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Effective Design and Operation of Large-scale Hybrid Ground Source Heat Pump System: A Case Study of Hubei Province library

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ABSTRACT

The added complexity of hybridizing a ground source heat pump system (GHPS) with auxiliary cooling equipment in large buildings could bring technical challenges in design and operation stage. A hybrid GHPS in a large public building named Hubei Province library in China's Wuhan was taken as an example. Considering the effect of the balance of air conditioning load demands on the heat transfer characteristics of large-scale buried pipe groups, the design measures and operation strategies of large-scale hybrid GHPS were analyzed. On the basis of the monitoring data after operating, the impact on unit performance, system energy efficiency, economy and environment were studied to demonstrate the effectiveness for the hybrid GSHPs. Further improvement measures were proposed based on the design and operation experience, which can help to achieve the reliable utilization of hybrid GHPS in buildings.

1. INTRODUCTION

The world faces the challenges of energy shortages and climate change. At present, China is the largest emitter of greenhouse gases over the world and a consumer of fossil resources (Wu et al., 2020). In order to achieve carbon neutrality by 2060, carbon emission reduction in China's construction sector was a key focus (Tan et al., 2018). China's construction sector has accounted for 30% of total emissions. And with the increasing degree of urbanization, China's annual new construction area would be about 2 billion square meters, which meant that greenhouse gas emissions in the construction sector would continue to climb further (Koondhar, et al., 2018; Zhang, et al., 2021). For the winter heating in Northern China, coal-fired warming has been shown to cause significant damage to the environment (Zhang et al., 2020). As a utilization technology of shallow geothermal energy, the ground source heat pump (GSHP) technology can simultaneously meet cooling demand and heating demand in buildings, so it should be considered a crucial measure to decarbonize the building sector (Ren et al., 2018).

Ground-source heat pump technology has been widely used in China (Zhang et al., 2022). In 2017, China's had installed the capacity of ground source heat pumps up to 2/3 of the global total, which ranked first place in the world (IEA, 2021). In January 2017, the Ministry of Construction of the People's Republic of China released the first special plan for geothermal energy development, “the 13th Five-Year Plan for the Development and Utilization of Geothermal Energy”, which upgraded the development of geothermal energy to the level of national energy strategy and greatly promoted the large-scale application of GSHP projects (Hou et al., 2018). By the end of 2020, the building area of heating and cooling of GSHP systems using shallow geothermal energy had reached 5.58×10^8 square meters (China Renewable Energy Development Report, 2020), the GSHP engineering project shows the characteristics of large-scale and upsizing (Yu et al., 2012). For example, Chongqing Jiangbei CBD had built a district cooling and heating system based on surface water source heat pump systems using Jialing River water resources and ice storage technology, which was divided into 2 energy stations for heating and cooling of the surrounding buildings of 6.52×10^6 square meters (Wang et al., 2014). Daxing International Airport used 10,680 buried pipes inserted into the soils to serve the surrounding buildings of 2.48×10^6 square meters (Dong, 2021).

In recent years, GSHPs had been generally used in building energy utilization systems, but in engineering applications, they were affected by the type of ground source heat pump, buried pipe configuration, soil conditions, building load characteristics, equipment selection, system utilization scale, local climate, etc., so there were high initial cost and poor design effect to conduct the certain limitations (Kwesi et al., 2017; Xi et al., 2017; Qian et al., 2014; Choi et al., 2018; Li et al., 2019; Ma et al., 2017). Therefore, it was necessary to reduce costs and improve the overall efficiency of GSHPs through optimized design (Lazaros et al., 2018). Therefore, based on the air conditioning load characteristics of Hubei Provincial Library, the design strategy of the GSHP system from the aspects of buried pipes layout, auxiliary heat removal equipment setting, systems control and so on. The design reliability and energy efficiency of the GSHP will be verified through field testing. Please be very careful to use styles throughout the document, so that all the papers will have a similar appearance.

2. PROJECT DESIGN

2.1 Building Load Characteristics

As a landmark key cultural project, the library located in Wuhan, Hubei Province should be required to build the air-conditioning system reflecting the characteristics of green, ecological, efficient and environmentally friendly. The library had a total construction area of 100,523 square meters and an air-conditioned service area of 79,699 square meters including eight floors above ground and two floors underground. The design temperature was controlled at 26°C~27°C in summer and 18°C~20°C in winter. The humidity was controlled at 50%~60% in summer and 35%~40% in winter.

Based on the climatic conditions of Wuhan City and the temperature and humidity indicators of each room, the cooling and heating load of air conditioning throughout the year was shown in Figure 1 according to the thermal parameters of the envelope structure.

