An experimental study of a built-middle Photovoltaic Trombe wall system

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ABSTRACT. This paper proposed a PV-integrated Trombe wall system (PVTW) with the photovoltaic panel installed in the middle of air channel, named as built-middle photovoltaic Trombe wall system (PVMTW). The system has multiple functions: such as photovoltaic power generation, passive space heating, heat preservation and heat insulation. A series of tests were carried out in winter between the comparable hot-boxes to investigate the thermal and electrical performance of the PVMTW system. The results showed that the average electrical efficiency and thermal efficiency were 0.12 and 0.40, respectively, under the natural convection mode. The total efficiency of the PVMTW system was calculated to be 0.587, which is 11.4 % higher than that of traditional PVTW system with the solar cells laminated on the glass cover.

1 Introduction

PV-Trombe wall (PVTW) has attracted more and more attention because it has multiple functions such as power generation, space heating in winter and heat preservation. The PVTW system can be grouped into three major types according to the installation position of the PV panel in the Trombe wall system from the published literatures. One is that the PV panel was laminated on the surface of glass, also known as built-out photovoltaic integrated Trombe wall (PVOTW) system[1]. The one Su et al. [2] proposed to attach to the PV panel on the massive wall, also known as built-in photovoltaic integrated Trombe wall (PVITW) system. In addition, Hu et al. [3] proposed another different design structure of PV blind-integrated Trombe wall (PVBTW) system, for the PVBTW system, the PV blind was used for shading devices as well as electricity

generator.

According to the survey, among the various techniques employed to improve the performance of the PVTW system, few people previously have proposed to install the PV panel in the middle of the air channel. Therefore, a new design of the PVTW system is proposed in this paper. The PV panel laminated on the heat absorber plate is installed in the middle of the air channel of the Trombe wall system, which is called as built-middle photovoltaic integrated Trombe wall (PVMTW). The schematic diagram of the PVMTW system is presented in Fig.1. This new PVMTW system has multiple functions: space heating, thermal insulation and electricity generation. The purpose of this paper is to investigate the thermal and electrical performances of the PVMTW system through experimental studies by comparison with the traditional PVOTW system.

Fig.1 The schematic of Trombe wall with photovoltaic cells (a-the traditional PVOTW system, b-PVMTW system)

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2 Description of the experimental setup

The experimental rig contains two hotbox buildings with the same dimension of 3900 mm (depth) × 3800 mm (width) × 2600 mm (height), as shown in Fig.2. Two types of PVTW systems are installed on the south facade walls of two hot box buildings in Hefei (117° E, 32° N), China. Expect for the south wall, the other orientated wall of the two hot-box are constructed to be the same. Both types of

PVTW systems consist a glass cover with a thickness of 3.2 mm, PV cells, absorber plate, and an air channel with 1700 mm (height) × 900 mm (width), a 50-mm- thick insulation backplane and a south-facing massive wall, as shown in Fig.1. There are four air vents of the same size of 800 mm (length) × 80 mm (width) in the each of PVTW system. The PV panel as the power unit consists of 50 pieces mono-crystalline silicon cell of the same size 156 mm (length) × 156 mm (width) in parallel by a wire, with 0.60 PV cells coverage ratio (Fig.2b).

Fig.2. Photo of south facade wall of comparative hot boxes with PVTW system and the front view of PV Cells Panel (a-contrast hot box with PVTW system, b- the front view of PV Cells Panel)

Fig.3. Environmental temperature and vertical solar irradiation

The experiments were carried out from December 20th, 2017 to December 22nd, 2017 (9:00-16:00) and the weather was characterized mostly by sunny conditions during the test period, as shown in Fig.3. Radiation intensity on the vertical surface and temperature of all measuring points are measured by pyranometer and thermocouples, respectively. The power generated by PV cells is charged to the storage battery by the charging controller. All test data will be recorded and saved by a portable data acquisition instrument (Agilent34980A) during the experiment. The time step for the data acquisition instrument is set to be 30s. During the experiment, the vent 2 and vent 3 are kept open, and the other vents are closed at daytime, while at night all vents are closed to reduce the heat loss.

3 Performance evaluation of PVTW system

The instantaneous thermal and electrical efficiency of PVTW system is given by:

$$\eta_e = \frac{U \cdot I}{G \cdot F_g \cdot \zeta} \quad (1)$$

$$\eta_{th} = \frac{Q_{th}}{G \cdot F_g} \quad (2)$$

where the heat gains are given as:

$$Q_{th} = u_a \cdot F_{ch} \cdot \rho_a \cdot c_a (T_{a,upper} - T_{a,lower}) \quad (3)$$

In view of electrical energy is high-grade energy, total efficiency (η_{total}) is now introduced to evaluate the combined performance of PVTW systems [4], expressed as:

$$\eta_{total} = \eta_{th} + \zeta \cdot \eta_e / \eta_{power} \quad (4)$$

where η_{power} is the power generation efficiency of coal-fired power plants, and its value is 0.38.

