Application of GSHP System in Nearly Zero Energy Building (NZEB)

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Abstract

Global energy demand from buildings is projected to grow by an additional 838 Mtoe till 2035 compared to 2010 (IEA, 2012a)[1]. Reducing energy consumption in the building sector is one of the most important measures for global energy reduction and climate adaptation. Nearly/net zero energy building is one promising path leading to further building energy conservation for the future direction of building development. Proactive measures, with renewable energy sources, are recognized to help to realize energy saving.

Nearly zero energy building has met its big time in China, more than 30 demo buildings either public or residential has finished or is under construction countryside. The first standard related to nearly zero energy building “Passive Low-Energy Green Building Technical Guideline (Residential)” has launched in 2015 by MOHURD. Many cities such as Beijing and Qingdao has published active policies to promote the development of nearly zero energy buildings.

Heating, cooling and ventilation has account roughly 50% of building energy consumption, which matters more in low energy building. Regarding the heat pump, as one of the most popular energy systems particularly in nearly zero energy building, it is important to consider and emphasize the procedure to perform more efficiently, make more contribution and increase the compatibility with other energy in nearly zero energy building.

The CABR NZEB demonstration project, located in Beijing, China, set up ambitious annual energy consumption cap of 25 kWh/(m^2.a) (including heating, cooling and lighting energy). It integrated cutting-edge building technologies and strived to lay the foundation for China’s NZEB standard. Ground source heat pump combined with solar thermal serves as the primary energy system of the building. Under specific and delicacy control management, preliminary energy consumption data shows that CABR NZEB is meeting its energy consumption target. Integrated utilization of heat pump system with the ground source and solar energy system demonstrated success for NZEBs in the cold climate region.

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Keywords: nearly zero energy building; renewable energy; ground source heat pump

1. Background

Reducing energy consumption in the building sector is one of the most important measures for global energy reduction and climate adaptation. Nearly/net zero energy building is one promising path leading to further building energy conservation for the future direction of building development. Proactive measures, with renewable energy

sources, are recognized to help to realize energy saving, jointly with "passive design".
Nearly zero energy building/zero energy building has widely developed in Europe, America and Asian countries, where developing roadmap has been proposed. Germany has successfully developed "passive house", whose design ideas and technical details have been adopted by other countries. Germany planned to provide "passive house" heating and cooling without fossil fuels in 2020. England estimated to realize zero carbon emission in 2016. Finland launched passive house standard in 2015. Meanwhile, China has also build nearly zero energy demo building nationwide to advance technologies and explore further path for building energy saving.
Reduce heating and cooling load through building itself by high-performance envelopment insulation application. The building also adopts nature lighting, ventilation to a maximum extent by nature resource application, utilizing renewable energy to realize nearly/net zero energy technology. Renewable energy has been highly enhanced to help a building to realize zero energy consumption.
More than 30 demo buildings have been built nationwide, in different climate zones including public buildings and residential houses. Due to the high performing heating and cooling and environmental friendly properties, Ground source heat pump system has used worldwide, especially in China, which has the biggest ground source heat pump application in the world. Because of its qualities of inexhaustible in supply and availability for use, solar energy has been widely used for heating and cooling as well.
Ground source heat pump system, solar energy, wind biomass and other energies, have been widely adopted in buildings as energy system to provide high performance heating and cooling and to realize energy saving simultaneously. To realize zero energy buildings, two or three renewable energies are integrated used in some projects.
The target of energy consumption comes to zero or nearly zero in nearly zero energy buildings. The PV system, which is installed in building roof or envelopments to provide electricity, serves better. Furthermore, the energy consumption is important for the entire building's energy level. Building's operation and delicacy management are essential to the nearly zero energy building.

2. Nearly Zero Energy Building in China

Nearly zero energy building has met its spring in China. Either business, market or government pays considerable attention to it. Qualified housing products are welcomed in the market. The first standard related to nearly zero energy building "Passive Low-Energy Green Building Technical Guideline (Residential)" has launched in 2015 by MOHURD. It defined the passive green low energy house in China, which rendered key points on nearly zero energy building design, construction and installation. Many local standards are based on the above standard. Many cities and province such as Beijing and Qingdao have publicized active policies to promote the development of nearly zero energy building.

