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MULTIPLE UTILIZATION OF GEOTHERMAL ENERGY IN TIANJIN OLYMPIC CENTRE

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ABSTRACT

The report describes the proposed multiple utilization of geothermal energy in the Tianjin Olympic Centre. Geothermal energy will be used for space heating, domestic hot water, swimming pool (as a heat source) and mineral water in the new stadium of Tianjin Olympic Centre, which has been designed for the 2008 Olympic Games. The stadium is constructed to meet the requirements for football matches of the Olympic Games, training and other needs of competitive sport activities.

1. INTRODUCTION

Geothermal energy has generally been accepted as an environmentally benign energy source, and has been used widely in China in recent years as a heat source for district heating systems due to its suitable temperature, cleanliness and low operating costs.

Tianjin is the largest open city by the sea of North China, one of 4 municipalities directly under the Central Government of the People's Republic of China (Figure 1). It is by the Bohai Gulf in the eastern part of the North China Plain, north of the Yan Mountains. The distance from the centre of the City to Beijing, China's capital, is 120 km, and 50 km to the east is the Bohai Gulf. It takes one hour by train to reach Beijing.

FIGURE 1: Location map of Tianjin, China

Geothermal energy is abundant in Tianjin. It has been utilized for space heating, bathing, swimming pools, greenhouses, fishfarming and so on. In order to decrease air pollution and save conventional energy, geothermal energy will be used as the heat resource in the Tianjin Olympic Centre.

For the 2008 Olympic Games, the Tianjin Olympic Centre is building a new big stadium. The total area of the new stadium is about 158,000 m^2. The stadium includes three main parts: the football field, public buildings and a swimming pool. Geothermal water will be used for space heating of the buildings and the swimming pool.

1.1 Geothermal potential and wells

Tianjin is rich in low- to medium-temperature geothermal resources. The geothermal reservoir is of sedimentary type. There are five strata, in a vertical order, the minghuazhen, guantao, Ordovician, Cambrian and wumishan formations. By 2004, 10 geothermal fields had been discovered with temperature gradients ≥30°C/km; the total area of the geothermal fields is 2328 km^2 (Figure 2, Table 1). A total of 244 geothermal wells had been drilled and they are used in different ways, such as for space heating, greenhouses, fish farming, a medicinal physiotherapy spa, swimming pools etc.

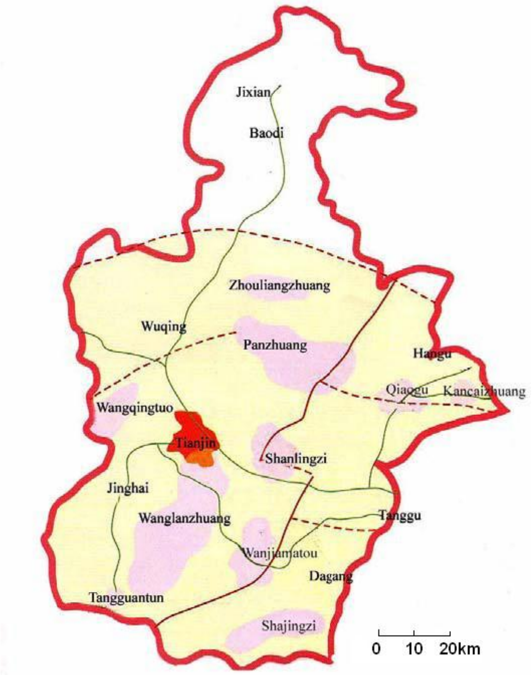

FIGURE 2: Geothermal fields in Tianjin

The total area of space heating is about 8.44 million m^2, constituting 70% of current geothermal space heating in China. Normally, the depth of the geothermal wells ranges from 1000 to 3000 m; the deepest well is 4043 m. The temperature gradient ranges from 30 to 88°C/km, and the maximum temperature is 102°C in a geothermal well drilled in 2004 in Zhouliangzhuang area.

TABLE 1: Basic data on the geothermal fields in Tianjin

Geothermal field	**Area (km^2)**	**Highest gradient (°C/km)**
Wang lan zhuang	534	80
Shan ling zi	315	83
Wanjiamatou	235	88
Panzhuang	610	69
Zhouliangzhuang	180	55
Qiaogu	90	55
Wangqingtuo	114	50
Shajingzi	190	45
Tangguantun	40	76
Kancaizhuang	20	
Total	2328	

The geothermal wells located near the Olympic Centre provide the heat source for the scheduled buildings. Three wells were drilled for this project. Wells 1 and 3 are directional wells, well 2 a straight well. In this project, wells 1 and 2 will be used for production and well 3 for re-injection. The characteristics of the geothermal wells are shown in Table 2.

