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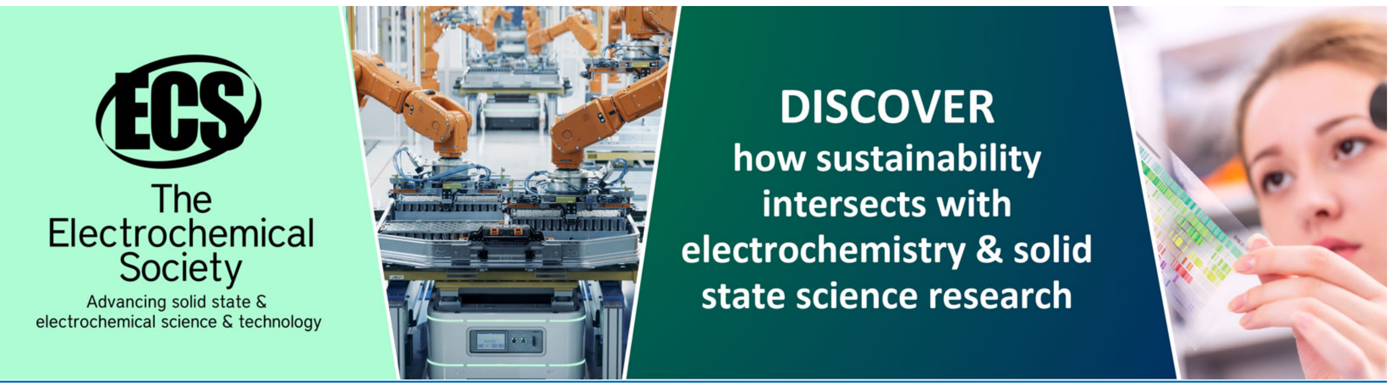

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Applicability Analysis of Solar District Heating in North Rural Areas

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Abstract. Coal is still the main energy of space heating in North rural areas in China, and coal stove, coal fired boiler are most common heating technology through literature analysis of North rural areas heating status. With the development of clean energy heating in rural areas, solar heating gets people's attention. In 2016, through investigating 15 solar heating projects in North rural areas, we find that all rural solar heating is household heating, due to factors such as collector installation, heat storage technology, operation and maintenance, solar household heating has not been accepted by rural residents. But large scale solar assisted ground source heat pump district heating technology (SAGSHP) is popularized, one successful case is Xiaowangjiapu village project, we measured operation factors of this system, including indoor air temperature, relative humidity, heating demand etc. And setting up software simulation model by using TRNSYS 18.0. Taking the measured outdoor meteorological parameters and heating demand as software input parameters, by contrast to model output parameters of heat pump and test data, checking the software model. And then analyze the performance of the system for the whole year. Simulation results show that average storage temperature of soil decreases from 12.80℃ to 12.54℃, solar fraction (SF) is just 17.6%. Based on the experience of European cases, the reason for small SF is no preheat of soil and loss of soil heat dissipation.

1. Introduction

In recent years, haze pollution has seriously threatened air quality in the north, and China's energy structure has been dominated by coal for a long time. In 2013, the number of deaths due to coal-burning pollution reached 366 thousand (GBD MAPS.2016). In 2015, China's energy consumption of rural buildings by 1.97 million tons (CBECA.2017). According to "BP world energy statistics annual report 2017", in 2016, the proportion of coal in China's energy structure is 62%, while more than 60% of energy demand in rural areas is used for heating in winter. Space heating energy source is mainly bulk coal, which causes serious environmental problems (BP.2017). And clean heating in northern rural areas is imminent. Many clean heating policies have been promulgated, "coal to electricity" and "coal to gas" are actively carried out. However, because of economic conditions and district energy structure constraints, many regions have encountered resistance in the implementation of these policies. Clean coal technology and renewable energy auxiliary heating are gradually developed to solve space heating. The investigation of 10 cities and 8 county towns in Shanxi shows that 89.3% of rural residents use coal for space heating in winter (Xie Wolong, Zhang Huaide, et al.2018). The investigation of clean heating in Shandong rural areas has found that heating technology is mainly district heating, the proportion of district heating is 24 %(Zhao Jianbo, Shi Ying.2017). The survey of 15 rural areas in North China shows that poor thermal performance of rural building envelop is one of the main reason of large energy consumption in rural areas(Xu Shuhui, Liu Xiaorui.2015). The rural heating survey in Northwest China shows that the rural heating is dominated by fire Kang and coal fired boiler, proportion is more than

90%. The heating energy source is coal and biomass (Zhang Wei.2012). In addition, solar energy is rich in this area, under the encouragement of clean heating policy, many solar heating pilot projects are carried out. The main constraints of solar heating in Northwest China rural areas are limited roof areas, long distance between rural residents (Guo Huaiyun.2015).

