1 Introduction

In Slovakia, a survey is made every year before the summer season. This survey before the 2023 summer season showed that 80 natural water areas and 258 artificial swimming pools with a total number of 658 pools were registered in Slovakia – 197 of them is filled by heated cold water and 461 pools by thermal water. Currently in Slovakia, we have 47 thermal baths, which are the biggest consumers of thermal water [1, 3, 6].

In general, recreational facilities often struggle with the problem of discharging waste pool water with too high temperatures, even if the owners do not like to talk about this problem very much. Waste pool water is in most cases discharged into the rivers. Recreational facility owners are obliged to ensure the required quality conditions for safe discharge of waste pool water into the river [2, 6]. One of the most important conditions is the waste pool water temperature, which is set by laws to a maximum value of 26 °C. This temperature is set by the Law No. 364/2004 on water and amending the Law by Slovak National Council No. 372/1990 Coll. on offenses as amended (water law) and the Regulation of the Government of the Slovak Republic No.

269/2010 from May 2010, which establish requirements for achieving good water status [4, 5]. In many cases, this requirement is not met, resulting in penalties for environmental pollution.

The temperature of the waste pool water is also related to the energy utilization rate of the thermal water which is used in the recreational facility. Many thermal baths have pools in which they do not use thermal water directly, but thanks to its high temperature, they heat cold water, which is then drained into the pools (mainly pools for swimming). From cooperation with thermal baths in Slovakia, we know that there is often a phenomenon where only 40 % of thermal water energy potential is used in the operation. From experimental measurements that took place in a thermal bath in southern Slovakia, we know that the temperature of waste thermal water flowing from the engine room of the pool can reach a temperature of up to 55 °C. The article will further describe the methodology of calculating the energy balance of the thermal bath and the evaluation of thermal water energy utilization. The conclusion of the article will be devoted to possibilities for increasing the rate of use of thermal water energy.

2 Energy balance calculation methodology

Pavol Jurka (2009) and Igor Štefanička (2011) partially described the methodology for energy balance calculation for thermal baths in their dissertations. Later (2023), the dissertation of the author of this article was built on the previous theoretical foundations. In order to mathematically define the energy balance of a geothermal resource, it is necessary to know:

- thermal water flow m_0 (l/s),
- thermal water temperature θ_0 (°C),
- total pool water flow M_c (m^3).

The first step of energy balance calculation is the theoretically usable energy of geothermal source, which can be calculated by equation:

$$E_{theo} = \frac{M_c \,.\, c_v \,.\, (\theta_0 - \theta_r)}{3600} \tag{1}$$

where: E_{theo} – is theoretically usable energy of geothermal source (MWh),
c_v – specific heat capacity of water (kJ/(kg.K)),
θ_0 – thermal water temperature (°C),
θ_r – required waste pool water temperature (°C).

The calculation of theoretically usable energy is mainly based on temperature differences, while the temperature of the thermal water and the required temperature of the waste pool water, which is determined by laws, enter the calculation. The next step is to determine usefully used energy, which can be calculated by equation:

$$E_u = \frac{M_c \,.\, c_v \,.\, (\theta_0 - \theta_{pw})}{3600} \tag{2}$$

where: E_u – is usefully used energy (MWh),
c_v – specific heat capacity of water (kJ/(kg.K)),
θ_0 – thermal water temperature (°C),
θ_{pw} – waste pool water temperature (°C).

Compared to the first formula, the change in the temperature difference is key in the calculation. In order to calculate usefully used energy, it is necessary to use the temperature difference between the thermal water and the waste pool water, which is higher than the required temperature of the waste pool water (26 °C) set by laws.

If the theoretically usable and usefully used energy is known, the unused energy can be calculated by simple subtraction. The correctness of the result of unused or waste energy can by also verified using the equation:

$$E_w = \frac{M_c \,.\, c_v \,.\, (\theta_{pw} - \theta_r)}{3600} \tag{3}$$

where: E_w – is unused or waste energy (MWh),
c_v – specific heat capacity of water (kJ/(kg.K)),
θ_{pw} – waste pool water temperature (°C),
θ_r – required waste pool water temperature (°C).

