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PRE-FEASIBILITY STUDY OF GEOTHERMAL DIRECT USE RECREATIONAL CENTRE: A CASE STUDY OF SONGWE PROSPECT IN TANZANIA

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ABSTRACT

Direct use of geothermal energy provides heating or cooling to applications that relate to low-temperature resources and are proven to have economic and environmental benefits. Since ancient times people have utilized geothermal energy for recreational purposes like bathing and swimming. This project proposes a recreational centre of 4000 m^2 in Songwe geothermal field in Tanzania. The total water surface area and volume is 420.5 m^2 and 470 m^3, respectively. Preliminary conditions are used to design the swimming pools and the water circulation system for a specified turnover period. At design conditions, the power and flow of geothermal water required for the swimming pools is 755 kW and 4.6 kg/s. The total annual energy required for the pools is 15.5 TJ, corresponding to 3.3 kg/s of geothermal water as an annual average. The recreational centre is located at a distance of 1322 m from the planned well TGH-1. The pools have a closed heating system with the use of plate heat exchanger as heat transfer equipment. The total project investment cost is estimated to be USD 492,500 excluding the exploration, drilling and transmission pipeline cost. The source of finance is through 30% equity and a 70% bank loan given a deferment duration of 3 years from the inauguration of the project. For 15 years of operation, the project gives an IRR of 42% and a NPV of $4,005,000 indicating that the project is worth undertaking.

1. INTRODUCTION

Direct use of geothermal energy is one of the oldest, most versatile and most common form of geothermal energy utilization (Dickson and Fanelli, 2003). Direct applications of geothermal energy relate to low-temperature resources below 150°C and the resource temperature limits the possible use as shown in Figure 1. The notable areas for direct use in thermal applications are greenhouses, space heating, swimming pools, bathing and balneology, aquaculture, heat pumps and industrial applications.

According to Lund and Boyd (2015), the worldwide installed capacity of geothermal direct utilization is 70,329 MWt, a 45% increase since 2010 and growing at an annual compound rate of 7.7%. The annual energy use is 587,786 TJ (163,287 GWh), indicating a 38.7% increase since 2010 and growing at an annual compound rate of 6.8%. The majority of this energy use is in ground source heat pumps, or about 49%, and swimming and bathing account for 24.9%. Iceland is the world leader in direct use of geothermal energy in terms of market penetration and population, where more than 90% of the population enjoys geothermal heat in their homes and 68% of the country's total primary energy use is derived from geothermal resources (Ragnarsson, 2015).

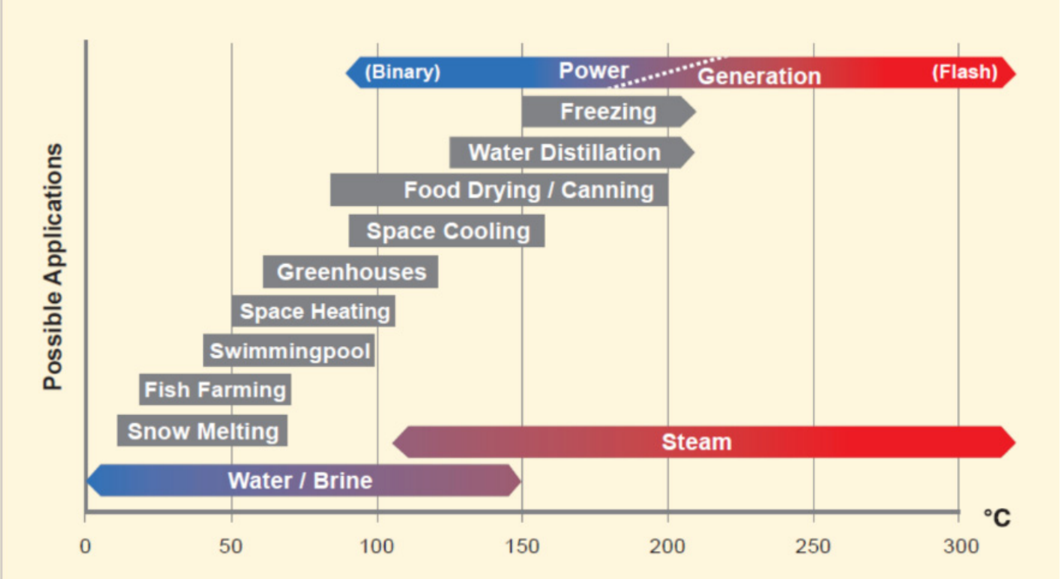

FIGURE 1: Modified Lindal diagram (Gehringer, and Loksha, 2012)

In Tanzania, there is no formal geothermal utilization but the local community uses the sinters for feeding animals, washing and skin bathing. The oldest documented use of geothermal for skin bathing was when Henry Morton Stanley visited Mtagata hot spring in Karagwe district, Northwest Tanzania, in 1876 (Mnjokava, 2014). He reports a temperature of 54°C and that the water had healing properties for sick people. There are no commercial usages of geothermal water but there are various opportunities ranging from swimming pools, agriculture, and aquaculture to industrial heating, once the resource is brought to the surface. The exploration of the geothermal resource is ongoing in parallel with evaluating the direct use in the respective project areas.

Songwe prospect is one of the fields under development. It is identified as a potential prospect for geothermal direct use due to its strategic site location, National Plan Priority, infrastructure, geographical area and because the geothermal system supports low- to medium-temperature applications. It is located in southwest Tanzania and northwest of the Ngozi prospect, and it is characterized by travertine depositions, several hot springs, bat caves, natural and manmade features that differentiate it from other sites and make it more attractive. Thus, it provides significant opportunities for direct use of geothermal energy through the construction of swimming pools, tourist hotels and other facilities suitable to attract many tourists to the area and provide the region with significant amount of foreign exchange, employment and business opportunities to the locals. The area is 23 km from Mbeya region, and both regions receive a number of tourists. According to regional tourism offices, about 30,000 registered and non-registered tourists visit the regions every year.

According to a report on economic statistics (TNBS, 2016; Energypedia, 2017), the tourism sector in Tanzania increased at a rate of 12.9% in 2016, compared to 2015, see Figure 2. The 2015 Economic Impact Report from the World Travel and Tourism Council (WTTC, 2015) indicates that international tourist arrivals increased from 622,000 to 1,140,156 in the period from 2006 to 2014, making the country the 7th most popular destination in the Sub-Saharan region after South Africa, Zimbabwe, Mozambique, Uganda, Kenya, and Namibia. The WTTC predicts that the Tanzanian tourism sector will rise by 4.9% to 7.7% of GDP in 2015-2025.

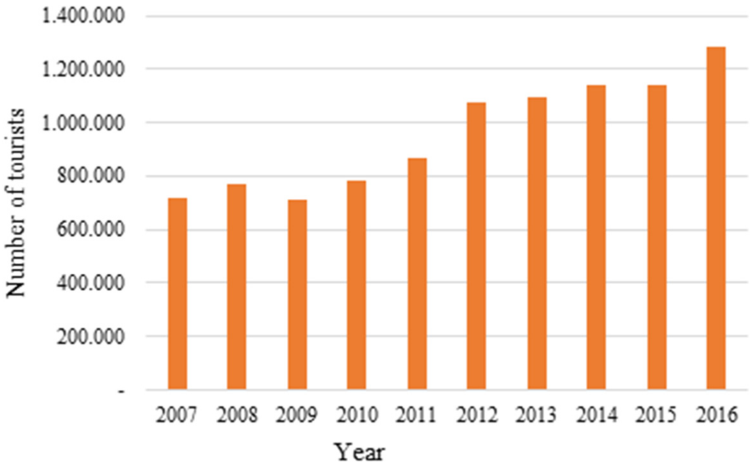

FIGURE 2: Statistics of tourists visiting Tanzania (TNBS – Tanzania National Bureau of Statistics, 2016)

1.1 Project significance

This project intends to encourage investment in energy advantageous sectors with the use of geothermal energy for economic, environmental and social benefits. The use of geothermal energy for swimming pools will promote tourism, the health industry, employment creation and business opportunities through the benefits associated with geothermal water, such as healing properties. The existence of different, attractive geothermal manifestations and travertine deposits within the field, presents Songwe geothermal prospect as an opportunity to invest in different energy beneficial projects. Presently, there is no commercial use of geothermal water for recreational uses and this represents a lost business opportunity. Therefore, implementing this project is worth considering for the local community and nation at large.

1.2 Objective of the study

The main objective of this study is to design a geothermal recreational centre at Songwe geothermal prospect that will provide an opportunity to natives and tourists to relax, refresh and enjoy the therapeutic effects of geothermal water. The specific objectives to realize the main objective are:

- To determine the location for constructing the geothermal recreational centre.
- To develop design specifications for the pools.
- To determine the energy requirement of heating the pools and the amount of geothermal water required.
- Preliminary design of the swimming pool pipe system from the geothermal well to the centre.
- To develop preliminary design layouts.
- Pipe diameter optimization for the transmission pipeline from the well to the heat exchanger.
- Market and economic analysis.

2. GEOTHERMAL POTENTIAL IN SONGWE PROSPECT

2.1 Surface geology and manifestations

The Songwe geothermal system is a fault controlled or fault hosted geothermal system located in the Rukwa rift, about 42 km west-northwest of Ngozi (Hochstein et al., 2000). The location of Songwe hot springs is hydrologically related to the location and water levels of the Songwe River, which originates from the metamorphic basement rock granulites. Most of the thermal springs are aligned along the major NW-SE trend that controls the long-term development of the Rukwa and Nyasa Rift basins.

The strong NW-SE alignment of the springs suggests that the fluid flow is likely controlled by fracture permeability along the active faults. The geothermal field has numerous hot springs associated with travertine deposition that has become massive over its 360,000 year duration, which shows the migration of spring discharge points to the northwest. The Songwe spring and the nearby springs are separate and they are fault controlled geothermal systems that discharge water at low temperatures. The geothermal field is characterized by hot springs in Songwe, Iyola, Ilatile and Madibira, as well as surface thermal features like warm springs, cold, rich gas discharge, altered ground, steam vents, fumaroles, mineral depositions such as travertine and steam heated pools as shown in Figure 3. The hot springs discharge water at different temperatures (Table 1).

FIGURE 3: Surface geothermal manifestations from the Songwe prospect

TABLE 1: Songwe hot springs discharge

Hot spring name	Temperature (°C)	pH value
Songwe	75	6.5
Iyola	70	
Ilatile	86	7
Madibira	68	7
Kaguri	68	7

TABLE 2: Chemical composition (mg / kg of fluid) in Songwe hot springs (TGDC, 2016)

Composition	Concentration
Na	811 ± 37
HCO_3	1883 ± 77
Cl	201 ± 18
SO_4	158 ± 11
K	101 ± 12
SiO_2	68 ± 40
Ca	27 ± 13
Mg	12 ± 50
F	8.2 ± 0.7
Total dissolved solids	3271 ± 115

2.2 Geochemistry findings and scaling potential

The hot springs of the Songwe area represent the discharge of a fault controlled geothermal system hosting geothermal waters at relatively low temperature. The hot spring waters have similar chemistry, suggesting that mixing with shallow groundwater is nil to negligible. The chemical composition of the fluid in Songwe hot spring is dominated by Na and HCO_3 (Table 2). The Na - HCO_3 composition is typical of all the other hot spring waters in the area between Lake Rukwa and Lake Nyasa, as well as of the geothermal systems in the continental rift zone of East Africa. Their total natural discharge is between 50 and 75 kg/s ($T = 55\text{-}80^{\circ}C$, pH = 6.5). The silica and K-Mg geothermometers indicate that the temperature of the waters in the geothermal system is between 96 and 128°C, with an uncertainty of approximately 10°C.

