Experimental and Simulation Study of Thermal Performance of Amorphous Silicon Photovoltaic Double-skin Façade

Z Y Wang¹, P Jiang¹, J J He¹, W J Zhang¹ and S B Ma¹
¹Nanjing University of Science and Technology, No.200 Xiaolingwei Street, Xuanwu District, Nanjing City, Jiangsu Province, China

zhangwenjie001@139.com

Abstract. In order to study the thermal performance of amorphous silicon photovoltaic double-skin façade (a-Si PV DSF), the experimental cabin of a-Si PV DSF was designed and established in Nanjing, China (118.80° E, 32.06° N). The thermal performance of a-Si PV DSF was experimentally tested, and the influence of a-Si PV DSF on the heat gain of the cabin was studied. Using EnergyPlus to establish a simulation model of the experimental cabin, the model was verified by experimental data, and the verified model was used to simulate and analyze the heat transfer performance of a-Si PV DSF. The results show that a-Si PV DSF has better cooling and heat insulation effect during the day than at night, which can effectively reduce the heat gain of the external wall of the building. A-Si PV DSF has good energy-saving effect in different climate areas and reduce the heat gain of the external wall by more than 38%.

1. Introduction

As the energy and environmental problems become more and more serious, the development of renewable energy industries such as solar energy has become the trend of energy application. According to the statistics, building energy consumption accounts for nearly 30% of the total energy consumption of the whole society in China [1]. Amorphous silicon photovoltaic double-skin façade (a-Si PV DSF) has a good energy-saving effect, and has been widely studied by many scholars. Yu et al. [2] concluded from his research on the power generation of photovoltaic (PV) façade in Beijing and ventilation has an important influence on the thermal performance and power generation performance of PV façade. Peng et al. [3] studied the thermal performance of ventilated PV façade under different ventilation modes. The U of the model was 3.4, 3.8 and 4.6W/(m²·K). The ventilation PV façade has the best thermal insulation effect. Zhu et al. [4] carried out the simulation calculation by Fluent on the a-Si PV DSF in Tianjin, China, and the results showed that the optimal thickness of the air channel of the a-Si PV DSF was 0.15m. Bi [5] tested and programmed the PV façade of a building in Shenzhen, China, and the results showed that the external surface temperature of PV modules during the power generation period was much higher than the common building envelope, while the external surface temperature of PV modules during the non-power generation period was lower than the common building envelope. Zhang et al. [6] have found that non-energy-saving walls combined with thin-film PV modules can achieve an energy saving rate of 72%; energy-saving walls combined with thin-film PV modules can achieve an energy saving rate of 34%. Zhang et al. [7] used the fourth-order Runge-Kutta methods to solve the heat balance equation of PV façade. The results show that the peak cooling load of the hollow PV façade system can be reduced by 38.97% compared to the single-layer PV façade system, and the total thermal load can be reduced by 67.75%. Luo et al. [8]
conducted experiments in China's hot summer and cold winter zone and found that the average daily heat transfer coefficient of double skin facade using photovoltaic blinds is 2.247. This study used experimental testing and numerical simulation methods to analyze the relationship between a-Si PV DSF and the common wall in terms of heat gain. Comparatively study the thermal performance and energy saving of a-Si PV DSF.

2. Experimental research

2.1. Experimental platform and test equipment

The experimental platform is shown in Figure 1. The experimental platform is a double-decker cabin in Nanjing, China (118.80° E, 32.06° N). The outer layer size of the cabin is 1.4m×1.18m×1.4m, and the material is 50mm rock wool board. The inner layer size of the cabin is 1.25m×1.28m×1.08m, and the material is 30mm XPS board. The thickness of the air layer inside and outside the bulkhead is 20mm. The air layer can make the internal temperature of the cabin more stable. The test components are two amorphous silicon PV modules with a size of 0.64m×1.25m×0.03m, a PV module rated power of 70W and open circuit voltage of 36V.

![Figure 1. Experimental platform and measuring point arrangement](image)

In the study, thermal resistance was used to measure the temperature, and pyranometer to measure the radiation intensity. The data was recorded by the data recorder. The data recording interval was 10 minutes. The main measuring equipment and their technical parameters were listed in Table 1.

