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Cascade Uses of Geothermal Energy in Sabalan - Iran

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ABSTRACT

The Sabalan geothermal area in northwest of Iran is potentially an important place for tourism in Iran. After realizing the plans for building the first geothermal electric power plant in this region and developing swimming pools, using the geothermal water available in this area, hopefully it will be more attractive for tourists and also provide good sanitation facilities for the local people. According to calculations described in the paper, Gheynarjeh hot spring has been found to be suitable as a heat source for a swimming pool, both with regard to the required temperature and flow rate. The paper also describes the design of a district heating system for Moeil village. The heat load for one sample building was calculated. Comparison of mass flow for a geothermal and fuel-fired system was done, and the influence of radiator size on indoor temperature was analyzed based on a steady-state model. In addition to this, a district heating network was designed and calculations done for it. The simulation results are reasonable and provide a good starting point for a real project.

1. INTRODUCTION

Iran has the second largest gas reservoirs in the world and also big oil reservoirs; additionally it has high potential for renewable energy like geothermal, solar, wind, biomass, etc. In 1975, a contract between the Ministry of Energy of Iran (MOEI) and Ente Nazionale per L'Energy Electrica of Italy (ENEL), for geothermal exploration in the north of Iran (Azerbaijan and Damavand regions) was signed. According to the final ENEL reports, priorities should be given to the Sabalan, Damavand, Khoy-Maku and Sahand regions. After the establishment of the Electric Power Research Centre (EPRC) and SUNA (the Renewable Energy Organization of Iran), and after more investigations, the Sabalan region was recommended for the first exploration drilling and electrical generation from geothermal energy in Iran. Hopefully, direct use of geothermal energy will also be established in this area.

Meshkin Shahr is a city in NW-Iran with a population of 164,000. Sabalan Mountain is located southeast of Meshkin Shahr, 4811 m high and at 25 km distance from the city. Meshkin Shahr geothermal prospect lies in the Moil valley on the western slopes of Mt. Sabalan, approximately 16 km southeast of the Meshkin Shahr city. Mt. Sabalan was previously explored for geothermal resources in 1978, with geological, geochemical and geophysical surveys carried out (Fotouhi, 1995). Renewed interest in the area resulted in further geophysical, geochemical and geological surveys being carried out in 1998. The area includes three geothermal fields located in the northern, eastern and southern parts of the Sabalan central volcano, and a number of geothermal prospects are associated with these (Sahabi et al., 1999). The Meshkin Shahr prospect has been identified as the best of these prospects.

In this paper, two alternatives for direct use of geothermal in the Sabalan geothermal area will be discussed, a swimming pool and a district heating system for the Moeil village. These systems are to be operated in connection with a geothermal power plant for electricity generation that hopefully will be established soon in this area.

2. SWIMMING POOL IN THE SABALAN GEOTHERMAL AREA, MESHKIN SHAHR

Swimming has been one of the favorite sports in Iran for many years. Also, based on religion and cultural background, swimming is very important from the point of sanitation. Public baths have existed in most parts of Iran for many years. Coal, wood, oil, etc. are used for heating the water. In almost all areas where hot springs are found, the geothermal water is used for pools for bathing, mainly because of therapeutic effects but also for relaxation. In present time, especially in the Meshkin Shahr and Sarein cities (NW-Iran), there are many swimming pools using geothermal water directly. In this part of the paper the design of a swimming pool for the Moeil village by using geothermal water as a heat source will be discussed.

2.1 Methodology and Design

The size of a swimming pool is one of the important items for design of the pool; it is a basic factor for determining the pool's service, water value, selection of equipment etc. Here swimming pools are being built for students who are learning to swim, people who swim for sport and their relaxation, and for tourists.

The swimming area of a pool should be based on 3.5 m^2 per swimmer. For proper swimming, a lane at least 2.0 m wide and 5.0 m long is required. The designer feels that in a pool which is intended only for swimming, and not for diving and water polo, the maximum depth of water need not to exceed about 1.5 m. For the teaching part of a swimming pool, the amateur swimming association recommends a minimum length of 12.0 m and a minimum width of 7.0 m. The depth generally varies from 0.8 m to 1.0 m. The maximum depth should not exceed 1.2 m (Perkins, 1988). Further, it is assumed that the maximum number of swimmers in the pool at the same time will be 60. Thus, the required surface area is 210 m^2, which is the minimum requirement according to standards. The pool shall have two parts, one part of the size 25 × 13 m with the depth 1 m in the shallow end and 1.8 m in the deep end. The second part is to be a teaching pool of the size 12.5 × 7 m with the depth 0.75 m in the shallow end and 0.90 m in the deep end of the pool. Thus the total water volume of the pool needs to be 527.2 m^3 and the total pool area is calculated as 412.5 m^2.

2.1.1 Schematic Diagram of the Swimming Pool

Figure 1 shows a schematic diagram of the swimming pool. The method adopted for distributing the purified water to the pool and the withdrawal of the contaminated water is of the utmost importance in maintaining the whole of the water in the pool at the required standard of purity and temperature if the water is heated.

A balancing tank is required to even out variations in the quantity of water leaving and entering the pool. A reasonable basis for calculation of the size of the balancing tank is the following: 1. 70 liters per swimmer for the estimated maximum number of customers; 2. Quantity of water required to back-wash one filter; 3. To the total of 1 and 2 add 10% to cover overflow from the pool due to wave action. The total of 1, 2 and 3 gives the net capacity of the balancing tank (Perkins, 1988).

2.1.2 Water Circulation in the Pool

The turnover period is one of the most important factors in operation of the swimming pool. It is the time it takes to circulate all the water in the pool through all the outlets and inlets and all circulation lanes. It changes with the pool loading and mostly depends on the type of pool. For the teaching part of the pool, the turnover period is defined as 1.5 hours and for the other part of the pool 4 hours according to standards (Perkins, 1988). For maintenance of water quality, at least 2 m^3 of properly treated water should be returned to the pool each day for each bather.

