Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Comparison of Two Different Approaches for Geothermal Heating Systems

Cao Fenglan and Li Bo

Tianjin Geothermal Exploration and Development Designing Institute, 189 Weiguo Road, 300250 Tianjin P.R.CHINA

cfl2003@live.cn

Keywords: Geothermal Heating; Floor Heating; Radiator; Investment; Operation Cost

ABSTRACT

This project compares two different design approaches for achieving a geothermal district heating system in Huang Hua city, He Bei province. The Jinxiuhuacheng building project, with a heat load of 4.6 MW for more than 116,000 m^2, has been used to assess these design approaches. This project presents the specificity of having buildings heated with only floor-heating or with only radiators grouped together and located nearby the heat central.

The first design approach is based on the traditional Chinese way with two distribution systems in the heat central. Hot water is produced via heat exchangers connected in series, using return water from the radiators heat exchanger as supply water for production of floor-heating hot water. In this case, radiators are designed for 65/50°C supply/return temperatures and floor heating for 45/35°C.

The other design approach has only one distribution system carrying supply water produced at 70°C via one heat exchanger at the heat central. Radiators are designed for 70/35°C supply/return temperatures. Floor-heating, requiring lower supply temperature, is directly connected to the supply pipelines and equipped with mixing devices to mix (cold) return water to the district heating supply water.

Results of the assessment are discussed in three parts, the production system, the distribution system and the space heating system. Finally, an economic analysis of the two different approaches is made. The main conclusions are that the new approach allows simplification of the control system, reduces the distribution system cost and yearly operational cost. On the other hand it increases the indoor system investment cost. On the whole, it seems to be more economical, with more attractive and space efficient radiators. In addition, it can supply good quality domestic hot water heating.

1. INTRODUCTION

In China, most geothermal resources belong to low-temperature resources. This clean and renewable energy has been used more and more widely in recent years, especially for district heating, replacing the burning of coal. Huang Hua is located in the centre of "Bohai Sea, Beijing and Tianjin′ s double loop" and in the northeast economic circle. It is an open city by the sea. The location is shown in Figure 1 (Wang Liancheng, 2005). The exploration and development of the geothermal resources can play an important role in many aspects of Huang Hua′ s economical development, such as in improving environmental quality and the living level of people in a sustainable manner.



Figure 1: Location of Huang Hua City

The geothermal development in Huang Hua is still in its initial stages. The main geothermal resources are porous geothermal reservoirs in Tertiary rocks, and the hot water temperature ranges from 60 to 95°C. Use of geothermal energy for space heating started a few years ago, but today it is developing very fast. The Jinxiuhuacheng building project is located in the western part of Huang Hua city.

The construction and heating area are shown in Table 1.

Table 1: Project information

Name	Area(m^2)
Construction area	116,550
Total heating area	116,100
Radiator heating area	64,050
Floor heating area	52,050

2. PROJECT BACKGROUND

The Jinxiuhuacheng building project uses geothermal water as the heat source for space heating. The current system includes production and distribution systems together with the heating systems at the end-users. Currently, house heating is made with either radiators or floor heating. The supply water and return water temperatures for the radiator system are 65 and 50°C, respectively, while they are 45 and 35°C, respectively, for the floor heating system. An example of the buildings in Jinxiuhuacheng is shown in Figure 2.

In this paper, a different approach in designing the heating systems will be assessed with radiators designed for a higher temperature difference, or 35°C instead of 15°C for a conventional Chinese system. Radiators are expected to be modern and/or larger in the new design approach.

The current distribution system is a double distribution system, with one supply pipeline and one return pipeline for

each type of heating system. In the new design approach there is only one supply pipeline and one return pipeline, common for the radiators and for the floor-heating. Nevertheless, buildings equipped with floor-heating in the new design approach need to be equipped with mixing devices to cool down the supply water. The heat central is currently equipped with two heat exchanger units connected in series while the new design approach proposes to install only one heat exchanger unit producing hot water for both floor-heating and radiators.



Figure 2: Building of Jinxiuhuacheng

3. GEOTHERMAL WELL INFORMATION

In Jinxiuhuacheng project, there is only one production geothermal well, As mentioned before, geothermal development is in its initial stages, so there is no reinjection well. The geothermal reservoir is in the Tertiary Guantao group. The average water flow, during the heating season, is 100 m^3/h and the maximum flow rate is 120 m^3/h. The water temperature is 75°C, the depth of the well is 2000 m, and the water level is at 60 m depth (Zhang et al., 2007).

