ANALYSIS OF SOLAR SEASONAL STORAGE IN RURAL RESIDENCES WITH ZHONGYUAN REGION AS AN EXAMPLE

by

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A combined system of refrigeration and heating unit with seasonal solar thermal storage was presented in this paper. Based on the climate character of the Zhongyuan region, China, the system's performance in rural residences was studied. A computational program was established based on the DEST software, the solar heat collecting capacity, heat collecting efficiency, and other parameters were analyzed. The results showed that the system can supply 76.28% heating load and 40.14% cooling load, when the total collector surface area equals to 40 m^2 and heat collecting temperature is 80 °C. The results will provide theoretical support for the system's optimization.

Key words: *solar energy, seasonal storage, rural residence, combined refrigeration and cooling system*

Introduction

The importance of using renewable energy sources is significant with the energy crisis growing. The utilization of renewable energy such as solar energy and geothermal energy has been paid more and more attention. The solar seasonal storage system has an obvious effect in decreasing the air-conditioning energy consumption of buildings. Storing thermal energy, or heat, from the Sun for long periods of time is often referred to as seasonal solar thermal energy storage (SSTES).

In recent years, many researches have been to expand wider application for SSTES in the field of air-conditioning by utilizing solar energy. The representative examples of the buildings that use seasonal solar thermal storage system are Douglas Villa of China Solar Valley and a single-family house in Malaga, Spain [1, 2]. Some other buildings utilizing this system also have a good result, such as Drake Solar Community in Canada, Anneberg residential area in Sweden and a seasonal heat storage reservoir vessel has a capacity of 12.000 m^3 in Friedrichshafen, Germany [3-5]. Eleven solar heating plants with seasonal heat storage were built in Germany from 1996 to 2010 in the programs of *Solarthermie 2000* and *Solarthermie 2000 plus* [6]. Tao *et al.* [7] studied a solar heating system with seasonal thermal energy storage in Hebei, China. Wang *et al.* [8] presents the experimental study of a solar-assisted ground-coupled heat pump system with solar seasonal thermal storage installed in a house in Harbin, China. Ye [9] studied a solar assisted ground source heat pump system in an office building, and the solar fraction reach 62.5% under the given calculation condition. Wang

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et al. [10] analyzed the experimental data of solar storage uniting soil source heat pump system, and the *COP* value is largest compare with two kinds soil source heat pump. Zhu *et al.* [11] proved that the *COP* of solar seasonal storage coupling with ground-source heat pump system and heat pump unit increased 3.4% and 2.4% compared to the operation data without solar seasonal storage.

From the cited literatures, it is confirmed that refrigeration and heating with seasonal solar thermal storage system (RHSSTSS) would widely be used in the future. However, the study of the RHSSTSS in Zhongyuan region is has not been archived in the literature. In the present study, a computational program has been established based on the DEST software, and the performance of the RHSSTSS has been researched about a 200 m^2 rural residence located in Zhongyuan region.

Description of the RHSSTSS

The RHSSTSS is composed of thermal collecting system, heating system, cooling system, and hot water storage system. Figure 1 shows the schematic of RHSSTSS. In this system, the floor radiant system is used in winter, and the solar ejector refrigeration system has been researched by our research group [12, 13]. Heat gained from solar collectors is transported into the central solar heating plant and distributed to the residence. In transition season, the excess energy will be stored in the underground energy storage region when domestic hot water supply can be met. In cooling or heating season, give priority to the use of thermal collected on that day, followed by the thermal stored in transition season. At last, the conventional air-conditioning systems will be used when the thermal stored can not meet the air-conditioning demand.