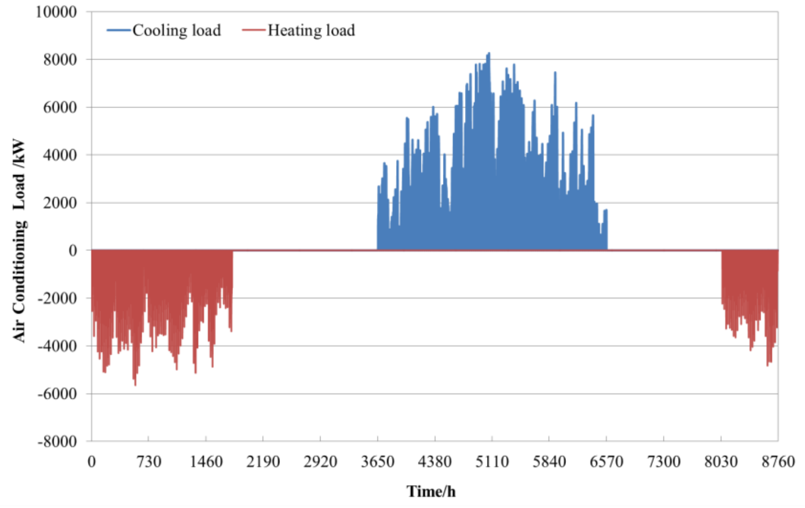

Figure 1: Hourly distribution of building cooling and heating load throughout the year

The annual peak cooling load was 8205kW and the peak heating load is 5499kW, which showed that the maximum cooling load was 1.5 times the maximum heating load. The cumulative cooling load for the whole year was 5269975kWh (June 1 to September 30), and the cumulative heating load was 1979747kWh (December 1 to March 15). It was 2.66 times the cumulative heat load, and its imbalance was quite obvious.

2.2 Cooling and Heat Source Systems

The centralized cold and heat source for the library was provided by combining the Hybrid GSHP system with the ice cold storage system, in which the cooling source was provided by the GSHP system combined with ice storage system and the heating source was provided by the GSHP system. The heat extraction and heat removal of heat pump unit adopted the method of buried pipe as the main and the cooling tower as the supplement, as shown in Figure 2.

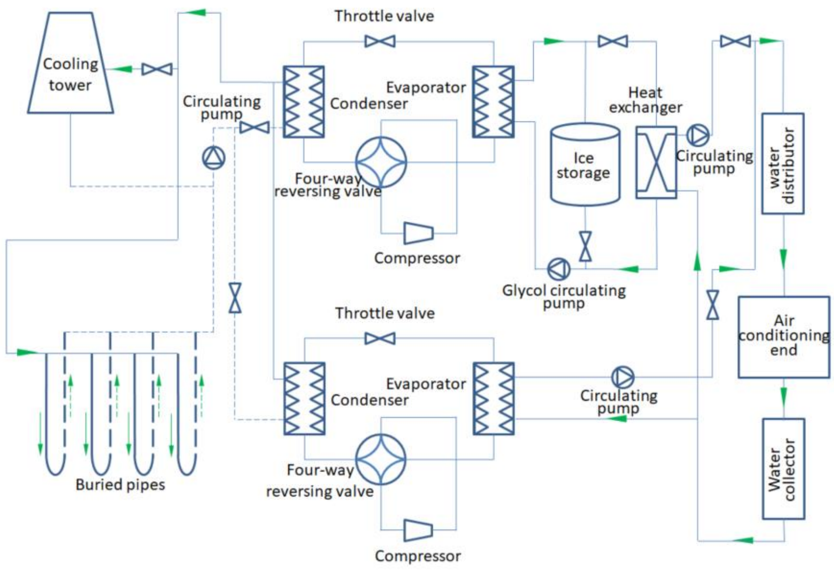

Figure 2: Schematic diagram of the Hybrid ground source heat pump system

The energy station was set up on the first basement under the ground. Four three-condition screw heat pump units and one screw-type high-temperature heat pump unit with full heat recovery were configured according to the refrigeration condition 8050kW and the heating condition 4600kW (Base-load heat pump unit). The performance parameters of the heat pump units and circulating water pump were shown in Table 1 and Table 2.

Table 1: Performance parameters of heat pump units

Device name	Working conditions	Refrigeration to heat /kW	Evaporator temperature /°C	Condenser temperature /°C	Input power /kW	COP value

Three-condition screw-type heat pump (Evaporator side.) 25% glycol).	refrigeration	1443.3	6/11	32.5/37	265.9	5.43
	Ice making	919.4	-2.6/-6	32.5/37	253.9	3.62
	Heating 1	1626.2	10/6	40/45	319.4	5.09
	Heating 2	1459.8	7/3	40/45	322.9	4.52
Screw-type high-temperature heat pump (Total heat recovery)	refrigeration	367.9	7/12	32.5/37.5	67.6	5.44
	Heating	395.9	10/6	40/45	79.9	4.95
	Full heat recovery	361	10/6	50/55	101.6	3.55

Table 2: Performance parameters of water pump devices

Unit	Flow /m^3/h	Water raising capacity /mh2o	Power /kW	Type	Set number
Circulating water pump for air conditioning end	315	36	45	NL150/315-45/4	4
Circulating water pump for ground source side	360	37	55	NL150/400-55/4	4
Circulating water pump for ground source side	75	38	15	IL80/170-15/2	2
Glycol circulating pump	310	37	45	NL150/315-45/4	4
Heat recovery circulating water pump	80	39	15	IL180/170-15/2	2

The ice-storage device used 9 sets of non-completely frozen metal ice storage coils. Each ice-storage had the capacity of 920RTh. The ice-storage rate was up to 39%, storing the ice during electrical low peak hours from 0:00 to 7:00 at night.

