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A DEMONSTRATION GEOTHERMAL PROJECT IN BEIJING - MULTIPLE UTILIZATION OF GEOTHERMAL ENERGY

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ABSTRACT

This report describes a demonstration project for direct use of geothermal energy in Beijing. The object of the project is to find a suitable way to optimise utilization of geothermal energy in Beijing with a water temperature range of 45-88˚C. Geothermal water, 71˚C warm and with a flow rate of 140 m^3/h, comes from the so-called Share-6 well, and is used for district heating and a swimming pool. Several different terminal systems are discussed in this paper. A heat pump is used as a reserve for peak load during the heating period. It is also used for cooling in summer with shallow groundwater as a cold resource. Cascaded uses and automatic control systems contribute to lower energy consumption which, in turn, enable more extensive use of the geothermal energy. The use of a heat pump further extends the field and capacity of geothermal utilization. The environmental advantageous effects of geothermal energy are significant.

1. INTRODUCTION

Beijing is the capital city of People's Republic of China. The total population of Beijing is 14 million; of that, more than 7 million people live in the centre of the city and need heating in the winter. The energy for space heating came mostly from coal a few years ago; at least 2.8 million tons standard coals were required per year. Hence, the environment was heavily polluted by emissions from burning coal. This has caused much concern in recent years. Government and public both want to change the situation. Now, it is forbidden to construct new coal boilers for heating and the use of clean and renewable energy is encouraged instead. This will lead to a big improvement in the energy sector.

Geothermal energy is a clean and renewable form of energy, which has been widely used around the world in the last century for electricity generation, space heating, spas, green houses etc. Beijing is situated on top of a large and deep sedimentary basin with several (~10) geothermal fields. The hot water ranges in temperature from 45 to 88˚C, and has been exploited from surface springs and geothermal wells varying in depth from 1000 to 3500 m. The yearly production of geothermal water is about 10 million m^3, 10% of the estimated potential capacity, primarily used for aquaculture, recreation and bathing etc. Geothermal water used for space heating only started a few years ago. Due to the great benefit to the environment and significant efforts towards a better economy, geothermal heating systems have been developing rapidly.

With rapid development, a high technical level, efficiency and economic systems are strongly demanded, as well as a reasonable impact management system. This proposed project is a demonstration project with the purpose of investigating geothermal utilization in district heating and cooling with the aid of a heat pump. The plan is to use geothermal hot water from Share-6 well as a heat resource and four shallow water wells as cooling sources.

All the buildings used in this demonstration project belong to the the Geological Technical Institute of Beijing. They are three old residential buildings (12,000 m^2) built in 1975; one office building (3,800 m^2) refitted in 2000; one old apartment building (5,900 m^2) built in 1970; a new hotel and sport museum (4,000 m^2) an indoor swimming pool (space area, 2000 m^2); and a new restaurant (1500 m^2), as shown in Figure 1.

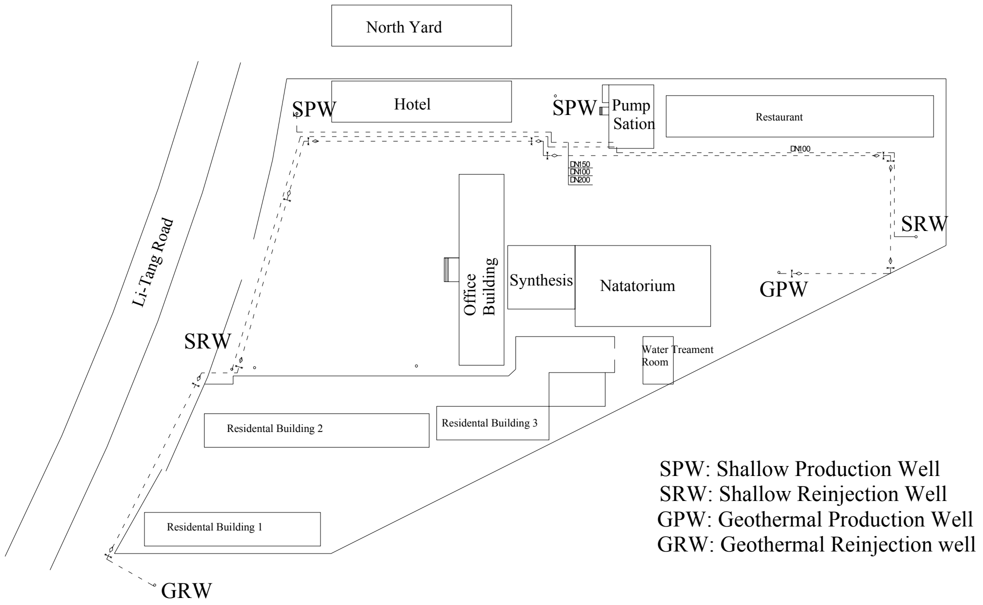


FIGURE 1: Distribution map; the three districts composed of several buildings are shown and location of wells with net-pipes connected to the pump station

2. GEOTHERMAL FIELD AND SHARE-6 WELL

The geothermal well in this project is well Share-6, which was drilled during the winter of 1999/2000 to a depth of 2418 m. It is located at No. 2 Jia, Liushuiqiao and belongs to the Shehe geothermal field (Zhu et al., 2001). Liushuiqiao is an area located in the northern part of Beijing, in close proximity to the site of the future Olympic area.

When well Share-6 was finished, the wellhead pressure was 2.7 bar. Initial artesian flow rate was about 120 m^3/h; the maximum pumped discharge capacity is believed to be more than 140 m^3/h. But for the whole proposed area only 45 m^3/h geothermal water are needed. In other words, the capacity of Share-6 is higher than the demand of the project. The main purpose of the project is to use the geothermal energy as economically as possible for the most optimal heating system. The plan is to sell the remaining geothermal resource to the neighbouring residential district, or connect to another much bigger geothermal district heating system, the Beiyuan Garden geothermal district heating project with a 400,000 m^2 space heating area in the first phase and 800,000 m^2 in the second phase.

At the beginning of 2002, a reinjection well was successfully finished, 1000 m southwest of well Share-6. This winter, 2002-2003, it will be connected to the present system for reinjection experiments. But the head pressure of this well is also relatively high. Therefore, high reinjection pressure and equipment is needed. Careful monitoring should be taken, in order to get detail information about the reinjection capacity and to estimate the rate of scaling and corrosion.

Some water samples were taken from well Share-6. The conclusion of geochemical analysis is that there are no silica, calcite or magnesium deposits associated with utilization of this well. And there is no dissolved oxygen component in this water, but hydrogen sulphide (H_2S). Because of the fast reaction between dissolved oxygen and hydrogen sulphide, they are not present in the water at the same time. Hence, copper pipes and components in contact with the water should be avoided in the system. It is recommended to use a closed-loop system. If the high iron content of the geothermal water gets into contact with the atmosphere it may oxidize to iron hydroxide, causing the water to turn a brownish colour.

3. DIRECT USE OF GEOTHERMAL WATER

3.1 Space heating and cooling

Due to the relatively low temperature of the geothermal water, its use for district heating had not developed much in Beijing before the end of the last century. In recent years, technical insulation of buildings has been significantly improved and various terminal equipment with high heat transfer efficiency have been taken into use. Hence, hot geothermal water is considered suitable for space heating systems, in some cases associated with other energy suppliers. The purpose of this project is to find the best way of utilizing geothermal water in district heating systems.

Both in direct and indirect geothermal heating systems, traditionally geothermal water has been discharged to drain even at temperatures above 45˚C as it was deemed unsuitable for heating. Iceland and some other European countries have employed heat pumps to boost the water temperature by using absorbed heat from the waste geothermal water for more than ten years. Results indicate that it is an efficient and economical way of using geothermal resources. An important benefit of installing a heat pump is that it can be used for cooling during the summer. More discussion about using a heat pump associated with a geothermal district heating system will be presented in this paper.