Because the chemical content of the water can have serious effect on equipment, tests were made to check the geothermal water, using water samples taken from the wells. Results of the geochemical analysis show that the total hardness is 317.8 mg/l, TDS is 2419.9 mg/l, and pH is 7.56. The chemical type of geothermal water is $Cl\cdot SO_4$-Na. No $CaCO_3$ or silica scaling is to be expected during utilization, but there is a possibility of $CaSO_4$ scaling.

TABLE 2: Geothermal well characteristics

Well no.	Finishing time	Well type	Depth (m)	Aquifer thickness (m)	Flowrate (m^3/h)	Temperature (°C)
1	96.07	Directional	2680	570	110	77
2	97.08	Straight	1300	1300	100	76
3	97.11	Directional	125	125	82	63

1.2 Building information

The Tianjin Olympic Centre is located in Nankai district in Tianjin, where already, there are some public sports buildings. In order to host football matches of the 2008 Olympic Games, some new buildings will be built beside the old buildings. The main stadium will be heated by geothermal water (Figure 3).

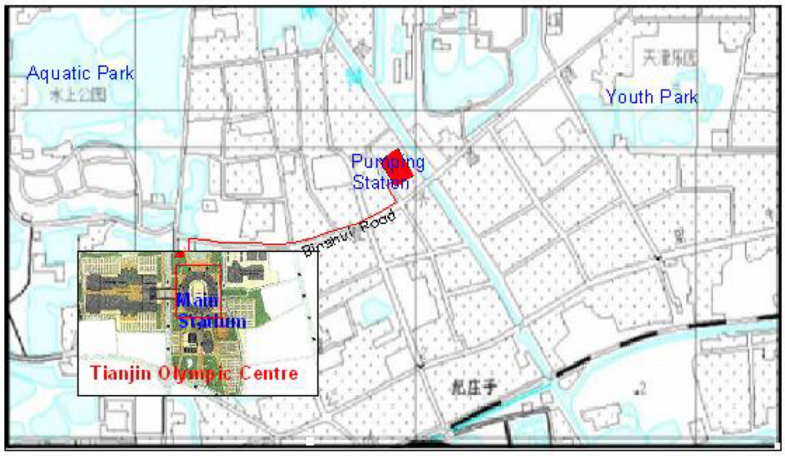

FIGURE 3: The location map of Tianjin Olympic Centre and pumping station

The total area of the main stadium is about 158,000 m^2 and it will be able to accommodate up to 80,000 spectators. The main part of the stadium comprises the football field, public buildings and a swimming pool. The area that needs to be heated is 50,000 m^2 (Figure 4). The geothermal water will be used in space heating for the buildings and the swimming pool. In this paper, the design concept of the pumping station, pipelines and the heating system of the project is described.

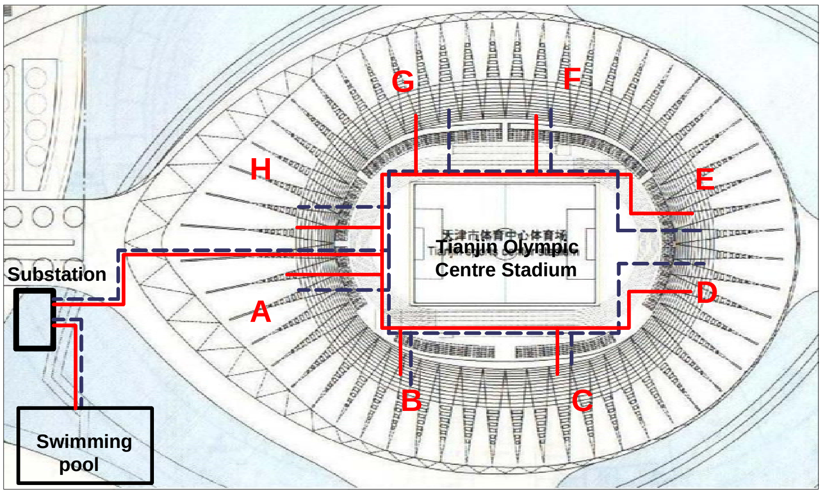

FIGURE 4: Scheme of the main stadium

Associated with the stadium is a large building complex of 6 floors that includes athletes' rooms, referees' rooms, news centre, offices, health centre, shops, balcony, show centre, refectory, comfort station etc. The design concept of the building is shown in Table 3. B1st, C1st, A3rd, H3rd are only used when there is a match. In Tianjin, it is assumed that in general there will be 3 matches held month.

TABLE 3: Building information

Type	**Area (m^2)**						
	First	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**	**Total area**
A	2500	1875	1500	750	500	250	7375
B	2500	1875	-	750	500	250	5875
C	2500	1875	-	750	500	250	5875
D	2500	1875	-	750	500	250	5875
E	2500	1875	-	750	500	250	5875
F	2500	1875	-	750	500	250	5875
G	2500	1875	-	750	500	250	5875
H	2500	1875	1500	750	500	250	7375
Total	20000	15000	3000	6000	4000	2000	50000

2. SPACE HEATING DESIGN

The design premise is that the stadium rooms will be heated with a fan-coil system with the parameters 60/30/20°C (supply /return /indoor temperatures). And the design indoor temperature is 20°C.

