Study on Heating Performance of Solar Fresh Air Systems

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Abstract: Due to the global spread of COVID-19, indoor air quality has been paid more and more attention by many countries. However, the ventilation of buildings often causes a significant increment in buildings' heating and cooling load, especially in the winter of the Northern Hemisphere. Solar fresh air systems can provide heated fresh air to buildings on sunny days. This system can provide not only fresh air to buildings but also improve indoor air quality. At the same time, the heating load of buildings will be significantly decreased by the application of this new system. Solar fresh air systems can even take the existing heating energy source's place under high solar irradiation. The solar heating performance of the solar fresh air system is affected by many factors. The two most important factors are the structure of the solar heating panel and the performance of solar absorption coating on the solar heating panel. This research project has built three sets of real solar fresh air systems to test the influence of different solar absorption coatings and different solar heating panel structures on the heating performance of the solar fresh air system. This paper focuses on the test of stagnation performance and solar heating efficiency.

Keywords: Solar fresh air system, Solar heating panel, Stagnation performance, Solar heating efficiency

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1. Test system introduction

Indoor heating is the most prominent single energy usage in most heating climates such as North America, Europe, and China [1]. Therefore, solar air heating is developed to provide an economical and applicable solution for heating and ventilation [3]. The panel structure and solar absorption coating are the most critical factor in this system [2]. This paper will compare the system stagnation performance and solar heating efficiency in different absorption coating and different positions. Three sets of solar fresh air systems are developed in Figure 1.

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Fig. 1: Test system

1.1 External dimensions: three sets of solar fresh air systems in the test have the exact external dimensions: 3 m in length, 2 m in height, and 15 cm in thickness of air interlayer.

1.2 Porosity of solar heating panel:1% for all three systems.

1.3 Structure of the solar heating panel: for System 1 and System 2, the front side of the solar heating panel is provided with solar absorption coating, and the backside is provided with heat emission coating. For System 3, the front side of the solar heating panel is provided with solar heat absorption coating, and the backside is not provided with heat emission coating.

1.4 Types of solar absorption coating: for System 1, the solar absorption coating is non-selective. For System 2 and System 3, the solar absorption coating is selective.

Tab 1: Parameters of test system

Project	System 1	System 2	System 3
Length	3 m		
Height	2 m		
Area	6 m^2		
Thickness of air interlayer	15 cm		
Porosity of solar heating panel	1%		
Absorbance of frontal coating	0.944	0.937	0.937
Emittance of frontal coating	0.899	0.452	0.452
Emittance of back coating	0.899	0.908	None

2. Test methods

2.1 Build the test system according to Table 1 and Figure 1.

2.2 Arrange temperature sensors in the same position of each system (the temperature sensors have been uniformly calibrated before installation), as shown in Figure 2.