The average equilibrium Pco_2 of the Songwe liquid is 0.47 ± 0.12 bar as indicated by the K-Ca Pco_2 indicator. These Pco_2 values are about 20 times higher than the full equilibrium of Pco_2 which is constrained at 0.025 ± 0.010 bar by the coexistence of K-mica, K-feldspar, Calcite and Ca-Al-Silicate, either laumontite, epidote or wairakite depending on temperature (Giggenbach, 1984). These high values of Pco_2 and the chemical composition of the Songwe hot spring waters indicate a very likely occurrence of calcite precipitation upon CO_2 loss. Mitigation of calcite scaling is important during any type of commercial exploitation of the Songwe geothermal system.

2.3 Exploratory drilling

At Songwe, MT, TEM, gravity and magnetic surveys are consistent with low-density sediments filling a half graben thinning to its southwest margin. It has been proposed to drill five or six temperature gradient wells to measure formations, structures and the temperature gradient near the Songwe hot springs. Figure 4 shows the locations of the proposed temperature gradient wells in areas A, B and C.

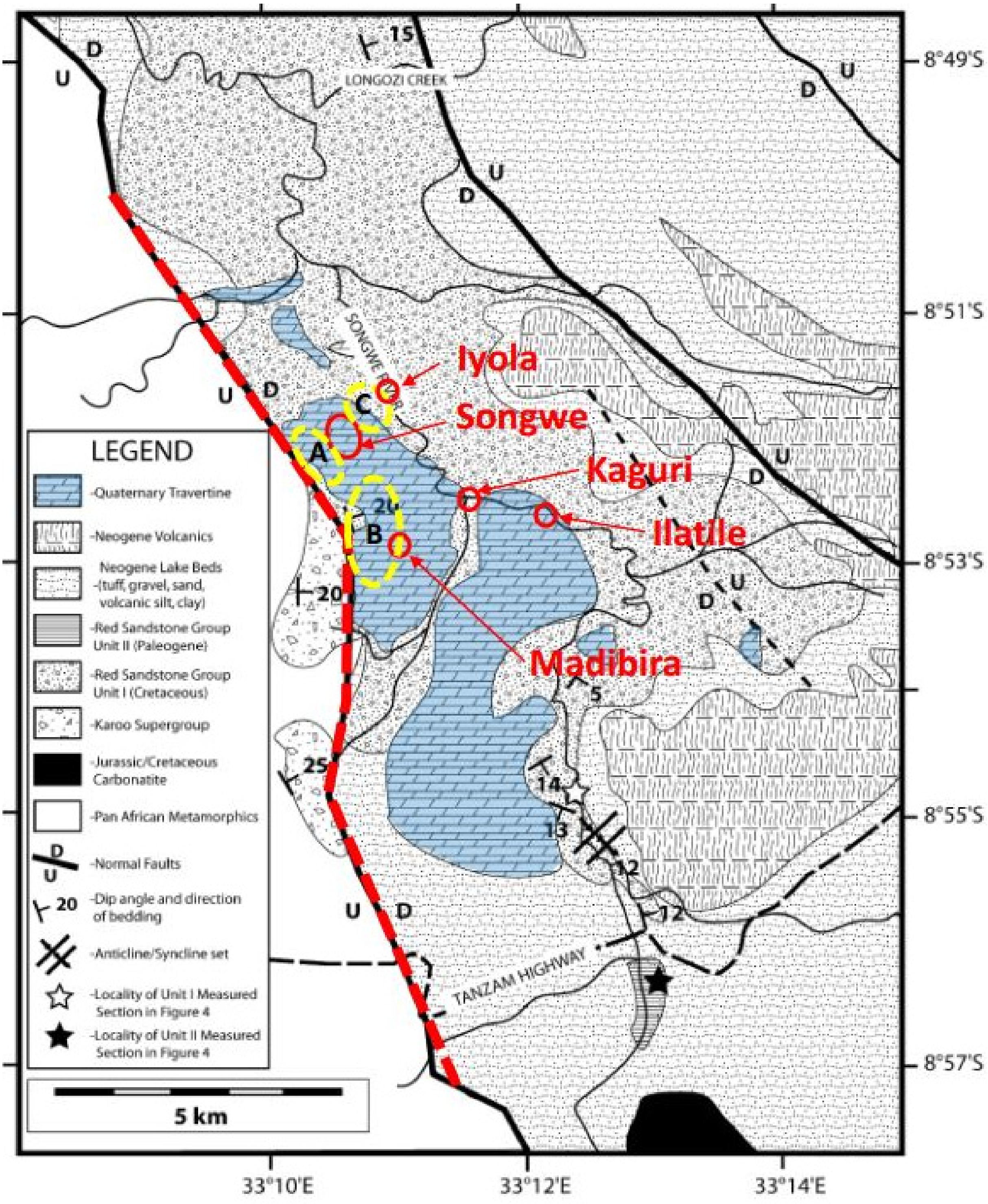

FIGURE 4: Location of the exploratory wells (TGDC, 2016)

3. GEOTHERMAL SWIMMING POOLS AND SPAS

3.1 Review of geothermal swimming pools and spas

Geothermal water has been used for thousands of years for recreational purposes, people have used geothermal water and mineral waters for bathing and for health benefits (Lund, 1996). Bathing in geothermal swimming pools has a number of benefits, not only for recreational purposes but also for therapeutic effects on the human body (Kinyanjui, 2013) as shown in Figure 5. The use of spas for medical treatment and preventive therapy is now accepted in Europe and Japan, though it is done under supervision. The mineral composition of geothermal waters, especially silica, has also been proven to have considerable healing effects for psoriasis skin disease (Pétursdóttir and Kristjánsson, 1995). Getting rid of stress, relaxation, body and mind revitalization, health and skin benefits, musculoskeletal effects and socialization are the main reason why many people worldwide enjoy geothermal spas and swimming.

FIGURE 5: Different medical and therapeutics use of spas (Ragnarsson, 2017)

Bathing and swimming in geothermally heated pools, natural spas or natural springs contributes to the development of sustainable tourism and eco-tourism. The leading countries are China, Japan, Turkey, Brazil and Mexico. African countries like Kenya, Ethiopia and South Africa have developed a number of geothermally heated swimming pools for recreational uses and Algeria is popular for using geothermal hot springs for balneological therapy. Worldwide, the geothermal utilization for bathing and swimming has increased between 1995 and 2015 from 1,085 to 9,140 MWt in terms of installed capacity and in terms of annual energy utilization from 15,742 to 119,381 TJ/yr (Lund and Boyd, 2015). This shows a rise in awareness and popularity of geothermal bathing and swimming for health benefits and business opportunities.

In Iceland over 90% of swimming pools are heated by geothermal energy all the year round (Orkustofnun, 2013). In 2010, there were 163 recreational swimming centres operating in Iceland, out of which 134 used geothermal energy, in total close to 1400 TJ (Björnsson et al., 2010). Swimming and bathing is popular with all age groups in all seasons and has become a part of the culture. The Blue Lagoon is among Iceland´s most famous, well known and unique attractions to both natives and tourists from around the world, with over a million visitors in 2016. The lagoon was formed in 1976 as effluent of geothermal water discharged from the Svartsengi power plant into the surrounding lava field (Pétursdóttir and Kristjánsson, 1995). The lagoon fluid is the mixture of 65% seawater and 35% fresh water, coming from wells drilled deep into a geothermal reservoir at 2000 m depth, where the temperature is around 240°C. The fluid is rich in silica, which starts to polymerize and precipitate as the fluid cools down and at 37-39°C lagoon temperature, pH 7.5 and salt content of 2.5% a white silica mud layer forms on the bottom (Ólafsson and Sigurgeirsson, 2003)

3.2 Existing swimming pool in Songwe and Mbeya

Based on field observation and interviews there is no evidence of swimming pools in the area surrounding Songwe geothermal site. However, swimming pools are found in Mbeya city, mainly located in hotels and supplied by cold water. The weather conditions are not supportive for swimming as shown in Figure 6, where the annual minimum, maximum and average temperatures are 10.5, 23.7 and 17.1°C (WTTC, 2015) and the wind speed is on average 5.4 m/s at 1.8-2 m a.s.l. (Energypedia, 2017).

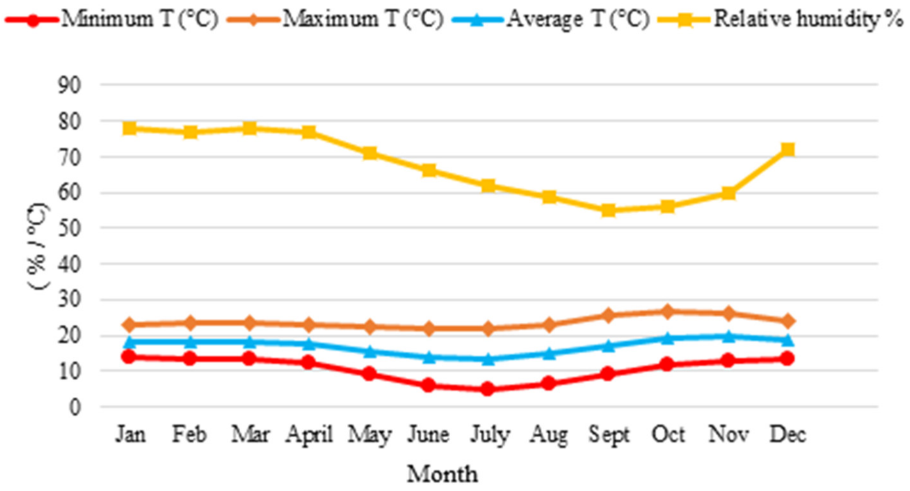

FIGURE 6: Weather statistics for Mbeya city between 2013 and 2015 (TNBS, 2016)

Benefits of pools are for different reasons also associated with bad awareness. In this favour, the use of geothermal energy for heating swimming pools, hot tubs and other facilities, which need heating, will attract local communities and tourists to enjoy the health benefits of geothermal water and create more business opportunities.

3.3 Proposed recreational centre

The centre will be located within the geothermal field at the Easting coordinates of -8.875387 and Northing coordinates 33.170665. This is 1.3 km from the well TGH-1 (located at -8.872265 and 33.182140) (Figure 7). Figure 8 shows the proposed recreational centre incorporating the different components.

The outgoing geothermal fluid will be re-injected into the planned well TGH-2, 594 m from the recreational centre. The location is about 10 km from the main road connecting Mbeya region with Zambia and Malawi and 21 km from the Songwe International airport. Geographically the location is feasible for the establishment of a recreational centre with an average of 5700 m^2 flat area and sufficient space for more facilities. It has natural guano caves, plenty of attractive geothermal manifestations, natural atmosphere and a good view of the mountains that can attract different people. An area of 4000 m^2 is proposed for the recreational centre.