Based on the current situation of rural space heating and economic development in various provinces, many provinces have formulated policies to support the development of solar heating in rural areas to alleviate the serious environmental and energy problems. Europe has also set up a number of SAGSHP projects, and operating successful, these solar plants provide reference for the design and operation for Chinese projects (LindenBerger D, Bruckner T, et al.2000. Nussbicker J, Heidemann W, et al.2005. Reuss M, Mangold D.2011. Pavlov G K, Olesen B W.2011. Sibbitt B, Mcclenahan D, et al.2012.). Hirvonen J summarized experience of solar assisted ground source heat pump system in Europe and America. The solar fraction of European has remained at a high level of 55% (Hirvonen J, Ur Rehman H, et al.). See table1.

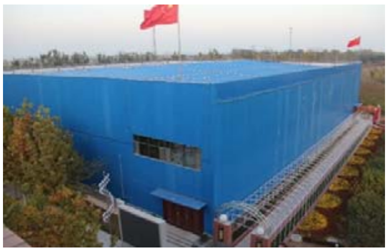
Table 1. Reference solar plants.

Solar plant	Solar collector area	BTES volume	Design SF	Operation SF	Scale of district heating
Germany Neckarsulm community	5263m^2	63360m^3(528 boreholes)	50%	30 ~ 40%	300 residential buildings
Germany Crailsheim community	7500m^2	37500m^3	-	35%	-
Denmark Braedstrup	18600m^2	19000m^3	-	41%	1500 buildings
Canada Drake Landing Solar Community	2312.8m^2	22094m^3(144boreholes)	-	96%	52 independent houses

Xiaowangjiapu village is located in the northwest of Yanqing County, Beijing. Including 180 village houses and one village committee, with a total heating area of 19000m^2. In 2017, a new SAGSHP heating and cooling system is built. In order to keep the heat balance of soil, solar heat is used to heat the soil. In this paper, based on the measurement and TRNSYS Simulation result of this system, we will evaluate the applicability of this technology in North China rural areas.

2. Solar community in North China

In China, there are 3 completed solar community, solar plant of Hebei university of economics and business, solar district heating plant of Xiaowangjiapu village, solar plant with tank thermal energy storage in middle flag of Bayannaoer, Inner Mongolia. Among them, solar plant of middle flag of Bayannaoer has been stopped running. A detailed description of other two solar plant in Figure 1 and figure2.



Solar plant of Hebei university of economics and business: all glass vacuum tube collector: 11600m^2, seasonal tank thermal energy storage: 20000m^3, design solar fraction: 60%.

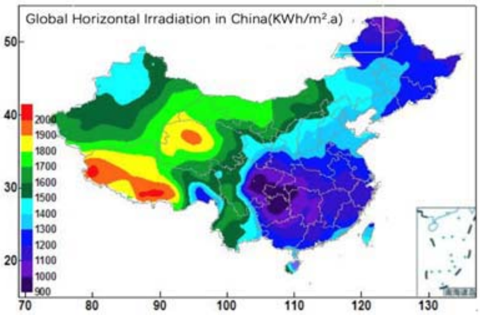
Figure 1 Solar plant of Hebei University of economics and business

solar district heating plant of Xiaowangjiabao village: ground mounted flat plat collector: 2400 ㎡, seasonal borehole thermal energy storage:508 boreholes with 100m depth, providing heating services for 180 houses. Design solar fraction: 45%.