In the inner zone or the upper part of the hall that needed to be cooled all year round, air conditioning chilled water of 12/7 °C was provided by a special plate heat exchanger in the energy station.

At night in winter, the heat pump unit with fully heat-recovery operated under air conditioning heating conditions to meet the heating needs of a small part of the library.

The base-load heat pump with the fully heat recovery can provide free sanitary hot water during cooling in summer. The full heat recovery can be taken as an auxiliary heat source for solar sanitary hot water systems in winter.

The buried pipe adopted the combination of vertical drilling buried pipe and the engineering pile buried pipe in. The cooling tower was a closed cooling tower, which not only reduced the initial investment cost of the buried pipe but also avoided the serious thermal imbalance in the soil.

2.3 Buried Pipe Heat Exchange System

Before the design of buried pips, the engineering geological investigation and geothermal physical property testing should be carried out according to the "Ground Source Heat Pump System Engineering Technical Specification"(GB 50366). A total of 3 test boreholes (SK1, SK2, SK3) was drilled, in which the soil geological distribution was shown in Table 3. The upper drilling backfill was raw stock plus cement mortar, and the upper part was cement mortar plus 10% bentonite.

Table 3: Soil geological distribution

Code	Geotechnical name	Geotechnical grade	geotechnical formation /m			Drillability /m/h
			SK1	SK2	SK3	
1	Mixed filling	II	6.7	4.5	6.4	1.2 ~ 4.5
3	Powdery clay	I	2.3	4.0	1.8	7
4	Silty fine sand	I	4.1		3.6	6
5	Silty clay, clay	I	9.9	10.8	11.8	6.5

6	pebble	VII	3.4		2.3	0.45
8.1	Strongly weathered silty mudstone	IV	2.1		1.4	1.3
8.2	Weathered silty mudstone	IV	17.2	24.5	17.9	1.15
8.3	Slightly weathered silty mudstone	V	49.3	51.2	50.8	1
Total well depth/m			95	96	96	
Estimated well formation time/hours			78	76	77	

The initial soil temperature in situ of 3 testing boreholes was 18.9°C. The soil thermal property test was shown in Table 4.

Table 4: Soil thermal properties

Borehole name	Buried form	Depth /m	Flow rate /m^3/h		Average inlet/outlet water temperature /℃		Average thermal conductivity /W/(m.k)
			Heat removal	Heat extraction	Heat removal	Heat extraction	
SK1 well	Double U	90	1.05	1.12	36.2/32.4	8.6/11.6	2.15
SK2 well	Single U	90	1.04	1.10	36.9/33.8	7.9/10.7	2.04
SK3 well	Single U	90	1.07	1.04	37.0/33.8	9.7/12.8	2.1

According to the thermal physical property test data above, the soil thermal conductivity was 2.1W/m.k. The heat removal of the double U-shaped buried pipe was up to 60W/m (Borehole depth), and the heat extraction was up to 35W/m (Borehole depth). The heat removal of the W-type buried pipe in the engineering pile was up to 75W/m (Pile depth), and he heat extraction was up to 50 W/m. All of these can be used as the calculation basis for the design of the buried pipes.

The buried pipe capacity was calculated according to the winter heat extraction, and the insufficient heat removal in summer can provided by the cooling tower heat release and unit heat recovery to achieve the thermal balance in the soil.

The vertical buried pipe was a double U-shaped pipe with De25 HDPE, which were distributed around the museum. The design effective depth was 106m. The drilling spacing was 5m×5m. The drilling diameter was 150mm. The vertical buried pipe group was divided into 4 zones, such as Zone A, Zone B, Zone C and Zone D. There were a total number of 848 boreholes and a total depth of 89888m. The engineering pile was a mud retaining borehole pile with a diameter of 800mm and an effective pile depth of 19m. The two adjacent W-type pile buried pipes were connected in series to form a double W-shaped loop. A total of 104 loops were formed in 208 pile buried pipes in Zone E, and their distribution was shown in Figure 3.

