The United Nations University

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 2005
Number 18

A DIFFERENT APPROACH FOR AN EXISTING GEOTHERMAL UTILIZATION PROJECT IN BEIJING

Sun Caixia
Beijing Institute of Geo-Exploration and Technology
No. A2, Lishuiqiao 102218,
Chaoyang District, Beijing
P.R. CHINA
zswx800616@126.com

ABSTRACT

This report describes a different approach for an existing district heating system project in Beijing. The project is one of the largest geothermal space heating systems in China at present, designed as a centralized heating centre to supply the total heating requirement for a specific area established in 2002. In this report, a new improved approach with separated decentralized substations is discussed in order to make an economic comparative analysis to guide further development.

1. INTRODUCTION

Geothermal energy, as a clean and renewable form of energy, has been used more and more widely in the world during the second half of the last century for electricity generation, district heating, balneology, agriculture and aquaculture, etc. It makes substantial contributions to the energy supply even when the resource temperature is not high enough for electricity generation. Low-temperature geothermal resources are found in almost every country in the world. Due to the huge potential of low-temperature geothermal energy in China, direct use of geothermal energy is developing rapidly and steadily. In 2004, energy production for direct use in China accounted for the largest proportion among the nations of the world, 12,605 GWh/a.

Beijing is located on top of a large and deep sedimentary basin with 10 defined geothermal fields. The hot water temperature ranges from 45 to 88°C. The geothermal energy has been exploited from surface springs and geothermal wells varying in depth from 1000 to 4000 m. Use of geothermal energy for space heating only started a few years ago but developed very fast because of the great benefit to the environment and the low operational cost. This system can obviously reduce air pollution caused by the emission of fossil fuel burning. This is profound, especially in Beijing, due to the Green Olympics scheduled in the near future.

Along with rapid development, reliable technologies, high efficiency and economical systems are urgently demanded, as well as system with easy management. Geothermal district heating system design consists of two main parts: a heating system design and a pipeline network design (or distribution system design). There are different ways and means to be compared for optimizing the system. The following text describes a different approach that could be used for the largest single geothermal district heating system in China, namely Beiyuan Garden Area-6.

Beiyuan Garden is located in the northern part of Beijing, very close to the Olympic Park (Figure 1). Area-6 is at present, the newest part of the Beiyuan Garden where more than 10,000 people are expected to live. The total construction area is nearly 400,000 m^2, composed of 19 commercial and residential buildings, mainly high-rise buildings. The highest floor is the 25th with a height of 75.2 m. The geothermal district heating system was established in 2002.

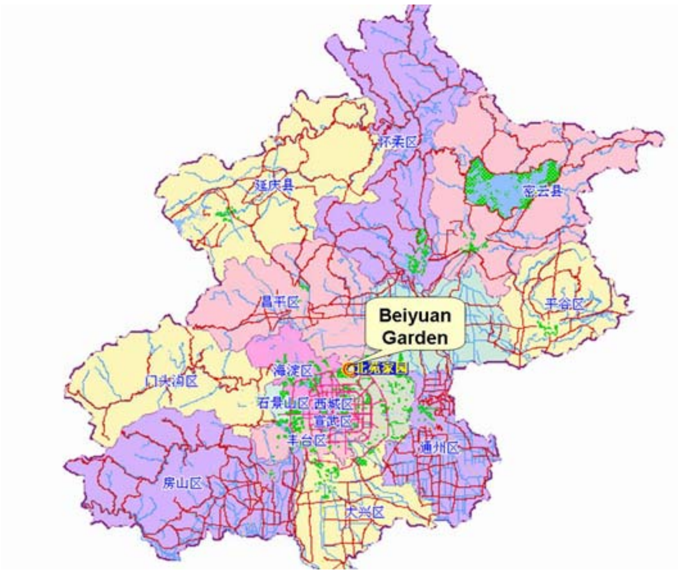

FIGURE 1: The location of Beiyuan Garden in Beijing

2. PROJECT BACKGROUND

The main design of the current Beiyuan Garden Area-6 district heating system includes a solution for heating hot water for both space heating and hot tap water for the whole estate in a single centralized heat central, using geothermal water as the heat source. A gas-fired boiler is used for replenishment during peak heat load periods. A heat pump is used to extend the utilization of the low-temperature geothermal energy for both heating in winter and cooling with a cooling tower in summer.

FIGURE 2: Airscape of Beiyuan Garden Area-6

Here the temperature and pressure of the various heating systems for all buildings is controlled in one place, irrespective of the individual building's demands. Each system and pressure zone is supplied with a set of supply and return pipelines dedicated to that single purpose. As mentioned before, there are mostly high-rise buildings in Area-6, (as can be seen in Figure 2), divided into 3 main pressure zones for both space heating and hot tap water systems. There is a large and complex pipeline system from the Heat Central to the buildings. The connections at the consumer end (in buildings) are simple but do not facilitate control of temperature in each building individually.

In addition to the energy provided by the geothermal fluid for the district heating system, additional energy required to meet peak load demand is provided by an existing gas boiler located approximately 700 m northwest of the pumping station. The gas boiler is used to heat water for the primary district heating system of surrounding areas and a pipeline connecting the station to Area-6 is in place. The gas boiler station provides hot water at 130/90°C (supply/return) while the district heating system operates under design temperatures of 80/40°C.

The system has experienced some problems since being put online in 2003. The operating status is not quite perfect. For instance, the temperature of the domestic hot tap water cannot be controlled very well, and the piping network has had some problems in circulation because of the low boost pumping. At present, only one production well is operated for heating and hot water systems due to few consumers. But consumption will rise as more and more people move into the buildings.

3. GEOTHERMAL POTENTIAL AND WELLS

As mentioned before, Beijing is situated on top of a large and deep sedimentary basin. There are 10 defined geothermal fields mainly distributed in the plain and Yanqing Basin. The main fault namely Huangzhuang-Gaoliying Fault, passes through Beiyuan Garden. According to exploration, there is a rich geothermal resource in this area. And this has also been proved by successful exploitation.

Three geothermal wells were drilled for the project. All wells, except BY1, are doublet wells, equipped in such a manner that they can be operated as both production wells and re-injection wells. Two of the three available wells serve as production wells. They can produce a total of 150 m^3/h of geothermal water at 75°C. The total re-injection capacity is also 150 m^3/h. Two of the boreholes, BY2 and BY3, are located outside Area-6, towards the north, within 1100 m radius from the middle of the area. The third borehole, BY1, is located within Area-6 at its southern perimeter (Figure 3).

Individual collection pipelines were constructed from each of the three boreholes, joining each well to the same pumping station, the Well Central Station, located approximately 500 m north-northwest from the centre of Area-6. A double pipeline then directs the geothermal water from the pumping station to the heat central and back after use.

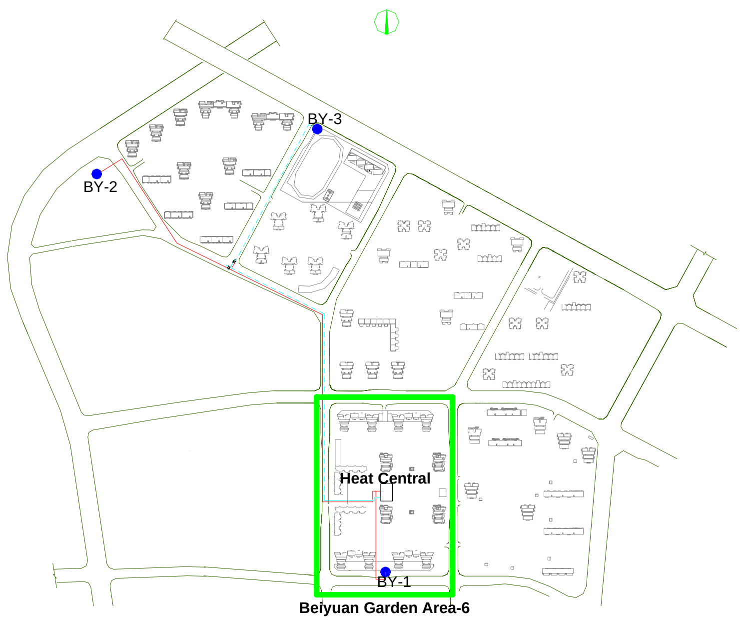

FIGURE 3: The location of the geothermal wells

Some water samples have been taken from these wells. The conclusion of geochemical analysis is that there are no silica, calcite or magnesium deposits associated with utilization. And there is no dissolved oxygen component in this water, only a small amount of hydrogen sulphide, (H_2S). Due to the fast reaction between dissolved oxygen and hydrogen sulphide they are not simultaneously present in the water. 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, because of a high iron content of the geothermal water, so when it comes into contact with the atmosphere it may oxidize to iron hydroxide causing the water to take a brownish colour.

