Experimental study on power generation of PV material façade in three typical cities in East China

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Abstract. In this study, experimental investigations on photovoltaic (PV) façade systems were conducted to study the electrical power generation in three typical cities in East China. The window glass consists of 6mm thick semi-tempered glass, polyvinyl butyral (PVB)/ethyl vinyl acetate (EVA) film, solar cells, PVB/EVA film, and 6mm thick semi-tempered glass. The walls are made by insulation yamnian with an inner thickness of 12 mm. Test facility was established in Beijing, Wuhan, and Guangzhou, respectively. The building process and test details were introduced. The current-voltage (I-V) curve and the power-voltage (P-V) curve of the present PV façade were obtained and the voltage corresponding to maximum power point (MPP) is 17 V. Daily, monthly, and yearly electrical power generation in the three cities were obtained to show all-around PV performance in East China. Beijing has the maximum power output (~180 kWh) for horizontal panels, larger than those panels faced at south direction. While in Wuhan and Guangzhou, the maximum power outputs only are ~140 kWh also with horizontal panels. Besides, it also discovered that orientation is the key parameter in Beijing and Wuhan, while orientation is not the key parameter in Guangzhou.

1. Introduction

The applications of photovoltaic (PV) façade systems are becoming increasingly popular in residential and commercial buildings because they serve as a functional part of the building envelop, thus decreasing structural installation costs while improving architectural integration simultaneously [1-3]. The typical applications include the China Pavilion in 2010 world expo, the London Guildhall, the Dutch PV Atrium, the Solar City in Linz, Austria, etc. The solar energy absorbed by the PV panels is partially converted into electricity and heat, and the rest is reflected. PV façade systems not only can serve as a renewable source of electricity, but also can provide thermal energy for the Heating Ventilation Air Conditioning (HVAC) for the buildings.

Due to the promising applications, the studies through both experiments and simulations are increasingly prevailing. Hossain et al. increased the solar cell’s efficiency using a compound parabolic concentrator (CPC) and sun tracking system [4]. Yoo and Manz modeled the building integrated PV (BIPV) system as a shading device in Korea. Experiments were conducted to validate their simulations [5]. Gan simulated the BIPV to optimize the adequate air gaps [6]. Liao et al. studied BIPV systems as well by CFD simulations and obtained the correlations of convective heat transfer coefficients [7]. He et al. through both approaches investigated the thermal performance of amorphous silicon (a-Si) PV window in Hefei city in East China. Compared between their experimental and numerical results, the
temperature difference of PV modules was only 1.7% and 1.1% for PV double-glazing and PV single-glazing window respectively [8]. Peng et al. developed a novel ventilated BIPV double-skin façade (DSF) and analyzed the thermal performance by experiments. They found that the ventilated PV-DSF provided the lowest solar heat gain coefficient, while the non-ventilated PV-DSF better reduced heat loss in their systems [9].

China has a large area and its climate varies from region to region. The Ministry of Construction in China has divided the whole country into several regions, as shown in Fig. 1 [10]. To fully study the PV performance in East China, only one city is not enough. Thus we built the PV façade systems in three typical cities, namely Beijing (116°28'E, 39°54'N), Wuhan (114°21'E, 30°37'N), and Guangzhou (113°16'E, 23°06'N), to experimental investigated the power generation of PV façade in this study. These three cities are located at different climate region, as shown in Fig. 1, namely Cold region, Hot-Summer Cold-Winter region, and Hot-Summer Warm-Winter region, respectively. The yearly and monthly electrical power generations were studies respectively in these three cities. The effects of the PV panels’ orientation and façade system’s shape were also investigated.

2. Experimental Setup
In these three cities, we respectively built PV façade test facility with same dimensions. The test facility is shown in Fig. 4, 5 and 6. The whole dimension is 4.65 m × 3.4 m × 3.6 m. The area of the PV window is 1.43 m². Schematic diagram of cell arrangement of PV window is shown in Fig. 2. The PV window contains 6×6 array PV panels and the dimension of each panel is 125 mm × 125 mm, as shown in Fig. 3. The reference output power is 95 W and the light transparency is 60%. The area ratio between the PV panels and the PV window is nearly 39.3%. The window glass consists of 6mm thick semi-tempered glass, polyvinyl butyral (PVB)/ethyl vinyl acetate (EVA) film, solar cells, PVB/EVA film, and 6mm thick semi-tempered glass. The walls are made by insulation yamnian with an inner thickness of 12 mm. The inner room temperature is controlled by an air conditioner (GREE) with power of 1000 W.
In our study, we used a static-state GPS analyzer to measure the coordinate and orientation of the test facility before the PV performance test. The horizontal solar radiation and the vertical solar radiation on each orientation were tested by actinometer (TBQ-2). A maximum power point tracker (MPPT) was fabricated to track the solar radiation [1]. An energy consumption record meter was used to record the energy consumption of the air conditioner. All the data were recorded by a data acquisition unit (Agilent 34972A). A small real-time station was used to record the meteorological parameters, like temperature, humidity, air speed, etc.
Fig. 5. The construction process of the test facility

Fig. 6 Photograph of the test facility with PV window

3. Results and Discussions

The current versus voltage (I-V) curve and the power versus voltage (P-V) curve of the present PV panels are shown in Fig. 7. From Fig. 7, it is seen that under certain solar irradiance levels, there exist unique points where the output electrical power is maximum. These points on the P-V curves are known as the maximum power points (MPPs). The idea of MPPT is developed in the solar system to utilize PV panels at the optimal efficiency by tuning the duty cycles of the power converters inserted between the PV source and the load [1]. For the present system, the voltage should be about 17 V in order to maximize the output power. Therefore, in later experiments, we kept the voltage at 17 V.