Some water samples have been taken from this well. Based on the analysis it can be concluded that there is no silica or calcite scaling. There is a dissolved oxygen component in the water, and a high chlorine component. Due to the chemistry and the temperature of the geothermal fluid, corrosion problems in the utilization system can be expected and it is not recommended to connect the geothermal production system directly to the district heating system. Both design approaches take this issue into consideration with heat exchanger(s) producing hot water at the heat central.

4. GEOTHERMAL BUILDING INFORMATION AND HEAT LOAD CALCULATION

Based on the specifications of Chinese building construction, pertinent weather data, and the “standard of building economies” on energy, the specific heat loads for each building in Jinxiuhuacheng project are shown in Table 2, as well as the type of heating system for each building. Outdoor/indoor design temperatures are -9/18°C. Table 2 shows the heat load for each building or building units.

5. THE HEATING STATION DESIGN

5.1Current Heat Central Design

The system currently in use for Jinxiuhuacheng is designed using China‘s traditional method. District heating systems consist of two distribution systems, based on use of radiators, or on use of floor heating. Because of the water quality, it is necessary to use heat exchangers in the heat central. Based on the heat load and conditions of the building, the design is as follows:

There are two heat exchanger systems, the temperature of geothermal fluid decrease to 55□ after the first exchange, and to 40□ after the second exchange. For the radiator system, the supply and return water temperature is 65/50°C, temperature difference is 15□. For the floor heating system, the supply and return water temperature is 45/35°C, temperature difference is 10□.The flow chart of heating system is shown in figure 3(Cao Fenglan, 2007).

Table 2: Building information and heat load

Building no.	type	Heat load（kW）
18	Floor heating	126
1,7,11,15 19,23,26	Floor heating	140
2,3	Floor heating	168
6,10,14,22	Floor heating	160
5,9,13,16,17	Radiator	252
4,8,12,21	Radiator	168
20,24	Radiator	210
25	Radiator	210
Total heat load (kW)		4651

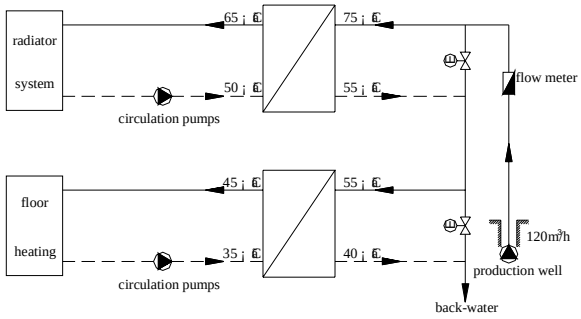

Figure 3: Flow chart of current heating system

5.2 New Heat Central Design

Only one distribution system is required with the new design approach. The heat central is equipped with only one heat exchanger unit producing hot water for both radiators and floor-heating. The supply and return water temperatures are 70/35°C; the temperature difference is 35°C. After the geothermal water has been used, the temperature of the geothermal fluid decreases to 40°C. The flow chart is shown in Figure 4.

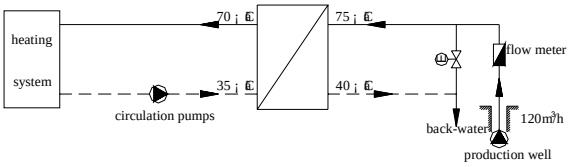

Figure 4: Flow chart of new heating system

For health reasons, floor-heating shall not have too high supply and floor system temperatures. It is therefore not possible to use supply water from the geothermal district heating directly in the floor-heating system. As aresult, buildings with floor-heating are equipped with a secondary

system or a substation in each building, aiming at mixing " cold" return water from floor-heating to supply water from district heating (Figure 5). A pressure pump is installed in each. Also, a one-way valve and an electrical control valve are installed to control the mixing of the cold and hot water. The supply water and return water are mixed through the one-way valve. Supply and return temperatures are the same as for the traditional floor-heating system.

