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OPTIMIZATION PERFORMANCE OF DOUBLE SKIN FAÇADE INTEGRATED SEMI-TRANSPARENT PHOTOVOLTAIC

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ABSTRACT

This paper investigated the energy performance of an innovative double skin façade integrated semi-transparent photovoltaic and optimized the design parameters and the operation mode. The simulation model was built and utilized with Grasshopper plug-in Ladybug and Honeybee. The overall energy performance of the innovative DSF-PV including thermal, day lighting and electricity productive performance was investigated in the numerical model. The result indicates that the optimal dimension of this innovative DSF-PV is 0.5m air gap depth, 3.6m floor height, and 0.45 height of the top and bottom opening. The optimal operation mode pf DSF-PV in Tianjin is natural ventilation in cooling season and No ventilation in heating season, which can save about 20%~23.95% energy consumption. The power generation of the PV façade can achieve about 70KW h per unit area, electricity yearly in Tianjin, that is considerable potential for office building integrated the PV façade on the external skin. Thus, if the optimal operation mode of DSF-PV, the overall energy performance conversion efficiency would be improved.

Keywords: Double-skin-facade, BIPV, CIGS, Ventilation façade, Semi-transparent photovoltaic

NONMENCLATURE

Abbreviations	
DSF-PV	Double skin façade integrated Photovoltaic
OH	Opening height
FH	Floor height
AGD	Air gap depth
VM	Ventilation mode
VT	Visible Transmittance
SHGC	Solar heat gain coefficient
U-value	Thermal transmittance

Symbols	
η	*solar cell efficiency*

1. INTRODUCTION

The Building is a critical element in our modern society and accommodates a variety of needs and functions. Unfortunately, the energy consumed by buildings accounts for 32% of global final energy consumption and 19% of energy-related greenhouse gas emission. [1] The existing building stock, therefore, offers great potential for CO2motigation of up to 50%-90% using existing technologies. Of these proposed technologies, building integrated photovoltaic have been recognized as a viable path to supply the energy need of a building. [2]

Developments in efficiency, appearance, colors, and costs of semi-transparent BIPV technologies have brought new flexible nature allows for easier and more aesthetically pleasing integration into the building envelope. [3,4] Building envelops which separated the interior conditioned space form the exterior unconditioned environment, are the key determinants of building energy efficiency and indoor environment. As we know, glass façades are widely used for modern buildings, particularly commercial buildings, due to their aesthetics, lightweight and day lighting potential. [5] However, it cannot provide a comfortable indoor environment, sound protection, and sometimes bring high energy consumption. Double skin facades became an important architectural building element due to their high potential to provide energy, comfort, aesthetic and structural advantages, as well as to provide space for integrated PV panels. [6] A DSF normally consists of exterior and interior skin separated a ventilated air cavity used as an air channel. This cavity is considered as a buffer zone and it is located between the exterior skin

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and the insulated interior one. The cavity of the DSF can also create a micro-climate around the building, adding climate resilience to it and made it possible to adapt the weather changes. The temperature difference inside the cavity can facilitate natural ventilation or hybrid ventilation and it can be used for heat recovery purposes. [7,8] The integration of semi-transparent photovoltaic on the exterior skin gives the opportunity to design an energy positive DSF-PV façade. This can achieve by the generation of electricity through integrated PV, the control of solar heat gain and by the extraction of heat from the PV and air flowing within the cavity.

Although many papers concerning the semi-transparent PV-façade performance has been published, there is limited research focusing on the CIGS and double skin façade integrated the CIGS semi-transparent photovoltaic. In this paper, the cooling load, heating load, lighting load, and power generation and the whole performance of the DSF were investigated. [7-15]

2. *METHODOLOGIES*

2.1 Basic model and design parameters

AS shown in the Fig.1, the DSF-PV module is a standard floor of a typical model of a high-rise office building in Cold region of China. The length and the width of the building is 38 m. The depth of the functional zone is 11m.Its WWR is 0.5 and the assistance space amounts about to 17%; the depth of the functional zone is 11m. The DSF-PV consists the exterior skin integrated 10 semi-transparent CIGS PV panels and an interior skin with an operable window which the WWR is 0.5. The air can flow in the cavity between the DSF-PV. The ventilation cavity has the following characteristics. Firstly, the top and bottom opening of the external skin is operable to make the fresh air flow in the cavity between the DSF-PV. The cold air entered the DSF-PV through the bottom opening, exchange the heat with the PV façade and finally exhaust a considerable amount of waste heat via the top opening. Secondly, the DSF-PV can receive solar and daylighting through the semi-transparent PV façade. The fresh air flowing in the cavity can not only cool down the solar cell and enhance the PV electricity production but also decrease the cooling load of the building saving potential of the DSF-PV in China Cold Climate zone, taking Tianjin region as the case.

