

Study on the Control Strategy of Ground Source Heat Pump of Complex Buildings

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Abstract. The complex building group is a building group which integrates residential, business and office. Study on the operation of buried tube heat exchanger (BHE) with 30%, 50%, 70% and 100% occupancy rate by numerical simulation under the condition of full operation of the business and office, the optimal operation control strategy of a hybrid ground-source heat pump (HGSHP) system with different occupancy rates can be obtained. The results show that: at low occupancy rate the optimal operation control of the heat pump system is to use the cooling tower in the valley load period (June and September) and the heat absorption of the buried tube in winter; While at high occupancy rates, opening the cooling tower when the temperature of the outlet of the BHE is 2 degrees centigrade higher than the temperature of the wet bulb at the corresponding time is the optimal operating strategy. This paper is based on the annual energy consumption and optimization of soil temperature rise, which has an important guideline value for the design and operation of HGSHP system in complex buildings.

1. Introduction

With the fast development of city, the supporting commercial facilities in residence community are more and more general. The ground-source heat pump (GSHP) is widely applied in residential building for its efficient and energy saving. However, the low occupancy rate of the newly-built district has immediate impact on the operating efficiency of GSHP system [1]. Recently, most studies were concentrated on the analysis of control strategy and energy consumption of GSHP under the condition of an individual building at full load operation [2-3], but there are few studies concerning GSHP of complex buildings. Therefore, it is of practical importance to study on the control strategy of GSHP system with different occupancy rates in complex building group.

How the hybrid ground source heat pump (HGSHP) system achieves the optimal operation at low occupancy rate? This work aims to study the operation conditions of GSHP in complex building group with 30%、50%、70% and 100% occupancy rate under the condition of full operation of business and office, and its optimal operation control.

2. Project overview and building load simulation

2.1 Project overview

This project is a complex building group with residential building, commercial building, and office building. There are 13 mid-rise apartment buildings and 1 office building for property management. The ground floor is commercial and the second floor is parking. The complex building group is applied with GSHP system for cooling in summer and heating in winter, and supplying domestic hot water throughout the year. The system adopts a centralized buried heat exchange system, a decentralized small-scale



ground source heat pump unit, and 681 ground tubes. The main equipment are consistent of 249 small GSHP integrated machines with a cooling capacity 13.7 kW, of which 210 are equipped with heat recovery, 1 closed cooling tower with a cooling water volume 300 m³/h is used as an auxiliary heat dissipation, 4 sets of ground source circulation pump with flow rate of 250 m³/h, and 2 cooling water circulation pumps with a flow rate of 300 m³/h.

2.2 Cooling/heating load simulation

The simulation is based on the modeling by Revit, and the hourly load of the whole year (8760 hours totally) was calculated by Hongye. The Revit model of complex building group is shown as Fig. 1. Cooling period is 1 June–30 September, heating period is 15 November–15 March. The heat transfer coefficients of building envelope are: Wall, 0.99 W/(m²·K); Roof, 0.47 W/(m²·K); Window, 2.4 W/(m²·K).

The household of the residential community is 210, and the GSHP system provides domestic hot water for 24 hours throughout the year. Based on <Code for design of building water supply and drainage>, according to the standard of 45 t hot water 0.4 t/d per household (family of 5 persons), 84 tons of water per day is required, and each household is equipped with a 200 L hot water tank [4]. The hourly load of domestic hot water can be calculated according to the rule that tap water inlet temperature is 25 °C in summer, 15 °C in spring and autumn, and 5 °C in winter. The maximum of cooling load is 4464 kW in summer, 2059 kW in winter. The annual accumulated cooling load is 4371 MWh, heating load is 2039 MWh, and domestic hot water load is 1421 MWh. The hourly load of whole year is shown as Fig. 2.

