# LOW TEMPERATURE GEOTHERMAL ENGINEERING COST ANALYSIS AND COMPARED TO TRADITIONAL HEATING IN CHINA

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## ABSTRACT

In the last ten years, as a result of economic **growth** and increasing environmental concerns, the Chinese geothermal engineering has been developed considerably. One typical geothermal heating system is described and with a detailed ***cost*** analysis. The analysis includes drilling, well pump, variable frequency system, water treatment, heat exchangers and terminal **user** equipment. **The** total cost has been reduced substantively and is suitable for developing countries. Compared to **Chinese** traditional heating system of burning coal, the low temperature geothermal heating system is very competitive.


## INTRODUCTION

In general, the geothermal system **with** reservoir temperature below 90°C are called law temperature geothermal system. However, the 10 years experiences of the author **on** space heating in China shows that the **lowest** temperature which geothermal water can be used is about 45°C. **The** increasing quality of life leads more people to ask to live in **a region** with district heating, especially **in** areas with a prolonged heating season. Low temperature geothermal resources are available in many regions of China. The increase in the price of coal and the increasing people's concern for air pollution gives the chance for developing geothermal **space** heating in China. Tianjin alone, has about 1.8 million square meters of **floor area** using geothermal heating in \hinter, 1993. **The** exploration of geothermal water also spurs the development of tourism and sanatorium Nowadays, many places urgently need to set up geothermal projects, afler all the economic and environment are considered.

The energy utilization efficiency of China is lower than that of developed countries. There are many reasons for this, however, one of these is that energy recovery for the law temperature heat sources is poor. These **energy** resources **seems** insignificant when considering just their temperatures, but their quantity is large enough that any ignorance of these **energy** resource has **a** negative effect an the total energy efficiency. Of course, there some technical difficulties associated with using low temperature heat sources, an economic analysis has to be made in order to get maximum economic and social benefits.

In previous years, the government of China controled the main raw materials such **as** coal and steel with their **so** called subsidized prices. Therefore, any cost analysis using these subsidized prices are faulty, **as** the market is opened for those materials, and their prices are up and down according to market changes. Meanwhile, the **investor** guided by the market commodity economy system is more concern with the ratio of input to output. The conclusions made by investors according to **a** reasonable and objective selected interest rate, payback duration, land **cost** and market prices are useful and helpful.

Burning coal accounts for about **75%** of the energy consumption in China Since the heat source of traditional space heating depends almost merely an **coal** burning plants, the cost analysis of coal **burning** plants becomes the only comparable reference to that of geothermal **space** heating.

## 'THE GEOTHERMAL SYSTEM OF 'TLANJM EVENING NEWS BUILDING

Tianjin Evening News Building is located in the center of the city. and it has 37 floors. The total space heating area is about 109,000 $m^2$. Two geothermal wells($JWB_1$ and $JWB_2$) were completed **in** Sep., 1993 near the building. The production well ($JWB_1$) has **a** depth of 3658 meters. The injection well ($JWB_2$) is **a** directional well and its vertical depth is 1612 meters. The two wells are 6 meters apart at the well head. They are shown in Fig. 1. The maximum pumping flowrate ofthe production well according to the well tea is limited to 140 $m^3/h$. The outlet temperature of the geothermal water is 83°C.

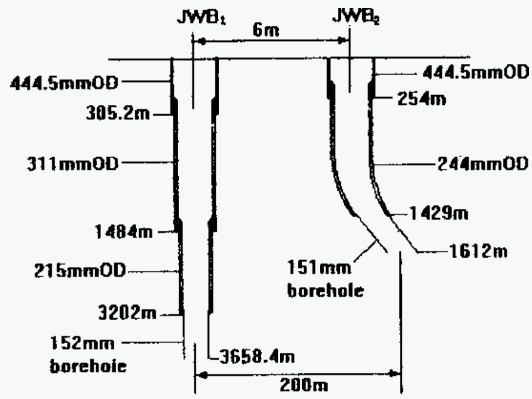
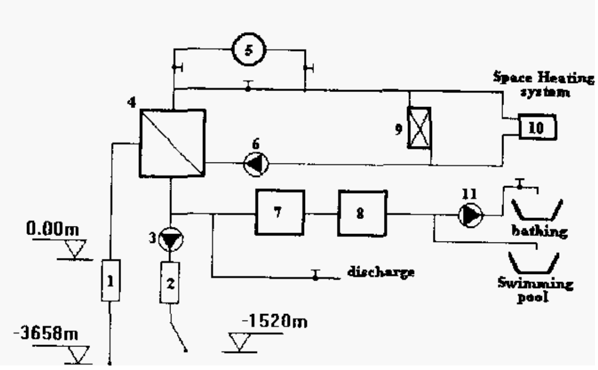



Figure 1. The layout of production and injeciton wells

The chemical species repon shows that the chloride content is high and is about 524.7 *mg/l.* So an indirect heating system of which plate heat exchangers made **of** titanium had to be selected. **While** $Fe^{3+}$ and $Fe^{2+}$ contents **are** 0.92 *mg/l* and 0.16 *mg/l* respectively, removing iron is necessary when the water is used for domestic hot water.

