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Design of a Geothermal Spa using fluids from well MW-07 in the Menengai Geothermal field, Kenya

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ABSTRACT

Design of a geothermal spa must include vital considerations which include, but are not limited to cleanliness and sanitation standards, accessibility, the surrounding environment and its target clientele. In Kenya, emphasis for utilization of geothermal resources is inclined towards electric power generation, although in recent years, Direct Use is becoming popular, and one of the areas being pursued is construction of geothermal spas. The Menengai geothermal field is currently under development and geothermal fluids are now abundant from geothermal wells, among them, well MW-07. In this paper, a 1,000m^2 geothermal spa alongside a 100m^2 children's pool is designed to utilize the fluids from MW 07 after generation of 546kW electric power using the binary power generation method. This research paper being presented is part of a report prepared as part of a six-month training at the United Nations University – Geothermal Training Programme (UNU-GTP) in Iceland.

1. INTRODUCTION

Geothermal energy is defined as heat from the earth. It has been exploited since the ancient times mostly in primitive applications, but most recent developments concentrate on a more formal structured Direct Use alongside power generation. Application for Geothermal energy is mostly governed by resource temperatures and location, and often by composition of the fluids obtained. Gehringer and Loksha (2012) classified the resource based on temperature as shown in Table 1 below.

TABLE 1: Classification of geothermal resources (Gehringer and Loksha, 2012)

Type of Resource	Temperature (°C)	Use / Technology
Low enthalpy	<150	Power generation with binary power plant technology, and direct uses
Medium enthalpy	150-200	Power generation with binary power plants like the Organic Rankine Cycle (ORC) and the Kalina cycle
High enthalpy	>200	Power generation with conventional steam, flash, double flash or dry steam technology

Conventionally, only about 20% of energy from geothermal resources is used for power generation, leaving the remainder and all low enthalpy producing resources available for alternative applications.

Geothermal spas provide a comforting, yet stimulating atmosphere for the bathers, making it a fast growing industry in the recent past due to the growing need for leisure and relaxation in today's population. Menengai, one among the many geothermal prospects in Kenya is located in Nakuru, the fourth largest urban center in Kenya, in a county whose population is more than two million. The county boasts of many touristic attractions, has good weather all year round, is easily accessible from Nairobi, Kenya's capital, making it a good host for a geothermal spa since it has a great impetus for socio-economic growth.

2. GEOTHERMAL ENERGY IN KENYA

Kenya enjoys abundance of geothermal resources of more than 7,000MW$_e$ (Simiyu, 2010) situated in different geothermal fields all located along the East African Rift Valley System (EARS). The most developed geothermal field is Olkaria, closely followed by Menengai which is under development by Geothermal Development Company (GDC), and Baringo-Silali where drilling began recently. In Olkaria, electricity has been generated since the 1980s, while in Menengai, a power plant is set to be commissioned in the first quarter of 2023. Figure 1 below indicates the location of geothermal resources in Kenya. Exploitation of geothermal resources in these prospects is currently inclined to electricity generation currently standing at 950 MW$_e$. Alternative applications have, however, recently received more interest with the two mainly developed geothermal fields earmarked for development of industrial parks. One of the alternative applications is geothermal spas. Direct utilization of geothermal energy in Kenya has been done by:

i. Heating of a greenhouse where rose flower is grown, at Oserian in Naivasha using fresh water heated by brine from a 1.28MW well through a heat exchange process, Carbon dioxide (CO_2) enrichment and soil fumigation. This lowers the operational cost and increases productivity of the cut flower for export (Lagat, 2010).
ii. Drying of crops in a dryer that utilizes natural steam from fumaroles at the Eburru geothermal field.
iii. Domestic water harvesting from fumaroles at Suswa and Eburru
iv. Bathing at the Lake Bogoria geothermal spa, and in the recently constructed geothermal spa in Olkaria.

Geothermal Development Company (GDC) also constructed a Direct Use demonstration unit in the Menengai geothermal prospect, showcasing the use of heat from geothermal energy to pasteurize milk, dry grains, heat greenhouses, launder and dry garments and improve growth of fish. The company is currently pursuing engagement of investors, among them those interested in construction of recreational facilities like spas.