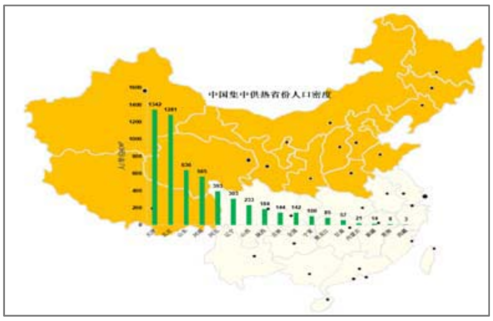
Figure 2 solar district heating plant of Xiaowangjiabao village

3. Advantage of SDH in China

Solar energy resources is rich in China. The solar annual irradiance of Tibet, Qinghai, Western Inner Mongolia and Eastern Xinjiang is above 1700KWh/ m^2 .a, and part of Tibet is more than 2000KWh/m^2.a. In addition to northeast area, annual solar irradiance of the traditional central heating area is above 1400KWh/m^2.a, which has energy advantage to develop solar district heating. On the other hand, area of central heating occupies 70% land area of China, but the population density of Gansu, Inner Mongolia, Xinjiang, Qinghai and Tibet in Northwest China is low, which is under 60 people /km^2, and the land is rich and cheap. See Figure 3.



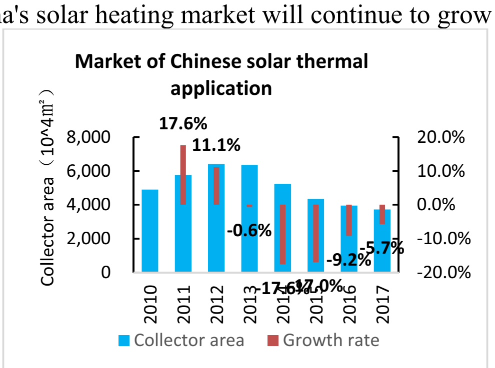
Solar resource of China



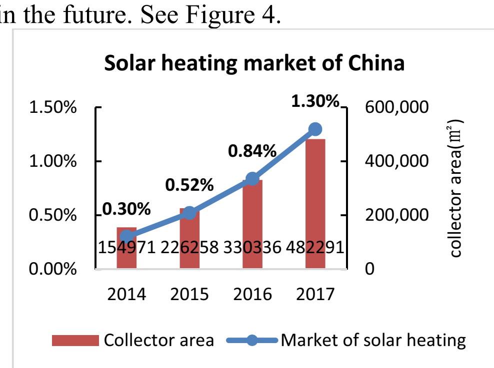
Population density of traditional central heating area

Figure 3 solar energy resource and population distribution of China

The market of solar thermal application in China has fallen sharply since 2013, but the solar heating market has been rising year by year, the average annual growth rate is about 45%. By 2017, the area of solar heating collector in China reached more than 480 thousand square meters, and the market of solar heating accounted for 1.3%. It can be predicted that with the development of clean heating in rural areas, China's solar heating market will continue to grow in the future. See Figure 4.



Market of solar thermal application in China



Market of solar heating in China

Figure 4 Market of solar thermal application and solar heating in China

From 2011~2016, central district heating area in China's villages and towns grew from 193 million to 523 millionm^2. Central district heating area of villages and towns in Beijing, Tianjin, Shandong, Inner Mongolia and Liaoning have developed rapidly. In particular, central district heating area of Shandong is much larger than other provinces, and the trend of growth is faster[29]. In 2016, the district heating area of villages and towns in Shandong reached 216 millionm^2. The rapid development of district heating in village and town level provides a strong support for solar village, which is beneficial to reduce the cost of solar plant heat transportation, and provide the possibility of solar heating network or other renewable energy heating network integrated with district heating network. See Figures 5.