4. POWER AND ENERGY DEMAND

4.1 Weather conditions

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

The three main factors were analysed. Ten years of climate data, from September 1991 to September 2000, were obtained from the Meteorological Bureau of Beijing (Yin Heng, 2002). Observations on highest, average and lowest air temperatures, 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 4 such average data are shown, along with two standard deviation confidence intervals for outdoor air temperature.

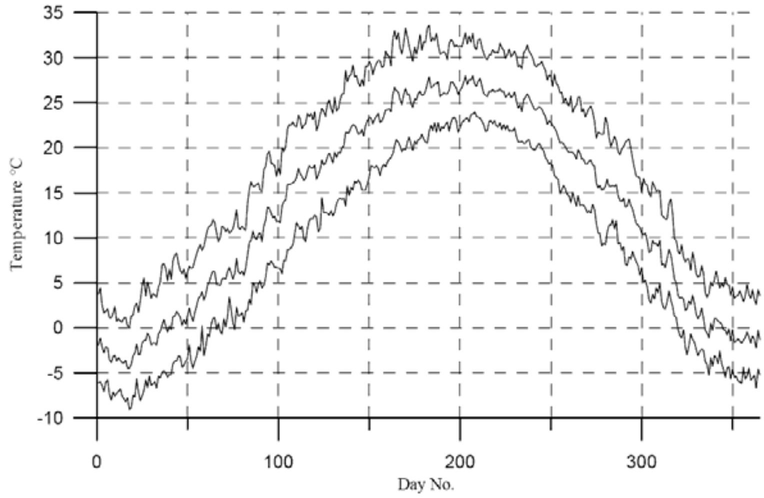

FIGURE 4: Daily average, maximum and minimum outdoor air temperature in Beijing 1990-2000 (Yin Heng, 2002)

The outdoor temperature of –9°C was chosen as the heating design temperature for Beijing. It is the mark under which the actual outdoor temperature should not be expected to fall for more than 1% of the limit hours of the year. Unfortunately, the weather data collected are only sufficient for a static study, but insufficient for purposes of evaluation by a dynamic model. More detailed data with intervals of not more than 2 hours should be obtained for a dynamic model simulation. Figure 5 shows the outdoor temperature duration curve.

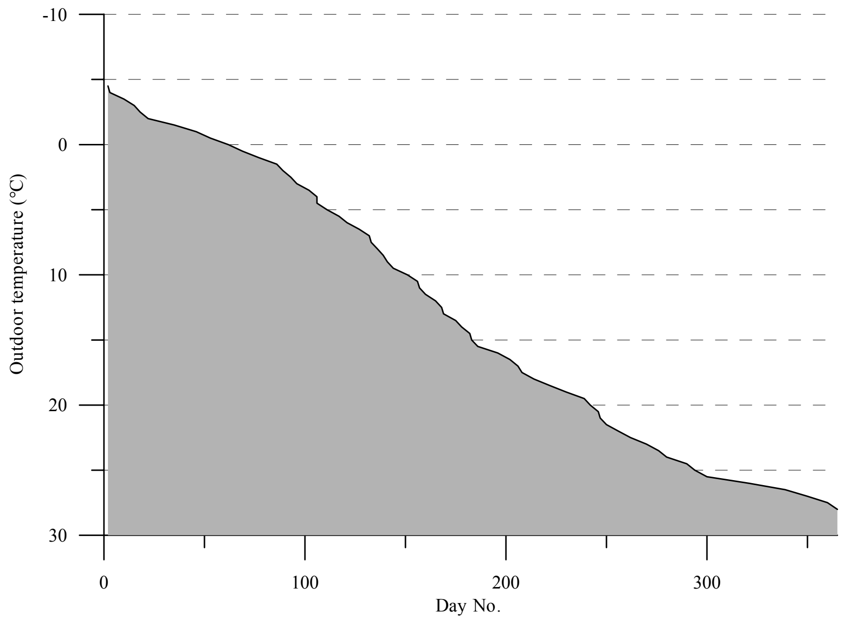

FIGURE 5: Outdoor air temperature duration curve (Yin Heng, 2002)

Beiyuan Garden is located in the northern part of Beijing, very close to the Olympic Park (Figure 1). Area-6 is at present, the newest part of the Beiyuan Garden where more than 10,000 people are expected to live. The total construction area is nearly 400,000 m^2, composed of 19 commercial and residential buildings, mainly high-rise buildings. The highest floor is the 25th with a height of 75.2 m. The geothermal district heating system was established in 2002.

According to the Chinese Building Code, the indoor heating temperature should be above 18°C during the heating period in winter. And the reference value of outdoor temperature for heating design during the heating period is -9°C.

4.2 General building information

Table 1 lists the main parameters of the buildings in Area-6, which influence the design of the district heating system. The parameters are shown for each of the 19 different types of buildings. The total area is about 387,165 m^2 with 3218 apartments in all.

The first row listed in the table is the height of each building, from ground to roof level. The height has an effect on the pressure needed to deliver water to the different elevations within it. As can be seen from Table 1, up to 3 different pressure zones are needed in the high-layer buildings, consisting of higher and lower floor heating zones and a radiator heating zone.

TABLE 1: Building parameters

Type	Building height (m)	Floors	Total area (m^2)	Floor area (m^2/floor)	Floor height (m)	Pressure zones	Total no. of apartments
601#	75	30	23015	767.2	2.49	3	184
602#	50	21	9432	449.1	2.37	3	72
603#	75	30	22939	764.6	2.49	3	184
604#	75	30	23015	767.2	2.49	3	184
605#	50	21	9448	449.9	2.37	3	72
606#	75	30	22939	764.6	2.49	3	184
607#	72	29	24441	842.8	2.50	3	208
608#	72	29	24441	842.8	2.50	2	208
609#	5	2	1640	820.0	2.25	1	0
610#	37	16	28124	1757.7	2.29	2	273
611#	37	16	28124	1757.7	2.50	2	273
612#	72	29	24441	842.8	2.50	2	208
613#	72	29	24441	842.8	2.50	2	208
614#	72	29	23257	802.0	2.50	2	208
615#	50	21	9676	460.8	2.38	2	72
616#	69	28	23241	830.0	2.48	2	200
617#	72	29	23257	802.0	2.50	2	208
618#	50	21	9676	460.8	2.37	2	72
619#	69	28	23241	830.0	2.48	2	200

A more detailed description of the variables is called for. In general the highest buildings are divided into three pressure zones for the heating system. The annexes are categorized within the radiator heating zone. The other floors up to the 14th floor are categorized within the lower zone and the remaining floors from the 15th and up fall within the higher zone. The majority of all the apartments are installed with a floor radiation heating system. Only some annexes of the buildings from 601# to 606# are installed with a traditional radiator system.

In the existing system, the pressure zones for the domestic hot water are divided so floors from the 1st to the 3rd are categorized within the lower zone; floors from the 4th to the 14th are categorized within the middle zone, and floors from the 15th up are categorized in the higher zone.

4.3 Space heating

Based on the specifications of Chinese building construction, pertinent weather data, and the differences between the different rooms of the building, the specific heat load of buildings in Beijing are shown in the Table 2 as well as the heat load of each building.