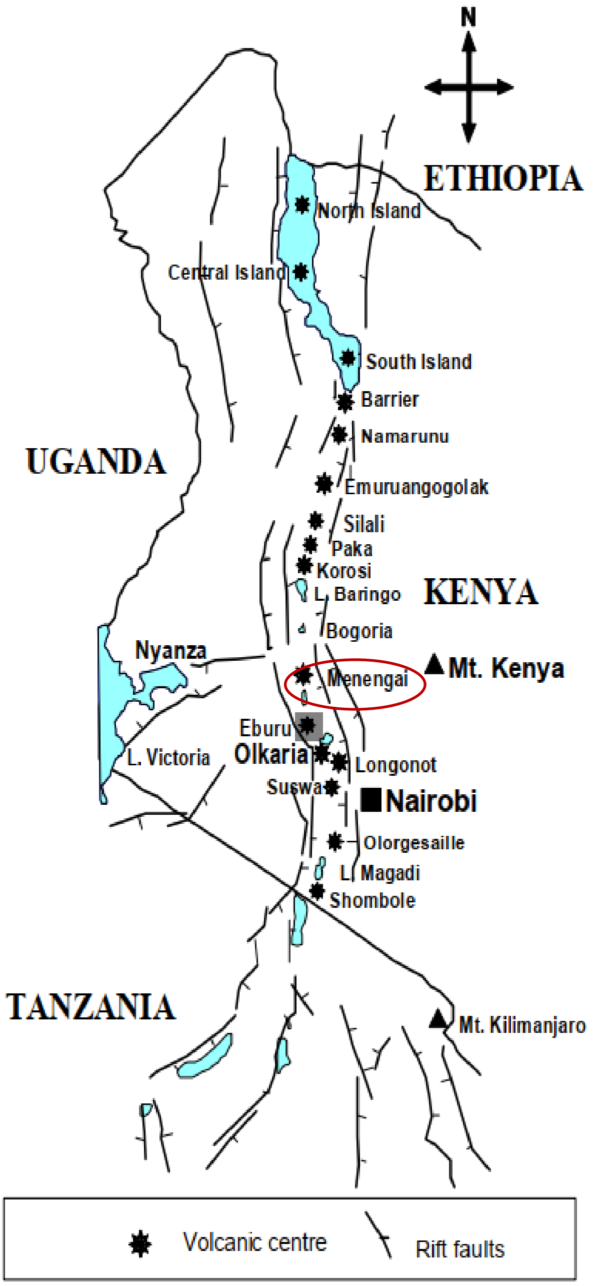

Figure 1: Kenya's Geothermal Rift (Muchemi, 2010)

2.1 The Menengai Geothermal field

The field is located in the Kenya's Nakuru County along the Rift Valley (Figure 1), approximately 30 kilometres North of Nakuru town and approximately 185 kilometres Northwest of Kenya's capital city, Nairobi. The field comprises of the Menengai Caldera, the Ol 'Rongai volcanic area and parts of the Solai Graben in the North East (Mibei et. al., 2016). It is one of the largest calderas in the world and boasts of rich histories, spectacular views of numerous flowering plants and grasses, animals and birds, and is, therefore a common place for hiking and picnics. The field has been categorized as one of the high temperature geothermal fields from scientific studies, and has an estimated geothermal potential of about 1,600 MWe (GDC, 2017). GDC began exploratory drilling in 2011, and has drilled more than fifty deep wells with an aim of getting high-pressure geothermal steam for electricity generation. Construction of power plants has begun with the first of three 35 MW units currently under construction. Steam is currently estimated at 160 MW (GDC, 2017). Among these wells are a few whose temperature and pressure are lower than the required minimums for the conventional power plants. These wells are good candidates for direct applications of geothermal energy.

3. HEATED SWIMMING POOLS AND SPAS

3.1 Background

Geothermal energy has been used since ancient times for balneology and leisure. Swimming in geothermal waters has been confirmed to also bring a sense of relaxation and in some cases cure diseases like Rheumatoid Arthritis and Psoriasis. The heat from geothermal resources has also been used to heat fresh water for swimming pools.

A swimming pool is a structure or basin on or above the ground capable of holding water that can be used for swimming, leisure, exercise or recreational activities, and sometimes for hydrotherapy. Swimming facilities can be heated or unheated. A geothermal spa, on the other hand utilizes natural fluids from the earth. The design of a heated swimming pool differs from that of a geothermal spa in that swimming pools commonly utilize fresh water, which is treated, mostly by adding Chlorine or Bromine, while the spas require minimal treatment of the bathing fluid as long as the fluid is chemically safe and can be replaced fast enough using non-contaminated brine.

Therapeutic effects from thermal mineral water baths and spa therapy have been known worldwide for centuries. Balneological therapy emerged important in the 1800s first in Europe then in the United States of America (Huang, et. al., 2018), causing spas to quickly gain popularity due to their unique elements, which differentiate them from ordinary swimming pools. The word spa has an origin from a Latin abbreviation expanded as "Salud Per Aqua" meaning "health through water" (Lund, 1999). In modern times, the term spa has been used to identify pools or bathing facilities that are primarily used for health and relaxation. Spas are naturally supplied with warm ground water or brine without addition of any chemicals, maintained at comfortable bathing temperature. The natural waters mostly contain minerals that are beneficial for health reasons (GeothermEx, 2000). Some of these benefits are believed to be detoxification, improved blood circulation and a general feeling of wellbeing and relaxation.

