

Designed and simulation of the ground source heat pump system used in archives

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ABSTRACT: The Ground Source Heat Pump (GSHP) system used in Shanghai Minhang archives is the first archives project using the GSHP system in China. This archives covers with an area of 8000 m², and the peak load in summer is 1000 kW, which in winter is 700 kW. To abate the inference made by difference between the heat emanated to the soil in summer and the heat absorbed from the soil in winter, this project has used the heat recover technique, and the recovering heat quantity is 495 kW with calculating. According to the peak load and the located situation, the underground exchanger of this GSHP system is composed with 280 holes in which there are single U pipes with 80 m deep, and the distance between each hole is 4 m. We divided the 280 holes to 10 sections for the purpose of adjustment when the load is low. Two heat pumps were chosen for this project. Besides satisfying the load in summer and winter, the heat pumps will supply hot water for daily use in the whole years. Because of the specialization of the archives which demands a steady temperature and humidity, the heat pumps have to run all the years, but we can use only one heat pump in low load days like spring and autumn. Based on this project, the paper simulates the GSHP system with the actual condition. The result of simulation shows that it should reasonably increase the deepness of the underground pipes if allowed, and the heat recover technique can alleviate the heat store in soil without influencing the performance of the heat pump.

Keywords: Files saving; Ground source heat pump; Underground exchanger; Pipe deepness; Heat recover

Nomenclature

c	specific heat($\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$)
COP	heating coefficient of performance
F	area(m^2)
h	specific enthalpy($\text{kJ}\cdot\text{kg}^{-1}$)
k	Coefficient of heat exchange($\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$)
m	mass flow rate($\text{kg}\cdot\text{s}^{-1}$)
t	temperature($^{\circ}\text{C}$)

Subscripts

a	Air
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c	condenser
ci	input of condenser
co	output of condenser
e	evaporator
eafter	after the cooling coil
efront	in front of the cooling coil
ei	input of evaporator
eo	output of evaporator
g	underground heat exchanger
1	after the evaporator
2	in front of the condenser
3	after the condenser
4	in front of the evaporator

1. INTRODUCTION

Now there are more than 40 billion square meter buildings in cities and towns in China, which 95 percent of are high energy cost building. The building energy has taken 28% of the whole society energy cost. The archives are belong to the high energy cost building, and have a higher request in the indoor environment than other government office buildings. According to the <Archives design code> issued by China national archives in 2000, the temperature in archives must be 14°C to 24°C and the relative humidity in archives must be 45% to 60%, and once the temperature and the relative humidity have been decided, they should not be beyond $\pm 2^{\circ}\text{C}$ and $\pm 5\%$ respectively in a whole day. For these request, the cartularies have a high energy cost in air conditioning, and have potential in saving energy. It's efficient to saving energy and environmental conservation to use reproducible energy sources which is an efficient way to solve the problem of high energy cost in buildings.

Ground source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs), are attractive alternatives for both conventional heating and cooling systems because of their higher energy efficiencies [1,2]. In a comprehensive study conducted [3], it is reported that GSHPs have the largest energy use and installed capacity according to the 2005 data, accounting for 54.4% and 32.0% of the worldwide capacity and use. And compared with other air conditioning mode, the GSHPs have a more stable source. Due to the heat capacity of soil, ambient air temperature variations are directly reflected only on the surface soil temperature, their effect being reduced at deeper layers. As a consequence, soil temperature is stabilized at the yearly average air temperature after the depth of about 10 m [4,5].

As the society developed, the personal files have been kept on from papers in the past to computers now, but the paper files have their characteristic as the only originality, the un-replace voucher, the intimacy of content, the stable security and the immediacy in using, so they are also very

important to save. The project of GSHP introduced in the paper is the first archives in China using the GSHP system for air conditioning, and there are few archives projects in the whole world using the GSHP system.

2. THE GENERAL SITUATION OF THE PROJECT

The Shanghai Minhang archives is located in Zhuanqiao town in Shanghai Minhang area, which covers with an area of 8000m². It's divided to tow parts, one is office building with an area of 2000 m², and the other is archives house with an area of 6000 m².

The paper files are easily influenced by the air in the archives house. It's confirmed that the air environment is the most important factor to the paper files saving. If the temperature and the humidity are too low, the files could be easily broken when we use them and if the temperature and the humidity are too high, the chemic change would happen in files which would break the files. So the air conditioning is very important to the files saving and is necessary in a whole year.

The designed peak load in summer and winter is showed in table 1. Because of the imbalance of load between summer and winter, the heat recover technique has used in the project. A part of the heat that would emanate to the soil in summer will be taken to the AHU according to the heat recover technique. And the recovering heat quantity is 495 kW with calculating.