TABLE 2: Beiyuan Garden Area-6 heat load list

Type	**High zone load (kW)**	**Load per area (W/m^2)**	**Area (m^2)**	**Low zone load (kW)**	**Load per area (W/m^2)**	**Area (m^2)**	**Load of annexes (kW)**	**Load per area (W/m^2)**	**Area (m^2)**
601#	562.5	53	10613.2	723.0	58	12401.4			
602#	132.7	40	3317.4	267.2	44	6114.2			
603#	568.3	54	10543.4	700.4	57	12395.6	444.0	53.0	8377.4
604#	561.4	53	10613.2	723.0	58	12401.4			
605#	132.7	40	3334.0	267.2	44	6114.2			
606#	568.3	54	10543.4	700.4	57	12395.6			
607#	515.0	47	11004.3	649.0	48	13436.9			
608#	515.0	47	11004.3	649.0	48	13436.9			
609#							86.92	53.0	1640.0
610#				1223.4	44	28123.6			
611#				1223.4	44	28123.6			
612#	515.0	47	11004.3	649.0	48	13436.9			
613#	515.0	47	11004.3	649.0	48	13436.9			
614#	521.3	50	10489.3	715.0	56	12767.5			
615#	84.8	40	2119.9	328.7	44	7556.3			
616#	515.0	49	10488.9	714.1	56	12752.2			
617#	521.3	50	10489.3	715.0	56	12767.5			
618#	84.8	40	2119.9	328.7	44	7556.3			
619#	515.0	49	10488.9	714.1	56	12752.2			
Total	**6828.1**		**139178.0**	**11939.5**		**237969.2**	**530.9**		**10017.4**
Total heated area (m^2):			**387164.6**						
Total heat load (MW):			**19.3**						

It can be seen that the buildings are divided into three zones to calculate the heat load, and different buildings have different specific heat loads according to practical experiences. To heat the total, 38,164.6 m^2 area, 19.3 MW of thermal power is needed.

4.4 Domestic hot water

The design of the existing system for domestic hot water calls for cleaning and filtering the geothermal hot water in the heat central until it attains standards for water for domestic purposes. The purified hot geothermal water is then distributed to consumers for direct consumption from the heat central. This solution involves the removal of large quantities of geothermal water from the reservoir without the possibility of re-injection, which might compromise the stability and long-term exploitation of the geothermal reservoir. It requires official permission to withdraw geothermal water for domestic hot water purposes without having to re-inject the fluid, at a high expense of geothermal water.

A more reasonable approach would be to use the main district heating distribution system (4 bar supply and 2 bar return) to supply energy for domestic hot tap water as well as space heating. Here, cold water (with a temperature of around 10°C) would be heated using heat exchangers in separate substations in the individual buildings. The heated cold water would then be supplied to the domestic hot water systems installed in the buildings. For this approach, only 2 pressure zones would be needed to meet demand.

The method used to estimate the annual average load for domestic hot water consumption, uses comparable values from four European studies regarding the use of hot tap water. These studies were performed in Denmark, France, Norway and Iceland. All methods were adjusted to take into account the temperature of Chinese domestic hot water, or 50°C (Jóhannesson, 2002).

4.4.1 Annual average demand

According to Danish standards, the annual average consumption of hot tap water in a single apartment is 81 l/day, assuming the apartment is occupied by two persons. This provides the key variable 40.5 l/day/person for Denmark. Using this value to estimate the hot tap water consumption for Area-6, it is concluded that for 10,000 inhabitants the annual average would be 5.0 l/s. A basis for calculating the annual average provided by French guidelines uses the value 154 l/day per average apartment, or 6.5 l/s in total for Area-6. Using an empirical value from Norway, or 4.0 kWh/day/person, it is estimated that the annual average consumption of hot tap water for Area-6 would be 10.0 l/s in total. A similar empirical value from Iceland is 107 l/day/person, which results in the estimation for Area-6 of 12.5 l/s in total.

As one can see, consumption values per person differ between countries. The key factor regarding how much tap water is used annually is the energy price. The price of thermal energy is the lowest in Iceland, or 0.012 US$/kWh. Therefore the consumption of hot tap water is higher in Iceland than in continental Europe where the price is 3-4 times higher.

According to a cautious analysis and experience it is estimated that the annual average hot water consumption in Beiyuan Garden Area 6 would be *7.0 l/s.* To heat up enough cold water to meet this demand, i.e. from 10°C up to 50°C, an annual average of *1.2 MW* of power is required.

4.4.2 Maximum daily average demand

It is clear that on certain days during the year, average consumption will be less than the 7 l/s set forth as the annual average hot domestic water consumption in Beiyuan Garden. This can be expected on days when people are away from home, on holidays, etc. Accordingly, there will also be days where the daily average is much higher than the annual average value of 7 l/s. In Iceland, the highest daily consumption of hot tap water occurs on days during the Christmas holidays. The multiplication factor that provides the maximum daily average demand, uses the annual average value times 1.8 in France, but around 1.4 in Iceland.

We estimate that the maximum daily average of hot tap water consumption in Beiyuan Garden Area-6 will be 12.0 l/s. To heat up enough cold water, i.e. from 10°C up to 50°C, to meet this maximum daily demand, requires 2.0 MW of power.

4.4.3 Maximum instantaneous demand

In addition to fluctuations within the year it is also clear that consumption of hot tap water during the day is not constant. Various different methods can be used to estimate the instantaneous demand of hot tap water.

Employing French guidelines we find that the instantaneous demand for hot tap water in Beiyuan Garden Area-6 can be expected to go as high as 55 l/s. To heat up enough cold water, i.e. from 10 up to 50°C, to meet this maximum instantaneous demand requires 9.2 MW of power.

4.5 Meeting the power and energy requirements

As mentioned before, the maximum flow of 75°C geothermal hot water from each production well is 75 m^3/h. This provides a maximum power utilization of 7.0 MW at periods when the space heating load is 19.3 MW and the hot water load is 1.2 MW as calculated before. Thus, geothermal energy can account for 34% of the total peak load. The rest will be supplied by a gas-boiler.

According to the outdoor temperature duration curve of Beijing, the perfect heating period should be 180 days. The heat load duration is shown in Figure 6. From this curve, we can see clearly the power requirement and the energy demand. The total energy demand both for space heating and hot tap water is around 50 MWh. The geothermal water can supply about 26 MWh, the other part is supplied by a natural gas boiler.

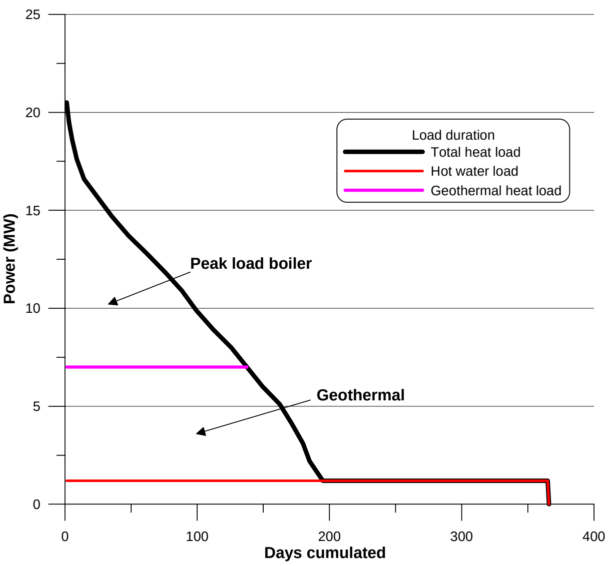

FIGURE 6: Total heat load duration curve

5. NEW SYSTEM DESIGN

5.1 Primary heating system design (pumping station)

District heating system design consists of two parts: a heating system design and a piping networks design. Here, the proposed heating system design for Area-6 is given in detail. The existing system used a centralized heat centre with a large and complex piping network, with a heat pump used to extend the use of geothermal energy. At the same time because of its high investment cost, a natural gas boiler system is used to supply the peak heat load.

The proposal is based on the design of a decentralized district heating system (Figure 7). This can reduce the investment in the large piping network and make it simpler. Also, a natural gas boiler heating reinforcement system is compared with the heat pump system, both economically and environmentally.