2.1 Weather conditions

Outside air temperature affects the indoor temperature through heat conduction and free and forced infiltration, so the load on the heating systems is closely related to the temperature of the outdoor climate. Tianjin is located in the northern temperate zone with an annual mean temperature of 12.3°C. The average temperature during the heating period is about -0.5°C. Figure 5 shows the outdoor temperature over one year in Tianjin. According to the Chinese Building Code and the specifics of the stadium, the indoor temperature should be above 20°C during the heating period in winter.

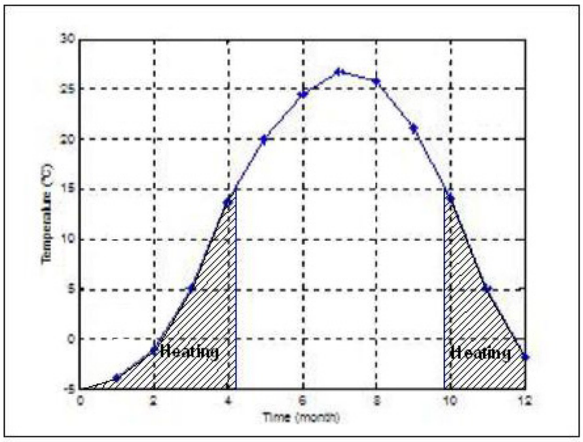

FIGURE 5: Monthly mean temperature in

As the standard of the stadium is higher than for a normal building, the demand of comfortable indoor temperature during winter, the heating duration and the quality of heating are accordingly higher than for a normal building. In this project, to achieve the expected indoor temperature of 20°C in relation to weather conditions and the outdoor temperature duration curve, the heating period will last for 180 days, i.e. when temperatures are below 15°C.

2.2 Heating system design and heat load assessment

Design heat consumption per unit area of 46-70 W/m^2 in typical residential buildings is used to calculate the heat load of a conventional heating system in China. The value indicates that heat consumption is expected for a period of 147 days, with a standard minimum outdoor local temperature of -9ºC, and an indoor temperature of 20ºC. It would be easiest to use the value from the handbook, but a value should be selected with respect to the actual situation. With a detailed approach, the value can be calculated.

In principle, heat consumption is a function of the building's structure, its insulation characteristics, building volume and local climate. Following the reference from the Heating Design Handbook (Tang Huifen and Fan Jixian, 1992) and the Specifications of Chinese building construction, pertinent weather data, the different temperature demands among the different rooms of the building and the experience of sports hall designing, the space heat load of the main stadium can be calculated. On the first and sixth floor, the heat load is 100 W/m^2; on other floors, the heat load is 90 W/m^2; the total heat load is about 5 MW. Then, 770 kW is only needed when there is a football match. The data are shown in Table 4.

TABLE 4: Heat load in the main stadium building

Room type	**Heat load**						
	First	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**	**Total heat load (MW)**
A	250	170	135	70	45	25	0.7
B	250	170	0	70	45	25	0.6
C	250	170	0	70	45	25	0.6
D	250	170	0	70	45	25	0.6
E	250	170	0	70	45	25	0.6
F	250	170	0	70	45	25	0.6
G	250	170	0	70	45	25	0.6
H	250	170	135	70	45	25	0.7
Total heated area (m^2)					50,000		
Total heat load (MW)					5.0		

3. DOMESTIC HOT WATER

Hot tap water will be distributed to consumers from the substation by heating fresh water and will be used for bathing, washing, showers and other uses. Cold water (around 10°C) will be heated to about 70°C using heat exchangers in the substation, then pumped into the hot top water system installed in the building. It is assumed that the hot tap water reaching the user is a mixture of 70°C hot water and 10°C cold water. The hot water system is separated into two parts, one part for normal hot tap water, and the part only used when there is a match. According to the experience of large stadium design, the stadium's peak load for hot tap water is assumed to be about 250 kW.

4. SWIMMING POOL DESIGN

There are many swimming pools using geothermal water in Tianjin. Geothermal water is used directly for some pools, while other pools use the geothermal water only as a heat resource (Yin Heng, 2002). In this project, the swimming pool will be constructed as a part of the stadium. It is planned to use the geothermal water as the heat source for the pool; a heat exchanger will be employed to heat the swimming pool circulation water. Appropriate municipal water supply will be added into the circulation for the top up and regular replacement of pool water. In the following, a geothermal swimming pool heating system and processing equipment will be described. Some methods are based on swimming pools by Perkins (1988).