The **space** heating system diagram is shown in Fig. 2. The peaking load for space heating is 7,493 MW. **When** the average daily temperature in Tianjin is **≤+8°C,** space heating is necessary, **with** the duration of the heating season being about 147 days, The average outdoor temperature for the entire heating season is 0.3°C. Considering the radiated heat from the ***sun*** and the other heat source **in** the houses, 14°C is chosen to be the design temperatwe in **space** heating. Therefore the day-degree value of **space** heating is 147×(14-0.3) = 2013.9 day.degree. **The** day-degree diagram of Tianjin is **shown** in Fig. 3.




1. production well 2. injection well 3. injection pump
4. plate heat exchanger 5. peaking load boiler
6. circulating pump 7. water treatment 8. water tank
9. fan coil 10. radiator 11 auxilary pump

Figure 2. Principle diagram of doublet spare heating system of Tianjin Evening News Building

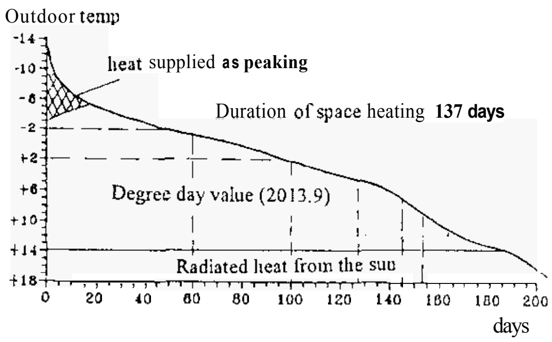



Figure 3. The heating degree day diagram of Tiajin City

The space heating load per unit floor area can be calculated as following equation(in $J/m^2$),

$$Q = H.D.D \times \frac{1}{t_n - t_w} \times q \times \frac{24hr}{day} \times \frac{3600\text{seconds}}{hour} \qquad (1)$$

where $H.D.D$ = day. degree value
$t_n$ =indoor design temperahue ($t_n$ = 18°C)
$t_w$ = outdoor design temperature ($t_w$ = -9°C)
$q$ = standard heat supply unit area (q = 68.74 $w/m^2$)

therefore,

$Q = 0.443\times10^6 kJ/$ (heating season. $m^2$)

$Q_{total}$ = $Q\times$(total area)
$= 0.443\times10^6\times109000$
$= 48{,}294\times10^6 kJ/$(heating season)

The peak load of domestic hot water is 30 $m^3/h$ and the average hot water consumption per day is 180 $m^3/day$. So the accumulated heat load of hot water per year is $11{,}000\times10^6$ $kJ/year$.

Indoor swimming pools heat consumption for a whole year is 1,885 $\times10^6$ $kJ/year$.

The calculated results above are listed in Table 1 below.

## TECHNICAL AND ECONOMIC PARAMETERS IN CEO. SPACE BEATING SYSTEMS

A complete space heating system should include three parts, first is the heat source, e.g. boiler and/or geothermal well; second is the outdoor transmission pipelines and the third is indoor terminal equipments.

Geothermal space heating systems may have different designs, however, the first thing that should he done is to make a technical and economic assessment, i.e., to pursue the minimum "space heating cost per square meters of floor" and then to compare the cost with that of usmg a bailer plant which bums cod.

Table 1: Space heating design parameters and results list

| No. | Items | Unit | Value |
|---|---|---|---|
| 1 | Indoor average design temperatwe | °C | 18 |
| 2 | Outdoor design temperature | °C | -9 |
| 3 | Standard heat supply per $m^2$ | $w/m^2$ | 68 74 |
| 4 | Start and end outdoor temperature during a heating season | °C | 8 |
| 5 | Duration of a heating season | days | 147 |
| 6 | Average outdoor temperature during a heating season | °C | 0 3 |
| 7 | Base temperature of space heating | °C | 14 |
| 8 | Heating degree.days of the whole heating season | °Cdays | 2013.9 |
| 9 | Accumulated heat load per $m^2$ per year | $kJ/m^2y$ | $0.443\times10^5$ |
| 10 | Space heating area | $m^2$ | 109,000 |
| 11 | Accumulated heat load of a whole year | kJ/y | $18.294\times10^5$ |
| 12 | Design temperature of domestic hot water | °C | 45 |
| 13 | Design flowrate of domestic hot water | ton/h | 30 |
| 14 | Accumulated heat load of domestic hot water | kJ/y | $11{,}000\times10^5$ |
| 15 | Accumulated indoor swimming pool heat load of a year | kJ/y | $1{,}885\times10^5$ |
| 16 | Accumulated heat load of a whole year | kJ/y | $61{,}179\times10^5$ |