2.1 Demo Building Introduction

More than 30 demo buildings are constructed in China, including residential and public buildings. Figure.1 shows the distributions of some of these demo buildings, and detailed information of 22 projects are listed in table 1.

Figure 1. Distribution of Nearly Zero Energy Projects in China

Table 1 detail information of demo nearly zero energy projects in China

#	Project	Type	Location	Climate Zone	Implementation Status	Floor Area(m^2)	Floor No	
							Above Ground	Under Ground
1	Riverside QHD	Resid	Qinhuangdao, Hebei	HD	In Operation	28,050	18	-2
2	Tianjin SSEC Pubhouse	Resid	Tianjin	HD	Construction Documents	13,000	16	-2
3	Changcheng Employee Tower	Resid	Baoding, Hebei	HD	Construction Documents	120,000	18	-2
4	CABR NZEB	Office	Beijing	HD	In Operation	4,025	4	0
5	Qingdao Eco-Park Demo Center	Mixed	Qingdao, Shandong	HD	Construction Completed	13,769	5	-2
6	Qingdao Soccer Training Facility	Office	Qingdao, Shandong	HD	Construction Documents	2,070	2	0
7	Crystal School	School	Qingdao, Shandong	HD	Design Documents	6,500	4	-1
8	SCCC Training Center	School	Jinan, Shandong	HD	In Construction	20,700	5	-2
9	Taiyuan SME Imcubator	Office	Taiyuan, Shanxi	HD	Design Documents	11,800	5	-1
10	UN-CIFAL Training Center	Office	Zhenjiang, Jiangsu	HCB	Construction Documents	12,800	6	0
11	Xinhua Office	Mixed	Zhuozhou, Hebei	HD	In Operation	7,500	4	0
12	Velux Langfang HQ	Office	Langfang, Hebei	HD	In Operation	2,014	2	-1
13	Shunda	Resid	Baoding, Hebei	HD	Construction Completed	8,016	9	-1
14	Hebi VLEB	Office	Hebi, Henan	HD	Construction Completed	2,675	4	-1
15	Gree nZEB	Exibit	Guangdong	CD	Design Documents	650	2	0
16	Menred Low-carbon building	Exibit	Wenzhou, Zhejiang	HCB	Construction Completed	480	2	-1
17	Landsea Bruck	Hotel	Huzhou, Zhejiang	HCB	In Operation	2,500	5	0
18	HappinessBurg	Mixed	Urumqi, Xinjiang	HD	In Operation	7,668	6	-2
19	Tianjin SSEC Pubhouse Center	Office	Tianjin	HD	In Operation	3,529	2	0
20	CGCEC Chengdu Office	Office	Chengdu, Sichuan	HCB	Construction Documents	4,500	4	-1
21	Lahsa nZEB	Office	Lahsa, Xizang	HD	Construction Documents	2,750	4	0
22	Jinglan Hotel	Hotel	Hangzhou, Zhejiang	HCB	Design Documents	3,480	4	0
note: HD-heating dominant; HCB-heating and cooling balanced, CD-cooling dominant					Total:	278,476		

Total floor areas of the 22 demo buildings are around 278476m^2. Almost 1/3 of the buildings are constructed, 1/3 of the buildings are in operation and the others are documented.

Building area distribution is shown in figure 2, building area up than 10000 m^2, among 5000 to 10000 m^2, and among 2000 to 5000 m^2 accounts for18.18%, 31.92%, and 40.91% respectively.

Distribution of building floors are shown in figure 3, buildings with floor less than 3F, 4-6F, 11 and up accounts for 59%, 22%, and 13.64% respectively.