3.1.1 Weather conditions

The load on heating systems is closely related to the influences of the outdoor climate. The main factors influencing the load are the air temperature, wind speed and solar radiation. Other minor influences are due to steep cold wave and precipitation, etc. The purpose of the analysis is to examine the dynamic characteristics of weather on heat demand.

The three main factors are analysed. Ten years of climate data, from September 1991 to September 2000, were obtained from the Meteorological Bureau of Beijing. Observations on highest, average and lowest air temperature, wind speed and sunshine radiation were made at daily intervals. Average year indicators can be established based on the ten years of weather data. In Figure 2 such average years are shown, along with two standard deviation confidence intervals for outdoor air temperature.

The outdoor temperatures of –9˚C and 33˚C were chosen as the heating and cooling design temperatures, respectively. These values were chosen based on the ASHRAE fundamentals from 1997. They give the limits under which the actual outdoor temperature should not be expected to fall for more than 1% of the limit hours of the year (Figure 3). Unfortunately, the weather data collected is only sufficient for a static study, but not for the purposes of evaluation by a dynamic model. More detailed data in intervals of not more than 2 hours, should be obtained for a dynamic model simulation.

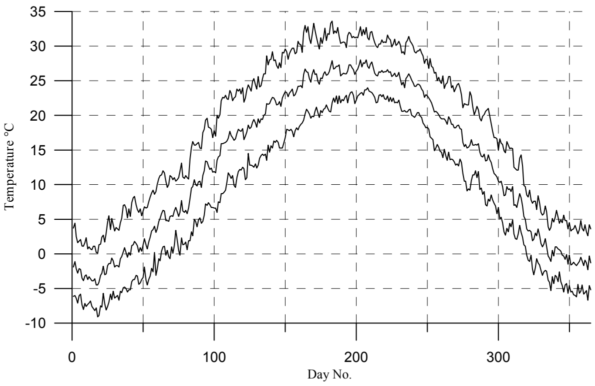


FIGURE 2: Daily average, maximum and minimum outdoor air temperature in Beijing 1990-2000

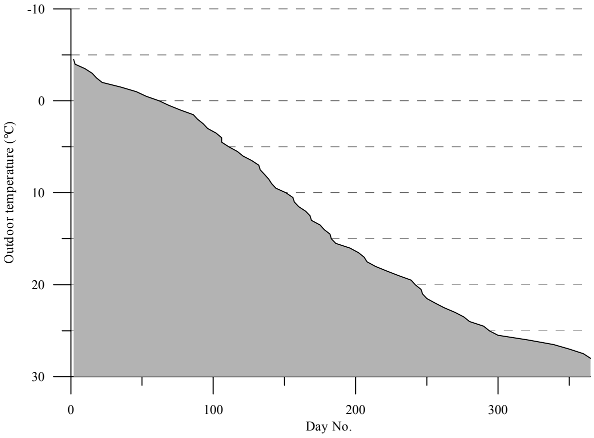


FIGURE 3: Outdoor air temperature duration curve

According to the Chinese Building Code, the indoor temperature of housing must lie between 16 and 18˚C during the heating period in winter and between 23 and 24˚C during the cooling period in summer. That means 18 and 24˚C were considered acceptable during cold periods and heat waves, respectively, i.e. when the outdoor temperature exceeds the design temperatures (-9 or 33˚C) for short periods of time.

3.1.2 General design and load assessment

As shown in Figure 1, the buildings (29,200 m^2 space area) are divided into three districts. The buildings are characterised by different types of insulation and heating methods and, for the purpose of the analysis, buildings of similar character are grouped together. District A includes the three old buildings in the south yard which use old single-pipe radiator heating systems. District B is another area with old buildings, in the north yard, which also use an old single-pipe radiator heating system.

District C is the biggest, and includes five subunits, i.e. a new hotel, a synthesis centre, an office building, a natatorium and a restaurant. New air fan coil unit systems are used here with different types and installation density, of different heating and cooling load capacity values. There are two tanks used for distribution and collection of supply and return water, respectively. Therefore, each district (A to C) must be analysed separately when simulating the thermal systems.

Figure 4 shows the system diagram of the whole project. There are four heat exchangers used for the three different districts. The circulation water is heated via heat exchanger 1, with 13˚C difference between the supply and return temperatures. The supply temperature can reach 65˚C, suitable for the old radiator system in district A. Simultaneously the geothermal water is cooled down from 71˚C to 59˚C and flows into heat exchanger 2. Due to the lower geothermal temperature in heat exchanger 2, the outlet (supply) temperature is lower, only 53˚C. But district B is small compared with the others. The required heat output may be reached by high circulation flow rate with lower temperature drop. The return water from the circulation is about 43˚C. The geothermal water cools down to 52˚C and then goes further to heat exchanger 3.

As mentioned before, District C includes five subunits; two tanks are used to distribute and collect the circulation water. The outlet water temperature from heat exchanger 3 is about 50˚C and the return water from the collection tank is 40˚C. The energy deficit of District C can be complemented by the heat pumps, with similar supply and return temperatures. The geothermal water temperature goes down to 42˚C and partly goes to heat exchanger 4 where it is cooled down to 15˚C, and another part goes to the

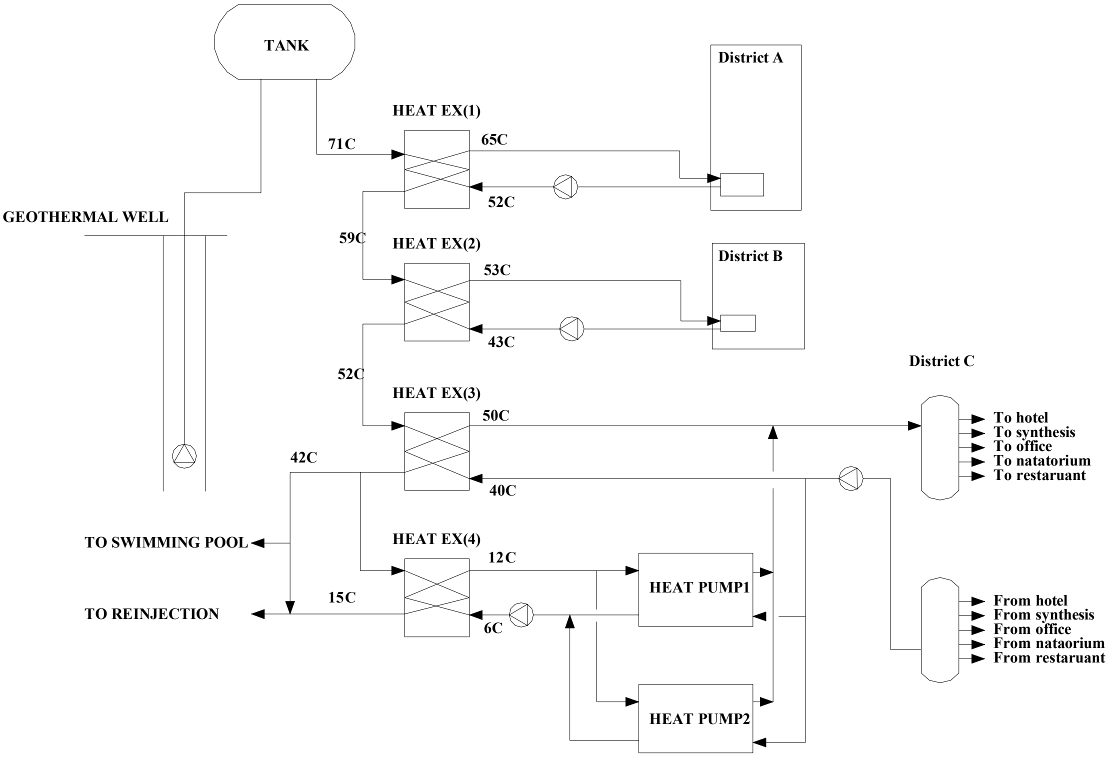


FIGURE 4: System diagram of the project

swimming pool. The geothermal water after heat exchanger 4 is mixed with the rest of the 42°C water, and then drained or injected into the reinjection well. Part of the geothermal water is transferred to a closed loop between heat exchanger 4 and the two heat pump units. On the heat pump side, the outlet and inlet temperatures of the heat exchanger are 12 and 6°C, respectively.