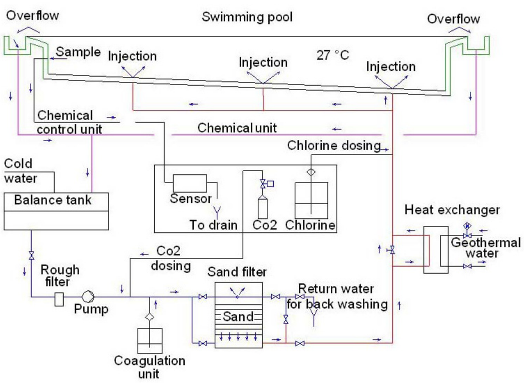

Figure 1: A schematic view of the swimming pool

2.1.3 The Piping System of the Swimming Pool

Water conveyance, water treatment, and in fact the entire swimming pool technology requires pipes and piping system components in large numbers. The selection of materials plays an important role for the water quality of the entire operation and its service life. Thermal water has curative properties, but it can also be very aggressive. All pipes made of polypropylene (PP) or polyethylene (PVC) have passed the tests, so the pipe material chosen is PVC and PP which can resist the above conditions. Before concreting of the floor, pipes with large diameter must be put in the bottom. It will provide good facility for the pipes so they can be connected and packed later. Also, if there are problems with the pipes during operation, they can be solved without any destruction of the walls or floor of the pool.

The water distribution system in the swimming pool is accomplished with the piping system. Considering the pool's volume and turnover period, the mass flow rate through each inlet nozzle in the floor of the pool was calculated. Figure 2 shows the water distribution system, pipe diameters and water flow in each pipe section in the pool's floor.

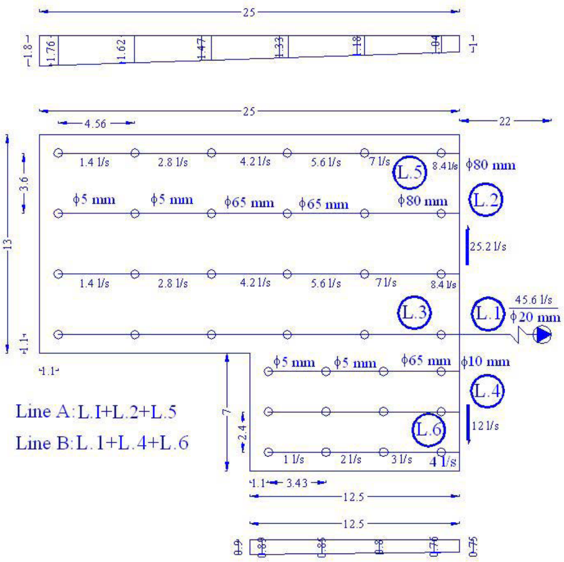

Figure 2: Overview of the pipeline layout

2.1.4 Pressure Drop

Based on the maximum flow rate calculated from the turnover time equal to 44.9 l/s and pressure drop in the water circulation system, circulation pumps can be selected. One way of calculating the pressure drop in the pipelines is using Equation 1 (Olson, 1973), assuming an appropriate value for the roughness factor:

$$\Delta P = \frac{\rho v^2}{2} \cdot \frac{fL}{D} \tag{1}$$

Where ΔP is pressure drop (kPa), k is roughness factor, ρ is density of fluid (kg/m^3), v is velocity of fluid (m/s), L and D are the length and diameter of pipe respectively (m) and finally $f = 1/(2\log D/2k+1.74)^2$.

Table 1 shows pressure drop for the heat exchanger and sand filter. These have not been calculated, but have been selected according to experimental and recommended values through the manufacturers, consultants and consumers.

Table 1. Pressure Drop in the Whole System.

No.	Pressure drop in different parts of the system	Pressure drop (kPa)
1	Heat exchanger	15
2	Sand filter	50
3	Different elevation of pump and pool	20
4	Pressure drop in the water lane	25
5	Total pressure drop in the whole system	110

2.1.5 Heat Loss From the Pool

Heat loss from outdoor pools is mainly due to convection, evaporation, radiation, conduction and rain (Svavarsson, 1990). The main heat losses from the swimming pool occur by convection and evaporation. The obtained results from earlier research and analyses show that heat losses due to the other three factors (radiation, conduction, rain) can be estimated to be equal to 10% of total heat loss due to convection and evaporation. Heat loss due to conduction is small, because of good insulation in the pool building materials. Heat loss by means of rain and radiation is also not very big. In the following calculation, 10% of total heat loss by convection and evaporation will be assumed for these three mentioned factors.

Heat loss due to convection: Heat loss due to convection depends strongly on the air temperature around the pool and the wind speed. Equation 2 shows that heat loss through convection will increase with higher wind speed and lower outside temperature:

$$q_C = h_c(T_w - T_a) \quad (2)$$

where q_C is the amount of heat loss by convection (W/m^2), T_w is water temperature in the pool (°C), T_a is air temperature in the pool's around (°C) and h_c is the convection heat transfer coefficient (W/m^2°C) which is very dependent on wind speed.

The relationship between heat transfer coefficient and wind speed is shown in equation 3 that is named Rimsha-Doncenko formula:

$$h_c = 4.19(k + 0.45v) \quad (3)$$

Where v is wind speed at 2 meter height from the ground surface (m/s) and k is the empirical coefficient (W/m^2°C) as shown in equation 4.

$$k = 0.93 + 0.04(T_w - T_a) \quad (4)$$

Heat loss due to evaporation: Heat loss due to evaporation takes place when there is different partial pressure of water vapour at the pool's surface and in the air over the pool. This will cause evaporation of water at the pool surface, and this requires energy that is taken from the water. This kind of heat loss in the pool can be calculated with Equation 6 from Rimsha – Doncenko (Svavarsson, 1990):

$$q_E = (1.56k + 0.70v^2.(e_W - e_a) \quad (5)$$

Where q_E is the amount of heat loss by evaporation (W/m^2), e_W is the partial pressure of steam at surface (mbar) and e_a is the partial pressure of steam in the air over pool (mbar).