The cost of space heating per quare meters is calculated as the total annual cost per unit floor area:

$$Cost = \sum AC / Area \qquad (yuan/m^2) \qquad (2)$$

where,
$\Sigma AC$ is total annual cost which includes the capital investment payback, operating cost, administration cost, depreciation charge of equipment, annual maintenance cost, major maintenance cost and salvage value. ($yuan/y$)
$Area$ is total space heated floor area.($m^2$)

note:

(1) The annual cost here did not include the land cost, insurance premium, tax and profit, they can be added if necessary.

(2) The annul cost for each part of the whole project can he calculated independently and finally made an algebraic sum of these results. This calculation method is suitable for a personal computer.

(3) The annual cost method eliminates the problem of alternatives with different lives, the cash flow can be counted annually, therefore alternatives comparison can be conducted in terms of a same period " a year".

## MAIN COST ITEMS

### *Capital investment (I)*

Capital investment should include all capital costs of equipment of an alternative These are: geothermal well(s)(1); heat exchanger station(2); peaking load station(3); outdoor pipelines(4) and terminal fan coil and radiators(5) five pans.

***Total annul cost of operation and maintenance(C')***

The 'total annul cost of operation and maintenance includes the operating cost, such as the fees for water and electricity(or fuel), drainage allowance charges, workers' salary, administration cost. annual equipment maintenance cost, major maintenance cost and annual equipment depreciation, etc..

***Annual cost (AC)***

$$AC = I(A/P) + C' - (S_v + W)(A/F) \quad (3)$$

where, AC = annual cost
I = total capital investment
C' = total annual cost of operation and maintenance
$S_V$ = salvage of equipment at the end of a calculation period
W = cash flow saving at the end of the calculation period
( P/F, i, t ) =present value factor
i = interest rate per period of time
n = number of period
( A/P, i, n) =rate of cash return

Here, the salvage is given as 5% of the total investment; the three alternatives do not have much difference in flowing cash, let W = 0; annul percentage rate of loan (I) is taken as 10%; n is 15 years.

In order to use ordinary annuity table directly and simplify calculation as much as possible, the equation above can change to:

$$AC = I(A/P, 10\%, 15) + C' - S_v(A/F, 10\%, 15) \quad (4)$$

Looking up ordinary annuity table:

$$(A/P, 10\%, 15) = 0.13147$$
$$(A/F, 10\%, 15) = 0.03147$$

Generally, in China. the cost of the terminal radiator is included in the building construction cost. The capital investment and total annual equipment cost cover only the two pans of heat source and outdoor pipelines, and the cost of the terminal heat radiator is not included. In order to fully use geothermal energy, the heat transfer area of the radiator should be increased, thus increasing the capital cost. This happens especially when the discharge temperature is low. The increased part of cost is considerable, therefore, it cannot be ignored.

To be compatible with the cost data of geothermal space heating systems, the traditional coal burning systems with an outlet temperature of hot water ranging from 95 to 70°C is selected as the comparison alternatives. After calculating the total cost of the low temperature geothermal heating system, the extra cost using alternative of geothermal energy can be obtained by subtracting the total cost of the traditional heating system. This extra payment can be called cost increment, due to the larger heat radiator, which is included in capital cost.

According to the economic analysis above, a mathematic model describing the geothermal space heating systems war set up. As explained above, the geothermal space heating system is composed of five pans, so models corresponding to these pans were set independently. A computer programme was written in "C" language, which has a strong modularized function. A sub programme can be run separately as well as be called in the main programme. In the main programme, the total annual cost is calculated by making a sum of the five parts, i.e., $\sum AC$. After dividing by the total floor area, the annual cost per square meters for the geothermal space beating system can be obtained.

Using the developed software, the calculations of a geothermal space heating system with four kinds of peaking load methods were run on a computer. The four peaking load methods are: (1) with a coal burning boiler; (2) electricity consumption; (3) gas burning; and (4)with heat pumps. Among these alternatives, the method of gas burning has the minimum capital cost and its technical data are listed in Table 2 and the results are listed in Table 3 and 4.