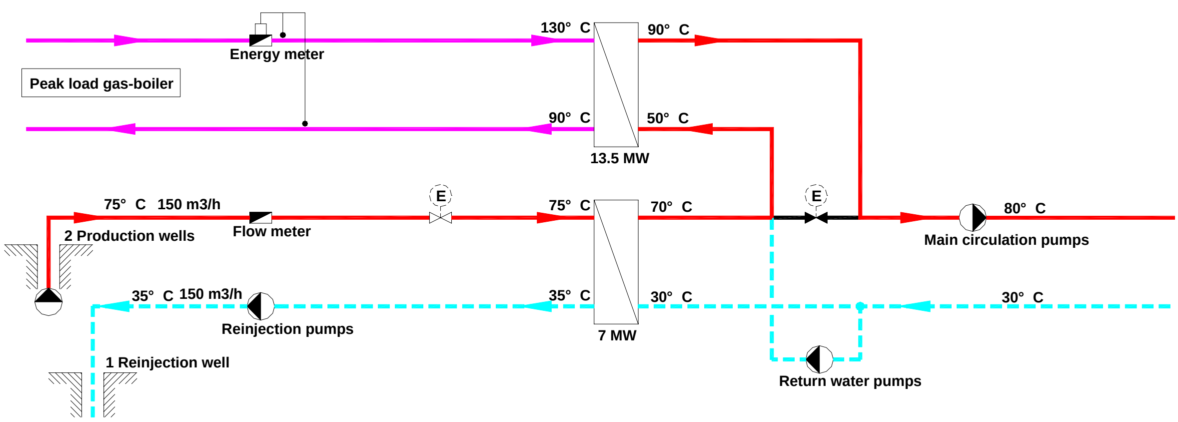

FIGURE 7: Layout of the main

In this system geothermal water from the two production wells is brought via pipelines to the pumping station. A heat exchanger is employed to transfer the heat to cold water which is circulated to supply the total heat demand. A gas boiler is added as a reinforcement to increase the heat. The layout of the heating system is shown in Figure 7.

5.1.1 Heat exchanger for geothermal water

Heat exchangers transfer heat, Q, from one flow stream to another, without mixing the fluids. They are, thus, elements with four connection points. The temperatures of hot and cold fluids in a counter-flow heat exchanger is given in Figure 8. Note that the hot and cold fluids enter the heat exchanger from opposite ends, and the outlet temperature of the cold fluids in this case may exceed the outlet temperature of the hot fluid. Theoretically, the cold fluid will be heated to the inlet temperature of the hot fluid. However, the outlet temperature of the cold fluid can never exceed the inlet temperature of the hot fluid, since this would be a violation of the second law of thermodynamics.

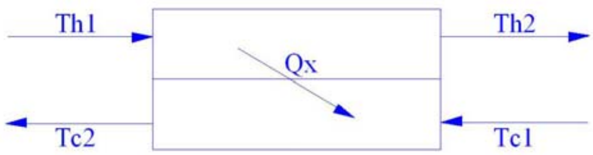

FIGURE 8: Sketch of a heat exchanger (Lei Haiyan, 2004)

The related equations (Gengel and Turner, 2001) are:

$$Q = m_h C_p (T_{h1} - T_{h2}) \quad (1)$$

$$Q = m_c C_p (T_{c1} - T_{c2}) \quad (2)$$

$$Q = UA\Delta T_m \quad (3)$$

and

$$\Delta T_m = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln \dfrac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}} \quad (4)$$

where m_c = Mass flowrates of water required for circulated in the system (kg/s);
m_h = Mass flowrates of geothermal water as a heat source (kg/s);
C_p = Specific heat capacity of water (J/(kg °C));
T_{c1} = Temperature of inlet cold water before heating by heat exchanger (°C);
T_{c2} = Temperature of outlet heated cold water by heat exchanger (°C);
T_{h1} = Temperature of inlet geothermal water at heat exchanger (°C);
T_{h2} = Temperature of outlet geothermal water at heat exchanger (°C);
Q = Heat transfer capacity of the heat exchanger (W);
U = Overall heat transfer coefficient (W/m^2 °C);
A = Surface area of the heat exchanger (m^2);
ΔT_m = Log mean temperature difference (°C).

For specified inlet and outlet temperatures, the log mean temperature difference for a counter-flow heat exchanger is always greater than that for a parallel-flow heat exchanger. Therefore, it is common practice to use counter-flow arrangements in heat exchangers. In a counter-flow heat exchanger, the temperature difference between the hot and the cold fluids will remain constant along the heat exchanger when the heat capacity rates of the two fluids are equal (that is ΔT = constant when $C_h = C_c$). Then we have $\Delta T_1 = \Delta T_2$ (that is (T_{h1} - T_{c2} equals (T_{h2} - T_{c1})), and the log mean temperature difference relation above gives $\Delta T_m = 0/0$, which is indeterminate. In this case we have $\Delta T_m = \Delta T_1 = \Delta T_2$, as expected.

The total heat capacity of the geothermal wells can be calculated and the same quantity of heat must be supplied to the buildings. This is done through a heat exchanger that transfers heat from geothermal water to the fresh cold water that is used in the piping network. According to Equation 1, the heat capacity of the geothermal wells equals *6975 kW*.

The heat flow for the heat exchanger elements is then calculated by:

$$Q = UA(T_{h1} - T_{c2}) = UA(T_{h2} - T_{c1}) \tag{5}$$

Now there is a 5°C difference, with U = 3000 W/m^2°C, Q = 6975 kW, T_{h1} = 75°C, T_{h2} = 35°C, T_{c1} = 30°C, T_{c2} = 70°C.

Hence, the area of the main geothermal water heat exchanger is calculated as: $A = 465\ m^2$.

The specific heat capacity of water was assumed to be constant or C_p = 4.186 (kJ/(kg °C)), and the dependence of temperature was neglected.

5.1.2 Heat supplied by the gas-boiler

Considering the total investment of the whole district heating system and the geothermal reservoir, a natural gas boiler is selected to supply the peak load of the system. The economic and environmental comparisons will be discussed in the following section.

According to the previous section, the total heat requirement of the system is 20.5 MW, which is composed of 19.3 MW space heating load and 1.2 MW hot water load. The geothermal water can supply nearly 7.0 MW, so the remainder will be supplied by a natural gas boiler.

The heat exchanger size for the gas boiler is calculated in a similar way to the one for the geothermal water. According to Equation 5, there is a 40°C difference. U = 1500 W/m^2, Q = 13500 kW, T_{h1} = 130°C, T_{h2} = 90°C, T_{c1} = 50°C, T_{c2} = 90°C.

Hence, the area of the gas boiler heat exchanger is calculated as: $A = 225\ m^2$.

5.2 Secondary heating system design (substations)

This decentralized approach requires building separate substation in different individual buildings. The boost pumps for the higher zone and a heat exchanger for hot tap water are assembled in each substation in the basement. The optimal way to supply floor heating and a radiator heating system is to place a small substation on each floor. It is easy and convenient for controlling the temperature and pressure on each floor. The flow meter is fixed in each apartment.

It is feasible that in most buildings one room is reserved in the basement for general utilities (electricity, cable-TV, telephone, water, etc) and it should have enough floor space to accommodate the compact heating substation. The substation is with a width of 500 mm to enable transportation through the corridors and doors. The weight of the substation is sufficient for hauling by manpower, thus eliminating the need of any high-duty lifting equipment. The substation does not need any specially designed room. The only connections needed are power and the supply and return pipes of the primary and secondary networks. The power connection of the substation is usually 220 V; a 10 A fuse is enough. No specific power supply arrangement is, therefore, needed.

On each floor there are also some rooms reserved for the equipment utilities. The small substation for the floor heating system on each floor involves circulation pumps; the control valves can be assembled easily, and this does not cause any disturbing noise. The hydraulic balancing of the network is easy as the pipe distances on each floor inside the building are limited.

As the substation in the basement includes a domestic hot water heat exchanger, the building can be equipped with hot tap water piping (plastic, no corrosion) and unauthorized use of radiator water does not exist, thus minimizing the need for make-up water. The secondary network is equipped with an expansion tank to eliminate any water volume changes occurring. If some make-up water is needed, an automatic pressure sensor will supply measured make-up water from the primary side to the secondary network.

