Simulation Study on the Optimization of Solar Water Heating System in Passive Solar House - Case Study

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Abstract

The design of the active solar heating system is different in the passive solar room due to its passive additional heat. The passive additional heat affected the active solar heating system thermal performance. So the optimization of the system is necessary. In this paper, a solar heating building with active and passive combination as the object of study. The TRNSYS simulation model of solar heating system was established. The accuracy of the simulation model was verified by field test of indoor thermal environment for three consecutive days in the heating season. Under the condition of typical meteorological data, the indoor thermal environment of the whole heating season was simulated and compared under four different conditions. The results show that when the active and passive solar heating technology coexists, the indoor air temperature has been significantly improved. The design of the active system does not take into account the influence of the passive solar room. The design parameters and operating parameters of the system were analyzed by simulation in this paper. The research can provide the basis for the optimization of the active solar heating system in the passive solar room, which is beneficial to the popularization and application of solar heating technology.

Keywords: Optimization research, SWHS, TRNSYS, Passive solar house

1. Introduction

Almost all of China's heating areas are solar energy resources rich areas, with solar heating conditions. Therefore, solar heating should be the village buildings heating and energy conservation priority development direction. Active solar hot water heating technology has been correspondingly mature, many areas have formed corresponding demonstration buildings (Wang et al., 2014; Yu et al., 2014; Zheng and Han, 2013). The corresponding technical specifications and evaluation criteria have been formed (GB 50495-2009; GB/T 50604-2010; Zheng et al., 2012), to provide the basis for engineering application and construction. In addition, many studies on solar hot water heating systems at domestic and abroad, mainly in the system components optimization, operation control analysis and system evaluation research (Shukla et al., 2013; Wang et al., 2015). The research on system component optimization mainly included thermal collectors, water tanks and heat exchangers.

Although these studies provide a reference for the design and application of solar hot water heating systems, these studies are less concerned with passive solar construction. Due to the larger additional heat of the passive solar room, the heating needs of the building had significant difference between the day and night, and the heat storage capacity of the active system had a great influence (Liu and Wang, 2016). At the beginning of the design, the calculation method of the average heat consumption was used to determine the design parameters of the active solar heating system (GB 50495-2009). It shows that active solar heating system design in the passive solar building is not reasonable.

In order to obtain optimization design parameters of active solar heating systems in the passive solar rooms. The TRNSYS system simulation model was established in this paper. The influence of the design parameters and operating parameters of the typical meteorological year on the solar energy assurance rate and indoor thermal environment of the whole heating season were compared and analyzed. For the passive solar rooms' active solar heating systems to provided the basis for optimization. It was conducive to the promotion and

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application of solar heating.

2. The demonstration project

2.1. The demonstration project of solar heating system with passive solar house

The study object consists of two types of passive solar rooms, included thermal storage walls and additional sun-space. The photo of the exterior feature of the demonstration project was shown in Fig. 1. The external envelope of the building is a brick wall with 240mm thick. A 50mm thick XPS thermal insulation layer on the South wall, and 80mm thick XPS thermal insulation layer on other walls. The roof consists of 160mm thick Reinforced concrete and a 100mm thick XPS thermal insulation layer. The ground consists of a 150 mm thick Reinforced concrete and a 60 mm thick XPS thermal insulation layer. All of the windows adopt plastic steel material Insulating glass, on both sides containing 16mm thick air layer and 4mm thick glass. Southward, Northward and other directions to the windows with the height of 1800mm, 1500mm and 900mm respectively. The building plane is shown in Fig. 2. The basic parameters of the passive solar house are shown in Table 1.

The active solar heating system is designed for heating the demonstration building. Included 7 flat plate heaters modules with a total area of 14 m^2, a storage tank of 200 L volume, a thermal collector circulating water pump, a heating circulating water pump, water segregator and collector, controller and floor heating end etc. Radiant floor heating using DN15 coil, spacing 300mm.

