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EVALUATION OF GEOTHERMAL ENERGY AS HEAT SOURCE OF DISTRICT HEATING SYSTEMS IN TIANJIN, CHINA

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ABSTRACT
The major energy structure for Tianjin, China includes the conventional energy sources such as coal, petroleum and natural gas. There is abundant medium/low temperature geothermal energy reserve in Tianjin. Since 1960s, geothermal energy has been explored and utilized, and step by step, it has also become an important supplemental energy resource, thanks to the outstanding results achieved in its comprehensive utilization.

How is the performance of geothermal energy as a district heating energy source compared with those conventional sources? Using a newly developed community district heating system as case study, this paper describes the evolution of the geothermal heating system with fossil fuel-fired boiler house for peak load shaving in Tianjin. It analyzes the energy saving of that heating system. Finally, this paper quantitatively compares the performance of low/medium geothermal water heating system with the systems using those conventional energy sources. The comparison is in three major areas: economic impact, energy utilization efficiency and environmental impact. The Net Present Cost (NPC) model is used to evaluate the overall cost impact considering both capital cost and annual operating and maintenance cost. In addition, this paper explores the environmental impact of using the conventional and geothermal energy sources.

INTRODUCTION
Tianjin is one of the biggest cities in China. It has a population of 10 million and consumes 8.3736×10^5 GJ energy per year. Tianjin is located in the north temperature zone with annual mean temperature of 12.3 ^oC. During 122 days of heating season, the mean temperature is – 0.9 ^oC. In winter, the energy consumption in space heating takes 10% of the total energy consumption in the city.

Tianjin has to import various kinds of energy to support the city 's development. Coal is the major heating energy resource and others are natural gas, oil products and geothermal energy. Since 90's developers in Tianjin have built many buildings with district space heating fuelled by coal, natural gas and geothermal energy. A lot of individual coal burning stoves in household was replaced by district heating. The energy efficiency has been improved and large amount of coal was saved, meanwhile the emission of particulate, SO_2 and CO_2 was reduced. The air quality has been greatly improved. However, the pollution caused by burning of coal is still a hot spot of the public concerns since coal accounts for 80% energy consumption in the city. Therefore, the city's energy consumption mix should be altered as soon as possible.

Tianjin is rich in geothermal energy. Based on its climate, energy reserve, and distribution of geothermal energy, geothermal energy is very suitable to use as heat source for district heating in Tianjin. Since its exploration and development, geothermal energy has quickly attracted significant attention from more and more people in Tianjin despite of its late start in the application as heat source. This is because geothermal energy has the following advantages: compactness of its heat supply station, low in operating cost, effectiveness in its comprehensive utilization, fast in capital cost return, and especially its limited contribution in air pollution. Up to today, the area that are heated by the geothermal energy in Tianjin has reached 500×10^4 m^2 . In almost 20 years, in Tianjin, geothermal energy has played an important role in the supplement of energy supply, alleviation of environmental pollution and improvement of resident living.

This paper briefly describes the evolution of district heating system using geothermal energy in Tianjin. Using a district heating system in a residential community with 12×10^4 floor space as a case study, a techno-economic calculation and comparison of four widely used energy sources in Tianjin (coal, natural gas, fossil fuel and low/medium temperature geothermal energy) are presented to show the feasibility and practical results of geothermal energy utilization in district heating. The evaluation considers the capital cost and operating cost based on results of on-site measurement and engineering calculation.

THE EVOLUTION OF THE GEOTHERMAL HEATING SYSTEM WITH FOSSIL FUEL FIRED-BOILER HOUSE FOR PEAK LOAD SHAVING IN TIANJIN
China has abundant geothermal reserve and has a long history in its application. But the study of its application as a new energy source did not started until 1970's. Tianjin is one of the cities in China that started earlier in the exploration and utilization of geothermal energy. For the base rock thermal reservoir geothermal water that is currently explored in Tianjin, the single well output flow rate ranges from 100 to 150 m^3/h, the well head temperature is in the range of 70°C to 100°C, and the salinity of geothermal water is between 1600~2500 mg/l. Since 70's, geothermal researchers in Tianjin has been focusing on creating and optimizing a comprehensive utilization process of the low/medium temperature geothermal water, mainly, as district heating. The process design is based on the temperature drop of the heating water used in the specific application. In designing the process of district heating systems, the focus has become not only on energy utilization efficiency, but also the special medical function of some substances in geothermal water. For instance, geothermal tail water from the heating systems has been treated and used for special therapy and relaxation, and spring water swimming pool. It is even introduced to individual families. As the result of the ever accumulating experiences in exploration and development of geothermal energy for many years, Tianjin has become more and more mature in using geothermal energy for district heating.