Examples of geothermal springs and spas include the Blue Lagoon and the Mývatn Nature Baths in Iceland, the Dead Sea in Israel, famous for its balneological therapy and the La Roche Posay Thermal Centre in France also used to help in dermatologic thermal treatment (Huang, et. al., 2018). In order for a spa to be a successful venture, good hygiene, good service to the customer, and unique attractions and scenery must be maintained (Lund, 1999).

3.2 Swimming pools and geothermal spas in Kenya

Kenyans are generally not culturalized into swimming, and mostly only a small part of the population do it for leisure only. As a result, most swimming pools belong to the hotel industry and are usually not heated. Heating swimming pools and constructing spas in Kenya would, therefore, bring value addition and attract more customers. There are currently two geothermal spas in Kenya; the Lake Bogoria Geothermal Spa (Figure 2) operated by a hotel, utilizing warm water from a natural spring near the hotel, and the recently constructed geothermal spa (Figure 3) in the Olkaria geothermal field operated by the Kenya Electricity Generating Company (KenGen), which utilizes brine tapped from the main re-injection line to wells OW-R2 and OW-708 (Mangi, 2014). In other geothermal fields, for instance in Kapedo in the Silali geothermal field, the local population also use the warm springs to bathe and launder their clothes, although on a small scale.

Figure 2: The Lake Bogoria Geothermal Spa

Figure 3: The Olkaria Geothermal Spa

Constructing a spa in the Menengai geothermal field would go a long way in supplementing tourism in the Nakuru County, which is also home to many lakes as well as boost utilization of geothermal resources. Menengai is also host to a large part of the population which tours to enjoy the serene environment, watch birds and the crater and also do hiking. Since power plants are under construction, part of the separated and "waste" fluids would be useful in the spa.

3.3 Menengai well 07 (MW 07)

This was the seventh well in the Menengai geothermal field, 2118 meters deep and was completed in June 2012. The well site is characterized by a spectacular view with a beautiful indigenous forest, and is served by an all-weather road. Its location has an elevation of 1942m above sea level on 1704887.000 Eastings and 9977450.999 Northings. The well produces a liquid dominated mixture of geothermal steam and water. Table 2 below outlines some of the physical and chemical characteristics of Menengai well 07.

3.3.1 Chemistry

Waters for use in balneotherapy are different in hydro geologic origin, temperature and chemical composition. While there may be no standard protocols for treatment obtained from bathing in thermal waters, different chemicals could have different effects on the human skin and body. There are different classifications of thermal spring water, depending on their chemical compositions (bicarbonate, sulphate, sulphide, chloride and trace metal mineralization or by temperature; cold (<20°C), hypothermal (20-30°C), thermal (30-40°C) or hyperthermal (>40°C) (Huang A., et al., 2018).

Thermal water having curative properties is termed as mineral water (Shakhin-Uz-Zaman, 2013), while the chemical composition of the water determines its curative and therapeutic effects. Mineral waters have also been classified based on the total minerals, ion and gas composition, temperature, its active therapeutic components, acidity and alkalinity. Thermal water is considered curative if it possesses the properties outlined in Table 3 according to the International Association of Spas, Health Resort and Balneology, the International Society of Medical Hydrology, the International de Technique Hydrothermale (SITH) and the German Health Resorts Association (Shakhin-Uz-Zaman, 2013).

According to the properties of Menengai well MW-07 outlined in Table 2, a preliminary check on the chemical characteristics indicate that the geothermal fluid from the well is suitable for bathing and consist minerals beneficial to the human body and skin especially when maintained at temperatures above 27°C. However, a detailed chemical test of the brine will need to be done to confirm the safety and suitability of the fluid before bathing.

TABLE 2: Physical and Chemical Characteristics of Menengai Well 07 (Taking density of brine as 1,000 kg/m^3)

Parameter	**Unit**	**Value**
Downhole Temperature	°C	117.46
Wellhead Temperature	°C	100
Well head Pressure	bar-g	2.84
Discharge Enthalpy	kJ/Kg	557
pH	-	9.2
CO_2	mg/l	8,088
H_2S	mg/l	0.39
Boron	mg/l	0.95
SiO_2	mg/l	324.15
Na	mg/l	1,176.75
K	mg/l	115.37
Ca	mg/l	0.06
F	mg/l	108.15
Cl	mg/l	681.18
Sulphates (SO_4)	mg/l	469.46
Ammonia (NH_4)	mg/l	14.51
TDS	mg/l	7351.88
N_2	mmole/kg	59.74
O_2	mmole/kg	3.67
Conductivity	μΩ/cm	15290
Total Mass Flow Rate (t/hr)	t/hr	110.00
Water Flow Rate (t/hr)	t/hr	100.18

TABLE 3: Curative Properties in thermal fluids (Shakhin-Uz-Zaman, 2013).