Table.1: The design load of the system

type	Cooling	Heating
	load/kW	load/kW
Office building	240	199. 5
Archives house	760	500

2.1 The design of underground heat exchanger

For the underground heat exchangers, vertical borehole configuration is usually preferred over horizontal trench systems because less ground areas are required. The vertical ground heat exchanger consists of a number of boreholes, each containing a U-tube pipe. The depth of the borehole ranges usually between 40 and 150 m, and the diameter 0.075–0.15 m [6]. In Shanghai, the soil underground is mainly clay with grit in it, and the soil is full of water, so it's hard to bury the pipes to a very deepness place. The holes are not more than 100m deep in general in Shanghai.

According to the data that tested in locale, we can calculate that the heat exchange of the hole is 47.8 W/m, and we have make an experiment in locale and also got the result. Base on the result of the experiment and the condition of the locale, the underground heat exchanger is composed with 280 holes in which there are single U pipes with 80 m deep, and the distance between each hole is 4 m. We divided the 280 holes to 10 sections in which the holes were divided to 4 parts, and there are 7 holes in each part. Fig. 1 illustrates the distribution of the underground heat exchanger. We can only see the sixth section was divided to 4 parts in the figure, and the other 9 sections are the same to the sixth in fact. And then we can easily adjustment when the peak is low.

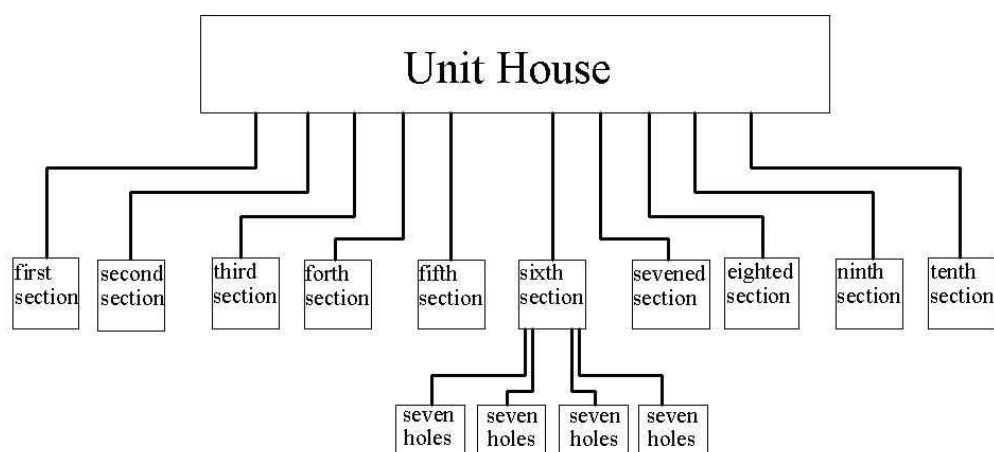


Fig.1: The distribution of underground pipes

2.2 The heat pump

The project use two ground source heat pumps with heat recover system, whose type are RTHDB2D2C2. The pump's parameter is showed in table 2.

Table.2: The parameter of the heat pump

Capaci ty/kW	Evaporator temp/°C	Recover heat/kW	Condenser temp/°C
543	7~12	580	45~40

This pump can make cool and heat in the same time, so the pump could supply hot

water for living when it's supplying cool in summer. Fig.2 illustrates the principle of the heat pump. Taking summer for example, when the pumps run, the condensers will supply hot water a part of which is used for heat recover and the other for living. When the temperature of hot water is over 45°C, the valve connected the underground exchanger and the condensers will be open so that the condensational temperature will not too high.