Fig. 1: Photo of the exterior feature of the demonstration project

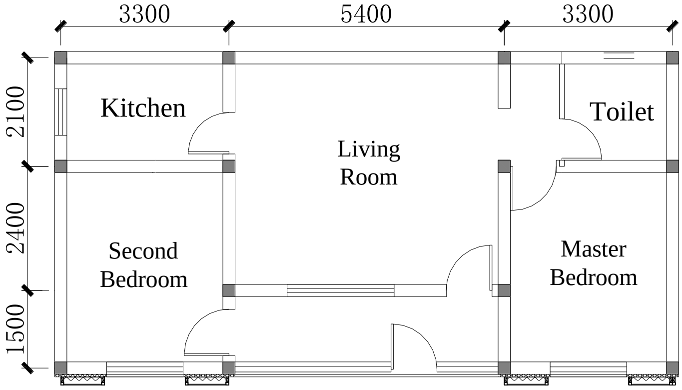

Fig. 2: Plane layout and size of the demonstration project (unit: mm)

Tab. 1: The components of the passive solar house

Types	Component	Descriptions
Trombe wall	Air vent	Size: 200mm×200mm, locate upper and lower three and two respectively
	Glazing	4mm thick simple glass
	Coating	10mm thick red corrugated sheet iron
	Air layers	100 mm thick

Attached sunspace	Sunspace	There are windows with a size of 1800mm×2100mm on the wall
	Glazing	The attached sun-space covered with 5mm wire glass

3. TRNSYS modeling and validation

3.1 Thermal performance simulation model

Used TRNSYS17.1 (TRNSYS 17.1) to build the simulation model of the combined active and passive solar heating system, as shown in Fig. 3. The building model in the system model was built in Google SketchUp according to Section 2.1.1. And imported it in the TRNBuild to set parameters, further as an external file for Type 56. There are two house connected forms in the actual building. The demonstration building has the same house type, so one house of the building was chosen to build model. Assume that the walls of the two rooms are adiabatic. Building adopted floor radiant heating. Living room, master bedroom and second bedroom belonged active heating room, other rooms were non-heating. The heating temperature of the heating room was set at 18 °C. The main TRNSYS components and parameters adopted were explained in Table 2.

