SYSTEMIC DESIGN METHOD OF GROUND COUPLED HEAT PUMP

Xiao Long, engineer, China Academy of Building Research Beijing, China
Zhu Qing-yu, researcher, China Academy of Building Research Beijing, China
Xu Wei, researcher, China Academy of Building Research Beijing, China

Abstract: “Systemic Design of Ground Coupled Heat Pump”, simplified as “SDGCHP”, is the original design method and concept that is created by CABR (China Academy of Building Research) according to its own scientific research strength and engineering practice and it also provides a method for making the system operation maintenance strategy. This paper introduces the systemic design of ground coupled heat pump based on the Trnsys analysis platform through a actual case, shows the analysis process of SDGCHP, provides the paradigm of “Systemic Design of Ground Coupled Heat Pump”.

Key Words: Systemic, Underground buried pipes, Trnsys

1 INTRODUCTION

The foundation of ground coupled heat pump technology theory originated from French Carnot’s works (Xu et al. 1988) in the early 19th century, in about 1950, Britain and the United States began to research on household ground coupled heat pump, today about 80% of American ground coupled heat pump air conditioning systems adopt vertical buried tube or horizontal buried tube (Menzer and Medepalli, 2005). The engineering application of ground coupled heat pump technology only has over ten years in China, from the earliest 《Engineering technical guidelines of ground coupled heat pump》 to the subsequent 《Engineering technical specifications ground coupled heat pump systems (GB50366-2005)》, the designing methods of ground coupled heat pump systems in main domestic engineering technical manuals and criterion were used in early Europe and USA and mainly in USA, the traditional designing methods have gradually displayed its drawbacks, cannot adapt to domestic ground coupled heat pump technology's development request.

The traditional design of ground coupled heat pump systems adopts the static method, obtained heat transfer quantity per extended meter along vertical buried tube by the field test or engineering experience, determines total length of vertical buried tube according to buildings’ design cooling load or heat load, with vertical buried tube’ s spacing of 4.5 m ~ 5.0 m, the selection of heat pump units is through design cooling load or the amplification of heat load according to certain insurance coefficient, the traditional design method can be defined as “heat transfer quantity per extended meter design method”.

“Heat transfer quantity per extended meter design method” is a simple design method with limitation, 《Engineering technical guidelines of ground coupled heat pump》 has explained the calculation process and limitation of the relationship chart between and heat exchanger length and heat absorption and releasing quantity, but the limitation of this design method is ignored in engineering application, the main reason lies in that the system’s irrationality resulting from" heat transfer quantity per extended meter design method" often appears after long time since the ground coupled heat pump projects in Europe and America, etc have much lesser area, and building load is not big. However, in China, ground coupled heat pump projects are different, more and more ground coupled heat pump systems are used in the newly built projects with large area and big load, the projects with over 1,000 drilling are very common, the insufficient of "heat transfer quantity per extended meter design method" must cause enough attention in such large projects.

2 THE EFFECT OF SOIL IN SYSTEM HEAT TRANSFER PROCESS

The design method Of ground coupled heat pump system originates from cognition of the system heat transfer process, as for the effect of soil in system heat transfer process, there still exist many different opinions in China.

2.1 Heat Source Theory

On this view, the people think that soil body plays a role of heat source in ground coupled heat pump system, as long as that buildings have needs, energy can be arbitrarily extracted from soil body by the heat pump units working. Naturally, building fully usable energy is defined as the energy that underground 100m thickness soil can provide or absorb with 1℃ decrease or increase of soil average temperature, this definition overlooks a basic physical parameter influencing heat conduction ——heat conduction coefficient.