2.1.6 Results and Discussion

Both input and calculated parameters are shown in Table 2. The final result is that the total heat loss from the pool is 711 kW.

Table 2. Input and Calculated Parameters to Calculate the Required Heat for the Swimming Pool.

known factors - design conditions	**Parameter**	**Value**	**Unit**
Air temperature	T_a	-5	°C
Wind speed	v	5	m/s
Humidity (max)	H	60	%
Amount of required water for circulated in the system	m_1	45.6	l/s
Specific heat capacity of water	c_p	4.18	kJ/kg°C
Temperature of pool's cold water before heated by heat exchanger	T_1	27	°C
Temperature of inlet geothermal water at heat exchanger	T_3	75	°C
Temperature of outlet geothermal water at heat exchanger	T_4	35	°C
Pool's area	A	413	m^2
Calculated values			
Amount of required heat for the pool	Q_i	711	kW
Amount of geothermal water as a heat source	m_2	4.25	l/s
Temperature of pool's heated water by heat exchanger	T_2	30.7	°C
Coefficient depends on temperature difference	k	9.25	W/m^2.°C
Heat transfer coefficient	h_C	18.7	W/m^2.°C
Convectional heat loss	q_C	598	W/m^2
Partial pressure of steam at water surface	e_W	35.7	mbar
Partial pressure of steam in the air over pool	e_a	2.41	mbar
Amount of heat loss by convection	q_E	968	w/m^2
Total heat loss from the swimming pool	q_T	1723	w/m^2

Energy Requirement for Heating the Pool

The total heat loss from the swimming pool has been calculated and the same quantity of heat must be added to the water supplied to the pool. This is done through a heat exchanger that transfers heat from geothermal water to fresh water that is used as pool water, or:

$$q_T = q_i \tag{7}$$

where q_i is required quantity of heat for the pool (W/m^2). Equation 8 (wark, 1988) is used for calculation of the amount of geothermal water needed as a heat source and the temperature of pool's heated water by heat exchanger. The results are 4.25 kg/s and 30.7°C respectively. Equation 8 is known as the energy balance equation in the steady-flow condition:

$$Q_i = m_1 c_{p1}(T_2 - T_1) = m_2 c_{p2}(T_3 - T_4) \tag{8}$$

where m_1 is the amount of water required for circulated in the system (kg/s), m_2 is the amount of geothermal water as a heat source (kg/s), c_p is specific heat capacity of water (J/kg°C), T_1 is the temperature of pool's cold water before heated by heat exchanger (°C), T_2 is the temperature of pool's heated water by heat exchanger (°C), T_3 is the temperature of inlet geothermal water at heat exchanger (°C), T_4 is the temperature of outlet geothermal water at heat exchanger (°C) and Q_i is the amount of required heat for the pool (W). The results are m_2 = 4.25 l/s and T_2 = 30.7°C. Table 2 shows all input and calculated parameters in the calculation of the required heat for the pool, the geothermal water's flow rate, pool water temperature after heat exchanger and the total heat loss from the swimming pool.

3. DISTRICT HEATING FOR MOEIL VILLAGE

Moeil village is the nearest residential place to Sabalan geothermal field. According to the weather conditions in this area, space heating for Moeil is an important project. Presently, oil is used for space heating. In this part of the paper, a district heating system for Moeil will be discussed.

3.1 Methodology

Analysis of the outdoor temperature in the area being surveyed is the first step for district heating system design and simulation.

Figure 3 shows the duration curve of outdoor temperature in the moeil village from May 2000 to April 2001. The maximum and minimum temperatures are about 30°C and -22°C in July and January, respectively. The annual average temperature is about 7°C.

3.1.1 Heat Transfer in Buildings

In order to calculate the heat load in buildings, the relationship between the building and its surroundings must be defined. Heat transfer is a transient flow of thermal energy from one system to another due to temperature difference between two systems. There are three kinds of heat transfer including conduction, convection and radiation. In most cases, heat transfer is dominated by conduction and convection.

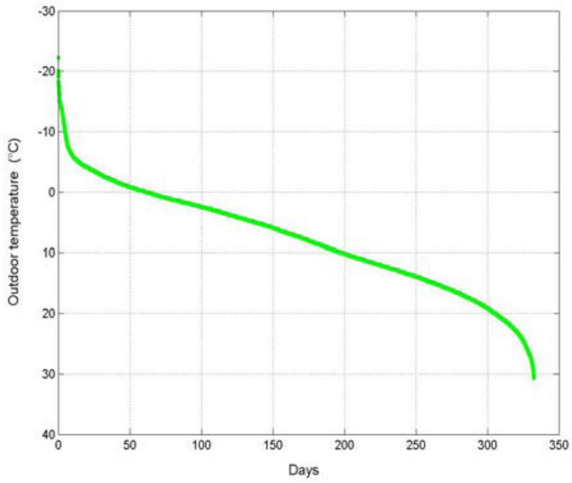

Figure 3: Duration curve of outdoor temperature

Heat transfer calculation

According to fourier's law and considering the composite wall made of different layers and number of materials, using firm thermal resistances of the fluid, the heat transfer from the building to the environment can be calculated according to the following formula:

$$q_c = UA(T_i - T_o) \tag{9}$$

Where T_i and T_o are the inside and outside design temperature respectively.