Table 2. The optimum technical parameters of burning gas peaking system

| Items | Value |
|---|---|
| Flowrate of geothermal water | 140t/h |
| Discharge temperature of geothermal water | 45°C |
| Return temperature of circulating fresh water | 41°C |
| Design heating load | 7493kW |
| Peaking load | 1218kW |
| Space heating floor area | 109,000 $m^2$ |
| Heat Supplied for peaking(kJ) | $959\times10^5$ |
| On peaking start temperature | -5.3°C |
| outlet temperamre of circulating water from PHE | 76°C |
| Percentage of heating load of geothermal water | 83.8% |
| Percentage of heating load design for peaking | 16.2% |
| Percentage of heat supplied as peaking | 1.99% |

Table 3. Initial investment

| | | |
|---|---|---|
| 1 | Drilling | 724.0 |
| 2 | Well head Equipment | 32.3 |
| 3 | Heat exchanger station | 165.5 |
| 4 | Terminal heat radiator | 85.4 |
| 5 | Outdoor pipeline | 59.2 |
| 6 | Gas burning peaking load station | 46.6 |
| sum | | 1120.1 |

unit: $US 1, 000 ($US1 0 = 8.7 Chinese yuan)

Table 4. Annul total cost

| | | |
|---|---|---|
| 1 | Water fee | 4.72 |
| 2 | Fuel charge | 4.01 |
| 3 | Disposal charge | 2.74 |
| 4 | Electricity fee | 8.37 |
| 5 | Workers' salary | 3.38 |
| 6 | Welfare funds extraction | 3.38 |
| 7 | Administration fee | 6.26 |
| 8 | Equipment depreciation | 63.47 |
| 9 | Maintenance and major maintenance | 21.24 |
| Sum | | 117.57 |

unit: $US 1000.0

Summing up the results from Table 3 and 4. we have: the capital investment (I) is $1,120,100., the total annul cost (C') is $117,570., the annul cost per floor area($m^2$) is $1,079 and the total annul equivalent cost is $263,067.

## ECONOMIC EVALUATION

The economic evaluation include three basic parameters. The first is the annual cost (AC). It covers many imponant factors far the return of capital investment according to a benefit-cost calculation. The alternative selection based on $AC$ method is most reasonable while it is in line with national regulations. The second is capital investment. The third is the annual total equivalent cost ($C$), which includes operating cost, administration cost and equipment not included in annual cost calculation. etc..

revenue rate is assumed to be 5% and profit rate is assumed to be 10%, the annul cost of heat is $C'_B = 1.523 \times 85\% = \$US 1.294/m^2$ per heating season.

Comparing with the annual cost of geothermal space heating, the difference is $C'_B - C'_{GEO} = 1.294 - 1.079 = \$US\ 0.215/m^2$ per heating season. The annul cost ofgeothermal space heating is about 16.6% lower than that of a coal burning plant.

In the calculations, the heat of combustion of gas is given as 14,561$kJ/m^3$(3,500$kCal/m^3$), the price per cubic meters of gas is $US 0.046 and heat efficiency of a gas burning boiler is given as 75%. The heat of combustion of coal is given as 20,930*kJ/kg*(5,000kCal/kg), the price of coal pet ton is $US 23.103, and the heat efficiency of a coal burning boiler is *given* as 65%.

## CONCLUSION

One geothermal well can supply heat for a building with 109,000$m^2$ floor area. After same technical parameters were fixed, an optimum alternative has been chosen, and a decision was made which is geothermal space heating with gas burning for peaking. The total equivalent *cost* is low and the annual cost is about 16.6% lower than that of a coal burning plant. The peaking load heat supplied 2.4%. and the rea of 97% is by geothermal.

Economic analysis shows that the interest rate has the maximum effect on economic profit of the project. Sensitivity anaiysis shows that the annual equivalent capital *cost* will increase by 9.6% if the flowate of geothermal water decreases by 20%, and it will increase by 14.6% ifthe payment for the geothermal resource is quadrupled. In this case, the geothermal space heating is will competitive in the market, so the geothermal project risk is small

In the calculation only 10% of the geothermal water is used for the domestic hot water. but the supplied covers a whole year and it has very good profit. Its potential deserves to be explored further.

The *cost* of a completed geothermal well is about 2-4 times that of a coal burning boiler plant. The cost calculation above is only based on annual cost. Since space heating projects are financed by the government as public affairs, there is no consideration for the return of capital investment in China.

The geothermal well at Tianjin Evening News Building can save 4,603 tons of coal per year. The efficiency of geothermal being used is about 45%. The indirect saving of environmental cost if coal burning plant were used is $US 31,800 per year. Because it is a doublet system, it can eliminate the problems of waste water disposal and surface heat pollution. It has both social and environmental benefits. Now, the two wells had been completed and the surface construction has started.