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

Reports 2008
Number 12

COMPARISON OF TWO DIFFERENT APPROACHES FOR A GEOTHERMAL HEATING SYSTEM

Cao Fenglan
Tianjin Geothermal Exploration and Development Designing Institute
189 Weiguo Road, Hedong District
300250 Tianjin
P.R. CHINA
cfl2003@live.cn

ABSTRACT

This project compares two different design approaches for achieving a geothermal district heating system in Huang Hua city, HeBei 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: Location of Huang Hua City

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.

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.

FIGURE 2: A building in the Jinxiuhuacheng project

In this report, 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

3. GEOTHERMAL WELL INFORMATION

In Jinxiuhuacheng project, there is only one production geothermal well, located near building number 23. 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).

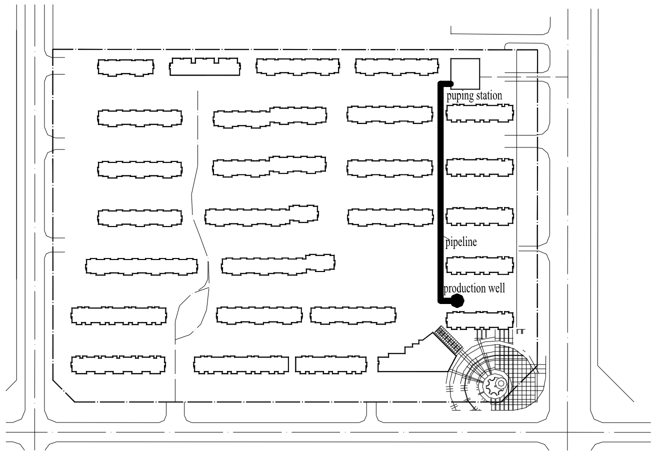

FIGURE 3: Location of geothermal well and the main hot water pipeline

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. The geothermal well and the main pipeline are shown in Figure 3.

4. BUILDING INFORMATION AND HEAT LOAD CALCULATIONS

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 together with their heating system.

TABLE 2: Building information and heat load

Building no.	Area (m^2)	Heating type	Load/area (W/m^2)	Heat load (kW)
18	3150	Floor heating	40	126
1, 7, 11, 15, 19, 23, 26	3500	Floor heating	40	140
2, 3	4200	Floor heating	40	168
6, 10, 14, 22	4000	Floor heating	40	160
5, 9, 13, 16, 17	6300	Radiator	40	252
4, 8, 12, 21	4200	Radiator	40	168
20, 24	5250	Radiator	40	210
25	5250	Radiator	40	210
Total area (m^2)	**116100**			
Total heat load (kW)	**4651**			

The total heated space is 116,100 m^2 for a peak load of 4.65 MW. About 55% of the space is heated with radiators and 45% with floor-heating.

5. THE HEATING STATION DESIGN

5.1 Current 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 units. The temperature of the geothermal fluid decreases to 55°C after going through the first exchanger unit, and to 40°C after the second unit. For the radiator system, the supply and return water temperatures are 65/50°C, giving a temperature difference of 15°C. For the floor heating system, the supply and return water temperatures are 45/35°C, giving a temperature difference of 10°C. The flow chart of the district heating system is shown in Figure 4 (Cao and Liu, 2007).

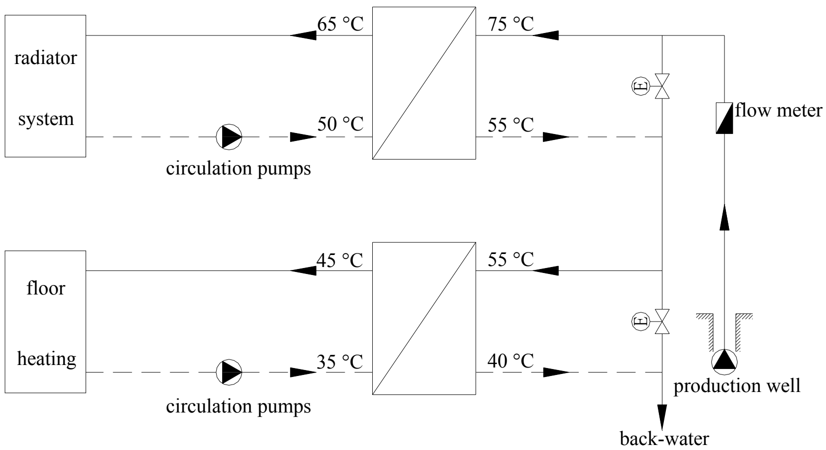

FIGURE 4: Flow chart of current heating system

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 5.

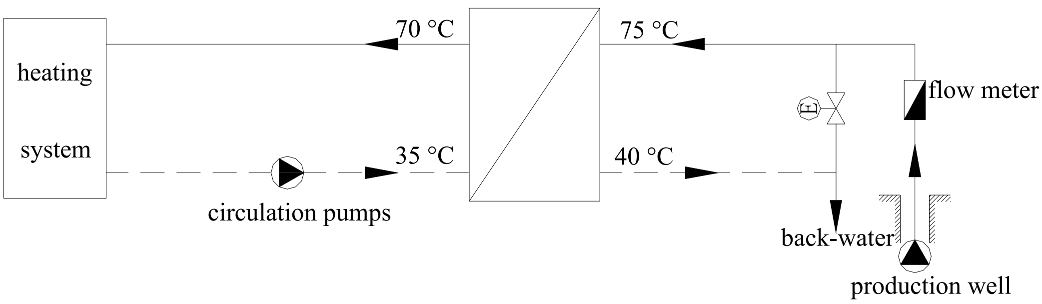

FIGURE 5: Flow chart of the new heating system

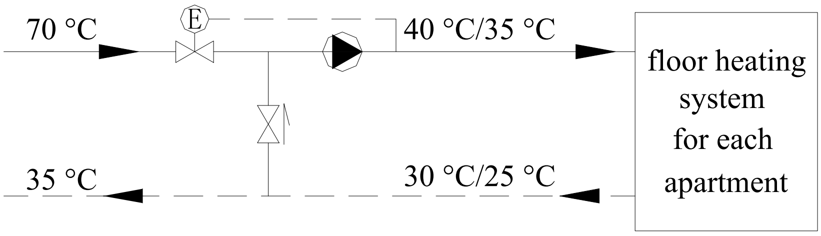

FIGURE 6: Flow chart of the new substations

For health reasons, floor-heating shall not have too high supply and floor temperatures. It is therefore not possible to use supply water from the geothermal district heating directly in the floor-heating system. As a result, 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 6). 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.

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.

