Study on Operation Scheme Optimization of Compound Ground Source Heat Pump System in Severe Cold Area

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Abstract. Aiming at the imbalance of soil heat caused by the application of Ground Source Heat Pump System in severe cold areas, the energy supply performance of the system under the control of conventional operation scheme and multi-mode switching scheme was simulated by using TRMSYS system simulation software. The results show that the CGSHPS has good energy supply performance under the control of multi-mode operation scheme; Under the multi-mode switching operation scheme, the total heat extraction of the heat exchanger in the whole year is less than the heat storage, the energy consumption of the unit is less, and the soil temperature increases by 0.09℃ after the periodic operation of the system.

Keywords: Severe cold area; Composite heat pump; Operation scheme; Numerical simulation.

1. Introduction

It is difficult to meet the requirements of building heating, cooling and domestic hot water by using the GSHPS alone in severe cold areas[1,2]. Using solar energy as the auxiliary heat source of GSHPS to jointly supply energy to buildings is a more efficient, energy-saving and environment-friendly energy utilization mode than the single heat source heat pump system[3,4]. The coupling system meets the energy-saving requirements of buildings, and gets more and more attention[5,6]. In view of this, this paper puts forward a year-round operation scheme for the Solar-Ground Source Heat Pump coupling system, establishes a system simulation model by using TRNSYS software, and analyzes the simulation results. The research work in this paper will have guiding significance for the popularization of SGSHP coupling system in severe cold areas.

2. Establishment of Model

2.1. Building Model

The simulated building is modeled one by one according to the actual project, with a total air-conditioning area of 462m², including 225m² on the first floor and 237m² on the second floor[7,8]. The building faces north-south, and the indoor end is powered by fan coil unit plus independent fresh air system.

Building model is established by TRNSYS, and each hot zone is set. Type56, a multi-zone building, was selected in the simulation. The model framework was designed in Simulation studio, and the building envelope parameters, penetration, heating and cooling parameters were set in Trnbuild. Save it as. bui file and import it into Type56 to calculate the building load. The calculation model of target building load is shown in Figure 1. The maximum heat load and maximum cooling load of the research building are calculated to be 35kW and 27kW, respectively.
2.2. System Model
The system modeling uses TRNSYS transient simulation software to connect each module according to the operation principle of the coupling system, and builds the system simulation model according to the system schematic diagram. The system schematic diagram is shown in Figure 2. The periodic simulation operation of the coupling system is realized by setting the internal parameters of each module and the input-output relationship between modules. The main modules used in this system simulation model are shown in Table 1.

Figure 2. System schematic diagram.

3. Operation Scheme
In this paper, the energy supply performance of an office building with an air-conditioning area of 462m² in Harbin is studied by using the SGSHP coupling system under the control of two different schemes, and the fan coil unit plus independent fresh air system is adopted at the end of the load side. Between 8:00 and 18:00, when the heat of the heat storage tank is not enough to heat the DHW tank, both schemes use the auxiliary heater to heat the domestic hot water tank to supply DHW. The GSHPS starts from 7:00 am to 18:00 pm, and the fresh air system starts at 8:00 am and closes at 18:00 pm. According to the heating and cooling dates in Harbin specified in the code, the whole year is divided into three quarters: winter (10.15~4.15), summer (6.15~8.15) and transition season (4.15~6.15, 8.15~10.15). According to the working principle of the coupling system, the annual solar radiation intensity and outdoor temperature changes, the system operation scheme is designed as follows.
Table 1. Modules selected in system simulation model.

| module       | Icon | module       | Icon | module       | Icon |
|--------------|------|--------------|------|--------------|------|
| Type753e     | ![Icon] | Type649      | ![Icon] | Type4c       | ![Icon] |
| Type508c     | ![Icon] | Type114      | ![Icon] | Type534      | ![Icon] |
| Type109-TM Y2| ![Icon] | Type11h      | ![Icon] | Type11b      | ![Icon] |
| Type642-2    | ![Icon] | Type11f      | ![Icon] | Type14b      | ![Icon] |
| Type646-2    | ![Icon] | Type557a     | ![Icon] | Type69b      | ![Icon] |
| Type648-2    | ![Icon] | Type5b       | ![Icon] | Type28b      | ![Icon] |
| Type56a      | ![Icon] | Type71       | ![Icon] | Type33e      | ![Icon] |
| Type77       | ![Icon] | Type14h      | ![Icon] | Type15-6     | ![Icon] |
| Type65a      | ![Icon] | Type515      | ![Icon] | Type2b       | ![Icon] |
| Type668      | ![Icon] | ———          | ——— | ———          | ——— |

3.1. Conventional Operation Scheme of CGSHPs
In the conventional operation scheme of compound GSHPs, the system operation mode consists of GSHP heating, solar energy storage tank supplying domestic hot water, solar energy storage tank supplying DHW and storing soil heat, ground source heat pump cooling and auxiliary heating supplying domestic hot water. The specific operation mode is shown in Table 2.