And the overall heat transfer coefficient of the wall is defined as follows:

$$U = \frac{1}{R} \tag{10}$$

Where, R is the total thermal resistance of heat transfer.

Convection heat transfer

Newton's law of cooling in the following equation is the general equation for heat transfer by convection:

$$q_h = h.A(T_w - T_o) \tag{11}$$

Where h is the convection heat transfer coefficient (W/m^2°C) and its value depends on the complexity of the system, A is the heat transfer surface area (m^2), T_w is wall surface temperature (°C) and T_o is the air temperature (°C).

Radiation heat transfer

Heat transfer by conduction and convection require a medium for existence, this activity by radiation can take place in vacuum, and it is an electromagnetic radiation. The net heat exchange by radiation between two objects is given by the following equation:

$$q_r = \sigma A_1 F_{1-2} \varepsilon (T_1^4 - T_2^4) \tag{12}$$

Where q_r is the rate of heat transfer by radiation (W), σ is Stefan-Boltzman constant (5.669*10-8 W/m^2.K^4), A_1, A_2 are the area of surface 1 and surface 2 (m^2), F_{1-2} is the factor that indicates the fraction of energy between two objects, ε is the common emissivity of the objects and

T_1, T_2 are the temperature of surface 1 and surface 2 respectively (°C).

3.1.2 Building Calculations

There are two kinds of common buildings in the Meshkin Shahr city. In the old part of city, the buildings have at least two stories but without any heat insulation. In the new part of city, the buildings are with four or five stories and with good heat storage capacity. Building heating systems in the Moeil village are not standard in view of its structure and energy storage, so new buildings close to Moeil village that are expected to be built following the building of the first geothermal electric power plant will be discussed. A sample building with four stories is shown in Figure 4. The reference outdoor temperature is -5°C and indoor temperature is 20°C. It has single glass windows and wooden doors.

Building parameters

1) heat transfer coefficient:

Heat transfer coefficient is a constant describing the heat transfer between the building and its environment due to conduction, convection and radiation heat loss, the calculation according to the following formula:

$$U_{tatal} = \frac{U_1 A_1 + U_2 A_2 + ...}{A_{tatal}} \qquad (13)$$

Where U_n is heat transfer coefficient of different components constituting building surroundings (walls, windows, ceilings and floors), (W/°Cm^2), A_n is each component surface area (m^2) and A_{total} is the total surface area of the building (m^2). The heat transfer coefficient is calculated under no insulation. After determining each surroundings heat transfer coefficient, the total buildings heat transfer coefficient can be easily determined using Equation 13, it is shown in the Table 3.

Table 3. Building´s total heat transfer coefficient.

Surface	U (W/m^2.°C)	A (m^2)	U*A (W/°C)
Roof	2.53	212.0	536.36
Floor	2.22	212.0	470.64
external walls	2.00	499.2	998.40
Windows	6.00	67.2	403.20
Total		990.4	2408.60

$U_{total} = 2408{,}6 / 990{,}4 = 2{,}43$ (W/m^2°C)

2) Building Thermal Mass (C):

Thermal mass is the ability of building to storage heat. It is the second parameter needed for simulation. There is a temperature gradient through the wall layers, with the lowest temperature at the layer adjacent to the outside. So the concept of efficient thermal mass is defined by which part of the wall that can store heat for the indoor temperature of 20℃. Figure 5 shows the heat transfer through composite walls. The theoretical equation for calculations is given in Equation 14 (Valdimarsson, 1993):

$$\frac{E}{A} = \int_0^s (T_x - T_0) c_p(x) \rho(x) dx = \int_0^s (T_i - T_0) c_p(x) \rho(x) dx \quad (14)$$

where E is wall´s thermal energy (J), A is wall´s areas (m^2), S is wall´s thickness (m), T_x is material´s mean temperature (°C), T_i is the indoor temperature (°C), T_o is the outdoor temeperature (°C), c_p is material´s specific heat (kJ/kg.°C) and ρ is the material´s density (kg/m^3). Equation 15 gives a simplified one, used for practical calculations:

$$Q = \frac{T_o - T_1}{R_o} = \frac{T_1 - T_2}{R_1} = \frac{T_2 - T_3}{R_2} = \frac{T_3 - T_4}{R_3} = \frac{T_4 - T_5}{R_4} = \frac{T_5 - T_i}{Ri} \qquad (15)$$

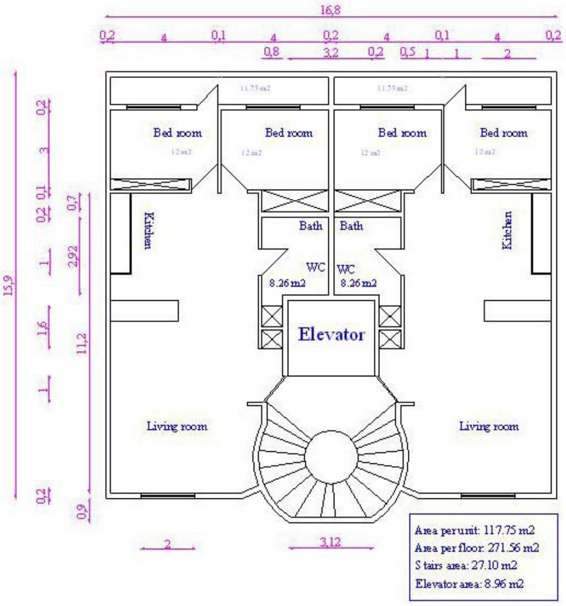

Figure 4: Selected sample building’s plan and details

From Table 3, Equation 15 can be solved giving the following (figure 6):