Element	Value	Units
TDS	>1,500	mg/l
Fe	20	mg/l
I	1	mg/l
H_2S	1	mg/l
F	1	mg/l
Temperature	>27	°C

4. DESIGN OF THE GEOTHERMAL SPA

The design of this spa will be adopted and modified from lessons learnt from two geothermal spas in Iceland (The Blue Lagoon and the Mývatn Nature baths).

The Mývatn Nature Baths located in North Iceland east of the Grjotagja rift, west of the Namafjall mountain are served with brine from Landsvirkjun's (National Power Company of Iceland) in Bjarnaflag at 130°C. The hot brine flashes into a big pot, which serves as a cooling system and helps in getting rid of any present harmful geothermal gases. Cooling is achieved through loss of heat by latent heat of vaporization in the pot and convection through heating of fresh water for use in the showers through a heat exchange process. Brine at around 90°C is then mixed with a percentage of cold brine from the spa and the mixture then flows by gravity into the lagoon in five feeding points. Temperature in the lagoon is controlled using temperature sensors located in the feeding points to ensure that the temperature is maintained at 36-40°C. the baths occupy an area of 5,000m^2 and receive more than 400,000 guests every year.

The Blue Lagoon located in the Southwestern Iceland in the Reykjanes Peninsula in the high temperature Svartsengi geothermal field has an average depth of one meter. It occupies an area of 8,700 m^2 and receives more than 1,000,000 guests every year. The lagoon gets its hot brine at around 160°C from the nearby Svartsengi geothermal power plant and is located in the midst of craggy black lava, giving the spa a stunning scenery. The hot geothermal brine is fed into the lagoon at high pressure in mixing boxes, which are equipped with temperature control sensors, and allow mixing with cold brine already in the lagoon. The lagoon receives a daily average of 3,000-4,000 guests with an average dwelling time of two hours. For safety reasons, bi-weekly samples of the brine in the lagoon are taken and subjected to tests to ensure a healthy bathing environment for the guests with a reference to the Blue Flag Standards.

A comparison of the chemical constituents of the brine at the Blue Lagoon and Mývatn in relation to Menengai well 07 is shown below (Table 4).

4.1 Scope of works

The spa will comprise of a large adult lagoon and a small children's pool alongside other accompanying facilities. The sidewalls will contain benches (sitting allowances) in about 30% of its area. A binary power plant will be installed and will generate electricity as well as cool the hot brine before use in the spa. The surroundings of the entire spa area will be made of lava rocks from the Menengai Geothermal field. Brine will enter the spa in five locations which will comprise of a mixing chamber with thermostats for temperature control. A tank with a large surface area will be required for cooling the brine in case the power plant is not operational, is being maintained or any additional cooling is required.

A spa building will be constructed and will have the shower areas and toilets for both genders. There will also be a reception area which will require at least one extra rest room for each gender. A beverage service area on one side of the spa where guests can be served with a drink while inside the spa will also be factored in. There shall be a room where medical equipment will be available and a medical staff positioned in it, to attend to guests with medical needs. Provision shall be made for a parking lot that will have outdoor lighting.

A pipeline will be put in place to transport the brine from its source (Menengai well 07) to the binary power plant, to the heat exchanger, to the spa and to the reinjection well after use. There will also be a pipeline for the fresh water. A heat exchanger which will use hot brine to heat the cold fresh water for the showers will be purchased and installed. The heated water will be stored in an

TABLE 4: Comparison of physical and chemical constituents of the Blue Lagoon, Mývatn Nature baths and Menengai well 07 in mg/kg

Parameter	Menengai well 07	The Blue Lagoon (Sigurgeirsson and Ólafsson, 2003)	The Mývatn Nature Baths (Ármannsson et.al., 1998)
pH	9.2	-	7.04
CO_2	-	16.5	30.1
H_2S	-	0.00	0.14
SiO_2	324.15	-	280.8
Na	1,176.75	9,280	142
Mg	-	1.41	0.29
Ca	0.06	1,450	2.02
K	115.37	1,560	20.1
SO_4	469.46	38.6	-
Cl	681.18	18,500	-
F	108.15	0.14	-

insulated tank to ensure continuous availability and a balanced pressure during use. A sewerage system shall also be provided for and will comprise of a concrete septic tank and a drain field capable of handling all the waste water from the shower rooms and the service areas in the spa. Brine that has already been used in the spa shall flow to the reinjection well in Menengai.

4.2 Location of the proposed spa in Menengai

The spa will be located near Menengai well 07 where the brine will be sourced. However, provision will be made for a future connection for brine separated at the power plant before re-injection. The location is ideal since it is served by an all-weather road and is near a 3-phase electricity connection and a source of fresh water.

4.3 Type and size of the spa

It is necessary that the facility meets the standards for a geothermal spa. Geothermal spas should also offer benefits of health, beauty and body relaxation as a minimum threshold. In comparison with the Blue Lagoon and the Mývatn Nature baths, the brine from Menengai meets the minimum quality of a good fluid for bathing supposedly with health benefits because of its composition of silica. It is predictable that the spa will assume a blue colour typical of most geothermal spas.