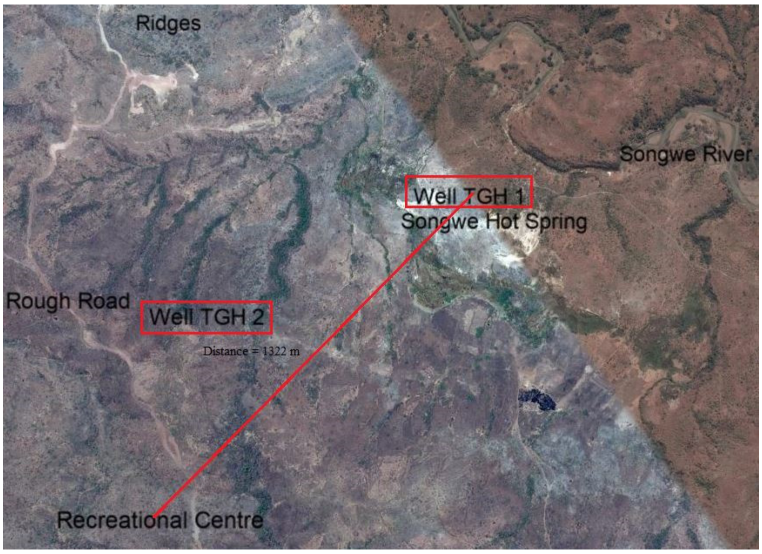

FIGURE 7: Location of the recreational centre in the field (Google Earth Pro, 2017)

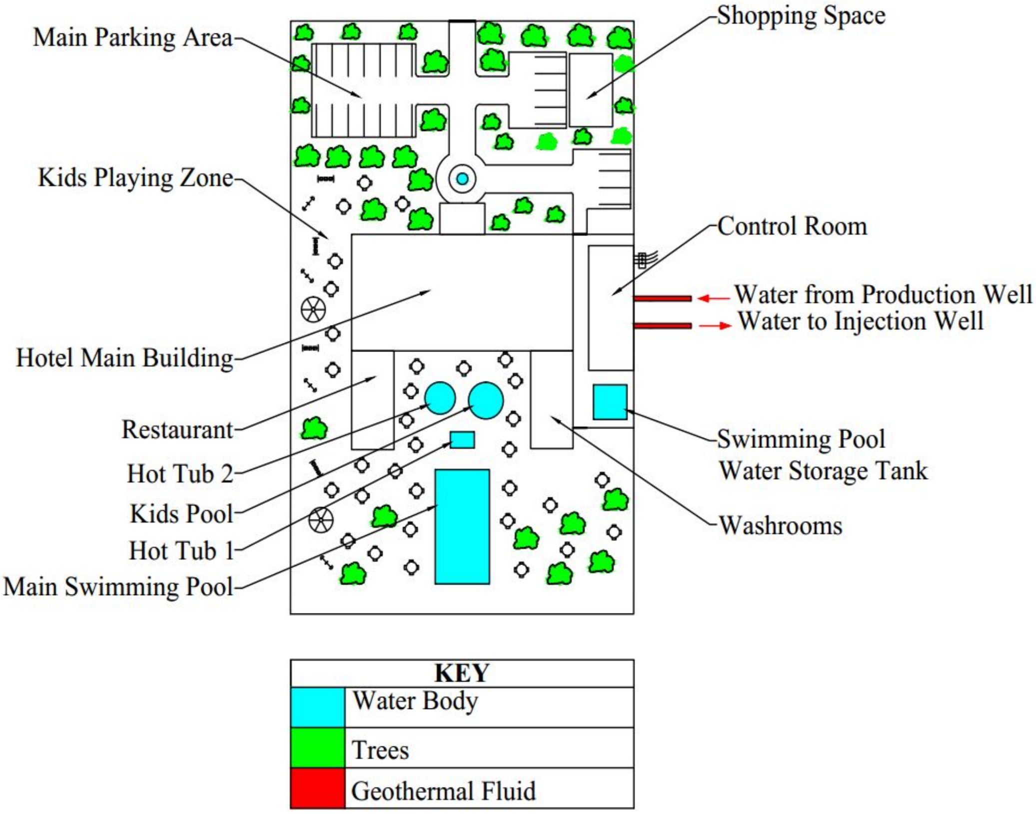

FIGURE 8: Recreational centre layout

3.4 Dimensions of the swimming pool and hot tubs

The dimensions of the swimming pool are one of the basic prerequisites in designing public pools as it determines the bather load, water requirement, capacity, pool services and equipment selection. Pools designed for leisure and relaxation are intended to serve different groups of people, such as children, adults, swimmers, beginners but they are not intended for competitions. According to international standards, the size of the pool depends on the bather load for the quality and treatment of the swimming pool water, and at least 2 m^2 of water surface area per bather is required in the pool (Silver Pools, 2017).

However, the surface area required for each bather is dependent upon the pool depth. If the depth is 0.5 m the surface area per swimmer should be 2 m^2 while if deeper than 1.35 m^2 the surface area per swimmer should be 4.5 m^2 (Halldórsson, 1975). Bather load is the measure of the number of bathers a pool can accommodate and it is determined by the surface area of the pool required per bather as a function of water depth. As water depth increases a larger surface area per swimmer is required. Table 3 shows the dimensions of the pools designed and their capacities. The bather load in each pool is calculated from:

$$BL = \frac{PA}{SA} \tag{1}$$

where BL = Bather load;
PA = Pool area (m^2); and
SA = Surface area per bather/swimmer (m^2).

TABLE 3: Dimensions of pools designed and their capacity

Pool type (Outdoor)	Dimensions	Depth	Bather load
Main pool: Temperature: 29°C	Length: 25 m, Width: 12.5 m, Transition slope: 2.3°, Area: 312.5 m^2, Volume: 406.25 m^3	Shallow end: 0.8 m Deeper end: 1.8 m	69
Kids pool: Temperature 32°C	Radius: 4 m, Area: 50.27 m^2, Volume: 25.13 m^3	Uniform: 0.5 m	25
Hot tub 1: Temperature: 38°C	Length: 5.5 m, Width: 3.5 m, Area: 19.25 m^2, Volume:19.25 m^3	Uniform: 1 m	10
Hot tub 2: Temperature: 40°C	Radius: 3.5 m, Area: 38.48 m^2, Volume: 19.24 m^3	Uniform: 0.5 m	19

3.5 Water circulation system

A circulation pump is used for the water circulation system for swimming pools and hot tubs. The system is designed to move water from the pool to a filtration, heating and treatment system and then return it to the pool. Using this kind of closed loop system, the quality of the pool water can easily be controlled. For water quality and clarity, 2 m^3 of properly treated water should be returned to pool each day for each bather (Perkins, 1988). Figure 9 shows the water circulation system for the designed pools with all required equipment and pipe work.

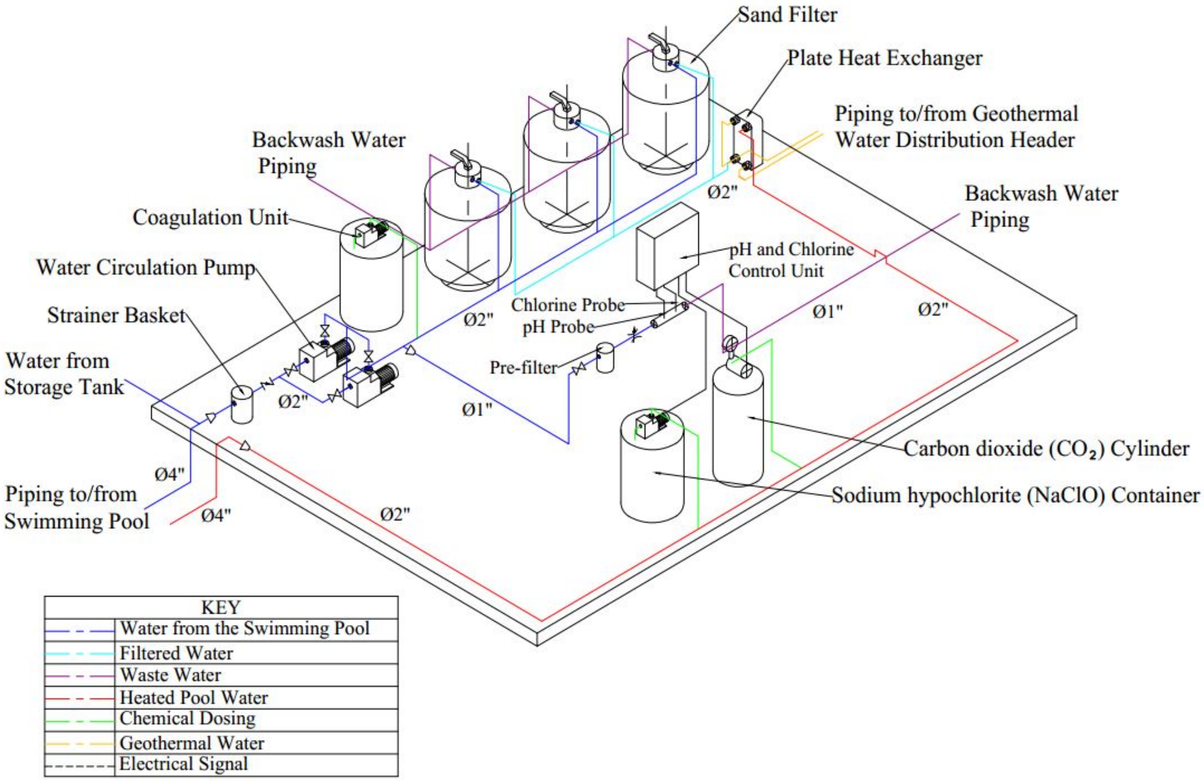

FIGURE 9: Water circulation layout for designed pools

The turnover period is the time taken for the pool water to circulate through the filters, treatment system and back to the pool inlets. The turnover period varies from pool to pool and depends mainly on pool loading. According to NSW (2013), shallow pools and spas have a relatively short turnover time of 1 hour to 30 minutes as they are subject to more bather pollution per volume of water than public pools that have a 4-8 hours turnover period.

For the above reasons, the turnover periods of the main pool, children's pool and hot tubs are selected as 6, 4 and 0.5 hours, respectively. Thus, the flowrate of recirculated water is calculated as follows: 67.71 m^3/h for the main pool, 6.3 m^3/h for the children's pool and 39 m^3/h for the hot tubs. During the recirculation process, it is assumed that the temperature of the re-circulated pool water decreases by 1°C.

3.5.1 Circulation pump size and selection

The maximum flow rate and pump power influence the selection of the circulation pump. The pump should deliver the required total water flow rate and create the pressure that is used to overcome the total head losses. A centrifugal pump driven by directly coupled electric motors is selected. Each pool is installed with two circulation pumps connected in parallel with a gate valve at the suction and delivery part, each capable of 100% maximum duty as shown in the water circulation layout. The pumps will run alternately as standby pumps and in case of any breakdown the two valves will close and the pump is removed for maintenance. Table 4 shows the selected pump models and their respective efficiency as required. The pump performance curves as described by the manufacturer (EBARA Pumps Europe, 2017) are shown in Appendix I. The curves show the relationship between the flowrate, efficiency, pump power and head. The results of the pump power, head losses, fluid velocity and pipe system within the circulation system given are given in Appendix II.

TABLE 4: Pump selection

Pool type	**Head loss (m)**	**Pump power (kW)**	**Pump head (m)**	**Total flow rate (m^3/h)**	**Pump model**	**Pump efficiency (%)**
Main	20.28	4.06	19.5	67.71	MD 50-160	73
Children´s	6.97	0.14	8.27	6.3	MD 32-125	50
Hot tub 1	14.61	1.64	15.61	39	MD 50-125	73
Hot tub 2	14.62	1.67	15.93	38.48	MD 50-125	73

3.5.2 Filtration of pool water and filter selection

Filtration is the most important process in any swimming pool system as it determines the water clarity. The filter traps visible dirt, particles, debris and gravel. As shown in Figure 9, a strainer basket that acts as a rough filter is installed before the circulation pump in order to protect the pump by trapping all large particles that may provide shock to the pump, reduce filter efficiency and decrease the backwashing requirement. When the pressure drop over the filter increases above the required level, the filter needs backwashing by reversing the flow. The quantity of the pool water through the filtration equipment should be 2 m^3/ hr per bather. The filtration efficiency increases as the flow rate decreases (Halldórsson, 1975).

Sand filter of the type Pro Series Top from the manufacturer Hayward is selected due to its high performance, reliability, low initial capital cost, low maintenance costs, and long life span. The filter has a six-position control valve that offers both easy operation and maximum efficiency, and is constructed of corrosion proof polymeric material. The filtration clarity ranges from 40 to 50 micron and it has excellent resistance to high pressures up to 3.5 bar. Table 5 gives the performance details of the filter model selected, according to the filter manufacturer.

TABLE 5: Performance of selected filters (Hayward, 2016)

Model number	Pool type	Filtration area (m^2)	Design flow rate (m^3/h)	Total flow rate required (m^3/h)	Number of filters required	Sand (kg)
S0310TXE	Hot tub 1	0.45	22	39	2	227
S0310TXE	Hot tub 2	0.45	22	38	2	227
S0360TXE	Main	0.64	30	67.7	3	320
S210TXE	Kids	0.20	10	6.3	1	227

3.5.3 Chemical treatment of pool water

Bacteria, algae and fungi of various kinds can multiply very rapidly and cause problems to people, so there is a need for a chemical treatment of the pool water for pool water balance, pH values and disinfectant levels within a set range. Proper pool water balance determines the bather comfort, prevents calcium scaling, and corrosion and prolongs the lifespan of the pool and its fittings. Table 6 shows the required standards and the optimum range for the pool water balance (SA Health, 2008).