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 flow rate and any incompressible fluid, written as follows (Sun, 2005):

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{1}$$

where h_f = The head loss (m);
f = The Darcy-Weisbach friction factor;
D = Pipe diameter (m);
L = Length of the pipe (m);
V = Velocity (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:

$$f = \frac{1.325}{\left[\log_e\left(\frac{k}{3.7D} + \frac{5.74}{RE^{0.9}}\right)\right]} \tag{2}$$

where f = Friction factor;
k = The roughness height (0.0489 mm);
RE = The Reynolds number, VD/v for turbulent flow;
V = The velocity (m/s); and
D = The pipe diameter (m).

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. The distribution system is shown in Figure 7 and the calculation for the network is given in Appendix I.

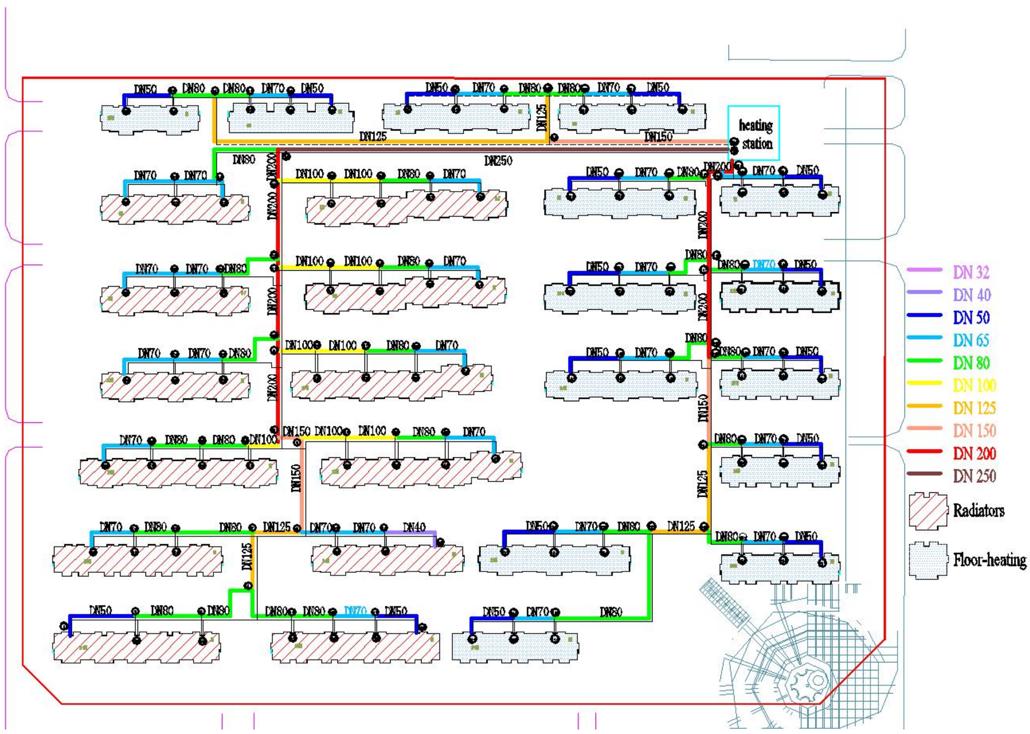

FIGURE 7: Distribution system layout for the current heating system

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 theory as the traditional system. The distribution system layout is shown in Figure 8 and calculated parameters for the network are given in Appendix II.

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.

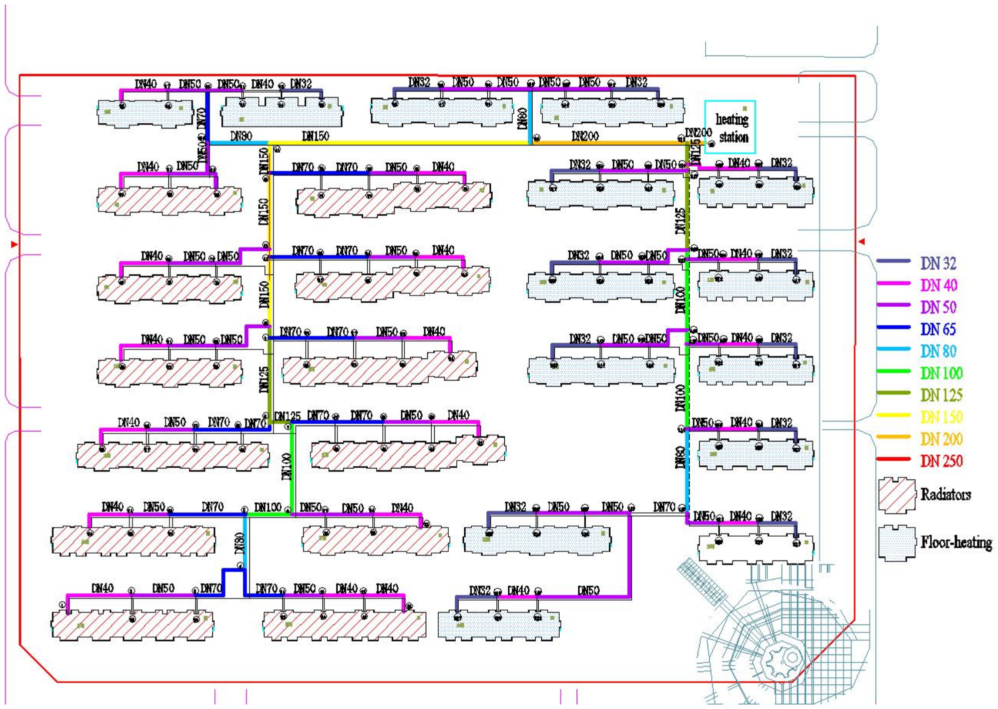

FIGURE 8: Distribution system layout for the new heating system

7. INDOOR HEATING 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 Figure 9.

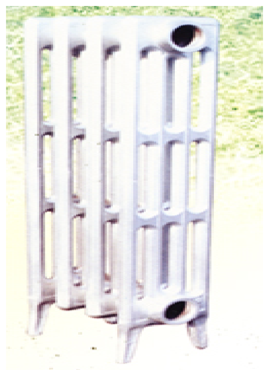

FIGURE 9: Current type of radiator used

When designing a terminal heating system, the heat load per square meter for each room is estimated 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 each apartment, as follows:

$$F = Q\, \beta_1\, \beta_2\, \beta_3 / (K\, \Delta t) \qquad (3)$$

where F = Radiator surface (m^2);
Q = Heat load (kW);
β_1 = Correction factor of radiator pieces, 1.0;
β_2 = Correction factor of radiator connection, 1.0;
β_3 = Correction factor of radiator installation, 1.05;
Δt = Average temperature difference of radiator (°C);
K = Radiator heat transmission coefficient (kJ/m^2 °C)

The radiator heat transmission coefficient K is a function of the relative average temperature difference of the supply water and return water; the values of K can be determined from the following equation:

$$K = 2.237 \times \Delta t^{0.302} \tag{4}$$

where Δt = The average temperature difference of supply water and return water (°C).