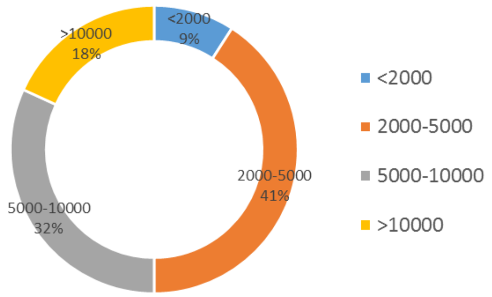


Figure 2 Building distribution by floor area

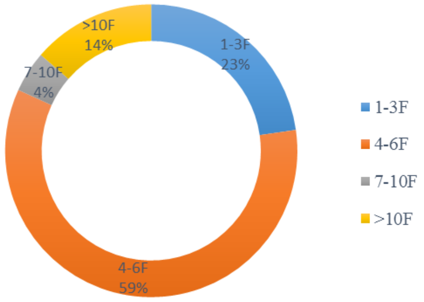


Figure 3 Building distribution by layer

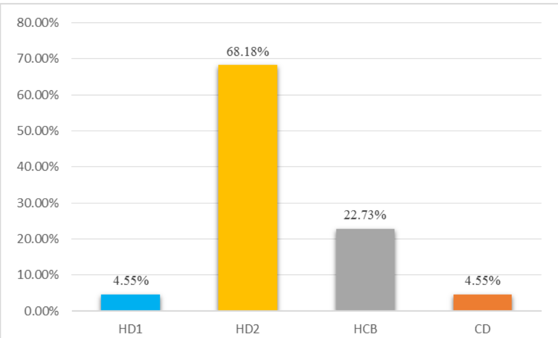


Figure 4 Climate zone distribution

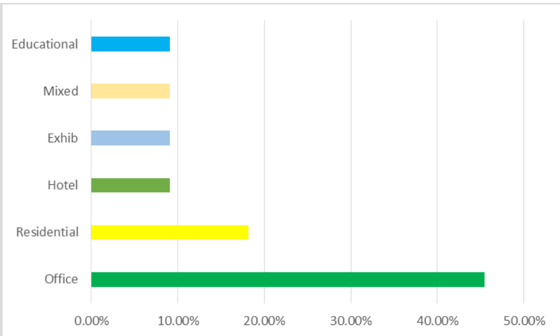


Figure 5 Building type distribution

2.2 Technology Introduction

Renewable energy is the main energy resolution to achieve low energy or nearly zero energy house. Almost 50% of the nearly zero energy building employed heat pump system as the main energy choice. By incomplete statistics, ground source heat pump is the primary choice for office buildings, which account for almost 70% of its market (Figure 6). Moreover, air source heat pump is often the first choice for residential buildings.

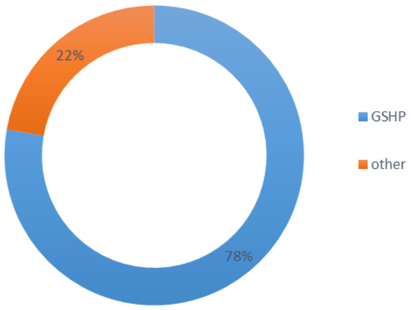


Figure 6 Proportion of GSHP application in office buildings

3. Technology Introduction of China Academy of Building Research Nearly Zero Energy Building

China Academy of Building Research Nearly Zero Energy Building (CABR NZEB) (Figure 7) is a 4-floor office building, with the floor area of 4025 m^2 and occupancy of approximately 180 full-time employees. CABR NZEB is the demonstration building of U.S. China Clean Energy Research program（CERC）on building energy efficiency. The aim of this demo building is not only to meet a requirement of the CERC project, but it is also a summary of CABR’s research in the field of building environment and energy over decades.
The project will address fundamental issues about the building energy efficiency in China. CABR demo building can be considered as a newly Chinese attempt to achieve Nearly Zero Energy Building (NZEB) with affordable cost. The experience acquired from CABR project will be a valuable input to the development of future Chinese standard and roadmap toward NZEB.

Figure 7 North Facade of CABR Nearly Zero Energy Building

3.1 Energy System

Achieving a minor heating and cooling load and an acceptable indoor environment, the research in the passive house or nearly zero energy building becomes particularly popular.
Energy system design and operation of this project explore the integrated design, which is expected to effectively solve the problem of energy system design for nearly zero energy buildings in China.
Ground source heat pump has developed for more than 30 years in China, and has been successfully applied in different projects. Due to its high performance and good environmental effects, it is one of best choices in areas with balanced heating and cooling demands.
To maximize the utilization of renewable energy, to improve energy efficiency to reach energy goal and to explore the new solution for nearly zero energy building, the combined solar-thermal and ground source heat pump system was determined as final choice of the energy system, after considering detailed calculation, analysis, design, on a variety forms of energies.