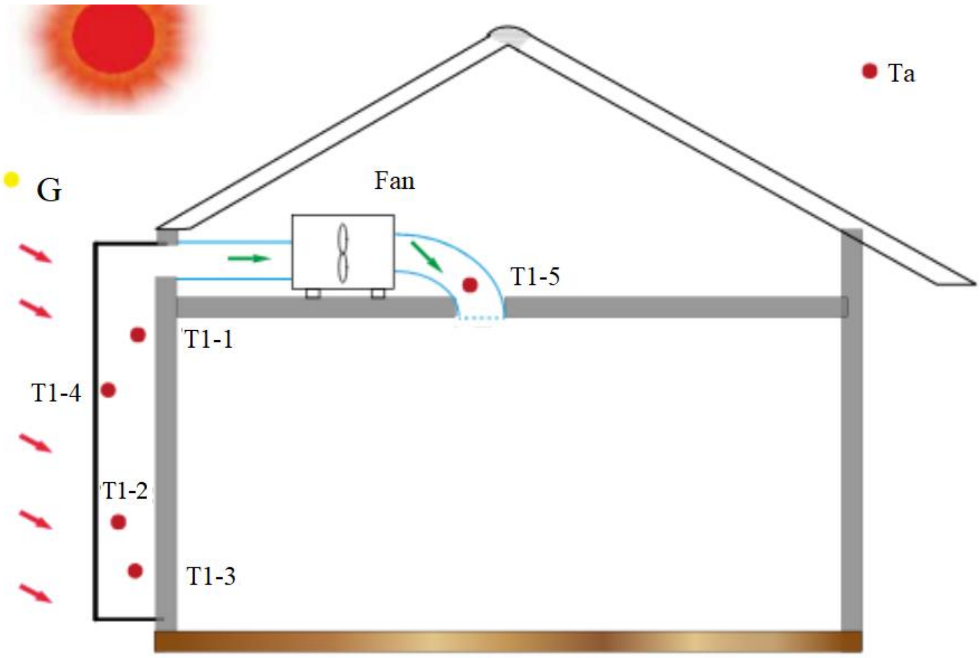

Fig. 2: Distribution diagram of temperature sensors in the test system

2.3 The pipe size, fan type and installation position of the three test systems are precisely the same. The handheld anemometer is used for air volume measurement.

2.4 Acquire simultaneous ambient temperature and real-time solar irradiation on the south facade.

2.5 Total fifteen temperature sensors are adopted in three systems besides ambient temperature. The serial number can be found in Table 2.

Tab 2: Temperature position and function

Function	System 1	System 2	System 3
System top temperature	T1-1	T2-1	T3-1
System middle temperature	T1-2	T2-2	T3-2
System bottom temperature	T1-3	T2-3	T3-3
Panel temperature	T1-4	T2-4	T3-4
Air outlet temperature	T1-5	T2-5	T3-5

3. Test result analysis

3.1 Stagnation temperature of air interlayer

It can be found that an air interlayer will be formed between the panel and the south building facade. The interlayer's highest temperature is defined as system stagnation temperature. The fan is turned off on a typical sunny day, then the temperature variation in the air interlayer is measured when the system has no heat output.