Heat transfer between soil and buried tube is unstable heat conduction, the effect of heat conduction coefficient in the unstable heat conduction process is very important. Heat conduction coefficient $\alpha=\lambda/(\rho c)$, indicates the speed of object interior temperature verging to equilibrium, as for the heat transfer process of the project with small value of α, as the accumulated or consumed heat caused by the object’s own temperature change is big, the residual heat transferring to the interior of the object is small. Compared to metal, soil has smaller value of α, heat transfer between buried tube and the near soil takes much longer time to spread to far distance, in this process buried tube transfers heat continuously making the near soil temperature rise or fall, so the temperature difference between buried tube and the near soil reduces continuously, and finally the heat transfer of buried tube cannot continue.

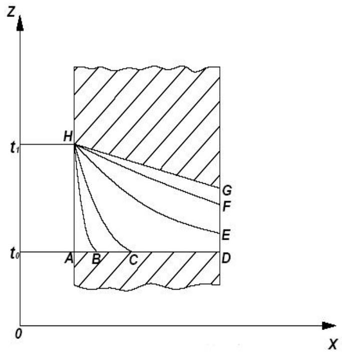


Fig.1 Temperature distribution chart in the unstable heat conduction process

Lots of soil average body temperature rise or fall can transfer huge heat, however, due to the soil’s small temperature conductivity, using soil temperature difference to produce all the heat will inevitably need huge amount of heat exchangers, for the same reason, if soil average temperature changes, it needs a long time for soil itself to realize temperature recover, for large-scale heating heat pump systems, soil cannot be regarded as stable heat source.

2.2 Additional Heating Theory

On this viewpoint, the people argue that the released energy of soil body in heat pump systems’ heating process can be added by the soil natural heat absorption or solar radiation, and the soil can get huge added heat, buried tube system can extract a lot of heat from soil for a long time.

This view also takes soil as heat source, but the difference is that heat doesn't come from soil itself but from the outside. Even though there is plenty of heat for soil to absorb, the process of soil absorbing this part of heat is similar with that of heat transfer between buried tube and soil. Heat conduction coefficient α still plays an important role in the process of soil absorbing heat. However, the outside heat source that may play a part doesn't exist.

Inside of Earth core can product heat, and will transfer part of the heat to the ground surface, the heat through the ground surface per unit time and unit area is called ground heat flux density, if considered that the heat that soil body releases in heat pump systems' heating process can be supplied by geothermic heat, thus the heat flux of soil body releasing heat should equal to that of heat pump systems absorbing heat from soil, actually it is considerably different. Computed quickly, $1m^2$ construction area's heat load is 30 W/m^2, ignoring heat storage, also without considering temperature change of soil body, GCHP's low-temperature heat source only comes from the earth heat flux, then it needs about 300 m^2 land (Dong et al. 2009, Hu et al. 2001), sheet relies on geothermal supplement may not meet heat pump system of the soil heat demand. Only depending on geothermic heat cannot meet GCPH's soil absorbing heat demand.

Soil has not only the absorption effect on solar radiation heat, and soil is influenced by solar radiation heat, the soil temperature field has diurnal variation, seasonal change and years of periodic change. The crust layer is called external thermal layer that has temperature change on the influence of solar radiation heat, and the influence of the ground temperature difference change on the external thermal layer weakens gradually from the surface to the downward. The average depth of thermal layer is about15m, and the biggest is no more than dozens of meters. Although the external thermal layer may be influenced by solar radiation heat, but the direction of heat transfer between heat pump system and external thermal layer is opposite with the solar radiation. In winter, as heat pump system needs to absorb heat from the external thermal layer, the external thermal layer radiates heat to the atmospheric at the same time, and its temperature reduces. In summer, as heat pump system needs to release heat to the external thermal layer, the external thermal layer is absorbing solar radiation at the same time, and its temperature rises. Therefore, not only geothermic heat but also solar energy cannot provide steady heat supplement for soil.