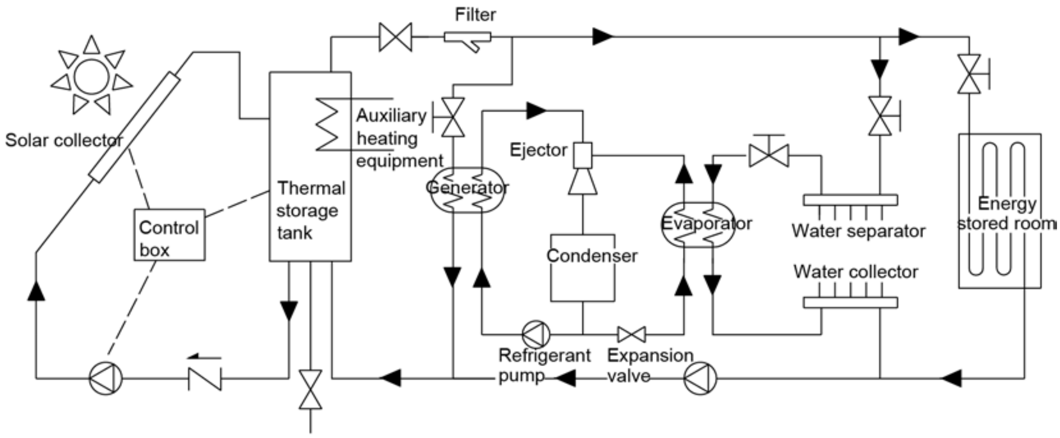

Figure 1. The schematic diagram of RHSSTSS

Figure 2 shows the solar energy distribute in various regions of Henan province based on the measurements of the meteorological data in Henan meteorological offices from 1971 to 2003 [14], and the rich solar energy resources of Zhongyuan region can supply a strong guarantee for promoting RHSSTSS from the fig. 2.

Mathematical model

Based on the evacuated tube collector area equals to 40 m^2 and the villa area equals to 200 m^2, the hourly heating load and cooling load of the residence is calculated by the DEST software (the building thermal environment simulation design software packages), and the data of typical meteorological year in Zhengzhou area is from [14]. Table 1 shows the time division of heating season, cooling season and transition season, and the distribution of solar energy in each stage.

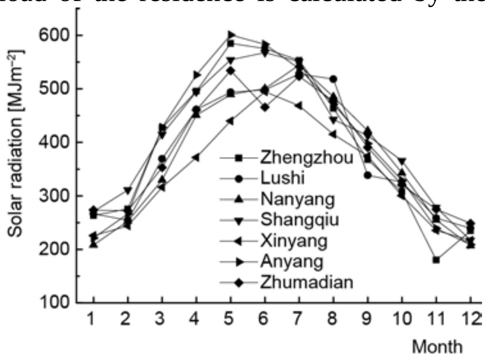

Figure 2. Analysis of solar energy resources in Henan province

Table 1. Each stage of time division and solar energy distribution

Stage	Period	Application
Heating season	11.15-3.15	Heating, hot water
Transition season	3.16-5.31	Thermal storage, hot water
Cooling season	6.01-8.31	Cooling, hot water
Transition season	9.01-11.14	Thermal storage, hot water

The calculation flow chart of this system is shown in fig. 3. The 200 m^2 rural residence calculation model was designed by DEST software, and the hourly heating and cooling load of residential building in Zhengzhou region is calculated. The meteorological data based on *China building thermal environment analysis dedicated meteorological data sets* [14].

The heating rate is analyzed based on the meteorological conditions from September to March in Zhengzhou, when the evacuated tube collector area equals to 40 m^2 and the rural residential building area equals to 200 m^2 in this paper.

The efficiency of an evacuated tube solar collector is defined by:

$$\eta_{sc} = \alpha - \beta \frac{T_i - T_{amb}}{G} \tag{1}$$

The energy collected by solar collector is:

$$Q = G A \eta_{sc} \tag{2}$$

where α and β are the collector characteristic coefficients and $\alpha = 0.80$, $\beta = 3.5$ for the evacuated tube collector in this research. The T_i represents inlet-temperature of the collector, and it could be commonly taken as 10 °C greater than the generator temperature as an assumption. That is, $T_i = T_g + 10$ °C. The G is the average total solar radiation, T_{amb} is the ambient temperature, and A is the solar collector area.

Based on the performance equations, and neglecting the electricity input to the pump, the overall coefficient performance of the system is:

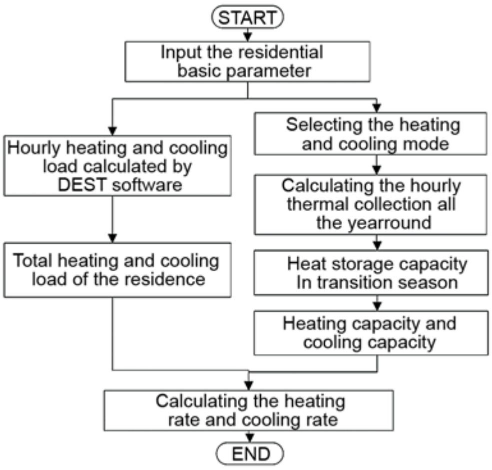

Figure 3. Flow chart of this solar seasonal storage system

$$COP_0 = \eta_{sc} COP \tag{3}$$

where *COP* is the coefficient performance of the normal ejector cooling system, and η_{sc} – the efficiency of an evacuated tube solar collector.