Based on the specifications of Chinese building construction and the pertinent weather data, the specific heat load of buildings in Beijing is defined as follows:

- Residential buildings: 50 W/m^2;
- Public buildings: 70 W/m^2;
- Natatorium: 125 W/m^2.

And specific cooling capacities are

- Public buildings: 90 W/m^2;
- Natatorium: 160 W/m^2.

The design temperatures relative to design load capacities are

- Heating design temperature:
  - ✓ Outdoor temperature T_{a0} = - 9°C;
  - ✓ Indoor temperature T_{i0} = 18°C.
- Cooling design temperature:
  - ✓ Outdoor temperature T_{a0} = 33°C;
  - ✓ Indoor temperature T_{i0} = 24°C.

The maximum energy load capacity of the whole area, both in winter and summer was calculated with the results listed in Table 1.

TABLE 1: Maximum heating and cooling load

District	**Area (m^2)**	**Heating load (kW)**	**Cooling load (kW)**
A	12,000	600	-
B	5,900	295	-
C_1	2,400	168	249
C_2	4,000	280	360
C_3	3,800	266	342
C_4	2,000	250	320
C_5	1,200	105	108
C - total	13,400	1,069	1,379
Total	**30,100**	**1,964**	**1,379**

Real-time energy demand depends on weather conditions, temperature, wind, and so on. Here we can simply consider the air temperature to estimate the energy demand. The heat transfer from houses to the outdoor surroundings (heat lost), or from the outdoor surroundings (heat gain), is a linear fraction of outdoor temperature:

$$Q = k\Delta T \tag{1}$$

where k = Transfer coefficient of buildings [kW/˚C];
ΔT = Difference between indoor and outdoor temperatures [˚C].

Assume the indoor temperature as constant. Q is only a function of outdoor temperature. Compared with the reference conditions also called design conditions, k can be omitted:

$$\frac{Q_t}{Q_o} = \frac{T_i - T_a}{T_i - T_{ao}} \tag{2}$$

or,

$$Q_t = \frac{T_i - T_a}{T_i - T_{ao}} Q_o \tag{3}$$

where T_a, T_i and Q_0 are given as reference parameters, but different in heating and cooling phases. The energy consumptions were evaluated in the following two diagrams in the form of duration curves (Figures 5 and 6). For the cooling load duration of District C (Figure 6), values are based on average outdoor temperatures.

The normal heating period in Beijing is from 15 November to 15 March, a total of 120 days. But according to weather analyses (Figure 2), in the coldest 120 days the highest outdoor temperature is only about 6˚C. If we extend the heating period to 150 days, it will be 10˚C and more suitable for customers than the conventional method. Accumulating the energy demand for one winter, it is estimated that 2.89×10^6 kWh or 96 kWh/m^2 will be needed.

The cooling area does not include districts A and B. District cooling operates when the outdoor temperature is higher than 24˚C. According to weather analyses (Figure 2), it is about 80 days from 10 June to 30 August. Accumulating the energy demand for one summer, it is estimated that 660×10^3 kWh or 48.5 kWh/m^2 will be needed.

In the following chapters, more details of energy performance in the system will be discussed. Some models and simulations will be set up for analysis.

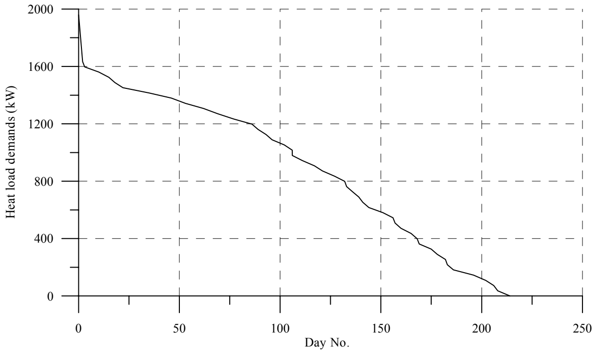


FIGURE 5: Maximum heating load duration

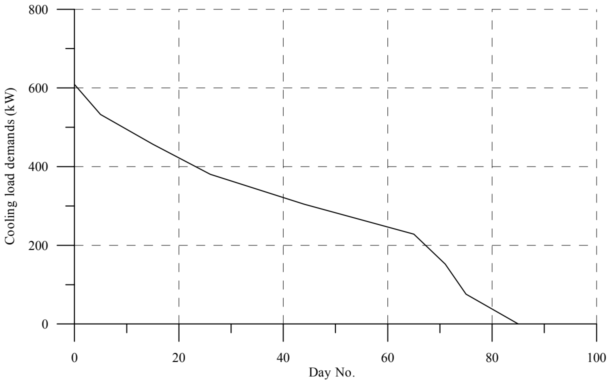
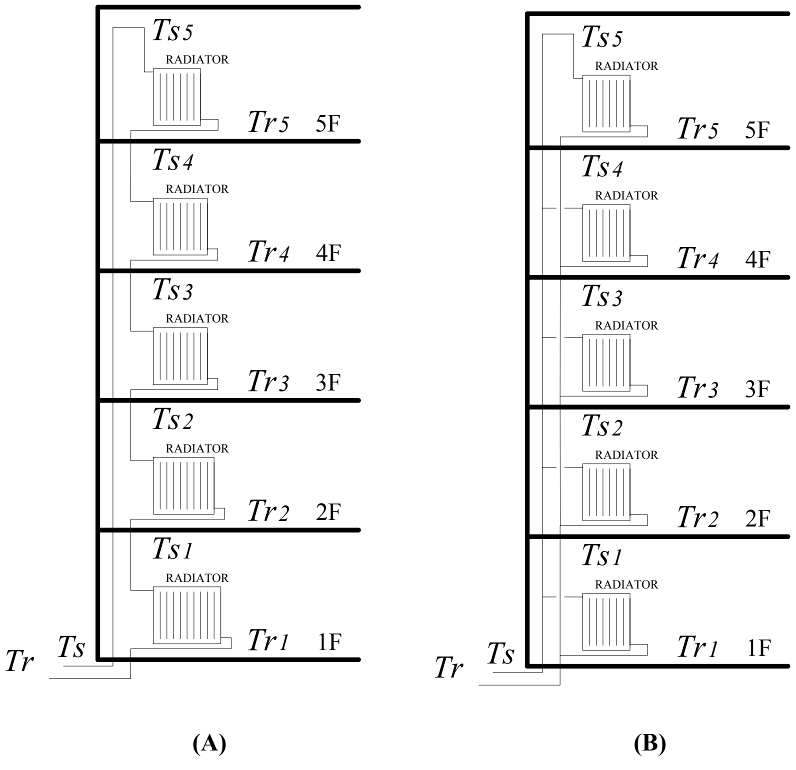


FIGURE 6: Cooling load duration of District C based on average outdoor temperatures

3.1.3 Old radiator system

In districts A and B, the old heating system was designed to use hot water coming from a coal boiler station. Supply and return water temperatures were 90 and 70˚C, respectively. It is clear that the system cannot maintain the indoor temperature above 18˚C after the system has been changed to use the geothermal resource with a supply temperature which is not above 70˚C. The distribution system was supplying first the radiator at the top floor, and subsequently all the radiators on each floor down to the last one connected to the return pipe. This was a single pipe system from top to bottom with a gradually falling temperature. Hence, the size of radiators on each floor is different, increasing from top to bottom. It is not easy to change the whole system because of all the inhabitants living in those buildings. As a solution, we can increase the number of radiators. First we have to know the ratio of each floor as shown in Figure 7 (A).



