# Meeting the annual heat demand

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**Abstract**

The paper describes a study of the optimum utilization of a low temperature geothermal field in one of the larger cities in China. The main task is to meet the annual space heating demand by seeking the combination of geothermal energy (low running costs) and conventional boilers and/or heat pumps (low investment cost) that result in the overall lowest energy cost. Different combinations of heat sources are compared for different sizes of areas are considered. The solutions for different sizes vary and play a main role in finding a strategy to meet the heat demand. The environmental aspects of the district heating system are considered as well. Finally the energy price to the consumer is calculated for the project's amortization time of 10 and 25 years respectively.

***Keywords:*** *geothermal utilization, heat pumps, boilers, district heating, emissions.*

# 1 Introduction

The task of how to utilize a low temperature geothermal field is a practical one. In its most general form, the goal is to find a solution where as few wells as possible need to be used. The demand of power for space heating is unfortunately not uniform and there is a peak demand during the coldest days. To meet the demand a trade-off has to be considered to combine geothermal energy (low running costs) and conventional boilers (low investment cost) for the lowest overall energy cost. Not only must the project be evaluated on an economic basis, the environmental aspect also plays an important role and should be given due consideration.

# 2 Load curve

The district-heating load depends strictly upon two factors: weather conditions and thermal insulation of the buildings in question. The weather conditions encountered are continental, i.e. cold winters and hot summers. The insulation (resistance to cold during cold days and vice versa) is estimated to be R = 0,93 ($m^2K$)/W (or k = 1,08 W/$m^2K$). An average apartment is 65 $m^2$ inhabited by roughly 3 persons. The total load for an area of 400.000$m^2$ of housing, during an average year is 65 GWh. Of those, 46 GWh are used for space heating, while the remaining 19 GWh are used for heating of domestic hot water. Figure 1 depicts the average load duration curves for the appropriate buildings in the area. Curves are set forth assuming 3 different values of total floor space to be heated.

The geothermal field in question has been explored during recent years. Its production potential has been estimated from wells already drilled. Based on a pre-feasibility analysis of the wells, the estimated annual average flow from each well is 20 l/s of 70°C water and the maximum flow 35 l/s. All additional wells in the field are expected to posess the same capacity. In their article the authors discuss the different approaches of meeting the heat demand, for a short period, when these constraints are relaxed.

Figure 1 indicates the geothermal usage of two 35 l/s production wells and one reinjection well for three given values of heated floor space.

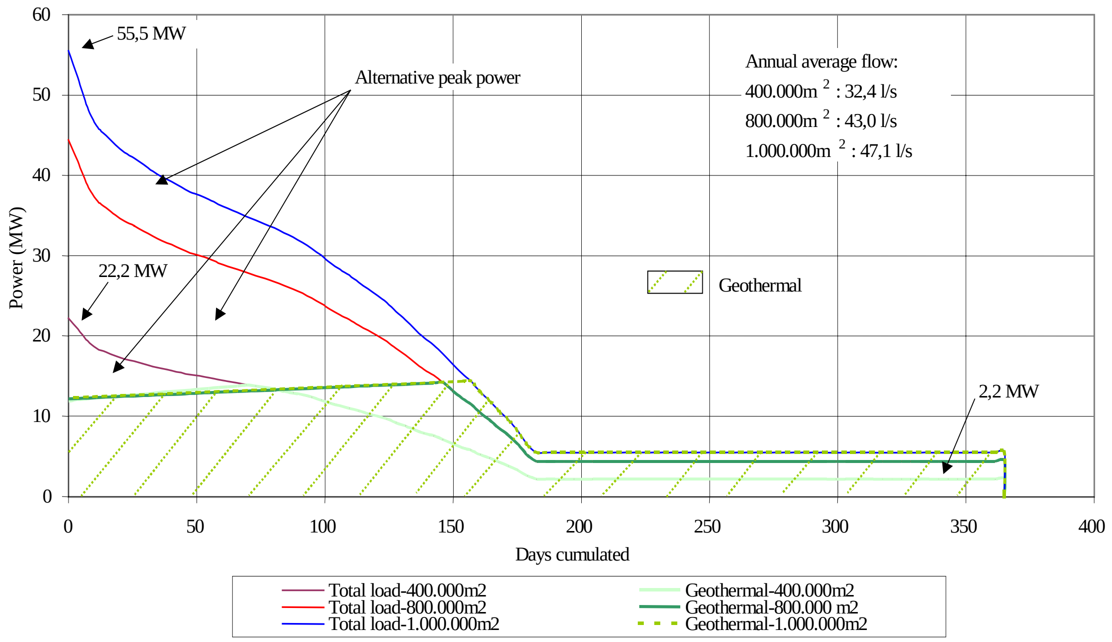


**Figure 1: The load duration curves in the cases of 400.000 m$^2$, 800.000 m$^2$ and 1.000.000 m$^2$ floor space. The utilization of geothermal water is shown as well.**

