

# The Utilization Strategies and Case Study of a Compound Geothermal Heating System

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**Abstract:** Geothermal energy is a kind of renewable energy source, which is widely employed for heating purpose. There are problems that the temperature of tail water from heating is too high and geothermal energy is not taken full advantage of. Hence, boilers (coal-fired, oil-fired, gas-fired or electric) are often used as supplement to meet the massive heating load in the coldest season. Nowadays, moderately high temperature heat pump is gradually applied to recover heat from tail water thanks to its features of energy savings and environmental protection. Obviously, geothermal heating system, boilers and heat pumps make up of a so-called compound geothermal heating system. This paper presents a feasible operating modulation strategy for the compound system based on dividing the heating period into slight cold period, moderate cold period and severe cold period, as well as a calculating method to determine the operation of each sub-system according to heating system modulation curves. A case study indicates the strategies can make the compound system operate steadily and save energy compared with conventional systems.

**Keywords:** geothermal energy, moderately high temperature heat pump, utilization strategies, practical application, energy savings

## NOMENCLATURE

|             |                                                                             |
|-------------|-----------------------------------------------------------------------------|
| COP         | coefficient of performance                                                  |
| $\bar{Q}_n$ | relative heat load, i.e., the ratio of actual heat load to design heat load |
| $t_n$       | indoor temperature [°C]                                                     |
| $t_w$       | outdoor temperature [°C]                                                    |
| $t_n'$      | design indoor temperature [°C]                                              |
| $t_w'$      | design outdoor temperature [°C]                                             |
| $t_g$       | water outlet temperature of heating system in user side [°C]                |
| $t_h$       | water inlet temperature of heating system in user side [°C]                 |
| $t_g'$      | design water outlet temperature of heating system in user side [°C]         |
| $t_h'$      | design water inlet temperature of heating system in user side [°C]          |
| $\beta$     | heat transfer exponent of radiator, generally let $\beta=0.3$               |
| $\bar{G}$   | relative flow rate, i.e., the ratio of actual flow rate to design flow rate |
| $Q_D$       | heating capacity of geothermal energy [W]                                   |
| $G_D$       | flow rate of geothermal water [kg/s]                                        |
| $t_1$       | water outlet temperature of geothermal well [°C]                            |
| $t_e$       | geothermal backwater temperature [°C]                                       |

## 1. INTRODUCTION

The geothermal energy used for heating purpose has been widely employed overseas, as well as in some cities abundant in geothermal resource such as Beijing, Tianjin, Xi'an, Daqing in China, thanks to the characteristics of energy savings and environmental protection. However, the tail water from heating with higher temperature has not been utilized very well in China. On the other hand, the heating capacity of geothermal wells is usually smaller than the heat load needed for space heating in most heating projects. Thus, some coal, oil and gas boilers have to be used as auxiliary equipment in geothermal heating system to meet the heat demands in the coldest season. Recently, the geothermal heat pumps, which could recover the energy from tail water with higher temperature, have been employed gradually in China. So the fresh geothermal water heat exchangers, the geothermal heat pumps and the boilers construct the so-called compound geothermal heating system. Obviously, there are some heat sources in one single heating system. Therefore, people are very interested in how to match these heat sources for the goal of energy savings, and how to optimize the operation of the whole system for the goal of money savings. This paper discusses the issues both in theory and in practice.

## 2. OPERATING MODULATION STRATEGY

### 2.1 Establishment of Modulation Method

Due to the characteristics of high first cost and low operating cost, the geothermal heating sub-system should be employed as adequately as

possible. And the boilers and heat pumps are merely used to fulfil the extra heat load that geothermal heating sub-system can not afford. In addition, the heating period can usually be divided into slight cold period (about 70 days), moderate cold period (about 40 days) and severe cold period (about 20 days)[1]. Based on the above insight, we present the following modulation method for the compound geothermal heating system, which is illustrated in Fig.1.