TABLE 6: Pool water balance / chemistry (SA Health, 2008)

Standard	Optimum range
Appearance	Clear and free from suspended particle
pH	7.2 - 7.6
Free chlorine level	1 - 3 mg/l
Total alkalinity	60 - 200 mg/l
Total calcium hardness	150 - 400 mg/l
Total dissolved solids	Less than 500 mg/l

Figure 9 shows the carbon dioxide (CO_2) cylinder and sodium hypochlorite (NaClO) container for the pool. If the pH value of pool water goes below the setting point, the pH and chlorine control unit will give the electrical impulse signal to turn on the pump and inject carbon dioxide and chlorine agents as needed to maintain the disinfectant level. The addition of chlorine into the pool water forms hypochlorous acid (HOCl) that makes organic material in the pool inactive by partially dissociating in water and get in equilibrium with the hydrogen ion and hypochlorite ion concentrations. Prominent Gamma/4 is a common equipment used for chloride mixtures and has been proved to work well with a chemical resistant chloride tank capable of 100 litres (Svavarsson, 1990).

3.5.4 Pipe systems and pool cross-sectional view

The piping system for the pool system plays significant part for the water recirculation system and service life. The system is divided into inflow and outflow pipes as discussed below.

Inflow pipes: These are inflow / inlet pipes connected to different distributions spouts at the pool bottom. The bottom inlet system provides better water circulation, cleansing and blending compared to a wall inlet. Polyvinyl chloride (PVC) pipes are selected for all pools because of their low thermal expansion compared to Polyethylene (PE) and low prices compared to stainless steel (SS).

Outflow pipes: These are overflow pipes fitted at the top of the pool wall and they surround the perimeter of the pool. Impurities such as body fats and hair, which get into the pool, float on top of the water.

Figures 10 and 11 show the top view, side view and 3D view of the main pool with uniformly spaced bottom inlets (1.5 m × 1.5 m). The floor inlets are adequate in design, number and location to ensure effective distribution of treated water and maintenance of pool water.

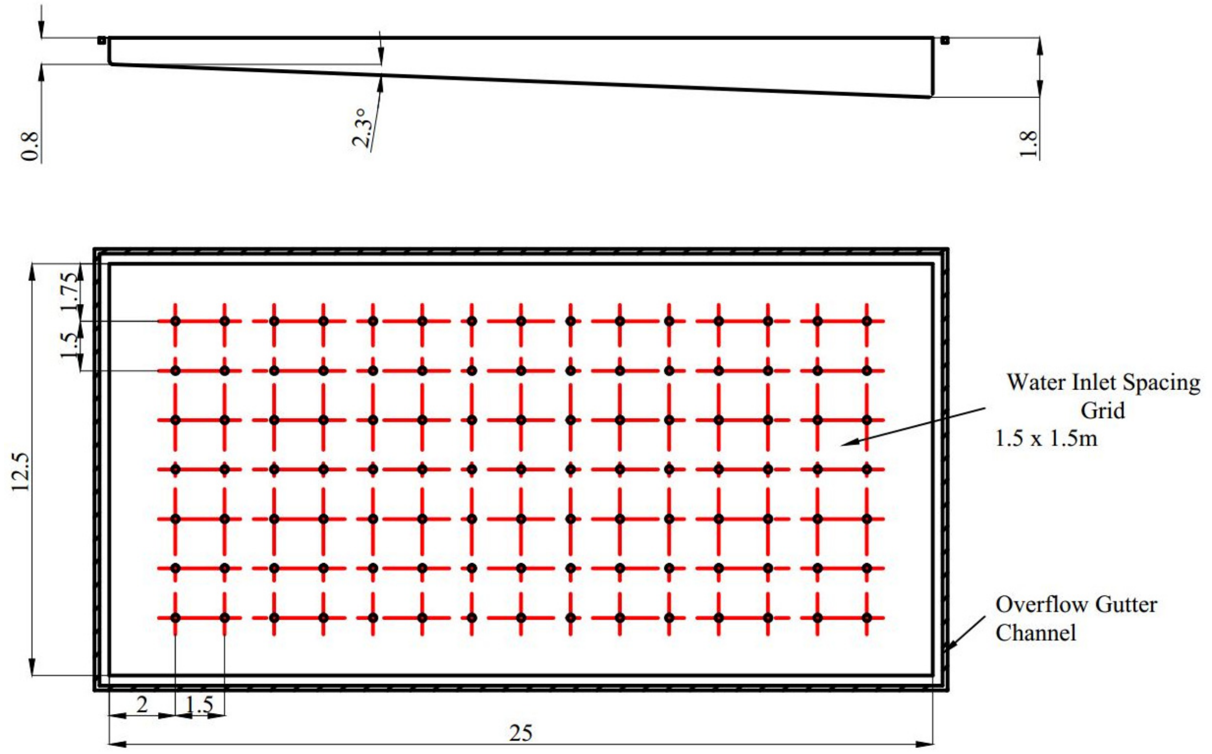

FIGURE 10: Cross-sectional view of the main pool

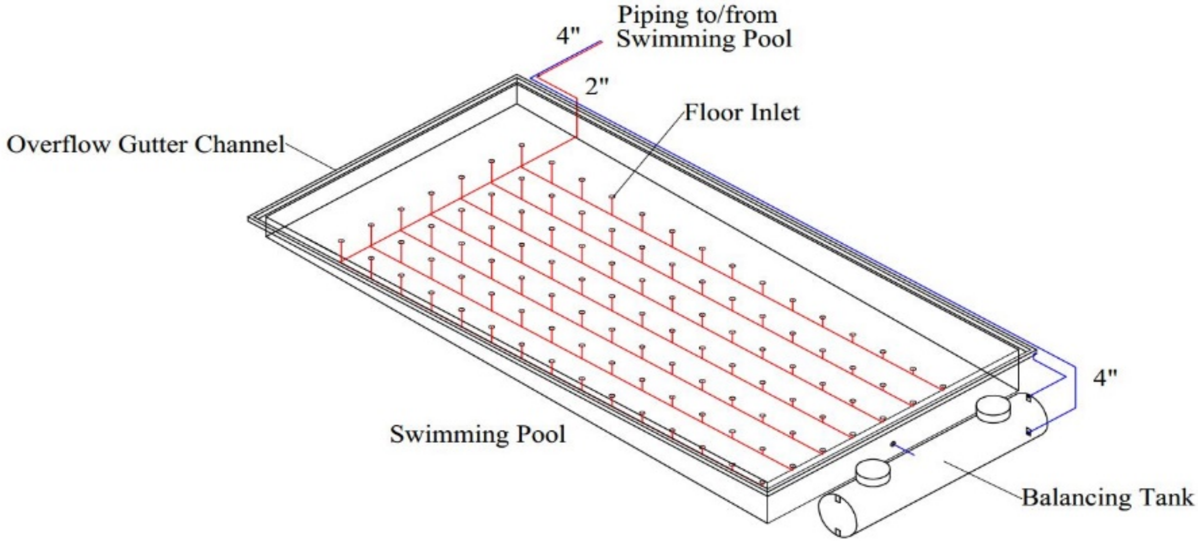

FIGURE 11: 3D view of the main pool

The pools are constructed with concrete with PVC liners and pre-fabricated with steel for durability, and faster and easier emptying compared to pools constructed by concrete with tiles. The concrete must be of high quality and tight to withstand chlorine. A large diameter pipe is placed down to the bottom of the pool before concreting the floor, as it helps to eliminate any problems that may occur during operation without any destruction of the walls or floor of the pool (Kristján Th. Hálfdánarson, VERKÍS, pers. comm.).

3.5.5 Heat exchangers

The task of the plate heat exchangers is to transfer heat from the geothermal fluid to the closed pool water loop. The use of a heat exchanger is vital as most geothermal fluids have a high temperature and contain a variety of dissolved chemicals that are corrosive or form scaling toward the construction material. Therefore, the selection of the heat exchanger essentially depends on the temperature and the temperature difference between the incoming and outgoing geothermal fluid, which is significant as it administers the feasibility, equipment selection and flow requirements for the system. Table 7 shows the various specifications for the heat exchangers for each swimming pool considered in this study.

TABLE 7: Plate heat exchangers performance specification

Heat exchanger model	Pool type	Side	T_{in} (°C)	T_{out} (°C)	Pressure drop (kPa)	Nominal capacity (kW)	Heat transfer area (m^2)	LMTD[1]	NTU[2]
B6-1200	Main pool	A B	75 27	35 32.4	25.2 47	352	2.14	20.17	0.3
B6-390	Kids pool	A B	75 31	35 36.7	30.6 26.8	114	0.60	15.19	0.4
B6-280	Hot tub 1	A B	75 45	45 41.6	22.4 14.4	82	0.47	17.18	0.3
B6-700	Hot tub 2	A B	75 41	45 44.0	14.3 25	205	1.15	13.18	0.3

[1] Logarithmic Mean Temperature Difference; [2] Number of Transfer Units

3.5.6 Layout of the main swimming pool

Figure 12 shows that the water enters the swimming pool through the distribution spouts on the bottom of the pool and rises to overflow gutter channels on the surface of the pool. From there it passes through the balancing tank to be mixed with fresh water from the storage tank. Furthermore, a strainer basket traps all large particles before the water enters the circulation pump and passes through a coagulator unit that aggregates small particles. These serve as a protection for the circulating pump and the filter. The water goes through the sand filters where a filtration process takes place; and the cleaned water goes to the heat exchanger where it is heated by the geothermal fluid. The control system injects chlorine and carbon dioxide to the pool water to maintain the disinfectant levels and pH values within the required range. A balance tank with a capacity of 5% of the pool volume is provided for all swimming pools to collect water from the overflow system. One large storage tank is installed for the fresh water supply for the pools on a daily basis and when water is needed for backwashing the filters or topping up the pool.

3.6 Energy requirements for heating the pools

For outdoor pools, the heat remitted or absorbed by the pool is significantly influenced by its location, surroundings, and day or night-time. Figure 13 shows the general view of the energy exchange between a swimming pool and its environment.

In this study, the pool water is circulated in a closed loop where it passes through heat exchangers and extracts heat from the geothermal water, which passes through the other side of the heat exchanger. Evaporation and convection accounts for more than 90% of the total heat losses compared to other forms of heat losses. The losses were calculated from the equations below (Ragnarsson, 2017).