3.2 Introduction of Energy system

The construction of the energy system is shown in figure 8, and one absorption chiller and two GSHP units are involved in this energy system. In summer, the absorption chiller, driven by two types of solar collection systems, which were the biggest solar thermal air- conditioning system in Asia, processes the ventilation load in summer, supplemented by a 50kW GSHP unit (GSHP 1#), and in winter, GSHP 1# provides heating load of the first and fourth floor. The other 100kW GSHP unit (GSHP 2#) is in place to meet both heating and cooling demands from the radiant terminals for the second and third floor in the whole year. Coupled with ground source heat pump, solar collection systems provide direct heating in winter with thermal storage. A hot water tank is installed to storage thermal energy in the form of hot water.

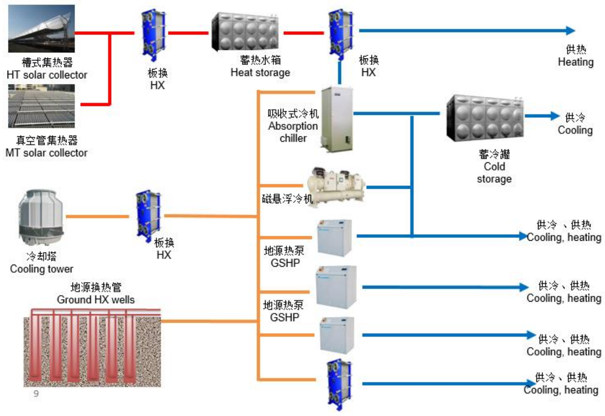


Figure 8 Energy System

Borehole distribution is illustrated in Figure.9. Seventy boreholes are placed in open space of the demo building boundary, with 20 for double U-tube with 100 meters in depth to the south, and 50 for single U-tube with a depth of 60 meters to the north and west. These boreholes are grouped in 7 sub-loops and ground water join in a header before entering the building. Water flow was balanced by adjusting valves and monitored before being distributed to different units.

Five observation wells were drilled in consideration of soil temperature variation to monitor the impact from summer operation of the GSHP systems.

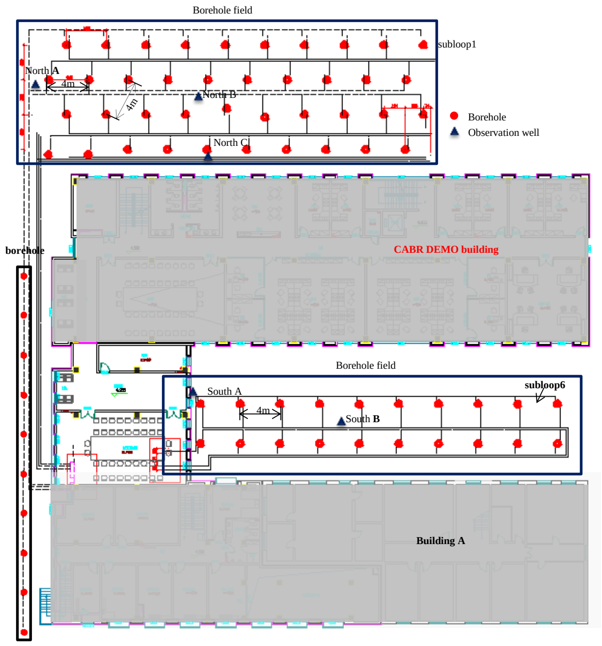


Figure 9 Distribution of the borehole system

3.3 Operation Strategy

The project, which involves multiple energy sources, should heavily consider and emphasize the efficient performance and compatibility with other energies in the energy system for nearly zero energy building. Operation strategy determined the coordination of the energy system, which is vital for energy saving, system performance and reflection on the understanding of the operation manager to designers' ideas.

The major principle of the system operation is the solar thermal first—in winter, once the solar thermal is available, it will be used first.

As described above, a hot water tank is installed to storage solar thermal by forms of hot water. Due to solar radiation strength, hot water temperature could above 40 -50℃ at that beginning of the winter season, and with winter goes ahead, the hot water temperature remains above 40℃ approximately. According to outside air and indoor temperature, hot water only can heat the building at the beginning of the winter season, and then will cooperate with GSHP together to supply heating in cold winter season.