4.3.1 Size of the spa

The following factors will be considered when assessing a suitable spa size:

i. Availability of brine for the spa
ii. The desired number of customers
iii. Energy balance of the fluids for the spa

The design of the spa will be based on the following assumptions:

1) Table 2 indicates the parameters of the well
2) The chemical composition of the brine is beneficial for bathing
3) Two hundred guests will bathe in the spa every day for 360 days in the year; 50 international and 150 local.
4) International guests will pay an entrance fee of USD 25, while local tourists will pay USD 5
5) Each guest will occupy an area 5m^2 and the spa can accommodate 200 guests at a time
6) Each guest will take a shower before and after bathing in the spa
7) Each guest will use the rest rooms at least once during their stay at the spa

From the assumed number of guests and the area each guest will occupy in the spa, then a 1,000 m^2 spa is designed. Provision for an extra 100 m^2 will be made to allow room for children accompanying parents and guardians to also bathe in the spa. A temperature of 37°C is required in the main lagoon and the highest temperature for the steam room 60°C. A binary cycle power plant is incorporated in the design to utilize the heat energy in the brine that would otherwise evaporate during cooling. This comes with the advantage that the produced power can be used for the facility's electricity needs. Provision shall however be made for further cooling of the brine after power generation, and this step could serve as alternative cooling in case the power plant is not running or is being maintained. Alternative cooling of the brine will be done using a big tank where brine will be flashed into enabling the fluid to lose a considerable amount of heat through latent heat of vaporization before it is mixed with colder brine in the lagoon in the mixing boxes under pressure. The boxes shall be equipped with thermostats, which will regulate the temperature in the spa, by increasing or decreasing the flow rate of the hot brine into the spa.

4.3.3 Energy balance of the fluids for the spa

Heat in a spa or a swimming pool is lost mainly through convection and evaporation while other contributors of heat loss are radiation, conduction and rain.

Figure 4 indicates the various ways that heat is lost in a spa, while assumed weather parameters for wind speed, air temperature, relative humidity and rainfall were used to calculate the heat losses for the spa, which will influence the quantity of brine required to keep the temperature of the spa 37°C. The assumed parameters are shown in Table 5.

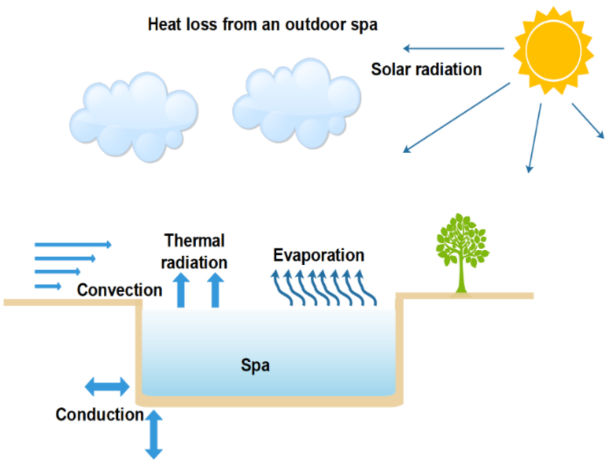

FIGURE 4: Heat loss in the spa

TABLE 5: Assumed parameters

Parameter	Units	Value
Wind speed at 2m above ground	m/s	4.8
Air temperature	°C	17
Relative humidity	%	65
Air temperature when raining	°C	10
Average rainfall in 24 hours	mm	5
Inflow brine temperature	°C	60
Spa (bathing) temperature	°C	37

Heat loss by convection, Qc

Convection is the transfer of heat within a fluid by the displacement of one portion of the fluid by another. The flow of the heat depends on the properties of the fluid and the shape of the surface. It is, however independent of the properties of the material of the surface (Rajput, 2007). Heat loss by convection is defined using the equation (1) below:

$$Q_C = h_c\,(T_w + T_a) \tag{1}$$

where Q_c = Heat loss by convection (W/m^2);

T_w = Water temperature (°C); and

T_a = Air temperature (°C).

$$h_c = K + 1.88V \tag{2}$$

$$K = 3.89 + 0.17\,(T_w - T_a)\ (W/m^2 °C) \tag{3}$$

where V = Wind speed measured 2m above the ground (m/s)

Assuming an air temperature of 17°C and a spa temperature of 37°C, then the calculated value for heat loss by convection would be 326 W/m^2.

Heat loss by evaporation, Q_E

This is calculated in W/m^2 using equation 4 below:

$$Q_E = (1.56K + 2.93V)(e_w - e_a) \tag{4}$$

where Q_E = Heat loss by evaporation (W/m^2)

e_w = Partial pressure of steam at the surface (mbar)

e_a = Partial pressure of steam in air (mbar)

Assuming that the average humidity of the air is 65%, the partial pressure for the steam at 17°C is 12.6 mbar. Saturation pressure at 37°C when humidity is 100% is 62.82 mbar. The calculated value for the heat lost by evaporation is, therefore, 1,277 W/m^2.