Table 1. Main measuring equipment and their technical parameters.

| Name              | Model            | Technical Parameters                           | Accuracy |
|-------------------|------------------|-----------------------------------------------|----------|
| Pyranometer       | YIGU YGC-TBQ     | Measuring range: 0-2000W/m² Resolution: 1W/m² | ±3%      |
| Thermal resistance| MEACON MIK-WZP   | Measuring range: -50~200°C                    | ±0.3%    |
| Data recorder     | MEACON MIK-R9600 | Thermal resistance input signal: pt100 Solar radiation input signal: (4-20)mA |          |
| Micro inverter    | JIZIDA WVC-300   | Maximum input power: 300W Input voltage range: 36-50V Maximum working current: 13A |          |

2.2. Experimental results and analysis

This study carried out a long-term experimental test. Finally, the experimental data of December 4 was selected as the analysis samples of the sunny day, and the experimental data of January 4 was selected as the analysis samples of the rainy day. Use these data to analyze the performance of a-Si PV DSF. The temperature distribution in sunny day and rainy day is showed in Figure 3. It is seen that at night when the solar radiation was 0, the temperature difference between the PV module and the environment was small, and the maximum temperature difference in sunny days was 3.1°C, and in rainy days was 0.5°C. During the day, when the solar radiation intensity reaches its peak, the temperature difference between the airflow channel and the environment, the PV module, and the
external surface of wall are 8.3°C, 21.2°C, and 5.9°C in sunny day, respectively. But in rainy day, the temperature difference between the airflow channel and the environment, the PV module and the external surface of wall was 0.1°C, 1.1°C and 0.4°C, respectively. This showed that the air in the airflow channel had a cooling effect on the PV module and the wall of the cabin. This cooling effect was stronger in sunny day, weaker in rainy day, stronger in the daytime and weaker at night.

![Figure 2. Temperature distribution: (a)sunny day; (b) rainy day](image)

3. Numerical simulation
This study used EnergyPlus to establish a numerical simulation model according to the structure size of the experimental cabin and verified it. At the same time, a cabin model without PV modules was established for comparative analysis.

3.1. Model verification
The experimental data on December 3 was used for model verification. MBE (Mean Bias Error) and RMSE (Root Mean Square Error) was used to evaluate the deviation between the simulation results and measurement results [9][10]. The comparison between measurement results and simulation results is showed in Figure 3. After calculation, MBE and RMSE of the surface temperature are 47.7% and 28.7%, respectively. MBE and RMSE of internal air temperature are 10.0% and 33.0%, respectively.

![Figure 3. Comparison of measured and simulated results: (a) External surface temperature of wall; (b) Internal air temperature](image)

It can be seen that the errors basically meet the ASHRAE standard. Therefore, we believed that the model can be used to simulate the thermal performance of a-Si PV DSF.

3.2. Comparative analysis of PV façade and common wall on a typical day
This study used the established numerical simulation model to compare the heat transfer performance between PV façade and common wall (wall without PV modules).

The comparison of the temperature and heat gain of the PV façade and the common wall is shown in Figure 4. It is seen that the peak temperature of external surface of wall with PV modules was 33.6°C, which was 22.5°C lower than the common wall. The PV modules played an obvious role of shading and heat insulation from 11:00 to 16:00. The heat gain of the cabin wall can be calculated by using the
model. According to simulation data, the peak heat gain of the common wall was 35.4 W/m², and the peak heat gain of the wall with PV modules was 21.3 W/m². In comparison, the heat gain of the cabin wall was reduced by about 40%, the insulation effect of PV façade was very significant.

Figure 4. Comparison of the PV façade and the common wall: (a) temperature; (b) heat gain

3.3. Comparative analysis of PV façade and common wall in different climate zones of China
In this study, four Chinese cities including Guangzhou (hot summer and warm winter zone), Nanjing (hot summer and cold winter zone), Taiyuan (cold zone) and Harbin (severe cold zone) were selected as representative cities. The study simulated the heat transfer process of PV façade and common wall, and analyzed the energy-saving effect of a-Si PV DSF in different climate zones.