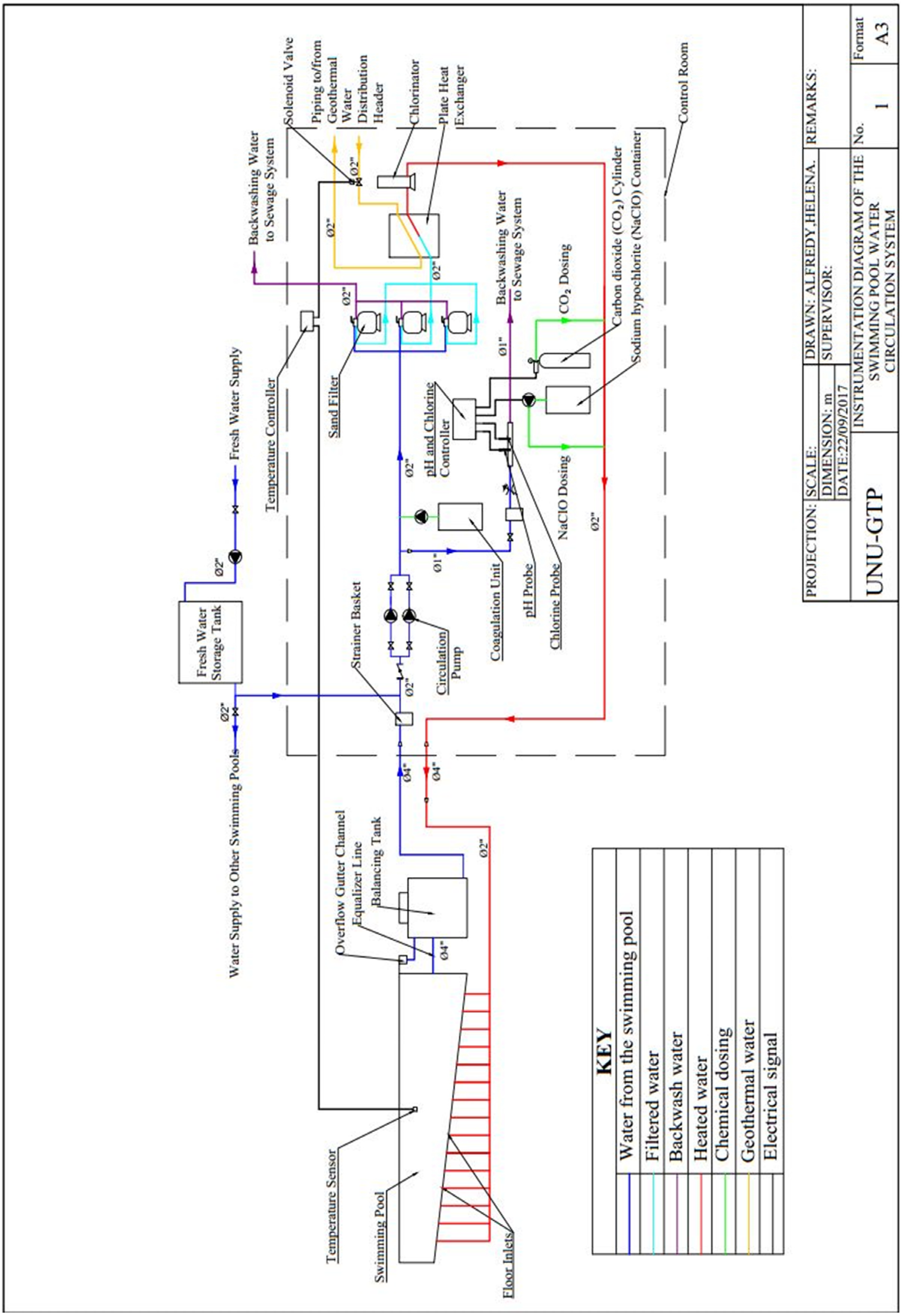

FIGURE 12: Instrumentation diagram for the swimming pool

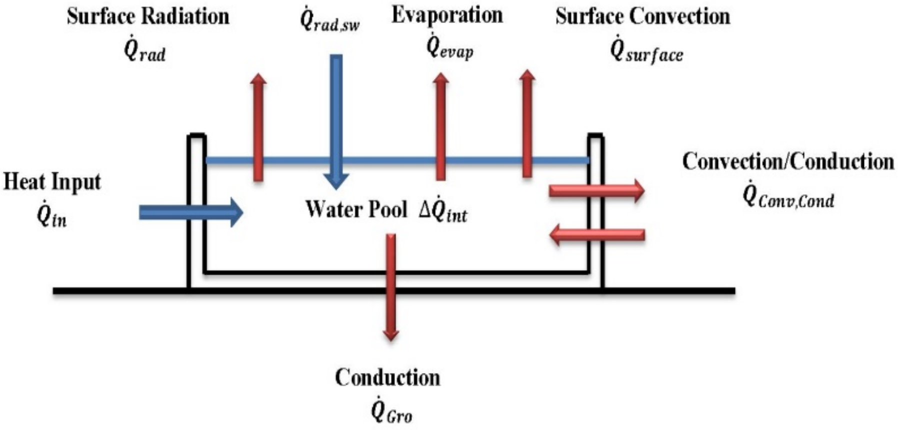

FIGURE 13: Heat transfer mechanism in a swimming pool

3.6.1 Evaporation heat losses

This is the energy delivered to the pool, which is required to counterbalance the heat discarded from the surface due to evaporation. The losses are influenced by the difference in partial pressure between the pool surface and the air and wind velocity. The required heat to compensate for the evaporation loss is calculated by:

$$Q_E = (1.56\,k + 2.93v_2) \times (e_w - e_a) \tag{2}$$

where Q_E = Heat loss due to evaporation (W/m^2);
e_w = Partial pressure of steam at surface (mbar);
e_a = Partial pressure of steam in air (mbar);
v_2 = Wind speed above the ground (m/s);
k = 3.89 + 0.17 ($T_w - T_a$) (W/m^2 °C);
T_W = Water temperature (°C);
T_a = Air temperature (°C).

3.6.2 Convection heat losses

Convection heat losses should also be compensated as part of the total design requirement. They depend mainly on the temperature difference between the pool surface and the air as well as the velocity of the wind passing over the pool surface. The temperature difference is a time dependent variable but for steady state heat losses it is considered as the highest for design heat losses. Convection losses increase with higher wind speed and lower outside temperature. The losses are calculated from:

$$Q_C = h_c \times (T_w - T_a) \tag{3}$$

$$h_c = k + 1.88v_2 \tag{4}$$

$$k = 3.89 + 0.17\,(T_w - T_a) \tag{5}$$

where Q_C = Heat loss due to convection (W/m^2);
h_c = Convection heat transfer coefficient, which is dependent on wind speed (W/m^2 °C).
k = Empirical coefficient (W/m^2 °C).

Heat losses due to conduction, rain and radiation are of minor consequences. Here, they are assumed to be 10% of the total heat loss by convection and evaporation and are calculated by the equation:

$$S = 0.1 \times (Q_E + Q_C) \tag{6}$$

where S = Sum of heat losses due to radiation, conduction and rain (W/m^2);
Q_E = Heat loss due to evaporation (W/m^2);
Q_C = Heat loss due to convection (W/m^2).

The total specific heat loss can be calculated by the equation:

$$Q_T = Q_C + Q_E + S \tag{7}$$

where Q_T = Total specific heat loss from the swimming pools (W/m^2).

The total load at design conditions to heat and maintain the pool at set point temperature is calculated from:

$$E = Q_T \, x \, A \tag{8}$$

where A = Area of a pool (m^2).

The energy balance equation at steady flow conditions is used to calculate the amount of geothermal water needed as a heat source, based on the temperatures at the inlet and outlet of the heat exchangers of both the pool water and the geothermal water (Wark, 1988):

$$Q = m_c \, C_p \, (T_P - T) = m_g \, C_p \, (T_i - T_O) \tag{9}$$

where m_c = Amount of water to be recirculated in the system (kg/s);
m_g = Amount of geothermal water as a heat source (kg/s);
C_p = Specific heat capacity of water (J/kg°C);
T_i = Temperature of incoming geothermal water at heat exchanger (°C);
T_O = Temperature of outgoing geothermal water (°C);
T_P = Temperature of pool water after passing the heat exchanger (°C);
T = Temperature of pool water before being heated by heat exchanger (°C).

Design conditions used in the calculations and calculated values are shown in Appendix III. The outside air temperature is chosen as 5°C based on the fact that in the period 2013-2015 the average temperature in months June to August was 5.7°C. For the design case, the worst condition is assumed when the temperature is 5°C and the wind speed 5.4 m/s.

As shown in Figure 14 the heat loss from the pools designed is largely due to evaporation losses. The evaporation process reduces the temperature of the pool surface because as each kilogram of water evaporates from the pool surface, approximately 2400 kJ are lost with the escaping vapour. The energy required to compensate for these losses comes mainly from the pool water. The convective process cools or warms the surface water according to the value of the ambient temperature. It cools the water when the air temperature is low and warms it if the air temperature is high. Other losses are relatively small.

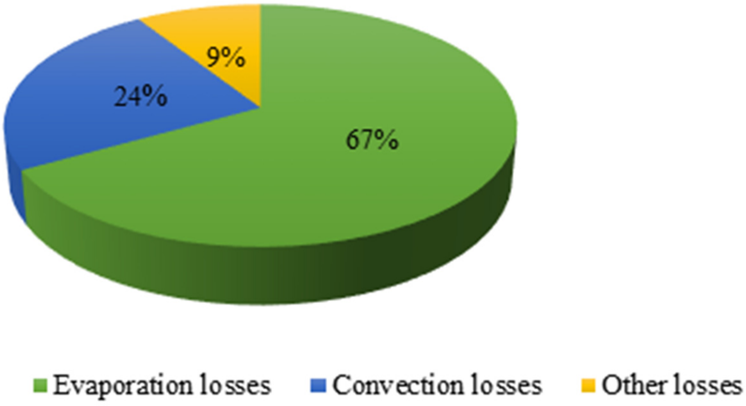

FIGURE 14: Distribution of heat losses for the designed pools in percentages

The ambient air temperature and wind speed play significant roles in the evaluation of the predominant heat loss components and the heat load. At design conditions, the total heating power required for all pools is 755 kW and the amount of geothermal water required is 4.56 kg/s. Figure 15 shows the monthly average heat load for the individual pools and hot tubs. The months: May, June, July and August require the greatest heating power requirement. The pool water temperature will rise about 4.5°C after passing through the heat exchanger. Tables 8 and 9 shows the monthly energy and geothermal water required for each pool when the demand increases from May to August.

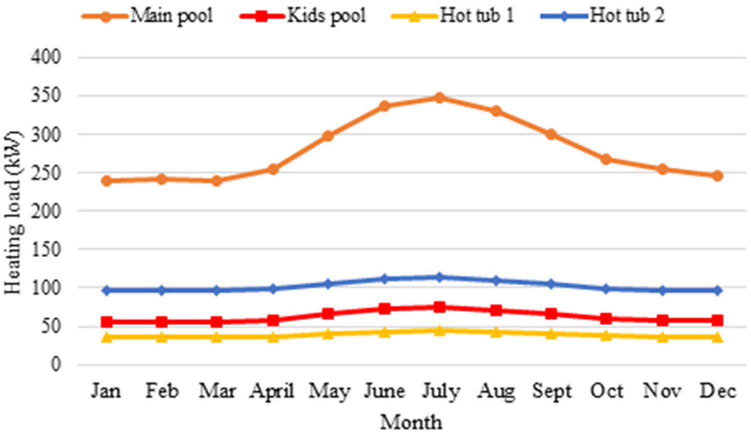

FIGURE 15: Monthly heating load requirement

TABLE 8: Geothermal water demand in kg/s for the designed pools for each month

Month	Main pool	Children's pool	Hot tub 1	Hot tub 2	Total
January	1.54	0.33	0.24	0.77	2.88
February	1.55	0.33	0.24	0.77	2.89
March	1.54	0.33	0.24	0.77	2.88
April	1.63	0.35	0.25	0.79	3.02
May	1.89	0.39	0.27	0.84	3.39
June	2.11	0.43	0.29	0.89	3.72
July	2.17	0.44	0.30	0.90	3.81
August	2.07	0.42	0.29	0.88	3.66
September	1.89	0.39	0.27	0.84	3.39
October	1.70	0.36	0.26	0.79	3.11
November	1.63	0.35	0.25	0.78	3.01
December	1.58	0.34	0.25	0.77	2.94

TABLE 9: Energy demand (TJ) for the designed pools for each month

Month	Main pool	Children's pool	Hot tub 1	Hot tub 2	Total
January	0.67	0.15	0.09	0.25	1.15
February	0.63	0.14	0.09	0.23	1.08
March	0.67	0.15	0.09	0.25	1.16
April	0.71	0.15	0.10	0.26	1.21
May	0.82	0.17	0.10	0.27	1.37
June	0.91	0.19	0.11	0.29	1.50
July	0.94	0.19	0.11	0.29	1.54
August	0.90	0.18	0.11	0.29	1.48
September	0.82	0.17	0.10	0.27	1.36
October	0.74	0.16	0.10	0.26	1.25
November	0.71	0.15	0.09	0.25	1.21
December	0.68	0.15	0.09	0.25	1.18

The predominant heat losses increase as wind velocity increases, Figure 16 show the effects of wind speed on evaporation loss, heating load and geothermal water use at the design condition of 5°C and relative humidity of 62%. This indicates that the pools do not lose much energy at lower wind velocities as compared to high wind speed, resulting in a shorter preheating period.