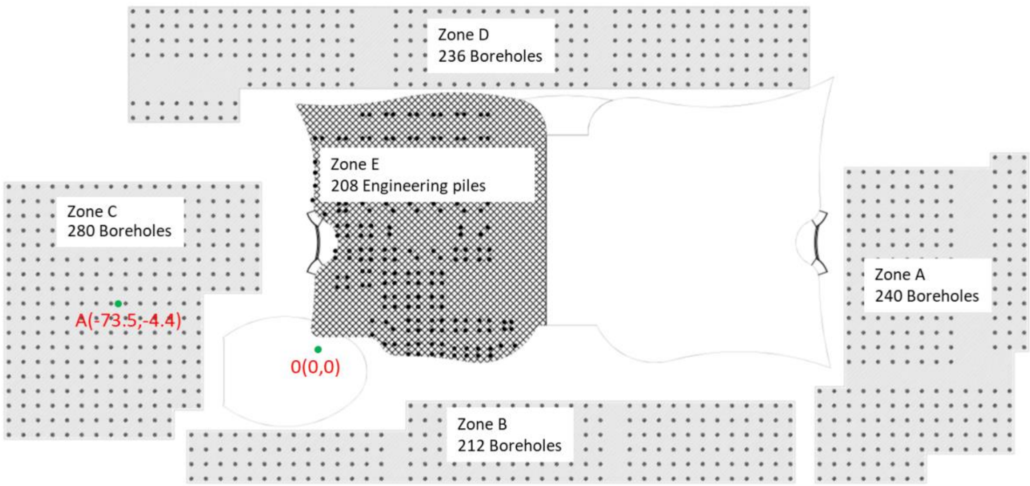

Figure 3: Distribution of buried tube heat exchangers

According to the site situation, the five buried pipe zones were divided into 68 supply and return water loops. The inlet water manifold of each secondary water distributor was equipped with a static flow balance valve to ensure the hydraulic balance effect of each loop. The two ends of each buried pipe were connected to the collector and distributor in the corresponding supply and return loops. The reversed return system was adopted. The horizontal header design of buried pipe adopted a single-well to single-well connection mode to minimize the number of joints of underground buried pipes, where it would only cause the damaged buried pipe to be unusable but the others can still use no matter which drill was damaged.

2.4 Cooling Tower Capacity

According to the obvious imbalance between heating load and cooling load of the air conditioning load in the library, the closed cooling tower was used as the auxiliary cooling equipment for balancing. The cooling tower was located in the outdoor green area on the east side of the building, close to the energy station with a semi-underground setting. Aiming at the cooling tower heat removal priority operation mode, the operation under the cooling conditions was statistically analyzed, as shown in Table 5.

Table 5: Detailed annual total heat dissipation of the cooling system

Total cooling load in summer /10^4kWh	Ice storage capacity at night /10^4kWh	Heat dissipation of cooling tower /10^4kWh		Load of the heat pump units during daytime /10^4kWh	Total heat dissipation of buried pipe during /10^4kWh	
		at night	during daytime		at night	during daytime
527	300	283	211	227	100	59

It can be seen that the total heat removal of the air conditioning system to the soil through the buried pipe system in summer was 1.59×106 kWh, and the total heat extraction from the soil in winter is 1.584×106 kWh. The imbalance rate was within 10%, which can ensure the thermal balance of the earth soil throughout the year. The cooling capacity of the cooling tower set was calculated to be 3550kW. Considering that the capacity of the cooling tower should meet the number of heat pump units, the final total design cooling capacity of cooling towers was 4100kW, which can fully meet the cooling needs of the units.

2.5 Operational Control Strategies

Considering the complexity and hysteresis of the GSHP system, the fuzzy control system was used to optimize the operation with the closed cooling tower and the buried pipe system in parallel, as shown in Figure 4.

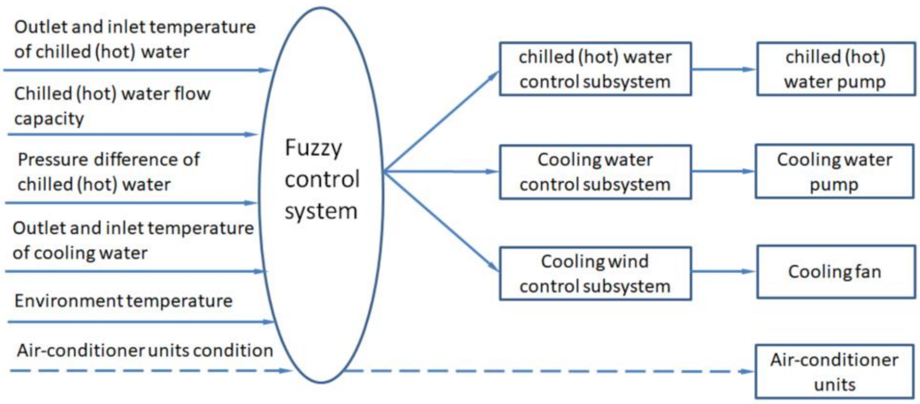

Figure 4: Fuzzy control mechanism of ground source heat pump system

According to the ambient temperature, air conditioning load, cooling water pump characteristics, cooling tower efficiency characteristics, and unit efficiency characteristics at that time, the fuzzy control system can performs fuzzy reasoning to calculate the cooling water flow rate (circulating water in buried pipes and cooling towers)corresponding to the optimal conversion efficiency of the system, and controlled the speed of the cooling water pump to dynamically adjust the optimal flow of cooling water, so as to ensure that the central air conditioning system was running at the best efficiency all the time.