Δt is a function of supply and return water temperature and indoor temperature, calculated by using the following equation:

$$\Delta t = \frac{(t_s - t_i) + (t_r - t_i)}{2} \tag{5}$$

where t_s = Supply water temperature (°C);
t_r = Return water temperature (°C);
t_i = Indoor temperature (°C).

Based on the architectural drawings of each apartment, a more detailed calculation is shown in Appendix III.

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 Figure 10.

FIGURE 10: the type of radiator used in the new system

In the new system, the heat load is designed the same way as in the current system. When designing this radiator 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):

$$P/P_0 = (\Delta t_m / \Delta t_{m,0})^{1.3333} \tag{6}$$

where P = Heat emitted from radiator to building;
P_0 = Heat emitted from radiator to building at design conditions;
Δt_m = Average temperature difference;
$\Delta t_{m,0}$ = Average temperature difference at design conditions.

And

$$\Delta T_m = \left(\frac{T_1 - T_2}{\ln\left(\frac{T_1 - T_i}{T_2 - T_i}\right)} \right) \tag{7}$$

where T_1 = Supply temperature (°C);
T_2 = Return temperature (°C);
T_i = Indoor temperature (°C).

Based on the architectural drawings of each apartment, a more detailed calculation is given in Appendix IV.

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 the ASHRAE handbook (ASHRAE, 2000), the heat dissipation of the unit floor area is calculated using the following set of equations:

$$\begin{gathered} q = q_f + q_d \\ q_f = 5\times10^{-8}\times [(t_{pj}+273)^4 - (AUST + 273)^4] \\ q_d = 2.13\times(t_{pj}-t_n)^{1.31} \end{gathered} \tag{8}$$

where q = Heat dissipation of unit floor surface (W/m^2);
q_f = Radiation heat of unit floor surface (W/m^2);
q_d = Convection heat of unit floor surface (°C);
t_{pj} = Average temperature (°C);
$AUST$ = Area-weighted average temperature of uncontrolled surfaces in room (°C);
t_n = Indoor temperature (°C).

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

$$q_x = Q/F \tag{9}$$

where q_x = Necessary heat dissipation of unit floor surface (W/m^2);
Q = Necessary heat dissipation of the room (W);
F = Floor surface of pipe installation.

When determining the heat dissipation of the floor, it is necessary to check the average floor temperature. To check the average floor temperature, one can use the following formula:

$$t_{pj} = t_n + 9.82 \times (q_x/100)^{0.969} \tag{10}$$

where t_{pj} = Average temperature of floor (°C);
t_n = Indoor temperature (°C);
q_x = Necessary heat dissipation of unit floor surface (W/m^2).

Based on the architectural drawings of each apartment, more detailed calculations are given in Appendix V.

7.4 Analysis of the current system and the new system

A comparison of the return temperatures at end-users for the two systems is given in Figures 11 and 12. As indicated in Figure 11, in the radiator system, the return temperature in the current system is higher than that in the new system. During the winter season, the highest return temperature of the current system is 50°C when the outdoor temperature is -9°C and the lowest is 38.8°C when the outdoor temperature is 5°C, while the highest return temperature of the new system is 35°C and the lowest is 30.1°C.

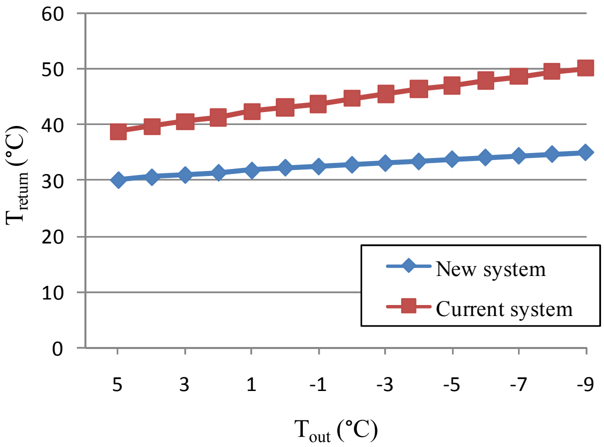

FIGURE 11: Change of return temperature according to outdoor temperature in the radiator systems

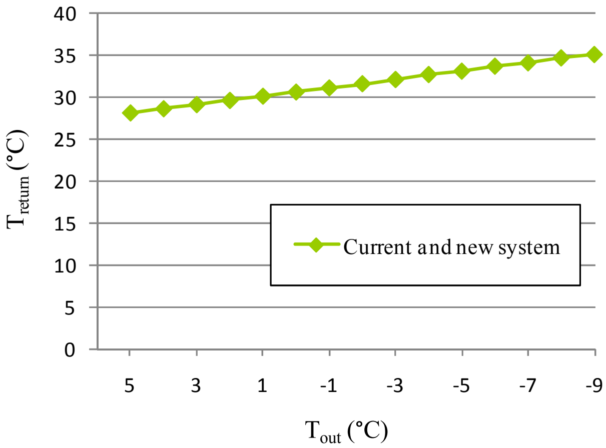

FIGURE 12: Change of return temperature according to outdoor temperature, for the floor heating system

As indicated in Figure 12, in the floor heating system, the return temperature in the current system and the new system are the same. During application in winter, the highest return temperature is 35°C and the lowest is 28°C.

8. COMPARISION OF INVESTMENT COSTS AND OPERATING COSTS

8.1 Calculation of capital costs

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. More details of calculations of the investment costs of the heat central, distribution system and heating system are shown in Appendices VI, VII and VIII.

TABLE 3: Investment cost of current system

No.	Type	Investment cost (USD)	Remarks
1	Heat central	401,963	
2	Distribution system	422,978	
3	Heating system	1,427,375	
4	Installation	1,126,158	
5	Total cost	3,378,474	

8.1.2 Investment costs for the new system

As Table 4 shows, for the new system, the total investment costs are USD 3,473,415, while the unit construction area cost is 30 USD/m^2. Further details of the investment costs for the heat central, distribution system and heating system are given in Appendices IX, X and XI.

TABLE 4: Investment cost of new system

No.	Type	Investment cost (USD)	Remarks
1	Heat central	507,503	Incl.substation
2	Distribution system	252,671	
3	Heating system	1,555,436	
4	Installation	1,157,805	
5	Total cost	3,473,415	

8.2 Operating costs

For comparison of the two different approaches, an estimate of the operating costs was done, including the electric power, water cost, and manpower. However, this cost does not include the cost of geothermal water. In Huang Hua city, the heating period is about 120 days, and the equipment operation time at full capacity is about 2000 h/year, the price for electricity is 0.1 USD/kWh, and water cost is 0.9 USD/t. From the calculations given in Table 5, we can see that the operation cost of the current system is 74,709 USD/year, while the operation cost of the new system is 69,317 USD/year. Further details for the two systems are calculated in Tables 5 and 6.