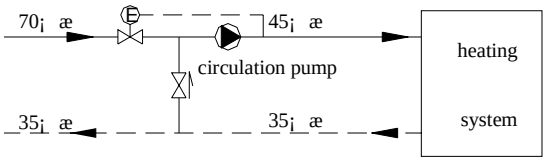

Figure 5: Flow chart of new substation

6. DISTRIBUTION SYSTEM DESIGN

The distribution system is an important part of district heating engineering, because the distribution system is a tremendous investment. Depending on the project, it can represent from 20 to 40% of the total geothermal district heating investment.

The surface of outdoor pipes is covered by asbestos to minimize temperature losses. For the outer protection of the pipe, PE or FRP are always used. For heat insulation polyurethane is used. The inner pipe is made of Q235 or similar low carbon steel.

For the current and new heating systems, there are two kinds of distribution systems to design. According to the "Specification of urban heat network design", the piping material is based on a trade-off between economics and reliability, the target pressure loss (TPL) per unit length of pipe, and the installation type of the distribution system, all common design parameters of a distribution system.

For the distribution system design, the pressure loss (TPL) is a common parameter, and the most important. When designing the distribution system, the pressure loss (TPL) of the appropriate loop is controlled to be within 40-80 Pa/m. Also, if the pressure loss is high, there will be a lower capital cost and a higher pumping cost during the operation, thus it is very important to design an economical pressure loss for the distribution system.

In the current system, water is supplied to radiators on the one hand and to floor-heating on the other hand via two separate distribution systems. Design temperature difference between supply and return water is 15°C for the radiators and 10°C for floor-heating.

In the new system, the radiator and floor heating system share one distribution system to supply water for each building. The temperatures of the supply water and return water are 70/35°C and the temperature difference in the system is 35°C. The system has been designed with the same design

Although the distribution system designed the traditional way has a double distribution system, the total pipe length is almost the same as for the new system with one distribution network. It is because buildings are either equipped with floor-heating, or radiators and grouped together accordingly nearby the heat central. The main difference between the two design approaches is that pipelines are smaller with the new design philosophy.

7. INDOOR SYSTEM DESIGN

7.1 Current Radiator System Design

The material used for a traditional radiator is steel; the popular radiator type is 813-radiator with 4 units. This kind of radiator has a big storage capacity and good thermal inertia. It is corrosion resistant and has a long life; and is thus most commonly used in indoor heating systems. The radiator type is shown in Figure6.



Figure 6: Current radiator system

When designing a terminal heating system, the heat load per square meter for each room is stimated at 60 W/m^2; which is bigger than for the district heating system. It is because of the simultaneity factor used for the dimensioning of district heating allowing to use a lower peak load value. The radiator system is designed as an additional radiator system, thus there is a general equation for use in calculating the surface of a radiator for eachapartment, as follows:

$$F = \frac{Q \times \beta_1 \times \beta_2 \times \beta_3}{K \times \Delta t} \quad (1)$$

where F, Q , β_1 , β_2 , β_3 ,K , Δt are radiator surface (m^2), the heat load (kW), the correction factor of radiator pieces (1.0), the correction factor of radiator conection(1.0), the correction factor of radiator installation(1.05), radiator heat transmission coefficient (kJ/m^2 × °C) and the avarage temperature difference of radiator(°C), respectively.

Radiator heat transmission coefficient K, is a function of the relative the average temperature difference of supply water and return water, the values of K can be determined from the euqation as follows:

$$K = 2.237 \times \Delta t^{0.302} \quad (2)$$

Where Δt is the average temperature difference of supply water and return water (°C).

Δt is a function of supply and return water tempwerture and indoor temperature, calculate follow the equation:

$$\Delta t = \frac{(t_s - t_i) + (t_r - t_i)}{2} \quad (3)$$

where t_s , t_r , t_i are supply water temperature (°C), return water temperature (°C) and indoor temperature (°C), respectively.

7.2 New Radiator System Design

In the new radiator system, the selected radiator is a Quinn radiator, different from the current radiators in use. Heat is released through narrow waterways closed to each other. This means that less water flows through the radiator, which makes it heat up faster as well as warm up the surroundings faster. The height of the radiator is 500 mm. The radiator is shown in Figure7.