3. RESEARCH METHODS

3.1 Numerical Simulation Analysis

In the hot summer and cold winter region, the heat removed into the soil in summer was greater than the heat extracted from the soil in winter, resulting in a continuous increase of the soil temperature around the buried pipe. So a rise in the circulating water temperature in the buried pipe could greatly reduce the performance of the heat pump unit. Therefore, it was necessary to analyze the soil thermal balance. Generally, the excessive heat can be removed into the air by configuring the cooling tower to solve the problem of soil heat imbalance. In this paper, the soil temperature change regularity under the heat removal condition of the buried pipe alone and the buried pipe combined with cooling tower will be compared and analyzed.

Due to the zonal arrangement of buried pipes, the thermal interference among the buried pipe zones was smaller. 280 buried pipes in Zone A were selected as the simulation calculation area, as shown in Figure 3.

In the process of heat transfer in soil, the general calculating equation for water, solid and air was set in.

$$\frac{\partial\ (\rho\varphi)}{\partial t} + div(\rho\vec{v}\varphi) = div(\Gamma_\varphi grad\varphi) + S_\varphi \tag{1}$$

Where φ was general variables, such as temperature T, velocity u, v, w, turbulence energy κ, turbulence dissipation rate ε, etc.; ρ was the density of the medium; $\vec{V}$ was a velocity vector; Γ was the diffusion coefficient; S was the source term.

The soil thermal property parameters and vertical buried pipe dimensions were shown in Table 6.

Table 6: Soil thermal property parameters and buried pipe size

Parameter	Value
Soil density soil specific heat	3.4×10^6 J/m^3.kg
Soil conductivity	2.1W/m.k
Initial soil temperature	18.9℃
Pipe diameter	25mm
Borehole diameter	170mm
Shank spacing	12mm
Buried depth	100m

The accuracy and reliability of this numerical calculation model had been verified and compared with the experiment testing data in previous studies (Yu et al., 2012).

3.2 Field Testing

As a demonstration project for renewable energy applications in buildings, the GSHP system project of Hubei Provincial Library was measured and evaluated in accordance with the test requirements of the "Renewable Energy Building Application Engineering Evaluation Standard" (GB/T50801-2013) through a number of indicators.

The energy consumption changes of the GSHP system under the alternating conditions of intelligent fuzzy control mode and conventional mode were tested within 4 days. The energy conservation of the intelligent fuzzy control system was compared and analyzed.

The energy management system was used to monitor the operation process of the GSHP system and obtained the annual operation data. Annual operation performance of the GSHP system was analyzed.

The test contents and instruments are shown in Table 7.

Table 7: Test contents and instruments

The test contents	Test plan	Test instruments	Accuracy
Indoor temperature	Every 0.5 hour	Temperature automatic recorder	±0.5℃
Indoor humidity	Every 0.5 hour	Temperature and Humidity automatic recorder	±3%RH
Power consumption of equipment	Every 12 hour	Electric meter	±0.5%
Supply and return water temperature	Every 0.5 hour	Platinum resistance thermometers	±0.2℃
Supply and return water flowmeter	Every 0.5 hour	Ultrasonic flowmeter	±1%

3.3 Performance Analysis

The performance coefficient of the unit was calculated according to the test results.

$$COP = \frac{Q}{N_i} \tag{2}$$

Where COP was the performance coefficient of the unit during the test period; Q was the average cooling or heating capacity of the unit during the test period, kWh; N_i was the total consumed power of the unit during the test period, kWh.

The cooling or heating capacity of the unit during the test was calculated as follows.

$$Q = V\rho c\Delta t / 3600 \tag{3}$$

Where V was the average flow rate on the user side of the heat pump unit, m^3/h; Δt was inlet and outlet water temperature difference on the user side of the heat pump unit, °C; ρ was average water density, kg/m^3; c was average constant pressure specific heat, kJ/kg.k。

The energy efficiency coefficient of the heat pump system is calculated according to the test results as follows.

$$COPs = \frac{Q}{N_i + \sum N_j} \tag{4}$$

Where COP_s was the performance coefficient of the system during the test period; $\sum N_j$ was the total consumed power by the pump during the test period, kWh.

4 RESULTS AND DISCUSSION

4.1 Soil Thermal Balance Analysis

According to previously analysis, whether it was reasonable to use cooling tower auxiliary heat dissipation will have a great impact on the balance between heat extraction and heat removal in the soil. The monitoring point temperature variation in the soil under the conditions with cooling towers and without cooling towers were shown in Figure 5 over a 4-year period.