4 Results and discussion

Fig.4 depicts the comparison of heat gains and thermal efficiency between the PVOTW system and the PVMTW

system. The results show the daily heat gains obtained from the PVMTW system is 11.74 MJ, 11.57MJ and 12.43 MJ, while that from the PVOTW system is 8.87 MJ, 8.30 MJ, and 9.32MJ on 20th December, 21st December and 22nd December. It is also found that the instantaneous thermal efficiency of the PVMTW system ranges from 0.28 to 0.48, and that of PVOTW system ranges from 0.21 to 0.36 during the experiment. According to the

calculation, the average thermal efficiency of two kinds of PVTW systems are 0.40 and 0.29, respectively. The former is 1.38 times that of the latter. It is obvious that the thermal load reduced by the PVMTW system is greater than that reduced by the PVOTW system. therefore, the PVMTW system contributes more to building energy saving.

Fig.4. Comparison of heat gains and thermal efficiency between the PVMTW system and PVOTW system (Q_t , η_t -heat gains and thermal efficiency; M-PVMTW system; O-PVOTW system).

Fig.5 shows the changes in power output and the photoelectric conversion efficiency of the two types of PVTW system. According to the data in the Fig.5, the daily output power of the PVMTW system is 0.58 kWh, 0.62 kWh, and 0.64 kWh during the experiment, and that of the PVOTW system is 0.73 kWh, 0.74 kWh and 0.77 kWh respectively. The average photoelectric conversion efficiencies of the two types of PVTW system are 0.12 and

0.15, respectively. The reason is that the higher temperature of PV cells of the PVMTW system reduces the photoelectric conversion efficiency. The change of temperatures on PV cells for both PVTW systems is shown in Fig.6. Through the temperatures curve in the Fig.6, we can find that the PV cells temperature of the PVMTW system is significantly higher than that of the PVOTW system during the experiment.

Fig.5. Comparison of electricity output and electrical efficiency between the PVMTW system and the PVOTW system (E_e -electricity output; η_e - electrical efficiency; M-PVMTW system; O-PVOTW system).

Fig.6. Comparison of the temperature of PV cells (M-PVMTW system; O-PVOTW system)

Table 1 summarizes the comparison results of the two types of PVTW systems. The results show that during the experiment, the average daily total efficiency of PVMTW system is 0.59, 0.59 and 0.58, while that of PVOTW system are 0.54, 0.52 and 0.52, respectively. The former average is 0.587, which is 11.4 % higher than that of the latter. This indicates that the proposed PVMTW system has more advantages in the utilization of solar energy than the conventional PVOTW system.

Table 1 Comparisons of the comprehensive performance of two PVTW systems.

Parameters	20/12/2017		21/12/2017		22/12/2017	
	PVMTW	PVOTW	PVMTW	PVOTW	PVMTW	PVOTW
thermal efficiency	0.404	0.305	0.390	0.280	0.393	0.295
electrical efficiency	0.118	0.150	0.122	0.150	0.119	0.145
Total efficiency	0.59	0.54	0.59	0.52	0.58	0.52

5 Conclusions

In comparison with the traditional PVOTW system, a series of experiments were conducted in winter to investigate the thermal performance, electrical performance and total performance. Some conclusions can be drawn as follows.

(1) The average thermal efficiency of two kinds of

PVTW systems are 0.40 and 0.29, respectively. The former is 1.38 times that of the latter.

(2) The results show that the electricity efficiency of the PVMTW system is 0.12 and that of the PVOTW system is 0.15.

(3) The average of the total efficiency of the PVMTW system is 11.4 % higher than that of the PVOTW system, which indicates that the proposed PVMTW system has more advantages in the utilization of solar energy than the conventional PVOTW system.

Nomenclature		Subscripts	
G	solar radiation intensity, W/m ²	g	glass
T	Temperature, K	a	air
c	specific heat capacity, J/(kg·K)	upper	upper vent
u	speed, m/s	lower	lower vent
F	area, m ²	th	thermal energy
Q	energy, W	e	electricity
U	voltage of PV module, V	ch	air channel
I	current of PV module, A	power	coal-fired thermal power plants total
ζ	packing factor,-	total	
Abbreviations			
PVOTW built-out photovoltaic integrated Trombe wall			
PVMTW built-middle photovoltaic integrated Trombe wall			
PVITW built-in photovoltaic integrated Trombe wall			
PVBTW PV blind-integrated Trombe wall			

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