The rate of use of the thermal water energy can be calculated by the equation:

$$\eta = \frac{E_u}{\mathrm{E}_{theo}} \,.\, 100 \tag{4}$$

where: η – is the rate of use of the thermal water energy (%),
E_{theo} – is theoretically usable energy (MWh),
E_u – is usefully used energy (MWh).

The total volume of pool water required for filling and operating pools is included in the previous calculation. The calculation can be applied to each pool separately, but also to the entire thermal bath. To calculate the total volume of water required for filling and operation, it is necessary to know the input values:

- volume of one pool or all pools in thermal bath (m^3),
- time need for pool filling or operating (hours, days),
- pool water temperature (°C),
- cold water temperature (°C),
- thermal water temperature (°C).

The calculation must be made separately for filling and operating of the pools. In the beginning, it is necessary to calculate the volume flow of pool water required for filling and operation. To calculate the filling, it is necessary to use the value T, which characterizes the time it takes for the empty pool to be filled. To calculate the operation, it is necessary to use the value T, which characterizes the number of days a year when the pool is in operation. The volume flow of pool water required can be calculated by the equation:

$$m_{pw} = \frac{V}{(\tau \,.\, 3{,}6)} \tag{5}$$

where: m_{pw} – the total volume flow of pool water (l/s),
V – volume of pool/pools (m^3),
τ – the time needed for filling of the pool, or the number of days a year the pool is in operation (hours, days).

In many cases, thermal bath uses the principle of mixing thermal water with cold water in order to achieve the qualitative parameters (temperature) of pool water. In this case, it is necessary to calculate the volume flow of thermal and cold water needed during the filling and operation of the pool using equations:

$$m_{tw} = \frac{m_{pw\,.}\,(\theta_{pw} - \theta_{cw})\,.\,P_r}{(\theta_0 - \theta_{cw})} \tag{6}$$

$$m_{cw} = m_{pw} - m_{tw} \tag{7}$$

where: m_{pw} – is the volume flow of pool water (l/s),
m_{tw} – the volume flow of thermal water (l/s),
m_{cw} – the volume flow of cold water (l/s),
θ_{pw} – required pool water temperature (°C),
θ_{cw} – cold water temperature (°C),
θ_0 – thermal water temperature (°C),
P_r – addition for heat losses in pipe system.

To achieve the required pool water temperature, it is necessary to mix thermal and cold water in a suitable ratio. The percentage of thermal and cold water can be calculated by equation:

$$\eta_1 = \frac{m_{tw}}{\mathrm{m}_{pw}}\,.\,100 \tag{8}$$

$$\eta_2 = \frac{m_{sw}}{\mathrm{m}_{pw}}\,.\,100 \tag{9}$$

where: m_{tw} – the volume flow of thermal water (l/s),
m_{cw} – the volume flow of cold water (l/s),
m_{pw} – the volume flow of pool water (l/s).

In addition to the flow rates, it is also necessary to calculate the volume of pool, cold and thermal water. The volume of pool water required to fill the pool depends on its volume and the number of days in operation. It can be summer season, winter season, or all-year operation. The number of fillings of the pool during its operating time and the required total volume of pool water will influence the volume of thermal and cold water which can be calculated by equations:

$$M_{tw} = \frac{\eta_1}{100}\,.\,M_{pw} \tag{10}$$

$$M_{cw} = \frac{\eta_2}{100}\,.\,M_{pw} \tag{11}$$

where: η_1 – is the percentage of thermal water (%),
η_2 – is the percentage of cold water (%),
M_{pw} – total volume of pool water needed during the filling or operation (m^3).

The total volume of pool water needed during the filling or operation of the pool can be calculated by equation:

$$M_{pw} = \mathrm{V}\,.\,\mathrm{n} \tag{11}$$

where: V – is the volume of the pool/pools (m^3),
n – is the number of the pool filling, or the operation days during the year (days, x/operation).

In the Table 1 can be seen the summarization of all values which must be calculated according to mentioned equation. As mentioned, all equations must be calculated twice – first calculation for the filling of the pool and second calculation for the operation of the pool.