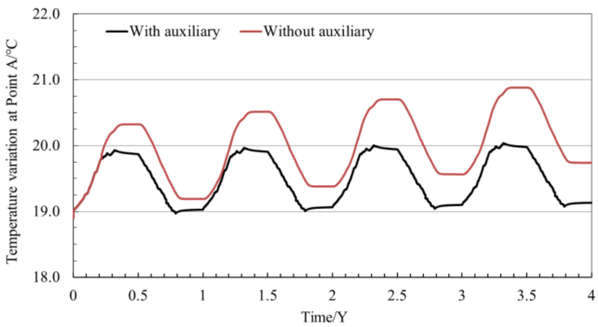

Figure 5: Soil temperature change under cooling and heat load balancing conditions

As can be seen from Figure 5, the soil temperature at various points showed annual cyclical fluctuations with the regulation of first rise, then recovery, again descend and finally up due to alternate cooling and heating of the ground source heat pump system, which showed an overall upward trend of temperature. When the cooling tower was closed, the cumulative cooling and heating load imbalance rate can reach 160%, so that the cumulative soil temperature rise was up to 2°C within the 4-year operation period. The temperature increase was getting higher and higher in later years. After the cooling tower was opened, the cumulative load imbalance rate was within 10%, so the average soil temperature rose by 0.9°C after 4 years. The degree of soil temperature rise was gradually less and the increase tended to be stable, which can ensure the heat exchange efficiency of the buried pipes to meet the design requirements.

It can be seen that when the heat exchange load of buried pipes was almost balanced, the annual soil temperature rise and temperature drop were roughly equal, which can ensure the stable operation of the GSHP system, so the design strategy and operation control of buried pipe group was very important.

4.2 Field test analysis

4.2.1 Room Temperature and Humidity

The large hall with a large space and the reading room on the first floor with more people were selected as typical rooms for temperature and humidity measurement, and compared with the outdoor weather conditions. The data of typical daily temperature and humidity under the cooling condition were shown in Figure 6.

Compared with the wide range of fluctuations in outdoor temperature, the temperature in the hall and reading room was basically maintained between 25 °C and 27 ℃, which can meet the design requirements of the "Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings" (GB50736-2012). However, the temperature of the reading room was generally higher than the temperature of the hall because the reading room on the first floor was for children with high-density personnel distribution. The temperature variation was not large, basically maintained at 25.4°C~25.9°C. But the hall personnel flow was larger, so the temperature variation amplitude was 2℃。

As can be seen from Figure 6, air humidity increased as the height of the testing point position increased. In the hall, the humidity at the 2m position was the highest and the humidity at the 20m position decreased. The lowest humidity occurred between 1:00 and 2:00 p.m., when the indoor temperature rose and more moisture evaporated.

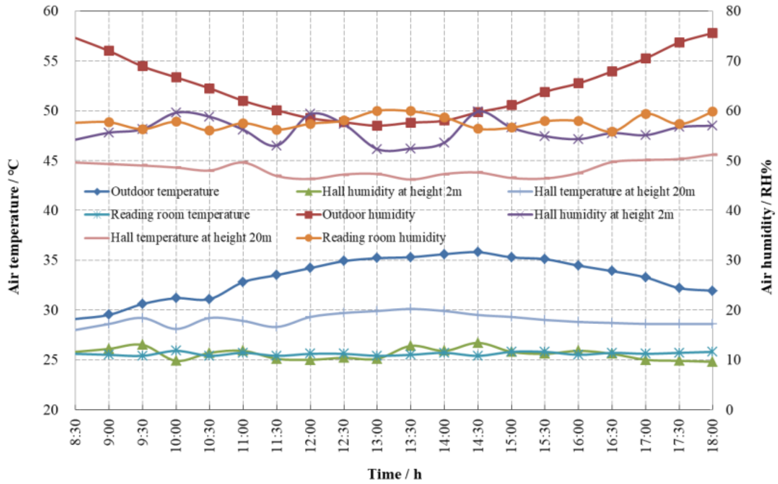

Figure 6: Typical daily indoor and outdoor temperature and humidity variations in the library

4.2.2 Inlet and Outlet Water Temperature of Buried Pipes

The water temperature variation at the inlet and outlet of the buried pipe reflected the heat transfer effect of the buried pipe in the soil, which also greatly affected the operating performance of the heat pump units. So the water temperature variation was the focus of the GSHP system during operation. Figures 7 and 8 showed the water temperature variation of buried pipes from January 1 to December 31 in a typical year.

