Study of the Design Method of an Efficient Ground Source Heat Pump Thermal Source System in a Cold Area

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Abstract: The ground source heat pump (GSHP) system-an energy efficiency and environment friendly system-is becoming popular in many parts of China. However, an imbalance usually exists between the annual heat extracted from and rejected to the ground due to the different heating and cooling load of a building, which will consistently deteriorate the heat pump efficiency leading even to the breakdown of the heat pump. This paper brings forward a design method of adding supplemental heat rejection equipment, a cooling tower, in the system to solve the problem in a cold area. Taking an office building in Beijing as an example, the authors simulate the GSHP system with two different connection methods between the cooling tower and vertical buried-pipe heat exchangers (in series and in parallel) using TRNSYS simulation software, and put forward several design schemes that can ensure the whole system continually operates with high efficiency. This also makes it possible to perform a more detailed economic optimization of the GSHP-based system in the future.

Key words: Ground source heat pump, heat balance, system design, TRNSYS simulation

1. INTRODUCTION

Ground source heat pump system (GSHP) is usually energy efficient and environment friendly by utilizing the thermal energy in the ground. So the system arouses great interest among the researchers and potential users.[1,2,3,4] In the GSHP system with vertical buried pipes, the heat transfer between the buried pipes and adjacent ground is heavily dependent on the temperature and physical properties of the ground. And the fluctuation of ground temperature can not only affect the heat exchange rate of buried pipes apparently[5], but also change the condensation and evaporation temperature of the heat pump. So the heat balance between released to and absorbed from the ground around the buried pipes and the system's long-term performance prediction should be carefully examined especially when the system is adopted to satisfy quite different heat and cooling load of users to ensure the energy efficiency of the whole system. The paper will further study this problem by using TRNSYS simulation software, and discuss some reasonable design schemes of GSHP thermal source system.

2. BRIEF DESCRIPTION OF THE SIMULATION SYSTEM

An office building in Beijing is taken as an example for the convenience of elaborating the different GSHP thermal source system design schemes. The four-storey building is 15.6m high, with a total floor area of 2100m^2. The air-conditioning design scheme of the building is shown in figure 1, in which the heat/cooling load is undertaken by fan coil units and the hot/chilled water is provided by the heat pump unit. The glycol and water solution with 25% glycol mass concentration is used as the circulation liquid in buried-pipe heat exchangers. The freezing temperature of the solution is -10℃ and its thermal conduction is 0.51 w/m·k. Here the commonly used single U-bend vertical buried pipes is selected as heat exchangers whose material is HDPE (high density polyethylene) with a thermal conduction of 0.46w/m·k.The whole system will be simulated by TRNSYS software (ver.16) developed by Solar Energy Laboratory of Wisconsin-Madison University in USA.

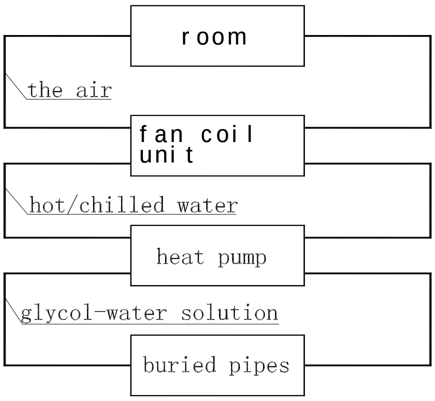

Fig.1 Schematic of air-conditioning design

3. STUDY OF DESIGN SCHEMES OF GSHP THERMAL SOURCE SYSTEM AND ITS PERFORMANCE

3.1 Heat/cooling Load Calculation Results

The multi-zone building model in the TRNSYS software is used to calculate the dynamic heat/cooling load of the building. Figure 2 and 3 are the calculated heat and cooling load duration profiles in which the maximum hourly heat and cooling load are 104kw and 131kw, and the annual total amount of heat and cooling supply reach 55.2MWh and 119.6MWh respectively.

