

MEETING THE ANNUAL HEAT DEMAND

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Introduction

This paper describes a study of the optimum utilization of a low-temperature geothermal field in one of the larger cities in China. 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.

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 $R = 0.93 \text{ (m}^2\text{K)/W}$ (or $k = 1.08 \text{ W/ m}^2\text{K}$). An average apartment is 65 m^2 inhabited by roughly three persons. The total load for an area of $400,000 \text{ m}^2$ 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 three 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 possess the same capacity. In Jóhannesson and Ólafsson (2203), the authors regard the different approaches of meeting the heat demand, for a short period, when these constraints are relaxed.

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 $400,000 \text{ m}^2$ 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 $1,000,000 \text{ m}^2$, 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 150th and 75th day on the chart for $800,000 \text{ m}^2$ and $400,000 \text{ m}^2$ 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.

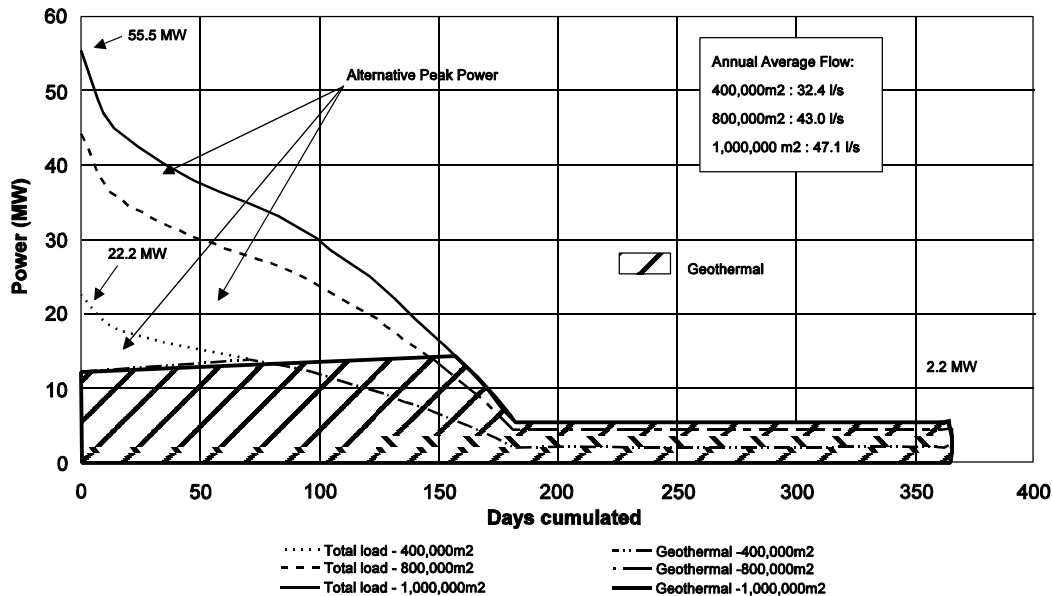


Figure 1. Indicates the geothermal usage of two 35 l/s production wells and one reinjection well for three given values of heated floor space.

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 m² and beyond). Thus, when the total floor space is larger than 400,000 m², three or more production wells are needed to meet the demand, or the use of alternative peak power sources.

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.

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	\$450,000	\$50
Boiler	\$40,000	\$30,000
Heat pump	\$240,000	\$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 m², 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 CO₂. All values are set forth for weather conditions encountered over an average year.

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:

$$PV = I + A * \sum_{n=1}^N \frac{1}{(1+r)^n} = I + A * \frac{1 - \frac{1}{(1+r)^N}}{r} = I + A * PV_N$$

for finite N's (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 2 shows the results, for a total floor space of heating of 400,000 m². In Figure 2, system 2-1 means 2 production wells and 1 reinjection well; system 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.

As seen in Figure 2, the most economical way to heat the 400,000 m² 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 m², many other different combinations of heat sources can be put forth. These combinations are listed in Table 3.

Table 2. The Investment and Operating Costs in 1000 \$ for Various Ways of Meeting the Annual Heat Demand and Their Respective CO₂ Emissions in Tons. The Total Floor Space of Housing is 400,000 m².