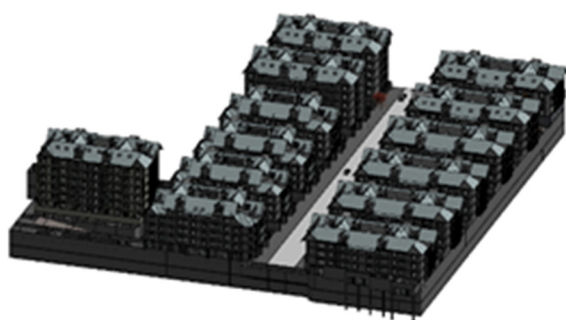


Fig. 1 Revit model of building group

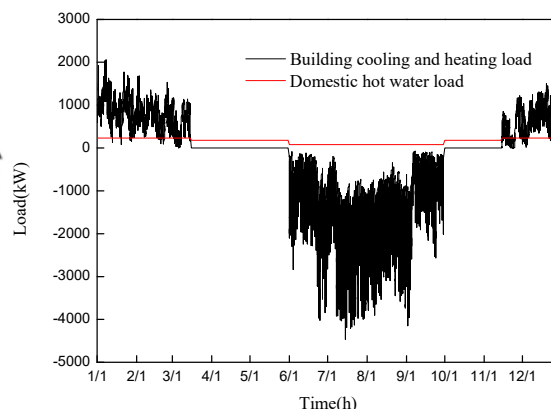


Fig. 2 Hourly load of whole year

3. Numerical simulations

3.1 Geometric model and grid settings

The three-dimensional heat transfer model of parallel double U shaped buried pipe was built based on the real project. The soil domain is 5 m×5 m×100 m, the diameter of the drill hole is 110 mm, the pipe is made of high density polyethylene, and the outer diameter is 25 mm, the inner diameter is 20.4 mm, the spacing between pipes is 50 mm.

The U shaped buried pipe and soil are meshed by structured grids, and the backfill soil is meshed by non-structured grids. The straight part of the U shaped buried pipe is meshed by 0.5 m isometric grids, and the bend part is set by dense grids. The grid settings are shown as Fig. 3.

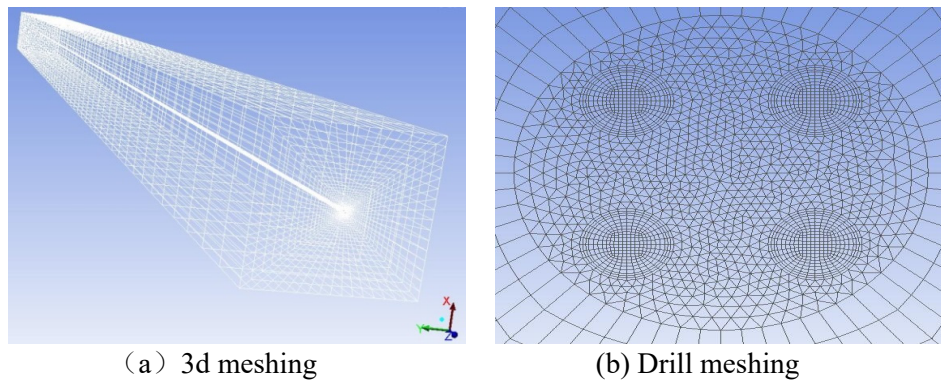


Fig. 3 Schematic of 3d meshing for buried pipe

3.2 Boundary conditions

Inlet boundary is defined as inlet velocity; outlet boundary is defined as free flow. The upper and lower surfaces of the soil are set as insulated. The interface between regions is set as the coupling boundary layer. Pressure and velocity coupling is based on the SIMPLE algorithm. Convection item differential using the QUICK format. Standard wall function method is used to deal with the wall of each region. The time step is 1 h, and the simulation run time is 1 year. The thermal properties of each material are shown in Table 1.

Table 1 Parameters of thermal properties

	Density /kg/m ³	Heat conductivity coefficient/W/(m • K)	Specific heat capacity/J/(kg • K)
HDPE pipe	950	0.44	2300
Backfill soil	1700	1.97	1200
Soil	2700	1.9	1800

4. Results

Owing to the particularity of the complex buildings, this paper mainly considers the operation of BHE with 30%、50%、70% and 100% occupancy rate by numerical simulation under the condition of full operation of the business and office. Fig. 4 shows the outlet temperature of the ground heat exchanger under different working conditions and Fig. 5 shows the soil temperature change rule.