Figure 7: New radiator system

In the new system, the heat load is designed the same way as in Figure 7: the type of the current system. When designing this radiator system, radiator used in the new system determining the length of each room is most important. In the traditional system, the design condition of supply and return water temperature are 75/65°C; while in the new system, the supply and return water temperatures are 70/35 °C. Hence it is necessary to modify the parameters of this radiator, using the following formula (Karlsson, 1984):

$$P / P_0 = (\frac{\Delta t_m}{\Delta t_{m,0}})^{1.3333} \quad (4)$$

where P, P_0, Δt_m, $\Delta t_{m,0}$ are heat emitted from radiator to building, heat emitted from radiator to building at design conditions, the average temperature difference and the average temperature difference at design conditions, respectively.

$$\Delta t_m = \lg \frac{T_1 - T_i}{T_2 - T_i} \quad (5)$$

where T_1, T_2, T_i are supply temperature (°C), return temperature (°C) and indoor temperature (°C), respectively.

7.3 Floor Heating System Design

The current and new systems have similar floor heating systems. For the floor heating system, the supply water and return water temperatures are 45/35°C, respectively. The key to designing floor heating is to determine the diameter of the pipe, the distance between two pipes, and also the length of the pipe. Based on previous experience in designing floor heating, PE-X pipes with a diameter of 20 mm were used. Determining the distance between the pipes depends on the heat dissipation of the floor, indoor temperature, average water temperature and the heat transmission resistance of the floor. Pipes are generally spaced at a distance of 100 to 300 mm in the subfloor. Wide spacing under tile or bare floors can cause uneven surface temperatures.

According to 2000 ASHRAE HANDBOOK (ASHRAE, 2000), the heat dissipation of unit floor area calculated follows the equation as:

$$\begin{aligned} q &= q_f + q_d \\ q_f &= 5\times10^{-8}\times\left[(t_{pj}+273)^4 - (AUST+273)^4\right] \\ q_d &= 2.13\times(t_{pj}-tn)^{1.31} \end{aligned} \quad (6)$$

where q, q_f, q_d, t_{pj}, $AUST$, tn are the heat dissipation of unit floor surface(W/m^2), the radiation-heat of unit floor surface(W/m^2), the convection heat of unit floor surface(°C), the average temperature(°C), area-weighted average temperature of uncontrolled surfaces in room(°C) and indoor temperature(°C), respectively.

The necessary heat dissipation of unit floor surface calculated as follows:

$$q_x = \frac{Q}{F} \quad (7)$$

where q_x, Q, F are the necessary heat dissipation of unit floor surface(W/m^2), the necessary heat dissipation of the room(W) and the floor surface of pipe installation, respectively.

When determine the heat dissipation of the floor, it is necessary to check the floor average temperature. To check the floor average temperature should follow the fomular:

$$t_{pj} = tn + 9.82\times\left(\frac{q_x}{100}\right)^{0.969} \quad (8)$$

where t_{pj}, tn, q_x are t the average temperature of floor(°C), indoor temperature (°C) and the necessary heat dissipation of unit floor surface(W/m^2), respectively.

8. COMPARISION OF INVESTMENT COST AND OPERATION COST

8.1 Calculation of Capital Cost

For comparison of the two different approaches, the estimate of the investment cost includes the heat central, distribution system, substations at the end-users and the indoor heating system. But this cost does not include the power connection fee. The price of the equipment is based on market prices in China. Total installation costs are given separately.

8.1.1 Investment Costs for the Current System

Table 3 shows that for the current system, the total investment cost is USD 3,378,474 and the unit construction area cost is 29 USD/m^2.

Table 3: Investment cost of current system

No	Type	Investment cost($)
1	Heating station	401,963
2	Piping network	422,978
3	Indoor system	1,427,375
4	Installation	1,126,158
5	Total cost	3,378,474

8.1.2 New System Investment Cost

As the table 4 shows, for current system, the total investment cost is USD 3,473,415, the unit construction area cost is 30 USD/m^2.

Table 4: Investment cost of current system

No	Type	Investment cost($)
1	Heating station	507,503
2	Piping network	252,671
3	Indoor system	1,555,436
4	Installation	1,157,805
5	Total cost	3,473,415

8.2 Operation Cost

For two different approaches, the estimate of operation cost for comparision includes the electric power, water cost, and manpower. But this cost does not include the cost of geothermal water cost.

In Huang Hua city, the days for heating is about 120, the equipment operation time of fully capacity is about 2000h/year, the price for electricity is 0.1 USD kW·h, water cost is 0.9 USD /t. From the calculation of the table , we can see the current system operation cost is 74,709 USD/ year, the new system operation cost is 69,317 USD /year.