As can be seen in Figure 1 the utilization of the geothermal energy increases with the size of the total floor space. The smallest area considered consists of 400.000 m$^2$ of floor space, and at maximum demand times, the peak power demand is 11 MW. The utilization of geothermal water and the peak power demand increases, as the total floor space increases. In the case of a total floor space area of 1.000.000 m$^2$ the maximum demand for peak power is 44,2 MW.

Figure 1 also shows that when the peak geothermal utilization of the water is reached (around the 150$^{th}$ and 75$^{th}$ day on the chart for 800.000 m$^2$ and 400.000 m$^2$ of floor space respectively) the lines representing geothermal utilization at higher loads are not fully parallel. This occurs since the return temperature from heating systems at different relative loads is not constant.

The annual flow of geothermal water exceeds the permissible limits for two production wells (2 x 20 l/s) for the larger areas, i.e. for 800.000 m$^2$ and beyond. Thus, when the total floor space is larger than 400.000 m$^2$, three or more production wells are needed to meet the demand, or the use of alternative peak power sources.

## 3 Alternative peak power sources

Alternative peak power sources evaluated are boilers and heat pumps. Boilers can be driven with various kinds of fossil fuels or natural gas while the heat pumps can be driven with electricity or heat (compressor or absorption heat pumps). For this study the potential peak power sources considered are a natural gas boiler and an absorption type heat pump, driven by a natural gas boiler station.

## 4 The price of energy

The price of energy differs greatly between geothermal energy sources and their alternatives. The costs influencing the energy price are the initial investment costs of the district heating system and the system’s operational costs. Investment cost consists of all equipment and its installation, and any related work (e.g. drilling of wells) but does not take into account costs related to exploitation rights. Operational cost consists of basic operational costs (such as maintenance) and fuel costs (fossil fuels or electricity). Table 1 shows a comparison of typical investment costs per produced MW, as well as operational costs per GWh. Investment costs and operating costs set forth in Table 1 do not include costs related to distribution systems nor house connections.

**Table 1: Typical basic investment cost and operational cost for different sources of energy.**

| | Initial cost / MW | Running cost / GWh |
|---|---|---|
| Geothermal | US$450.000 | US$50 |
| Boiler | US$40.000 | US$30.000 |
| Heat pump | US$240.000 | US$18.000 |

**Table 1** is only instructive for a geothermal system in this particular geothermal area.

With total floor space of housing amounting to 400.000 $m^2$, the district heating demand can be met by using various energy sources in combination. The following table summarizes the associated costs, investment and operational, now including costs associated with distribution systems and house connections for each of the options. It also shows an estimate of the emitted $CO_2$. All values are set forth for weather conditions encountered over an average year.

**Table 2: The investment and operating costs in thou. US$, for various ways of meeting the annual heat demand and their respective $CO_2$ emissions in tons. The total floor space of housing is 400.000 $m^2$.**

| Power sources | Investment costs | Annual average fuel costs | Annual operational costs | Total annual operational costs | Annual average $CO_2$ emissions |
|---|---|---|---|---|---|
| 22,2 MW boiler only | 3.610 | 1.980 | 91 | 2.071 | 14.022 |
| System 2-1 + 11 MW boiler | 10.530 | 181 | 263 | 444 | 1.368 |
| System 2-1 + 10,5 MW heat pump | 12.570 | 107 | 314 | 421 | 805 |
| System 3-2 + 5 MW boiler | 13.980 | 20 | 350 | 370 | 163 |
| System 4-2 | 15.230 | 1 | 381 | 382 | 17 |

A general assumption would be to assume that the lifetime of the power plant is finite. When the power plant is shut down the wells and boilers are assumed to be worthless, for the sake of simplicity. Under these conditions, a known formula can be used to calculate the accumulated present value of the project. This formula is as follows:

$$PV = I + A * \sum_{n=1}^{N} \frac{1}{(1+r)^n} = I + A * \left( \frac{1 - \left( \frac{1}{1+r} \right)^N}{r} \right) = I + A * PV_N, \quad \text{for finite N's} \qquad (1)$$

where: PV: present value,
I: Total investment cost,
A: Total annual operational costs,
N: number of years,
r: interest rate.