The cooling capacity of solar ejector cooling system is:

$$Q_e = COP_0 \, G \, A \tag{4}$$

Based on the previous analysis, designed and developed a parameter simulation model about solar seasonal storage system. The input parameters includes solar radiation, solar collector area, residential area, the output parameters includes the cooling and heating load, thermal collection, heating capacity and refrigeration capacity.

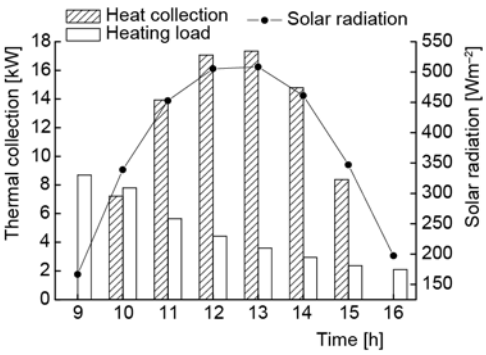

Figure 4. Hourly variation of the thermal collection and heating load on December 28

Results and discussion

Figure 4 gives the hourly variation of thermal collection and building heating load with solar radiation. It can be seen that the thermal collection increases with solar radiation increasing, and the maximum value can be reached 14.79 kW at 14:00 p. m. By the detailed calculation, it is determined that the RHSSTSS system can meet 67.5% of the total heating load in that day.

Figure 5 shows the daily heat collection from September to March. Figure 6 gives the relationship among the monthly heat storage capacity, the heating capacity supplied by solar heat collection and the heating load of the residence in transition season. It is found that the quality of heat supplied by thermal stored in transition season is 1.17, 2.65, and 0.93 MW for November, December, and January, respectively.

Based on the calculation results using previous calculation process, the thermal collected capacity and stored capacity are obtained in the transition season and heating season. The heat loss rate of the storage system is set to 30% referring to the previous experiment and simulation results in [7, 8]. As can be seen from the tab. 2, the heating rate can increase 33.29% when the thermal storage system was adopted.

The hourly variation of the cooling capacity, cooling load and solar radiation during the June 19 in the cooling season for the operating temperatures (T_g = 353 K, T_e = 283 K, T_c = 303 K) is shown in fig. 7. From fig. 7, one can

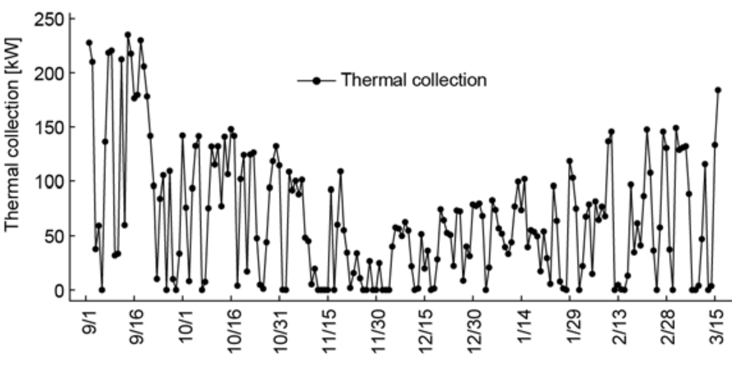

Figure 5. Daily heat collection from September 1 to March 15

see that the refrigeration capacity increases first and then declines by the time sequence, and reaches the maximum value during 12:00 a. m.~14:00 p. m., and the maximum refrigeration capacity can reach about 12.93 kW. The hourly refrigeration capacity fluctuates from 6.2 kW to 13 kW between 8:00 a. m.~17:00 p. m. The refrigeration capacity of RHSSTSS can undertake 167% of the cooling load during 8:00 a. m.~17:00 p. m.