The heating system is often designed according to the severe cold period. But the severe cold period lasts very short and the annual peak load only account for 15%-18% of the total heat load in the same year. Furthermore, the peak load is 1.5-2.0 times as much as the basic load. So joint operation of several heat sources can enormously save the high first cost while not remarkably increase the operating cost. When the compound system is run, the geothermal sub-system should take on basic heat load, and then the heat pump and boiler (oil or gas), the operating cost of which is relatively higher, will be started up in turn with the decrease of outdoor temperature. This makes the whole heating system economical.

The heat sources in the compound system can work solely, which makes it possible for another heat source to operate when a heat source is in failure or need to examine and repair. Obviously, even if the whole heat load is not met, the compound system would not be inactive entirely. Thus, the reliability of the compound system can be enhanced.

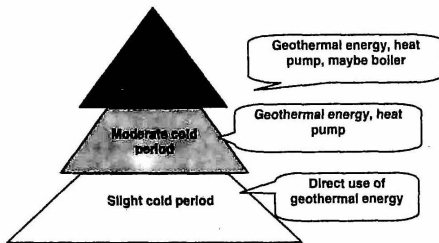


Figure 1: Modulation strategy sketch

The heat source can be added as the heating area increases, which is propitious to the development of heating system.

In order to stand out the advantages of the compound heating system, some principles should be considered. The connection between main heat source and peakload heat source is of importance. The connecting modes include temperature lift, combining net, departing net, backwater heating, etc. Owing to the fact that the COP of heat pump decreases with the increase of the water temperature difference between inlet and outlet, the heat pump is only suitable for combining net, departing net and backwater heating connection. And the boiler can be applied to all these modes. The best mode lies on the working conditions at jobsite.

Because of the characteristic of the least operating cost, geothermal heating should be taken

full advantage of and the temperature of discharge and injection geothermal tail water should be lowered as possible as it can.

## 2.2 Calculating Method for Modulation

In the compound heating system, the startup and its order of peakload equipment, such as the heat pump and the boiler, should be determined according to the outdoor temperature. And the outdoor temperature corresponding to the startup of these devices is defined as conversion temperature. This section brings forward a calculating method for quality modulation.

The basic operating modulation formula is as follows

$$\bar{Q}_n = \frac{t_n - t_w}{t'_n - t'_w} \quad (1)$$

Generally,  $t'_n$  is 18°C and  $t'_w$  is -9°C for Beijing and Tianjin region. The change of relative heat load with the outdoor temperature is shown in Fig.2.

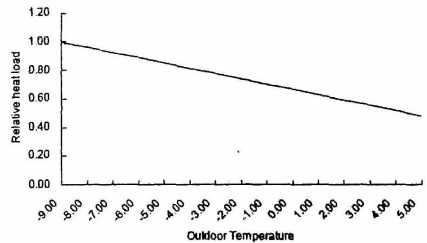


Figure 2: Change of relative heat load with outdoor temperature

The quality modulation of the heating system can be expressed as follows

$$t_s = t_n + \frac{1}{2} \left( t'_s + t'_h - 2t_n \right) \left( \frac{t_n - t_w}{t'_n - t'_w} \right)^{\frac{1}{1+\beta}} + \frac{t'_s - t'_h}{2} \left( \frac{t_n - t_w}{t'_n - t'_w} \right) \quad (2)$$

$$t_h = t_n + \frac{1}{2} \left( t'_s + t'_h - 2t_n \right) \left( \frac{t_n - t_w}{t'_n - t'_w} \right)^{\frac{1}{1+\beta}} - \frac{t'_s - t'_h}{2} \left( \frac{t_n - t_w}{t'_n - t'_w} \right) \quad (3)$$

$$\bar{G} = 1 \quad (4)$$

The heating capacity of geothermal energy is calculated according to the following formula

$$Q_D = G_D (t_1 - t_2) \quad (5)$$

where,  $t_2$  is slightly lower than  $t_h$ .