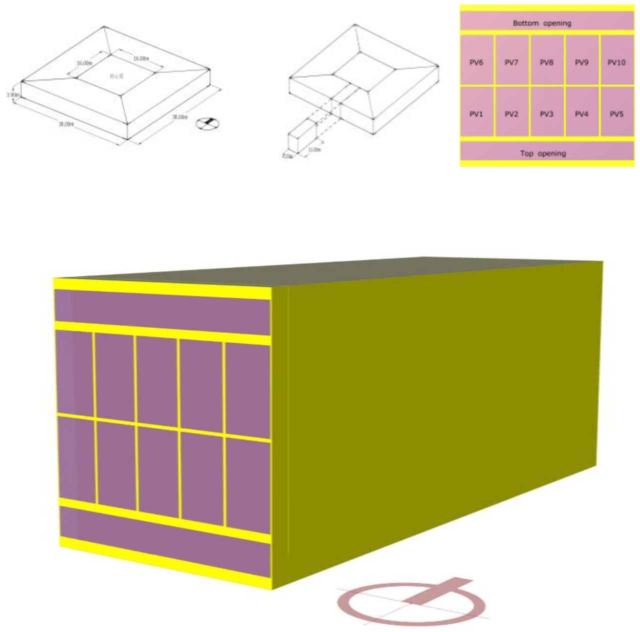


Fig 1 The simulation model in Honeybee

The key design parameters of the DSF-PV are listed in Table 1. The physical characteristics of the CIGS PV panel are given in Table2[16].

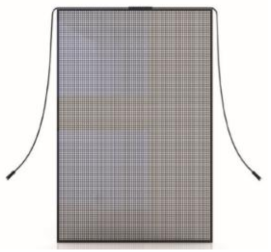
Table1 Dimension parameters of the DSF-PV model

Parameters	*Value*								
FH	*3.6*	*3.7*	*3.8*	*3.9*	*4.0*	*4.1*	*4.2*		
AGD	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*
OH	*0.3*			*0.45*			*0.6*		
VM	*No Ventilation*					*Natural Ventilation*			

2.2 *Tools and methods*

To calculate the whole energy characteristics of the DSF-PV module, the simulation model was developed in the Grasshopper with the plug-in----Honeybee and lady bug which the core engines are Daysim, Radiance and energyplus. *Fig.2* illustrates the simulation workflow. The work was started by development a geometry model with the parametric method in Grasshopper; then input the physical characteristics of the building and the Semi-transparent PV façade including the thermal properties and electrical properties.

Table2 Propertied of the Semi-transparent PV panel

1	Product	Hanergy	P-BASIC SERIES
2			
3	Parameters	Unit	Value
4	Length	[mm]	1192
5	Width	[mm]	792
6	Thickness	[mm]	33
7	Cell technology	CIGS	
8	P_{max}	[W]	95
9	U-value	[W/㎡]	2.62
10	VT		0.23
11	SHGC		0.31
12	η	[%]	11

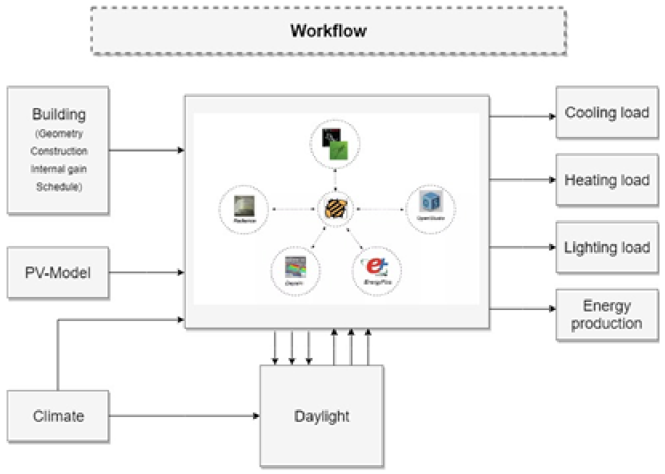


Fig 2 The work flow of the simulation

3 SIMULATION MODEL

As mentioned above, the engine of GH is energyplus. Energyplus is a whole building energy simulation program that engineers, architects, and researchers used to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. During the simulation, different class and objects, such as the airflow network, Sandia PV model, daylighting control model of energyplus were employed to simultaneously simulate the power, thermal and daylighting performance of DSF-PV. [8]The Sandia model was adapted to calculate the energy production of the PV façade because it can achieve versatility and accuracy, especially for thin-film solar cells, as all the coefficient used in this model are derived from special tests using the same kind of solar cells. [9] Airflow network was adopted to simulate the heat transfer and air flow in the air gap to investigate the impact of ventilation on both the energy generation improvement and the cooling load reduction. The day lighting model performance of DSF-PV of different design parameters, as well as to investigate the impact on lighting energy use.