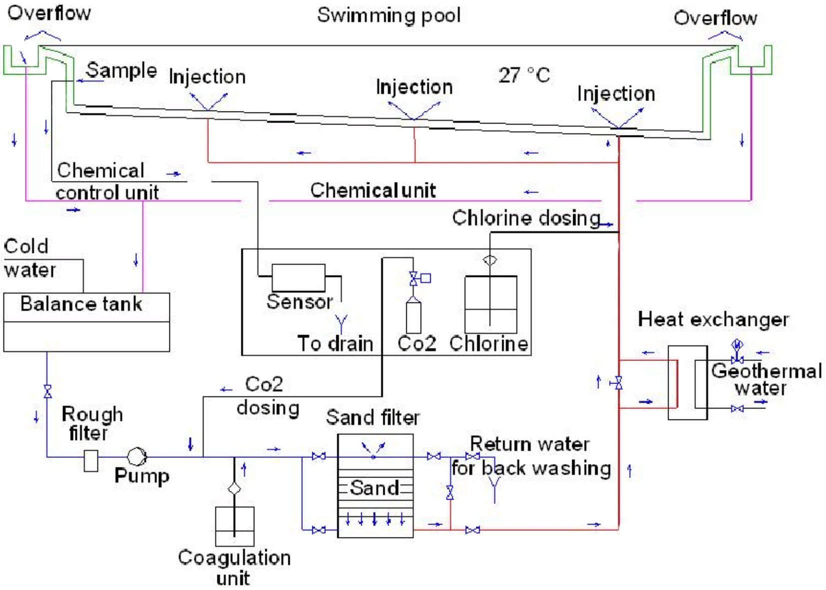

FIGURE 6: A schematic diagram of the swimming pool (Jalili-Nasrabadi, 2004)

4.1 Basic conditions

The swimming pool is designed to be an outdoor swimming pool, located beside the main stadium. It is designed according to the legal requirements for a competition pool. The length of this pool is 50 m and the width is 25 m, thus the surface area is 1,250 m^2. The depth of the pool is as follows: 0.8 m in the shallower end of the pool and 2 m in the deeper end. The volume of the water in the pool is defined by Equation 1.

$$V = LW \frac{d_1 + d_2}{2} \tag{1}$$

where V = Water volume (m^3);
L = Length (m);
W = Width (m);
d_1, d_2 = Minimum and maximum depth of pool (m).

The total volume of the system is approximately 1,750 m^3. In Figure 6, a schematic diagram of the technical systems of a swimming pool is shown.

4.2 Technical outlines

Preliminary research and design involves the following parts: the pipeline system for the swimming pool, the filtration system for the water, the energy demand to warm up the water and to maintain the pool temperature, equipment choice etc., the draft of the swimming pool system, discussion of energy saving and economical issues.

The pipeline system: The water sources for the swimming pool will be municipal water. Supplied geothermal water heats the circulation water through heat exchangers to maintain pool temperature at 27°C. The inflow pipes for the pool are placed in the bottom of the pool and connected to 36 distribution nozzles on the bottom, and outflow pipes are distributed evenly around the periphery of the pool. The water distribution system is becoming very common in pools and is considered to give better circulation and blending as well as being more efficient for cleaning the pool water. This overflow system has been very successful, as much of the impurities which get into the pool float on top of water, such as body fat and hair and can be cleaned easily with this system (Maharjan, 1995).

Cleaning requirements and capacity of the swimming pool: The turnover period is the main factor for determining piping system properties and the amount of mass flow through the pipes in the bottom of the pool. The maximum design capacity of this pool is 200 guests at a time. The average area for each person is about 6.2 m^2. The flow rate of the pool water through the filtration equipment should be at least 2.0 m^3/person/h (Perkins, 1988). Hence, 400 m^3/h (111 l/s) of water need to go through the filters continous. The volume is 1750 m^3. This means in just over 4 hours, all the water in the pool will circulate once through the filtration equipment. From the number of inlet nozzles in the floor of the pool, the mass flow through each of them can be calculated as:

$$m_{in} = \frac{m}{n_o} = \frac{111}{36} \approx 3 \text{ l/s per inlet nozzle}$$

where m_{in} = Mass flow through each inlet nozzle;
n_o = Number of inlet nozzles in the bottom of the pool.

It is common to use only closed sand filters to clean pool water. The filtration equipment consists of a water tank of fibre plastic, 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 an 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 quality of the rinsing depends on the speed of the water; the slower the flow rate, the better the quality of filtered water.

In this system, the pressure of the inflow and outflow pipes must be monitored at all times. When the pressure drop over the sand has reached a certain value, 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. Reverse flow rinsing is controlled manually. It is possible to increase the cleansing of pool water by adding alum to the water before it enters the cleansing equipment.

4.3 Energy requirement for heating swimming pool

As mentioned before the swimming pool is an outdoor one. According to Svavarsson (1990) heat loss from outdoor pools is mainly due to the following:

- Convection
- Evaporation
- Radiation
- Conduction
- Rain

The main heat losses from the swimming pool occur by convection and evaporation. The results obtained 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 the total heat loss due to convection and evaporation. Heat loss due to conduction is small, with a good insulation in the pool building materials. Heat losses by means of rain and radiation are not large either so in the following calculations 10% of the total heat loss by convection and evaporation will be assumed for these three mentioned factors. The common conditions of a swimming pool are shown in Table 5.