2.3 Heat Storage Object Theory

On this standpoint, the people think that, in winter GCHP system not only absorbs heat from soil but also stores refrigeration capacity in soil, if necessary, the stored refrigeration capacity can be used to meet refrigeration needs in summer. As for refrigeration capacity, it is stored in winter and used in summer. Likewise, as for heat, it is stored in summer and used in winter. Soil plays the role of "heat storage object" in the heat transfer process. Therefore, GCHP system is more suitable for the projects with the winter load as big as the summer load. As for the projects with the considerably different winter and summer load, GCHP system should the combined system with additional cold source or heat source.

Soil's thermal and physical properties of its own determine that soil as heat storage object can restore the actual heat transfer process of heat pump system scientifically, this is also the reason that various engineering technical manuals and specification pointed out that GCHP system should guarantee equivalent of the cumulative absorption heat and cumulative release heat.

No matter "heat source theory" or "additional heating theory" actually considers soil as continuous and stable energy source, this kind of understanding is the theoretical basis of "heat transfer quantity per extended meter design method". Because of basing on this understanding, the effect of actual operating conditions, accumulation effect of soil heat transfer, etc. can be ignored, and make system design of heat pump according to the test value of test operating conditions or even the estimated experience value of heat transfer quantity per extended meter. Theoretical basis and actual deviation will inevitably lead to the error of design method. Different from "heat transfer quantity per extended meter design method", "Systemic design method of ground coupled heat pump" ,considering soil as heat storage object, restores the actual soil's heat transfer process of heat pump system under the effect of the hourly building load.

According to water temperature change inside the buried tube in the energy accumulation and extraction process, conduct design selection of heat pump units, and put forward proposals on operation debugging.

3 SYSTEMIC DESIGN OF GROUND COUPLED HEAT PUMP

3.1 Systemic Design of Ground Coupled Heat Pump

GCHP system's working process is combined action process of buried tube heat exchangers system, heat pump's main units and air conditioning's terminal system, is coupled heat transfer process of soil, heat pump's main units and air conditioning's terminal system. Buildings produce load, load is meet by heat pump, buried tube system corresponding with load transfers heat with soil, working conditions of heat pump's main units change hourly, and the absorption and release heat of buried tube change hourly.

In the coupled heat transfer process of GCHP systems, the thermal physical parameters of soil are the foundation of GCHP systems design, building dynamic load is the basis of GCHP systems design. Soil's thermal physical parameters represent the nature of soil, only related to soil composition and thus can be obtained through on-the-spot test. Building dynamic load is buildings' own nature, building dynamic load distribution is relatively constant after the construction scheme and using rule are fixed, can be obtained through calculation. Attaining soil's thermal physical parameters and building dynamic load both need computer-aided calculation.

System design of buried tube heat exchangers may be conducted after determining soil's thermal physical parameters and building dynamic load, under the condition of computer-aided design, the buried tube heat exchangers program can obtain inlet and outlet temperature water of buried tube systems by calculation, and the capacity of heat pump's main units can be determined according to the most unfavorable condition obtained by calculation, namely: according to the respectively corresponding building heating and cooling capacity of the lowest temperature water in winter or the highest temperature in summer on buried tube side. Therefore the basic of SDGCHP lies in the coupled heat transfer characteristics of GCHP systems, systematic design should include: the testing of thermal physical parameters of soil, the calculation of building dynamic load, system design of buried tube heat exchangers system, of heat pump host design. The tie combining these 4 parts is computer-aided design software.

3.2 The Process of SDGCHP

Systemic design of heat pump is a dynamical coupled design method. First, calculate building year-round dynamic load, then conduct on-the-spot test of rock-soil's thermal physical parameters that are taken as input parameters of coupled design. Finally, transform building year-round dynamic load into absorption or release year-round dynamic load quantity of buried tube, input the parameters of absorption or release heat into coupled calculation module of buried tube heat exchangers, then the dynamic distribution of supply, back water temperature during the operation of any buried tube heat exchanger program. Controlling the lowest and highest temperature of supply, back water can adjust and determine the number of buried tube heat exchangers.