Using formula (1) and the values provided in Table 2, the present value (cost) of the district heating system's life cycle cost can be calculated as a function of the system lifetime. Figure 3 shows the results, for a total floor space of heating of 400.000 m$^2$. In **Figure 3**, sys 2-1 means 2 production wells and 1 reinjection well, sys 3-1 means 3 production wells and 1 reinjection well and so on. In Figure 3, the interest rate is assumed constant at 6% per annum.

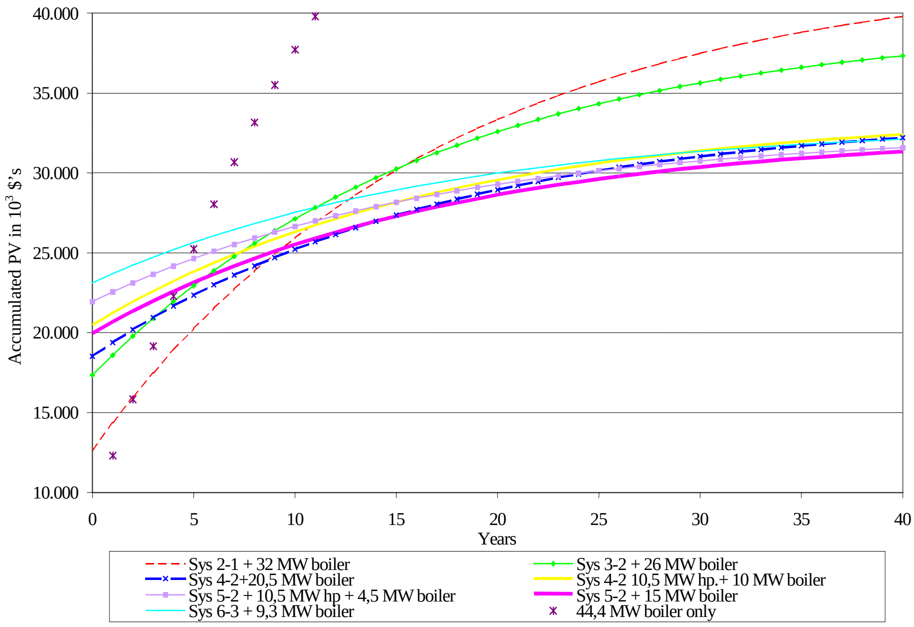


**Figure 3: The present value (cost) of the district heating system's life cycle cost as a function of system life. Total heated floor space is 400.000 m$^2$.**

As seen in **Figure 3** the most economical way to heat the 400.000 m$^2$ of floor space is to use system 2-1 and an 11 MW boiler, unless the system is intended to operate for 3 years or less.

When the total floor space is 800.000 m$^2$, many other different combinations of heat sources can be put forth. These combinations are listed in Table 3.

**Table 3. The investment and operating costs in thous. $ for different ways of meeting the annual heat demand and their respective $CO_2$ emissions in tons. Total floor space is 800.000 m$^2$.**

| Power sources | Investment costs | Annual average fuel costs | Annual operational costs | Total annual operational costs | Annual average $CO_2$ emissions |
|---|---|---|---|---|---|
| 44,4 MW boiler only | 4.590 | 3.960 | 115 | 4.075 | 28.044 |
| System 2-1 + 32 MW boiler | 12.660 | 1.487 | 317 | 1.804 | 11.224 |
| System 3-2 + 26 MW boiler | 16.010 | 929 | 400 | 1.329 | 7.501 |
| System 4-2 + 20,5 MW boiler | 17.610 | 469 | 440 | 909 | 3.569 |
| System 4-2 + 10,5 MW heat pump + 10 MW boiler | 19.690 | 300 | 492 | 792 | 2.297 |
| System 5-2 + 15 MW boiler | 21.270 | 224 | 532 | 756 | 2.081 |
| System 5-2 + 10,5 MW heat pump + 4,5 MW boiler | 19.210 | 159 | 480 | 639 | 1.596 |
| System 6-3 + 9,3 MW boiler | 22.530 | 597 | 563 | 1.161 | 233 |

As indicated in Table 3 the solutions for a total floor space of 800.000 m$^2$ are not mere duplications of the solutions for a total floor space of 400.000 m$^2$. For instance, the sys 2-1 and a 11 MW boiler solution, for 400.000 m$^2$, are not duplicated but has changed to sys 4-2 and a 20,5 MW boiler, since the tap water load does not double as the area doubles.