Figure 5. Comparison of wall net heat gain with and without PV module in different climate zones of China: (a) Guangzhou; (b) Nanjing; (c) Taiyuan; (d) Harbin

Comparison of wall net heat gain with and without PV modules in different climate zones of China is showed in Figure 5. Net heat gain is positive for heat gain and negative for heat loss. In Guangzhou, the annual load is dominated by cooling load. From April to December, the net heat gain of the PV façade was reduced by about 60.3 % compared with the common wall. From January to March, the heat gain of the wall with or without PV façade is not different. The energy saving effect of PV façade was strong in summer and weak in winter. In Nanjing, cooling load is greater than heating load. From May to October, the net heat gain of the PV façade decreased about 59.4% compared with the common wall. From November to April, the net heat loss of the PV façade was reduced by about 40.6% compared with the common wall. PV façade in reducing cooling load in summer and heating load in winter had a better effect. In Taiyuan, heating load is greater than cooling load. From May to September, the net heat gain of the PV façade decreased by about 59.9 % compared with the common wall. From October to April, the net heat loss of the PV façade was reduced by about 36.5% compared...
with the common wall. PV façade has energy saving effect in summer and winter, and winter is better than summer. In Harbin, the annual load is dominated by heating load. From October to May, the net heat loss of PV façade was reduced by about 46.5% compared with the common wall.

4. Conclusions
In this paper, an experimental platform was built to test a-Si PV DSF, and a numerical model was established to compare a-Si PV DSF with the common wall. The main conclusions are as follows
①In sunny day, a-Si PV DSF takes away the heat due to the air flow in the airflow channel, and the PV modules and the wall surface have a significant cooling effect. In the daytime, the cooling effect of the airflow passage on the PV modules and the outer wall is very weak. In rainy day, the airflow channel has a very weak cooling effect, and the insulation effect of a-Si PV DSF is not obvious.
②The temperature of PV façade is 22.5℃ lower than that of the common wall at noon. The thermal insulation effect of a-Si PV DSF reduces the heat gain by about 40%, which can effectively reduce the cooling load of the cabin.
③For different climate zones, a-Si PV DSF can significantly reduce the net heat gain of the outer wall of the building, thus reducing the indoor cooling load in summer and the heating load in winter. The hot summer and warm winter zone is dominated by cooling load throughout the year, and the most significant cooling load reduction effect is achieved by a-Si PV DSF, while the most significant cooling load reduction effect is achieved by the a-Si PV DSF.

References
[1] Tsinghua University Building Energy Conservation Center 2018 China building energy saving annual development research report (Beijing: China Building Industry Press)
[2] Yu Y, Xia L and Zhang Z 2008 Study on temperature-dependence performance of amorphous and crystalline silicon solar cells in PV application Taiyangneng Xuebao 29 8 984-987
[3] Peng J, Lin L, Yang H and Ma T 2015 Comparative study of the thermal and power performances of a semi-transparent photovoltaic façade under different ventilation modes Appl. Energy 138 572-583
[4] Zhu L, Huo Y, Sun Y and Zuo J 2018 Study of thermal performance of double layers translucent thin film PV curtain wall in Tianjin Taiyangneng Xuebao 39 4 21-23
[5] Bi Y 2010 Research on thermal environment characteristics of one photovoltaic façade in Shenzhen Chongqing university
[6] Zhang J, Zheng X, Lv J, Dou X and Yu B 2010 Structure and energy saving performance analysis of thin film photovoltaic curtain wall Gas. heat. 030 005 21-23
[7] Zhang R, Hao G, Yu X, Ye C and Li H 2008 Design and analysis on ventilated cavity for building rooftop integrated photovoltaic Build. Sci. 39 4 1026-1031
[8] Luo Y, Zhang L, Wang X, Xie X, Liu Z, Wu J, Zhang Y and He X 2017 A comparative study on thermal performance evaluation of a new double skin façade system integrated with photovoltaic blinds Appl. Energy 199 AUG.1 281-293
[9] Wang M, Peng J, Li N, Yang H, Wang C, Li X and Lu T 2017 Comparison of energy performance between PV double skin façades and PV insulating glass units Appl. Energy 148-160
[10] Yun G and Kim K S 2013 An empirical validation of lighting energy consumption using the integrated simulation method Energy. Build. 57 FEB. 144-154

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