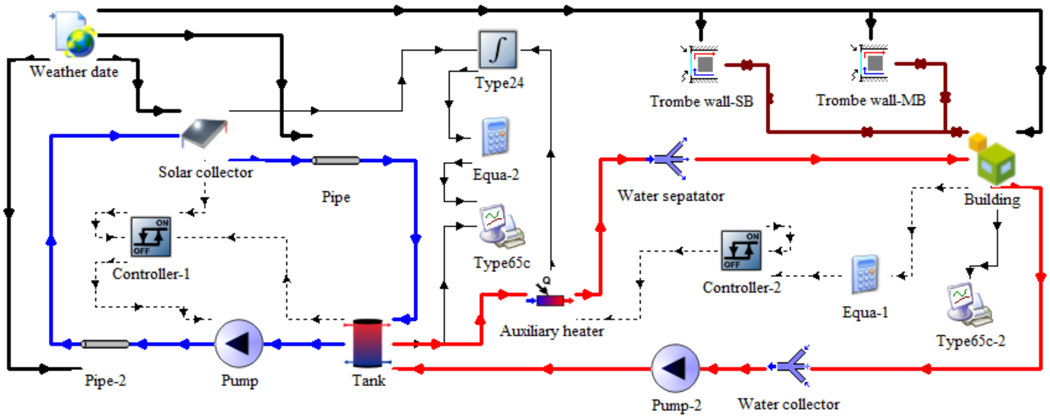

Fig. 3: TRNSYS modeling

Tab. 2: The main TRNSYS components and parameters

Name	**Component**	**Main parameters**	**Descriptions**
Weather date	Type 15-2	Number of surfaces: 2; slope of surface-1: 30°; slope of surface-2: 90°.	The external file contains the TMY-2 weather date of Gangcha. Used for the optimization analysis.
Weather date in test conditions	Type 99	The measured meteorological conditions during the test were inputted.	Used for the model validation.
Building	Type 56	The room air exchange rate: 0.5 h^{-1}; the active layer of 3 rooms were added.	The building model was built in Google Sketch Up, and imported to TRNBuild for setting the parameters. For the thermophysical properties please see Table 1.
Tank	Type534	Tank volume: 0.2m^3, tank height: 0.9m, number of tank nodes: 2, outer tube diameter: 0.025m, length of coiled tubes: 5.7m, HX cross sectional area: 0.45m^2, coil diameter: 0.3m.	There has a heat exchanger in the tank.
Controller	Type73	Collector area: 14m^2, collector slope: 30°.	The thermal performance parameters obtained from the manufacture.
Auxiliary heater	Type 6	Maximum heating rate: 10800 kJ h^{-1}, efficiency of auxiliary heater: 0.95.	Used for supplying the auxiliary heater

		Base case: set point outlet temperature: 40 °C.	
Trombe wall	Type 36b	Wall height: 2.9m, wall width: 1.5m, wall thickness: 0.33m, vent outlet area: 0.2m^2.	Used for calculating the energy of trombe wall flow to MB and SB.

3.2 Tests and model validation

A demonstration project of solar heating in Northwest China is taken as the research object. One dwelling with active and passive solar heating was test under the overall heating modes operating conditions. Conducted a three-day continuous test on April 25 - 27, 2016. Test contents had outdoor weather conditions, the indoor temperature of various function rooms of the two buildings and solar heating system operating parameters etc. The main parameters of the test included: the global solar irradiance on the inclined collector surface and the horizontal surface, ambient temperature, indoor temperature of various function rooms, the inlet and the outlet temperature of each device, flow rate of each system. Time interval of the data acquisition was 30 min. The measuring instruments and corresponding accuracies are listed in Table 3.

Tab. 3: Measuring instruments for the tests

Test instruments and type	Accuracy	Measurement parameter
Solar pyranometer (TBD-1) Recrding meter(QTS-4)	±8.789 W m^{-2} ——	Solar radiation intensity
Thermo recorder(TR-72ui)	±0.2 °C	Indoor and outdoor air temperature
Ultrasonic flowmeter(PH204)	±1.0% rdg	Flowrate of the pipes
Thermocouple thermometer(CENTER309)	±(1 °C+0.3% rdg)	Import and export temperature of main components

Meteorological conditions of weather data were tested as the input meteorological conditions for the model validation. According to the reference Denget al. (2016), the meteorological conditions were added to the input data in order to remove the initial thermal inertia of the building since the begins in the heating season in this area. Comparion of heating room master bedroom indoor air temperature test data and simulation data, as shown in Fig. 4. It can be seen that the overall correlation is good, although there is still a certain gap in temperature. It may be due to the following reasons: The opening and closing time of the ventilation holes of the heat storage wall was not set; residents and testers into and out of the room led to the actual increase in the amount of cold air penetration etc. During the test, the maximum relative error between the master bedroom test and the simulated temperature was 8.9% and the average of the relative error was 3.7%. Therefore, the simulation results show that the calculation error can be accepted, the simulated model can be trusted in the later analysis.