Table 2. Routine operation scheme of the system.

| Seasonal operation mode | Operation mode |
|-------------------------|----------------|
| Winter GSHP system heating | GSHP system heating |
| Summer GSHP system for cooling | GSHP system for cooling |
| Transition season Heat storage of soil by solar heat collection system | Heat storage of soil by solar heat collection system |
| Winter, summer and transition season Auxiliary heater heats DHW tank | Auxiliary heater heats DHW tank |
|                         | DHW tank heated by solar heat collection system |

3.2. Multi-mode Switching Operation Scheme of CGSHPs
In the multi-mode switching operation scheme of the CGSHPs, the system operation mode is based on the conventional operation scheme, which uses the heat storage tank for auxiliary heating in winter, and the GSHPs uses solar energy for soil heat storage in the intermittent operation of cooling in summer. The specific operation mode is shown in Table 3.
Table 3. Multi-mode switching operation scheme of system.

| Season                        | Operation mode                                      |
|-------------------------------|-----------------------------------------------------|
| Winter                        | SGSHPS heating                                      |
| Summer                        | GSHPS heating                                       |
| Summer and transition season  | GSHPS for cooling                                   |
| Winter, summer and transition season | Heat storage of soil by solar heat collection system |
|                               | Auxiliary heater heats DHW tank                     |
|                               | DHW tank heated by solar heat collection system      |

4. Result Analysis and Discussion

4.1. Energy Supply Performance of Heat Exchanger under Different Operation Schemes

Fig. 3 shows the monthly variation of heat release from the Ground Heat Exchanger to the soil in the whole year under the control of two schemes. It can be seen from the figure that under the control of conventional operation scheme, the total heat intake of the CGSHPS is greater than the total heat storage throughout the year. The maximum heat storage in the whole year occurs in July in summer, January and December in winter, and the heat storage is taken at the beginning and end of heating. This is because the heat load required by buildings in winter is completely borne by the GSHPS alone, and there is no heat storage condition in winter, and there is a certain gap between cold and hot loads in winter and summer in severe cold areas, which leads to the total heat extraction in the whole year being greater than the total heat storage. Under the control of multi-mode switching operation scheme, the total heat intake of the system is less than the total heat storage. The month in which the maximum heat collection and storage occurs in the whole year is the same as the conventional operation scheme, and the GHE stores heat to the soil all year round. This is because one part of the heat load required by buildings in winter comes from soil and the other part comes from solar energy. When the conditions are suitable, the system operation mode is switched to SGSHP heating mode. Therefore, the underground pipes take less heat from the soil, and the total heat storage throughout the year is greater than the total heat extraction.

![Figure 3](image_url)

Figure 3. Monthly change chart of annual heat collection and storage of GHE.

4.2. Energy Consumption of HP Units under Different Operation Schemes

Fig. 4 shows the monthly change of annual energy consumption of HP units under the control of two schemes. It can be seen from the figure that the energy consumption of the system under the control of the conventional scheme in winter heating period is greater than that of the multi-mode switching
scheme, and in June of summer, the energy consumption of the HP unit under the multi-mode switching scheme is greater than that of the conventional mode. This is because when the system is used to heat buildings in winter, the start-stop time of intermittent operation of the unit is longer due to the addition of solar energy, which reduces its power consumption. However, when the multi-mode operation is switched in summer, the heat exchanger stores heat on the soil, the soil temperature rises and it is thermally inert, so the heat dissipation to the distant place is slow, and the system is in the cooling condition, and then the energy consumption of the HP unit becomes larger in June at the early stage of cooling.

![Graph](image)

**Figure 4.** Annual monthly energy consumption change diagram of HP units under two schemes.

### 4.3. Analysis of Soil Temperature Variation Characteristics under Different Operation Schemes

Fig. 5 is a time-by-time change diagram of soil temperature variation characteristics of the system in one year under two schemes. It can be seen from the figure that the soil temperature under the control of conventional operation scheme decreases after one cycle of system operation, and the soil temperature under the control of multi-mode switching operation scheme increases after one cycle of system operation. Compared with conventional scheme, the difference between them is 0.3 °C. It can be seen that the system has good soil thermal balance under the multi-mode switching operation scheme proposed in this paper.

![Graph](image)

**Figure 5.** Time-by-time change diagram of soil temperature change after one year of system operation under two schemes.

### 5. Conclusion

1. When the CGSHPS is used to supply energy to buildings in severe cold areas, the system function condition is greatly affected by its operation scheme.
2. Compared with the conventional operation scheme, the multi-mode switching operation scheme proposed in this paper can improve the energy supply performance of the system to a certain extent. The annual heat intake of the GHE under the multi-mode switching scheme is less than the heat
storage, which solves the problem of soil heat imbalance caused by the long-term operation of the GSHPS.

(3) The multi-mode switching operation scheme can reduce the energy consumption of HP units when the system meets the cold and hot loads required by buildings. It is concluded that the operation scheme is suitable for energy supply in severe cold areas.

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