The layout of this decentralized heating system can be seen in Figure 9. It shows a typical heating system sample which is divided into three zones: the radiator heating zone, the lower floor heating zone, and the higher floor heating zone. The flow meter is assembled in the floor heating system of every apartment. The boost pumps and the heat exchangers for hot water are placed in the substation in the basement of each building. An energy meter (fixed for a return temperature of 30°C) is assembled in the basement substation to measure actual heat consumption.

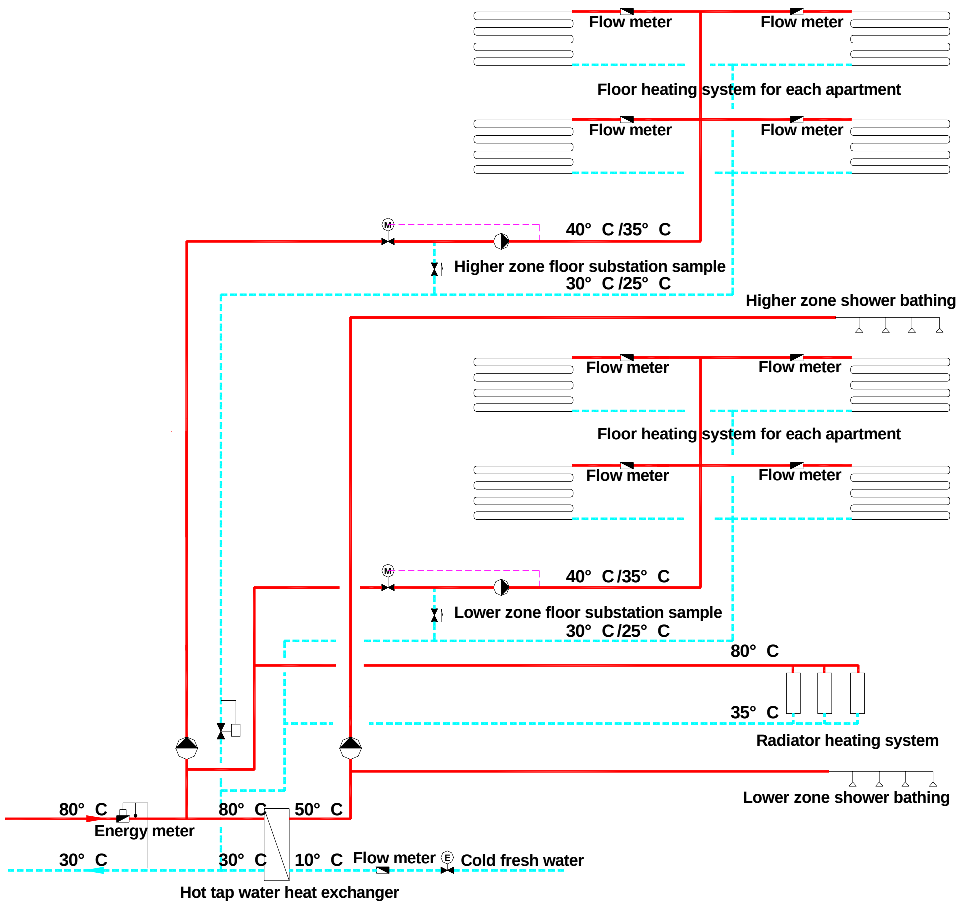

FIGURE 9: Decentralized heating system substation and terminal layout

5.3 General piping network design

The piping network is an important part of the total investment cost. Thus, the design of the district heating piping network is of vital importance to the economics of the system. There is always a trade-off between economics and reliability depending upon the piping material, the target pressure loss (TPL) per unit length of pipe, the location of the heat central and the installation type of the piping network, all common design parameters of the piping network.

Target pressure loss (TPL) is a common design parameter of piping network. The district heating practice is to design for 50~100 Pa/m pressure loss. There is a trade-off between the pressure loss of the piping network and the economy of the system. If the pressure loss is high, investment cost of the pipe is low, but operational cost is high. On the other hand, if the pressure loss is low, the investment (pipe diameters are larger) is badly utilized, but the pumping cost is low (Yildirim et al., 2005). Selected pipelines are pre-insulated pipes.

The Darcy-Weisbach Equation is a theoretically-based equation for use in the analysis of pressure pipe systems. It is a general equation that applies equally well to any flowrate and any incompressible fluid, written as follows:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \tag{6}$$

where
h_f = The head loss (ft, m);
f = The Darcy-Weisbach friction factor;
D = The pipe diameter (ft, m);
L = The length of the pipe (ft, m);
V = The velocity (ft/s, m/s);

The friction factor f, is a function of the relative roughness of the pipe wall, the velocity of the fluid, and the kinematic viscosity of the fluid. Appropriate values of f can be determined from the Swamme and Jain Equation:

$$f = \frac{1.325}{\left[\log_e\left(k/3.7D + 5.74/R_E^{\ 0.9}\right)\right]} \tag{7}$$

where
f = The friction factor;
k = The roughness height (ft, m);
R_E = The Reynolds number, VD/ν for turbulent flow;
V = The velocity (ft/s, m/s);
D = The pipe diameter (ft, m).

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, as the pressure loss along any closed path has to sum up to zero, making it therefore impossible to obtain target pressure loss in all the elements. A loop free network has a unique solution for nodal pressure.

5.3.1 The existing centralized system piping network

As mentioned in the project background, there is currently a Heat Central where heating of hot water both for space heating and hot tap water takes place in the middle of Area-6. This leads to a large and complex piping network. Because the buildings in Area-6 are almost all high-level buildings, the system needs to be divided into 3 main pressure zones both for the space heating system and the hot tap water system. This large and complex pipeline system is shown in Figure 10. The most complex pipelines direct to one building contain 12 pipes in total, namely radiator heating supply and return pipes, floor heating supply and return pipes for the high zone, floor heating supply and return pipes for the low zone, and the hot tap water supply and circulating pipes of the three individual pressure zones.

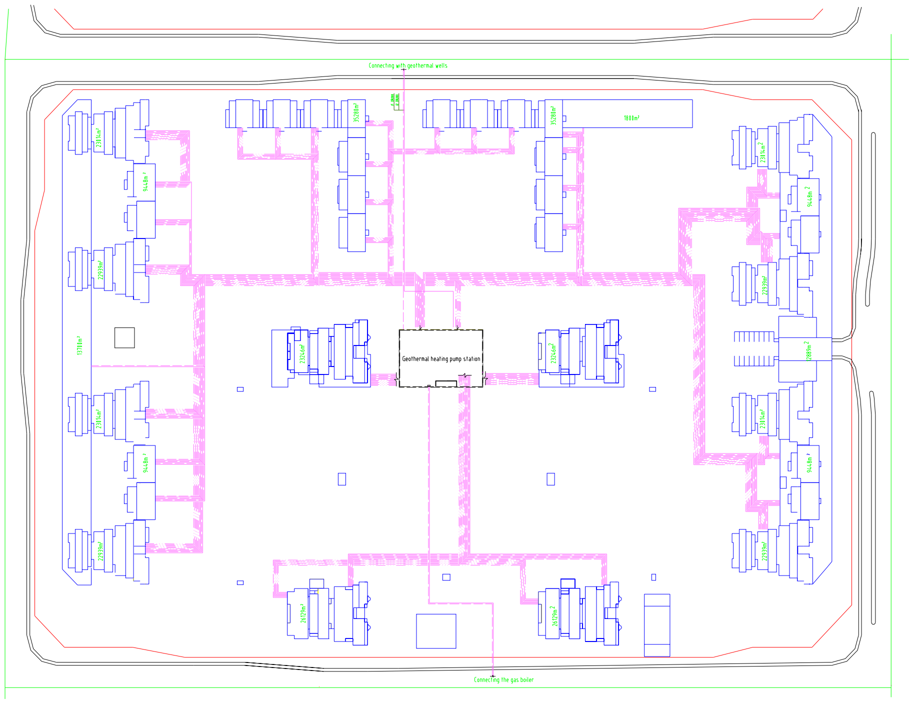

FIGURE 10: The centralized heating system piping network (Xie Donghui,

5.3.2 Decentralized system design

A single set of supply and return pipelines with a temperature of 80/30°C (supply/return) serves the heat demand of a single building (Figure 11). Temperature and pressure control of secondary water for space heating (floor and radiator heating) is taken care of in small decentralized substations, one for each floor. Hot tap water is also prepared in each building by heating cold water to the required temperature of 50°C in a heat exchanger in the substation which is located in the building basement.