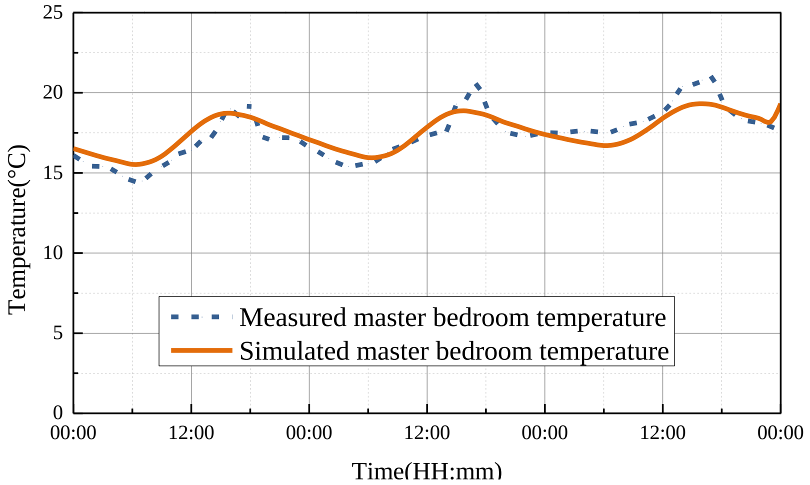

Fig. 4: Comparison of the simulated master temperature with the measured values during the test period

4. Optimizing the results and discussion

4.1. Comparison of indoor thermal environment during heating season

Simulated and compared the building with or without a passive solar room and active solar heating system, the master bedroom air temperature comparison shown in Fig. 5. It can be seen that the difference among the four types of indoor air temperature at the beginning and the end of the heating season was smaller. At the beginning and end of the heating season, the outdoor temperature was higher and the solar radiation intensity is larger, the heat load of the building was smaller, and the passive solar room had a higher additional heat. The passive additional heat can meet the heat required for the building basically. During the middle of the heating season, the indoor air temperature of the active system was significantly higher than that without the active system, the average temperature difference between the two is 14 °C or more. Because in the middle of the heating season, the outdoor temperature was lower, the building heat load was larger, the passive additional heat can not meet the heat supply of the building needs. The active solar heating system can provide a higher heat supply to meet the indoor temperature requirements. In addition, throughout the heating season, the active and passive combination of solar heating had the higher indoor temperature than other types, the average temperature can reach 19.8 °C. So the active and passive combination of solar heating technology is the most effective way to enhance the indoor thermal environment.