The thermal response experiment with the aim to test thermal physical parameters of the rock-soil on project location is a prescribed standard method, thermal physical parameters of rock-soil include the coefficient of thermal conductivity, heat, etc. Such parameters belong to the physical parameters of rock-soil, less affected by the outside world, can be applied directly to buried tube system design calculation. Besides, there is the other test method with testing heat transfer quantity per extended meter of buried tube for the purpose, heat transfer quantity per extended meter of buried tube is not constant in the actual operation process of buried tube heat exchangers, at the same time, it is influenced by operating conditions and external environment. This paper gives the cases with these parameters known, and thus doesn't introduce the content of rock-soil's thermal response test.

Systematic design method returns the working status of GCHP systems. Consider coupled heat transfer characteristics of buried tube systems and building users in the design phase, and the inlet and outlet water temperature and the calculated value of soil average temperature of buried tube systems can also be provided in the operation and maintenance stages after the systems are completed. Compared with the corresponding operation monitoring values, the operation and maintenance strategy of systems can be made.

In addition, this design method can solve thermal physical parameters calculation of rock-soil, building year-round dynamic load calculation, the system design of buried tube heat exchangers, selection of heat pump units and the problem of systems' operation and maintenance strategy, etc. It realizes systemic heat pump design.

4 THE CASE OF SYSTEMIC DESIGN

4.1 Overview of The Case

This project's combined air conditioning system user includes 2 new office buildings, 1 old office building and a new restaurant, the combined system provides full heating load and partial air conditioning load for new office buildings and the old office building, and full heating load and living water preheating load for the new restaurant, but don't provide the air conditioning load for the restaurant. The combined system's analysis method is that calculate year-round dynamic building load first, calculate the system's the biggest heat load on the basic of the largest possible amount of buried tube, under the condition of the known thermal physical parameters of rock-soil on the project location, taking equality of absorption and release heat of the buried tube system as criterion, distribute the summer load proportions of buried tube and cooling towers. This project's basic situation is shown in Table 1.

Table 1 The systemic design case's basic situation

	Building area/m^2	Building height/m	Design cooling load/kW	Design heating load/kW
New and old office buildings	12 687.5	18.9	1 161	518
New restaurant	2 500	14.5	-	265+living water preheating load
Total	15 187.5	-	1 161	783+ restaurant's living water preheating load

4.2 Year-round Dynamic Building Load

Making the project's building load calculation model can obtain this project's year-round dynamic building load, as shown in Fig.2. Based on the simulation results, it can be seen that the summer design load of about 1 100 kW, the winter design load of about 800 kW, the year-round heat of about 352 134 kWh, and the year-round release heat of about 747 510 kWh. Considering that this project's air conditioning gives priority to the cooling tower operation in summer, and only when the cooling tower operates at low efficiency at air conditioning's peak time operates the heat pump, under the condition of equality of year-round absorption and release heat of the buried tube system, providing necessary supplements for the cooling tower system, buried tube system should take winter heating load as the design basis.

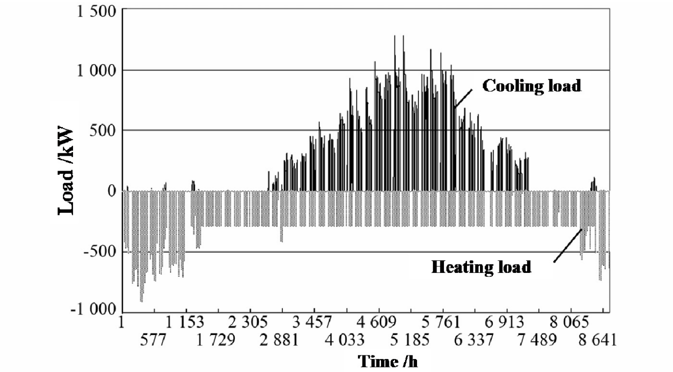
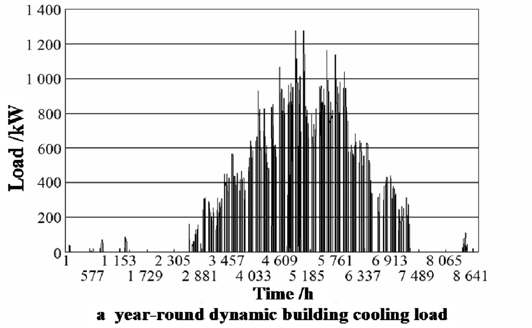