(A) **(B)**

FIGURE 7: (A) Radiator arrangement diagram of old buildings of District A using the single-pipe system; (B) Radiator arrangement using double-pipe system

First we will discuss District A, which has five floors. Then using the same method, it is easy to calculate District B with four floors, and so on. The area of each floor is the same. Ignoring the difference between different floors, top and bottom floors having different heat demands than intermediate floors, the heat loads of each floor can be assumed the same, i.e

$$Q_1 = Q_2 = Q_3 = Q_4 = Q_5 \tag{4}$$

The heat balance of each radiator, and the relationships of each radiator can be described by the following equations:

$$\begin{cases} (T_{s5} - T_{r5})C_P v_u = Q_5 \\ (T_{s4} - T_{r4})C_P v_u = Q_4 \\ (T_{s3} - T_{r3})C_P v_u = Q_3 \\ (T_{s2} - T_{r2})C_p v_u = Q_2 \\ (T_{s1} - T_{r1})C_P v_u = Q_1 \end{cases} \tag{5}$$

and

$$\begin{cases} T_s = T_{s5} \\ T_{r5} = T_{s4} \\ T_{r4} = T_{s3} \\ T_{r3} = T_{s2} \\ T_{r2} = T_{s1} \\ T_{r1} = T_r \end{cases} \tag{6}$$

in which C_p is the specific heat capacity of water and v_u is the flow rate of a single unit.

Combine these equations and the results are shown in Table 2:

TABLE 2: Inlet and outlet temperatures (˚C) of each floor radiators of District A

System	**Supply temp.**	**Return temp.**	**5th floor**		**4th floor**		**3rd floor**		**2nd floor**		**1st floor**	
			T_{s5}	T_{r5}	T_{s4}	T_{r4}	T_{s3}	T_{r3}	T_{s2}	T_{r2}	T_{s1}	T_{r1}
Old	90	70	90	86	86	82	82	78	78	74	74	70
New	65	52	65	62.4	62.4	59.8	59.8	57.2	57.2	54.6	54.6	52

The heat transferred from the terminal radiators to the surrounding air is given by the following equation (Karlsson, 1982):

$$Q = k_r n A \Delta T_m \tag{7}$$

where k_r = The overall heat transfer coefficient of radiators;
n = Number of radiators;
A = Surface area of each radiator;
ΔT_m = Logarithmic mean temperature difference for a radiator.

Here, the heat transfer coefficient of the radiators, k_r, is mainly determined by their natural heat convection behaviour inside the building. The empirically correlated equation between k_r and ΔT_m can be expressed in the form

$$k_r = \alpha \Delta T_m{}^{\beta} \tag{8}$$

in which α and β are empirical constants depending on the type of radiators. For the four-pole cast iron radiator, α is 0.25 and β is 0.34. The logarithmic mean temperature is defined as:

$$\Delta T_m = \frac{T_s - T_r}{\ln\left(\dfrac{T_s - T_i}{T_r - T_i}\right)} \tag{9}$$

In a low-temperature heating system, the transferred heat from radiators to the same area room should be equal to the high-temperature heating system. It means:

$$\frac{Q_o}{Q_n} = \frac{k_{ro} n_o A \Delta T_{mo}}{k_{rn} n_n A \Delta T_{mn}} = 1 \tag{10}$$

If we compare the two systems using the different value of the fifth floor, we can find the relationship of the necessary number of radiators (assuming that all radiators are the same size):

$$n_{n5} \approx 1.6\, n_{o5} \tag{11}$$

This means that in the new system, we have to add 60% of the original number of radiators on the fifth floor, in order to achieve the same heat transfer to the room, i.e. to maintain the indoor temperature T_i above 18°C. Furthermore, using the data in Table 2, we can calculate the relationship of the number of radiators on the fifth floor to the number of radiators on the other floors:

$$n_{n4} \approx 1.08\, n_{n5};\quad n_{n3} \approx 1.18\, n_{n5};\quad n_{n2} \approx 1.29\, n_{n5};\quad n_{n1} \approx 1.42\, n_{n5} \tag{12}$$

Using these equations it is easy to find out how many radiators must be added on each floor, if the number of units on the top floor is available. The resistance in the system will increase due to the increase in the number of radiators. Hence, it is recommended to use a bigger circulation pump to keep the flow rate, v_u, constant. Table 3 gives the results for District B calculated with the same methods.

TABLE 3: Inlet and outlet temperatures (°C) of each floor radiators of District B

System	**Supply temp.**	**Return temp.**	**4th floor**		**3rd floor**		**2nd floor**		**1st floor**	
			T_{s4}	T_{r4}	T_{s3}	T_{r3}	T_{s2}	T_{r2}	T_{s1}	T_{r1}
Old	90	70	90	85	85	80	80	75	75	70
New	52	43	52	49.75	49.75	47.5	47.5	45.25	45.25	43

The number of radiators are:

$$n_{n4} \approx 2.75\, n_{o4} \tag{13}$$

and

$$n_{n3} \approx 1.10\, n_{n4};\quad n_{n2} \approx 1.11\, n_{n4};\quad n_{n1} \approx 1.12\, n_{n4} \tag{14}$$

Figure 8 shows the conversion factor number of radiators needed if we change the system from high-temperature (coal boiler) heating systems to a low-temperature (geothermal) heating systems, with supply and return temperatures of 65 and 52°C, respectively.

Another possibility is to change the single-pipe system to a double-pipe one as shown in Figure 7 (B). This is better than a single-pipe system.

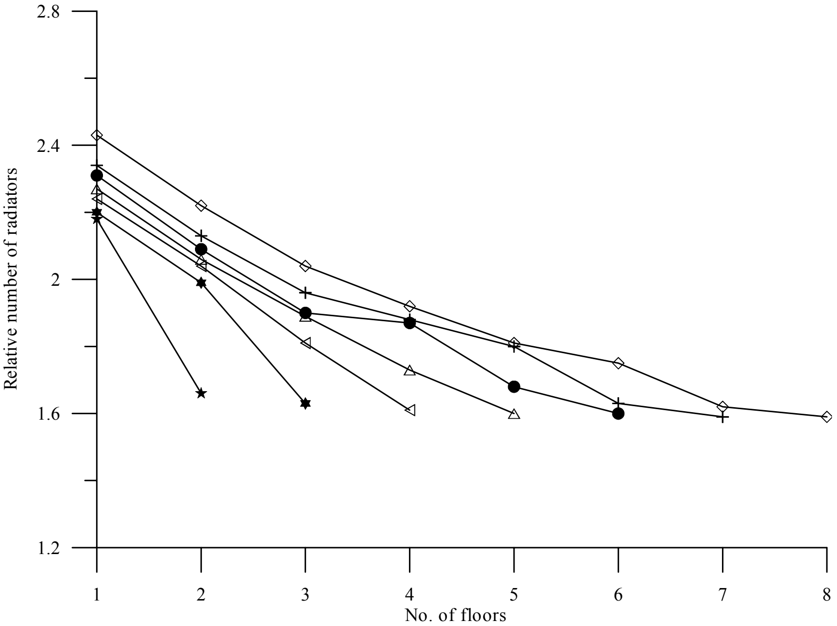


FIGURE 8: The factor of added radiators corresponding to the floor

3.1.4 Simulation of the circulation

In this subsection, the simulation of the heating circulation and the preferences for system type will be discussed. Due to the corrosive action and scaling problems that might occur with use of geothermal water, heat exchangers are used to avoid circulating the geothermal fluid directly through the district heating system. This is called Indirect Geothermal District Heating System (IGDHS) (Dai, 1996). Plate heat exchangers (PHE) are used because they have high heat transfer coefficients. The simple model is illustrated in Figure 9. Some necessary assumptions are made in this thermal simulation and analysis.