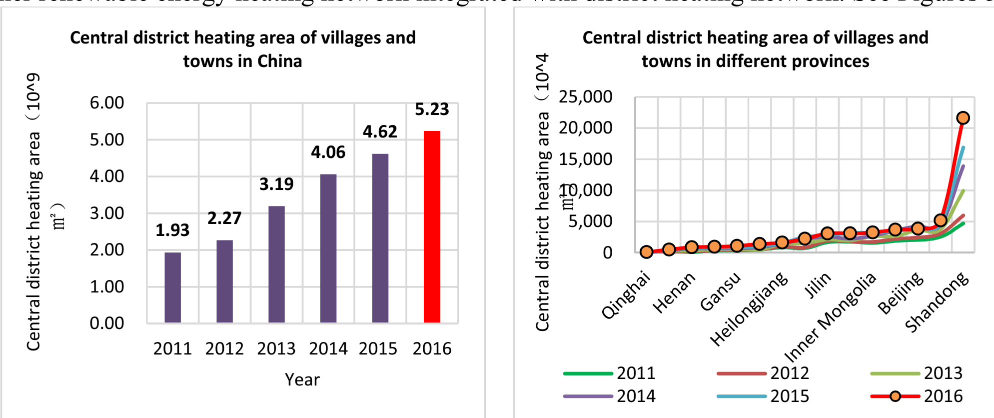


Figure 5 Central district heating area of villages and towns in China

Based on the above statistics and analysis, it is found that solar energy of central district heating area in northern China is rich, and these provinces has the inherent advantages to develop solar district heating. Village district heating of Beijing, Tianjin, Shandong province has developed rapidly, and urban area is basically covered by central district heating network. A large number of new district heating projects have also been built in villages and towns. Villages and towns also have rich land resources. Solar district heating should follow the route of "rural encircling the city", first, constructing demonstration projects in rural areas, and gradually extending to the county and urban outskirts. In North and Northeast China, the level of rural economic development is low, and lacking policies to promote the development of rural district heating, while the county towns district heating network will develop fast because of urbanization. At the same time, with the national "2+26" urban air pollution control and other clean energy heating policy support, solar district heating application should first consider county town. In Northwest China, the level of urbanization and economic development is far lower than the national average. The suburb has rich land area, the solar energy is rich, and the urban heating demand is large. At present, the solar district heating should be focused on the suburb of city. Qinghai and Tibet province is extremely rich in solar energy resources, the development level of urbanization is very low, and the urban area has sufficient land area. At the same time, in order to protect the local fragile ecological environment, the government strictly limits the use of fossil energy. Therefore, the development of solar district heating has become an important choice. Development trend of solar district heating in China see Table 2.

Table 2. Development trend of solar district heating in China.

The development stage / district of solar district heating	Beijing, Tianjin, Shandong	North China	Northeast China	Northwest China	Qinghai, Tibet
Stage I	Village	County town, town	County town, town	Suburb, industrial park	City, county town
Stage II	County town, town	Village	Village	County town, town	City, county town

Stage III	Suburb, industrial park	Suburb, industrial park	Suburb, industrial park	Village	Village

4. Case analysis of Xiaowangjiapu solar village

SAGSHP is mostly used in China (except Tibet). This paper will focus on SAGSHP district heating, through test and simulation analysis of the demonstration project, discussing the application of SAGSHP in North rural area. The research project is Xiaowangjiapu solar community. This system design idea is to provide heating and cooling service with ground source heat pump. The heating load in Yanqing is far greater than the cooling load. Therefore, the use of ground source heat pump for heating and refrigeration will inevitably lead to soil supercooling, so as to ensure heat balance of soil, the solar energy will be added to soil.

In order to evaluate the performance of this system, the solar irradiance, outdoor temperature, outdoor relative humidity, wind speed, the out water temperature of evaporator and condenser of ground source heat pump unit etc. are measured. 5 typical households were selected to measure the heating demand of building by installing remote transmission protocol heat meters, and indoor temperature and relative humidity of heating rooms were tested by Temperature and humidity meter. The numbers are No1~5, of which No1 and No4 are existing buildings, No2 and No5 are new buildings, No3 is an existing building, but no one lives in the early stage. The test time is 2018/01/20~2018/02/20. The test results show that district heating system can meet the requirements of the design temperature 18℃, the heating demand per unit area is about 50W/m^2, the heating room temperature and the unit area heating demand are shown in Figure 6 and Figure 7.