Fig.2 Distribution graph of year-round dynamic building load

4.3 Redistribution of Year-round Dynamic Building Load

Redistribution of year-round dynamic building load is to distribute year-round dynamic building load for buried tube and cooling towers to undertake, and the dividing principle is that air conditioning gives priority to the heat pump operation when the cooling tower operates at low efficiency at air conditioning's peak time, determining the open time under the condition of equality of year-round absorption and release heat of the buried tube system. Although heat pump system's overall refrigeration efficiency is not high in this condition, it is theoretically high than that of cooling tower system under this operation condition. Depending on this operation scheme, the compound system's overall efficiency can realize maximization. In accordance with the above principles, as shown in Fig.3, redistribute year-round dynamic building load. As shown by the graph, it is known that year-round dynamic building load**(a)** is total of the cooling load undertaken separately by the buried tube**(b)** and the cooling tower**(c)**.



a year-round dynamic building cooling load

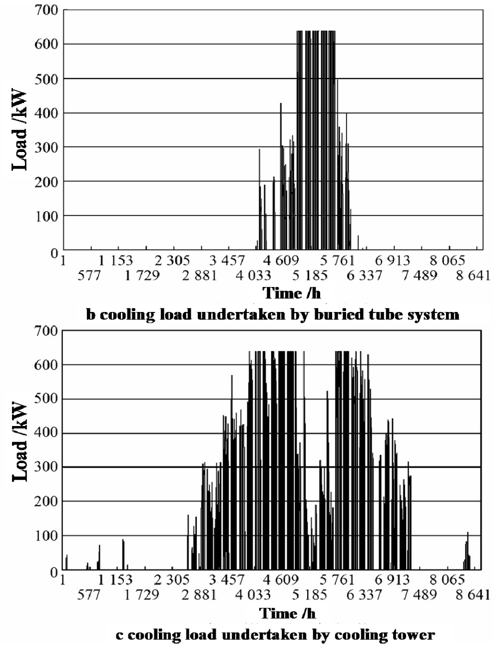


Fig.3 Redistribution of year-round dynamic building load

After the adjustment, the distribution of the cooling load undertaken separately by the buried tube and the cooling tower and the contrast are shown as Fig.4. As shown in figure, the light color curve represents the system's total load, and the deep color curve represents the load undertaken by the cooling tower, and subtracting two kinds of load can obtain the load undertaken by the buried tube system.

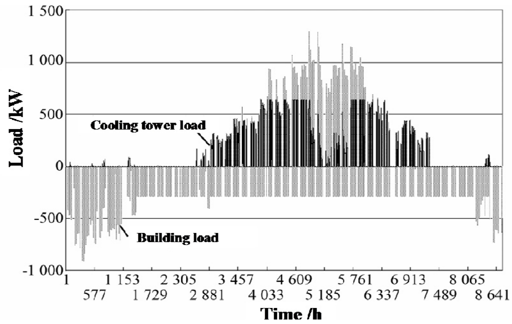


Fig.4 The contrast of the cooling load undertaken

4.4 Buried Tube System's Absorption and Release Heat

According to the performance curve of the chosen heat pump host, building load can be transformed into buried tube system's absorption and release heat. As shown in Fig.5, on the basic of buried tube undertaking building load, buried tube system's year-round absorption and release heat can be calculated, and the results are shown as Fig.6