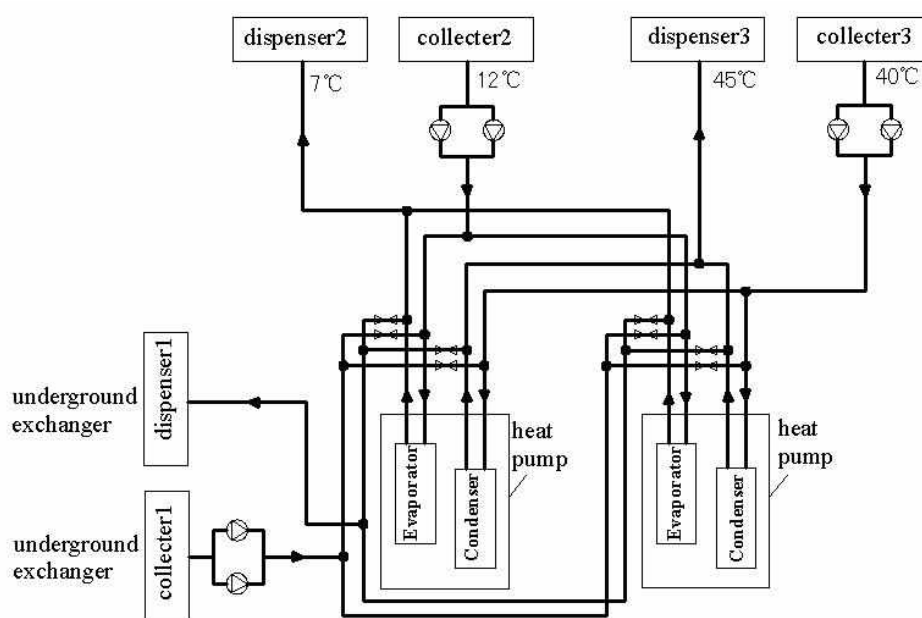


Fig.2: The principle of the heat pump

2.3 The AHU

The project used AHU which could control the temperature and the humidity in invariableness. Fig.3 illustrates the principle of the AHU. The pumps supply cool water with a temperature of 7°C to 12°C to the cooling coil and supply hot water with a temperature of 40°C to 45°C to the heating coil which is the equipment to use the recover heat. The AHU uses heating coil to

heat the air instead of electrical heat, which can not only save the energy but also use the heat that will emanate to the soil, so that the heat to the soil can decrease in summer. In Shanghai, the heat emanated to the soil is more than the heat absorbed from the soil in a whole year, so the soil's temperature will increase in a few years. The heat recover technique can alleviate the heat store in soil.

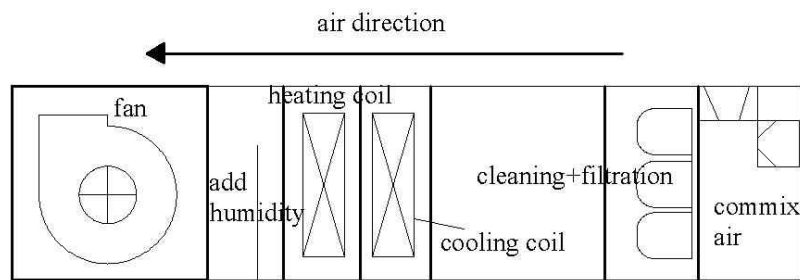


Fig.3: The principle of the AHU

3. MODELING OF THE SYSTEM

The underground heat exchanger is coupling with the heat pumps on ground in GSHP system. To modeling the system in reason is important to study the performance of the heat pumps. For a general steady-state, steady-flow process, the three balance equations, namely mass, energy and exergy balance equations, are employed to set up the model [5,7].

The equation of underground heat exchanger

The heat exchanged in underground heat exchanger is coupling with the heat pump's condenser.

$$m_c c_p (t_{co} - t_{ci}) = k_g F_g \frac{t_{co} - t_{ci}}{\ln \frac{t_g - t_{co}}{t_g - t_{ci}}} \quad (1)$$

where the c_p is the specific heat of water.

The equations of the condenser and the evaporator

The equations of the condenser:

$$m_c c_p (t_{co} - t_{ci}) = k_c F_c \frac{t_{co} - t_{ci}}{\ln \frac{t_c - t_{ci}}{t_c - t_{co}}} = m(h_2 - h_3) \quad (2)$$

The equations of the evaporator:

$$m_e c_p (t_{ei} - t_{eo}) = k_e F_e \frac{t_{ei} - t_{eo}}{\ln \frac{t_{ei} - t_e}{t_{eo} - t_e}} = m(h_1 - h_4) \quad (3)$$

where the m is the mass flow rate of the refrigerant, t_c is the condensational temperature, and t_e is the vaporing temperature.

The equation of the AHU

$$m_a (h_{after} - h_{front}) = m_e c_p (t_{ei} - t_{eo}) \quad (4)$$

4. SIMULATION CONCLUSIONS

4.1 The influence to the COP of heat pump with different deepness of the underground exchanger

We simulated the change of COP with the deepness changed from 60m to 100m. Fig.4 illustrates the result, and we only simulated the summer condition.

It's showed in the result that the COP of heat pump increases with the deepness increasing, but the increasing range is low, which is only 4.5% from 80m to 100m. That is said that we should consider both the deepness of underground heat exchanger and the situation of the locale when we do the design, and should not increase the deepness blindly. In this project, the deepness of the pipes is designed to 80m considering the situation of the soil and the influence of the deepness to the COP.