According to the rule of quality modulation, the water inlet and outlet temperatures will change with the variation of outdoor temperature, which is shown in Fig.3. The scenario in Fig.3 is obtained under the conditions that design water outlet and inlet temperature are 70°C and 50°C, respectively, and outdoor temperature is -9°C. Referring to Fig.3, during the slight cold period, water inlet temperature can

decrease remarkably, which means the heating capacity of geothermal energy will increase. Hence, geothermal energy is enough to meet the basic heating load in this period. The peak load equipment such as heat pump, oil boiler, and natural gas boiler will work in turn while the outdoor temperature drops.

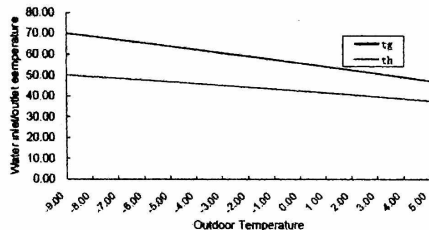


Figure 3: Quality modulation curve

As for the compound geothermal heating system including geothermal energy, heat pump and boiler, we assume the geothermal energy, the heat pump and the boiler can meet 70%, 20% and 10% of the total heating load in the severe cold period, respectively, as well as the water outlet temperature of geothermal well is 80°C. Additionally, the heating capacity of heat pump can be regarded as a constant independent of outdoor temperature and heat load because the decrease of needed heating temperature compensates the decline of heat pump heating capacity due to the decrease of geothermal tail water temperature. The heating capacity of boiler is also independent of outdoor temperature. Based on the modulation strategy illustrated in section 2.1 and Fig.2, the calculating conversion curves for peak load modulation can be obtained, as shown in Fig.4 (the longitudinal coordinate, relative heating capacity, is defined as the ratio of actual heating capacity to design heating capacity).

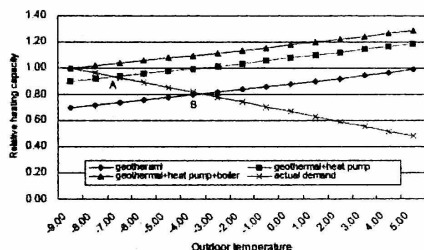


Figure 4: Calculating conversion curves for peak load modulation

In Fig.4, B is the intersecting point of actual demand curve and geothermal heating capacity curve, and A the intersecting point of actual demand curve and 'geothermal+heat pump' heating capacity curve. The temperatures of B ( $T_{WB}$ ) and A ( $T_{WA}$ ) are conversion temperatures for peak load modulation. When outdoor temperature exceeds  $T_{WB}$ , geothermal

energy is enough to meet the heating load by itself. When outdoor temperature is between  $T_{WB}$  and  $T_{WA}$ , the heat pump should be run so as to fulfil the increasing heating demand. When outdoor temperature becomes lower than  $T_{WA}$ , all three heat sources have to be operated for heating purpose.

Thus, we present the operation strategy and calculating method for peak load modulation of the compound heating system.

### 3. A CASE STUDY

#### 3.1 Project Description

There are two geothermal wells (one for yielding fresh geothermal water and the other for injecting used water back to aquifer), with water flow rate of 120t/h and outlet water temperature of 69°C, in a district in Beijing. In order to take full advantage of geothermal resource and lower the operating cost, we designed a compound geothermal heating system including direct geothermal energy use sub-system and heat pump sub-system (see Fig.5), which has been put to use.

The system is employed to heat  $15 \times 10^4 \text{ m}^2$  heating area. And heating purpose is carried out by three stages. In the first stage, fresh geothermal water passes through the first stage plate heat exchanger and its temperature is lowered to 50°C. At the same time, the heating circulating water is heated to a temperature of 65°C and then flows to water collector. These hot water, the heating capacity of which is 2651kW, is used to heat  $4.42 \times 10^4 \text{ m}^2$  heating area by radiators. Then the used water first enters water distributor and later returns to first stage plate heat exchanger with a temperature of 45°C.