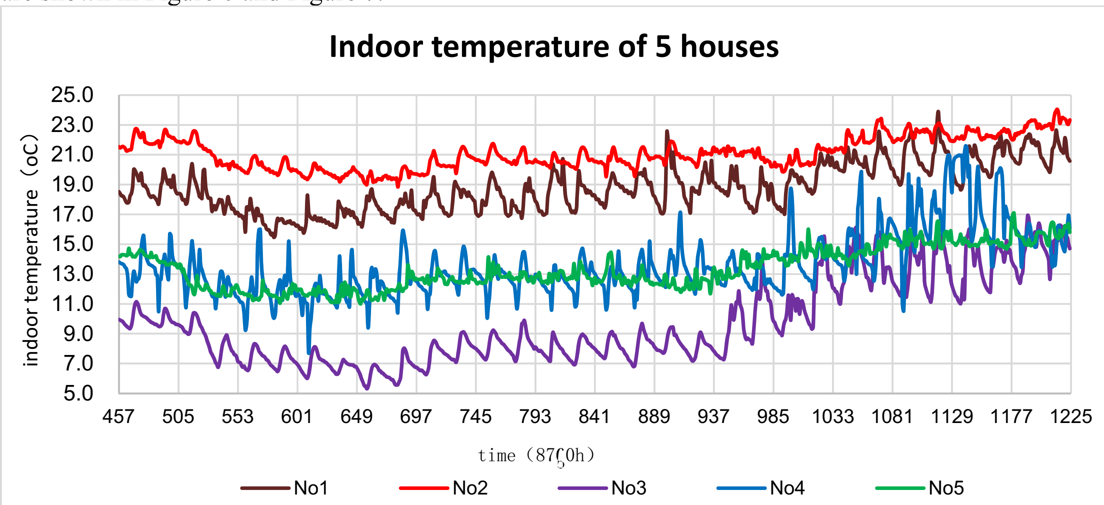


Figure 6 Indoor temperature of 5 houses

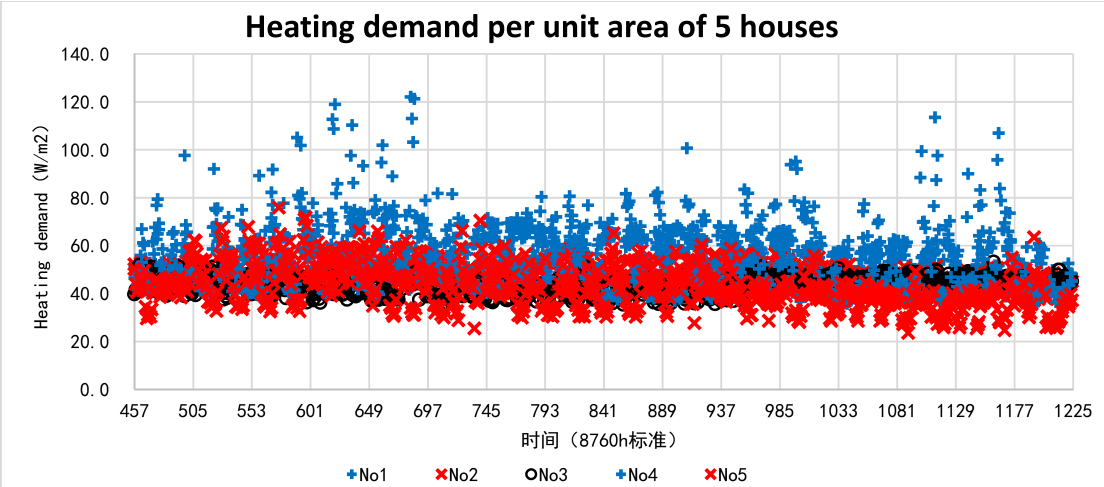


Figure 7 unit area heating demand

It can be seen from the figures that No. 1 and 2 indoor temperature reached 18℃, but the indoor temperature of No. 3, No. 4 and No. 5 did not meet the design temperature requirements, there are two reasons for this difference.

1) The thermal comfort demand of rural residents is lower than that of urban residents.
2) The large south window-wall ratio will cause more solar radiation during the day, so residents will automatically adjust the terminal position of the hot air heating to reduce the heating demand.
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4.1. TRNSYS model

System simulation model is established by using TRNSYS 18.0, see figure8. The solar irradiance, outdoor temperature and humidity, heating demand are used as the input parameters of the software. The model is checked and verified by comparing the outlet parameters and the measured parameters of the HP evaporator and condenser.