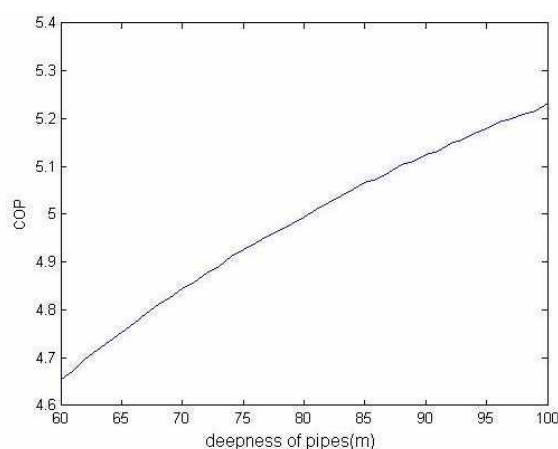


Fig.4: The relationship of COP and deepness of the underground pipes

4.2 The influence to the COP of heat pump with different recovering heat

We simulated the change of the COP of heat pump with recover heat changed. Fig.5 illustrates the result. It's showed in the result that the COP increases with the recover heat increasing, but the change is neglectable in fact. That is said that the heat recover technique would not influence the performance of the heat pump.

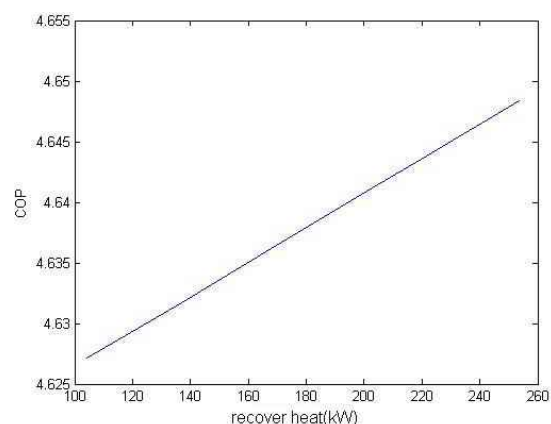


Fig.5: The relationship of COP and the heat of recover

4.3 The imbalance of the heat to the soil and from the soil

We simulated a whole year's situation for the GSHP system need to run all the year in archives building. The outdoor environment parameter of Shanghai is input to the model, and we simulated the heat emanated to the soil and the heat absorbed from the soil in a year. The result is showed in table 3. We can see that the heat emanated to the soil is more than the heat absorbed from the soil by 66.3%, which could call for the heat store in the soil if running for a long time.

Table 3: The heat to the soil and from the soil in a year

Type	To the soil	From the soil
Heat(kJ)	1.6575×10^6	5.5765×10^5

To solve the problem, the heat recover technique is adopted. We simulated the recover heat in a year and the heat could not emanate to the soil. The result is showed in table 4. We can see that if the heat recover technique was taken the heat emanated to the soil would be 6.9458×10^5 kJ, which is only more than the heat absorbed from the soil by 19.7%. That is said that the disparity between

the heat emanated to the soil and the heat absorbed from the soil decreased a lot after the heat recover technique was taken, which alleviate the heat store in the soil.

Table 4: The recover heat a year

Type	Recover heat	To the soil after recover
Heat(kJ)	9.6292×10^5	6.9458×10^5

5. EPILOGUE AND DISCUSSION

There are many advantages for the archives building to use the ground source heat pump system for heating and cooling.

- (1) For the archives building needs keep temperature and humidity invariable, the air conditioning needs to be run all the years. The GSHP system uses soil as the source whatever in summer or in winter, which can save the energy comparing with other air conditioning mode.
- (2) The GSHP system used in this project can supply hot water in a whole year. So the office building and the archives building can be both satisfied by a GSHP system.
- (3) In Shanghai there are some days need to be cooling, some days need to be heating and some days need to be wetting in spring and autumn. If other air conditioning mode like air source heat pump is taken, it's hard to satisfy in spring and autumn. The GSHP system used in the project can supply heat when it's supplying cool, so even in spring and autumn it can work well.
- (4) The heat recover technique is adopted in this project, which can alleviate the imbalance of the heat emanated to the soil and the heat absorbed from the soil. The result of simulation shows that the heat recover technique can solve the problem of heat store in soil in effect

without influencing the performance of the heat pump.

Also there are some limits for the GSHP system to use in Shanghai.

- (1) The main limit is the higher initial capital cost, being about 30-50% more expensive than air source units^[8]. This is due to the extra expense for burying heat exchangers in the earth.
- (2) In Shanghai, the soil underground is mainly clay with grit in it, and the soil is full of water, so it's hard to bury the pipes to a very deepness place. The holes are within 100m deep in general in Shanghai.
- (3) There is little space to bury the underground heat exchanger in Shanghai.

Although there are some difficulties to use the GSHP system in Shanghai, once the GSHP system is taken it's good for the energy saving.

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