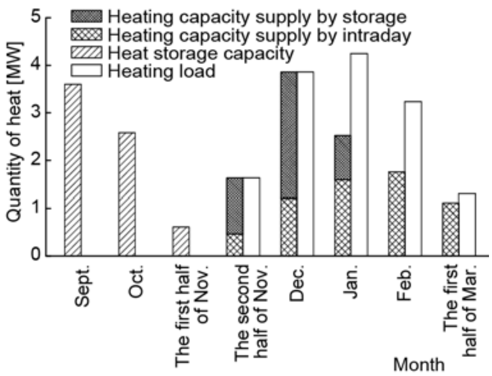

Figure 6. The comparison diagram of heat supplies and heating load

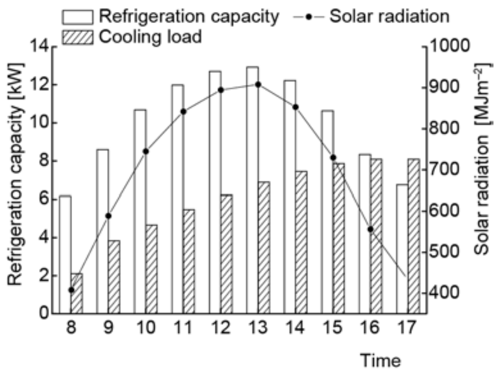

Figure 7. Hourly variation of the refrigeration capacity and cooling load on June 19

Table 2. The analysis of heating rate

<table>
<tr><th></th><th colspan="2">General heating capacity [MW]</th><th>Heating load [MW]</th><th>Heating rate [%]</th></tr>
<tr><td rowspan="2">RHSSTSS</td><td>Quantity of heat storage in transition season</td><td>Heat energy collected in heating season</td><td rowspan="3">14.274</td><td rowspan="2">76.28</td></tr>
<tr><td>6.790</td><td>6.136</td></tr>
<tr><td>SRHH*</td><td colspan="2">6.136</td><td>42.99</td></tr>
</table>

*SRHH - solar refrigeration and heating hybrid system.

Figure 8 gives the relationship among monthly heat storage capacity, the refrigeration capacity, the refrigeration capacity and the cooling load of the residence in transition season. In this paper, the 2.16 MW refrigeration capacity can be provided by the thermal storage in transition season.

Based on the calculation results, tab. 3 illustrates the cooling rate of the combined refrigeration and heating system with or without SSTES system.

In summary, the RHSSTSS can meet 76.28% of the heating load and 40.14% of the cooling load in the 200 m^2 rural residence with 40 m^2 solar collector. The SRHH system only undertake 42.99% of the heating load and 25.51% of the cooling load.

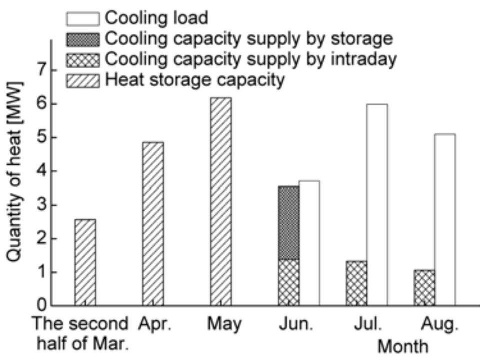

Figure 8. The comparison diagram of refrigeration capacity and cooling load

Table 3. The analysis of cooling rate

	General cooling capacity [MW]		Cooling load [MW]	Cooling rate [%]
RHSSTSS	Quantity of heat storage in transition season	Cooling capacity in cooling season	14.79	40.14
	13.6	3.78		
SRHH	3.78		14.79	25.51

Conclusion

Based on the 200 m^2 rural residence located in Zhongyuan region, the principle of the combined refrigeration and heating with seasonal solar thermal storage system was introduced in this paper. The heating rate and cooling rate is analyzed when the evacuated tube collector area equals to 40 m^2 combine the climate character of the Zhengzhou region. The results can be summarized as follows.

- The RHSSTSS can supply 76.28% heating load for the residence in winter.
- The heating rate can increase 33.29% compared with the traditional solar heating system.
- The system can provide more than 40.14% of summer cooling load, enhancing cooling rate by 15% compared with the system without thermal storage under the condition of $T_g = 353$ K, $T_e = 283$ K, and $T_c = 303$ K.

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