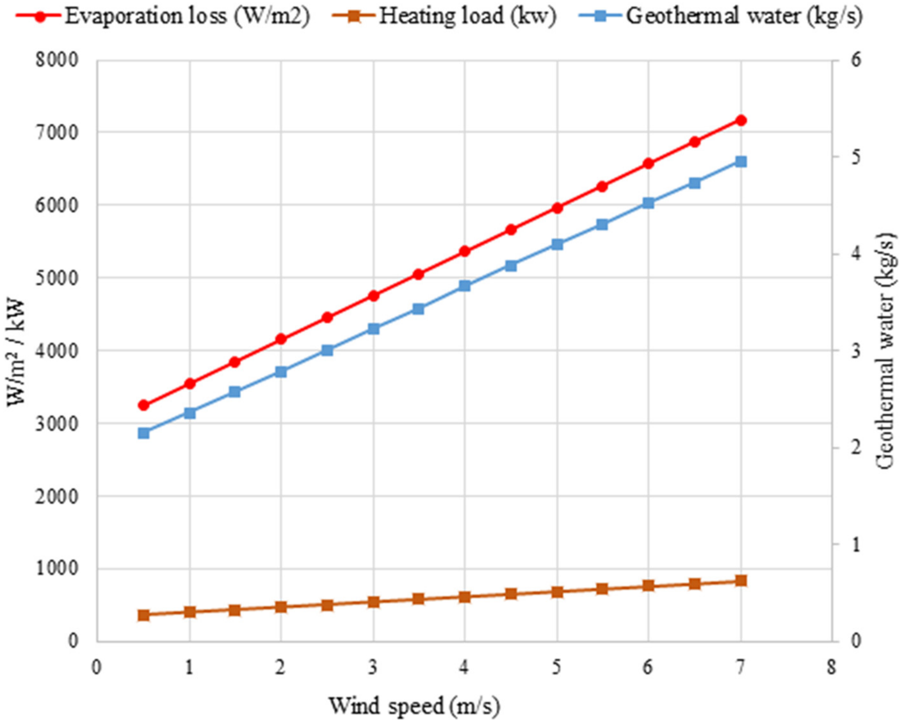

FIGURE 16: Relationship between wind speed and evaporation heat losses, heating load and geothermal water flow rate

To reduce the heat losses and minimize heating costs the author suggests the use of pool covers. At the beginning of the project, less expensive covers as solar covers can be used. They float on the pool, hindering evaporation but permitting solar radiation to pass through to warm up the water. This provides the highest energy savings when used regularly.

4. TRANSMISSION PIPELINE FROM THE GEOTHERMAL WELL

The transmission pipeline is from well TGH-1 to the distribution header where there are outlets to the heat exchangers of each swimming pool. However, the calculations were made to meet an objective of a minimum total cost at a maximum allowable velocity of the fluid. For a detailed design the pipeline route should be considered with the aim of following existing tracks and roadways where possible.

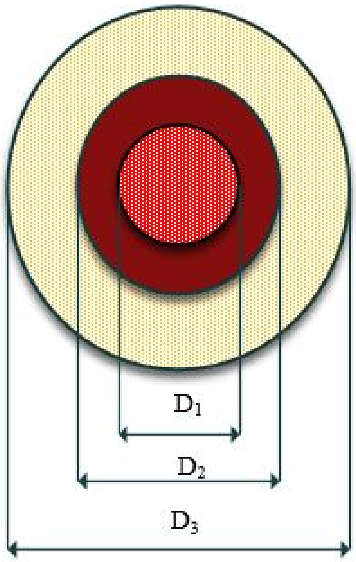

FIGURE 17: Cross-section of the insulated pipe

The pipe length is 1322 m from the well to the location of the recreational centre. It is laid 1-2 m above the ground supported by concrete foundations anchored into the ground. The cost of an above ground pipeline system is low compared to an underground system. A welded pipe of steel type S253 insulated by mineral rock wool covered with shiny metallic skin of aluminium is considered in this design as shown in Figure 17.

The assumptions made during calculations are:

- The source of geothermal water is from well TGH-1;
- Temperature of the geothermal water is 75°C;

- The cost of the pipes are estimated from prevailing prices in Iceland;
- Cost of fittings, pump and insulation is 70% of the total pipe cost; and
- The flowrate of the water transported from the well is 65 kg/s.

Below are the equations used to obtain the optimum pipe diameter (Jónsson, 2017):

$$C_T = C_C + \frac{C_a}{i} \times (1 - \frac{1}{(1+i)^n}) \tag{10}$$

where C_T = Total pipeline cost including investment and operation (pumping) (USD);
C_C = Initial capital cost (USD);
C_a = Annual energy cost (USD);
n = Expected lifetime of the pipeline = 25 years; and
i = Interest rate = 15%.

The capital cost is calculated from:

$$C_C = L_P\, C_p + Cost\ of\ fittings\ + Costs\ of\ pump + Cost\ of\ insulation \tag{11}$$

where L_P = Pipe length (m); and
C_p = Cost of pipe (USD/m).

The annual energy cost, C_a, is calculated from:

$$C_a = C_e\, O_h\, P \tag{12}$$

where C_e = Cost of electric energy (USD/kWh);
O_h = Operating hours in a year: $(365 \times 24) = 8760\ hours$; and
P = Power for pumping or losses (kW).

The frictional power of the pump, *P*, is calculated from:

$$P = \frac{g\rho H_f Q}{1000\, n} \tag{13}$$

where g = Gravitation constant (m/s^2);
ρ = Density of water at 75°C (kg/m^3);
H_f = Frictional head (m);
Q = Flow rate of fluid (m^3/s); and
n = Pump and motor efficiency.

For the frictional head to be calculated, first the velocity of fluid should be known and calculated from:

$$v = \frac{4Q}{\Pi d^2} \tag{14}$$

where v = Velocity of fluid in pipe (m/s);
Q = Flow rate of a well (m^3/s); and
d = Pipe inner diameter.

The Reynolds number is calculated from:

$$Re = \frac{\rho v d}{\mu} \tag{15}$$

where μ = Dynamic viscosity of water at 75°C (kg/m s).

Since the calculated Reynolds number is greater than 2100, the friction factor, *f*, is calculated from:

$$f = 0.11 \times (\frac{\varepsilon}{d} + \frac{68}{Re})^{1/4} \quad (16)$$

where f = Friction factor;
ε = Surface roughness of steel pipe – constant value = 0.0000457 m.

Frictional head loss is expressed by the Darcy – Weisbach equation:

$$H_L = f \times \frac{Lv^2}{d2g} \quad (17)$$

where H_L = Head loss (m);
g = Gravitation constant (m/s^2); and
L = Pipe length (m).

Pressure needed to pump is calculated by:

$$P_p = (H_L + \Delta Z) \times 0.0981 \quad (18)$$

where ΔZ = Elevation difference between the well and the centre (m);
P_p = Pump pressure (bar).

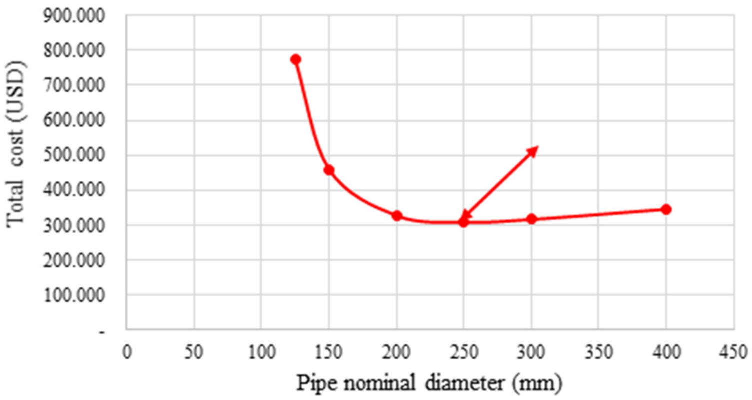

FIGURE 18: Optimum diameter of transmission pipeline based on the minimum total cost

The optimum diameter is obtained by balancing the capital costs for purchasing the pipe and the annual energy costs for pumping. A larger pipe diameter increases the total capital costs and at the same time decreases the frictional losses. The optimum result is the diameter giving the minimum total cost. By using this criterion for selection, the optimum pipe diameter is 250 mm ND as shown in Figure 18. The thickness of the rock wool insulation is chosen as 50 mm. The transmission pipeline is designed to be 250 mm in diameter because the geothermal fluid will be utilized in the recreational centre and other direct use applications and so the pipe needs to accommodate 65 kg/s.

4.1. Heat loss from the transmission pipeline

According to the literature, the temperature loss at flowing conditions in insulated pipelines is in the range of 0.1-1.0°C/km and in uninsulated pipelines the loss is 2-5°C/km. An uninsulated pipe costs about half of the insulated pipe (CanGEA, 2014). The heat loss, *Q*, per metre of an insulated pipe can be calculated from the following equation:

$$\frac{Q}{L} = \Pi \times D_3 \times U \times (T_{in} - T_{out}) \quad (19)$$

where D_3 = Outer diameter including the insulation (m);
U = Overall heat transfer coefficient based on outside of the insulated pipe (W/m^2°C);

T_{in} = Incoming geothermal fluid temperature (°C); and
T_{out} = Outside air temperature (°C).

The overall heat transfer coefficient is:

$$U = \frac{1}{\frac{D_3}{D_1 h_{in}} + \frac{D_3 \ln(\frac{D_2}{D_1})}{2\, k_{Pipe}} + \frac{D_3 \ln(\frac{D_3}{D_2})}{2\, k_{Insulation}} + \frac{1}{h_{out}}} \tag{20}$$

where D_1 and D_2 = Inner and outer diameter of the pipe (m);
k_{Pipe} = Thermal conductivity of steel pipe (W/m°C);
$k_{Insulation}$ = Thermal conductivity of the rock wool insulation material (W/m°C);
h_{in} = Heat transfer coefficient in the pipe (W/m^2 °C); and
h_{out} = Heat transfer coefficient at the outside insulation surface (W/m^2 °C).

Furthermore:

$$\Delta T = \frac{Q}{m\, C_p} \tag{21}$$

where m = Mass flow rate (kg/s);
C_P = Specific heat capacity of water (J/kg°C); and
ΔT = Temperature drop (°C).

The assumptions used in calculations are:

- Insulation thickness is 0.05 m;
- Thermal conductivity of the insulation material is 0.07 W/m°C;
- Thermal conductivity of the pipe material is 67 W/m°C;
- Heat transfer coefficient of the inside pipe is 1000 W/m^2 °C;
- Heat transfer coefficient of the outside insulation pipe is 8 W/m^2 °C);
- Temperature of fluid inside pipe is 75°C; and
- Ambient air temperature is 5°C.

For the pipe diameter selected, the temperature drop is about 0.2°C, but the temperature drop increases as the pipe diameter increase as shown in Figure 19.

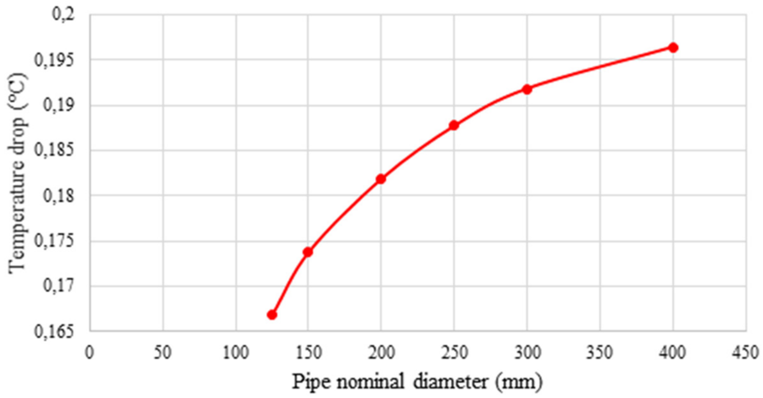

FIGURE 19: Temperature drop in the transmission pipeline calculated for different pipe diameters

5. MARKET AND ECONOMIC ANALYSIS OF THE RECREATIONAL CENTRE

5.1 Targeted customers and marketing strategies

At the beginning of the project, the targeted customers are 20,000 annually, equivalent to 0.74% of the total population of the region or 54 customers per day composed of:

- Children between 3 and 12 years old;
- Women and men between 18 and 55 years old; and
- Students.