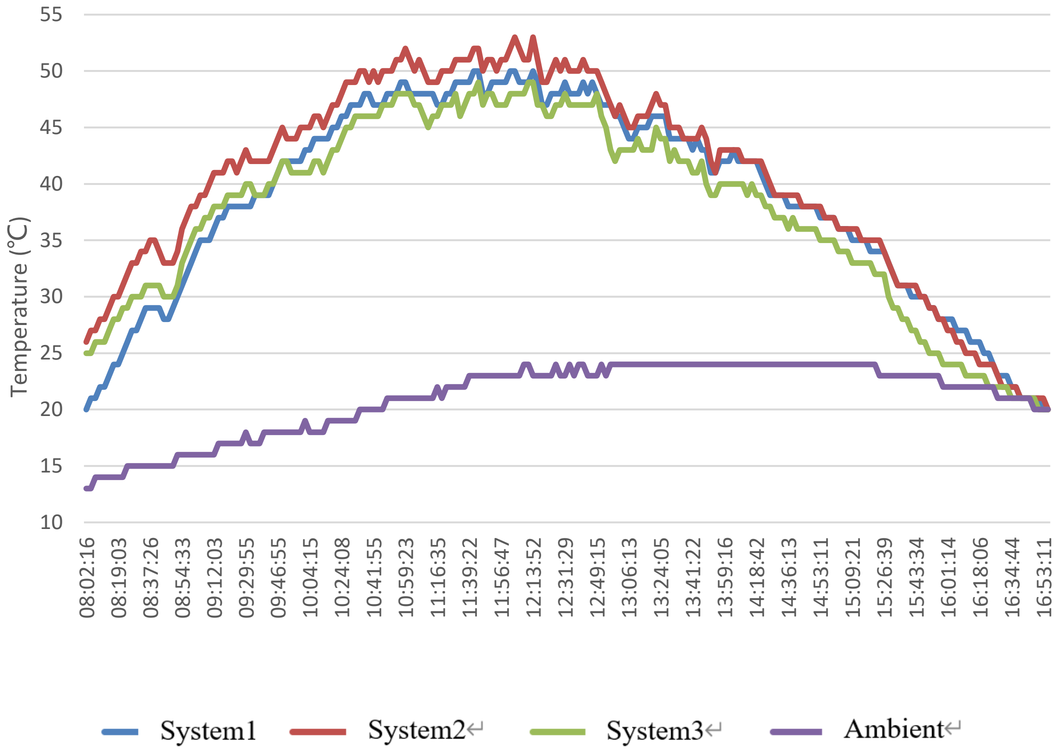

Fig. 3: Temperature changes in the air interlayer

It can be seen that System 2 has the highest stagnation temperature, followed by System 1 and System 3. System 2 always maintains good performance because it has a high-absorption coating on the front and a high-emission coating on the back. System 1 is compared with system 3, the temperature rise of system 3 is faster before 10 a.m. After that, system 1's temperature is always higher than system 3, which shows that the high-emission coating on the back can effectively increase the heat gain of the solar fresh air system.

After three days of operation, the interlayer temperature always reached the maximum at noon. The highest temperature of System 1 with the double-sided coating is 53 ℃, while System 2 is 50 ℃ and System 3 has the lowest temperature of 49 ℃.

3.2 Solar heating efficiency

Turn on the fan on a sunny day. The solar energy will turn to heat energy and be sent indoors by a fan. The temperature rise in the three systems is shown in Figure 4.

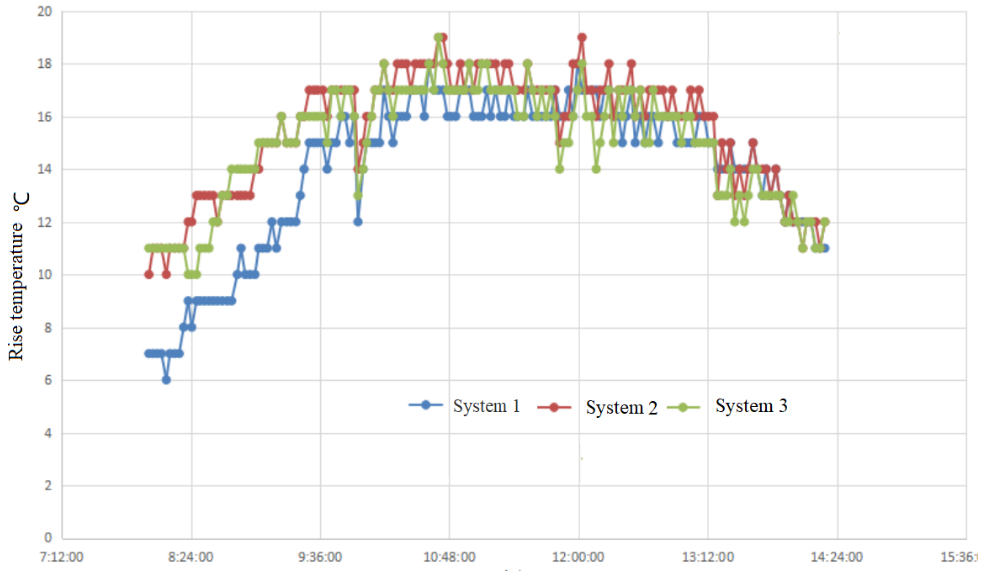

Fig. 4: Temperature rise comparison in three different systems

It shows that the temperature rise of the System 2 and System 3 using solar selective absorption coating is significantly higher than System 1 using non-selective coating when the solar radiation is low, indicating the use of selective coating can effectively improve the heat efficiency of the solar fresh air system in the morning, evening and windy days, which thereby increases the solar energy utilization rate of the system throughout the year.

Comparing System 2 and System 3 with the same selective absorption coating, System 2, which has a high-emission coating on the back, always performs better than the temperature rise of System 3 without the high-emission layer.