Table 1: Summarization of calculated values necessary for energy balance calculation [author]

Value	Filling	Operation
Volume flow of the pool water	$m_{pw,F}$	$m_{pw,Op}$
Volume flow of the thermal water	$m_{tw,F}$	$m_{tw,Op}$
Volume flow of the cold water	$m_{cw,F}$	$m_{cw,OP}$
The percentage of thermal water	$\eta_{1,F}$	$\eta_{1,OP}$
The percentage of cold water	$\eta_{1,F}$	$\eta_{1,OP}$
The volume of pool water	$M_{pw,F}$	$M_{pw,OP}$
The volume of thermal water	$M_{tw,F}$	$M_{tw,OP}$
The volume of cold water	$M_{cw,F}$	$M_{cw,OP}$

As was mentioned, it is necessary to make separated calculation for the filling and operation of the pool. All values can be marked with exponent “F – filling”, or “Op – operation”, which can be seen in the Table 1. If the separate values for filling and operation of the pool are known, it is possible to calculate the total volume of pool, thermal and cold water needed during the calculated period. This can be calculated by equations:

$$M_{tw,total} = M_{tw,F} + M_{tw,Op} \tag{12}$$

$$M_{cw,total} = M_{cw,F} + M_{cw,Op} \tag{13}$$

$$M_{pw,total} = M_{pw,F} + M_{pw,Op} \tag{14}$$

Where: $M_{tw,total}$ – the total volume of thermal water needed during the calculated time period,
$M_{cw,total}$ – the total volume of cold water needed during the calculated time period (m^3),
$M_{pw,total}$ – the total volume of pool water needed during the calculated time period (m^3).
This calculation method is applicable to the energy balance calculation for each pool separately, or for all pools in the thermal bath. In the next chapter will be the analysis of the energy balance for thermal bath described.

3 Energy balance of thermal bath analysis

From a geological point of view, the thermal bath is in the area called “Central depression of the Danube basin – Centrálna depresia podunajskej panvy”, which has a largest geothermal energy potential in Slovakia. In this area are 48 geothermal wells located. Two of them, named GTV1 and GTV2, are used by thermal bath. The geothermal well GTV1 provides thermal water with flow 7,0 l/s with temperature of 78 °C. The second geothermal well GTV2 provides thermal water with flow 11,62 l/s with temperature of 56,5 °C.

Table 2: Summarization geothermal sources characteristics [author]

Geothermal well	Thermal water flow (l/s)	Thermal water temperature (°C)
GTV1	7,00	78,00
GTV2	11,56	56,50

By applying the input values to the equations described in the second chapter, it is possible to calculate the theoretically usable energy potential provided by the both geothermal wells. The theoretically usable energy potential can be seen in the Table 3.

Table 3: Theoretically usable energy potential of the geothermal wells GTV1 and GTV2 [author]

Geothermal well	Thermal water flow (l/s)	Thermal water temperature (°C)	Theoretically usable energy potential (kW)	Theoretically usable energy potential (GWh/year)
GTV1	7,00	78,00	1497,21	13,12
GTV2	11,56	56,50	1458,26	12,77

By applying the calorimetric equation, it is possible to calculate the theoretically usable energy potential. In the calculation the density of thermal water was considered to be 997 kg/m^3 due to the change in water density when its temperature increases. The specific heat capacity of water used in the calculation was 4,127 kJ/(kg.K).
In cooperation with the thermal bath, the data about the thermal water flow pumped from geothermal wells were provided and in the energy balance calculation used. Thermal, cold and waste water balance in the year 2019 can be seen in the Table 4 and Figure 1.