There are two ways to cooperate the hot water with ground source heat pump—one is to heat the primary side of water in the pump, another is to heat the secondary return hot water of the heat pump. Restricted by pipeline arrangement, in cold winter, hot water connects to the secondary side of the heat pump, and heats the return water from the indoor.

The following section gives a detailed analysis of the GSHP unit in winter.

3.4 Operation Performance of GSHP

Two GSHP units work fully in winter, so the performance of the units in winter is analyzed first. Inlet and outlet water temperature variations of heat pump side, ground side, COP of the heat pump in a typical day and seasonal COP are shown below.

GSHP 1#

In winter, GSHP 1# process heating load for the first and fourth floor. Supposedly, if the system operation in the coldest day could satisfy room temperature comfort, it could meet the heating requirement of the building in whole winter well.

System operation in January 27th is analysed when outside air temperature is about -7℃ in this day as shown in Figure .10. The system works from around 7:00 am to 17:00 pm in this day. Supply (T_{2out}) and return (T_{2in}) water temperature of the secondary side is around 42 and 38℃ respectively, with about approximately 4℃ temperature difference. Inlet (T_{1in}) and outlet (T_{1out}) water temperature on the primary side is about 13℃ and 9℃. The temperature difference is approximately 4℃. T_{1out} was about 0.7℃ temperature decrease, and the system shows an interval operation on the day. The hourly coefficient of performance (COP) is plotted in Figure 11, daily COP varies between 3 to 5, and average COP is about 4.

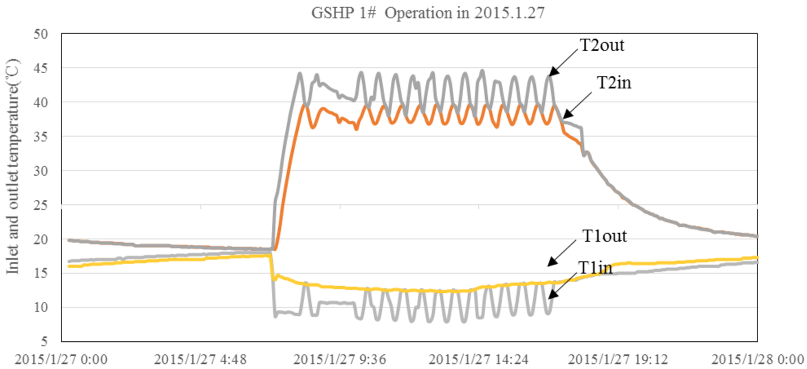


Figure 10 Inlet and outlet water temperature of GSHP 1# in 2015.1.27

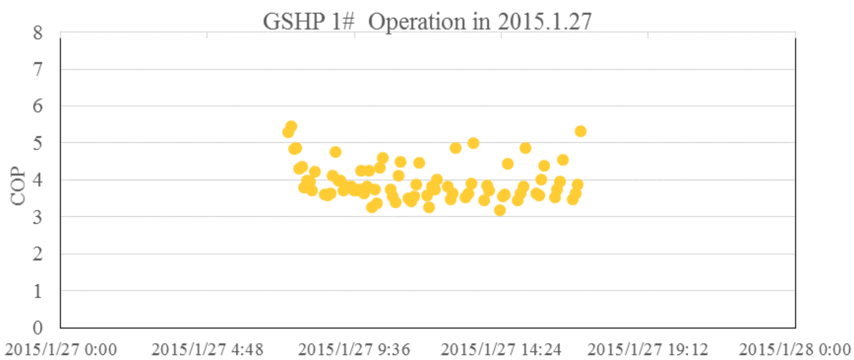


Figure 11 COP of GSHP1# in 2015.1.27

GSHP Unit2

GSHP 2# provides heating for radiation system of the building. Figure 12 presents inlet and outlet water temperature variation of the primary (T_{1in}, T_{1out}) and the secondary side (T_{2in}, T_{2out}) of GSHP 2#. HP 2# works from around 7:00 am to 14:00 pm in this day. Since outside temperature decrease quickly, T_{2in} and T_{2out} increased from 29℃ to 35℃ and 35℃ to 43℃ respectively about 5℃ temperature difference, and T_{1in} and T_{1out} is about 13 and 7℃, respectively. The average hourly coefficient of performance (COP) in this day is about 4.6 in Figure 13.