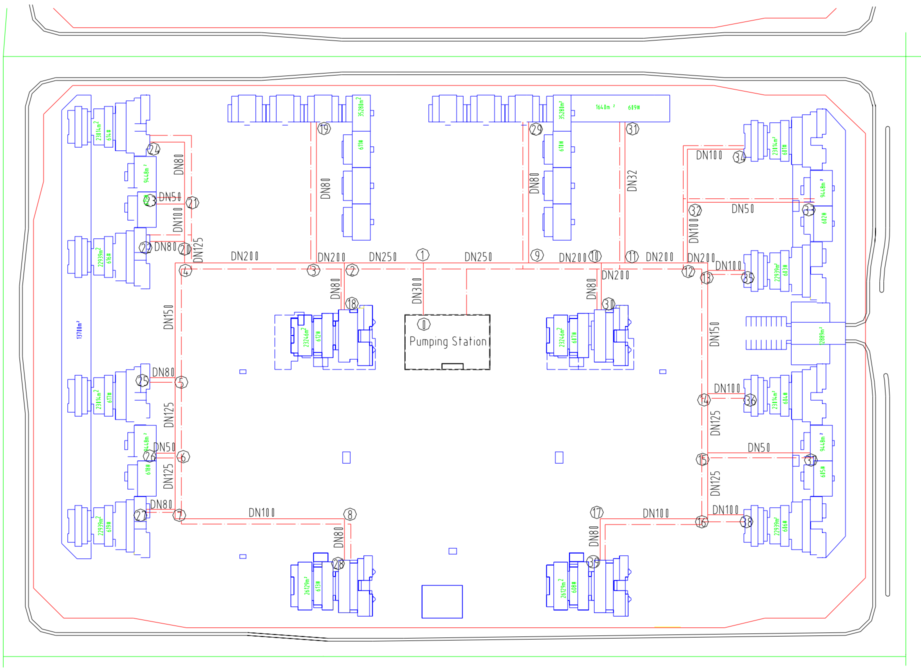

FIGURE 11: The decentralized heating system piping

The noticeable advantage of this decentralized approach is making the main piping network much simpler than the centralized approach. There is only one set of pipeline for the total space heating and domestic hot tap water load with a supply and return temperature 80/30°C. The piping network layout is shown in Figure 11 and the calculated parameters for the network in Appendix I.

5.4 Terminal system design

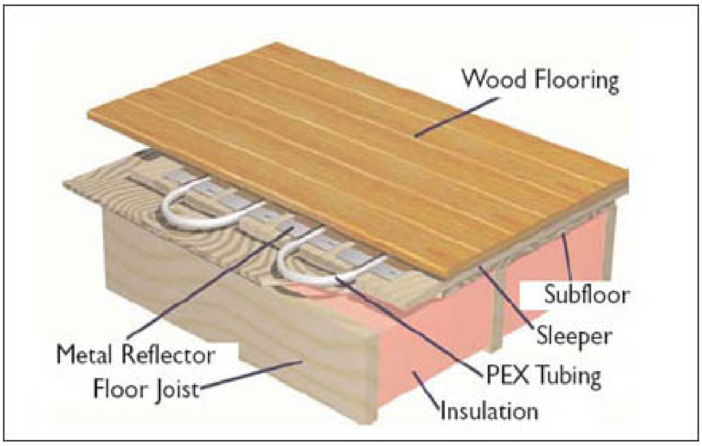

FIGURE 12: The structure of a typical floor heating system (CMHC, 2005)

The terminal system of a space heating system, such as a traditional radiator system uses fan-coils, or it uses a floor heating system. Obviously, the simplest system is floor heating (Figure 12). It only requires heat exchangers (usually plate type, which can easily be disassembled and cleaned in case of scaling) in which the geothermal water heats fresh water for space heating up to 40°C. This heated fresh water is then distributed to all consumers, flowing through pipes laid under the floor tiles. The heat supply is controlled by regulating the flowrate (using variable speed drives for the circulation pumps), while the inlet temperature is kept constant. It is a very efficient system especially for new buildings, having a relatively low cost, and also being reliable, comfortable, and aesthetic (no visible radiators). One important advantage is that, as only low-temperature water is circulated through the distribution network, the heat losses are lower than in classical systems.

The majority of the buildings in Area-6 are installed with a floor radiant heating system. The annexes are installed with a radiator system. The temperature of the floor heating system is 40/30°C (supply/return). And the radiator system is 80/35°C. The temperature can be regulated by the valve assembled on the supply pipe of each radiator.

Different subsystems with the manifolds are classified according to the doors in the floor heating system. The circulation pipes are arranged differently in different room. The length of the heated pipes connected with the same manifold should be almost the same.

Here the pre-assembled manifold is obtained from a drawn brass bar with flow-check valves on the supply manifold and thermostatic valves on the return manifold. It is supplied with mounting brackets for anchoring it to the cabinet. It is equipped with flow-check valves with a "memory", that is, once the system has been balanced, the maximum opening of the valves can be blocked so that they can be used as stop flow valves in the circuit. This is a special system in that the flow-check valve can be re-opened and it automatically brings itself to the number of turns corresponding to the balancing value. Another important aspect is that the manifolds are equipped with an automatic air vent on both the supply and return manifolds with a system drainage valve.

14×2 PEXAL pipe has an internal and external layer in crosslinked polyethylene PEX with an intermediate layer in butt-welded aluminium. The spacing between pipes is designed so: the spacing in the living room is 225 mm, the spacing in other rooms such as the bedroom or kitchen is 150 mm.

6. ANALYSIS AND COMPARISON

6.1 Heat load duration curve comparison

During former times and even now in China, the heating period is not based on people's comfort. The official heating period is commonly regulated to 120 days, resulting in people feeling cold in late autumn and early spring. Figure 13 shows the heat load duration curve according to the official heating period. We can see that the curve is steep as the load reduces close to the end. This means that the period of space heating is not long enough to satisfy the requirements of people. People may suffer from low indoor temperature before the beginning or after the end of the space heating period every year.

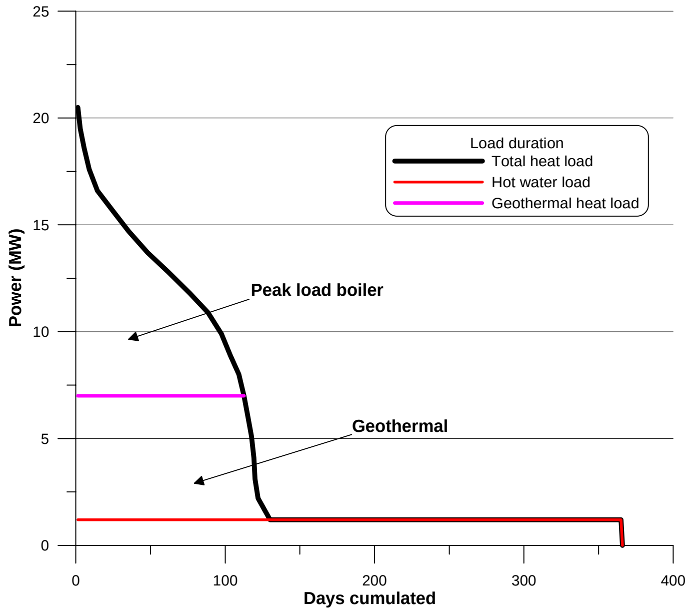

FIGURE 13: The heating load duration curve for 120 days

In a modern society, heating is no longer a "welfare service" provided by the municipal authorities. As living standards have been improving, the demand for comfortable indoor temperatures during winter, and a continuous hot water supply throughout the year have been more and more obvious. At the same time, awareness of energy conservation has become a major issue in China. Geothermal energy utilized in a space heating system would profoundly raise the quality of people's lives, in particular at the beginning and end of the heating period. The operational cost for this time would be very low, including just the expense of the pumping power.