Heat loss by radiation, Q_R

Transfer of heat by radiation occurs when energy is transferred across a system boundary by means of an electromagnetic mechanist solely controlled by temperature difference. Radiation does not require a medium unlike heat transfer by convection and conduction. Equation 5 below was used to calculate heat loss by radiation:

$$Q_R = 4.186\left((13.18 * 10^{-9} * {T_a}^4\,(0.46 - 0.06 * {e_a}^{0.5}) - G_0 * (1 - a)\right) * (1 - 0.012 * N^2) + 13.18 * 10^{-9}\,({T_w}^4 + {T_a}^4) \tag{5}$$

where Q_R = Heat loss by radiation (W/m^2)

G_0 = Radiation of the sun in clear weather in cal/s.m^2

a = Natural reflection of water

N = Cloudiness factor ranging 0-8

For maximum energy requirements in the design, a value of zero is assumed for both radiation of the sun and the cloudiness factor. The calculated heat loss by radiation is 216 W/m^2.

Heat loss by conduction, Q_L

Heat is transferred by conduction when substances are in physical contact with each other without appreciable displacement of molecules forming the substance or when heat is transferred from one part of the substance to another. In a spa, heat loss occurs due to the physical contact between the heated fluid and the walls and other substances. For this design, heat loss through the pool walls is estimated at 0.5 W/m^2 and the heat loss from the bottom is assumed negligible. It is also assumed that the total surface area of the walls is one third of the surface area of the pool as shown in equation 6 below:

$$Q_L = 0.5 * \frac{1}{3} (T_w - T_a) \tag{6}$$

where Q_L = Heat loss by conduction (W/m^2)

Heat loss by conduction is calculated as 3 W/m^2.

Heat loss due to rain, Q_P

Water falling in form of rain needs to be heated to acquire the temperature of the pool. Heat required for this can be calculated using equation 7 below:

$$Q_P = m_p * c_p (T_p - T_w) \tag{6}$$

where Q_P = Heat loss due to rain (W/m^2)

m_p = Rate of rainfall (kg/s)

c_p = Specific heat capacity of water (kJ/kg.K)

T_p = Rain water temperature (°C); and

T_w = Water temperature (°C)

The calculated heat loss by rain is 7 W/m^2.

Thermal power required, MW_t

Thermal energy is the energy responsible in a system for its temperature, while heat is the flow of the energy. Using the sum of the calculated heat loss, the calculated thermal power is 2.01MW_t. Using Equation 7 below, the amount of brine required to maintain the spa at 37°C from 17°C, assuming the specific heat capacity for the brine as 4.191kJ/kg/K, incoming brine at 60°C mixing with pool water at 35°C is 19.21kg/s.

$$Q_{MWt} = \dot{m}c\Delta T \tag{7}$$

where Q_{MWt} = Thermal power (MW_t)

$\dot{m}$ = Mass flow rate (kg/s)

c = Specific heat capacity (kJ/kg.K)

ΔT = Change in temperature (°C)

Table 6 below is a summary of the calculated results for heat losses for the proposed 1,000 m^2 spa and 100 m^2 children's pool, and the required average brine flow rate to maintain the spa at 37°C.

TABLE 6: Heat loss and brine flow rate

Item	Units	Value
Heat loss by convection	W/m^2	326
Heat loss by evaporation	W/m^2	1,277
Heat loss by radiation	W/m^2	216
Heat loss by conduction	W/m^2	3
Heat loss by rain	W/m^2	7
Total heat loss	**W/m^2**	**1,829**
Total thermal power required	MW$_t$	2
Brine flow rate required	kg/s	19

Heat loss by evaporation is the highest, its biggest influence being the wind speed. It is recommended that an anemometer is installed on site before the onset of construction to monitor the accuracy of the wind speed. A lower wind speed would lead to lower heat losses and vice versa which also influences the required quantities of brine for the spa. The size of the spa would, therefore, be varied depending on the brine available for the spa. Figure 5 is a graphical representation of the different types of heat losses.