TABLE 5: Operating cost of the current system

No.	Name	Quantity (kW)	Cost (USD)	Remarks
1	Circulation pump	22.5	4,500	Radiator
2	Circulation pump	30	6,000	Floor heating
3	Submersible pump	90	18,000	
4	Pressure pump	2	104	
5	Water		80	
6	Manpower		6,857	
7	Maintenance		39,168	
8	Total cost		74,709	

TABLE 6: Operating cost of the new system

No.	Name	Quantity (kW)	Cost (USD)	Remarks
1	Circulation pump	20	4,000	
2	Submersible pump	90	18,000	
3	Pressure pump	2	104	Heating station
4	Pressure pump	1	50	Substation
5	Water		80	
6	Manpower		6,857	
7	Maintenance		40226	
8	Total cost		69,317	

8.3 Investment costs and operation cost analyses

A comparison of the investment and operating costs is given in Figures 13 and 14, the information can be summarized as follows:

1) From the comparison chart, the investment cost of the two systems is quite similar, the difference is only USD 94,941.

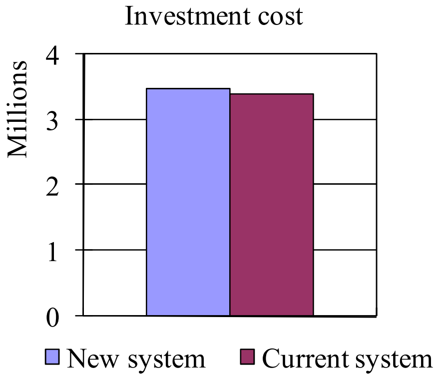

FIGURE 13: Comparison of investment costs

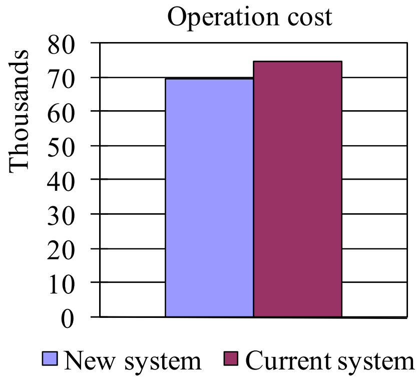

FIGURE 14: Comparison of operating costs

2) For the current system, the unit construction area cost is 29 USD/m^2, for the heating station it is 3.5 USD/m^2, for the distribution system it is 3.6 USD/m^2, and for the indoor system it is 12.3 USD/m^2.
3) For the new system, the unit construction area cost is 30 USD/m^2, for the heating station it is 4.4 USD/m^2, for the distribution system it is 2.2 USD/m^2, and for the indoor system it is 13.4 USD/m^2.
4) The operating cost of the new system is lower than for the current system for every year; for each year, there is more investment cost but less operating cost.

9. CONCLUSIONS

The main conclusions of this study are the following:

1) *Simplification of the 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 distribution system 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 in the indoor system investment cost.*
   For the radiator system, the temperature difference in the new system is much larger than for the current system, and the return temperature is low, causing an increase in 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.*
   Analysis of the investment cost and operating cost for the two systems shows that the investment cost of the new system is more than for the current system, while the operating cost of the new

system is less than for the current system. The investment recovery period of the new system is about 18 years.

6) *Attractive and space efficient.*
   In the new indoor system, the new radiators are more attractive than those used in the current system; they are also not as bulky, and so are more space efficient.
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.

ACKNOWLEDGEMENTS

I am deeply grateful to the United Nations University, and the Government of Iceland for having awarded me the opportunity of attending the Geothermal Training Programme, especially to Dr. Ingvar B. Fridleifsson, director, and Mr. Lúdvík S. Georgsson, deputy director, of the UNU Geothermal Training Programme, for their hospitality, guidance and advice throughout the training period. Thórhildur Ísberg, Dorthe H. Holm and Markes A.G. Wilde also deserve my gratitude for daily arrangements and help during the course. Thanks to ISOR – Iceland Geosurvey and Orkustofnun staff who offered their precious knowledge during the course. Finally and especially thanks to my supervisors, Professor Páll Valdimarsson and Engineer Thorleikur Jóhannesson, for their excellent support, deep knowledge and friendliness and great help in my project. I am grateful to my institute – Tianjin Geothermal Exploration and Development Designing Institute, especially to Dr.Sun Baocheng, for recommending me for this special training.

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

REFERENCES

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

Cao Fenglan and Liu Yang, 2007: *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.

APPENDIX I: Current distribution system calculation

Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)	Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)
1-2	4	50	82	85	43-45	10.8	80	67.2	46.4
2-3	8	80	42.7	60	42-43	5.4	70	45.7	45.2
3-4	12	80	81	71.4	43-44	5.4	70	45.7	6
4-5	24	125	38.6	53.6	45-46	5.4	70	45.7	6
5-6	36	125	79.5	45.4	45-47	16.2	100	52.7	45.8
6-7	45.7	150	48.9	88.6	47-48	5.4	70	45.7	6
7-8	60	150	83	21.6	47-7	21.6	100	93.4	41.4
8-9	74.6	200	34	80	49-51	3.2	50	60.6	45.6
9-10	89	200	41	11	50-51	3.2	50	60.6	6
10-11	98.7	200	49	66	52-53	3.2	50	60.6	6
11-12	113	200	60.4	7.4	52-10	9.6	80	143.1	65
12-13	122.8	200	71.2	73.4	51-52	6.4	70	64	37
13-14	137	200	84.2	28.8	54-55	5.4	70	45.7	45.8
14-15	146.9	250	31.5	418	55-56	5.4	70	45.7	6
16-17	3	50	53.3	38.4	57-58	5.4	70	45.7	6
19-20	3	50	53.3	6	55-57	10.8	80	67.2	46.4
21-22	3	50	53.3	6	57-59	16.2	100	52.7	45.8
21-4	12	80	82.1	60	59-60	5.4	70	45.7	6
2-28	4	50	82	6	61-62	5.4	70	45.7	45.8
3-29	4	50	82	6	62-63	5.4	70	45.7	6
17-19	6	70	56.3	39	64-65	5.4	70	45.7	8
17-18	3	50	53.3	6	62-64	10.8	80	67.2	47.2
19-21	9	80	46.8	38.4	64-66	16.2	80	52.7	45.2
24-27	6.4	80	31.2	45.8	66-67	5.4	70	45.7	8
23-24	3.2	50	60.6	46.4	66-11	21.6	100	93.4	47.6
24-25	3.2	50	60.6	6	68-69	3.2	50	60.6	45.6
26-27	3.2	50	60.6	6	69-70	3.2	50	60.6	6
27-6	9.6	80	53.2	31.4	69-71	6.4	70	64	37
30-31	4	50	82	38.8	71-72	3.2	50	60.6	6
31-32	4	50	82	6	71-12	9.6	80	143.1	65
33-34	4	50	82	6	73-75	5.4	70	45.7	45.8
33-5	12	80	82.1	72	74-75	5.4	70	45.7	6
31-33	8	80	42	38.4	76-77	5.4	70	45.7	8
35-36	5.4	70	45.7	44	75-76	10.8	80	67.2	47.2
36-37	5.4	70	45.7	6	76-78	16.2	80	52.7	45.2
38-39	5.4	70	45.7	6	78-79	5.4	70	45.7	8
40-41	8	80	42	6	78-13	21.6	100	93.4	47.6
40-8	21.6	100	93.4	35.4	80-81	3.2	50	60.6	45.6
36-38	10.8	80	67.2	45.6	81-82	3.2	50	60.6	6
38-40	16.2	100	52.7	45	83-84	3.2	50	60.6	8

Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)	Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)
84-14	9.6	80	143.1	89.2	125-112	13.8	100	38.4	42.8
81-84	6.4	70	64	37	127-128	4	50	82	35.8
85-87	5.4	70	45.7	44.6	128-129	4	50	82	6
86-87	5.4	70	45.7	6	128-131	8	80	42	38.4
87-93	10.8	80	67.2	39.2	130-131	4	50	82	6
93-91	12.6	80	91.3	33	132-134	4	50	82	35.8
91-92	4.2	50	97	6	133-134	4	50	82	6
89-90	4.2	50	97	6	134-136	8	80	42	38.4
89-91	8.4	80	40	37.8	135-136	4	50	82	6
88-89	4.2	50	97	37.4	136-114	12	80	81	30.2
93-94	23.5	125	34	352.8	137-138	4	50	82	35.8
95-96	4.8	70	36.2	44.6	138-139	4	50	82	6
96-97	4.8	70	36.2	6	138-140	8	80	42	38.4
98-99	4.8	70	36.2	6	140-141	4	50	82	6
98-105	14.4	100	41.8	40.6	140-115	12	80	81	30.2
96-98	9.6	70	43.2	45.2	142-143	4.6	70	33.3	45.8
100-101	4.8	70	36.2	43.8	143-144	4.6	70	33.3	6
101-102	4.8	70	36.2	6	143-145	9.2	80	48.9	46.4
103-104	4.8	70	36.2	6	145-146	4.6	50	33.3	6
101-103	9.6	70	43.2	44.6	145-116	13.8	80	109.4	48
103-105	14.4	100	41.8	33	147-148	4	70	33.3	35.8
105-94	24.8	125	37.9	44.8	148-149	4	70	33.3	6
94-106	52.4	150	64.2	168.4	148-150	8	80	42	38.4
107-108	4	50	82	38.4	150-151	4	70	33.3	6
108-109	4	50	82	6	150-117	12	80	81	30.2
110-111	4	50	82	6	152-154	4.6	70	33.3	45.8
110-112	12	80	81	168	153-154	4.6	70	33.3	6
112-113	25.8	125	41	55.4	154-155	9.2	80	48.9	46.4
113-114	37.8	125	37.9	81	155-156	4.6	70	33.3	6
114-115	50	150	58.5	80.6	155-118	13.8	80	109.4	48
115-116	61.9	150	89.1	13.4	157-158	4.6	70	33.3	45.8
116-117	75.7	200	31	68	158-159	4.6	70	33.3	6
117-118	87.7	200	36.5	8.8	158-160	9.2	80	48.9	46.4
118-119	101.5	200	48.7	76	160-161	4.6	70	33.3	6
119-120	115.2	200	62.7	7	160-119	13.8	80	109.4	37.4
120-121	127.3	200	76.5	40	162-164	4	70	33.3	35.8
122-123	4.6	70	33.3	45.8	163-164	4	70	33.3	6
123-124	4.6	70	33.3	6	164-166	8	80	42	35.8
125-126	4.6	70	33.3	6	165-166	4	70	33.3	6
123-125	9.2	80	48.9	46.4	166-120	12	80	81	30.2

APPENDIX II: New distribution system calculation

Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)	Node	Flow rate (t/h)	DN (mm)	Pressure loss (Pa/m)	Length (m)
1-2	1.7	40	67.6	85	43-45	3.08	50	56.2	46.4
2-3	3.4	50	68.3	60	42-43	1.54	40	55.6	45.2
3-4	5.1	70	40.8	71.4	43-44	1.54	40	55.6	6
4-5	10.2	80	60	53.6	45-46	1.54	40	55.6	6
5-6	15.3	100	47.1	45.4	45-47	4.6	70	33.3	45.8
6-7	19.6	100	77	88.6	47-48	1.54	40	55.6	6
7-8	25.8	125	41	21.6	47-7	6.2	70	60.1	41.4
8-9	32	125	62.9	80	49-51	1.4	32	95.3	45.6
9-10	38.2	125	81	11	50-51	1.4	32	95.3	6
10-11	42.3	150	42	66	52-53	1.4	32	95.3	6
11-12	48.5	150	55.1	7.4	52-10	4.2	50	103.6	65
12-13	52.8	150	65.2	73.4	51-52	2.8	50	46.5	37
13-14	58.8	150	80	28.8	54-55	1.54	40	55.6	45.8
14-94	69.6	150	113	249.8	55-56	1.54	40	55.6	6
94-121	77.9	200	29	150.4	57-58	1.54	40	55.6	6
121-15	114.3	200	61.7	18	55-57	3.08	50	56.2	46.4
21-22	1.3	32	82.3	6	57-59	4.6	70	33.3	45.8
21-4	5.2	70	42.4	60	59-60	1.54	40	55.6	6
2-28	1.7	40	67.6	6	59-9	6.2	70	60.1	35.4
3-29	1.7	40	67.6	6	61-62	1.54	40	55.6	45.8
17-19	2.6	50	40.2	39	62-63	1.54	40	55.6	6
17-18	1.3	32	82.3	6	64-65	1.54	40	55.6	8
19-21	3.9	50	89.7	38.4	62-64	3.08	50	56.2	47.2
24-27	2.8	50	46.5	45.8	64-66	4.6	70	33.3	45.2
23-24	1.4	32	95.3	46.4	66-67	1.54	40	55.6	8
24-25	1.4	32	95.3	6	66-11	6.2	70	60.1	47.6
26-27	1.4	32	95.3	6	68-69	1.4	32	95.3	45.6
27-6	4.2	50	103.6	31.4	69-70	1.4	32	95.3	6
30-31	1.7	40	67.6	38.8	69-71	2.8	50	46.5	37
31-32	1.7	40	67.6	6	71-72	1.4	32	95.3	6
33-34	1.7	40	67.6	6	71-12	4.2	50	103.6	65
33-5	5.1	70	40.8	72	73-75	1.54	40	55.6	45.8
31-33	3.4	50	68.5	38.4	74-75	1.54	40	55.6	6
35-36	1.54	40	55.6	44	76-77	1.54	40	55.6	8
36-37	1.54	40	55.6	6	75-76	3.08	50	56.2	47.2
38-39	1.54	40	55.6	6	76-78	4.6	70	33.3	45.2
40-41	1.54	40	55.6	6	78-79	1.54	40	55.6	8
40-8	6.2	70	60.1	35.4	78-13	6.2	70	60.1	47.6
36-38	3.08	50	56.2	45.6	80-81	1.4	32	95.3	45.6
38-40	4.6	70	33.3	45	81-82	1.4	32	95.3	6