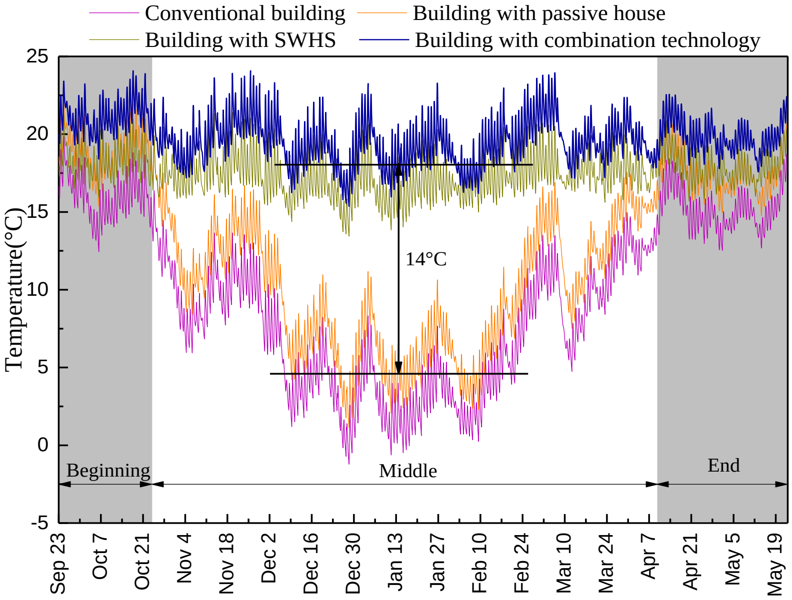

Fig. 5: Comparisonof air temperature in master bedroom

4.2. System design parameters optimization and comparison

(1) System capacity

In the building with or without passive components under different system capacity conditions (Solar collector area and storage tank volume). Compared the solar guarantee rate and indoor air temperature, as shown in Figure 6. It can be observed that the active and passive combination technoledge had more higher solar energy assurance rate and indoor temperature than the active solar heating significantly. Passive solar components for the building to provide a certain amount of heat, used to enhance the indoor temperature, and further reduced the amount of auxiliary heat, thereby enhancing the solar guarantee rate. In addition, in the active and passive combination heating technology, the solar energy guarantee rate increased with the system capacity increasing, the growth of initial stage was larger. When the system capacity reaches 49-700 (m^2-L), solar guarantee rate and master bedroom temperature increase gradually slow with the increasing in system capacity. At this point, the corresponding solar guarantee rate of 48.59%, master bedroom air average temperature of 20.16 °C. Therefore, a reasonable system capacity design is not only conducive to enhance the solar energy assurance rate and indoor thermal environment, but also to avoid blindly increase the system capacity and thus reduce the initial investment of system.

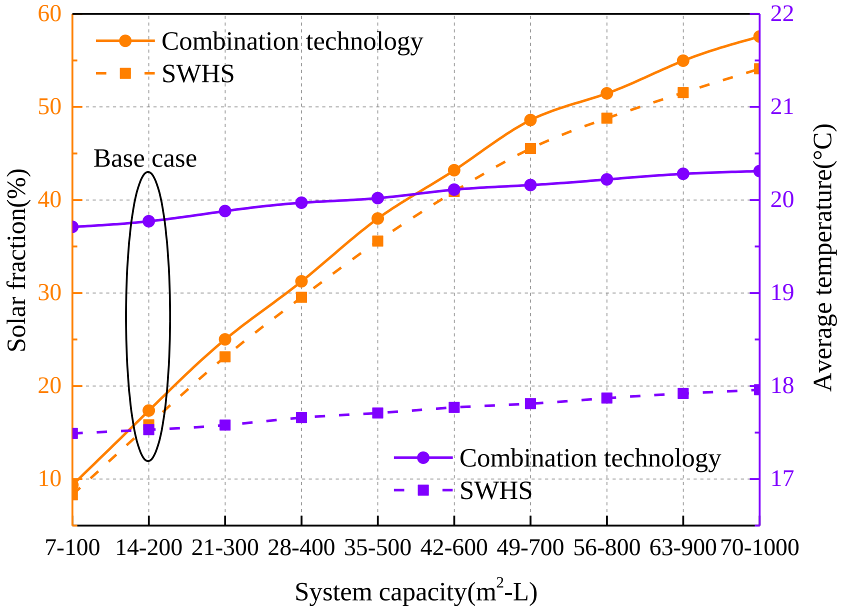

Fig. 6: Comparison of solar fraction and averagetemperature with the change of system capacity

(2) Tank volume

Under the condition of the building with or without passive components when the storage tanks had different storage capacities. The solar energy assurance rate and indoor air temperature had compared. Shown in Fig. 7. Similar to the system capacity change, the active and passive combination technolege can made higher solar energy assurance rate and indoor air temperature than only the active system. The average temperature of the indoor air increased slowly as the tank volume increaseing. The outlet temperature of the auxiliary heater was set to a constant value, affected the heating system inlet temperature directly, so the indoor air average temperature change was relatively small. The initial stage of changes of water tank volume , solar heating guarantee rate increased faster; with the further increased in the volume of the tank, solar heating guarantee rate growth rate gradually slow. It can be observed when the tank volume to a certain extent, although the storage capacity of the tank will become larger, but the system can gradually increase to the maximum heat storage capacity. Further increase the tank volume can not affect the stored heat amount of solar heating system. So the tank volume can be determined in a certain range. Do not have to increase the initial investment in the tank.