Several district heating systems use geothermal energy as the base energy source and boiler for peak load shaving.

Corrosion Considerations

In the design of geothermal comprehensive utilization system, the quality of geothermal water should be taken into consideration. The salinity of the base rock thermal reservoir geothermal water currently used in Tianjin usually ranges from 1600 to 2500 mg/l. In geothermal water, some of the substances are favorable to the health of human being However, the excessive concentration of ion such as Cl^-, SO_4^{2-}, Fe^{2+}, F^- and H_2S are harmful to the utilization system. In exploring and utilizing of geothermal water, the first problem encountered is the corrosion of geothermal water. Therefore, two alternatives are put forward for the district system: 1) adding corrosion inhibitor to the geothermal water and using it directly in the district heating system; 2) indirectly using geothermal water through heat exchanger. Years of experience show that the corrosion inhibitor can not protect the system from corrosion effectively. Furthermore, the corrosion inhibitor should not be exposed to human body and should not be discharged into the food chain of the ecology system. The emission and reinjection of geothermal water will cause environmental problems. Therefore, the indirect utilization system became popular. Especially, the practice in the recent 20 year has proved that titanium has a good performance in anti-corrosion in the geothermal system. The life time of the titanium plate heat exchanger can be as long as 30 years. In the past few years, the heat transfer efficiency (K) of the titanium plate heat exchanger has greatly improved (1.5 times higher than that of the legacy ones) as the result of the improvement of structure and processing technologies. The heat transfer efficiency of the new titanium plate heat exchanger is about 1.5 times higher than that of the legacy titanium plate heat exchanger. The logarithm temperature difference can be as low as 1 ^oC. In addition, the price of titanium plate heat exchanger has remarkably reduced . For the same service area, the capital cost of the titanium plate heat exchanger in 1998 is only 43 % of that in 1990. To use the Xinyuan residential community as an example, the capital cost of the titanium plate heat exchanger in 1998-1999 is 4.78% of that of the pump station. It has significantly improved the corrosion of the heating supply distribution system. From another point of view - comparison between the direct and indirect use of geothermal water in district heating system with the same serving floor area shows that the cost of corrosion inhibitor consumption in 7 - 8 years' operation of direct utilization system is almost identical to the cost of purchasing titanium plate heat exchanger in indirect utilization system.

Hence, from technical, economical, environmental and energy utilization points of view, indirect heating systems has obvious advantage over direct heating systems. Especially, the indirect heating system with heat exchanger has built a foundation for design of the geothermal heating system with fossil fuel-fired boiler for peak load shaving.

Base Load/Peak Load Heating System

In order to increase the heating area and improve the efficiency of geothermal energy utilization, systems with boiler house combined with geothermal energy have been designed to form the base load/peak load heating system, i.e. a heating system which uses geothermal energy for base load and boiler for peak load shaving. The object of the peaking equipment is to provide the capacity difference between the structure's requirement and the capacity of the base load (geothermal) system. An appropriate design of base load/peak load system can achieve substantial energy savings. With the Consideration of the following 1) maximum heating energy output of the base rock thermal reservoir geothermal water in Tianjin, 2) the comparison of capital cost of the peaking boiler house and its resulting benefit, in the design of the heating system, the base load is designed to be 66% of the peak load (the outside temperature of the base load system is -1^o). To meet the heating requirement of 56 w/m^2 in Tianjin, the heating area is designed to be around $12x10^4$ m^2 .

This paper uses Tianjin Xinyuan community district heating system as a case study and determines the ratio of the annual heat provided by geothermal energy and the total heat. The result is obtained based on engineering calculation according to existing chart/table and data from on site measurement.

Climate considerations – data and calculation

The rationale behind the design of the base load/peak load heating system lies partly in the annual temperature profile. Table 1 shows the annual temperature occurrences (number of hours when the outside temperature t_{wi} is equal to or lower than the temperatures in the table) in Tianjin, China.

The data shown in Table 1 and 2 are based on the statistic of the daily average temperature of 30 years (1951-1980). [1]

Table 3 is based on Table 1. The data in Table 3 is arranged in 2 ^oC increments (i.e., -2 - -3^oC). These 2^oC increments are called temperature "bins" and the data in each bin is referred to as bin data.

The cumulative heating requirement curve (as shown in Figure 1) is developed based on the data in Table 1 and Table 2.