$T_i = 20^o C$, $T_o = -5^o C$, $Q = 50.71 W$, $T_1 = -3.48^o C$

$T_2 = -3.03^o C$, $T_3 = -2.19^o C$, $T_4 = 14.71^o C$, $T_5 = 14.93^o C$

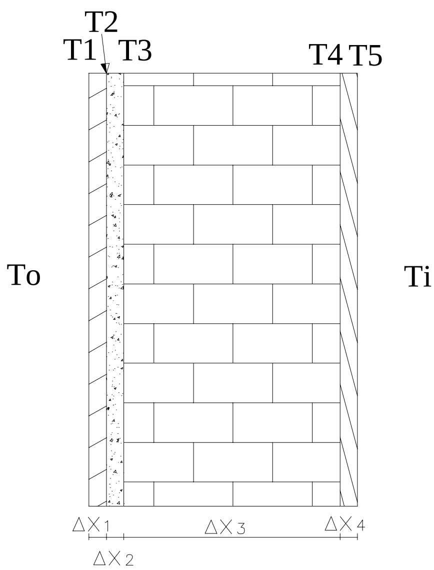

Figure 5: Heat transfer through composite walls

Then the mean temperature of each layer is found subtracted from the outdoor temperature and then multiplied by that material’s thermal capacity and density to get the walls thermal capacity. Table 4 summarizes the calculations of the thermal mass of the building.

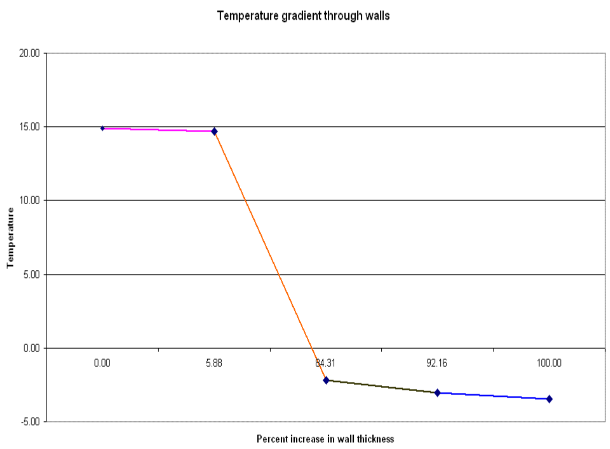

Figure 6: Temperature gradient through walls

Radiators

For heat transfer from the heating system to the heated place heat exchanger is used, that is known radiator. According to Anon (1977), the relative heat load of a radiator can be written as:

$$\frac{Q}{Q_0}=\left(\frac{\Delta T_m}{\Delta T_{m0}}\right)^{(4/3)}=\left(\frac{T_s-T_r}{\ln\left(\frac{T_s-T_i}{T_r-T_i}\right)}\cdot\frac{\ln\left(\frac{T_{s0}-T_{i0}}{T_{r0}-T_{i0}}\right)}{T_{s0}-T_{r0}}\right)^{(4/3)} \quad (16)$$

where Q/Q_o is the ratio of the actual heat output from the radiator to the heat output at design conditions, T_s is water supply temperature (°C), T_r is water return temperature (°C) and T_i is the room temperature (°C).

The logarithmic temperature difference (ΔT_m) for radiators is defined as:

$$\Delta T_m=\frac{(T_s-T_i)-(T_r-T_i)}{In\frac{T_s-T_i}{T_r-T_i}}=\frac{(T_s-T_r)}{\ln(\frac{T_s-T_i}{T_r-T_i})} \quad (17)$$

Table 4. Building's Thermal Mass.

Surface	C (kJ/°C)
Roof	82601.77
Floor	16797.52
External Walls	168409.6
Internal Walls	100972.6
Total	368781.5

Building heat loss

Heat loss through the building can be calculated with equation 18:

$$Q_{loss}=k_l(T_i-T_o) \quad (18)$$

Where k_l is building heat loss, which is a constant factor. Relative heat loss can be obtained as:

$$\frac{Q_{loss}}{Q_{loss0}}=\frac{T_i-T_o}{T_{io}-T_{oo}} \quad (19)$$

Pipe heat loss

In the district heating system there is heat loss through the pipe between pumping station and the buildings to be heated. This value of heat loss can be calculated by using district heating pipe transmission effectiveness parameter. According to Valdimarsson (2001) the transmission effectiveness τ is defined as follows:

$$\tau=\frac{T_s-T_g}{T_1-T_g}=e^{\frac{U_p}{mC_p}} \quad (20)$$

The reference value of the τ can be concluded from the reference flow conditions:

$$\tau_o=\frac{T_{so}-T_g}{T_{1o}-T_g}=e^{\frac{U_p}{m_oC_p}} \quad (21)$$

Parameters U_p and C_p is assumed to be constant all over the system. Combining the equation 20 and 21, the transmission effectiveness can be obtained:

$$\tau=\tau_o^{\frac{m_m}{m}} \quad (22)$$

Combining the equations 20 and 22, the supply temperature to the house can be calculated:

$$T_s=T_g+(T_1-T_g)\tau=T_g+(T_1-T_g)\tau_o^{\frac{m_o}{m}} \quad (23)$$

If the district heating network circulates water, the return water temperature at the pumping station is obtained from equation 24:

$$T_2=T_g+(T_r-T_g)\tau=T_g+(T_r-T_g)\tau_o^{\frac{m_o}{m}} \quad (24)$$

Building energy storage

When the heating of building is turned of the building does not cool down immediately. The building has heat capacity and it stores energy. The building energy storage model is:

$$\frac{dT_i}{dt}=\frac{1}{C}Q_{net}=\frac{1}{C}(Q_{supp}-Q_{loss}=\frac{1}{C}(mC_p(T_s-T_r)-k_l(T_i-T_o)) \quad (25)$$

All time derivatives equal to zero in steady state model, in dynamic modelling these parameters are effective.