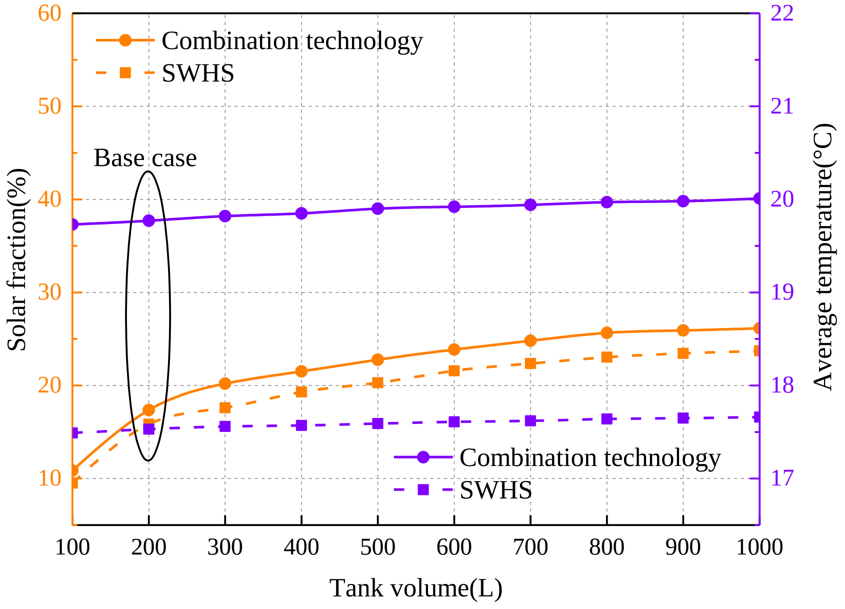

Fig. 7: Comparison of solar fraction and averagetemperature with the change of tank volume

(3) Solar collector area

Under the conditions of the building with or without passive components of different solar collector area. Comparison of the solar energy assurance rate and indoor air temperature shown in Fig. 8. When solar energy collector area changed, the average temperature of indoor air and solar heating guarantee rate changed similar to the changes of tank volume. With the increasing in solar collector area, the system heat collection increased. The heat of needed to store will increase gradually. But the tank capacity was limited, its thermal storage capacity was limited, and can not be stored excess heat of the system. Therefore, in order to meet the required heat supply in the night or rainy days of building. Need to increase the area of solar collectors also need increase the relative capacity of the system.

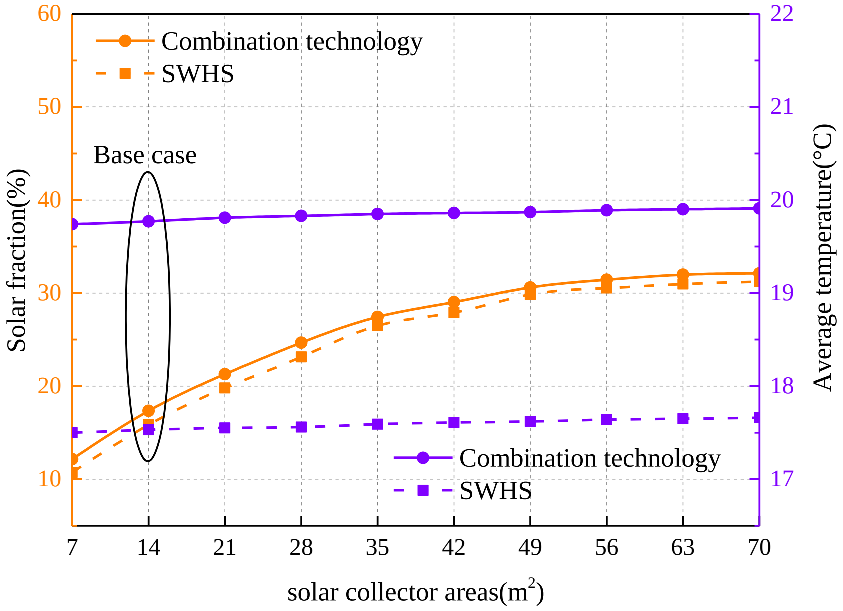

Fig. 8: Comparison of solar fraction and averagetemperature with the change of solar collector areas

Based on the comparative analysis of the above system design parameters. It can be observed that increasing the system's single component capacity can increase in the early play a certain effect. But blindly increased, will only increase the system investment costs, and not the relative gains. Should be combined with the system as a whole, while changing the design parameters of the system components to get more efficient solar heating system design. At the same time, should be combine with the system economic analysis in the follow-up study, and further evaluation of the system.