The resulting present value of the district heating life cycle cost is considered for 800.000 $m^2$ in Figure 4. Figure 4 compares the different options over time, and by doing so, it gives an overview of the most economical combination of power sources.

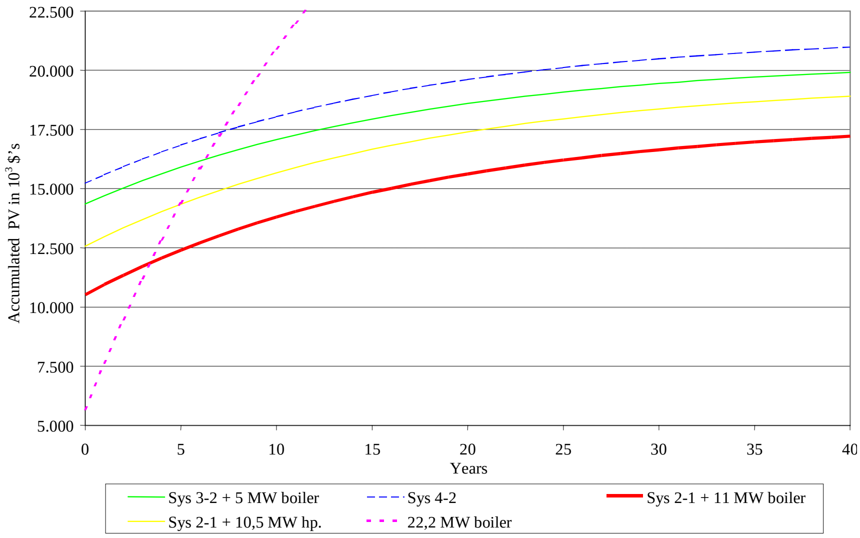


**Figure 4: The present value of the district heating life cycle cost as a function of system life. Total heated floor space 800.000 m². The result for a 44,4 MW boiler is only shown partially.**

The graph indicates that all attractive long-term solutions involve at least 4 production wells. One way to utilize the geothermal field would be to have a cautious preliminary drilling schedule, since the solutions differ very slightly. When four production wells and two reinjection wells have successfully been drilled, a decision could be made whether to add one more production well. This decision should above all be based on experience regarding the previous 6 wells (4-2). If, the total area of housing is expanded further than 800.000 $m^2$, towards a total floor space of 1.000.000 $m^2$ or even higher, additional wells seem to become more feasible than other alternative options, based on these two scenes. In such a case, a geothermal utilization time-schedule has to be laid out to simultaneously meet all needs of the area.

# 5 Environmental aspects

The estimated annual emissions of $CO_2$ for all options have been set forth in Table 2 and Table 3. Air pollution is a serious problem in some areas of China, partially since large amounts of $H_2S$, $SO_2$, $NO_x$ and $CO_2$ are emitted when the predominant energy source, coal, is burned in power plants. For this reason it might be feasible to select the more expensive solutions since they reduce overall pollution to a larger degree.

The Global Environment Fund (GEF), and other global funds such as the Prototype Carbon Fund (PCF), have provided grants to various geothermal projects, similar to this one. The policy of these funds is to grant a specific amount for each ton of $CO_2$ not released to the environment, compared with traditional methods. Here an initial grant of \$4/ton $CO_2$ over a period of 25 years (discounted at r=3,60%) will be considered for comparative purposes only. This amount has been granted from GEF, and similar institutions, in geothermal projects e.g. in East-Europe and is in line with environmental policies as of today. The expected amount of the grant for the various combinations of heat sources is shown in Table 4. If an environmental grant, as indicated in Table 4**,** is taken into account and added to the analysis of the district heating system, the order of feasibility does not change in the first phase of the project (400.000 m$^2$) and the changes for the second phase (800.000 m$^2$) are small (<5%).

**Table 4. Expected environmental grants in $ for the various combinations.**

| Area (m$^2$) | Sys 2-1+boil. | Sys 2-1+hp. | Sys 3-2+boil. | Sys 4-2+boil. | Sys 4-2+hp. | Sys 5-2+boil. | Sys 5-2+hp. | Sys 6-3+boil. |
|---|---|---|---|---|---|---|---|---|
| 400.000 | 825.000 | 862.000 | 904.000 | 913.000 | - | - | - | - |
| 800.000 | 1.097.000 | - | 1.369.000 | 1.596.000 | 1.679.000 | 1.693.000 | 1.725.000 | 1.814.000 |

# 6 Price to the consumer

When the total cost of the energy has been evaluated (Figure 3 and Figure 4), a price to the consumer can be calculated. The following table indicates the minimum price that each customer should be charged for the different combinations in order to break even. Table 5 assumes that all users pay for their energy usage, at the right time.