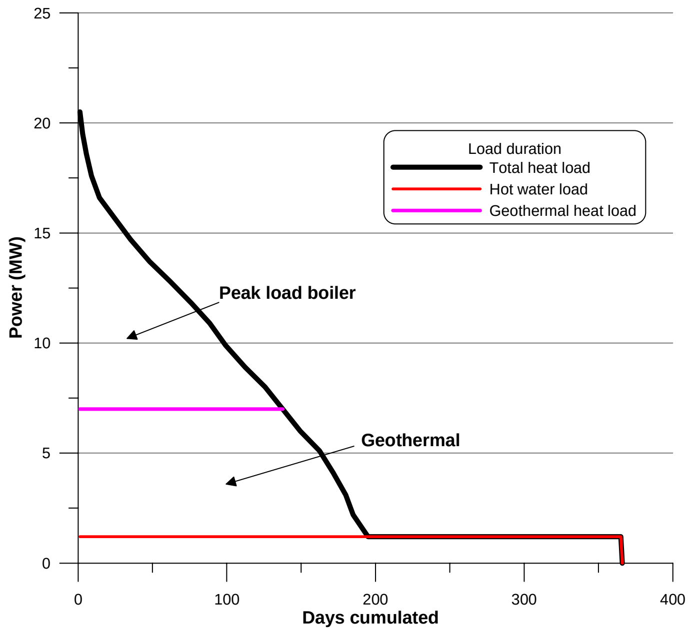

FIGURE 14: The heat load duration curve for 180 days

In this new approach, according to weather conditions and, the outdoor temperature duration curve, to achieve the expected indoor temperature of 18°C, the heating period should be nearly 180 days. The heat load duration curve is shown in Figure 14. This smooth curve is more reasonable and provides more comfort. The additional 60 days, compared with Figure 13, are surely supplied by geothermal energy. It is very economical and leads to ideal results.

6.2 The investment comparison of a centralized system and a decentralized system

In the new approach, heating is provided through small substations located in each building and floor. The piping network is only a set of supply and return pipelines with a bigger temperature difference.

The estimate of investment cost for comparison includes the investment needed for the substations and piping network from the pumping station connection point to the building entrance point. This calculation does not include the cost of civil works and electrical equipment (transformers, cubicles, etc.) or power connection fees to any extent. If these expenses would be included, it would make this decentralized approach more favourable.

TABLE 3: Decentralized system investment estimation

Type	Investment cost	
	(RMB)	(USD)
Piping network	1,983,278	688,889
Substations	5,580,000	244,849
Total	7,563,278	933,738

According to Table 3, we can see the investment cost of piping network for this approach is nearly 2 million RMB. In the existing system, the cost of the large and complex piping network is around 10 million RMB (Xing Hongju, 2003). The Heat Central where the solution of space heating and domestic hot water takes place costs about 15 million RMB, compared with the cost of the decentralized substations, 5.58 million RMB.

This comparison shows clearly that the investment cost would be much smaller when using a decentralized substation system. The main reason why the investment cost is lower is that the piping network routing can be done more efficiently and with a bigger temperature difference (50°C), thus reducing the pipe diameters and the size of circulating pumps.

6.3 Environmental impacts

6.3.1 Reservoir management

Geothermal resources are part of the environment, even though they are located underground. The impact on the resources due to utilization can be minimized through comprehensive and efficient management. The term sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, sustainable geothermal utilization involves energy production at a rate, which may be maintained for a very long time (100-300 years). Geothermal resource management implies controlling the energy extraction from a geothermal resource so as to maximise the resulting benefits without over-exploiting the resource. Energy-efficient utilization and careful monitoring are essential ingredients in sustainable management. Re-injection is also essential for sustainable utilization of geothermal systems with limited recharge, which is often the case in sedimentary geothermal systems, such as the one in Beijing.

In the existing Beiyuan Garden Area-6 geothermal system, the domestic hot water is prepared in the Heat Central. This hot tap water is actually the geothermal water just after the treatment, i.e. cleaning and filtering. This means withdrawing large quantities of geothermal water from the reservoir without the possibility of re-injecting it. It must compromise the stability and long-term exploitation of the geothermal reservoir. For the sustainable development of geothermal resources as mentioned above, it is not a proper solution of geothermal utilization.

In the new approach the solution is to use the geothermal energy just to heat the cold water for domestic hot tap water as well as space heating. This way, all the geothermal water can be re-injected into the reservoir after the utilization. So it is an ideal solution for the reservoir management and the sustainable development. At the same time, the investment cost for the domestic hot water could be reduced due to the elimination of the water treatment equipment.

6.3.2 Greenhouse gases

The environmental issue has been a typical concern since Beijing got the opportunity to hold the 2008 Olympic Games. The most noticeable concern is the control of air pollution. Greenhouse gases (GHG), such as CO_X, CH_4, CFC_S (list non-exhaustive), have a potential for negative impacts on global climate and are the object of international agreements for the reduction of their emission. GHG emission is usually given in equivalent tons of CO_2. A large part of this gas emission comes from energy production from fossil fuels such as coal, oil and gas. The reduction of air pollution in the production of energy for space heating and heating domestic hot water is one of the main advantages of a geothermal district heating system.

But at the same time, for the sake of sustainable development of the geothermal resources and efficient utilization, a heating system usually needs to be designed as a multiple utilization system. In this project, a natural gas boiler is employed to supply the peak load. In the existing system, both a gas boiler and a heat pump are employed. Here we will discuss the cost and the benefit to the environment for both of them so as to find the more efficient and economical approach.

Since the production of energy from geothermal resources does not emit greenhouse gases (GHG), the installation of a geothermal district heating system prevents the emission of a considerable amount of GHG. The amount of GHG emitted by the system depends on the type of fuel used for peak load production and on the efficiency of the system. The estimated avoided GHG emissions are shown in Table 4. The figures given in this table take into account the emissions of CO_2 only.

TABLE 4: Avoided greenhouse gases emission depending on production system used

Production system	**Energy amount from each source (GWh)**				**Total energy (GWh)**	**CO_2 released (10^3t/year)**	**Avoided CO_2 emission (10^3t/year)**
	Coal	**Natural gas**	**Electricity**	**Geothermal**			
Coal boiler only	50				50	23.0	baseline
Geo.+ coal peak boiler	24			26	50	11.0	11.9
Geo.+ gas peak boiler		24		26	50	**5.5**	**17.5**
Geo+El.HP+ gas boiler		12	3	35	50	**5.3**	**17.6**

According to Table 4, the amount of CO_2 emission from a coal boiler (as the baseline) gives obviously the highest values. The amount of CO_2 from the Geo+ Gas peak boiler and Geo+ El.Heat Pump+ Gas boiler are almost the same. It states that the environmental impact of these two systems is very similar. However, it is well known that the cost of an electrical heat pump unit is much more expensive than a gas boiler. And we should also consider the considerable investment cost of the electricity used for operating the huge heat pump units.

Due to the high cost of an electrical heat pump, it should be employed carefully, taking into account the geothermal water temperature, and simultaneous long periods of space heating and cooling needs. Because at present, most of the electricity in China is still generated by coal burning, electricity, as a high ranking energy, should be used in situations that are more efficient and necessary, such as illumination, industry and so on. On the other hand, a gas boiler has a low investment cost, low operational cost and easy maintenance. Therefore, this new approach is also feasible to this extent.

7. CONCLUSIONS

A decentralized approach for Beiyuan Garden Area-6 gives several remarkable benefits in different aspects:

1) *Reduction of investment cost*
According to the investment cost comparison, investment cost is reduced noticeably due to a single set of pipelines with large temperature difference, replacing the current large complex pipeline system.

2) *Lengthening the heating season*
The heating duration is lengthened considerably for people's comfort, and only by a reasonable utilization of geothermal energy.