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 describes the heat loss through convection and shows that it will increase with higher wind speed and lower outside temperature:

TABLE 5: Parameters for common conditions affecting a swimming pool

Known factors - design conditions	Factors	Value	Unit
Air temperature	T_a	-5	°C
Wind speed	v	5	m/s
Humidity (max)	H	60	%
Required water for circulation	m_1	111	l/s
Specific heat capacity of water	c_p	4.18	kJ/kg°C
Temperature of pool's cold water inlet 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	30	°C
Pool's area	A	1250	m^2

$$q_C = h_c(T_w - T_a) \tag{2}$$

where q_C = Amount of heat loss by convection (W/m^2);
T_w = Water temperature in the pool (°C);
T_a = Air temperature in the pool's around (°C);
h_c = Convection heat transfer coefficient ($W/m^2°C$), very dependent on wind speed.

The relationship between the heat transfer coefficient and wind speed, named *the Rimsha-Doncenko formula,* is shown in Equation 3.

$$h_c = 4.19(k + 0.45v) \tag{3}$$

where v = Wind speed at 2 m height from the ground surface (m/s);
k = Empirical coefficient as shown in Equation 4 ($W/m^2°C$).

$$k = 0.93 + 0.04(T_w - T_a) \tag{4}$$

Using the values assumed in the design conditions, q_c is calculated to be about **800 W/m²**.

Heat loss due to evaporation: Heat loss due to evaporation takes place when there is a difference in the partial pressure of water vapour at the pool's surface and in the air over the pool. With evaporation of water at the pool surface, certain energy has to exit, i.e. evaporation, and the energy is taken from the water. The heat loss of evaporation can be calculated by the following equation from Rimsha–Doncenko (Svavarsson, 1990):

$$q_E = 4.19(1.56k + 0.70v)(e_w - e_a) \tag{5}$$

where q_E = Amount of heat loss by evaporation (W/m^2);
e_w = Partial pressure of steam at surface at 25.6°C and 100% RH (35.7 mbar);
e_a = Partial pressure of steam in the air at -5°C and 60% RH (2.41mbar).

When the humidity is 60% and the temperature is about -5°C, e_a is about 2.41 mbar. For e_w it can be assumed that in the marginal layer at 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 35.7 mbar. Using these values, q_E is calculated to be about **1000 W/m²**.

Total heat loss for the swimming pool: From the above, the total energy demand of the pool Q (W) can be calculated as:

$$Q = (q_c + q_e + S)A_{pool}$$

where S = The three heat losses = 0.1 (q_c + q_e) (in W/s m^2)

The calculations give the heat load of the pool as Q ≈ **2.5 MW.**

In our 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). According to the calculated results, 2.5 MW of energy are needed to maintain the pool water above 27°C.

Heat loss for swimming pool showers: The maximum shower load for the swimming pool is obtained by assuming a maximum number of 200 persons/hour showering during the period of 8 hours, between 10:00 and 18:00. It is assumed that the shower is a mixture of 60°C hot water and cold water and takes about 10 minutes each time. The hot water demand is about 30 l/person, so the total daily rate is about 48 m^3/day. This means that about 34 m^3 of 60°C hot water are needed for one day. Calculation of the peak heat load for the shower when the pool is opened is equal to **250 kW**. This part of the heat load will be designed along with that for the hot tap water.

5. MINERAL WATER DESIGN – BALNEOLOGICAL BENEFITS

Research has shown that some chemical elements in hot water are beneficial for the health For example, F and H_2SiO_3 have a very important effect on the bones and teeth. In addition, they are beneficial to some illnesses of the vascular system and cardiopathy. As there are many healthy elements in geothermal water, it can be made into mineral water after having passed through the heat exchanger, and can serve the players and the public. Because the quantity is very small, here assumed to be about 3% of the total geothermal water, it will not affect re-injection too much.

5.1 Mineral water appraisal

As mentioned before, water samples were taken from the wells. After analyses and appraisal, it is known that there are many healthy elements in the water. Li, Sr, H_2SiO_3 and soluble solids have values that are acceptable according to the used standard, but F is above the limit. Table 6 shows the results of the chemical analysis of the water and the values of the international standard used for mineral waters, and the appraisal results. Mineral water can be produced using geothermal water, but some elements, such as F, need to be dealt with first.

5.2 Mineral water production system

In preparing the mineral water, the geothermal water will be treated as shown in Figure 7. The steps in the system are explained as follows:

1) *Cooling tank*: Geothermal water is transferred to a cooling tank, and the temperature is lowered until suitable for mineral water production.
2) *Medium filter*: When the geothermal water goes through the medium filter (manganic sand) some bigger granule impurities and iron in the water are removed.
3) *Active carbon filter*: Mainly gets rid of the organic matter in water, colloid silica, chlorine etc.; this action can protect the equipment, too.
4) *JP-500 filter*: Filters the smaller granule impurities, and ensures the quality of the mineral water.
5) *Electrodialysis*: Gets rid of the fluorine in the water without influencing the H_2SiO_3.