It appears that the outlet temperature increases with the increase of occupancy rate in summer. While the results are exactly opposite in winter (Fig. 4). The technical code for ground-source heat pump system [5] suggests that the maximum outlet temperature of the buried pipe in summer should be less than 33 degrees and the minimum outlet temperature in winter should be more than 4 degrees. Statistically, the outlet temperature is all up to standard when the occupancy rate is 30%. When the occupancy rate increases to 50%、70% and 100%, the unqualified hours are 19 h, 935 h, 1733 h respectively. The greater the strength of the load, the more serious the heat accumulation is.

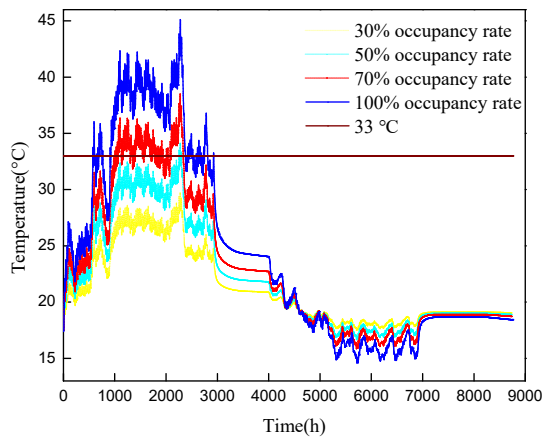


Fig.4 Outlet temperature of ground heat exchanger

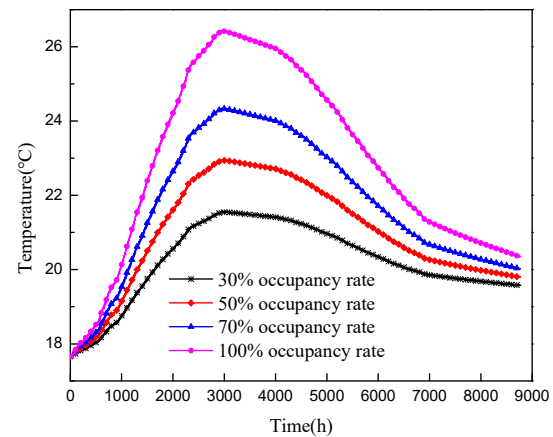


Fig.5 Variation of the soil temperature

The annual trend of soil temperature is consistent under different working conditions (Fig. 5). However, the highest temperature varies greatly in the soil, the occupancy rate differs 20%, the difference between the highest temperature will be 1.4 °C. The initial average temperature of soil is 17.66 °C, the soil is heated up to 2 °C~3 °C after one year of operation and the difference between different occupancy rates is 0.22 °C. It can be seen that the soil resilience is limited, continuous operation of ground source heat pump will cause serious soil thermal accumulation.

In order to alleviate the problem of soil temperature rise, we can open the cooling tower in summer for peak shaving or open that in the transition season to compensate for the cold storage of soil.

When the occupancy rate is 30% and 50%, the outlet temperature of the buried pipe basically stays below 33 °C in summer, however, the annual soil temperature rise is more than 2 °C, there is thermal accumulation in the soil. By opening the cooling tower to alleviate the thermal accumulation, three different operation strategies are put forward.

(1) In summer, the heat is dissipating by the ground pipe. In the transitional season, the cooling tower is used for heat dissipation. In winter, it absorbs heat from the buried pipe.

(2) In June and September (valley load period), the cooling tower is launched to dissipate heat. In July and August, ground pipes are used for heat dissipation, and they are used for heat absorption in winter.

(3) In summer, the 21:00pm-8:00am runs the cooling tower, and the remaining time uses the buried pipe to dissipate heat. In winter, the heat is absorbed by the ground pipe.

The operation simulation under low occupancy rate is shown in Table 2. With rising of occupancy rate, the maximum temperature of the outlet of the buried pipe increases. Among the three operation strategies, the cooling tower operation time of strategy 1 is the shortest, whose soil temperature control is the best. However, strategy 1 is not enough to control the water temperature of the pipe outlet, the outlet temperature is somewhat high which results in relatively low efficiency and increased energy consumption. Although Strategy 2 has slightly less control of soil temperature, its outlet is the lowest, the heat pump unit has the highest operating efficiency, and energy consumption is relatively minimal. Considering comprehensively, in the case of low occupancy rate, the cooling tower is started during the low load period, the operation effect is the best.