**Table 5: The prices for the project to pay off in 10 and 25 years.**

| | | The price to pay off in 10 years | | | | Price to pay off in 25 years | | | |
|---|---|---|---|---|---|---|---|---|---|
| Power source | Area (m$^2$) | US$/ kWh | US$/m$^2$ | Yuan/m$^2$ | Yuan/m$^2$ w. grant | US$/ kWh | US$/m$^2$ | Yuan/m$^2$ | Yuan/m$^2$ w. grant |
| **22,2MW gas boiler** | **400.000** | **0,044** | **6,71** | **55,0** | **55,0** | **0,040** | **6,19** | **50,8** | **50,8** |
| System 2-1 + 11 MW boiler | 400.000 | 0,030 | 4,60 | 37,8 | 35,5 | 0,020 | 3,15 | 25,8 | 24,5 |
| System 2-1 + 10,5 MW heat pump | 400.000 | 0,034 | 5,24 | 43,0 | 40,6 | 0,023 | 3,49 | 28,6 | 27,2 |
| System 3-2 + 5 MW boiler | 400.000 | 0,037 | 5,73 | 47,0 | 44,5 | 0,024 | 3,71 | 30,5 | 29,0 |
| System 4-2 | 400.000 | 0,039 | 6,06 | 49,7 | 47,1 | 0,025 | 3,92 | 32,1 | 30,6 |
| **44,4 MW boiler** | **800.000** | **0,040** | **6,18** | **50,7** | **50,7** | **0,038** | **5,85** | **48,0** | **48,0** |
| System 2-1 + 32 MW boiler | 800.000 | 0,028 | 4,23 | 34,7 | 33,2 | 0,022 | 3,45 | 28,3 | 27,4 |
| System 3-2 + 26 MW boiler | 800.000 | 0,029 | 4,48 | 36,7 | 34,8 | 0,022 | 3,33 | 27,3 | 26,2 |
| System 4-2 + 20,5 MW boiler | 800.000 | 0,027 | 4,20 | 34,4 | 33,7 | 0,019 | 2,93 | 24,0 | 23,1 |
| System 4-2 + 10,5 MW heat pump + 10,5 MW boiler | 800.000 | 0,029 | 4,39 | 36,0 | 33,7 | 0,019 | 2,98 | 24,4 | 23,1 |
| System 5-2 + 15 MW boiler | 800.000 | 0,028 | 4,26 | 35,0 | 32,6 | 0,019 | 2,88 | 23,6 | 22,3 |
| System 5-2 + 10,5 MW heat pump + 4 MW boiler | 800.000 | 0,029 | 4,47 | 36,6 | 34,2 | 0,019 | 2,93 | 24,0 | 22,7 |
| System 6-3 + 9,3 MW boiler | 800.000 | 0,029 | 4,53 | 37,2 | 34,6 | 0,019 | 2,95 | 24,2 | 22,7 |

As indicated in Table 5, an environmental grant does not influence the price to consumer greatly. Values in Table 5 assume a zero residual value of all system components. In actuality this residual value is higher since the distribution system, boilers and heat pumps etc. can be sold as second hand equipment when operations cease. The consumer price should thus be somewhat lower (3-10%), depending on the system's age upon closure. For some areas in China, a comparison with a pure boiler would be the most logical one, but in this case it is assumed that the use of pure boilers have already been permitted.

# 7 Conclusions

Different approaches of meeting the annual heat demand exist. The comparison between different selections discussed in this report can be of assistance in a final selection for housing areas of 400.000m$^2$ and 800.000m$^2$ in specific parts of China.

Estimated geothermal flows used in this analysis are based on a pre-feasibility analysis and the accuracy of the posted results depends on the exactness of results from that analysis. If the results from the pre-feasibility analysis turn out to be typical for geothermal wells in the area, this analysis may turn out to be useful in meeting the annual heat demand in the area.

## Acknowledgements

The authors thank Dr. Oddur B. Björnsson at Fjarhitun hf. for his advice, suggestions and help in completing the study.

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