The temperature in the low irradiation period will only preheat the air interlayer, which cannot be sent to the building. Meanwhile, the efficiency should be tested as a quasi-steady state. Therefore, the data between 10:32 a.m. and 11:54 a.m. is chosen for analysis and calculation. The solar irradiation can be seen in Figure 5.

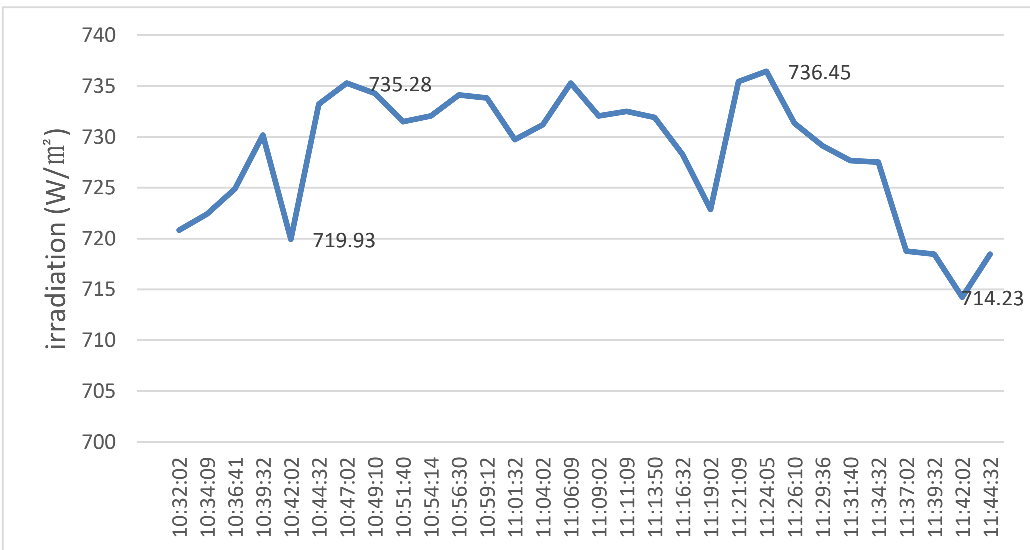

Fig. 5: Facade solar irradiation

The facade irradiation stability is in good condition during this period, with the minimum and maximum values of 714 W/m^2 and 736 W/m^2, respectively. The fluctuation is no more than 20 W/m^2. The ambient wind speed is about 1 m/s, which belongs to low wind speed weather.

The air energy brings to the building divided by solar irradiation is defined as the system heating efficiency.

$$\eta = c\rho q_v \Delta T/(3.6GA_c) \quad \text{(eq. 1.1)}$$

Where

c: Specific heat capacity of air [J/kg/K].

ρ: Density of air [kg/m3].

q_v: Total circulating flow [m3/h].

ΔT: Raised temperature [°C]. $\Delta T=(T_{out}-T_a)$. T_{out} is outlet temperature, and T_a is ambient temperature.

G: Solar irradiation [W/m^2].

A_c: System aperture area [m^2].

Three systems are simultaneously measured and separately calculated. The air volume is steadily kept at 73 m^3 /h, based on the supplier's panel parameter. The average system efficiency can be found in Table 2.

Tab. 2: Efficiency comparison of three different Systems

Project	System 1	System 2	System 3
Average temperature rise（℃）	16.44	17.44	16.88
Average irradiation W/m^2	728.46	728.46	728.46
Air density（kg/m^3）	1.14	1.136	1.14
Specific heat capacity (J/kg/K)	1000	1000	1000
Air volume per square meter (m^3/h)	73	73	73
Energy output (W/m^2)	380.07	401.77	390.61
Average system efficiency	52.2%	55.2%	53.6%

4. System heating performance

To test the heating effect of the solar air system, a small system is built whose panel has solar absorption selective coating on the front side and emittance coating on the back side, which has a better performance based on the above testing.