Table 5: Current system operation cost

No	Name	Quantity(kW)	Cost(USD)
1	Ciculation pump	22.5	4,500
2	Circulation pump	30	6,000
3	Sunmersible pump	90	18,000
4	Pressure pump	2	104
5	water		80
6	manpower		6,857
7	mantinance		39,168
8	Total cost		74,709

Table 6: New system operation cost

No	Name	Quantity(kW)	Cost(USD)
1	Circulation pump	20	4,000
2	Sunmersible pump	90	18,000
3	Pressure pump	2	104
4	Pressure pump	1	50
5	water		80
6	manpower		6,857
7	mantinance		40226
8	Total cost		69,317

Some information can be read from table 5, 6 as follows:

1) From the comparision table, the investment cost of two systems is quite similar, the difference is USD 94941.

2) For current system, the unit construction area cost is 29 USD /m^2,for heating station is 3.5 USD /m^2,piping network is 3.6 USD /m^2, indoor system is 12.3 USD /m^2.

3) For new system, the unit construction area cost is 30 USD /m^2, for heating station is 4.4 USD /m^2,piping network is 2.2 USD /m^2, indoor system is 13.4 USD /m^2.

4) The operation cost of new system is less than current system for every year, also to say, more investment cost less operation cost.

CONCLUSION

The main conclusions of this study are the following:

1) Simplification of controlling system

In the heat central for the current system, the radiator and floor heating systems are separated from each other, but the two systems are in series, a change in one will influence the other. But for the new system, there is only one heat central to supply water at 70/35°C. Thus, it is easier to control the new system than the current system.

2) Reduction of piping network investment cost

Because of the temperature differences for the two systems, the diameter of the distribution system for the current system is much larger than that needed for the new system; in the new system, the radiator and floor heating systems share one distribution system, and the investment cost for the new system is decreased significantly. Upon calculating the cost of the distribution system, the investment for the current system is 1.67 times that of the new system.

3) Increase the indoor system investment cost

For radiator system, the temperature difference in new system is much larger than current system, and the return temperature is low, cause the increasing of investment cost.

4) Reduction of yearly operational cost

For a running heating system, most of the operating cost is for electric power. The temperature difference of the new system is much larger than that of the current system. Therefore, the water flow rate of the new system is much lower than in the current system, so the electric power cost for the new system would be much lower than for the current system.

5) More economical

Analyze the investment cost and operation cost for the two systems, the investment cost of new system is more than current system, the operation cost of new system is less than current system, the investment recovery period of new system is about 18 years.

6) Nice appearance and save space

In new indoor system, the new radiator is used, this kind of radiator looks nice appearance than the current system, also this radiator is quite smaller than current system, it can save more space in the room.

7) Domestic hot water heating system

For the new system, if the primary side network reaches every building at 70°C, a substation can easily be installed with a domestic water heat exchanger to produce domestic hot water from 10°C cold water. Additional domestic hot water piping can be installed inside the buildings and every apartment can be provided with hot water. The new system can thus supply good quality domestic hot water in an economic way without using a gas/electric boiler installed in each apartment.

REFERENCES

ASHRAE, 2000: HVAC systems and equipment. ASHRAE, NY.

Cao Fenglan and Liu Yang: The designing of JinXiuHuacheng heating station. Tianjin Geothermal Exploration and Development Designing Institute, report (in Chinese), China, 3-20.

Karlsson, Th., 1982: Geothermal district heating. The Iceland experience. UNU-GTP, Iceland, report 4, 116 pp.

Sun Caixia, 2005: A different approach for an existing geothermal utilization project in Beijing. Report 18 in: Geothermal training in Iceland 2005. UNU-GTP, Iceland, 353-372.

Wang Liancheng, 2005: Multiple utilization of geothermal energy in Tianjin Olympic Centre. Report 22 in: Geothermal training in Iceland 2005. UNU-GTP, Iceland, 411-454.

Zhang Ziliang, Jin Baozhen, Jia Pei, and Liu Yang, 2007: The feasibility report of JinXiuHuacheng

drilling geothermal well. Tianjin Geothermal Exploration and Development Designing Institute, report (in Chinese), China, 4-13.