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

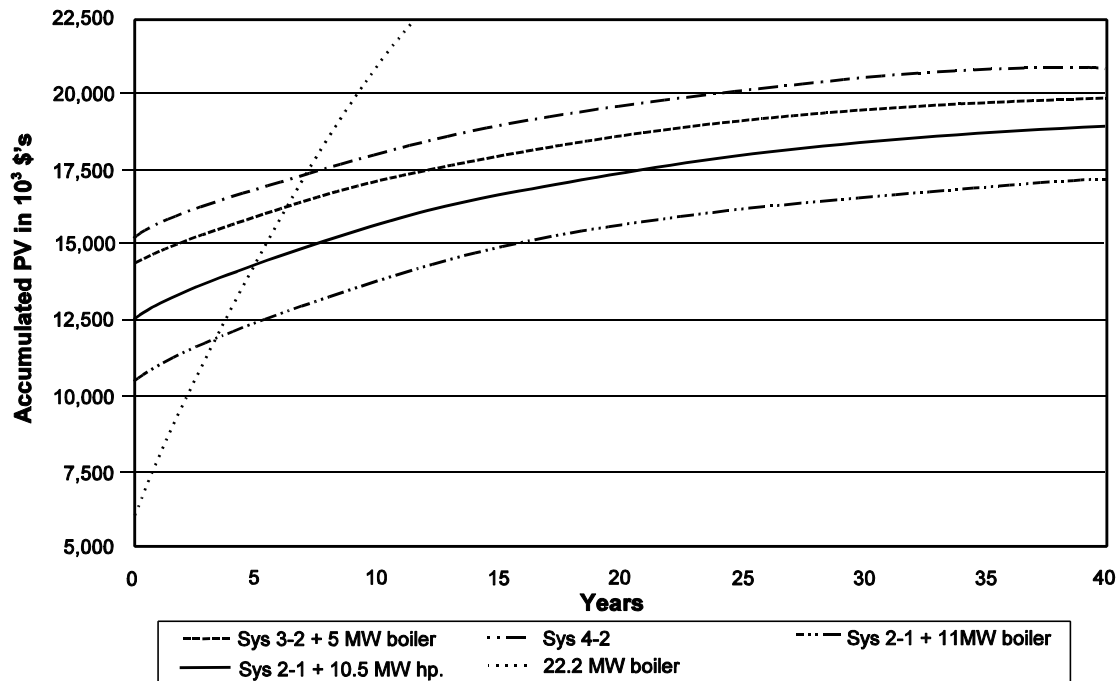


Figure 2. The present value (cost) of the district heating system's life-cycle cost as a function of system life. Total heated floor space is 400,000 m².

Table 3. The Investment and Operating Costs in Thous. \$ for Different Ways of Meeting the Annual Heat Demand and Their Respective CO₂ Emissions in Tons. Total Floor Space is 800,000 m².

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	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	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 m² are not mere duplications of the solutions for a total floor space of 400,000 m². For instance, the system 2-1 and a 11-MW boiler solution, for 400,000 m², are not duplicated but has changed to system 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 m² in Figure 3. Figure 3 compares the different options over time, and by doing so, it gives an overview of the most economical combination of power sources.

The graph indicates that all attractive long-term solutions involve at least four 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 six wells (4-2). If, the total area of housing is expanded further than 800,000 m², towards a total floor space of 1,000,000 m² 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.

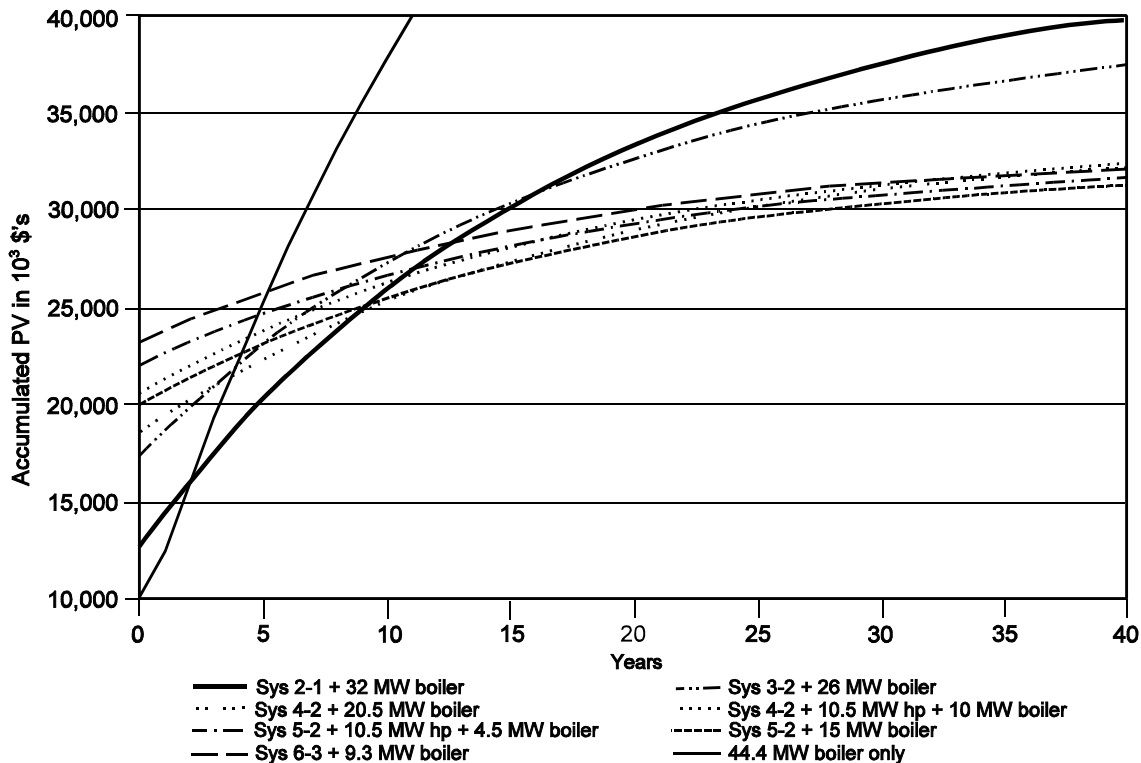


Figure 3. The present value of the district heating life cycle cost as a function of system life. Total heated floor space 800,000 m². The result for a 44.4-MW boiler is only shown partially.

ENVIRONMENTAL ASPECTS

The estimated annual emissions of CO₂ 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 H₂S, SO₂, NO_x and CO₂ 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 CO₂ not released to the environment, compared with traditional methods. Here, an initial grant of \$4/ton CO₂ 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 m²) and the changes for the second phase (800,000 m²) are small (<5%).

PRICE TO THE CONSUMER

When the total cost of the energy has been evaluated (Figures 2 and 3), 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.

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, 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.

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 400,000m² and 800,000m² in specific parts of China.

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

Table 5. The Prices for the Project to Pay Off in 10 and 25 Years

Power Source	Area (m ²)	The Price to Pay Off in 10 Years				Price to Pay Off in 25 Years			
		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 + 2.5 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

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.

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