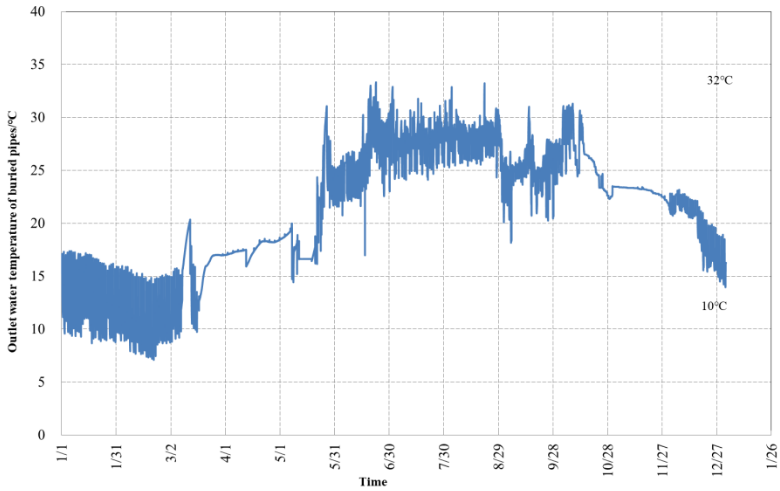

Figure 7: Change in outlet water temperature of buried pipes

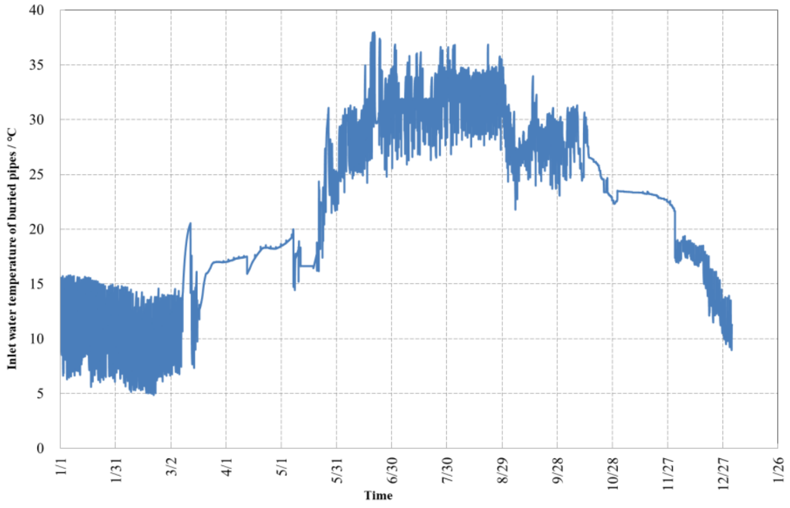

Figure 8: Change in inlet water temperature of buried pipes

It can be seen from the figures that the inlet and outlet water temperature of the buried pipe was always varying, which was subject to the influence of the opening and closing time of the library and the alternating of heating, cooling and recovery. All these affected the heat transfer performance of the buried pipe. In summer, the water temperature at the outlet of the buried pipe was basically maintained below 37 ℃, which can effectively improve the operating energy efficiency of the heat pump unit compared with the cooling tower. In winter, the water temperature at the outlet of the buried pipe was basically maintained above 10 ℃, which can effectively ensure the cooling effect of the heat pump unit. However, due to the continuous operation of the GSHP system, the water temperature at the outlet of the buried pipe could sharply reduce or increase in some time, which was not conducive to the efficient operation of the ground source heat pump unit. The operation strategy of the ground source heat pump system can be adjusted according to the change of water temperature.

4.2.3 Fuzzy Control Energy Saving

Four days with basically the same outdoor meteorological conditions and library opening hours were selected for the variable flow and constant flow alternate operation test (such as fixed frequency operation on August 6 and August 8, variable frequency operation on August 7 and August 9), The energy conservation of the intelligent fuzzy control system was analyzed, as shown in Figure 8.

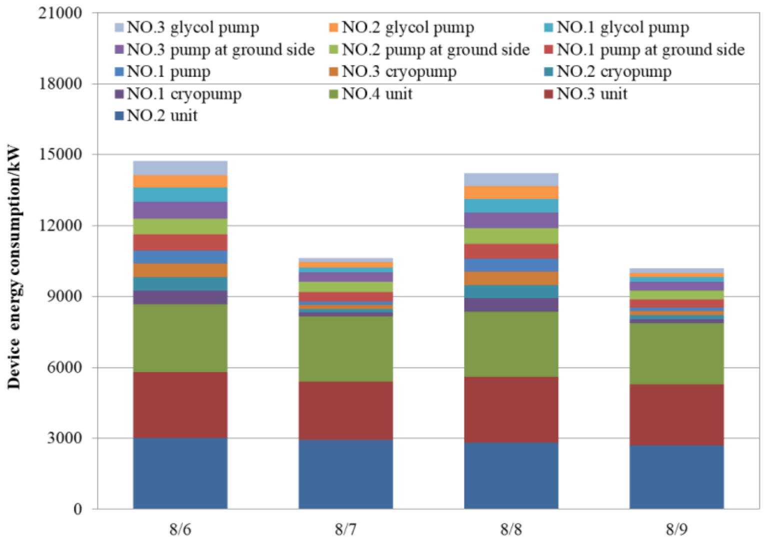

Figure 9: The GSHP system energy consumption with fuzzy controls in various operation conditions

From the analysis of the test data for the operation of the intelligent fuzzy control system of the library, the following conclusions can be drawn:

1) The intelligent fuzzy control system operated safely, stably and reliably. It can automatically track the operation of the terminal air conditioning load in a timely and accurate manner. The related indicators can meet the technical requirements of the equipment, which ensured the optimized safe and efficient operation of the GSHP system.

