Adaptability analysis of solar water heating system in Chongqing area

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Abstract. According to the simulation software TRNSYS, based on meteorological parameters and the distribution of solar energy resources in Chongqing area, the dynamic simulation method is used to analyze the application effect of the solar water heating system in Chongqing area. The results show that the application of solar water heating system in Chongqing area has potential, but it has obvious seasonal characteristics, with sufficient solar radiation in summer, followed by spring and autumn, and the least in winter. The simulation calculation shows that the monthly thermal efficiency of the collector fluctuates between 0.2 and 0.7 throughout the year, with an average value of 0.51. The solar fraction basically increases with the increase of solar radiation, which also has obvious seasonal characteristics.

1. Introduction

With the development of economy and the improvement of people's living standards, building energy consumption and environmental pollution have received more and more attention. Among them, building energy consumption accounts for more than 20% of the total energy consumption of the society [1], in which the energy consumption of the hot water system accounts for a large proportion, and the energy consumption of commercial buildings accounts for 10%-40% of the total energy consumption of buildings; the energy consumption of bathing and hot water in civil buildings accounts for about 20% in the city [2]. Solar energy is a kind of sustainable clean energy, which is inexhaustible. Therefore, making full use of solar energy will become one of the important ways to reduce building energy consumption.

Chongqing is an area lacking solar energy resources, the distribution of solar energy resources is unbalanced. The total solar energy resources in summer account for about 41% of the annual total, but it only has 10% in winter [3]. The use of solar energy has great potential in summer. Therefore, through the TRNSYS software, based on the meteorological parameters and solar resource distribution in Chongqing, the annual solar guarantee rate which changes with outdoor solar radiation, the water temperature at the entrance and exit of the collector, the water temperature of the hot water storage tank are analyzed. The feasibility and adaptability of solar water heating system in Chongqing area are obtained.
2. Main calculation basis and equipment parameters of solar water heating system

Based on the domestic hot water consumption of one household (5 people) in Chongqing area, the equipment selection and simulation calculation were carried out. According to “Design Standard for Building Water Supply and Drainage” (GB50015-2019) [4], when the hot water supply temperature is 60°C, the maximum hot water quota for residential houses with centralized hot water supply and shower equipment is 60-100L, and the design daily water heat is not high. Taking the lower limit value in the hot water quota, the daily hot water consumption is 40L/(person-d) according to the overall living standard, living habits and climatic conditions in Chongqing, so that the daily hot water consumption of a household is 200L.

2.1. Domestic hot water load calculation

The daily domestic hot water load can be calculated as follows:

\[
Q_d = \frac{cQ_w \rho (t_r - t_l)}{86400} \quad (1)
\]

In the formula, \( Q_d \) is the daily hot water load, kw; \( c \) is the constant pressure specific heat capacity of water, kJ/(kg·°C), taking 4.178; \( Q_w \) is the daily water quota, L; \( \rho \) is the density of water, kg/m³; \( t_r \) is the hot water temperature of domestic hot water, °C; it takes 60°C; \( t_l \) is the initial temperature of cold water, °C, it take 7°C.

2.2. Calculation of collector area

The area of the collector is determined based on the characteristic monthly solar radiation and domestic hot water load [5], which is calculated as follows:

\[
A_c = \frac{86400Q_d f}{Jr \eta_{cd} (1 - \eta_f)} \quad (2)
\]

In the formula, \( A_c \) is the total area of the collector of the direct solar heating system, m²; \( Q_d \) is the daily domestic hot water load, W; \( J_r \) is the average daily solar radiation on the inclined surface of the local collector installation, J/m², it takes 8.38×10⁶; \( f \) is the solar energy guarantee rate, which should be determined after comprehensive consideration of factors, such as solar irradiation conditions, system economy and user requirements during the service life of the system, generally 0.3–0.8; \( \eta_{cd} \) is the average heat collection efficiency in the service life of the system, this time is 0.42; \( \eta_f \) is the heat loss rate of pipes and water storage tanks, which is 0.2 this time.

2.3. Main equipment parameters

The selected equipment parameters are described as follows. For the heat collection side of the solar collector, the collector bears the daily domestic hot water load, and the collector is calculated by formula (2). In case of bad outdoor sunshine or rainy weather, there is electrical heating to bear the load. For the load side, the indoor hot water is set according to daily water usage habits, and the flow rate in the pipe is guaranteed to be within the scope of the national design standard. The hot water storage tank is selected according to the daily hot water consumption value which plus a safety margin. The parameters of the system components are shown in Table 1.

| Component     | The area of the collector /m² | Collector circulation pump flow /kg³/h | Hot water storage tank volume /L |
|---------------|-------------------------------|---------------------------------------|---------------------------------|
| Parameters    | 5                             | 200                                   | 300                             |

3. System simulation and simulation results analysis

This article adopts the TRNSYS software. TRNSYS is a kind of computer program code that is now widely used. TRNSYS uses a system-specific language to allow user program components. Users can
use C language, FORTRAN language and other programs to write the components they need. These components form different systems through configuration connections. The TRNSYS component is a modular design software. The system is composed of modules with different functions according to requirements. All modules in the system have their own unique functions, so that users can model the required thermal system with great flexibility. Each component is assigned a specific "type". According to the design parameters, the components are selected for connection according to the needs of the system. The connection mode of the solar water heating system constructed in this paper on the TRNSYS platform is shown in Figure 1.