Node	**Flow rate (t/h)**	**DN (mm)**	**Pressure loss (Pa/m)**	**Length (m)**	**Node**	**Flow rate (t/h)**	**DN (mm)**	**Pressure loss (Pa/m)**	**Length (m)**
83-84	1.4	32	95.3	8	125-112	3.9	50	89.7	42.8
84-106	4.2	50	103.6	30	127-128	1.2	32	70.3	35.8
81-84	2.8	50	46.5	37	128-129	1.2	32	70.3	6
85-87	1.54	40	55.6	44.6	128-131	2.4	40	34.4	38.4
86-87	1.54	40	55.6	6	130-131	1.2	32	70.3	6
87-93	3.08	50	56.2	39.2	132-134	1.2	32	70.3	35.8
93-91	3.6	50	76.5	33	133-134	1.2	32	70.3	6
91-92	1.2	32	70.3	6	134-136	2.4	40	34.4	38.4
89-90	1.2	32	70.3	6	135-136	1.2	32	70.3	6
89-91	2.4	50	34.3	37.8	136-114	3.6	50	76.5	30.2
88-89	1.2	32	70.3	37.4	137-138	1.2	32	70.3	35.8
93-106	6.7	70	70	50	138-139	1.2	32	70.3	6
95-96	1.4	32	95.3	44.6	138-140	2.4	40	34.4	38.4
96-97	1.4	32	95.3	6	140-141	1.2	32	70.3	6
98-99	1.4	32	95.3	6	140-115	3.6	50	76.5	30.2
98-105	4.2	50	103.6	40.6	142-143	1.3	32	70.3	45.8
96-98	2.8	50	46.5	45.2	143-144	1.3	32	70.3	6
100-101	1.4	32	95.3	43.8	143-145	2.6	50	40.2	46.4
101-102	1.4	32	95.3	6	145-146	1.3	32	70.3	6
103-104	1.4	32	95.3	6	145-116	3.9	50	89.7	48
101-103	2.8	50	46.5	44.6	147-148	1.2	32	70.3	35.8
103-105	4.2	50	103.6	33	148-149	1.2	32	70.3	6
105-94	8.4	80	40.8	44.8	148-150	2.4	40	34.4	38.4
107-108	1.2	32	70.3	38.4	150-151	1.2	32	70.3	6
108-109	1.2	32	70.3	6	150-117	3.6	50	76.5	30.2
110-111	1.2	32	70.3	6	152-154	1.3	32	82.3	45.8
110-112	3.6	50	76.5	168	153-154	1.3	32	82.3	6
112-113	7.4	70	85.4	55.4	154-155	2.6	50	40.2	46.4
113-114	10.8	80	67.2	81	155-156	1.3	32	70.3	6
114-115	14.2	100	40.6	80.6	155-118	3.9	50	89.7	48
115-116	17.7	100	62.3	13.4	157-158	1.3	32	82.3	45.8
116-117	21.6	100	93.4	68	158-159	1.3	32	82.3	6
117-118	25.1	125	38.8	8.8	158-160	2.6	50	40.2	46.4
118-119	29	125	51.7	76	160-161	1.3	32	82.3	6
119-120	33	125	66.8	7	160-119	3.9	50	89.7	37.4
120-121	36.4	125	81.3	20	162-164	1.2	32	70.3	35.8
122-123	1.3	32	82.3	45.8	163-164	1.2	32	70.3	6
123-124	1.3	32	82.3	6	164-166	2.4	40	34.4	35.8
125-126	1.3	32	82.3	6	165-166	1.2	32	70.3	6
123-125	2.6	50	40.2	46.4	166-120	3.6	50	76.5	30.2

APPENDIX III: Current radiator system calculation

Building no.	Equipment	Quantity		Remarks
	Radiator		4848	
		Thermostatic valve	312	DN20
		Adjusted valve	312	DN20
	Valve	Control valve	96	DN20
		Control valve	16	DN16
		Control valve	2	DN50
		DN40	64	
	Pipe	DN32	176	
5, 9, 13,		DN25	80	
16, 17		DN20	2698	
	Elbow	DN15	1152	
		DN50	2	
		DN20×DN20×DN15	672	
		DN50× DN40× DN20	96	
	Three-way valve	DN40× DN32×DN20	96	
		DN32× DN25×DN20	96	
		DN32× DN32×DN20	96	
		DN25× DN25×DN20	96	
	Radiator	4896		
		Thermostatic valve	384	DN15
		Adjusted valve	384	DN15
	valve	Control valve	80	DN20
		Control valve	16	DN15
		Control valve	2	DN50
		DN40	53	
	pipe	DN32	147	
4#,8,		DN25	67	
12,21		DN20	2248	
	elbow	DN40	2	
		DN15	772	
		DN20×DN20×DN15	672	
		DN40× DN40× DN20	80	
	Three-way valve	DN40× DN32×DN20	80	
		DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	
	Radiator	4160		
		Thermostatic valve	360	DN20
		Adjusted valve	360	DN20
	valve	Control valve	80	DN20
		Control valve	16	DN16
		Control valve	2	DN50
		DN40	64	
20,24		DN32	176	
25	pipe	DN25	80	
		DN20	2698	
		DN40	2	
		DN15	772	
	elbow	DN20×DN20×DN15	672	
		DN40× DN40× DN20	80	
		DN40× DN32×DN20	80	
	Three-way valve	DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	
		DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	