- The whole district heating area can be regards as a big radiator;
- The water heat loss during transfer in the pipes and heat loss in the heat exchanger are ignored; the efficiency of the heat exchanger is assumed 100%;
- The whole district heating system is thermostatic;
- The heat loss due to ventilation and heat gain from the sun radiation, etc. are ignored, all the influences can be represented by integration of the heat load capacity of the buildings.

Following the assumptions listed above, four energy conservation equations describing four heat transfer systems can be devised. They are as follows:

1) The energy losses from buildings to the outdoor atmosphere. As mentioned before, the energy, Q, required to maintain the indoor temperature, T_i, is a function of outdoor temperature according

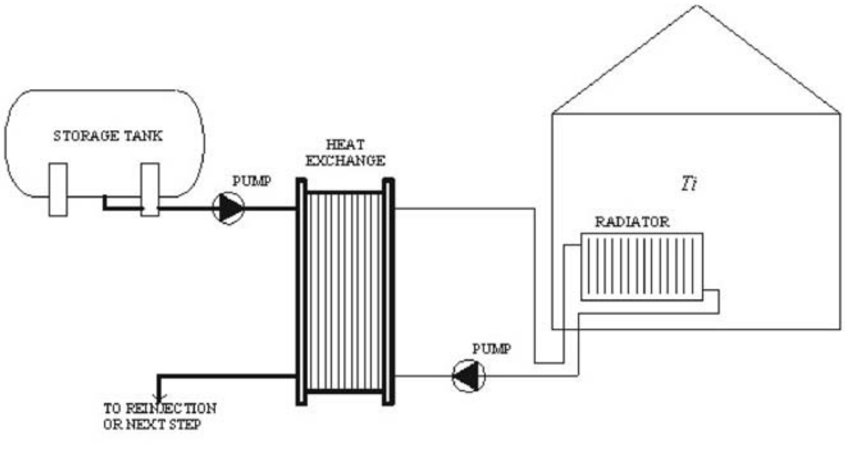


FIGURE 9: Sketch of a simple system

to the following equation:

$$Q_1 = \frac{T_i - T_a}{T_i - T_{ao}} Q_o \cdot A_{Total} \tag{15}$$

where T_i, T_{ao} and Q_0 = Reference condition parameters;
A_{Total} = Total given area of the buildings needing heating.

(2) The heat transferred from the terminal radiators to their surrounding air (indoor air) is given by the following equation (Karlsson, 1982):

$$Q_2 = k_r n A \Delta T_m \tag{16}$$

Fan coil units used in district C can also be considered a kind of "radiator" with specific empirical constants α and β.

(3) The heat transfer from the circulating water through the radiators or the heat gain of circulating water from the heat exchanger system can be easily calculated through available supply and return temperatures (T_s and T_r). The relevant equation is given by

$$Q_3 = F_c C_p \left(T_s - T_r \right) \tag{17}$$

(4) The heat transferred from the geothermal water to the circulating water through the plant heat exchanger (Dai and Liang, 2000) can be expressed by

$$Q_4 = \begin{cases} \dfrac{C_p \left(T_g - T_r \right) \left(S - 1 \right)}{\dfrac{S}{F_g} - \dfrac{1}{F_c}} & F_g \neq F_c \\ \dfrac{kA \left(T_g - T_r \right)}{1 + \dfrac{kA}{F_c C_p}} & F_g = F_c \end{cases} \tag{18}$$

where S is given by

$$S = e^{\frac{kAF}{C_p} \left(\frac{1}{F_g} - \frac{1}{F_c} \right)} \tag{19}$$

where k = Overall heat transfer coefficient;
A = Total area of the heat exchanger.

The temperature difference correction factor, F, is a function of the heat exchanger arrangement and the number of plates. In the cases encountered, S can be calculated using the performance conditions.

According to the previous assumptions

$$Q_1 = Q_2 = Q_3 = Q_4 \tag{20}$$

These are the essential equations of the system based on performance conditions. When the outdoor temperature changes, the heat demand changes. In other words, it is necessary to change the controllable parameters to achieve the changes and so on. The system can successfully maintain the indoor temperature as well as saving energy.

In the former model, three temperature sensors were installed to measure the outdoor, indoor and drained geothermal water temperatures. Frequency converters control the circulation pump and the geothermal water booster pump; in other words, the flow-rates of circulation water and geothermal water are variable.

If the outdoor temperature T_a decreases → T_r increases →
Decrease F_c → T_r and T_d both increase →
Decrease F_g → T_r and T_d both decrease →
    If T_d is lower than the set point → increase F_g
    If T_i is lower than the set point →increase F_c
    If T_i is higher than the set point →decrease F_c

The district heating return water temperature from a building is determined by the performance of the building radiator system. It is like a heat exchanger transferring heat from the district heating water to the indoor air. According to Valdimarsson, (1993) the relative heat duty of a radiator can be written as:

$$\frac{Q_1}{Q_o}=\left(\frac{\Delta T_m}{\Delta T_{mo}}\right)^n=\left(\frac{(T_s-T_r)}{\ln\left(\frac{T_s-T_i}{T_r-T_i}\right)}\cdot\frac{\ln\left(\frac{T_{so}-T_{io}}{T_{ro}-T_{io}}\right)}{(T_{so}-T_{ro})}\right)^n \qquad (21)$$

Here, the value of parameter n is equal to $(1+\beta)$. The index o refers to the reference conditions; they are design parameters for a certain building. For example, in District A of this project, the new reference conditions after increasing the number of radiators is

- T_{so} = 65°C;
- T_{ro} = 52°C
- T_{io} = 18°C
- T_{ao} = -9°C

Combining Equations 15 and 21, we can find the relationship between T_a and T_r without adjusting the flow rate, as shown in Figure 10.

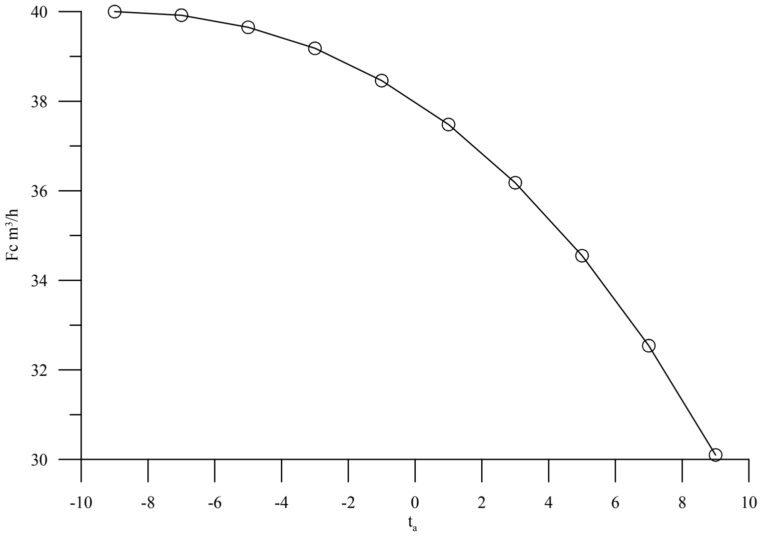


FIGURE 10: The relationship between outdoor temperature and circulation flow rate

The energy balance theory equations at each side of the heat exchanger are:

$$F_g C_p(T_g-T_r)=F_c C_p(T_s-T_r) \qquad (22)$$

Combine Equations 17, 18 and 22. In order to keep T_d constant, F_g should change its relationship to F_c. In a control system, the common method is that shown in Figure 11, using PID control.