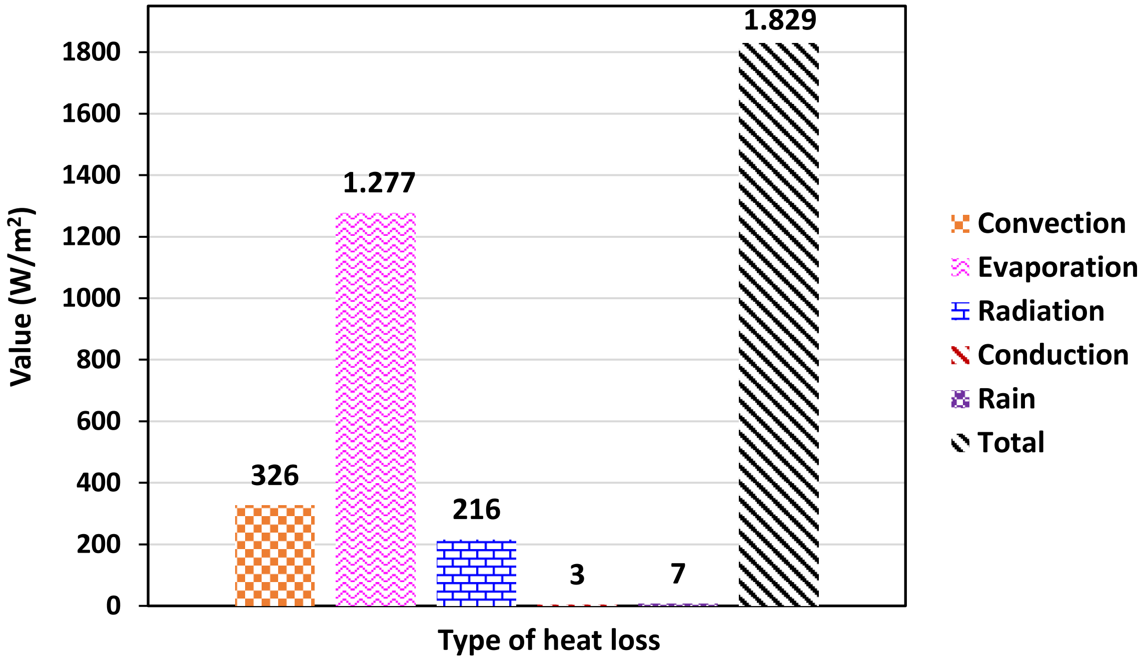

FIGURE 5: Graphical representation of heat losses

4.4 Heating water for the showers

It is required that every guest will shower before and after bathing. It is assumed that each guest will then require about 50 litres of water for bathing. For a minimum of 200 guests per day, then water for the showers will be 1,000 litres per day. This water will be heated by the geothermal brine through a heat exchange process and stored in an insulated tank. This will ensure a constant supply of hot water at relatively even pressure for the showers. There is potential for silica scaling and calcite deposition in the heat exchanger since its concentration is normally high in geothermal fluids and its temperature dependent solubility (Ontoy, et.al., 2003). As a result, during the heat exchange process, a higher flow rate of the brine will be maintained and its temperature kept high (>88°C), since it is expected that calcite scaling will not occur unless the brine is cooled below this temperature as per tests performed with brine from a nearby well in Menengai (Kipng'ok, 2011). It is also recommended that the heat exchanger will be made of stainless steel because it is corrosion-resistant.

A plate heat exchanger is designed for this project after evaluation of different types of heat exchangers. Considering a mass flow rate of the brine for heating water for bathing as approximately 3,000 litres every day. The calculated logarithmic mean temperature difference is 59.44°C and the product of overall heat transfer coefficient between brine and the fresh water, and the effective heat transfer area (UA) equal to 58.6 W/°C. Using the assumptions in Table 7 below, a pipe diameter of 0.178 m is designed with a pressure drop of 0.655 bar. To maintain the required pressure at the spa inlet and adding 5% to the calculated pressure drop to account for bends in the pipeline, the calculated size of a pump is then 139 kW.

TABLE 7: Assumptions for design of the brine pipeline

No.	Parameter	Limit	Units
1	Maximum distance between the spa and the source of the brine (Menengai well 07)	1	km
2	Brine flow rate	30	kg/s
3	Density of the brine	1000	kg/m^3
4	Kinematic viscosity (ν)	0.000000367	m^2/s
5	Dynamic viscosity (μ)	3.67*10^$^{-4}$,	kg/m s
6	Roughness factor	0.00005	m
7	Pump efficiency	70	%

4.6 Spa maintenance

It is necessary that a spa be maintained at high hygienic standards to avoid the risks and hazards associated with physical, chemical and biological factors. Outdoor pools face the additional risk of direct contamination by dust and animals like birds and rodents. Swimmers also introduce different contaminants into the water, for instance through faecal matter, skin shedding, hair and remains of cosmetics and perfumes. It is, therefore, recommended that water is continuously replaced in the pool within short periods. However, this depends on the bathing load, defined as the number of persons in a pool at a given time. Table 7 below indicates the turn over period for different types of bathing waters with a highlight on the hydrotherapy pools which would act as reference for the designed geothermal spa.

