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Research on Solar Heating Technology for Rural Single-Family Homes in Severe Cold and Cold Zones of China

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Abstract

China's solar energy resource is very abundant because of its vast area.The fact that the amount of solar energy growths with increasing latitude is just perfect suit for the heating demand of China. Currently, the technology of solar heating mainly focus on three issues: firstly, solar heat supplementary questions, secondly, safety issues of solar products, thirdly, solar system optimization problems. Take into consideration of general solar heating systems used in China, and follow the principle of priority use of the environmental heat resource, a solar thermal storage heating system and a solar air source heat pump combined heating system were established respectively under the TRNSYS platform. In the viewpoint of room temperature guarantee, the heat pump system performed better than the energy storage system. But the former expended much more electricity than the later. Finally, taking the comprehensive performance coefficient (SCOP) into consideration, the thermal storage system suits better for practical use in rural zones of China.

Keywords **:**solar heating; solar thermal storage; solar air-source heat pump combined system; coefficient of system performance; SCOP

1. Solar Resource Distribution in Severe Cold and Cold Regions

China's solar energy resource is very abundant because of its vast area. It is estimated that China's land surface solar radiation is about 50x1018 kJ each year, total annual solar radiation throughout the country is up to 3350 ~ 8370MJ / (m^2 • a), the mid value is 5860 MJ / (m^2 • a) [1]. The typical distribution of solar energy resources is: the highest and lowest values of the solar resource centralized in north latitude 22 ° ~ 35 °area. The Tibetan Plateau's solar energy is richest, and that of Sichuan is lowest. The distribution of solar energy varies with latitude law contrary, the fact that solar energy is increasing with the demand of heating demand provide a perfect chance for solar heating technology application[2].

As can be seen, solar resource varies in the same climate zone, but two-thirds of the severe cold and cold zones belongs to the rich solar resource zones, especially, Most parts of Qinghai, parts of Xinjiang and Tibet own abundant solar energy resources, these areas belong to the heating area. This will surely promote the solar heating technology application.

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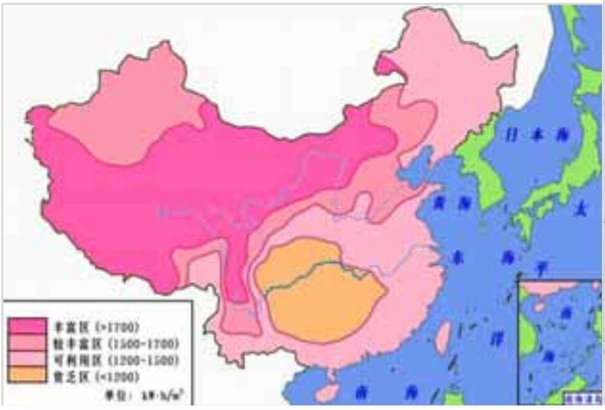


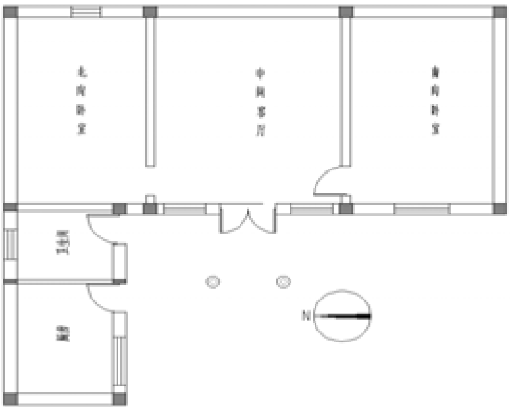
Fig.1:solar energy distribution in china **Fig.2: climate zone of china**

2. Energy Analysis Mode for Single-Family Building

Single-family residential dwelling is the most popular type in China's vast rural areas. Because of its small size, low total energy consumption, less the number of users, you can control its energy conveniently, these advantages provides a convenient use of solar energy resources.