Cumulative Heating Requirement Curve

This plot was developed according to the following parameters: the design heating load in Tianjin during the heating period – q_f=56 w/m^2, the indoor temperature is 18^oC, and the outside temperature is obtained from Table 3. From the data in Table 3, the quantity of annual energy required at a particular temperature bin is calculated using the number of hours at that bin and the temperature difference between it and the inside temperature of the structure. Summing the energy requirement in each bin leads to the annual total energy requirement. The percentage of annual energy requirement at a particular temperature bin in the annual total energy requirement is plotted and form the cumulative heating requirement curve. For example, for the heating system presented in this paper, base load is designed to be 66% of the peak load, the outside temperature in the base load system (geothermal system) is -1^oC. Figure 1 indicates that 60% of the annual heating needs occur above this temperature (-1^oC). In reality, since the base load system keeps in operation even when the peak load system kicks in, the energy provided by geothermal water should be higher than that presented in Figure 1.

Consider the heating system presented in this paper, the calculation based on the on-site measurement data during a entire heating period indicates that the annual energy requirement is 10336.5 x 10^3 kWh. The energy provided by geothermal water is 10216.96 x 10^3 kWh, which is 98.85% of the annual energy requirement.

It is clear that due to temperature occurrences in most northern China locations, with the implementation of a series of energy saving solutions, a base load system (geothermal) designed for approximately 57-67% of the peak load can actually meet over 90% of the annual heating requirements. As a result, the heating area of the base load/peak load heating system can increase by about 50% compared with single load (geothermal) heating system.

In addition, from a macro point of view, for this particular heating system, the annual energy requirement calculated using Table 3 (Annual Temperature Occurrences) is 13293.92 x 10^3 kWh. However, based the on-site measurement, the annual energy consumption is 10336.05 x 10^3 kWh. This indicates that the energy saving is 22.25% of the annual heating requirement.

ANALYSIS OF THE ENERGY SAVING OF THE GEOTHERMAL HEATING SYSTEM WITH FOSSIL FUEL-FIRED BOILER FOR PEAK LOAD SHAVING

The reasons of energy saving of the heating system demonstrated in this paper are detailed as follows:

1. The calculation of the annual energy requirement is based on the "annual temperature occurrences table", which is developed from the statistical data of the daily average temperature in 30 years (1951-1980). The result thus matches the actual temperature profile. However, since 80's the global warming phenomena has led to the increase of the heating period temperature, which in turn causes the decrease of annual energy consumption.
2. In a heating period, the peak load period is rather short relative to that of base load. Figure 1 indicates that over 60% of the annual heating needs occur above the outside temperature (-1 ^{o}C) of the designed base load system. Therefore, a peaking boiler was installed downstream of the geothermal heat exchanger to boost the supply water temperature to the heating equipment during the fairly short peak load period. In addition, the geothermal system continues to be in operation during the peak load period, which further improves the energy utilization efficiency and decreases the energy consumption. In the system presented in this paper, the capital cost of the peak load system is only 8% that of the entire heating station, Yet it is essential in achieving energy saving in the annual heating supply. In addition, the fossil-fueled peak load system offers a no-cost emergency backup in the event of a failure in the geothermal system.
3. The power frequency regulator for the deep well pump is incorporated in the system. A temperature transducer is installed to measure the temperature of geothermal tail water from the heat exchanger. When the heat load of the heating system changes, the temperature difference of the heat exchanger circulation water changes accordingly which in turn affects the geothermal tail water temperature. The change in the geothermal tail water temperature is captured by the temperature sensor, whose signal is sent to the power frequency regulator of the deep well pump. The output flow rate is thus adjusted to accommodate the change in heat load. Especially in the base load period, because the geothermal water is the only heat source, the approach mentioned above allows the output flow rate of the geothermal well changes with the outside temperature. Therefore, the geothermal water is saved without compromising the heating need. In addition, on-site measurement date indicates a 50% decrease in electricity consumption during heating period due to the integration of the frequency regulator. In general, the capital cost of the deep well pump power frequency regulator is only 8% of that of the entire heating station. Because the majority of the time, the system is under base load, the energy saving is quite substantial. This energy saving approach is widely used in the heating systems in Tianjin.
4. When the base load system can not meet the heating requirement, the climate compensating controller will reference the designated heating curve, automatically adjust the electronic 3-way valve and control the peaking boiler based on the signal input from the outside temperature transducer and supply water temperature transducer of the water distribution system. This control system allows the heating curve to match the outside temperature profile.
5. A thermal stat valve is installed on individual resident's radiator. Pressure differential control between the water distribution and accumulation systems in the heating system is implemented as well. The pressure transducer regulates the frequency control system of the circulation pump. The circulation water flow rate is consequently adjusted, which in turn lead to energy saving.