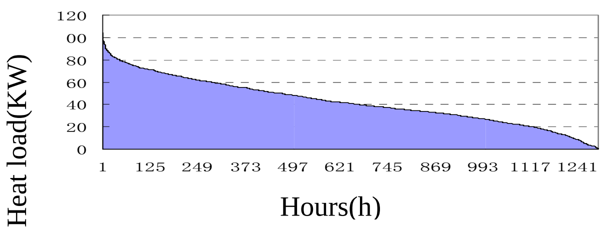

Fig.2 The heat load duration profile

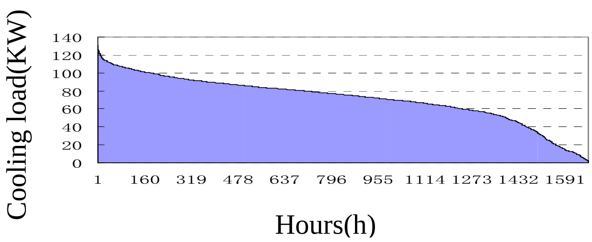

Fig.3 The cooling load duration profile

3.2 Design of GSHP Thermal Source System and Its Operation Simulation

It can be seen from the above calculation results that the annual total amount of cooling supply is much higher than that of heat supply for the same building. This means that the heat released to the ground is much greater than the heat absorbed from it. So the ground temperature level will be raised after long-term operation of GSHP system, and this will lead to the drop of the heat pump efficiency, even to the break down of the system. A quantitative study of this problem is developed in the following.

(1)Simulation analysis of GSHP system without any supplement equipment

In this case system, the heat pump unit is selected according to the cooling load as it is much higher than the heat load. Since the severe heat imbalance mentioned above exits in this case, yet there is not any supplement equipment in the system, a temperature fluctuation amplitude of 0.5°C is set for the highest or lowest heating/cooling media flowing into the heat pump unit in consecutive five years, in order to keep the system to operate with high efficiency. Table 1 lists the extreme temperatures of heating/cooling media that flows into the heat pump unit in consecutive five years. Obviously, the temperature rise after five years' operation is much larger than 0.5℃.

From calculation results, the total amount of heat rejected to the ground reaches 170.4MWh, and the heat extracted from it is only 72.2MWh during the first year. Just this heat imbalance leads to the continuous temperature rise of the heating/cooling media flowing into the heat pump unit.

(2)Simulation analysis of GSHP system with supplement heat rejection equipment

In order to solve the problem of large temperature rise of the heating/cooling media flowing into the heat pump unit, a cooling tower is added in the GSHP system as the supplement heat rejection equipment. Since there are only two methods that a cooling tower can be connected with buried-pipe heat exchangers—in series or in parallel, we will discuss them separately.

Tab. 1 The temperature results of the GSHP

system without any supplement equipment in continuous five years

Year	The annual highest temperature (℃)	The anuual lowest temperature (℃)
1	33.10	5.51
2	34.25	6.77
3	35.21	7.63
4	35.86	8.24
5	36.40	8.72
Temperature rise(℃)	3.30	3.21

①The cooling tower operates in series with buried-pipe heat exchangers

Because the heating/cooling media flow rate was set at the buried-pipe heat exchangers design stage, the capacity of the cooling tower is thus decided. So what we have to study is how to control the operating time of the cooling tower to make the GSHP system operate with high efficiency continuously. (We must point out that though the cooling tower could not be operated only without any buried pipes contribution, the buried pipes can really be operated independently.)

A trial-adjustment method is used here as it is not known exactly how much heat the cooling tower has to dissipate beforehand. At the beginning, let the cooling tower take up (Q_{SL}-$1.2Q_{XR}$) heat dissipation as suggested by literature [6]. (Q_{SL} stands for the total heat that should be rejected to the outside of the building and Q_{XR} stands for the amount of heat that the system should extract from the ground in a year). Then assume the cooling tower could make the cooling media temperature drop half of its total value. The number of cooling tower's operating hours is thus estimated. Usually, after a few times of adjustment, satisfactory result can be obtained. In this case study, the cooling tower has to be in operation all through the cooling season so as to make the extreme temperatures of the heating/cooling media flowing into the buried pipes every year vary within 0.5℃. (Refer to table 2 for the detail temperatures.)