In the second stage, the used geothermal water from the first stage plate heat exchanger enters the second stage plate heat exchanger and leaves with a temperature of 25°C. Three moderately high temperature heat pumps (QYHP-1580M) are employed to produce 65°C hot water by recovering heat from the geothermal water passing through the second stage plate heat exchanger, which also flows to water collector. The heating capacity of this stage is 4675kW and the input power is 1011kW. The hot water can heat  $7.16 \times 10^4 \text{ m}^2$  heating area with  $3.87 \times 10^4 \text{ m}^2$  by floor heating system and  $3.29 \times 10^4 \text{ m}^2$  by radiators. The second stage plate heat exchanger inlet and outlet internal circulating water temperatures are 22°C and 43°C, respectively.

In the third stage, three conventional heat pumps (QYHP-900C) are used to recover heat from geothermal tail water with a temperature of 25°C. The used geothermal water is finally injected into aquifer after its temperature drops to 10°C by the third stage plate heat exchanger. This stage can create the heating capacity of 2670kW on condition that the input power is 744kW. The stage applies fan-coil units to heat  $3.56 \times 10^4 \text{ m}^2$  heating area. The third stage plate heat exchanger inlet and outlet internal circulating water temperatures are 9°C and 16°C, respectively.

In all, the compound heating system can provide a 9996kW heating capacity at the cost of a 1755kW

input power. In addition, this system possesses of a 3500kW cooling capacity, which can cool 40000m<sup>2</sup> floor areas. The compound system is operated according to the modulation strategy presented in section 2.

### 3.2 Economic Feasibility Analysis

Because energy savings usually mean money savings (operating cost reduced), this paper only discusses economic feasibility of the compound system owing to limited space. The investment and operating cost for several heating modes are listed in table 1.

1) The average electricity price and valley electricity price are 0.5yuan/kWh and 0.2yuan/kWh, respectively; the time of valley electricity price lasts 8 hours per day. The natural gas price, coal price, oil price and tap water price are 2.0yuan/m<sup>3</sup>, 300yuan/t, 3.4yuan/L and 3.2yuan/t, respectively.

2) The heat load for equipment selection is 60W/m<sup>2</sup> and that for practical operation 31.82W/m<sup>2</sup> [2]. The annual heating period is 130 days.

3) The heat values of fuels can be looked up from related China national standards. We let the efficiencies of coal boiler, oil boiler, gas boiler and electric boiler be 0.55, 0.90, 0.90 and 0.95, respectively. Additionally, the COP of water source

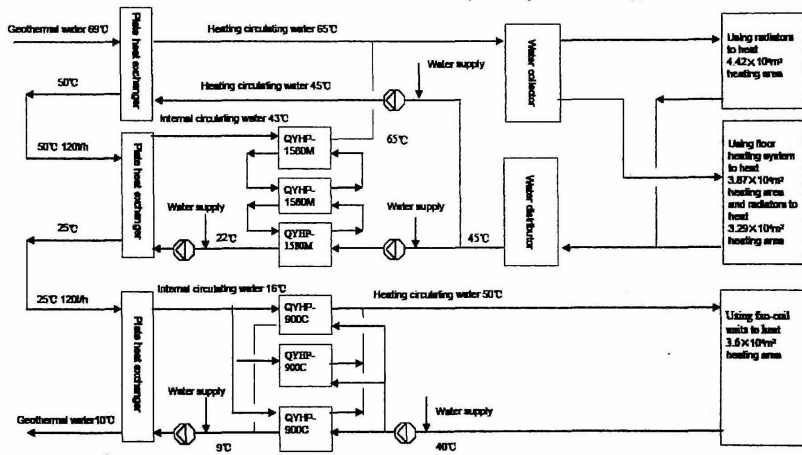


Figure 5: A practical compound heating system with direct geothermal heating and heat pumps  
heat pump is set as 3.75.