Table 2 Operation simulation of system under low occupancy rate

Working condition	30% (1)	30% (2)	30% (3)	50% (1)	50% (2)	50% (3)
Cooling tower opening time (h)	1080	1440	1464	1080	1440	1464
Maximum outlet temperature (°C)	29.69	28.19	28.28	33.35	32.05	31.96
Soil temperature (°C)	-0.05	0.59	1.13	-0.01	0.41	0.92

Heat pump COP	4.03	4.14	4.13	3.92	4.05	4.04
Total energy consumption (MW.h)	2156.08	1899.92	1938.24	2539.83	2351.82	2408.37

When the occupancy rate reaches 70% and 100%, the outlet temperature of the buried pipe exceeds 40 °C, and the soil temperature rises above 2.5 °C. The cooling tower can play a role of peak shaving. We can set the following three strategies to control the opening time of the cooling tower.

(1) Time control: priority operation of the cooling tower in June and September, cooling tower runs daily from 23:00 to 6:00 in July and August.

(2) Temperature difference control: the cooling tower is opened when the outlet temperature of the buried tube heat exchanger is 2°C higher than the wet bulb temperature at the corresponding time.

(3) Temperature control: the cooling tower is opened when the outlet temperature of the heat pump is over 32 °C.

Table 3 Operation simulation of system under high occupancy rate

working condition	70% (1)	70% (2)	70% (3)	100% (1)	100% (2)	100% (3)
Cooling tower opening time (h)	1 936	1 767	1 265	1 936	2 563	2 012
Maximum outlet temperature (°C)	33.43	32.41	32.33	38.64	36.11	36.54
Soil temperature (°C)	-0.23	-1.23	-0.87	0.28	-2	-1.4
Heat pump COP	3.99	4.00	4.00	3.86	3.89	3.87
Total energy consumption (MW.h)	2 615.72	2 539.53	2 594.29	3 337.55	3 085.41	3 154

The operation simulation under high occupancy rate is shown in Table 3. With the increase of occupancy rate, the total energy consumption continues to increase, but the average area energy consumption is decreasing. It shows that the higher occupancy rate of ground source heat pump system is, the higher the utilization rate of the system is.

It is found that the soil temperature is lower than initial temperature after one year. As the occupancy rate increases, the building load gradually rises. As a result, the outlet temperature continues to soar, with it the cooling tower opening time increases. It shows that the heat discharge of buried pipe is greater than that its heat absorption. This phenomenon is beneficial to the summer operation of the heat pump in the next year. It can be seen from table 2 that both strategy 2 and strategy 3 can control the outlet temperature of buried pipe within 33 °C. The cooling tower has played a good role in peak shaving. Among them, Strategy 2 has a lower soil temperature rise and a lower total energy consumption than Strategy 3, which has the highest operating efficiency.

5. Conclusion

The research on the operation strategy of hybrid ground source heat pump system under different occupancy rates is very important for energy saving of air conditioning system in hot summer and cold winter area. Operation conditions of full load of office and business. This article focuses on the research of comprehensive buildings, which is based on the premise of office and commercial full-load operation. Residential buildings with specific occupancy rates of 30%, 50%, 70%, and 100% are studied as examples to obtain the best control strategies for different occupancy rates.

- When only using the buried pipe for summer cooling, winter heating and providing domestic hot water throughout the year, the soil heat accumulation is serious. The soil temperature rises by 2~3 °C after one year of operation.
- In the case of low occupancy rate (30% and 50%), the ground source heat pump system uses cooling towers to dissipate heat during the low summer load (June and September). In addition, it uses the buried pipe to dissipate heat in July and August and absorb heat in winter. The method has the best operating control effect.
- In the case of high occupancy rate (70% and 100%), the ground source heat pump system adopts temperature difference control: the cooling tower is turned on when the outlet temperature of the

buried pipe is 2 °C higher than the wet-bulb temperature at the corresponding moment, and the buried tube heat exchangers are used at the rest of the time, which is the optimal operation control.

- With the increase of the occupancy rate, although the total energy consumption of ground source heat pump systems is rising, the energy consumption per unit area is decreasing, and the advantage of ground source heat pumps is highlighted.

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