The sales and marketing strategies enforced shall attract and convince customers to visit the recreational centre. The emphasis on 5P's of marketing is described in Table 10:

TABLE 10: 5P's of marketing strategies

Product Insights into customer needs, Innovation and research, Wide range of activities, Focus on swimming and wellness, Special wellness package for women; Develop activities for children, Being first to market.	**Price** Price difference for each targeted group; Special price lists for students; 10 days card, 1 month and year memberships; Low price and high quality services .
Place Neat and presentable environment, Infrastructure development and accessibility, Good view of natural features.	**People** Excellent customer services, Presence of qualified rescue team, Excellent communication skills.
	Promotion Increase awareness of the facilities, Special promotion seasons, Special prices for wellness packages, Extra sales promotion and advertisement, Post marketing messages on Facebook page and encourage followers to share and upload photos enjoying the pools and other services.

5.2 Project estimated cost and financing

The estimated project costs and their breakdown are shown in Table 11. The costs were estimated based on different sources like prevailing prices obtained through discussions with a local engineer in Tanzania, equipment costs obtained from manufacturers, cost of installing the swimming pool estimated from Clean Pool and Spa (2017). The total project cost required for investment is estimated as USD 492,495. The project source of finance is through 30% equity share and 70% bank loan. The loan is amortized with annual payment of USD 96,726 for 12 years, given a loan deferment period of 3 years. Table 12 shows the revenue projection in the first year, customers are estimated based on 50% of total bather load.

TABLE 11: Estimated project cost

SN	Description	Cost (USD)
1	Land, site development, building construction and equipment	204,225
2	Constructions of main pool and mechanical equipment	75,181
3	Constructions of children's pool and mechanical equipment	63,225
4	Constructions of hot tub 1 and mechanical equipment	54,969
5	Constructions of hot tub 2 pool and mechanical equipment	59,970
6	Shipping and transport	10,000
7	Working capital loan	24,925
Total estimated project		**492, 496**

TABLE 12: Revenue projection in the first year

Description		Cost (USD)	Revenue (USD)
Swimming pools			
Pool users per day	50	5	250
Operating days in a year	351	250	87,750
Revenue from pools			87,750
Hotel rooms			
Number of users per night	4	50	200
Revenue from hotel			70,200
Total revenue			**157,950**

5.3 Project economics analysis

Two discounted cash flow techniques are used to evaluate the financial viability of the project, the Net Present Value (*NPV*) and the Internal Rate of Return (*IRR*). The two techniques help in decision making of the project execution (Shine, 2014). The central assumption is that having money today is better than having it later. A positive value of *NPV* and a greater value of *IRR* than the discount rate gives the Go-On decision of the project implementation. The assumptions made in the calculations are:

- Number of customers that will use the pools per day are 50 at a cost of USD 5 per customer and 4 customers will use hotel services. The total sales are projected to increase by 15% each year.
- The marketing costs are higher in the first 5 years and decrease by 50% from year 6-15.
- The facility operates 351 days in a year leaving 14 days for maintenance.
- The discount rate used is 12% as per Tanzania central bank and a bank interest rate of 15%.
- The lifetime of the project is 15 years.
- Being new to the market, the cost of geothermal water is assumed as 0.6 USD/m^3 from the prevailing price of fresh water in Tanzania.
- The analysis does not consider the cost of the geothermal pipeline, exploration and drilling.
- Running cost increases by 1% each year while other costs remain constant.

Given the deferment duration of three years the future value is calculated from:

$$FV = \frac{L}{(1+r)^n} \tag{22}$$

where FV = Future value of money (USD);
L = Amount to be loaned (USD);
r = Bank interest rate (15%);
n = Loan deferment duration (three years).

The future value of money obtained is *USD 524,317* and amortized for the next 12 years to get the annual payment schedule of *USD 96,726*.

The *NPV* of the project is calculated from the equation:

$$NPV = -C_O + \sum_{T}^{N} \frac{C_T}{(1+K)^N} \tag{23}$$

where C_O = Initial capital investment (USD);
C_T = Project net cash flow (USD) at period 1, 2, 3... *N*;
K = Project discounting interest rate (12%);
N = Number of years.

The Internal Rate of Return (*IRR*) is the discount rate that forces the *NPV* to be equal to zero calculated from:

$$NPV_{IRR} = -C_o + \sum_{T}^{N} \frac{C_T}{(1+IRR)^N} = 0 \tag{23}$$

where IRR = Internal rate of return (%).

The project is worth undertaking as the *NPV* value is about USD 4,500,000 and the *IRR* is 42%, which is higher than the discount rate of 12% with a payback period of 6 years. Figures 20 and 21 show the cumulative *NPV* and the net cash flow of the project, which increases with time. The variables that most influence a project's net benefits and quantify the extent of their influence on the project are *NPV* and *IRR*. The most critical variables for the success of the project are the bank interest rate and the revenue generation. If the sales decrease by 50% the *IRR* becomes 14%, *NPV* USD 117,000 and the payback period 15 years.

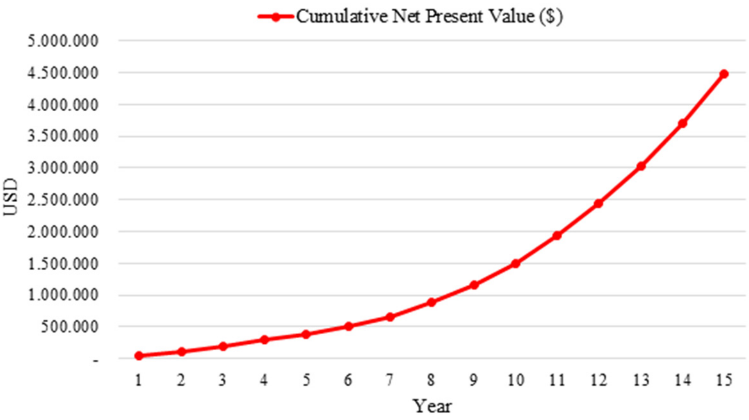

FIGURE 20: Cumulative NPV at 12% discount rate

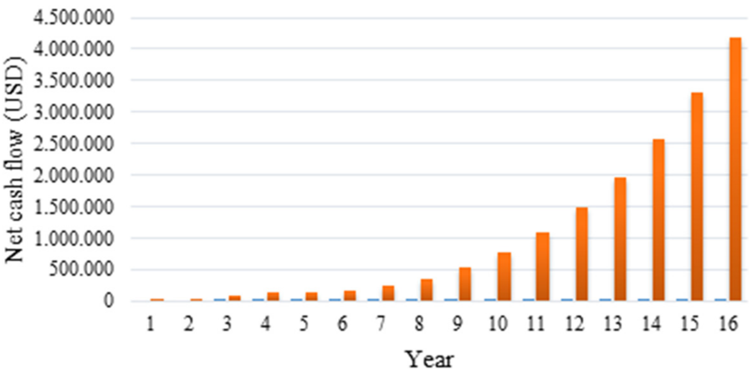

FIGURE 21: Net cash flow for 15 years of operation

6. CONCLUSIONS

The use of geothermal energy for bathing and swimming has deep roots in human history and has progressed in different parts of the world to advanced practices although it may differ from culture to culture. At present, Songwe attracts different people. This shows a potential opportunity to invest in a recreational centre that will attract many natives and tourists to enjoy the benefits of geothermal water. Based on the study, the implementation of the project seems to be potentially viable and might offer many social, economic and environmental benefits. The critical variables to the success of the project are the interest rate and revenue generation. To overcome this, the execution of sales and marketing strategies should be strongly practiced to convince more customers to use the services provided. Further studies on the calcite scaling, financial sides and detailed design are recommended.

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APPENDIX I: Pump performance curves as described by EBARA Pumps Europe (2017)

