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Performance evaluation of semi-transparent CdTe thin film PV window applying on commercial buildings in Hong Kong

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Abstract

The energy performances of c-Si PV windows and a-Si PV windows have been investigated comprehensively worldwide. However, CdTe thin film PV windows which are supposed to achieve better performance due to its higher efficiency are rarely studied. This study evaluated the energy performance of semi-transparent CdTe thin film PV window applying on commercial buildings. The results show that CdTe PV windows have large energy saving potential in Hong Kong, and the annual energy generation of per unit CdTe PV windows is 52.3kWh/m^2. Compared to the common window and a-Si PV window, the saving in net energy consumption is 19.6% and 15.3%, respectively.

Keywords: BIPV; semi-transparent PV windows; CdTe thin film PV; EnergyPlus; Energy performance

1. Introduction

Due to the shortage of energy, renewable energy is competitively developed all over the world. Building-integrated photovoltaic (BIPV) technologies provide the opportunity to generate electricity on buildings by incorporating PV materials in building envelope components [1]. As a typical application, PV windows have been

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attracting the attention of many researchers since its ability to generate power while providing daylighting illuminance.

The energy performances of PV windows applying on buildings were investigated experimentally and simultaneously. Miyazaki et al. [2] analyzed the energy performance of amorphous silicon (a-Si) PV window applying on office buildings in Japan. A simulation model was developed and the effect of solar cell transmittance and zone orientation was analyzed. Chow et al. [3] estimated the energy performance of semi-transparent a-Si PV window applying on an office building in Hong Kong. The optimal value of solar cell transmittance was estimated through simulation. Fung and Yang [4] investigated the thermal performance of crystalline silicon (c-Si) PV window by developing a one-dimension transient heat transfer model. Wong et al. [5] chose semi-transparent c-Si PV as top light material for residential application and evaluated its energy performance in five climate regions in Japan. Li et al. [6] measured the daylighting and power generation performance of a semi-transparent a-Si PV module and investigated the energy and financial performance through a case study in Hong Kong. Ng and Mithraratne [7] selected six commercially available semi-transparent BIPV windows and evaluated their lifetime environmental and economic performance in Singapore. Three of the PV windows adopt a-Si technology and the other three adopt μc-Si technology. Chae et al. [8] fabricated three types of semi-transparent a-Si PV windows and calculated the thermal-optical characteristics of PV windows. The overall energy performances of PV windows were simulated in various climate conditions in the United States. Peng et al. [9-12] investigated the overall performance of semi-transparent a-Si PV double skin façade (DSF) experimentally and developed a comprehensive simulation model to evaluate the energy saving potential of PV DSF in different locations. It was concluded that once cadmium telluride (CdTe) PV modules which had higher efficiency were adopted, the energy output of PV window could be even doubled. Wang et al. [13,14] evaluated the overall performance of semi-transparent a-Si PV insulating glass units (IGU) and compared the energy performance of PV DSF and PV IGU through experiment and simulation.

For now, however, there is rarely research on the energy performance of CdTe thin film PV windows; most of the research on PV windows is about a-Si and a few research is about c-Si. It is supposed that CdTe PV window would perform better than a-Si PV window due to its higher energy conversion efficiency. To figure out the benefit, this study investigated the energy performance of CdTe PV windows applying on a commercial building in Hong Kong.

In this study, the characteristics of CdTe PV module were tested firstly. Then the obtained parameters were incorporated into EnergyPlus model which could simulate the overall performance of PV windows comprehensively. At last, the energy performance of CdTe PV windows was investigated. The simulation model of PV window was developed based on a validated method [12]. Further study would be conducted to validate the simulation model.