4 RESULT AND DISSCUSSION

4.1 Effect of the top and bottom opening height of DSF-PV

The air-flow in the cavity of the DSF take away a considerable amount of waste heat and cool down the PV panel temperature. The opening size impacts the airflow in the cavity of the DSF-PV. Fig.3 presents the heating, cooling, lighting load and electricity production of DSF-PV variation under different opening size and ventilation mode. The lighting load slowly decreased as the opening size increased no matter which ventilation mode. More WWR of the external skin, the more daylight can enter the indoor space. This is the reason why lighting electricity demand decreased when the opening height increased. Under the NO-Ventilation mode, the heating load and cooling load are all increased when the opening height increased. As the Natural ventilation mode, the cooling load appeared a phenomenon that cooling load decline at the opening height of 0.45 and

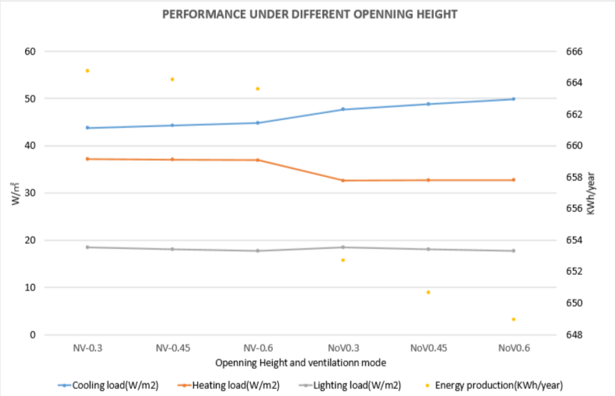


Fig 1 The impact of Opening size on the performance of DSF-PV

increased at 0.6; when the heating load declined continuously when the opening height increased.

4.2 Effect of the air gap depth of DSF-PV

As talked above, the fresh air entered the cavity from the bottom inlet and exhausted from the top outlet can take away a considerable amount of waste heat in the process. The air gap depth is an important impact factor of the performance of DSF-PV. The optimization of the air gap depth is beneficial in both decreasing the cooling load during the cooling season, heating load during the heating season and improving the efficiency of solar cells. Fig.4 presents the variation trends of the annual cooling load, heating load, lighting load, and the energy output. The lighting load gradually increase with the increase of air gap depth. Under natural ventilation mode of the top and bottom opening of DSF-PV, the cooling load decreased as the air gap depth increased when the gap was less than 0.4m; but increased when the gap was large than 0.4m. Thus, under the closed condition of the inlet and outlet opening, the cooling load increased as the air gap was less than 0.4; and increased as the gap was more than 0.4. The heating load of the DSF-PV increased as the air gap increased both the No-Ventilation mode and Natural ventilation mode.

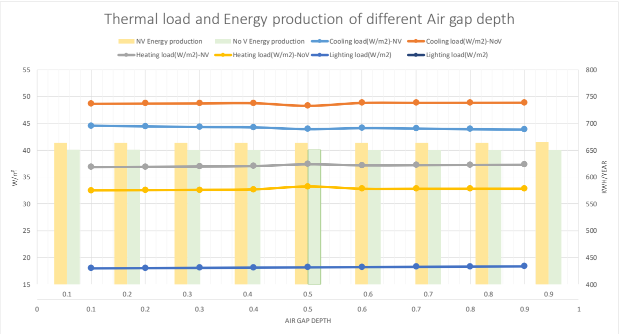


Fig 4 The impact of air gap depth on the performance of DSF-PV

Compared to the loading variation of the DSF-PV, the energy production of energy output was very small because the electricity of the thin-film CIGS PV module are to be used, the temperature coefficient of thin-film cell is very small. However, the ventilation mode of the DSF-PV has a significant influence on the energy output of the PV façade.