Some other important data is also obtained from simulation: the total amount of heat dissipated by the cooling tower reaches 81.6MWh, while the heat dissipated by the buried pipes drops to 85.9MWh, and the heat absorbed from the ground by the buried pipes is 71.6MWh in a year. So the ratio of the heat absorbed from the ground to that rejected to the ground is reduced to 1:1.20.

Tab. 2 The continuous five-year temperature results of the coupled GSHP system with the cooling tower connecting buried pipes in series

Year	The annual highest temperature (℃)	The annual lowest temperature (℃)
1	30.51	5.56
2	30.57	5.65
3	30.62	5.77
4	30.64	5.92
5	30.64	5.99
Temperature rise(℃)	0.13	0.43

② The cooling tower operates in parallel with buried-pipe heat exchangers

The keys of this connection method include calculating the ratio that the cooling media passes through the cooling tower branch and the cooling tower's operating hours. Obviously, there must be more than one solution by using this method, for the cooling tower is added to the GSHP system only to keep the imbalanced heat within a permitted limit, but this can be achieved by assigning a large proportion of the flow rate to the cooling tower branch with shorter operating time, or a small proportion with longer operating time. Though the solutions are infinite, the upper and lower limits must exit.

a. The upper limit

The largest capacity of the cooling tower could be selected in the condition that 100% of the flow rate of the cooling media passes through the cooling tower branch. In this situation, the cooling tower and the buried pipes need to be operated alternatively during the cooling season. After the cooling tower disperses its share of the equipment heat load (it is the total heat that should be dissipated by the condenser of the heat pump unit) to the ambient outdoor air, it should stop and let rest of the heat rejected to the ground by the buried pipes.

b. The lower limit

This refers to the smallest capacity of the cooling tower that could be possibly selected. It means that the cooling tower has to be in operation all through the cooling season in order to dissipate its share of the equipment heat load. In other words, the proportion of the flow rate of the cooling media passing through the cooling tower branch has its lower limit.

In the case studied here, if a cooling tower is selected by the upper limit, it needs to be in operation in the last 68 days of the whole cooling season (154 days altogether), and the cooling tower dispersed totally 83.6MWh heat, buried pipes 87.2MWh. The buried pipes absorbs 62.7MWh heat from the ground during the heating season. So the proportion of heat absorbed from the ground to rejected to it turns to be 1:1.21, and the fluctuation amplitude of the annual highest and lowest temperature of heating/cooling media are 0.47℃and 0.49℃.While if a cooling tower is selected by the lower limit, 63% of the flow rate of the cooling media should pass through the cooling tower branch. After the whole cooling season's operation, the cooling tower disperses 79.7MWh heat, and the buried pipes 87.8MWh. The heat absorbed from the ground by the buried pipes reaches 71.6MWh. So the proportion of heat absorbed from the ground to rejected to it becomes 1:1.23, and the fluctuation amplitude of the annual highest and lowest temperature of heating/cooling media are 0.47 ℃and 0.38℃ respectively in five years simulation.

4. CONCLUSIONS

(1) If a building is heated and cooled both by a GSHP system, when the accumulated cooling and heating load of the building are quite different, the imbalance of heat absorbed from and released to the ground will deteriorate the ground temperature condition and may lead to the lower efficiency of the heat pump unit and even to the break down of it..

(2) For the situation that the heat released to the ground is far greater than absorbed from it, the method of adding an auxiliary equipment—the cooling tower—can be used to solve the problem, and the cooling tower can be selected between an upper and lower limit when the cooling tower and the buried pipes are connected in parallel.

(3)As to the concrete design scheme what a GSHP system should adopt in a project, a technical economy analysis method is supposed to be used to help make the final decision.

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