2. Simulation models

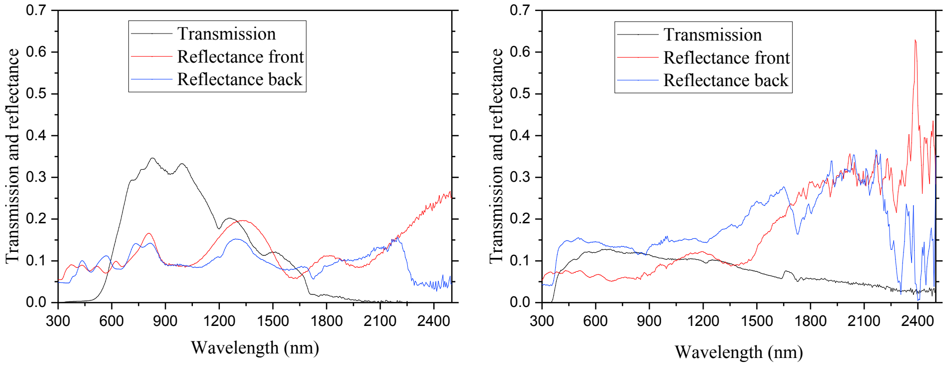
2.1. Model development

In this study, the energy performance of CdTe PV window was evaluated by comparing with a-Si PV window. The specifications of a-Si PV module and CdTe PV module are shown in Table 1.

Table 1. Specification of a-Si PV module and CdTe PV module.

Parameters	A-Si PV module	CdTe PV module
Maximum power, P_{max}(W)	85	51.4
Short circuit current, I_{sc} (A)	1.05	0.85
Open circuit voltage, V_{oc} (V)	134.4	104
Current at maximum power point, I_{mp} (A)	0.85	0.69
Voltage at maximum power point, V_{mp} (V)	100	74.5
Temperature coefficient (%/ºC)	-0.21	-0.21
Efficiency, η (%)	5.9	7.1
Dimension (mm×mm×mm)	L1300×W1100×T7	L1200×W600×T8
Transmittance (%)	6%	10%

The optical characteristics of the PV modules were measured by a spectrometer. Figure 1 presents the specific optical characteristics of a 6% transmittance a-Si PV laminate and a 10% transmittance CdTe PV laminate from 300 nm to 2500 nm.



a) 6% Transmittance a-Si PV laminate

b) 10% Transmittance CdTe PV laminate

Fig. 1. Optical characteristics of the semi-transparent CdTe PV laminate and a-Si PV laminate.

The Sandia Array Performance Model was employed to evaluate the power output performance of CdTe PV windows. In order to acquire the characteristic parameters to build the simulation model, indoor and outdoor tests were conducted. Figure 2 shows the outdoor test rig of CdTe thin film PV module.

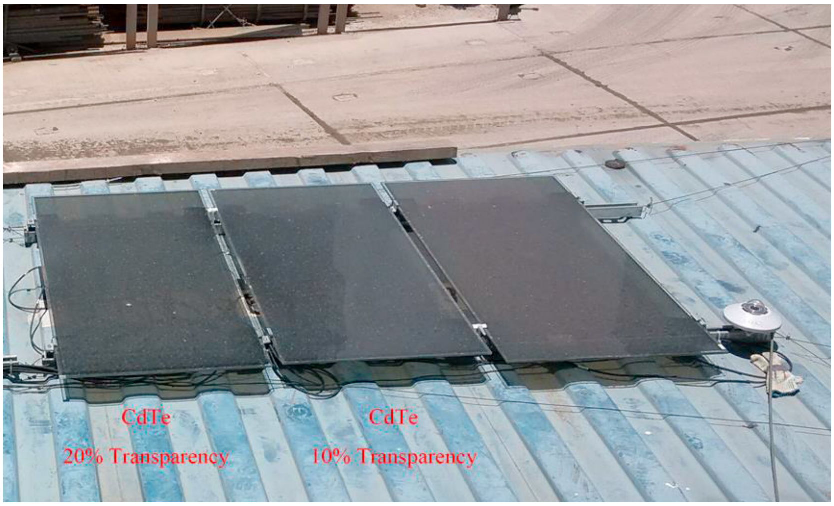


Fig. 2. Outdoor test rig of CdTe thin film PV module.

2.2. Simulation models

To evaluate the energy performance of CdTe PV windows applying on commercial buildings, a building model was built in EnergyPlus. The building model is referred to a reference commercial building model from the guidebook of the Hong Kong performance-based building energy code [15]. As showed in Figure 3, the targeted commercial building was a medium-sized commercial building which had 10 floors. The building had five thermal zones and the window to wall ratio was 0.6.