TABLE 8: Turnover periods for different types of pools (WHO, 2006)

Pool type	Water turn over period
50m long competition pools	3-4 hours
Conventional pools up to 25m long with shallow end	2.5-3 hours
Diving pools	4-8 hours
Hydrotherapy pools	0.5-1 hours
Leisure water bubble pools	5-20 minutes
Leisure waters up to 0.5m deep	10-45 minutes
Leisure waters 0.5-1m deep	0.5-1.25 hours
Leisure waters 1-1.5m deep	1-2 hours
Leisure waters over 1.5m deep	2-2.5 hours
Teaching/leaner /training pools	0.5-1.5 hours
Water slide splash pools	0.5-1 hours

The World Health Organization (WHO) provides guidelines to be followed in the running of swimming pools and similar facilities with a primary aim of protecting the public health from harm that would result from bathing. Accreditation to quality awards also acts as one way of ensuring that the spa is maintained at high international standards. For instance, the Blue Flag Standards, which the Blue Lagoon adheres to, specifies that bathing facilities must be free from plastics and must be equipped with waste management systems, must provide international amenities and clean water for its clients. It challenges local authorities and beach operators to achieve high standards in water quality, environmental management, environmental education and safety (Blue Flag, 2014). The standards implemented in Europe since 1987 and in areas outside Europe since 2001, provide detailed criteria on the required minimum standards for bathing facilities. It is required that bathing facilities position lifeguards who take care of any potential risks of drowning for the bathers.

Water and air quality in and around the spa is a necessary consideration, mostly achievable through treatment, disinfection and filtration, pool hydraulics, addition of fresh water, cleaning and adequate ventilation of indoor facilities (WHO, 2006). To ensure a healthy bathing fluid, brine is circulated at specified intervals depending on the bathing load. Cleaning is also regularly done to rid the spa floor of silica and dirt that settles at the bottom.

The chemistry of fluid in the spa must also be maintained at allowable levels to protect the bathers from chemical exposure through ingestion, inhalation of volatile and aerosolized solutes and through dermal contact and skin absorption. Table 8 below indicates the factors affecting water quality (Puetz, 2013). Selection of materials for the spa construction will also be done in consideration to challenges associated to scaling, corrosion and stain formation.

TABLE 9: Allowed range for water quality

Chemical factor	Allowed range
pH	7.2-7.8
Total alkalinity	80-120 ppm
Calcium hardness	100-400 ppm
Iron (stain producing elements)	Nil
Total dissolved solids	250-1500 ppm

Biological control in the spa must also be emphasized in order to keep at rest risks of illnesses and infections resulting from faecal contamination either from the bathers or from contaminated water or geothermal fluids (WHO, 2006). This can be maintained using the following measures:

- ❖ Enforcement that all bathers take a shower before admission into the facility
- ❖ Restricting the children in a pool that can easily be drained in case of an accidental faecal release into the water, and by
- ❖ Controlling the growth of algae

Sampling of water will be done as per the Blue Flag Standards or the World Health Organisation Standards to ascertain a clean and healthy bathing fluid. Table 9 below is an extract of the World Health Organization guidelines for microbial testing of natural spas and hot tubs.

TABLE 10: Recommended routine sampling frequencies and operational guidelines for microbial testing (WHO, 2006)

Pool type	Thermotolerant coliform / E. coli	Pseudomonas aeruginosa	Legionella spp.
Natural spas	Weekly (<1/100 ml)	Weekly (<10/100 ml)	Monthly (<1/100 ml)
Hot tubs	Weekly (<1/100 ml)	Weekly (<1/100 ml)	Monthly (<1/100 ml)

4.6.4 Waste treatment

Sewerage and wastewater

Since all guests are required to shower before and most likely after bathing in the spa, and are likely to use the rest rooms at least once, a sewerage system capable of handling at least 2,000 litres of waste water must be put in place. Waste water and sewerage will be treated separately. The location shall be in the direction of the wind from the spa and at least far away enough to keep the foul smell away from the spa. Areas around the spa and the parking shall be constructed to slant outwards to allow storm water collection for disposal downstream into a drain field. The ground in Menengai in generally highly porous and disposal of liquid waste may not be a major challenge.

Brine re-injection

Unlike in Iceland where most geothermal spas began without reinjection, due to environmental regulations and a need to seal off the ground water sources from contamination, a Kenyan spa would require that all brine be disposed into a re-injection well. A nearby re-injection well on the downstream of Menengai well 07 will then serve as a reinjection well.

CONCLUSIONS AND RECOMMENDATIONS

A conclusion can be drawn that Menengai well 07 is a viable location for a geothermal spa. Geothermal fluids from the well will not only be adequate for the designed spa, but would also be adequate for a small binary power plant. Since the well is also near the main re-injection line for the main Menengai geothermal project, more brine can be tapped to enhance and/or enlarge the venture. International standards for quality and hygiene must be emphasized in order to attract and maintain both local and international tourists. However, marketing must be done at the start and incentives factored in in order to draw populations to the spa. Partnership with other tourist attraction centres is encouraged when marketing in order to treat the venture as one tourism package. Construction of this spa will also enhance development of geothermal resources. Further tests on the chemistry of the fluids and its suitability for bathing is also recommended prior to opening the spa for bathing by the public.

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