Single-Family Building generally has the following characteristics: firstly、 Dispersion. As the rural economy accounting unit and product batch is generally small, decentralized operation and other reasons, often farmers scattered single-family residence, for productive activities in their residential area. Secondly, Compactness. Individual farming due to technical conditions, labor limit, rural house only for farmers living and storage life supplies to meet daily needs, it is generally small. Thirdly, small load. The general population of a single-family dwelling is about 4 to 6 people, which limit the need of heat. Fourth, more available space around the building. Due to the influence of traditional architectural forms, single-family-style farm house usually has a pitched roof, which just suit the arrangement of the solar collector. These unique characters create conditions for the use of solar energy in rural areas.

The analyze model came from an actual farmer dwelling lie in Qili town in Gansu province. The house has the typical features of a traditional farm house, with a typical representative in China.



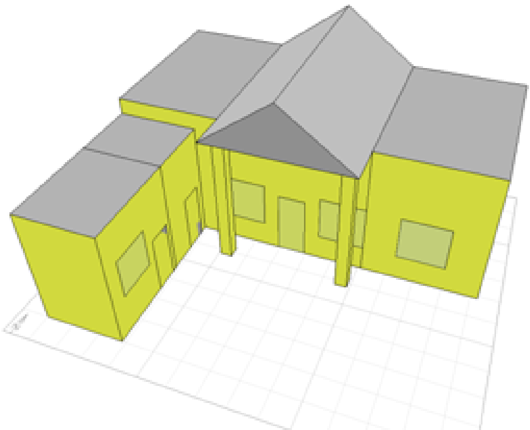


Fig.3: thermal zone of the model **Fig.4: 3Dmodel of the building**

Residential house is divided into two bedrooms, a living room, kitchen and bathroom, building with a pitched roof. the south side sloping roof can be arranged about 20 m2 solar collectors.

Due to the large area of cold regions in China, we choose four typical cities according to their Heating Degree Hours (HDH) and the Annual Amount of Solar Radiation (ASR). They are Lhasa in Tibet(high ASR, low HDH), Huhhot in Inner Mongolia(high ASR, high HDH), Altay in Xinjiang (low ASR, high HDH), and Beijing(low ASR, low HDH). We distinguish their climate zone by the amount heating demand and solar energy zone by daily average radiation. The HDH value is used to measure the heating demand, which can be calculated by summarizing the difference between hourly outdoor dry bulb temperature and the designed room temperature. We got the ASR value by integrating the hourly Solar Radiation value.

Tab. 1: Typical areas of heating degree hours and the annual amount of radiation

zones	Beijing	Hohhot	Lhasa	Altay
HDH /℃·h	62522	94326	63958	107970
ASR /MJ/m^2	4770.78	5579.58	7335.51	3955.18

Currently, the use of solar heating generally considered three issues need to be addressed: Firstly, auxiliary heat source. Building need to be heated continuously even at night , when the solar energy can’t be used. Secondly, the safety performance problems of solar products, namely the cracking problem in heating season and overheating problem in cooling season; Thirdly, the problem of solar piping system optimization[3].

To solve the above problems, we choose flat type air collector to use, and study on solar thermal storage system and solar air source heat pumps combined heating technology. This study focus on the heating performance difference between different technology scheme. In TRNSYS platform, establish these two systems analysis model for annual simulation. Analysis model contain these characters below :1) Conduct heating in heating season , and execute natural ventilation in non heating season . 2) Every analysis model contain the same solar collection system . 3) Each system has the same operation schedule.4) Using pebble bed as a thermal storage medium for thermal storage system. Air heated by solar collector flow through the pebble bed and then be cooled . In this process, the solar heat is saved in the pebble bed underground .At night , heat resource will be removed by low temperature air flow .5) No auxiliary heat resource .