Table 4: Thermal, cold and waste water balance in the year 2019 [author]

2019	Thermal water				Cold water		Waste water	
	GTV1		GTV2		CW		WW	
	(m^3)	(l/s)	(m^3)	(l/s)	(m^3)	(l/s)	(m^3)	(l/s)
January	14 711	5,49	27 410	10,23	8 054	3,01	50 175	18,73
February	13 661	5,56	23 920	9,89	7 987	3,03	45 568	17,01
March	12 676	4,73	25 880	9,66	9 902	3,07	48 458	18,69
April	11 412	4,40	25 440	9,81	13 707	5,29	50 559	19,51
May	11 624	4,34	26 350	9,84	16 642	6,21	54 616	20,39
June	8 508	3,28	24 760	9,55	26 102	10,07	59 370	22,17
July	8 853	3,31	26 620	9,94	29 531	11,03	65 004	24,26
August	6 927	2,59	26 050	9,73	25 847	9,65	58 824	21,96
September	8 852	3,42	25 210	9,73	21 223	8,19	55 285	21,33
October	12 383	4,62	25 410	9,49	18 077	6,75	55 870	20,86
November	13 512	5,21	24 860	9,59	11 558	4,46	49 930	19,26
December	15 624	5,83	26 430	9,87	9 943	3,71	51 997	19,41

It is clear from the graph in the Figure 1 that the volume and water flow of waste pool water during each month is really large. By laws, the temperature of waste pool water should be a maximum of 26 °C. For the experimental measurements that were carried out in the thermal bath, is known that the real temperature of waste pool water reaches a value up to 50 °C. Wastewater with such a high temperature has relatively large energy potential without any utilization. By applying the formulas in the second chapter, it is possible to calculate the energy potential of the waste pool water if the maximum temperature of 26 °C was observed. The actual usable energy potential will also be calculated using the real temperature of the wastewater of 50 °C. An important value is also the real temperature of the thermal water, which is used in the operation of the thermal bath. This value was also measured during the experimental measurements, during which the temperature of the thermal water from both geothermal wells (GTV1, GTV2) was measured. Considering that the thermal water is mixed during the operation, average thermal water temperature of 67,5 °C will be used in the calculation of energy balance.

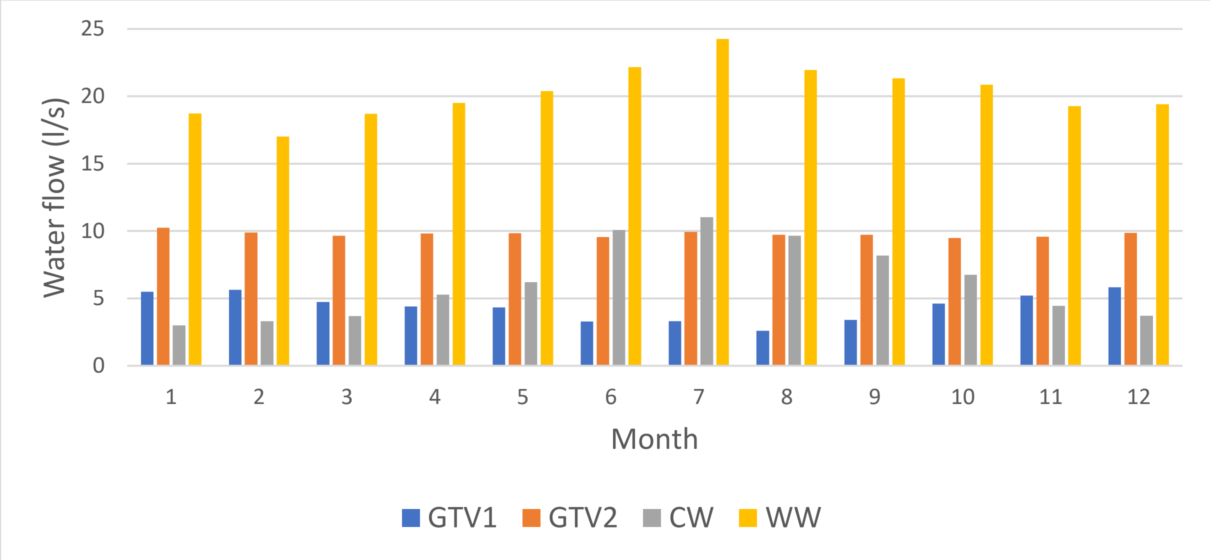

Figure 1: Thermal, cold and waste water balance in the year 2019 [author]

If we consider the actual flow of thermal water that is pumped from geothermal wells during the months, it is possible to calculate the theoretically usable energy potential of thermal water. The calculation will include the average temperature of thermal water found during the experimental measurements of 67,5 °C and the maximum waste pool water established by law 26 °C. The difference between the average thermal water temperature and the real waste pool water temperature of 50 °C will be included in the usefully used energy potential calculation. These results can be seen in Table 5 and Table 6.