4.3 Effect of the floor height of DSF-PV

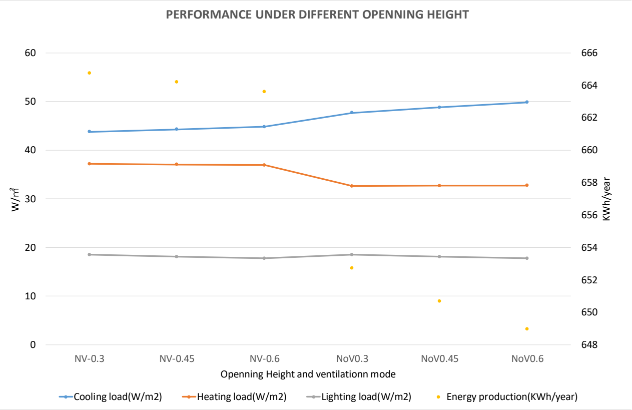


Fig3 The impact of Opening size on the performance of DSF-PV

The height floor has a significant impact on the buoyancy-driven ventilation of the air cavity in the DSF. The performance of DSF-PV with different floor height was calculated and shown on Fig5. Under No Ventilation condition, the heating and cooling load were continuously increased with the increase of floor height. As natural ventilation mode, the heating load continuously increased with the floor height increased. However, the cooling load increased when the floor height less than 3.9m， and decreased at 4.0m, then increased again when the floor height more than 4.0m. Fig6 presents the comparison of the annual power generation of the different floor height and Ventilation mode. With the increase of the floor height, the energy production increased in the meanwhile. As for the different ventilation mode, it is seen that the Natural ventilation DSF-PV façade has more 90 KW·h power generation per year than No ventilation mode average.

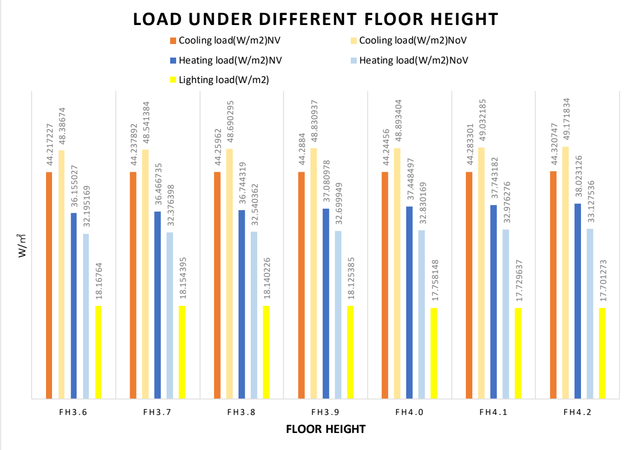
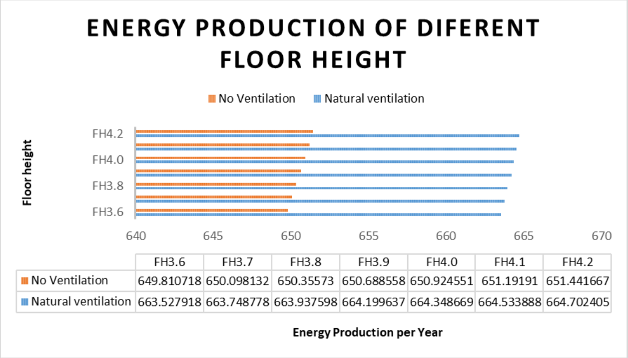


Fig 5 The impact of the floor height on the performance of DSF-PV



	FH3.6	FH3.7	FH3.8	FH3.9	FH4.0	FH4.1	FH4.2
No Ventilation	649.810718	650.098132	650.35573	650.688558	650.924551	651.19191	651.441667
Natural ventilation	663.527918	663.748778	663.937598	664.199637	664.348669	664.533888	664.702405

Fig 6 The impact of the floor height on the energy production of DSF-PV

5CONCLUSION

This paper investigated the performance of an innovative DSF-PV under different opening height, air gap depth, floor height and ventilation mode in cold climate zone in China. The valuable conclusions are drawn as follows:

(1) Generally, from the result of simulation; the optimal air gap depth of the DSF-PV is 0.5m, the optimal opening height is 0.45m, and the optimal floor height of the DSF-PV is 3.6m.

(2) This innovative DSF-PV under ventilation mode can increase power generation by2%, decreasing the cooling load about by 8.4~10.25% in the cooling season, and increased the heating load about by 12.6~13.7% in the heating season. Therefore, different ventilation mode in different seasons should be in motion in the cold climate region.

(3) The DSF-PV was able to generate about 70KW h per unit area, electricity yearly in Tianjin. The semi-transparent also produced good thermal and daylighting performance.

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