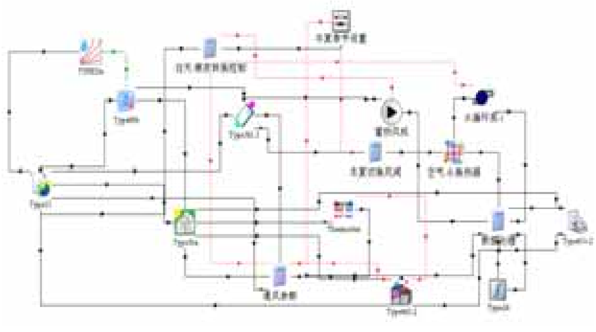


Fig.5:Solar-air source heat pump combined system

Fig.6:Solar thermal storage with pebble bed system

The main parameters of the system are bellow :

Tab. 2: The main parameters of the systems

<table>
<tr><th rowspan="2">Solar-air source heat pump combined system</th><th>Collector area</th><th>angle of dip</th><th>Emissivity</th><th>Air flow</th><th>Fresh air ratio</th><th colspan="2">Heating temperature extremes (℃)</th></tr>
<tr><td>20m²</td><td>Local latitude</td><td>0.94</td><td>400kg/h</td><td>0.1</td><td colspan="2">-20℃</td></tr>
<tr><th>Solar thermal</th><th>Collector area</th><th>angle of dip</th><th>Emissivity</th><th>average density of</th><th>Specific heat of</th><th>Air flow</th><th>Volume of</th></tr>
</table>

storage with pebble bed system	20 m^2	Local latitude	0.94	**pebble** 2200kg/m^3	**pebble** 0.8kJ/kg·K	400kg/h	**pebble** 30m^3

3 .Comparative Study of Rural Solar Heating Technology

Because of its relatively scattered, low-density, large investment character, Rural housing is not fit for central heating . As a kind of renewable resource, solar energy perform well in house heating. In the principle of rational use of environmental energy resource, we should take heat from the environment as much as possible to improve the indoor environment temperature. Current heat from the environment come from two main options: First Solar, the second is a heat pump (air, soil, water). We choose the solar energy and air as a heat source to study .In the TRNSYS platform we built a Solar-air source heat pump combined system and a Solar thermal storage with pebble bed system to find the room temperature variation character effected by the rational use of solar energy. Finally, we got comparative study result from the two system .

The indoor air temperature distribution result of natural ventilation (building insulation only), solar pebble bed heat storage, solar air source heat pump are shown below.

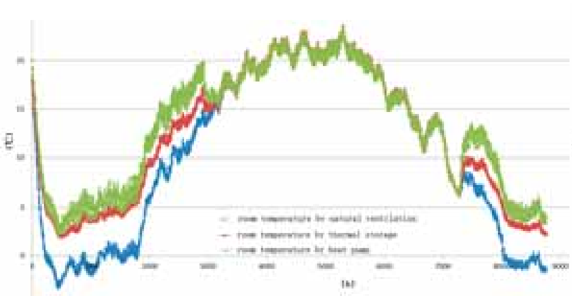
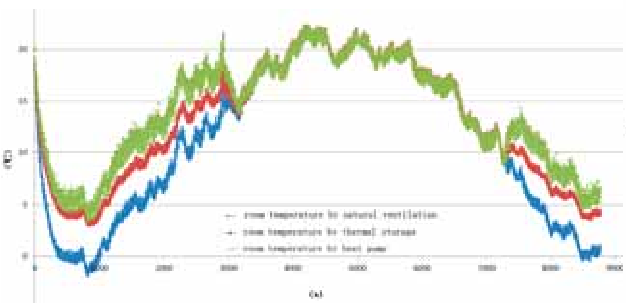


Fig.7: Temperature of room in 3 ventilation condition in Altay Fig.8: Temperature of room in 3 ventilation condition in Beijing