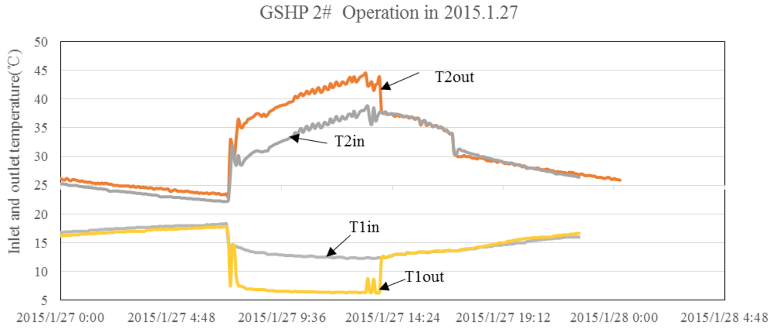


Figure 12 Inlet and outlet water temperature of GSHP 2# in 2015.1.27

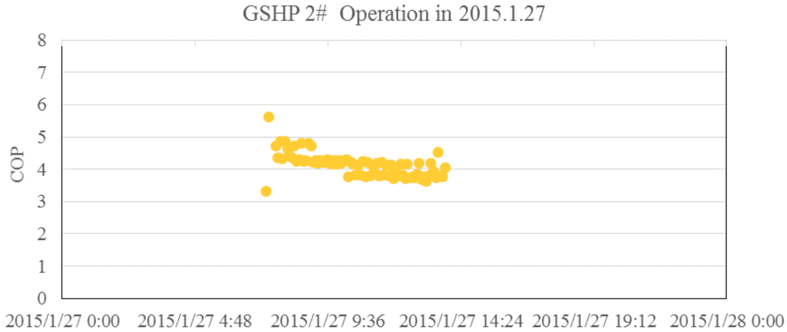


Figure 13 COP of GSHP2# in 2015.1.27

Seasonal COP of GSHP 1# and 2# is plotted in figure 14. It can be easily seen that the seasonal COP has an obviously decrease as time goes, and COP of GSHP 2# is about 5.5 at the beginning of winter season, and drops to about 4.6 at the time of winter end. Additionally, COP of GSHP 1# is about 5.0 at the beginning and drops to 3.5 at the end. COP of GHSP 2# is higher than that of GSHP 1#. Average COP of GSHP 2# and 1# is about 4.5 and 4 respectively.

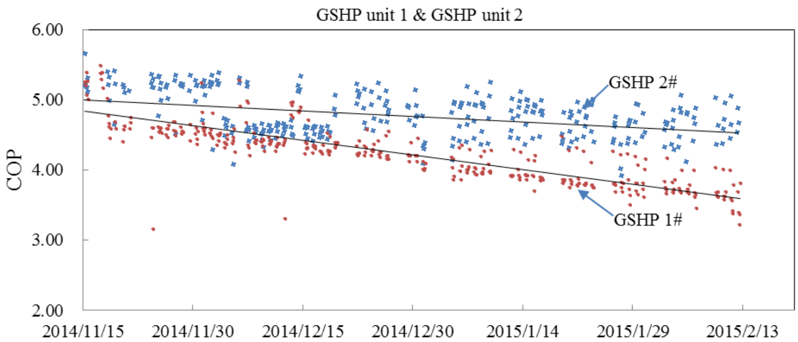


Figure 14 COP of GSHP1# and GSHP 2# in winter season

4. Operation Evaluation of GSHP System

4.1 Indoor Air Environment

Indoor air temperature and outside air temperature variation in the winter season are plotted in figure 10. The green line presents indoor air temperature and the grey line is the outside air temperature. Outside temperature drops to -12℃ at the coldest time and the room temperature remains above 20. In the entire winter season, room temperature maintains above 20 and sometimes ups to 25℃. Moreover, the lowest room temperature is about 18 ℃ when heating supply stops at night. It is safe to conclude from the room temperature variation that operation of GSHP system could well satisfy the room temperature requirement.