2) After switching from fixed flow operation to variable flow operation, the energy consumption was greatly reduced. There was a significant energy conservation g effect, in which the energy conservation rate of the units was 5.92% and the energy conservation rate of the auxiliary unit was 59.7%. The comprehensive energy conservation rate can reach 28.06%, saving 4059kWh per day.

3) An optimized operating strategy can be developed according to the actual operation situation to obtain more energy conservation space.

4.2.4 Energy efficiency of ground source heat pump systems

Some indirect measurement methods according to the actual operating conditions the energy station were chosen to measure. NO.1 heat pump unit of the energy station was selected to test the performance coefficient of the unit under cooling and heating conditions, as shown in Table 8 and Table 9.

Table 8: Performance test data of heat pump unit

Operation conditions	Flow rate /m^3/h	Temperature difference /℃	Density kg/m^3	Specific heat capacity /J/(kg.℃)	Cooling capacity /kW	Unit power /kW	Unit COP
Cooling	222.2	6.5	999.1	4.186	1669.4	284.6	5.86
Heating	324.3	4.2	987.4	4.186	1563.6	303.6	5.15

Table 9: Performance test data of ground source heat pump system

Operation conditions	Cumulative cooling capacity /kWh	Heat pump unit cumulative power consumption / kWh	The cumulative power consumption of the pump / kWh	Cooling tower power consumption / kWh	System COP
Cooling	15300.44	1898.6	680.48	120	5.67
Heating	21200.68	3125.1	1219.9	0	4.88

Under the cooling condition, the average supply water temperature on the user side of the unit is 12.2℃ and the average return water temperature was 18.7℃. So the average temperature difference was 6.5℃. The average water flow rate on the user side of the unit is 222.2m^3/h, and the consumed power of the unit was 284.6kW. The performance coefficient of the heat pump unit was up to 5.86. The performance coefficient of the GSHP system was up to 5.67.

Under the heating condition, the average supply water temperature on the user side of the unit is 46.3℃ and the average return water temperature was 42.1℃. So the average temperature difference was 4.1℃. The average water flow rate on the user side of the unit is 324.3m^3/h, and the consumed power of the unit was 303.6kW. The performance coefficient of the heat pump unit was up to 5.15 for cooling and was up to 4.88 for heating.

The operating performance coefficient for cooling and heating conditions was above the rated index of the unit, which may be that the heat transfer effect of the buried pipe was in a good state the fuzzy control system was configured. Correspondingly, the operating energy efficiency of the GSHP system also exceeded the highest level of 3.9 in the national standard "Renewable Energy Building Application Engineering Evaluation Standards" (GB/T50801-2013).

The incremental cost of the library project is 161.75¥/m^2, and the annual conventional energy conservation was 615.8tce. If the average standard coal consumption in the central China power network in recent years was 0.31kg/kWh, the project cost-efficiency ratio was 8.2¥/kWh. CO_2 emission reduction was 1521.1t in one year, SO_2 emission reduction was 12.3t in one year, and dust emission reduction was 6.2t in one year r for the library. There was a good economic and social benefit.

5. CONCLUSION

(1) From the imbalance between cooling and heating load of the library building, the hybrid GSHP system with cooling tower was used for cooling and heating combined with ice storage technology and fuzzy control technology, which can achieve to save initial investment and reduce operating costs.

(2) According to the annual cumulative load difference under cooling and heating conditions, the capacity and operation strategy of the cooling tower were determined, which can effectively reduce the soil heat imbalance and ensure the heat transfer capacity of the buried pipe through the simulation and measured data analysis.

(3) The temperature and humidity of the library met the requirements of comfort air conditioning standards through the typical testing in cooling condition. However, stack effect in winter can result in higher temperatures and lower humidity on the upper floors to reduce the level of comfort. How to ensure the thermal comfort of high-rise rooms through design and operation matching needed to be further studied.

(4) The fuzzy control system was used to optimize the operation of the GSHP system, which can greatly reduce energy consumption. The comprehensive energy conservation rate of the system can reach 28.06%, saving a total of 4059kWh electricity every day.

(5) The heat pump unit performance coefficient was 5.86 and the system performance coefficient was 5.67 for cooling and they were 5.15, 4.88 for heating, respectively, which was better than Level 1 requirements of the national standard "Renewable Energy Building Application Engineering Evaluation Standard" (GB/ T50801-2013).

(6) The energy conservation for the library's GSHP system was 615.8tce. The annual emission reductions of CO_2, SO_2 and dust were 1521.1t, 12.3t, 6.2t, respectively. The project cost-efficiency ratio was 8.2 ¥/kWh. The GSHP project of the library had a good effect on energy conservation and emission reduction to contribute to the protection of the local environment.

(7) For the GSHP system with large-scale buried pipes, there inevitably appeared the thermal interference among buried pipe groups after several years. How to optimize the operation through the rational layout and zoning of the buried pipes needed to be further analyzed and designed combined with the load variation characteristics and functional requirements of the buildings.

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