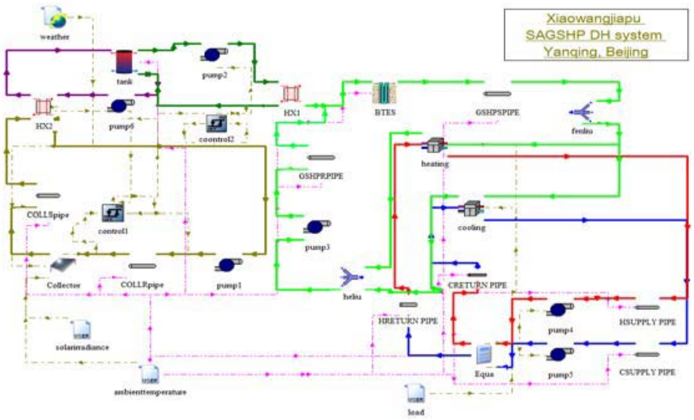

Figure 8 TRNSYS model of Xiaowangjiapu SAGSHP

Xiaowangjiapu village district heating system is equipped with two heat pump units. The heat capacity of single heat pump unit is 916.9KW, and cooling capacity is 929.KW. The water supply temperature of district heating network in winter is 40.5℃, and cooling supply water temperature is 14℃ in summer. The water temperature of the heat pump evaporator side and condenser side are simulated during the period of 02-10 ~ 02-20 in 2018. The time step is 2 minutes. The average water temperature in the source side of the two heat pump units is 6.5℃, 7.3℃, and TRNSYS simulated water temperature is 7.0℃, based on the measured result, error is 5.9%. The measured average temperature of heat pump units load side is 40.7℃, 40.6℃, and the TRNSYS simulated temperature is 43.0℃, the error is 4.9%. So it can be seen that the TRNSYS model is reliable.

4.2. All-year TRNSYS simulation analysis

Based on the above TRNSYS model, see figure8. Using the Energy plus meteorological document as the input parameter, through classification and investigation of village buildings, the information of the building envelope is obtained. And then building model is established for the year load calculation. The district heating and cooling load document is input into the TRNSYS model to conduct the annual system performance simulation analysis.

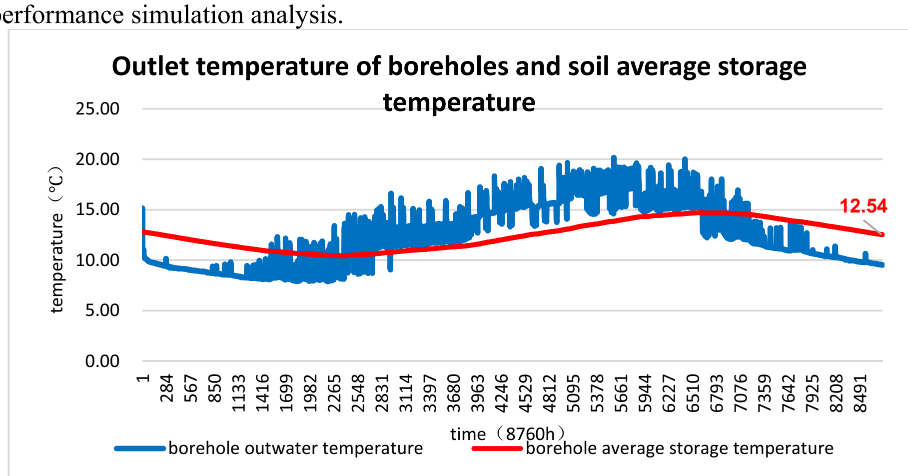

Figure 9 outlet temperature of boreholes and soil average storage temperature

The average temperature of outlet temperature of boreholes is 12.44℃, the average storage temperature of the soil heat storage is 12.51℃, the final temperature of the simulation is 12.54℃ in whole year, and the decrease of the initial temperature of the soil is 0.26℃ compared to the initial temperature of the soil 12.8℃. See Figure 9. The solar heating fraction in the first year is only 17.6%, which is lower than the design solar fraction. The reason for low solar fraction in the first year is that the soil does not carry out preheating and soil loss is large in the first year.

5. Conclusion

This paper analyzes the development direction of solar district heating in China from three aspects: current situation of rural heating, status of solar heating in rural areas and the development of solar district heating in China. Combined with the research accumulation of ground source heat pump and construction experience, it is considered that SAGSHP district heating is the priority development direction of solar district heating in China. Taking Xiaowangjiapu village solar district heating demonstration project as an example, testing the performance parameters of the heating season, and the software model is established for the whole year simulation analysis. The test data show that this system can meet the design indoor temperature requirement, but the thermal comfort requirements for the rural residents are low, Based on the minimum tolerance of thermal comfort, rural residents will actively adjust the hot air volume which can decrease heating demand, behavior of heating end device adjustment to reduce heating cost is the direct reason for large difference of actual heating demand and indoor temperature. Therefore, the calculation of district heating load between city and village is quite different. The simulation results show that COP of HP unit in the whole year is 3.3, but the solar fraction is only 17.6%, which is lower than design solar fraction.

6. References

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Acknowledgments

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