TABLE 6: Mineral water appraisal result

Element type		Test value (mg/l)	Standard GB8537—1995	Appraisal result
Health criterion	Li	2.86	≥0.20	Within standard
	Sr	3.44	≥0.20	Within standard
	Zn	0.03	≥0.20	Below standard
	Br	0.8	≥1.0	Below standard
	I	0.09	≥0.20	Below standard
	H_2SiO_3	71.5	≥25.0	Within standard
	Se	<0.001	≥0.010	Below standard
	CO_2	15.4	≥250	Below standard
	Soluble solid	2250.6	≥1000	Within standard
Upper limits	Li	2.86	<5.0	Measures up
	Sr	3.44	<5.0	Measures up
	I	0.09	<0.50	Measures up
	Zn	0.03	<5.0	Measures up
	Cu	<0.02	<1.0	Measures up
	Ba	0.156	<0.70	Measures up
	Cd	<0.001	<0.010	Measures up
	Cr	<0.005	<0.050	Measures up
	Pb	<0.01	<0.010	Measures up
	Hg	<0.0001	<0.0010	Measures up
	Ag	<0.01	<0.050	Measures up
	H_3BO_3	29.6	<30.0	Measures up
	Se	<0.001	<0.050	Measures up
	As	<0.005	<0.050	Measures up
	F	8.1	<2.0	In excess
	NO_3^-	1.62	<45.0	Measures up

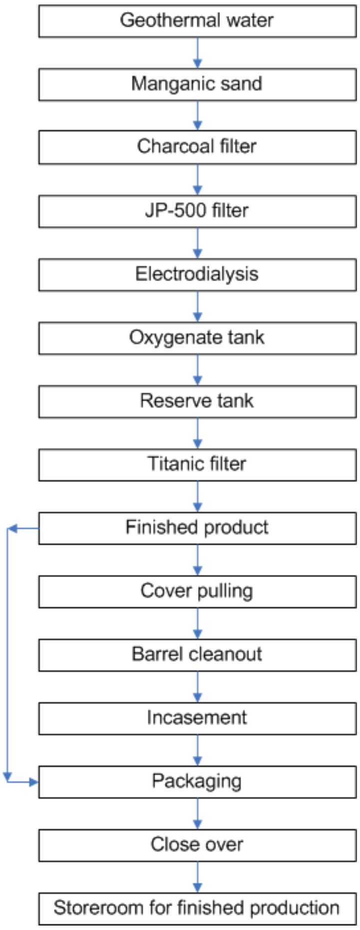

FIGURE 7: Production scheme for mineral water

6) *Ozone*: O_3 is used to get rid of microbes in the water by oxidization. Not only is the effect very good, but also it has no undesired side effects. In addition, after a period of time, O_3 can be deoxidized to O_2, making the mineral water taste better.
7) *Titanic filter*: Used to get rid of some medium granules. After this the mineral water can be stored in the reserve tank.

6. HEATING SYSTEM DESIGN

Once the energy requirement has been defined by calculation, the design of the design of the heating systems comprises the following: heating system design, piping networks design and heat exchanger calculation. From the data presented above, the heat load and the energy requirement for the main stadium can be calculated. Based on the results of the calculations, heating system of the main stadium can be designed. Due to the economic reasons, a natural gas boiler system is added as a supplementary heat source to meet the peak heat load. Based on the design of the heating system, we can calculate the flow rate of the system and then design the piping network and calculate the area of the heat exchanger.

6.1 Energy requirement for main stadium

The total energy demand of the main stadium has been determined. The peak load of the main stadium is about 8 MW. A model was created based on the above premises, the load duration curves for space heating, swimming pool and hot tap water, taking into account the gas boiler load. The load duration curve for the stadium has been drawn as shown in Figure 8.