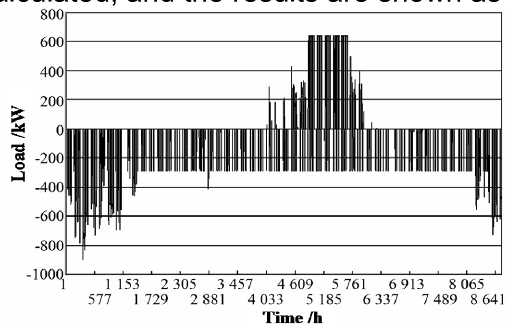


Fig.5 The load undertaken by buried tube system

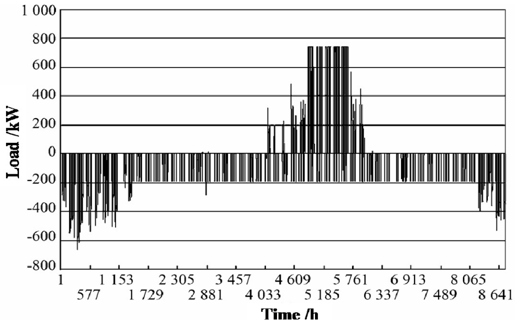


Fig.6 buried tube system's year-round absorption and release heat

4.5 The Average Temperature of Soil

On the basic of the buried tube system's year-round hourly absorption and release heat, on the TRNSYS platform, the heat transfer module of buried tube heat exchangers can be used to calculate the inlet and outlet water temperature's hourly change during the operation period of buried tube system, meanwhile, it can calculate the change of the soil's average temperature under the influence of the buried tube system's absorption and release heat, and the results are shown as Fig.7 ~ 8. The specific operation data are shown as Table 2. The calculation results show that, according to the buried tube decorated in 147 holes, after system runs 50a, the average temperature of soil will rise to 3.0℃, the buried tube system's highest input water temperature in summer is 36.0 ℃, and the lowest input water temperature in winter is about 5.2 ℃.