Fig. 6: Space heating system

The room covers an area of 8.5 m^2, and the heat load of the room in the heating season is 200 W/m^2 (based on previous test data). The aperture area of the panel is about 3 m^2. To test the heating effect, the solar air system is designed in the form of internal circulation, and a transparent polycarbonate cover is installed on the solar absorption panel, which can reduce the system's heat loss.

A typical day is selected in the heating season. Ambient temperature, the interlayer temperature, the room temperature, and the solar radiation on the south facade are all recorded.

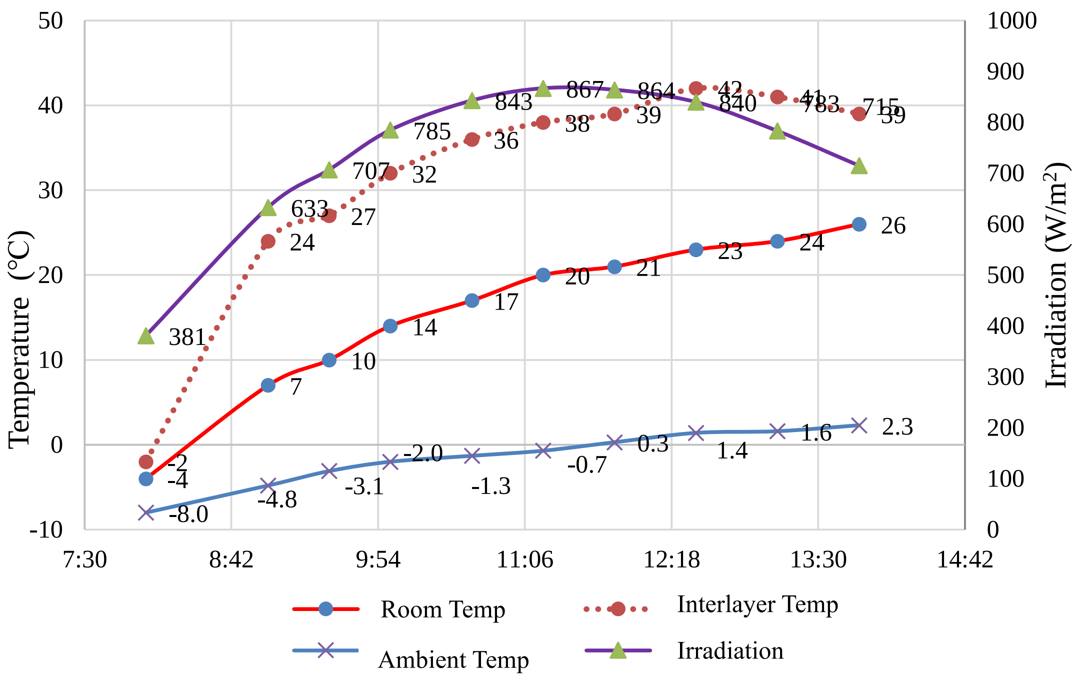

Fig. 7: Performance of solar air heating system

It can be found that the solar air heating system can significantly increase the temperature in the room during cold winter. On a sunny day, it can directly replace other energy sources to heat the building. The system also can provide energy on low solar radiation days, which will reduce the building heating load and energy consumption.

5. Preliminary conclusions and next steps

The emission coating on the backside of the solar panel can significantly improve efficiency. Meanwhile, the coating can improve the anti-corrosion performance of the panel and extend the system's service life. Using selective solar absorption coating on the front of the solar panel helps to improve the solar heating efficiency of the system. However, there are some problems such as complex processing technology, poor weather resistance, and high cost, which should be further studied.

More pilot projects of this solar fresh air system should be built to conduct a more comprehensive study on the solar heating efficiency of the system, the economy of actual use, and the improvement of indoor air quality to get better guidance on the development and utilization of this solar fresh air system.

6. References

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