Table 1: Investment and operating cost for several heating modes

| Heating mode                    | Investment cost (yuan/m <sup>2</sup> ) | Energy consumption (m <sup>3</sup> /year) | Operating cost (yuan/m <sup>2</sup> ·year) |
|---------------------------------|----------------------------------------|-------------------------------------------|--------------------------------------------|
| Geothermal water*               | 70                                     | 2.25t                                     | 6.75                                       |
| Municipal heating network       | 150                                    | 0                                         | 24                                         |
| Coal boiler                     | 50                                     | 38.7kg                                    | 11.6                                       |
| Oil boiler                      | 25                                     | 11L                                       | 37.4                                       |
| Gas boiler                      | 30                                     | 12.8m <sup>3</sup>                        | 25.6                                       |
| Individual household gas supply | 70                                     | 12.8m <sup>3</sup>                        | 25.6                                       |
| Electric boiler                 | 40                                     | 104.5kW                                   | 41.8                                       |
| Heat pump                       | 65                                     | 26.5kW                                    | 10.6                                       |

\* The investment cost of geothermal heating is dramatically different with the variation of actual conditions and this value is just for reference.

It is noted that the data in table 1 are obtained based on the following preconditions:

4) The operating cost only contains fuel cost, excluding management cost, maintenance and repair cost and depreciation cost, etc.

In fact, practical operating cost is lower than 10.6yuan/(m<sup>2</sup>·year) owing to load adjustment. We can consider this cost consists of labour cost and maintenance cost. If the heating cost is 16.5yuan/(m<sup>2</sup>·year), the compound system can save 88×10<sup>4</sup>yuan in an annual heating season. If the cooling cost is 30 yuan/(m<sup>2</sup>·year), the compound system can save 65×10<sup>4</sup>yuan in an annual cooling season. Thus, the system can save 153×10<sup>4</sup>yuan per year in all. Considering that the heat pumps do not operate in the slight cold period (the heat pumps only operate 90 days in practice), and this project is merely employed to heat an office building (the daily heating time is 12 hours), the operating cost of heat pumps is about 7yuan/(m<sup>2</sup>·year), which makes the system more economical.

### 3.3 Other Advantages

The compound system can recover heat from geothermal tail water with a temperature from 15°C to 60°C so as to take full advantage of geothermal resource. The temperature of produced hot water can

be adjusted according to user demands and the maximum temperature is up to 90°C, which meets different requirements such as cooling, heating and domestic hot water production. Also, this system is fit for existing heating network.

This system is environmentally friendly since heat pumps substitute for boilers, which are mainly responsible for environmental pollution. It effectively copes with the thermal pollution caused by low temperature geothermal water or geothermal tail water as well.

In the compound system, moderately high temperature water source heat pumps are used not only for heating purpose in cold winter months, but also cooling purpose in warm summer months, which avoids repeating investments in air conditioning systems and improves utilization ratio of equipment. The water source heat pumps can operate automatically, so it is easy to control them. The whole system is compact and its components need less floor area to install. As the temperature of geothermal water is relatively stable, and water source heat pumps can provide hot or cool water with relatively stationary temperature, people feel comfortable in the indoor ambient created by this compound system.

#### 4. CONCLUSION

In order to make the best of geothermal water resource, a renewable energy, a compound heating system is presented, which comprises fresh geothermal water heat exchangers, water source heat pumps and even boilers. As the compound system contains various heat sources, an operating modulation strategy is brought forth based on dividing the heating period into slight cold period, moderate cold period and severe cold period, as well as heating system modulation curves. Subsequently, a practical heating project using a compound heating system including direct geothermal heating sub-system and water source heat pumps sub-system is introduced. Analyses indicate the system is attractive both in economic consideration and other associated aspects. Obviously, similar compound systems are promising and worthwhile to popularize.

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