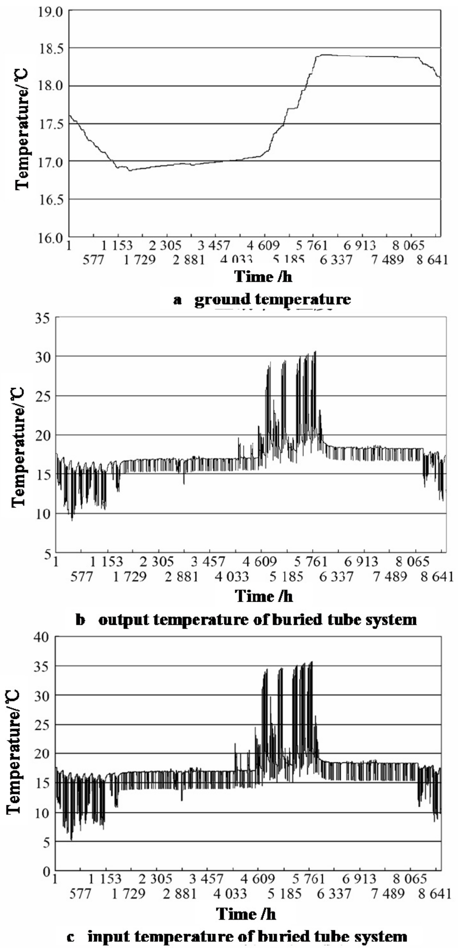


Fig.7 The buried tube system's operation data of the first year

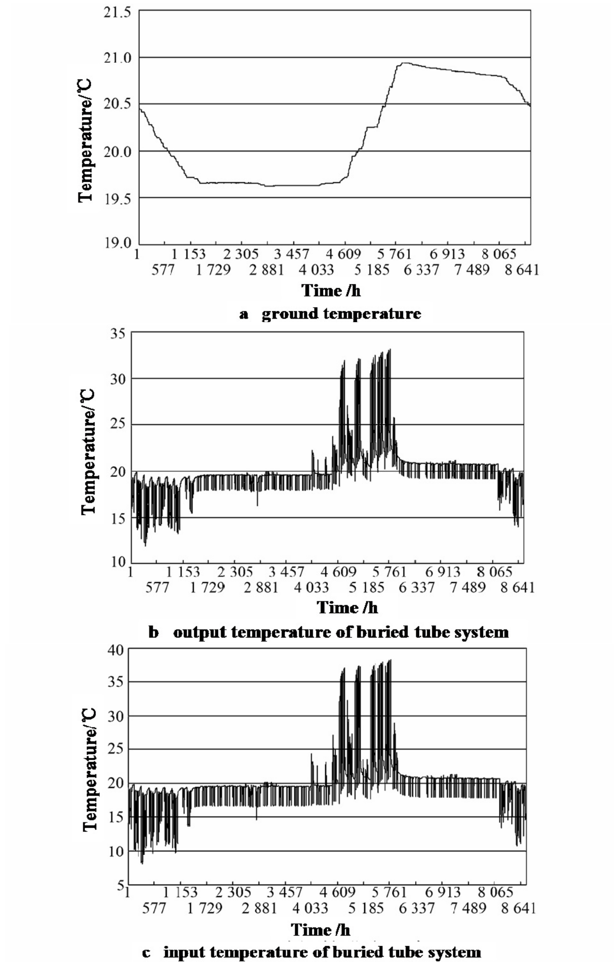


Fig.8 The buried tube system’s operation data of the 50th year

Table 2 The buried tube system’s specific operation data

Holes/number	Operation time/a	The initial average temperature of soil /℃	The average temperature of soil in the last operation phase /℃	The lowest winter input water temperature of buried tube /℃	The highest summer input water temperature of buried tube /℃
147	50	17.6	20.5	5.2	36.0

According to the calculation analysis result, it can be concluded that as the system runs under the existing scheme, the highest summer input water temperature of buried tube is much higher, but the high water temperature doesn’t last long, thus the system scheme is acceptable.

5 SYSTEM INTIAL SCHEME

After GCHP system is built, operation debugging, operation monitoring and making system responding timely through monitoring data are necessary conditions to guarantee long-term and stable operation of system. System design should consider the relevant monitoring of operation data, meanwhile, formulate response plan of monitoring data in the design stage, otherwise the operation maintenance of system is very passive, and debugging also will depend too much on experience.

According to the above analysis process, in addition to routine practice, the operation debugging of this project still needs to determine the open and close time of cooling tower. On the one hand, based on the calculated year-round building dynamic load, open or close cooling towers according to the time when they begin or begin or finish undertaking cool load respectively. On the other hand, based on the dynamic change data of the average temperature of soil, determine the time to open or close cooling towers through the monitoring data of the average temperature of soil during the operation period.

6 CONCLUSIONS

GCHP system is a coupled heat transfer system, thus the system design must solve of coupling heat transfer problem, meanwhile, should provide data basis for making single type and combined type systems' operation and maintenance strategy. Based on an engineering design case as an example, "Systematic Heat Pump Design" can completely solve the above problems, thereby creates a condition for the rational design and long-term and stable operation of single type and combined type GCHP systems.

Reference

Dong Fei, Ni Long, Yao Yang, Jiang Yiqiang, Ma Zuiliang. Shallow rock and soil energy storage combined with shallow geothermal energy sustainable low temperature source of ground source heat pumps [J]. Journal of HV&AC. 2009,39(2). 70-72

Hu Shengbiao, He Lijuan, Wang Jiyang. COMPILATION OF HEAT FLOW DATA IN THE CHINA CONTINENTAL AREA (3rd edition) [J]. Chinese Journal of Geophysics. 2001, 9. 611-626

M. Menzer, S. Medepalli. AN OVERVIEW OF NORTH AMERICAN HEAT PUMP MARKETS.2005

Xu Bangyu, Lu Yajun, Ma Zuiliang. Heat Pump [M]. China architecture &building press.1988