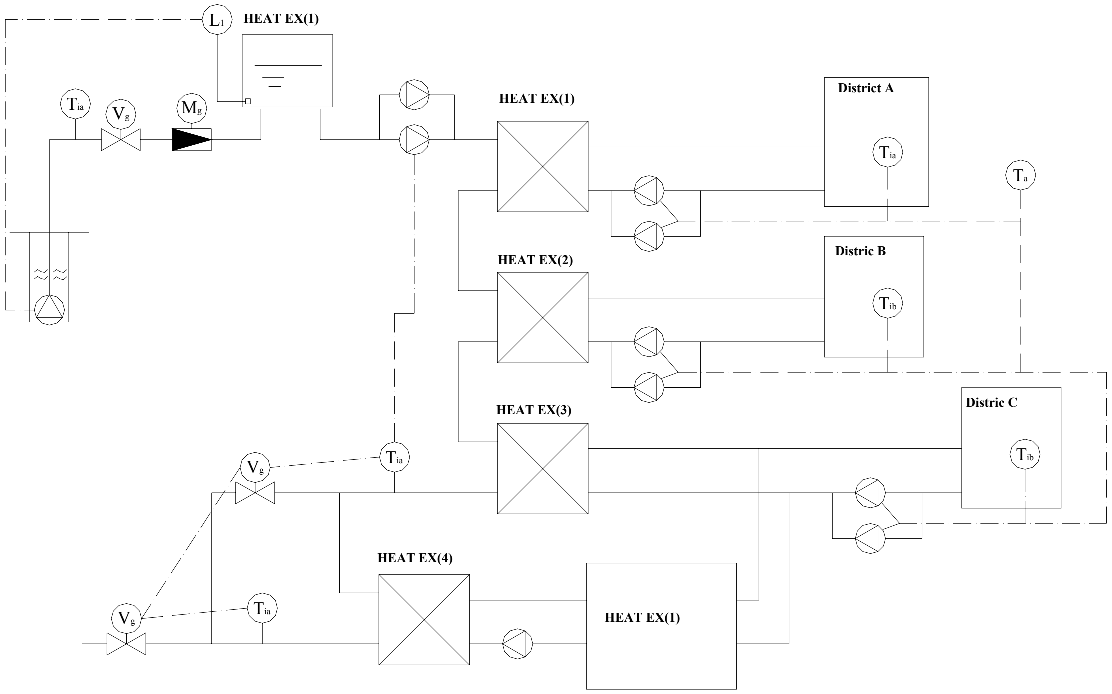


FIGURE 11: Schematic diagram of the proposed control system

4. THE CONTROL SYSTEM

The essentials of automatic control are

- Maintain the indoor temperatures of each district;
- Provide optimum operation and energy saving;
- Monitor and record operating data of the system.

The schematic diagram in Figure 11 shows the automatic control proposed for the system. Several sensors and control devices are installed. The function and presentation of them are listed in Table 5. All sensors and control equipment are connected to five programmable logic controllers (PLC). All pumps are controlled by suitable variable frequency speed drive converters and connected to the PLC. A net cable connect the PLCs and a PC. Included with every PLC is the following equipment:

- A CPU (Central Processing Unit);
- EEPROM for program storage. The memory keeps its contents even during power failures;
- A base where the input/output cards are mounted. Input and output cards in varying numbers and a field-bus controller are included with each PLC;
- An operating panel. The panel is mounted in the same cubicle as the PLC.

A bus-mastering cable connects the PLCs through a R232 protocol for communication with the PC control program. The programmable controllers are pre-programmed and delivered mounted in a cubicle, together with terminal blocks and associated equipment.

Brief logical control is discussed as follows:

- *Geothermal well unit.* First, geothermal water will pass through the de-aerator tank. Water level sensor L_t will control the speed of geothermal water pump F_g and control valve V_g to maintain a constant water level. V_g is, used in case of artesian flow from the well, is more than the demand. When the well, under certain low-demand conditions, provides enough water by artesian flow, the pump will not run. If demand is more than the artesian flow, then V_g is full-open and F_g is used to maintain the constant water level.

TABLE 5: Parameters of control system

PLC-1	T_g	Geothermal water temperature
	L_g	Geothermal water level
	L_t	De-aerator tank water level
	F_g	Variable frequency of geothermal well pump
	V_g	Control valve of geothermal water
	T_{d1}	Outlet temperature of Heat Exchanger 3
	F_s	Variable frequency of booster pump
	V_{d1}	First control valve of drain water
PLC-2	T_a	Air temperature
	T_{ia}	Indoor temperature of district A
	F_a	Variable frequency of circulation A
PLC-3	T_{ib}	Indoor temperature of district B
	F_b	Variable frequency of circulation B
PLC-4	T_{ic}	Indoor temperature of district C
	F_c	Variable frequency of district C
	V_{d2}	Second control valve of drain water
	T_{rc}	Return water temperature of district C
	V_h	Control valve on heat pump's outlet
	T_{h1}	Heat pump circulated water inlet temperature
	F_h	Variable frequency of circulation pump in heat pump units
	T_{d2}	Outlet temperature of Heat Exchanger 4
PLC-5	P_1	Pressure of circulation water
	F_{sc}	Variable frequency of supply pump

- *Circulation unit.* Combining outdoor and indoor temperatures of each district, adjust the circulation pumps' frequency to maintain the indoor temperature as a constant. On the side of the geothermal water, there are two cases.
  a) First if the heat load is low enough that it can be obtained only from energy extracted from geothermal water. Use the outlet water temperature T_{d1} of the heat exchanger to adjust the grade of control valve V_{d1} associated with totally open V_{d2}, to ensure T_{d1} is not higher than 40°C.
  b) On the other hand, when the heat load increases in colder weather, the heat pump is needed. The return temperature of circulation *C* is the set point to control the start or stop of the heat pump. Further, the status of the heat pump controls the circulation pump between the heat pump and heat exchanger 4. Combine valve V_{d1} and V_{d2} to adjust the flow rate into heat exchanger 4.

Usually, PLC has facilities to monitor the status of the main process parameters. In the event of a network failure individual PLCs will function independently.

Software combining the functions of monitoring, operating, recording and so on is used as a Men-Machine Interface for the control system. This control system (CS) includes graphical displays for the pump station and well station operation, event and alarm lists and reports. The system monitors and stores all processed data to an SQL relational database for trending and analyses of data over time. The use of a SQL database enables users of the system to access the processed data for easy numerical analysis of data with comprehensive data reporting possibilities and enables them to optimise the overall performance of the system.

The CS gathers data from the PLCs. From the CS system, PID loop controller set point and manual output and tuning can be performed. Starting and stopping of pumps, including well pumps, and adjusting the throttling of control valves, etc. can be performed by the system.

5. HEAT PUMP FOR COOLING IN SUMMER

Another important advantage of using a heat pump is the possibility of cooling in summer. In this project, District C needs cooling during summer. Figure 12 shows the system used for that. The supply water from the heat pump to buildings is 6˚C and the return water is about 12˚C. This circulation water passes the evaporator of the heat pump. Groundwater is pumped up from the shallow production well at 15˚C. After being heated by the condenser of the heat pump, it is pumped back to the reinjection well at 25˚C.