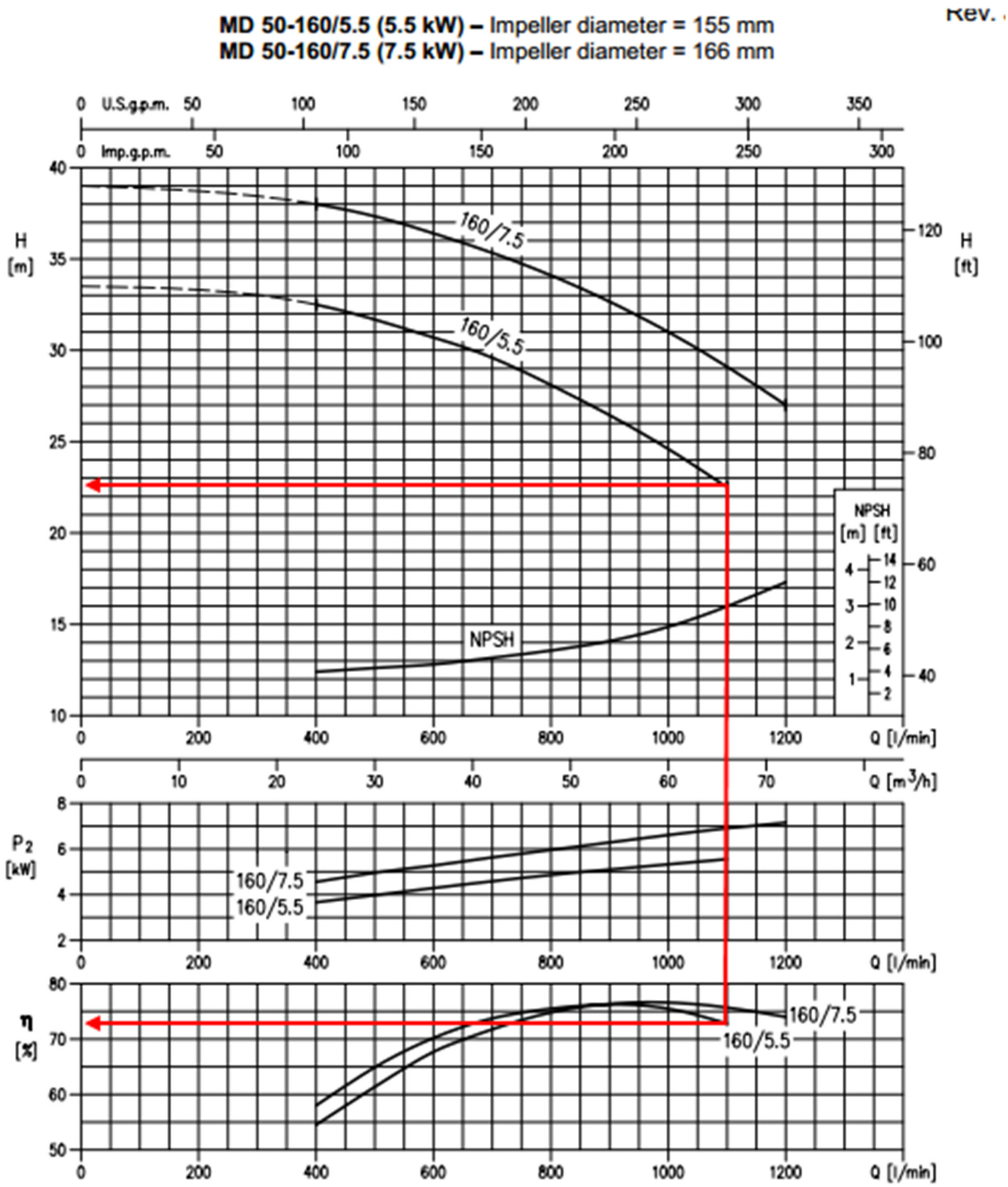

FIGURE 1: Pump performance curves for main swimming pool

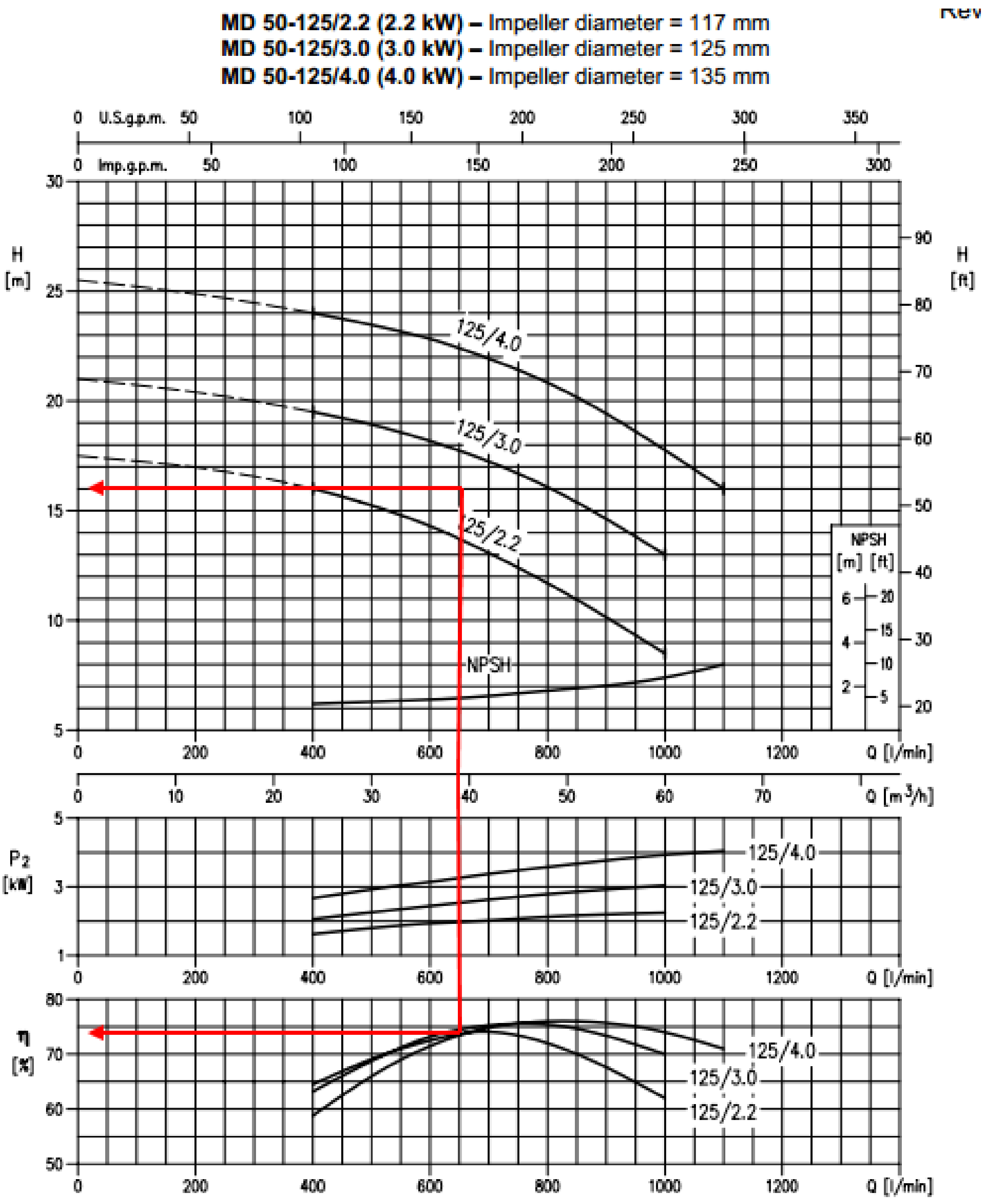

FIGURE 2 : Pump perfomance curves for hot tubs

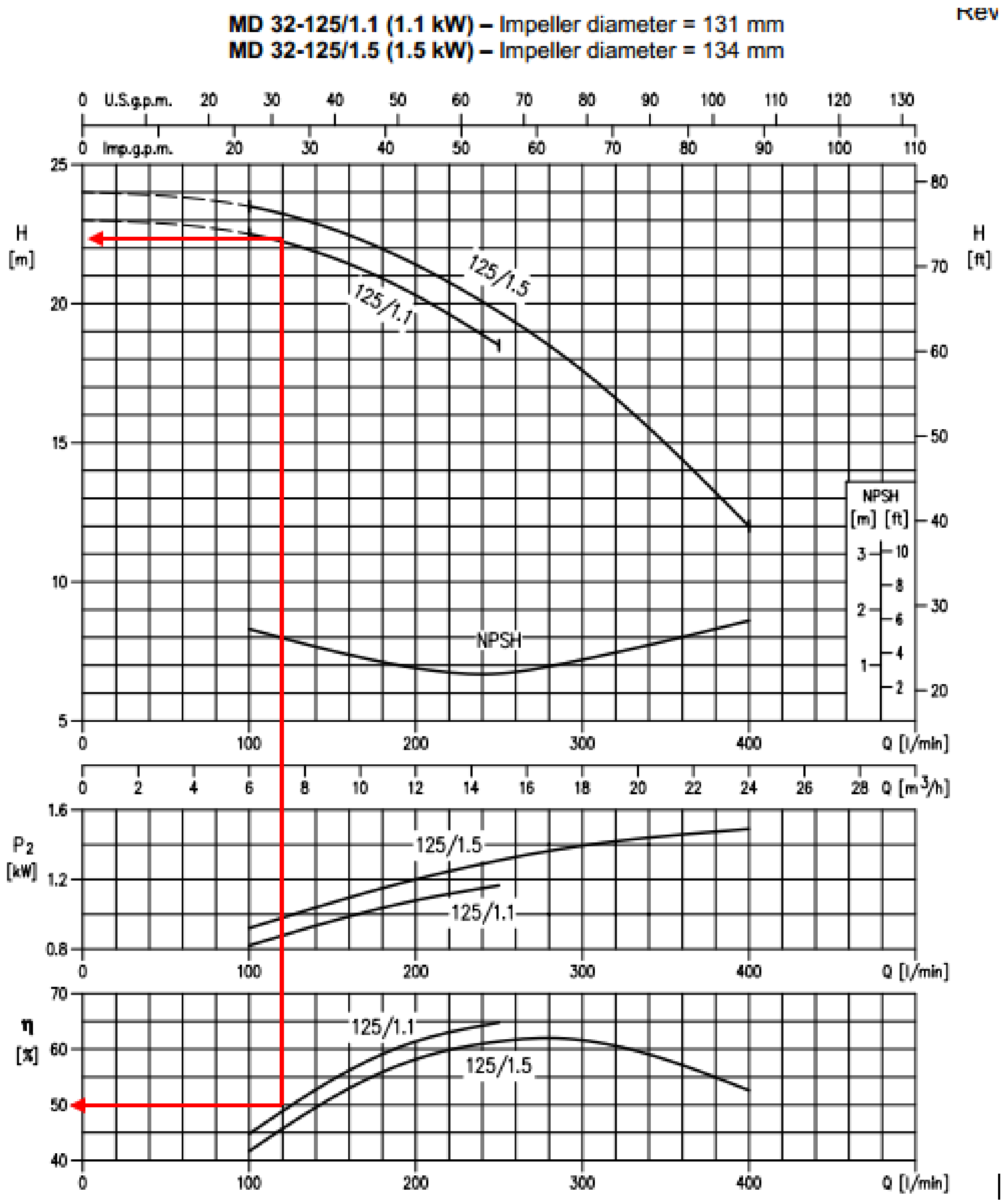

FIGURE 3 : Pump performance curves for childrens pool

APPENDIX II: Results of pump power, head losses, fluid velocity and pipe system within the circulation system

TABLE 1: Results of head losses and pump power

Pools	Pipe diameter (inch)	Fluid velocity (m/s)	Head loss (m)
Main pool			
Overflow pipe	4	0.37	1.02
Filter	2	3.093	4.90
Heat exchanger	2	2.320	3.37
Distributor pipe to pool floor inlet	2	1.326	0.21
Main pipe from swimming pool to control room	4	2.320	10.01
Total head losses			20.28
Pump head required [m]			19.50
Pump power required [kW]			4.06
Children's pool			
Skimmer pipe	2	0.304	0.046
Filter	1.5	1.531	3.69
Heat exchanger	2	0.215	1.02
Distributor pipe to pool floor inlet	2	0.144	0.003
Main pipe from swimming pool to control room	4	0.215	2.21
Total head losses			6.97
Pump head required [m]			8.27
Pump power required [kW]			0.14
Hot tub 1			
Skimmer pipe	2	2.638	1.15
Filter	2	2.638	4.21
Heat exchanger	2	1.319	1.02
Distributor pipe to pool floor inlet	2	1.319	0.29
Main pipe from swimming pool to control room	4	1.319	7.93
Total head losses			14.6
Pump head required [m]			15.61
Pump power required [kW]			1.64
Hot tub 2			
Skimmer pipe	2	2.637	1.26
Filter	2	2.637	4.21
Heat exchanger	2	1.319	1.02
Distributor pipe to pool floor inlet	2	1.055	0.145
Main pipe from swimming pool to control room	4	1.319	7.98
Total head losses			14.6
Pump head required [m]			15.93
Pump power required [kW]			1.67

APPENDIX III: Designed parameters and heat loss calculations

TABLE 1: Designed parameters and results of the heat loss calculations

	Parameter	Value	Unit
Design conditions			
Outside air temperature	T_a	5	°C
Wind velocity	v_2	5.4	m/s
Humidity	H	60	%
Specific heat capacity of water	C_p	4182	J/kg°C
Temperature of incoming geothermal water at heat exchanger	T_i	75	°C
Temperature of outgoing geothermal water	T_o	35	°C
Calculated values			
Main pool			
Heat loss due to convection	Q_C	434.9	W/m^2
Heat loss due to evaporation	Q_E	979.9	W/m^2
Amount of heat loss by radiation, conduction and rain	S	141.5	W/m^2
Total heat loss from the pool	Q_T	1556.3	W/m^2
Energy requirement for the pool at design conditions	E	486.3	kW
Amount of water to be circulated in the system	mc	22.7	kg/s
Amount of geothermal water as a heat source	mg	2.91	kg/s
Temperature of pool water after passing the heat exchanger	T_P	33.1	°C
Kids pool			
Heat loss due to convection	Q_C	503.1	W/m^2
Heat loss due to evaporation	Q_E	1225	W/m^2
Amount of heat loss by radiation, conduction and rain	S	172.9	W/m^2
Total heat loss from the pool	Q_T	1901	W/m^2
Energy requirement for the pool at design conditions	E	95.6	kW
Amount of water to be circulated in the system	mc	1.75	kg/s
Amount of geothermal water as a heat source	mg	0.57	kg/s
Temperature of pool water after passing the heat exchanger	T_P	36.7	°C
Hot tub 1			
Heat loss due to convection	Q_C	648.5	W/m^2
Heat loss due to evaporation	Q_E	1866	W/m^2
Amount of heat loss by radiation, conduction and rain	S	252	W/m^2
Total heat loss from the pool	Q_T	2767	W/m^2
Energy requirement for the pool at design conditions	E	53.3	kW
Amount of water to be circulated in the system	mc	10.7	kg/s
Amount of geothermal water as a heat source	mg	0.36	kg/s
Temperature of pool water after passing the heat exchanger	T_P	41.6	°C
Hot tub 2			
Heat loss due to convection	Q_C	699.7	W/m^2
Heat loss due to evaporation	Q_E	2133	W/m^2
Amount of heat loss by radiation, conduction and rain	S	283.3	W/m^2
Total heat loss from the pool	Q_T	3116	W/m^2
Energy requirement for the pool at design conditions	E	119.9	kW
Amount of water to be circulated in the system	mc	10.69	kg/s
Amount of geothermal water as a heat source	mg	0.72	kg/s
Temperature of pool water after passing the heat exchanger	T_P	41.7	°C