![Diagram of system](image)

**Figure 1. The simulation diagram of system**

3.1. Correlation analysis of solar collector system

Figure 2 shows the variation curve of solar fraction and inclined plane solar radiation quantity in Chongqing. It can be seen from the figure that the solar fraction $f$ is different every day during the simulation time. There are a few days when the solar fraction is close to 0%, which means that the effective solar heat gain is almost 0 in the past few days; and there are a few days when the solar fraction exceeds 100%, which shows that the average effective solar heat gain is greater than that required by the hot water system. It can also be seen from the figure that the solar fraction basically increases with the increase in solar radiation, with obvious seasonal characteristics. From the formula of solar fraction, it can be seen that solar fraction = solar effective heat gain/heat required by buildings, so solar radiation is one of the factors affecting solar fraction. So solar radiation is one of the factors that affect solar guarantee rate. The daily solar radiation throughout the year is accumulated by month to obtain the monthly solar radiation in Chongqing throughout the year, which shows in Figure 3. It can be seen from the figure that the annual solar radiation on the slope is 3148.5MJ/m². The solar radiation is mainly distributed from April to September, which is accounting for 71.47% of the annual total, and only 28.53% in other months. Solar radiation has obvious seasonal characteristics, reaching its maximum value in July in summer, about 500MJ/m²; but in winter, especially in December and January, its solar radiation does not exceed 100MJ/m².
Figure 2. The variation curve from solar fraction to total radiation on titled surface in Chongqing.

Figure 4 shows the average efficiency of solar collectors and the variation curve of solar irradiance in each month of the year. The figure shows that the efficiency of the collector increases with the increase of solar radiation. The efficiency of the collector fluctuates between 0.2 and 0.7 throughout the year, with an average value of 0.51.

Figure 3. Changes in monthly solar radiation in throughout the year Chongqing.

3.2. Thermal storage tank temperature analysis
According to the document[6] of heat storage solar heating system, the volume of the hot water storage tank corresponding to the solar collector per square meter is 50~150L. Increasing the volume of the hot water storage tank can improve the solar fraction of the solar heating system, but

Figure 4. The variation curve from heat collection efficiency and slope solar radiation throughout the year in Chongqing.
increasing the volume of the water tank will increase the heat dissipation capacity of the water tank. Therefore, the hot water storage tank of the short-term heat storage system should take into account the heat preservation cost of the water tank according to the heat preservation situation of the water tank. According to various factors, the volume of the hot water storage tank is calculated as 60L/m² and the area of the solar collector is 5 m², so the volume of the hot water storage tank is 300L. Considering that the density of water decreases due to the increase of temperature, layering will occur in the water tank. In order to be able to measure the temperature of the water tank more accurately, measuring points are set at different positions of the water tank to analyze the water temperature in the water tank \(^{(7)}\). The temperature simulation of each measuring point in the water tank in the coldest month of January is shown in Figure 5.

![Figure 5: The curve of water temperature from the tank in January](image)

The temperature measuring points are set at the top, middle and bottom of the water tank. In the figure, \(T_{\text{Top}}\) represents the temperature of the top of the water tank tested at the measuring point, that is the outlet temperature of the solar collector, \(T_1\) is the temperature of the middle of the water tank, and \(T_{\text{Bottom}}\) represents the bottom temperature of the water tank. From the figure, we can see that the average temperature in the hot water storage tank remained between 40 and 60°C in January, and did not reach the set temperature of 60°C. This shows that the size of the hot water storage tank is set reasonably. The solar heat has been fully utilized. The fluctuation of the water temperature in the water tank is mainly caused by the instability of solar radiation. When the solar hot water system cannot meet the water temperature requirements, the electric auxiliary heater set in the water tank is activated to heat the water in the water tank.

4. Conclusion

Using TRNSYS software to analyze the application effect of solar water heating system in Chongqing area, the following conclusions are obtained:

1) The application of solar water heating system in Chongqing area has potential, but it has obvious seasonal characteristics. There is sufficient solar radiation in summer, followed by spring and autumn, and the least in winter. The use of solar water heating system requires an auxiliary heat source to be turned on in winter.

2) Through TRNSY simulation calculation, the monthly thermal efficiency of the collectors throughout the year fluctuates between 0.2 ~ 0.7, with an average value of 0.51. The solar fraction basically increases with the increase of solar radiation, with obvious seasonal characteristics.

3) The average temperature in the hot water storage tank was maintained between 40 and 60 °C in January, and did not reach the set temperature of 60 °C, which indicates that the size of the hot water storage tank was set reasonably and the solar heat was fully utilized.
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References
[1] Research Center for Building Energy Efficiency, Tsinghua University. (2018) China Building Energy Efficiency Annual Development Research Report.China Building Industry Press, Beijing.
[2] Luo Haiqing, Tang Guangfa, Gong Guangcai, et al. (2007) Heat pump technology in building hot water energy saving. Water Supply and Drainage, 2007, 33(Z2): 98—101.
[3] Ding Yong, Lian Daqi, Li Baizhan. (2011) Potential analysis of architectural application of solar energy resources in Chongqing. Journal of Chongqing University, 32(2): 166-170.
[4] GB50015-2019,Design Standard for Water Supply and Drainage of Buildings.(2019) China Planning Press, Beijing.
[5] Zheng Ruicheng. (2011) Handbook of civil solar hot water systems engineering and technology (second edition). Chemical Industry Press, Beijing.
[6] GB50495-2019, Technical Standards for Solar Heating Engineering.(2019) China Building Industry Press, Beijing.
[7] Beckman William A, Broman Lars, Fiksel Alex et al. (1994) TRNSYS.Most complete solar energy system modeling and simulation software. Renewable Energy, 5(1): 486-488