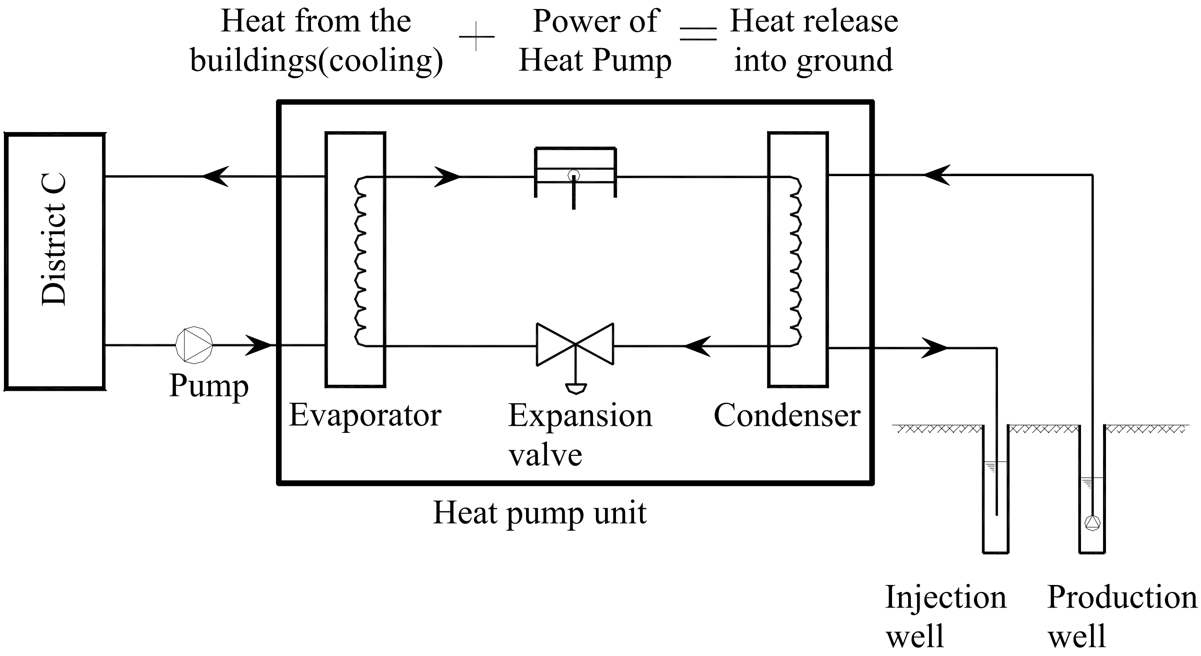


FIGURE 12: Heat pump for cooling system

The basic components of a standard heat pump are an electric motor-driven compressor, a reversing valve, an expansion device, and two heat exchangers. Refrigerant enters the compressor shell as a low-temperature, low-pressure gas. It passes around the motor and is heated before entering the intake of the compression chambers. The compression process elevates both the pressure and temperature of the refrigerant gas. This gas enters the reversing valve and is routed to the heat exchanger in contact with the groundwater. Since the gas is at a high temperature, the groundwater can be used to remove heat from the refrigerant in the heat exchanger. Removal of heat results in the cooling and condensing of the refrigerant. Pressure loss is usually small in the condenser; therefore, the refrigerant exits the condenser as a liquid with a temperature slightly above that of the environment. The liquid then experiences a drop in pressure across the restriction in the expansion device (Rybach and Hopkirk, 1995). This causes a rapid decrease in temperature. The temperature of the return water is much warmer than the refrigerant entering the indoor heat exchanger. Therefore, the liquid is evaporated, and in the process, heat is removed from the building air in the evaporator. Thus, we have the desired cooling effect. The evaporated gas is then passed through the reversing valve before returning to the compressor.

There are several sensors installed on the heat pump for measuring the temperatures and pressure of each inlet and outlet and phase of the refrigerant. All the operating information is sent to a PLC in the heat pump. Usually there are two set points of return water as signals of the heat pump's starting and stopping. For example, in this case, it is set at 6 and 8˚C; if the return water's temperature is lower that 6˚C, the heat pump stops, and starts again when the temperature is higher than 8˚C. All the operations are automatically controlled by the PLC.

6. SWIMMING POOL DESIGN

The history of geothermal water use for bathing and swimming in China can be dated back 3000 years. In this project, a swimming pool will be constructed as part of the recreation centre. It is planned to use geothermal water as the heat resource. A heat exchanger is employed to heat the swimming pool circulation water. Appropriate municipal net water will be added for regular replacement of pool water. Two additional small ponds will use the geothermal water directly and maintain the temperature a littler higher than in the swimming pool, about 40°C. Due to the special chemical characteristics of geothermal water, as well as its high temperature, the system needs a specific design different from conventional swimming pools.

In the following, aspects of geothermal swimming pool design and processing equipment will be discussed, as well as some aspects of common swimming pools.

6.1 Basic conditions

The swimming pool is located in the first floor of the recreation centre building. Due to limited area, it cannot be designed like legal competition pool, with one of the three regulations lengths, i.e. 25, (33.3), and 50 m. The length of the pool is 23 m, the maximum acceptable length in the recreation centre. The pool is 13 m wide and the surface area is thus 299 m^2. The depth of the pool is 0.8 m in the shallower end of the pool and 2 m in the deeper end, divided into progressively three deeper steps. The total volume of the pool approximates 525 m^3. Figure 13 shows a cross-section of the designed pool and basic equipment.

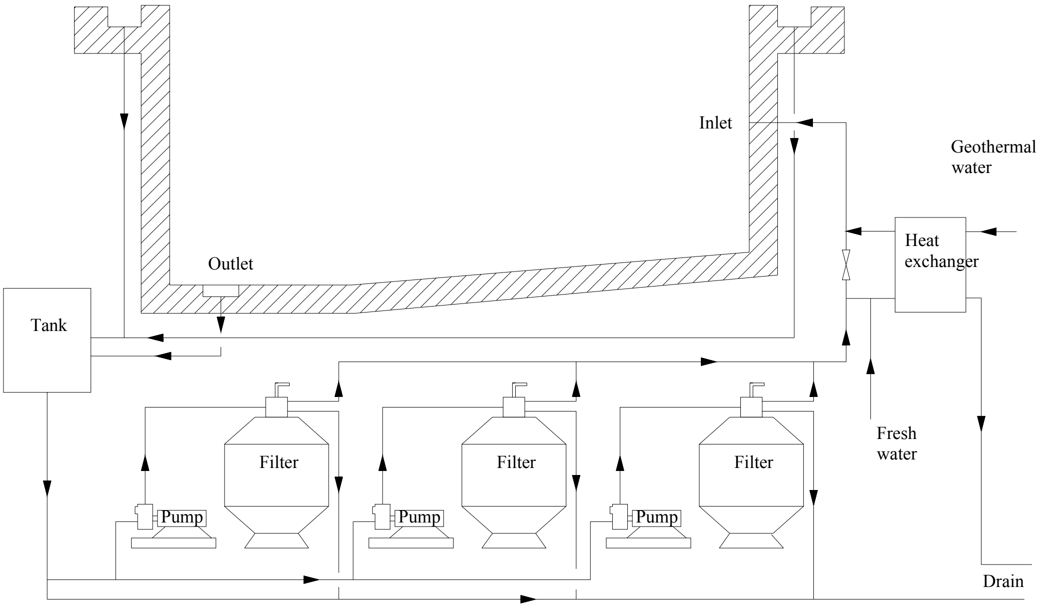


FIGURE 13: The swimming pool system

Preliminary research and design involves:

- Design of the pipe system for the basin;
- Design of the filtration system for the water;
- Decisions on the power needed to warm up the water and keep it warm;
- Choice of equipment, size of equipment etc.;
- A draft of the swimming pool system;
- Points of view on energy saving and economical issues.