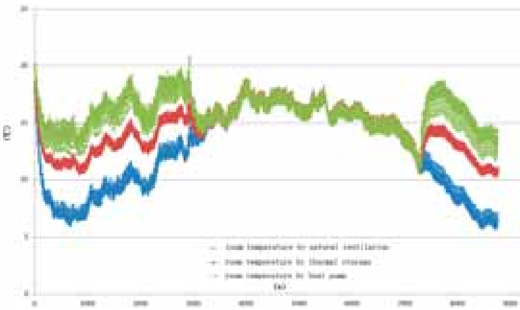
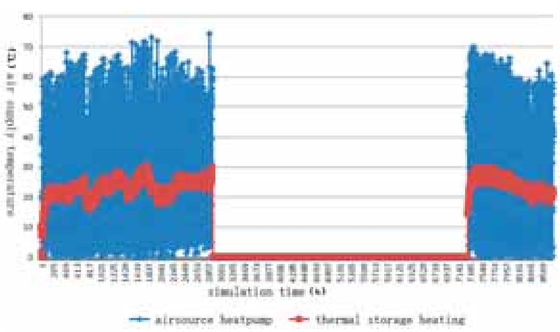


Fig.9: Temperature of room in 3 ventilation condition in HohhotFig.10: Temperature of room in 3 ventilation condition in Lhasa

As can be seen, after application of solar thermal storage, heat pump technology, indoor air temperature significantly improved in heating season, compared with nature ventilation. The average indoor temperature enhance about 6 ~ 8 ℃. Mostly, air-source heat pump operate better than solar heat storage system at night. This is mainly because the heat pump heating condition is relatively stable, the air outlet temperature is higher than the air out from pebble bed. We can conclude that heat generated from air by heat pump is more than that from heat storage bed.

For the study of performance differences in day and night, we conduct a comparative research on the heat supply temperature between the two system in Altay and Lhasa area. The conclusion is that the average air supply temperature of heat pump is about 24 ℃ in annual heating season, that of thermal storage heating system is of about 12.6 ℃. The average heating temperature difference is nearly doubled. The graph below showed the difference.



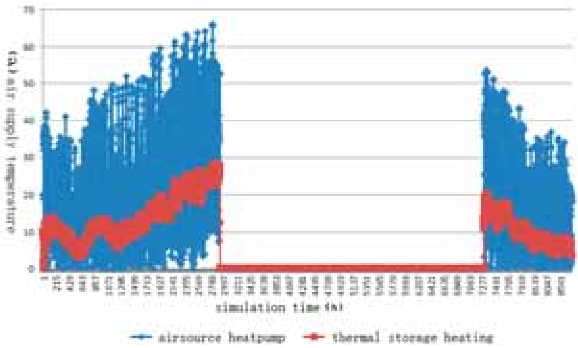
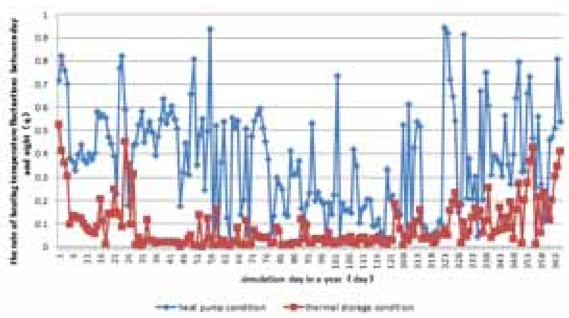


Fig.11: T-supply of heat storage and heat pump in Lhasa   Fig.12:T-supply of heat storage and heat pump in Altay

As can be seen, the air supply temperature of heat pump system fluctuate obviously throughout the year. The main reason is that at dusk and early morning the amount of radiation and the outdoor temperature are very low, but the heat pump system shutdown during this period, so the supply air temperature is low. This period is about8:00am to 10:00am, and 19:00pm to 20:00pm. Heat pump system showed poor stability Under simulated conditions . So, we defined a parameter called "the rate of heating temperature fluctuations between day and night(η)" to measure the heating effect differences between day and night of the two typical heating systems.

$$\eta = \frac{|max\ heatingtemperatureinday - max\ heatingtemperatureinnight|}{max\ heatingtemperatureindayandnight} \quad \text{(eq. 1)}$$

The "η" value distribution character of the two system in the four typical cities showed below.