3) *Reduction of water* losses
As well known, water losses in the secondary piping network, according to Chinese design standards, should be calculated to be about 2…3% of the secondary network flow. Some of these losses are due to leakages and unauthorized use of secondary network water, especially in the radiator systems. These losses cannot be found easily when using large heat central sections, and cannot be located from the secondary network. With the installation of small substations in every building or every floor, unauthorized use of radiator water will immediately result in pressure drop in the secondary system and can easily be located. A floor heating system installed according to this proposal would efficiently avoid this problem as well.

4) *Longer lifetime of pipe network*
As presented in point 3, the use of small substations would reduce water losses. It also would extend the lifetime of the network, as the amount of make-up water is smaller, resulting also in a decreased amount of oxygen entering into the secondary network system. This would reduce internal corrosion remarkably, and make it possible to use corrosion preventive inhibitors in secondary network water.

5) *Improved balancing of the secondary side flow parameters*
When using large group substations, the hydraulic design point of the secondary side circulation pump must be selected based on the pressure difference requirement of the furthest located building in the network. All other buildings then get too high pumping head and flow, resulting in unnecessary pumping electricity costs and unnecessarily high indoor temperatures in these buildings. Additionally, when the supply flow is high, the return temperature of the secondary side remains higher than with slower circulation. Furthermore, this results in higher return temperatures in the primary network, increasing the pumping costs at the power/boiler plant and increasing the total operation costs of the district heating system. The higher return temperature also reduces the total transmission capacity of the district heating network. On the other hand, when using small size substations, the flow and head of the secondary circulation pump can be selected precisely for each building, even each floor.

6) *Possibility to perfect domestic hot water distribution*
If the primary side network reaches every building, the heating substation can easily be equipped with a domestic water heat exchanger. Additional domestic hot water piping can be installed inside the buildings and every apartment can be provided with hot water. And this approach makes the supply of the domestic hot water steadier and of good quality.

7) *Beneficial to the environment*
The domestic hot water is supplied by means of heating cold water with geothermal energy instead of direct geothermal water supply after treatment. This is a big benefit to the geothermal reservoir protection. At the same time, a more economical approach towards space heating is used to reduce air pollution, i.e. multiple utilization combining geothermal heat and a natural gas boiler instead of an electrical heat pump.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Ingvar Birgir Fridleifsson and Mr. Lúdvík S. Georgsson, director and deputy director, respectively, of the UNU Geothermal Training Programme for their hospitality and selfless dedication to the fellows. My deepest thanks to Mrs. Gudrún Bjarnadóttir for her efficient help and kindness before and during the whole training period. I am also grateful to my institute - Beijing Institute of Geo-exploration and Technology, for supporting me during this 6 months. I especially want to extend my unreserved gratitude to my supervisors, Professor Páll Valdimarsson and Engineer Thorleikur Jóhannesson, for their excellent technical supports, deep knowledge and friendliness and great help in my project.

Additionally, I would like to thank all the lecturers and staff members at Orkustofnun and ISOR for the knowledge and assistance accorded to us during the lecture sessions. I also thank the UNU Fellows of 2005 for their unforgettable friendship and cooperation during our training time, especially the engineering group.

Finally, I would like to express my deepest appreciation to my family for their moral support during the six months.

REFERENCES

CMHC, 2005: *Hydronic radiant floor heating.* Canada Mortgage and Housing Corporation, website, www.hydronic radiant floor heating CMHC.htm.

Gengel, Y.A., and Turner, R.H., 2001: *Fundament of thermal-fluid sciences.* McGraw-Hill, NY, 1047 pp.

Jóhannesson Th., 2002: *Beiyuan Garden area-6, geothermal heating system, conceptual design phase 1.* ENEX, Comp., Reykjavik, report.

Lei Haiyan, 2004: Simulation in district heating in Tianjin, China. Report 8 in: *Geothermal Training in Iceland 2004.* UNU-GTP, Iceland, 131-158.

Xie Donghui, 2005: *Beiyuan Garden Area-6 geothermal heating system operational status.* Beijing Institute of Geo-exploration and Technology, report.

Xing Hongju, 2003: *Beiyuan Garden Area-6 geothermal heating system investment cost.* Beijing Institute of Geo-exploration and Technology, report.

Yildirim, N., Gokcen, G., and Toksoy M., 2005: Piping network design for IZTECH Campus geothermal district heating system, Izmir, Turkey. *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey,* CD, 7 pp.

Yin Heng, 2002: A demonstration geothermal project in Beijing - multiple utilization of geothermal energy. Report 19 in: *Geothermal Training in Iceland 2002.* UNU-GTP, Iceland, 395-430.

APPENDIX I: The decentralized heating system piping network calculation

Node	Node	Heat load, Q (MW)	Flow rate, m (kg/s)	Inside diam., D (mm)	Outside diam., D (mm)	DN (mm)	Velocity, V (m/s)	Length (m)	Cost of pipe (RMB/m)	Total price (RMB)	TPL (mm/m)
0	1	20.5	97.6	312.7	323.9	300	1.5	27	3777	101526	
1	2	9.3	44.3	263	273	250	1.2	39	3187	125249	
2	3	8.1	38.8	210.1	219.1	200	1.2	14	2139	29540	
3	4	6.9	33.0	210.1	219.1	200	1.2	66	2139	140105	
4	5	4.0	19.2	160.3	168.3	150	1	64	1624	104277	
5	6	2.8	13.3	132.5	139.7	125	1	39	1407	55351	
6	7	2.4	11.4	132.5	139.7	125	1	34	1407	47894	
7	8	1.2	5.5	107.1	114.3	100	1	84	1183	99372	
1	9	10.0	47.7	263	273	250	1.2	52	3187	166616	50
9	10	8.8	41.9	210.1	219.1	200	1.2	36	2139	77090	
10	11	7.6	36.3	210.1	219.1	200	1.2	12	2139	25176	
11	12	7.5	35.9	210.1	219.1	200	1.2	31	2139	66223	
12	13	5.7	27.2	210.1	219.1	200	1.2	14	2139	29946	
13	14	4.4	20.7	160.3	168.3	150	1	64	1624	103952	
14	15	3.0	14.2	132.5	139.7	125	0.9	31	1407	43364	
15	16	2.5	12.0	132.5	139.7	125	0.9	32	1407	45263	
16	17	1.2	5.5	107.1	114.3	100	0.8	55	1183	65621	
2	18	1.2	5.5	82.5	88.9	80	1	24	936	22764	
3	19	1.2	5.8	82.5	88.9	80	1	73	936	68665	
4	20	2.9	13.7	132.5	139.7	125	1.2	11	1407	15632	
20	21	1.7	7.9	107.1	114.3	100	1	19	1183	23033	
20	22	1.2	5.9	82.5	88.9	80	1	17	936	16146	
21	23	0.4	2.0	54.5	60.3	50	0.8	14	827	11570	
21	24	1.2	5.9	82.5	88.9	80	1	17	936	16146	
5	25	1.2	5.9	82.5	88.9	80	1	13	936	11803	
6	26	0.4	2.0	54.5	60.3	50	0.8	9	827	7741	
7	27	1.2	5.9	82.5	88.9	80	1	14	936	13488	
8	28	1.2	5.5	82.5	88.9	80	1	22	936	20227	
9	29	1.2	5.8	82.5	88.9	80	1	73	936	68665	100
10	30	1.2	5.5	82.5	88.9	80	1	24	936	22764	
11	31	0.1	0.4	37.2	42.4	32	0.5	73	758	55607	
12	32	1.8	8.7	107.1	114.3	100	1.1	32	1183	37288	
32	33	0.5	2.2	54.5	60.3	50	0.8	63	827	52200	
32	34	1.4	6.5	107.1	114.3	100	1	56	1183	65751	
13	35	1.4	6.5	107.1	114.3	100	1	18	1183	21874	
14	36	1.4	6.5	107.1	114.3	100	1	18	1183	21874	
15	37	0.5	2.2	54.5	60.3	50	0.8	51	827	42086	
16	38	1.4	6.5	107.1	114.3	100	0.8	18	1183	21164	
17	39	1.2	5.5	82.5	88.9	80	1	22	936	20227	
Total								1378		1983278	