The variations of the daily solar irradiance and PV power at different orientations in a sunny day are shown in Fig. 8. It is seen that let alone the orientations, the solar irradiance levels increase from the sunrise in the morning, and reach peaks at noon, and then decrease to zero at sunset. This is easy to understand when considering the sun’s position in the daytime. As for the orientation, it is seen that the horizontal surface has the largest solar irradiance because there is always sunshine on the horizontal surface although the solar irradiance strength might change. It is also discovered that the peak may change with different orientations as well. For the horizontal surface, the peak corresponds to the period of 12:00~13:00 at noon; for the East vertical PV panel, the peak appears at the period of 9:00~10:00 in the morning; for the West vertical PV panel, the peak appears at the period of 15:00~16:00 in the afternoon. This is because that the sun rises in the East and sets in the West. Since we performed this experiment in the north hemisphere, the trends are the same for the horizontal surface and the south vertical PV panel where the solar irradiance may become highest at noon. As for the power output from the south vertical PV panel, it has similar trend with its solar irradiance.
Fig. 7 I-V and P-V characteristic curves of the PV panel under different solar irradiance levels in Wuhan

Fig. 8 Daily solar irradiance and PV power with different orientations at Wuhan

The monthly electrical power generation obtained in three typical cities at different orientations is shown in Fig. 9. It is seen that in all cities, the horizontal surface has the largest power generation because it has the largest solar radiation and longest sunshine duration. The East and West vertical PV panels have approximate power output in the three cities due to symmetry property of the sun’s track. The North vertical PV panels in the three cities has the lowest electrical power output because the north orientation has the least solar radiation and shorted sunshine duration for the north hemisphere. For Beijing, the largest electrical power generation happens in May; for Wuhan, it is July. But for Guangzhou in the South China, the PV electrical power generation keeps at uniform level since it has Hot-Summer Warm-Winter climate there. When comparing the electrical power output, it is seen that Beijing has the largest output, Wuhan has the second, and Guangzhou has the least output. This is due to Beijing’s latitude is highest thus its sun duration is the longest; Guangzhou’s latitude is lowest thus its sun duration is the shortest.
Fig. 9 Monthly electrical power generation at different orientations in (a) Beijing, (b) Wuhan, and (c) Guangzhou

Fig. 10 Yearly electrical power generation in three cities at different orientations

When obtaining the monthly power generation, we can easily obtain the yearly power generation by summing up the monthly power generations. As shown in Fig. 10, the results of the three cities are consistent with Fig. 9. It is seen that Beijing has the largest power output and Guangzhou’s output is the least. In Beijing, the maximum power output can reach ~180 kWh for horizontal panels, while in Wuhan and Guangzhou, the maximum power outputs are about ~140 kWh also with horizontal panels. It is also seen that the variation at different orientation in Beijing is the largest, which imply that the orientation is the key parameter there. On the contrary, the variation at different orientation in Guangzhou is the smallest, which imply that the orientation is not the key parameter there.

Those results obtained from the experiments were somewhat contradicted with the normal practical experiences which always regard that the south direction was the optimism for the solar panels. Our results showed that for cold region in China (for example, in Beijing) south direction produced the lowest power in summer. This may be caused by the high velocity of wind in summer, the high frequency of rain or shade effects by the large leaves on the trees. This abnormal result needed to be investigated further in the next part of my study.

The solar panels used in this study may greatly affect the results of power generation in different directions. Other kinds of solar panels were needed to be compared with this panel in the same
environment to investigate the best directions for different areas. This work would be processed in my further researches.

4. Conclusion

In summary, experiments were conducted to investigate the electrical power generation of photovoltaic (PV) façade systems in three typical cities in East China, namely Beijing, Wuhan, and Guangzhou. The test facility was built in Beijing, Wuhan, and Guangzhou, respectively. The building process and test details were introduced. The current-voltage (I-V) curve and the power-voltage (P-V) curve of the present PV façade were obtained by the maximum power point tracking (MPPT) method and the optimal voltage is 17 V. With the test facility, the daily, monthly, and yearly electrical power generation in these three cities were obtained. It is found that Beijing has the maximum power output (~180 kWh), while in Wuhan and Guangzhou, the maximum power outputs only are ~140 kWh. The reasons behind the phenomena can be attributed to the sunshine duration. Besides, it also discovered that orientation is the key parameter in Beijing and Wuhan, while orientation is not the key parameter in Guangzhou.

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