Table 5: Theoretically usable energy potential of thermal water if the waste pool water temperature will be 26 °C [author]

2019	Thermal water			Average TW temperature	Maximum waste water temperature	Theoretically usable energy potential
	GTV1	GTV2	SUMM			
	(l/s)	(l/s)	(l/s)	(°C)	(°C)	(GWh/month)
January	5,49	10,23	15,72	67,5	26,0	2,010
February	5,56	9,89	15,45			1,794
March	4,73	9,66	14,39			1,840
April	4,40	9,81	14,21			1,759
May	4,34	9,84	14,18			1,813
June	3,28	9,55	12,83			1,588
July	3,31	9,94	13,25			1,693
August	2,59	9,73	12,32			1,574
September	3,42	9,73	13,15			1,626
October	4,62	9,49	14,11			1,804
November	5,21	9,59	14,80			1,832
December	5,83	9,87	15,70			2,007

Table 6: Usefully used energy potential of thermal water if the real waste pool water temperature will be 50 °C [author]

2019	Thermal water GTV1	Thermal water GTV2	Thermal water SUMM	Average TW temperature	Real waste water temperature	Usefully used energy potential
	(l/s)	(l/s)	(l/s)	(°C)	(°C)	(GWh/month)
January	5,49	10,23	15,72	67,5	50,0	0,841
February	5,56	9,89	15,45			0,750
March	4,73	9,66	14,39			0,770
April	4,40	9,81	14,21			0,736
May	4,34	9,84	14,18			0,758
June	3,28	9,55	12,83			0,664
July	3,31	9,94	13,25			0,708
August	2,59	9,73	12,32			0,658
September	3,42	9,73	13,15			0,680
October	4,62	9,49	14,11			0,754
November	5,21	9,59	14,80			0,766
December	5,83	9,87	15,70			0,839

It can be seen in the Table 7 and Figure 2 that the real rate of thermal water energy usage reaches less than 42 %. The remaining thermal water energy potential is discharged as the wastewater into the cooling channel without any use. If the waste water were cooled to the maximum prescribed temperature of 26 °C the thermal water rate of usage would rise to almost 90 % which would be an ideal state.

Table 7: Rate of the thermal water energy potential usage [author]

2019	Theoretically usable energy potential	Usefully used energy potential	Rate of the thermal water energy potential usage
	(GWh/month)	(GWh/month)	(%)
January	2,010	0,841	**41,8**
February	1,794	0,750	
March	1,840	0,770	
April	1,759	0,736	
May	1,813	0,758	
June	1,588	0,664	
July	1,693	0,708	
August	1,574	0,658	
September	1,626	0,680	
October	1,804	0,754	
November	1,832	0,766	
December	2,007	0,839	