3.1.3 Steady State Approach

When steady state condition, assume to be established in the district heating system, there is not heat to be stored in the buildings. Return temperature can be calculated according to Nappa (2000):

$$\frac{Q}{Q_0}=\left(\frac{T_s-T_r}{T_{s0}-T_{r0}}\cdot\frac{\ln\left(\frac{T_{s0}-T_{i0}}{T_{r0}-T_{i0}}\right)}{\ln\left(\frac{T_s-T_i}{T_r-T_i}\right)}\right)^{4/3}=\frac{T_i-T_o}{T_{io}-T_{oo}} \quad (26)$$

T_r can be calculated with iteration from equation 26 According to Valdimarsson (2003) fastest convergence is obtained, when T_r inside logarithm is calculated:

$$T_{r,n+1}=(T_s-T_i).e^{-z}+T_i \quad (27)$$

Where z is:

$$z = \frac{T_s - T_{r,n}}{T_{so} - T_{ro}} \cdot \left(\frac{T_{io} - T_{oo}}{T_i - T_o} \right)^{3/4} . \ln \left(\frac{T_{so} - T_{io}}{T_{ro} - T_{io}} \right) \quad (28)$$

When outside temperature data is given, T_i is assumed to be constant and supply temperature is known, $T_{r,n+1}$ can be found iteratively from the equation 27.

In the steady state model, the heat loss from buildings is the same as the heat load supply:

$$Q_{\sup p} = Q_{loss} \quad (29)$$

$$mC_p (T_s - T_r) = k_l (T_i - T_o) \quad (30)$$

Mass flow is obtained directly from equation 30.

$$m = \frac{k_l (T_i - T_o)}{C_p (T_s - T_r)} \quad (31)$$

Factor k_l can be calculated from the reference conditions

$$k_l = \frac{m_o C_p (T_{so} - T_{ro})}{T_{io} - T_{oo}} \quad (32)$$

Reference values and constants

All reference values are marked with subscript o. Common reference values for geothermal district heating network are:

Supply water temperature $T_{s0} = 80$ °C;

Return water temperature $T_{r0} = 40$ °C;

Room temperature 20°C.

The reference values used for fossil fired network are:
Supply water temperature for primary network $T_{s0} = 90$ °C;
Return water temperature for primary network $T_{r0} = 70$ °C;
Room temperature $T_{i0} = 20$ °C.
The reference outside temperature depends on climate. The reference value for moeil village $T_{oo} = -5$ °C was used here in both the geothermal and the fossil fired systems. Ground temperature was assumed to be constant 5°C. The reference mass flow of water is related to the size of network to be studied. Here it was selected to be 0.32 kg/s. The specific heat capacity of water assumed to be constant and dependence of temperature was neglected. The specific heat capacity (C_p) was assumed equal to 4.186 (kJ/kg.°C).

3.3 Results and Discussions

The steady state model was programmed with MATLAB. The weather data was used. In this section, some Figures are plotted and discussed.

Figure 7 shows the duration curve for outdoor temperature T_o, return temperature T_r and supply temperature T_s during one year (per half an hour). It is necessary to mention that all calculations were done in the Matlab program. Outdoor temperatures of more than 15°C were assumed to be 15°C as no heat is required under these conditions. In this figure, the Y-axis is reversed.

The mass flow duration curve is shown in Figure 8. There are 22 days per year with higher mass flow than assumed available. The system will not be able to supply the required heat during those 22 days, if such limitation is imposed. An economical analysis is due here to find the best value of such limit, considering cost of lack of heat versus the investment for additional wells.

Figure 9 shows the relationship between return temperature and mass flow. From this curve it can be seen that when mass flow increases, the return temperature also becomes higher. This means that most of the mass flow in the system has higher return temperature, as shown in Table 4. This is because when there is more heat requirement in the building (lower outdoor temperature), hot water circulation through the radiators will be increased (higher mass flow), and the temperature difference between the supply and return temperature will be smaller.

Figure 10 shows the water temperature in the district heating network. The water temperature at pump station (T_1), supply temperature to consumers (T_s), return temperature from consumer and return temperature to pump station (T_2). Temperature difference between T_r and T_2 shows heat loss through the pipe line.