4.3. System operation parameter optimization and design

Under the conditions of the building with or without passive components of different auxiliary heaters set the outlet temperature conditions. Compared to the solar guarantee rate and the indoor air temperature, as shown in Fig. 9. The solar energy assurance rate decreased as the auxiliary heater sets the outlet temperature increasing, while the indoor average temperature increased as the auxiliary heater sets the outlet temperature increasing. When the tank outlet temperature can not reach the auxiliary heater set temperature, auxiliary heater operation will result in auxiliary heat increasing, resulting in reduce solar energy assurance rate. When the outlet temperature is set above 45 ° C, the indoor air temperature is almost unchanged. As the heating room has a set indoor temperature value, when the indoor temperature reaches the set value, the auxiliary heater to stop running. Auxiliary heat was no longer changed, solar guarantee rate remained stable.

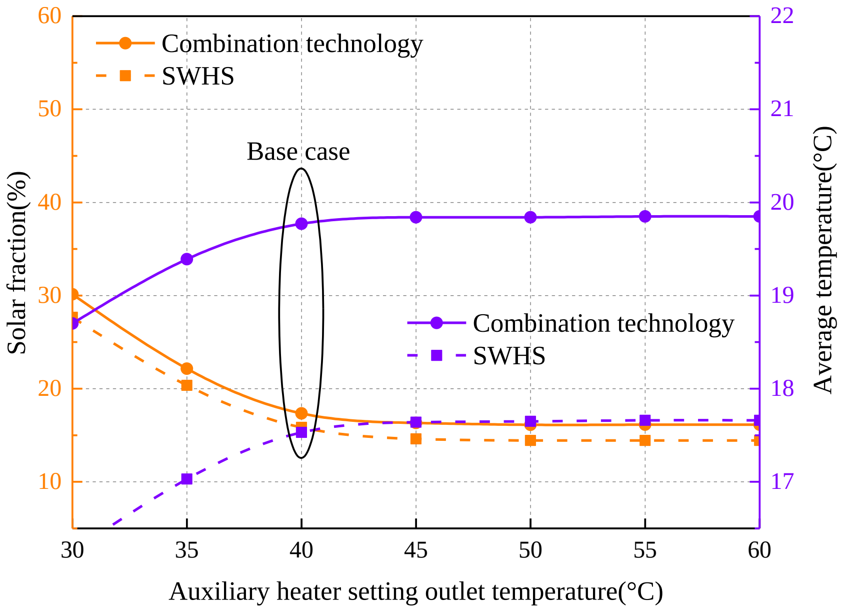

Fig. 9: Comparison of solar fraction and averagetemperature with the change of auxiliary heater setting outlet temperature

5. Conclusion

The indoor heating effects of SWHS in passive solar house were analysed, by means of dynamic simulation using TRNSYS software. The results have been well validated by comparison to the results of the demonstration short-term test in April 25-27. During the test, it was found that the maximum relative error of the master room test and simulated temperature was 8.9%, and the average relative error was 3.7%. Contrasted the four types of building indoor thermal environment, found that active solar heating technology had a significant role to enhance the indoor environment temperature.

Based on the simulation and optimization of the design parameters and operating parameters of the active SWHS in the passive solar building, it is found that: When the area of the solar collector and the size of the thermal storage tank are increasing in proportion, the growth rate of the indoor air temperature and the solar guarantee rate is gradually reduced. Only increased the capacity of the storage tank and solar collector area, can not enhanced the indoor thermal environment and increased the solar guarantee rate significantly. Reasonable outlet temperature settings of auxiliary heater had a greater impact on system performance. These findings can provide a basis for the application of active solar heating systems in passive solar rooms.

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