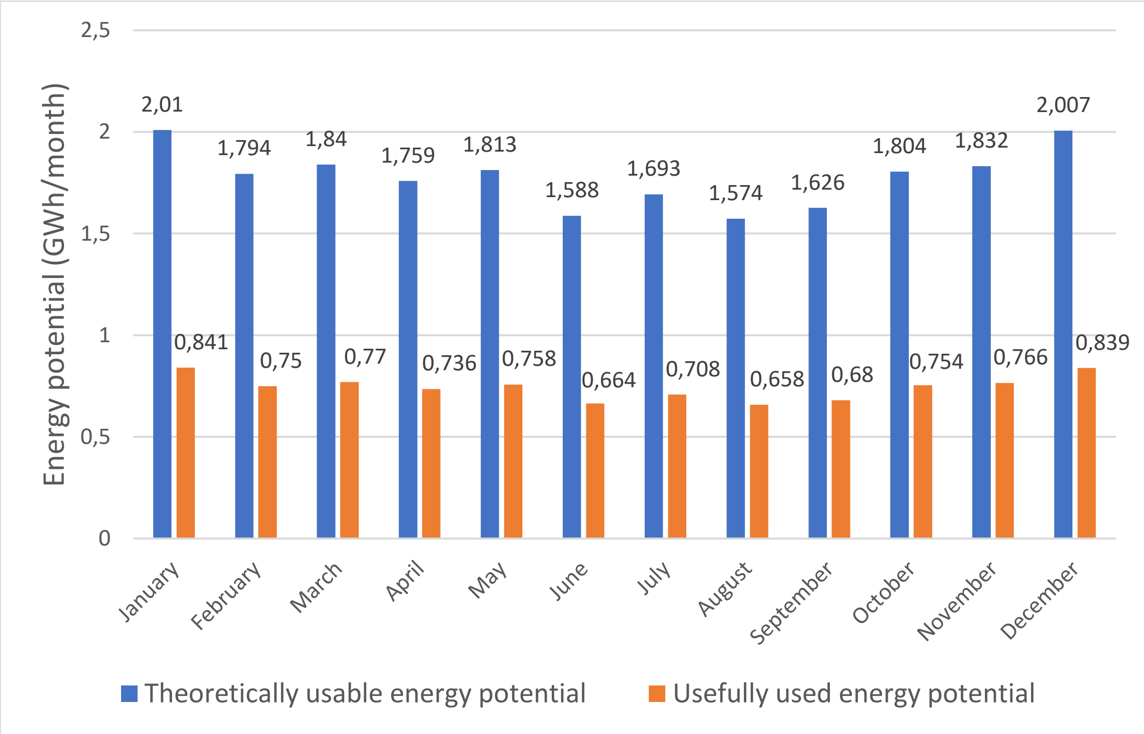

Figure 2: Comparison of the theoretically usable energy potential and usefully used energy potential of the thermal water [author]

4 Results and discussion

Through the mathematical model of the analysis of the use of thermal water energy in the swimming pool, it is possible to calculate the extent to which this energy is used. The analysis was performed with respect to the legally required maximum temperature of waste pool water, which is set by the laws at 26 °C, and with respect to the real temperature of waste pool water of 50 °C, which was found during experimental measurements. The results showed that the thermal water energy utilization rate in the solved case is only approximately 42 %. Other thermal swimming pools in Slovakia shows a similar rate of the thermal water energy use. If sufficient cooling of the waste pool water to the required temperature of 26 °C was ensured, the thermal water utilization rate would rise to approximately 88 %. With the increase in the rate of thermal water energy use, comes a decrease in the temperature of the waste pool water which is in accordance with the laws.

One of the most advanced countries in the field of geothermal energy utilization is Iceland, were, in addition to the high rate of geothermal energy use on the environment) [7]. According to studies by local experts such as Ragnarsson or Bjornsson, waste pool water from recreational facilities is used to melt snow on sidewalks and driveways. The energy utilization of thermal water drawn from many geothermal sources around Reykjavík is close to 90 %. These applications are used in the capital of Iceland, Reykjavík. This progressive country is an example that reusing the energy of waste pool water is possible, but it is technically and financially demanding [8, 9, 10].

5 Conclusion

The aim of the article was to acquaint the reader with the situation of thermal baths in Slovakia, to present the current and, above all, the real rate of thermal water energy use and to highlight applications that make it possible to comply with the requirements set by law for waste pool water. The mathematical model that was described in the article provides the possibility of calculating the energy balance of one pool or the entire swimming pool. It can be applied to any swimming pool. We know not only from calculations, but also from practice, that the rate of thermal water energy utilization in thermal swimming pools in Slovakia is very low. The excessively high temperature of the waste pool water is also connected with the rate of thermal water energy use. In order to achieve the legally required temperature of waste pool water, it is possible to apply many measures, either technologically and economically demanding, or simpler. By simply applying a heat exchanger to the waste pool water circuit, it is possible to ensure preheating for the domestic hot water preparation that is used in the showers of the thermal bath. Ensuring the melting of snow in the area of the thermal bath is a technologically and economically relatively demanding measure. In this case, Iceland is an exemplary country, where this measure is applied to a large extent not only in swimming pools, but in entire cities.

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