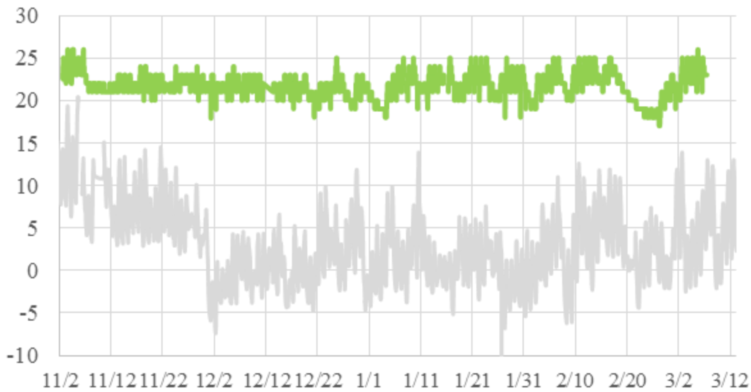
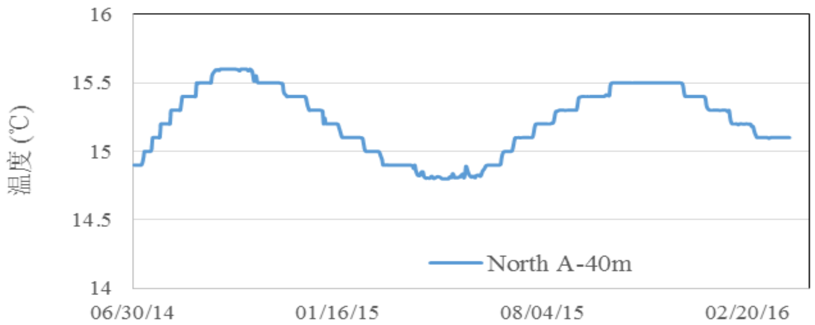


Figure 15 Indoor and outdoor air temperature variation in winter season (GSHP2#)

4.2 Soil Temperature Variation

Borehole system is the heat source and the sink of the energy system. Heat is extracted or released to the ground. There are 70 boreholes with a total length of 5000m distributed in the open space around the building. Double and single borehole tubes were arranged for experiments, when the soil temperature variation around the tube was monitored as well to check the impact on system operation to the ground.



.Figure 16 Soil temperature variation in single U-tube side

Figure 16 shows soil temperature variation at -40 m in middle observation well in single U-tube field. Soil temperature went up gradually in summer in 2014 from 14.8℃ to 15.6℃, about 0.8℃ increase, then dropped gradually to around 14.8℃ when winter ended. The soil temperature recovered to its original level. In the year 2015, soil temperature went up to 15.0℃ in summer and decreased gradually in winter. It is concluded that soil temperature recovered before the successive operation season.

Through soil temperature variation, it is known that the system works in an excellent operation mode, that indoor heating and cooling load gets a balance in a certain extent, and soil temperature balance could provide a good operation condition for the next year.

4.3 Contribution of Renewable Energy in Nearly Zero Energy Building

It is promised that the building could meet its indoor environment comfort without fossil energy consumption in winter and the energy consumption in summer could reduce to half than regular buildings.

With the operation of the energy system, indoor environment keeps in a superb condition. With the coordination of solar thermal, the ground source heat pump system will satisfy the heating and cooling requirements for the whole building.

Figure 17 is the energy flow chart of the system. In winter, solar thermal provides about 36% energy of the building heating requirement, and GSHP provides 63% by heat pump system. Assuming GSHP COP as 4.5 in winter, geothermal provides 51% of energy.

Figure 17 Energy flow chart of winter season

5. Conclusion

More than 30 demo buildings are constructed or under construction nationwide. The renewable energy is the key for buildings to realize low energy consumption or even to achieve energy-plus building. CABRNZEB is the first nearly zero orientated public building in the cold climate zone in China. Multiple energy solar thermal and ground source heat pump is utilized in this building. The cooperation of solar thermal and ground source heat pump in winter is analysed firstly and the operating performance of ground source heat pump are analysed secondly. Daily operation COP is about 4.5 and seasonal COP is better than 4. Indoor environment keeps above 20℃ in the entire winter season even on the coldest day, when the outdoor temperature is less than -15℃. The contribution of the ground source heat pump is about 63%, and more than 50% of the energy is provided by geothermal energy.

Acknowledgments

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