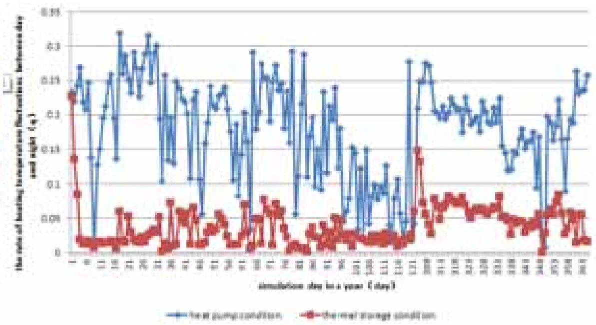


Fig. 13:Theη value in Lhasa Altay   Fig. 14:Theη value in Lhasa Lhasa

As can be seen from the figure, in the solar collector and the air source heat pump combination heating system, the two systems run at their respective temperature during the heating time. Solar collector system export parameters is completely dependent on the instantaneous amount of solar radiation, but air source heat pump in heating condition is largely constrained by night instantaneous air temperature, this lead to the obvious heating supply difference during the day and night, heating mode instability, and poor thermal comfort. Due to the presence of the storage material, collector thermal storage system heating temperature is relatively evenly distributed throughout the year, the annual heating temperature differences between day and night is small, most of the time. The indoor temperature distribution and heating conditions comparison of the two system showed by the table below.

Tab. 3: The annual heating conditions Statistics

	Solar thermal storage with pebble bed system		Solar-air source heat pump combined system			
zones	Heating	Heating	Heating	Heating	COP of	standard

	indoor average temperature /℃	temperature standard deviation / ℃	indoor average temperature /℃	temperature standard deviation / ℃	Heating	deviation of COP
Beijing	12.19	3.24	14.84	2.98	2.64	0.35
Hohhot	8.86	3.70	10.83	3.92	2.23	0.43
Lhasa	13.04	1.51	15.61	1.85	2.70	0.31
Altay	7.45	4.17	9.22	4.48	2.11	0.48

As is shown above, the annual standard deviations of the two systems are not small enough, in the absence of other auxiliary heat resource, the two types of systems completely rely on the environment (air, sunlight), but we know, the environment parameters change transiently. That is the reason why fluctuation occur. This fluctuation is more pronounced in these heating systems rely on solar energy as the main heating resource.

The indoor temperature of Solar-air source heat pump combined system is more than that of Solar thermal storage with pebble bed system about 2~2.5℃. That reflect the better heating function of air source heat pump. But we can see, in these areas HDH value is more than 80000℃·h, the heating COP of air source heat pump decrease obviously. With further decrease of temperature at night, the heat pump operating conditions tend to worse. This resulted in more need of heating area, the application of air-source heat pump units but more subject to limit. We made a further study on the entire effective heat gain (system effective heat transfer to the medium)、total heat release of storage system, total heat generation of pump system. Research data are shown below.