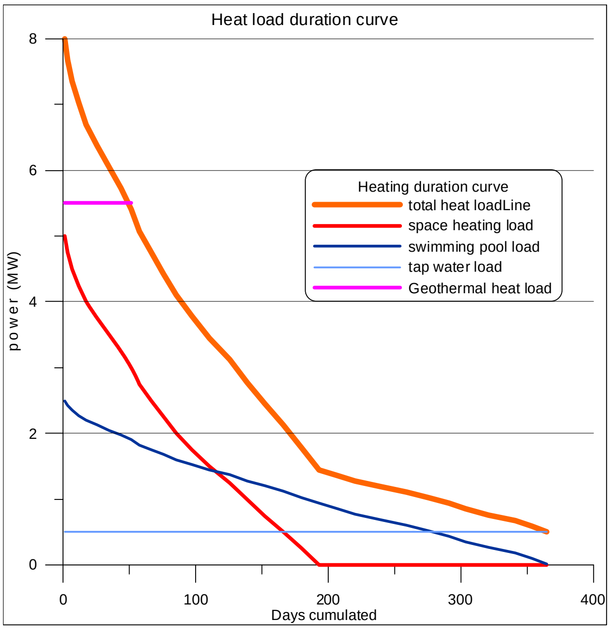

FIGURE 8: The heat load duration curve for the Olympic stadium

6.2 Heating system

The district heating system is designed using some methods presented in "*Comprehensive use of geothermal energy for large sports complexes the Icelandic approach*" (Erlingsson et al., 2002). In this system, a natural gas boiler heating reinforced system is used to compensate for the shortage of the geothermal energy.

The geothermal water from the two production wells is transferred to the substation. A heat exchanger is employed in the substation to transfer the heat to the cold water which is circulated to supply the total heat demand. When the heating system has a sharp peak load, the gas boiler is added as a supplementary energy to raise the supply temperature. The layout of the system is shown in Figure 9.

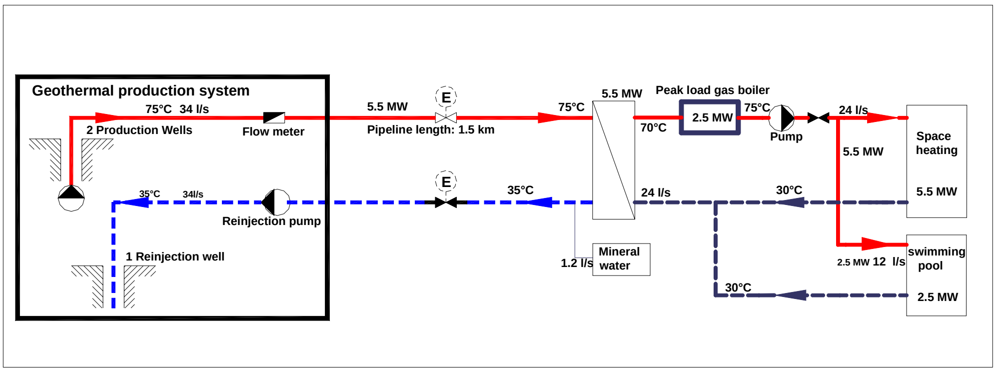

FIGURE 9: Layout of the main heating system

6.3 Piping network

Piping network calculations involve finding the system parameters in such a way, that a predefined cost function has a minimum. The pipes have a resistance defined by the *Darcy-Weisbach* equation, which is written as:

$$h=\frac{v^2}{2g}\frac{L}{D}f=\frac{8m^2Lf}{D^5\rho^2\pi^2g} \tag{6}$$

The friction factor f can be calculated indirectly from the Colebrook - White equation:

$$\frac{1}{\sqrt{f}}=\left(\frac{a}{\mathrm{Re}\sqrt{f}}+\frac{b}{kD}\right)^2 \tag{7}$$

In this report, based on experience, the pressure gradient (TPL) selected is 5 mm/m in the main pipe and 10 mm/m in the branch pipe. In this paper, we focus on the network with a total pipe length of about 1 km serving 8 sections of the building and the swimming pool. The different diameters of the decentralized heating system piping network are shown in Figure 10. From Table 7, we can find reasonable results for the pipelines.

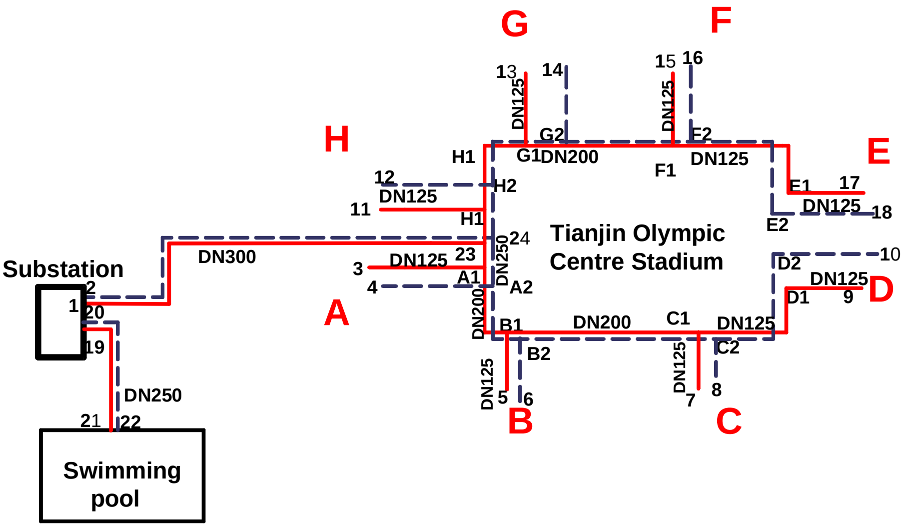

FIGURE 10: Parameters in the decentralized heating system piping network

6.4 Heat exchangers

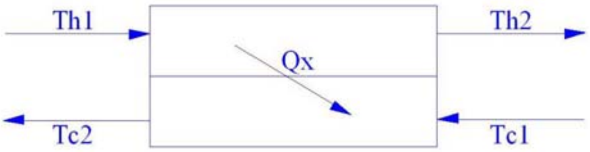

FIGURE 11: Sketch of a typical heat exchanger (Lei Haiyan, 2004)