A well designed base load/peak load geothermal heating system is the foundation for the accomplishment of energy saving. Whereas the energy saving approaches in each portion of the heating system such as heat source, heating distribution system, individual resident etc. are essential in enhancing the effectiveness of energy saving in the heating system.

EVALUATION OF HEATING SYSTMES WITH FOUR HEATING SOURCE ALTERNATIVES

Geothermal energy and three other heating source alternatives are available for district heating application in Tianjin. For a long time, *coal* has been used as energy source for space heating in winter in cities of northern China. Its technology is mature and it has become the traditional energy source for space heating in China. Currently in Tianjin, most coal-fueled space heating are in the form of large scale district heating systems using heat from CHP plant and district heating systems heated by coal burning boiler houses. In regards to using the *natural gas* or *fossil fuel* as heat source for district space heating, the process of district heating system fueled with natural gas is the same as that fueled with coal except that natural gas is from the city's natural gas transmission and distribution pipeline. A pressure regulation station should be built for the supply of natural gas to ensure an appropriate pressure to the boiler house. In addition a fossil fuel storage equipment with a certain volume and strength should be in place. A certain safety clearance between gas pressure regulation station, boiler house and the nearby buildings or structures should be considered.

Compared with the conventional heating system using solid fuel, gas fuel or liquid fuel, geothermal water has rather stable heat output, which is beneficial to a effective control and regulation system. Therefore, using natural gas, fossil fuel, especially geothermal water as heating source have the potential for energy saving. To sustain the geothermal energy, in the design of geothermal heating system, both the production well and return water well with a particular distance between them should be incorporated in the system.

Using a district heating system supplying a residential area of 12 x 10^4 m^2 floor space as an example, the four heating system alternatives are evaluated, i.e., heating system uses coal, natural gas, fossil fuel and geothermal water. Figure 2 demonstrates the capital cost of the four approaches. The capital cost takes into consideration the heat resource, transmission and distribution network, and consumer facilities. As can be seen, the capital costs of the heating systems using coal, natural gas and fossil fuel are fairly close, and are all lower than that of the geothermal system. However, based on the current market energy cost, the geothermal system has the lowest fuel/resource cost and lowest per unit heating energy cost – only 8.9% that of diesel fuel, 10.7% of natural gas and 45% of coal (Figure 4 and 5). The result of the comprehensive calculation reveals that the fossil fuel approach has the highest operating cost (Figure 3); The coal approach has the lowest operating cost – however, it has a fatal problem for its severe air pollution. Another problem with the coal approach is, for a district heating system serving a residential area with 12 x 10^4 floor space, the annual coal consumption will be 2467 tones, which is substantial considering a limited coal reserve. Therefore, the alternative of burning coal is less acceptable. The approach of using geothermal water has the highest capital cost, yet the lowest operating cost and the best energy utilization efficiency. More significantly, it is environment friendly. Geothermal energy is called green energy and is a renewable energy source. Proper utilization of geothermal energy can reduce green house effect and sustain global energy. Consequently, using geothermal energy for heating is favorable as long as the resource is available and the capital cost is acceptable. However, the resource should be protected from excessive exploitation and should be used and renewed rationally.

Geothermal energy has a great potential. The modern drilling technology allows us to use more high-temperature geothermal water or steam from deeper strata of the earth. This has given rise to wider applications of geothermal water. In order to sustain global energy to the 20^{th} century, the natural heat energy containing in dry hot rock in deeper earth is expected to be used in the near future. The geothermal energy will play an important role in the future energy in the world.

CONCLUSION

Analysis and evaluation of the district heating systems using the four energy resources indicate that geothermal heating system is technically feasible, financially reasonable. Especially it is environment friendly, and has substantial and easily achievable energy saving result It is an excellent city heating system in Tianjin.

Table 1. Annual Temperature Occurrences Tianjin, China

Temperature (°C)	≤5	≤3	≤0	≤-2	≤-4	≤-6	≤-8	≤-10
Hour / year	2928	2465	1833	1235	700	330	127	69

Table 2. Data used in the Calculation for Heating System Design

Days / heating period N (days)	Outside Temperature t_w(°C)	Indoor Temperature t_n(°C)	Heating period Daily Average Temperature $T_{p.i}$ (°C)	Heating period initial temperature t_{wk}(°C)
122	-9	18	-0.9	5

Table 3. Annual Temperature Occurrences (Bin Data) Tianjin

Temperature (°C)	Hour / year
4-5	463
1-3	632
-1-0	598
-3-2	535
-5-4	370
-7-6	203
-9-8	58
≤-10	69