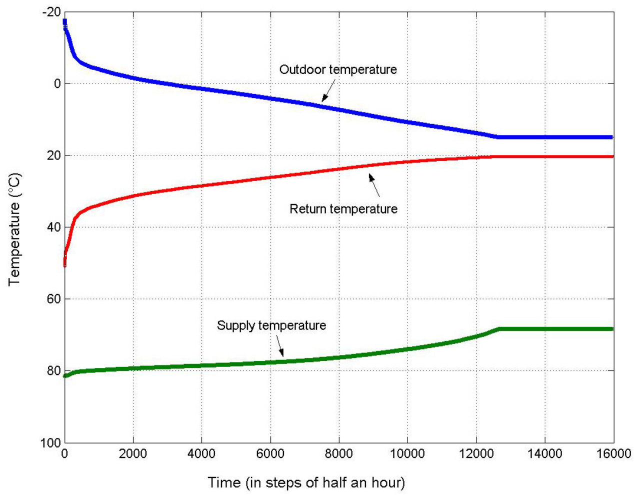

Figure 7: Duration curve of supply, return and outdoor temperature

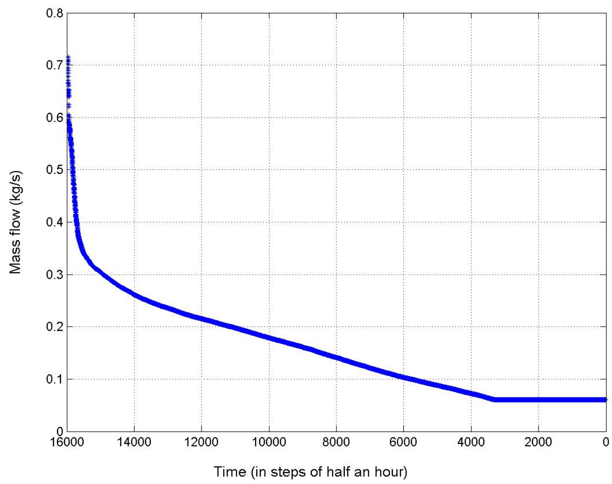

Figure 8: Duration curve of mass flow

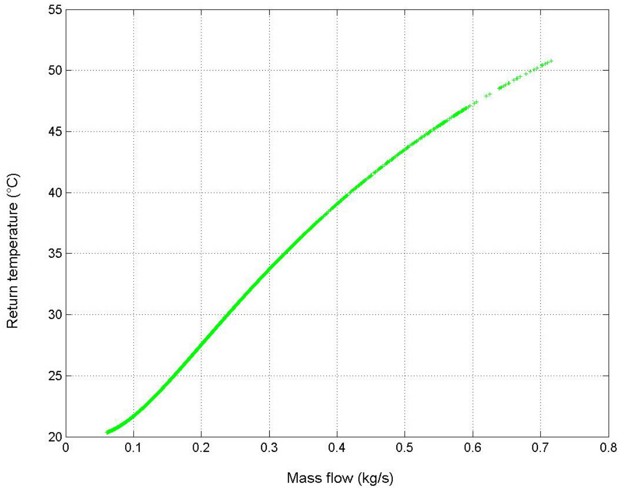

Figure 9: Return temperature as a function of mass flow

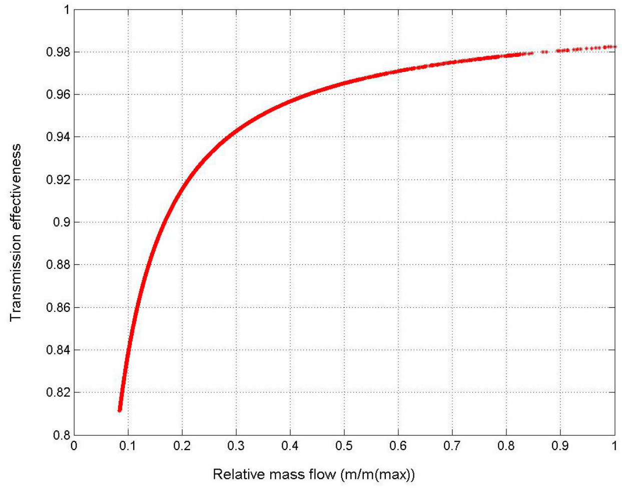

Figure 11: Pipe transmission effectiveness as a function of relative mass flow

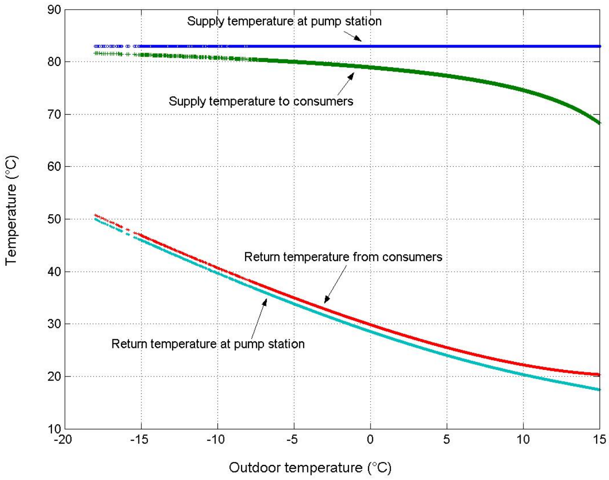

Figure 10: Different temperature in the network

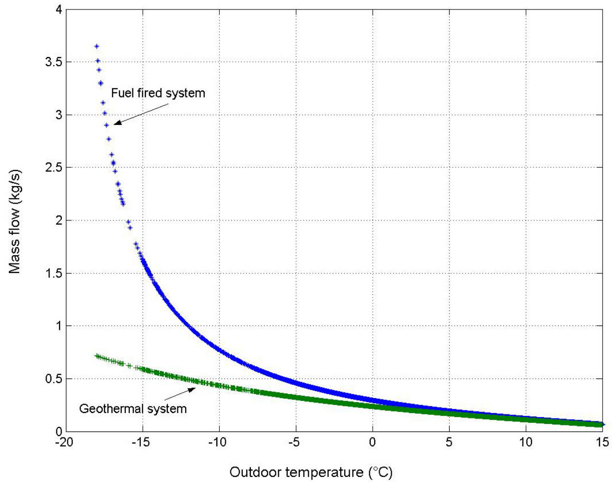

Figure 12: Comparison of mass flow for two heating systems

Figure 11 shows the pipe transmission effectiveness T , as a function of relative mass flow (m/m_{max}).

Figure 12 finally shows the relationship between outdoor temperature and mass flow for typical geothermal and fossil fuel fired systems. A typical geothermal system is taken to have 80/35°C design temperatures for supply and return, whereas a typical fuel fired system has 90/65°C as design temperatures. The geothermal system will require larger radiators, in order to obtain these design temperature. This investment is justified by less mass flow required from the wells. Else more wells will have to be drilled and the yearly utilization time of these additional wells will be low.

It is interesting to notice that when heat requirement is low, mass flow is low, so temperature drops in both the supply and return hot water will be high. Some critical temperatures are given in Table 4.

<u>Network optimization</u>

Optimization involves finding the system parameters in such a way, that a predefined cost function has a minimum. Scheme of network is shown in Figure 13.