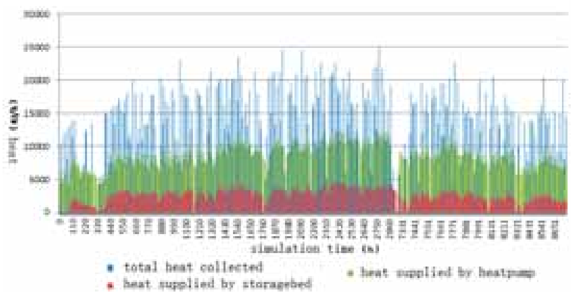


Fig. 15: heat production and supply data in Beijing

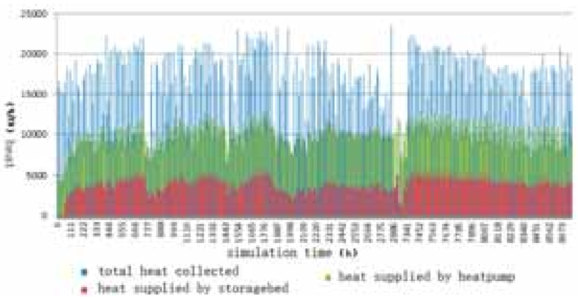


Fig. 16: heat production and supply data in Lhasa

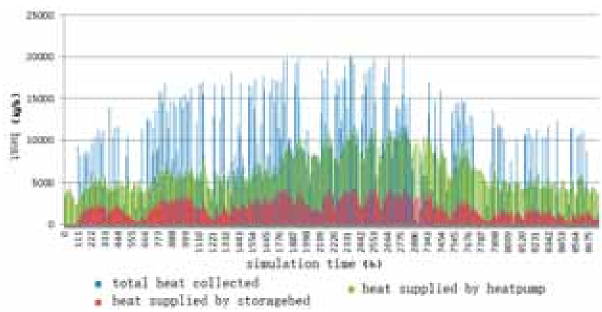


Fig. 17: heat production and supply data in Altay

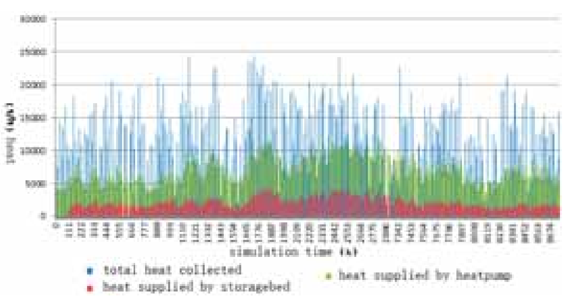


Fig. 18: heat production and supply data in Hohhot

The conclusion is that the amount of energy supplied by heat pump system is nearly 2 times that of the storage system at night. Just from the viewpoint of heat supply amount, the heat pump system performed better. Through a more in-depth study, we counted the annual energy consumption of the two systems and got the system performance coefficient which we marked as "SCOP". SCOP is the ratio of the total providing heat and the electricity consumed by the system the same time.

Tab.4:The annual heating energy consumption status in each typical city

Typical cities	Solar Thermal Storage Heating System			Solar Air Source Heat Pump Combined Heating System		
	Energy consumed	**Heat provided**	**$SCOP_S$**	**Energy consumed**	**Heat provided**	**$SCOP_P$**
Beijing	485.4kW·h	1751kW·h	3.61	1217kW·h	3492kW·h	2.87
Huhhot	469.8kW·h	1402kW·h	2.98	1128kW·h	2765kW·h	2.45
Lhasa	457.8kW·h	2613kW·h	5.71	1177kW·h	3346kW·h	2.84
Altay	522.6kW·h	1384kW·h	2.65	1131kW·h	2599kW·h	2.30

The table above shows the SCOP of solar thermal storage heating system is always much better than that of the solar air source heat pump combined heating system. The comprehensive judge based on HDH and ASR can provide us the appropriate proposal for plan determination.

The ability to obtain heat from the environment can be used as the basis to measure the energy-saving potential of the system. Many factors affect the assessment result of the heating systems. In the viewpoint of room temperature guarantee, the heat pump system performed better than the energy storage system. But the former expended much more electricity than the later. Finally, taking the comprehensive performance coefficient (SCOP) into consideration, the thermal storage system suits better for practical use in rural zones of China.

4. Conclusion

Today, in turning to the commercialization of rural energy structure, the growth in energy demand in rural areas is gradually increasing our energy burden. Relatively abundant solar energy resources in the majority area of the severe cold and cold areas provide the opportunity to solve this problem. Finally, benefits the whole country.

In the principle of rational use of environmental energy resource, we built a Solar-air source heat pump combined system and a Solar thermal storage with pebble bed system to study. Under the two TRNSYS analysis platform, the heating effectiveness of the two systems in the night can be studied. Theses parameters including room temperature, rate of heating temperature fluctuations between day and night, heating energy consumption, Coefficient of System Performance, etc can be used to measure the heating effectiveness. The main conclusions are as follows: 1) Mostly, air-source heat pump operate better than solar heat storage system at night, indoor temperature of heat pump is higher than that of heat storage system. This will lead to a better room thermal comfort. 2) In severe cold regions, the heat pump is running at low coefficient, in these zones, heat storage system perform better than heat pump system. 3) Because of the little room temperature difference, and taking the comprehensive performance coefficient (SCOP) into consideration, the thermal storage system suits better for practical use in rural zones of China.

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