Due to the corrosive nature of the geothermal water it cannot be used directly in the space heating systems. Thus, heat exchangers are used to transfer heat from the geothermal water to the system water, without mixing the fluids. Typical, a heat exchanger is an element with four connection points. The theory is shown in the sketch of the heat exchanger (Figure 11). The quantity of the heat exchanged can be calculated using the following equations:

$$Q = m_c\, C_p\, (T_{c1} - T_{c2}) \tag{8}$$

$$Q = m_h\, C_p\, (T_{h1} - T_{h2}) \tag{9}$$

$$Q = U A\ \Delta T_m \tag{10}$$

$$\Delta T_m = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln \dfrac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}} \tag{11}$$

In order to model the heat exchanger within the network, an equivalent model with two connection points has to be introduced. The equivalent heat transfer coefficient is associated with this simplification. This coefficient is non-linear and depends on the fluid temperatures, so iteration is necessary for an exact thermal solution. The heat flow for the heat exchanger elements is then calculated by:

$$Q = UA(T_{h1} - T_{c2}) = UA(T_{h2} - T_{c1}) \tag{12}$$

TABLE 7: The decentralized heating system piping network calculation

Node	Node	Heat load(Q)	Flowrate	Diameter	Length	Pressure
1	23	5	24	300	200	5
2	24		24	300	200	
23	A1	2.5	12	250	30	
A2	24		12	250	25	
A1	B1	1.8	8.6	200	40	
B2	A2		8.6	200	40	
B1	C1	1.2	5.8	200	100	
C2	B2		5.8	200	100	
C1	D1	0.6	2.9	125	60	
D2	C2		2.9	125	60	
23	H1	2.5	12	300	20	
H2	24		12	300	25	
H1	G1	1.8	8.6	250	45	
G2	H2		8.6	250	45	
G1	F1	1.2	5.8	200	90	
F2	G2		5.8	200	90	
F1	E1	0.6	2.9	125	80	
E2	F2		2.9	125	80	
19	21	2.5	12	250	100	
22	20		12	250	100	
A1	3	0.7	3.4	125	40	10
4	A2		3.4	125	40	
B1	5	0.6	2.9	125	30	
6	B2		2.9	125	30	
D1	9	0.6	2.9	125	40	
10	D2		2.9	125	40	
H1	11	0.7	3.4	125	40	
12	H2		3.4	125	40	

The total heat capacity of the geothermal wells can be calculated with Equation 8. The calculation shows that their heat capacity is 5.5 MW. Assuming the so-called pitch temperature difference is 5°C, with U = 3000 W/m^2, Q = 5.6 MW, T_{h1} = 75°C, T_{h2}= 35°C, T_{c1} = 70°C, and T_{h2} = 30°C, the area of the heat exchanger is calculated to be: $\boldsymbol{A}$ **= 373 m^2.**

7. CONCLUSIONS

The main conclusions of the study are the following:

1) Tianjin is rich in low- to medium-temperature geothermal resources. Ten geothermal fields have been discovered and 244 geothermal wells had been drilled by the end of 2004.
2) A new stadium will be built for the 2008 Olympic Games by the Tianjin Olympic Centre. The total area of the stadium is about 158,000 m^2, and the area needed to be heated is about 50,000 m^2. Geothermal energy will be used in the large building complex by the stadium as the heat resource for space heating, domestic hot water and the swimming pool. About 3% of the geothermal water will be used to procure mineral water.
3) A production system based on the low-temperature geothermal energy, combined with a gas boiler for peak load and supply/return temperatures of 75/30°C for the user is designed.
4) The heating system is designed to be a fan-coils system with 60/30/20°C (supply/return/indoor temperatures). Hot tap water will be distributed to consumers from the substation using heated

fresh water. The swimming pool is designed according to the most common standards regarding dimension and sanitary equipment requirements. Mineral water will be made from the geothermal water using suitable treatment, such as filters, etc.

5) The heat load of the district heating system is about 8 MW. The geothermal energy can supply 5.5 MW, so a gas boiler is selected to supplement it during peak loads.
6) Geothermal fluid is available year round. It is of great importance for providing sport complexes with hot tap water and waters for the swimming pool.
7) The use of geothermal energy is a benefit for Tianjin City and helps in the promotion of competitive sport activities and in other associated socio-economic ways.

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