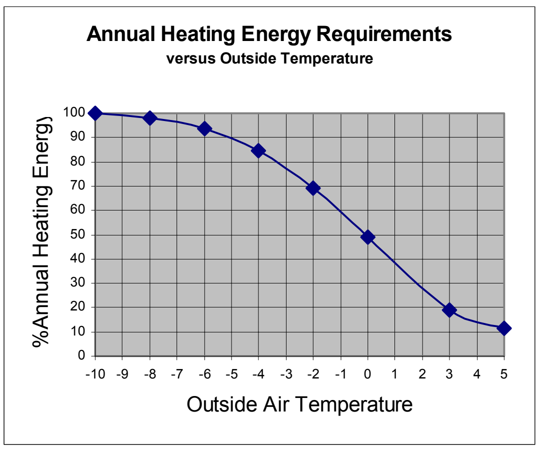

Figure 1. Annual Heating Energy Requirement vs. Outside Temperature

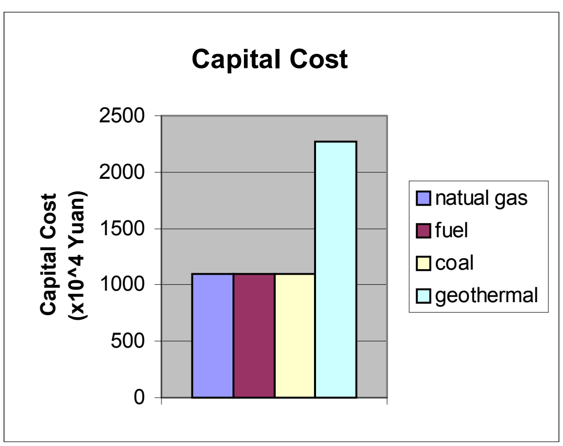

Figure 2. Comparison of Capital Cost of the Four Heat Source Alternatives

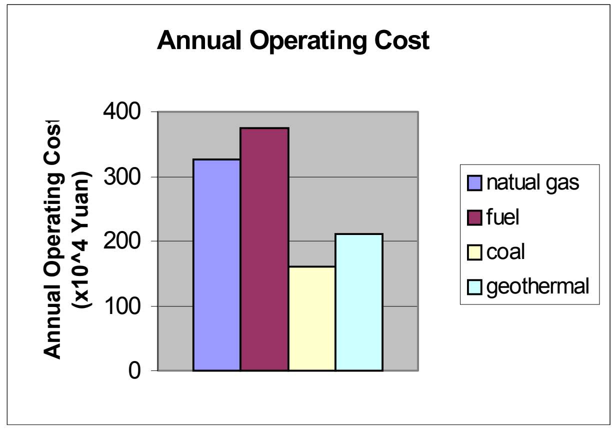

Figure 3. Comparison of Annual Operating Cost of the Four Heat Source Alternatives

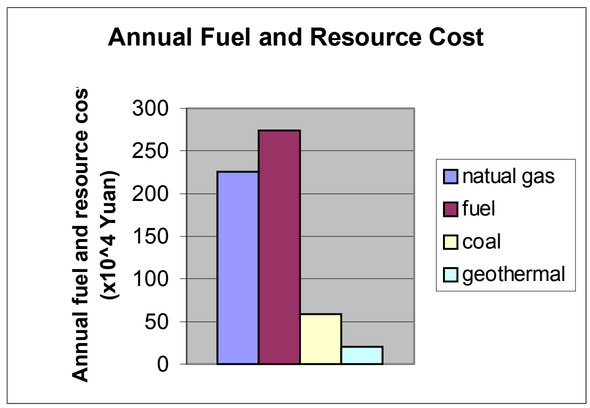

Figure 4. Comparison of Annual Fuel and Resource Cost of the Four Heat Source Alternatives

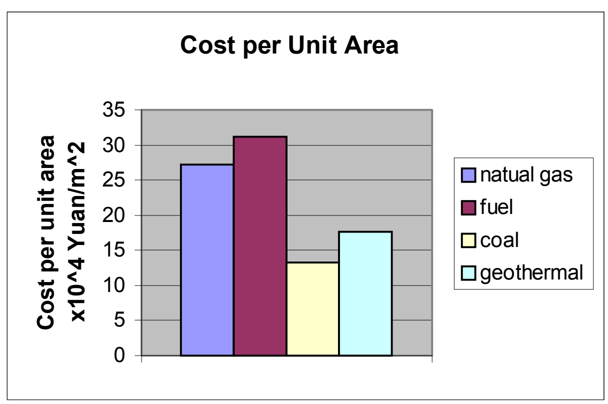

Figure 5. Comparison of Cost per Unit Area of the Four Heat Source Alternatives