APPENDIX IV: New radiator system calculation

Building no.	Equipment	Quantity		Remarks
	Radiator		410	
		Thermostatic valve	312	DN20
		Adjusted valve	312	DN20
	Valve	Control valve	96	DN20
		Control valve	16	DN16
		Control valve	2	DN50
		DN40	64	
	Pipe	DN32	176	
5, 9, 13,		DN25	80	
16, 17		DN20	2698	
	Elbow	DN15	1152	
		DN50	2	
		DN20×DN20×DN15	672	
		DN50× DN40× DN20	96	
	Three-way valve	DN40× DN32×DN20	96	
		DN32× DN25×DN20	96	
		DN32× DN32×DN20	96	
		DN25× DN25×DN20	96	
	Radiator		312	
		Thermostatic valve	384	DN15
		Adjusted valve	384	DN15
	Valve	Control valve	80	DN20
		Control valve	16	DN15
		Control valve	2	DN50
		DN40	53	
	Pipe	DN32	147	
		DN25	67	
4, 8,		DN20	2248	
12, 21	Elbow	DN40	2	
		DN15	772	
		DN20×DN20×DN15	672	
		DN40× DN40× DN20	80	
	Three-way valve	DN40× DN32×DN20	80	
		DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	
	Radiator		337	
		Thermostatic valve	360	DN20
		Adjusted valve	360	DN20
	Valve	Control valve	80	DN20
		Control valve	16	DN16
		Control valve	2	DN50
		DN40	64	
20, 24,		DN32	176	
25		DN25	80	
	Pipe	DN20	2698	
		DN40	2	
		DN15	772	
	Elbow	DN20×DN20×DN15	672	
		DN40× DN40× DN20	80	
		DN40× DN32×DN20	80	
	Three-way valve	DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	
		DN32× DN25×DN20	80	
		DN32× DN32×DN20	80	

APPENDIX V: Current and new floor heating system calculation

Building no.	Equipment	Quantity		Remarks
18	Pipe	DN50	450	
		DN32	120	
		DN25	30	
		DN20	10462	
	Elbow	DN50	4	
		DN32	120	
	Three-way valve	DN50× DN50× DN32	60	
1, 7, 11, 15, 19, 23, 26	Pipe	DN50	450	
		DN32	120	
		DN25	30	
		DN20	11624	
	Elbow	DN50	4	
		DN32	120	
	Three-way valve	DN50× DN50× DN32	60	
6,10 14,22	Pipe	DN50	450	
		DN32	120	
		DN25	30	
		DN20	13285	
	Elbow	DN50	4	
		DN32	120	
	Three-way valve	DN50× DN50× DN32	60	
2, 3	Pipe	DN50	450	
		DN32	120	
		DN25	30	
		DN20	13949	
	Elbow	DN50	4	
		DN32	120	
	Three-way valve	DN50× DN50× DN32	60	

APPENDIX VI: Investment cost of current heating station

No.	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
1	Heat exchanger	120 m^2	930	111600	Radiator
2	Radiator circulation pump	2	643	1286	Q=145 m^3/h, H=45 m one spare
3	Pressure pump	2	300	600	Q=15 m^3/h, H=25 m one spare
4	Heat exchanger	106 m^2	930	98580	Floor heating
5	Floor heating circulation pump	3	500	1500	Q=95 m^3/h, H=45 m one spare
6	Submersible pump	1	13428	13428	Q=125 m^3/h, H=120 m
7	Well head	1	2571	2571	DN339.7 mm
8	Filter	1	428	428	Radiator
9	Filter	1	440	440	Floor heating
10	Tank	1	500	500	7 m^3
11	Softener	1	6400	6400	7 m^3/h
12	Desander	1	1714	1714	Q=120 m^3/h
13	Electric valve	4	5000	20000	
14	Control system		71488	71488	
15	Other valves and so on	—		71428	
16	Total cost			401963	

APPENDIX VII: Investment cost of current distribution system

No	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
1	Pipe	690.6	29.2	20166	DN50
2	Pipe	1038.2	44.1	45785	DN70
3	Pipe	1865.3	50.8	94757	DN80
4	Pipe	432.7	55.7	24107	DN100
5	Pipe	552	73	40296	DN125
6	Pipe	372.6	87.7	32677	DN150
7	Pipe	466.4	124	57834	DN200
8	Pipe	418	137.8	57626	DN250
9	Elbow	4	20	80	DN40
10	Elbow	32	23.6	755	DN50
11	Elbow	18	37.8	680	DN70
12	Elbow	16	41	656	DN80
13	Elbow	2	44.8	90	DN100
14	Three-way valve	8	36.1	288	DN80×DN50×DN50
15	Three-way valve	4	37.7	150	DN70×DN40×DN40
16	Three-way valve	4	39.1	156	DN70×DN70×DN40
17	Three-way valve	56	40.8	2284	DN70×DN50×DN50
18	Three-way valve	4	41.8	334	DN70×DN70×DN70
19	Three-way valve	12	43.9	526	DN80×DN80×DN50
20	Three-way valve	56	45.8	2562	DN80×DN70×DN50
21	Three-way valve	16	47.8	765	DN80×DN70×DN70
22	Three-way valve	4	51.2	205	DN80×DN80×DN70
23	Three-way valve	8	54.9	439	DN100×DN80×DN70
24	Three-way valve	6	56.8	341	DN50×DN50×DN40
25	Three-way valve	2	59.3	119	DN100×DN100×DN70
26	Three-way valve	4	63.7	255	DN125×DN80×DN80
27	Three-way valve	2	66.6	133	DN125×DN125×DN80
28	Three-way valve	2	69	138	DN150×DN125×DN70
29	Three-way valve	2	72.7	145	DN150×DN125×DN125
30	Three-way valve	4	76.5	306	DN150×DN125×DN80
31	Three-way valve	4	79.5	318	DN200×DN200×DN80
32	Three-way valve	6	82	492	DN200×DN200×DN100
33	Three-way valve	2	84.7	169	DN250×DN200×DN80
34	Connection	278	33.5	9313	DN50
35	Connection	208	34	7072	DN70
36	Connection	190	34.3	6517	DN80
37	Connection	60	41.1	2466	DN100
38	Connection	68	45.6	3101	DN125
39	Connection	30	50.3	1509	DN150
40	Connection	64	63.4	4058	DN200
41	Connection	40	82.7	3308	DN250
42	Total cost			388854	