6.2 Technical outlines

6.2.1 The pipe system for the swimming pool

The water source of the swimming pool is municipal tap water. Geothermal water heats the circulation water through a heat exchanger to maintain the pool temperature at 28°C. The inflow pipes for the pool are put in the shallower end and connected to seven distribution spouts on the wall. Outflow pipes are put in the deeper end and connected to seven distribution drain outlets on the wall. In addition, the water flows through 12 overflow drains distributed evenly around the periphery of the pool. This water distribution system is becoming very common in pools and is considered to give better circulation and blending as well as providing for more efficient cleaning of the pool water. This overflow system has been very successful, as much of the impurities which get into the pool float on the top of water, such as body fat and hair (Rameswor, 1995).

The material most often used for the piping is polyvinyl chloride, but polypropane or polyethylene is a better choice, as these are more heat resistant (Svavarsson, 1990). Junctions and connections are usually butt welded together with equipment designed for that purpose. It is necessary to pressure-test all the pipes before final connection with at least 0.3 MPa for 30 minutes.

6.2.2 Cleansing requirements and capacity of the swimming pool

The maximum design capacity of this pool is 80 guests at a time. The average area for each person is about 3.7 m^2. The quantity of pool water flowing through the filtration equipment should be at least 2.0 $m^3/person \cdot h^2$ (Perkins, 1988). Hence, 160 m^3/h of water need to pass through the filters during peak hours. This means that in just over 4 hours, all the water in the pool has gone once through the filtration equipment.

It is common to use only closed sand filters to clean pool water. The filtration equipment consists of a water tank of plastic fibre, painted steel or stainless steel. Sand of a certain grain size is put in the tank, as sand is a very good natural filter. A water distributor is in the tank over the sand so that all the sand takes equal part in the filtration of the water. The water is pumped at a certain speed through the sand and the impurities are left in the sand. The rinsing quality depends on the speed of the water and increases if the flow is slow. Pressure gauges on the inflow and outflow pipes must be monitored.

When the pressure drop over the sand has reached a certain figure, the flow through the system is reversed to clean the sand. The rinsing water must be led into an open cistern, before letting it into the sewer system so that the rinsing efficiency can be evaluated. The reverse flow rinsing is controlled manually with faucets. It is possible to increase the cleaning of pool water by adding alum to the water before it enters the cleansing equipment.

6.2.3 Energy requirement for heating swimming pool

As mentioned before, the swimming pool is an indoor one. The conditions of the pool are relatively stable. The indoor temperature is mainly maintained by the air condition fans. The prerequisites needed to calculate the required energy to keep a pool warm are the following:

- Water temperature = 27°C;
- Outside temperature (indoor air temperature) = 20°C;
- Water from the geothermal well = 70°C;
- Water from the heating system = 42°C;
- Cold water = 15°C;
- Wind speed (due to ventilation and people moving) =1.0 m/s;
- Air humidity = 80%.

Heat loss from the pool is mainly due to the following:

- Convection;
- Evaporation;
- Radiation;
- Conduction.

A general equation is used to calculate *heat loss due to convection* [W/m^2] (Halldórsson, 1975);

$$q_c = h_c\,(\,T_W - T_a\,) \tag{23}$$

where h_c = $K+1.88\times V_2$ [W/m$^2\cdot$°C];
K = $3.86+0.17(T_w-T_a)$ [W/m$^2\cdot$°C];
T_w = Water temperature [°C];
T_a = Air temperature [°C];
V_2 = Wind speed at 2 m height [m/s].

The equation for the heat transfer coefficient h_c is named after Rimsha – Doncenko. The values of the prerequisites are used to calculate, q_c equal to 6.95.

Heat loss due to evaporation. Evaporation occurs because of different partial pressure of the water steam at the pool's surface and in the air over it. For water to evaporate, certain energy has to exist, i.e. evaporation heat. To calculate the heat loss [W/m^2], the following equation from Rimsha – Doncenko is used

$$q_e = (1.56 \times K + 0.70 \times V_2) \times (e_w - e_a) \tag{24}$$

where e_w = Partial pressure of steam at surface [mbar];
e_a = Partial pressure of steam in air [mbar].

The humidity pressure of the air, e_a, is about 5 mbar, when the humidity is 80% and temperature is about 20°C. e_w is the humidity pressure of steam at the water surface. It can be assumed that in the marginal layer on the pool's surface, the temperature is the same as in the water; the humidity in this marginal layer is 100%, i.e. saturation pressure is obtained. At this temperature the saturation pressure is 4250 Pa, i.e. e_a, is equal to 42.5 mbar. So q_e is equal to 411.61.

Because this pool is an indoor one, the heat loss from radiation and conduction are negligible. They are small in comparison to heat losses from convection and evaporation. The *total energy demand* [W] of the pool can thus be calculated as:

$$Q = (q_c + q_e + s)A_{pool} \tag{25}$$

where S is an additional value of heat loss [cal/s·m^2] given by

$$S = 10\%\ (q_c + q_e) \tag{26}$$

The calculated heat load of the pool is thus Q = 138 kW.

In this case, heat supplied to the swimming pool is exchanged between the geothermal water from the district heating system (42°C) and the circulation water (25°C). Assume that 138 kW energy is needed to maintain the pool water above 28°C, that 20 m^3/h fresh water (15°C) will be added into the circulation, and the efficiency of the heat exchanger is about 90%; then, about 25 m^3/h geothermal tail water is required. The circulation flow rate is 160 m^3/h and 17 m^3/h fresh water will be added to it. That means 20 m^3/h water in the swimming pool will drain though the overflow lane.

The swimming pool needs to be filled in the beginning, after repairs, and when the pool has been drained for special cleaning. The pool takes about 520 m^3 of water and filling takes about 6 hours. About 87 m^3/h fresh water (15°C) is needed and must be heated to 28°C. To heat that amount of water 1315kW are needed. Geothermal water from the district heating system is not abundant anymore, so an appropriate quantity of geothermal water should be added from the geothermal well.

7. ENVIRONMENTAL ASPECTS

To sustain development, more and intense attention should be paid to the environmental aspects associated with the utilization of a geothermal resource. First, the environmental cost of geothermal utilization is assessed and secondly the environmental benefits gained.

The common impacts of low-temperature geothermal systems are:

- *Well drilling and system operation noise.* This is the most common complaint in a crowded city like Beijing. Drilling noise is for a short time only, but necessary protection should be taken by avoiding using old instruments which would make noises quite higher than relevant standards. System operation noise, like pump and maintenance noises, are long term. The pump station should have good isolation or be constructed underground. Low-noise equipment and instruments should be considered in advance when designing the system.
- *Waste liquid disposal.* If the geothermal water is directly disposed of into the sewage system it will lead to chemicals and thermal pollution. This impact is a major concern, due to its potential danger to the local environment. Reinjection is the best solution for the problem.

The main environmental benefits are the local benefits in air quality, due to reduced burning of fossil fuel. Table 5 shows the main emissions from some alternatives of heating media in the proposed area of this project, compared to geothermal.

TABLE 5: Main emissions from some alternatives to geothermal utilization (MT/y)

	Coal boiler	**Gas boiler**	**Geothermal + heat pump**
CO_2	1.326	1.040	0.012
CO	2	0.75	0.225
SO_2	13	0.00525	1.4625
NO_X	2	1.275	0.225
N_2O	0.01	0.006	0.001125
$NMVOC_S$	0.2	0.0525	0.0225
PM_{tot}	3	0.0675	0.3375

In the above table, it is assumed that 73% of the electricity for heat pumps comes from coal fired power and the emission from those power plants are included. The table shows only the main substances of the emission from a natural gas boiler and coal-fired power plants. Many chemicals are emitted from gas boilers and the power plants, both organic and inorganic. Natural gas boilers are, from an environmental point of view a considerably better alternative than a coal boiler. The environmentally best alternative is geothermal usage with electrical heat pumps for peak power. This will by far give the least carbon dioxide emissions and chemical pollution comparable or less than mixed gas/geothermal heating.

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