The commercial building was occupied according to the office's schedule. The air conditioning and lighting work only when the building was occupied. The building employed a direct expansion cooling coil system (COP=3.0) and an electric heating coil (COP=1) for indoor cooling and heating. The heating and cooling thermostat set points were 21 and 24 ^{o}C, respectively. In the simulation, the people density was set to be 8 m^2 per persons, and the electrical equipment power density was considered to be 10 W/m^2. As for lighting, a load density of 15 W/m^2 was assumed. A continuous lighting control system which could regulate the lighting output according to the amount of indoor daylight illuminance was introduced to minimize the artificial lighting consumption.

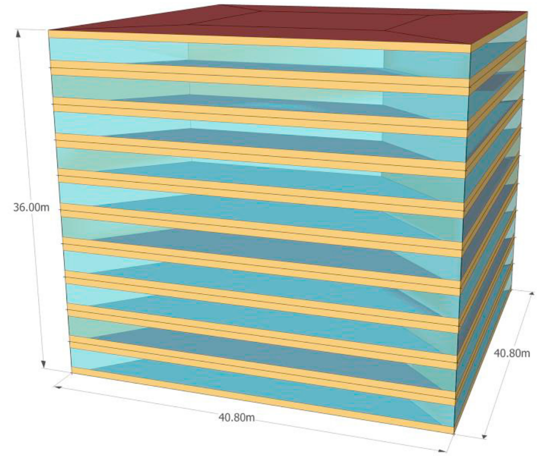


Fig. 3. The simulation model for the commercial building integrated with CdTe PV windows.

3. Results

The comparative buildings have the same properties in all aspects expect the window systems. Three different window systems are adopted for comparison, which are the common window, a-Si PV window, and CdTe PV window. The common window adopts 3 mm clear glass, which is widely employed in Hong Kong. Since the PV windows install in the south façade, only the energy consumption of south zone is taken into consideration. The comparison results are shown in Figure 4. The CdTe PV window has the best performance in reducing cooling energy consumption, while the common window has the worst performance. This is because the solar heat coefficient of CdTe is the lowest, and lower solar heat gains cause lower air conditioning consumption. As for heating energy saving, there is no remarkable difference between the three windows due to the low heating demand in commercial buildings. The common window performs best in reducing lighting energy consumption. This is because the transmittance of the common window is the highest, and the need for additional artificial lighting is least. The visible light transmittance of the a-Si PV window is lowest, which is the reason for the highest lighting consumption. Since the energy conversion efficiency of the CdTe PV window is higher than the a-Si PV window, the power generation performance of CdTe PV window is better. Averaged by the PV window area, the power generation of the a-Si PV window and the CdTe PV window are $41.8kWh/m^2$ and $52.3kWh/m^2$, respectively. The better performance is mainly attributed to the higher efficiency of the CdTe PV window. In general, the overall performance of CdTe PV window is best among the three types of windows. Compared to the common window and the a-Si PV window, the energy saving potential of the CdTe PV window is 19.6% and 15.3%, respectively. With the development of PV technology, the energy saving potential of PV windows would be further improved. Since the price of a-Si PV module and CdTe PV module are both nearly HKD 6.2/W, the cost of a-Si PV window and CdTe PV window are similar to each other. The low price and high efficiency makes CdTe PV technology more attracting to society in future.

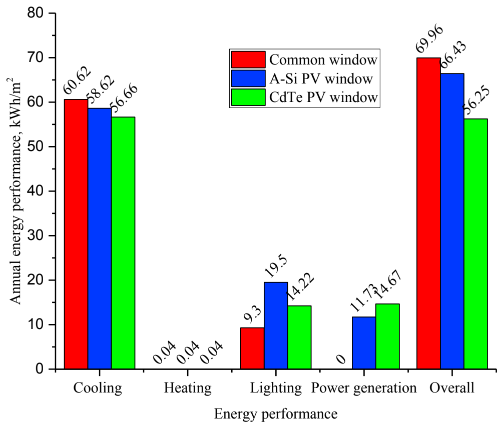


Fig. 4. Energy performance of different windows.

4. Conclusion

In this study, the energy performance of CdTe PV window was evaluated through simulation. This study built a simulation model for CdTe PV window and estimated the energy performance of a typical commercial building which adopted different window systems. The results show that the annual power generation of the a-Si PV window and the CdTe PV window are 41.8kWh/m^2 and 52.3kWh/m^2, respectively. Considering the overall performance, the energy saving potential of the CdTe PV window were 19.6% and 15.3% respectively compared with the common window and a-Si PV window.

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