APPENDIX VIII: Investment cost of current indoor system

No	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
Radiator system					
1	Radiator	47984	9.7	465445	Calculate in piece
2	Thermostatic valve	3456	42	145152	
3	Adjusted valve	3456	9.7	33523	
4	Control valve	160	18.6	2971	DN15
5	Control valve	880	20.7	18228	DN20
6	Control valve	30	26.4	792	DN50
7	Pipe	25180	1.5	37770	DN20
8	Pipe	948	1.7	1612	DN25
9	Pipe	1644	1.9	3123	DN32
10	Pipe	468	2.1	983	DN40
11	Elbow	9620	18.6	178657	DN25
12	Elbow	10	18.5	185	DN32
13	Elbow	10	20	200	DN40
14	Three-way valve	6720	11.4	76800	DN20×DN20×DN15
15	Three-way valve	480	14.3	6857	DN50×DN40×DN20
16	Three-way valve	880	17.1	15085	DN40×DN32×DN20
17	Three-way valve	400	18.57	7428	DN40×DN40×DN20
18	Three-way valve	880	22.85	20114	DN32×DN32×DN20
19	Three-way valve	880	25.7	22628	DN32×DN25×DN20
20	Three-way valve	480	27.1	13028	DN25×DN25×DN20
Floor heating system					
21	Pipe	172868	1.5	159302	DN20
22	Pipe	420	1.7	714	DN25
23	Pipe	1680	1.9	3192	DN32
24	Pipe	6300	2.1	13230	DN40
25	Elbow	56	18.5	1036	DN32
26	Elbow	1680	24	40320	DN50
27	Three-way valve	840	15	12600	DN50×DN50×DN32
28	manifold	410	357	146370	
29	Total cost			1312499	

APPENDIX IX: Investment cost of new heating station

No	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
1	Heat exchanger	250 m^2	930	232500	
2	Circulation pump	2	600	1200	Q=114 m^3/h, H=45 m one spare
3	Pressure pump	2	280	560	Q=10 m^3/h, H=25 m one spare
4	Submersible pump	1	13428	13428	Q=125 m^3/h, H=120 m
5	Well head	1	2571	2571	DN339.7 mm
6	Filter	1	428	428	Dn200
7	Tank	1	500	500	7 m^3
8	Softener	1	6400	6400	7 m^3/h
9	Desander	1	1714	1714	Q=120 m^3/h
10	Substa. pressure pump	42	143	6006	Q=10 m^3/h, H=20 m
11	One-way valve	42	38	1596	DN50
	Electric valve	2	5000	10000	
12	Electric valve	42	1800	75600	DN50
	Control system		80000	80000	
13	Other valves etc.	—		75000	
14	Total cost			507503	

APPENDIX X: Investment cost of new distribution system

No	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
1	Pipe	1003.4	18.32	18382	DN32
2	Pipe	622.6	22.73	14152	DN40
3	Pipe	1680.8	29.2	49079	DN50
4	Pipe	698.2	44.1	30790	DN70
5	Pipe	179.4	50.8	9114	DN80
6	Pipe	296	55.7	16487	DN100
7	Pipe	224.4	73	16381	DN125
8	Pipe	425.4	87.7	37308	DN150
9	Pipe	168.4	124	20882	DN200
10	Elbow	24	18.5	444	DN32
11	Elbow	28	20	560	DN40
12	Elbow	24	23.6	566	DN50
13	Elbow	4	37.8	151	DN70
14	Three-way valve	14	29.5	413	DN40×DN32×DN32
15	Three-way valve	14	31	434	DN50×DN40×DN32
16	Three-way valve	12	31.9	383	DN50×DN32×DN32
17	Three-way valve	12	34	408	DN50×DN50×DN32
18	Three-way valve	26	36	936	DN50×DN40×DN40
19	Three-way valve	2	41	82	DN40×DN40×DN40
20	Three-way valve	16	42	672	DN70×DN50×DN40
21	Three-way valve	2	44.7	89	DN80×DN70×DN70
22	Three-way valve	4	46.8	187	DN70×DN50×DN50
23	Three-way valve	4	47	188	DN80×DN70×DN50
24	Three-way valve	8	47.3	378	DN50×DN50×DN40
25	Three-way valve	10	48	480	DN70×DN70×DN40
26	Three-way valve	2	51	102	DN100×DN80×DN70
27	Three-way valve	2	54.9	110	DN100×DN80×DN50
28	Three-way valve	6	56.8	341	DN100×DN100×DN50
29	Three-way valve	4	59.3	237	DN125×DN125×DN70
30	Three-way valve	6	63.7	382	DN150×DN125×DN50
31	Three-way valve	4	66.6	266	DN150×DN150×DN70
32	Three-way valve	5	69	345	DN150×DN150×DN50
33	Three-way valve	4	72.7	291	DN125×DN100×DN50
34	Three-way valve	2	76.5	153	DN200×DN150×DN80
35	Three-way valve	2	79.5	159	DN200×DN200×DN125
36	Connection	100	29	2900	DN32
37	Connection	214	32.5	6955	DN40
38	Connection	228	33.5	7638	DN50
39	Connection	88	34	2992	DN70
40	Connection	36	34.3	1235	DN80
41	Connection	164	41.1	6740	DN100
42	Connection	26	45.6	1186	DN125
43	Connection	16	50.3	805	DN150
44	Connection	14	63.4	888	DN200
45	Total cost			252671	

APPENDIX XI: Investment cost of new indoor system

No	Equipment	Quantity	Unit price (USD)	Total price (USD)	Remarks
Radiator system					
1	Radiator	3536	183.2	647795	
2	Thermostatic valve	3456	30	103680	DN15
3	Adjusted valve	3456	6	20736	DN15
4	Control valve	160	18.6	2971	DN15
5	Control valve	880	20.7	18228	DN20
6	Control valve	30	26.4	792	DN50
7	Pipe	25180	1.5	37770	DN20
8	Pipe	948	1.7	1612	DN25
9	Pipe	1644	1.9	3123	DN32
10	Pipe	468	2.1	983	DN40
11	Elbow	9620	18.6	178657	DN20
12	Elbow	10	18.5	185	DN32
13	Elbow	10	20	200	DN40
14	Three-way valve	6720	11.4	76800	DN20×DN20×DN15
15	Three-way valve	480	14.3	6857	DN50×DN420×DN20
16	Three-way valve	880	17.1	15085	DN40×DN32×DN20
17	Three-way valve	400	18.57	7428	DN40×DN40×DN20
18	Three-way valve	880	22.85	20114	DN32×DN32×DN20
19	Three-way valve	880	25.7	22628	DN32×DN25×DN20
20	Three-way valve	480	27.1	13028	DN25×DN25×DN20
Floor heating system					
21	Pipe	172868	1.5	159302	DN20
22	Pipe	420	1.7	714	DN25
23	Pipe	1680	1.9	3192	DN32
24	Pipe	6300	2.1	13230	DN40
25	Elbow	56	18.5	1036	DN32
26	Elbow	1680	24	40320	DN50
27	Three-way valve	840	15	12600	DN50×DN50×DN32
28	manifold	410	357	146370	
29	Total cost			1555436	