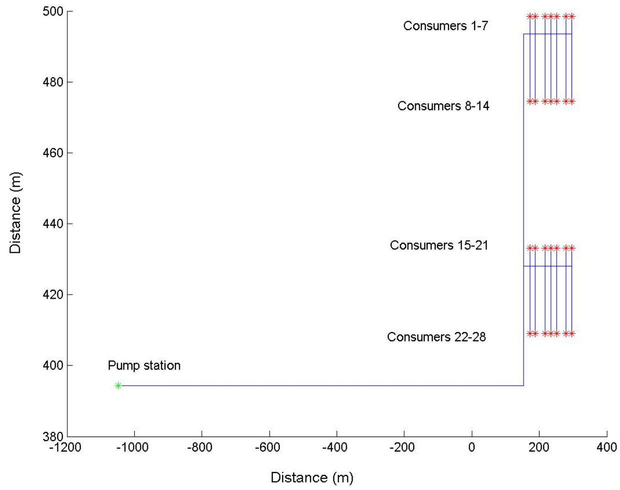

Figure 13: Scheme of network

Nodal pressure

The pressure at the nodes is determined by the element pressure loss. If a target pressure loss per unit length is defined, a target nodal pressure is also defined. The voltage law of Kirchhoff places restrictions on this, because the pressure loss along any closed path has to sum up to zero, and makes it therefore impossible to obtain target pressure loss in all the elements. A loop free network has a unique solution for the nodal pressure.

If the nodal pressure is considered an independent variable, the pressure loss per unit length can be calculated for all elements (Valdimarsson 2003). In this paper, we focus on the network with a total pipe length of 3.82 km and serving 28 buildings. So-called h/L diagrams are presented here to show the network performance. On these diagrams, the nodal head is plotted as a function of the distance from the inlet point, measured according to a selected tree set. Thus one pipe in each loop, the link, is not represented with correct length. The h/L diagram for the existing network is shown on Figure 14. The link pipes are shown grey on the figure. The network shown is the supply network with a total pipe length of 3.82 km. The return network has similar topology, but opposite flow direction, and is not treated in this paper.

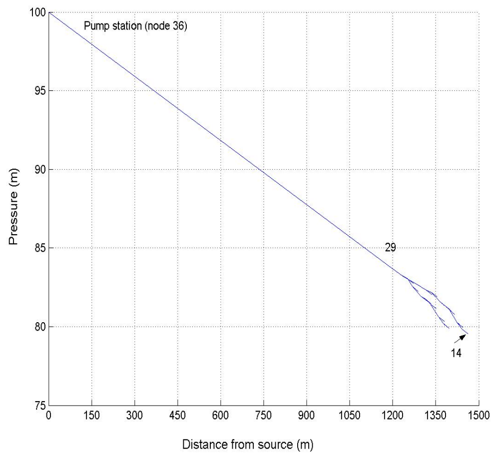

Figure 14: Pressure drop in the network

Figure 15 shows the temperature drop per node of network. From Table 5 it can be seen that the results are reasonable.

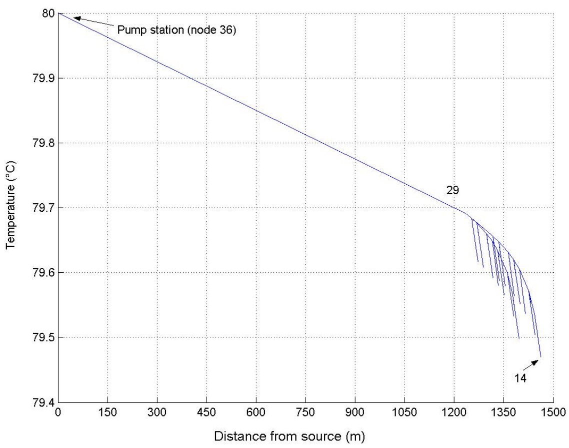

Figure 15: Temperature drop in the network

Table 5. Maximum and Minimum Values for Pressure and Temperature Drops.

Parameters	Max. (node 36)	Min. (node 14)	Peak value
Pressure (m)	100	79.55	16.32
Temperature (°C)	80	79.47	0.30

CONCLUSIONS

The main conclusions derived from this work are summarized as follows:

The swimming pool is designed according to the most common standards regarding the required dimensions and sanitary equipment. The surface area of the pool is designed as 412.5 m^2 and to keep the pool water temperature at 27°C at -5°C outdoor temperature, a heating capacity of 711 kW is needed.

The artesian hot water spring available in the Sabalan geothermal area, Gheynarjeh with a flow rate of 7 l/s, at temperature of 83°C, can be used as a eat source for a swimming pool. According to the calculations performed in the project, 4.25 l/s of 75°C hot water are required for this purpose.

A steady-state model for both a geothermal district heating system and a fuel-fired system has been developed and the relationship between outdoor temperature and mass flow in both of them compared. In the geothermal heating system, the mass flow is lower and the radiators larger, so it is both possible and favourable from an economical point of view.

The heating has a sharp peak load, so limitation of the maximum flow may be cost-effective compared to drilling additional geothermal wells with low utilization time.

A simulation model is a powerful tool for studying and analyzing district heating systems.

Maximum mass flow and radiator sizes are important parameters affecting the indoor temperature of district heating systems. The maximum mass flow can be controlled by a control valve.

In the long run, it can be economically advantageous to pay more attention to insulation of buildings and their energy storage ability in Iran. This is based on present condition of buildings and energy costs in the country.

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Table 4. Maximum and Minimum Parameters in the Geothermal District Heating System.

Parameters	**T_o (°C)**	**T_1 (°C)**	**T_2 (°C)**	**T_r (°C)**	**T_s (°C)**	**m (°C)**	**Q (kW)**	**ΔT**	**T_s-T_r (°C)**	**T_r-T_2 (°C)**
Maximum	15	83	49.98	50.78	81.63	0.72	92.34	Minimum	30.85	0.80
Minimum	-18	83	17.45	20.35	68.29	0.06	12.15	Maximum	47.79	2.90