The Influence of the Support Frame on the Annual Electric and Thermal Performance of a PV-Wall in Hong Kong

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Abstract

In this paper, the theoretical model is presented to study the influence of the support frame on the annual electric and thermal performance of a south-west-facing PV wall located in Hong Kong University. The effects of the orientation of the PV panel, the depth and the height of the air duct on the electric and thermal performance are investigated. In the case study, it is observed that EPV panel can obtain more annual electricity generation by 128.218 kWh through well-designed frame, i.e. changing the orientation of PV panel (solar azimuth 84.11^0) non-parallel to the massive wall (solar azimuth 95^0). Simulation results show the depth of the air duct should not be designed too narrow and the height of the PV panel should not be designed too tall. A narrow air-gap depth and a tall height of PV panel will decrease the annual power output and increase the heat gain through the PV wall. For this case study, the difference of the annual electricity generation and the monthly heat gain (August) between two cases, i.e. depth = 150 mm and depth = 775mm, can reach 22.223 kWh and 96.952 kWh. Considering another two cases, i.e. Height = 2 m and Heigh t = 24.8 m, the difference of annual electricity generation and the monthly heat gain (August) are 1.47 kWh/m^2 and 2.274 kWh/m^2, respectively.

Introduction

The integration of photovoltaics in buildings has been (since 1/1/97) the object of an international task (Task VII) operating under the International Energy Agency's PV Programme. Demonstration projects have been constructed and reported, however, none of these is sited in a tropical climate nor in a dense urban context [1]. The focus of installations is mainly crystalline technology and the largest proportion of built and monitored projects is in Germany where the report on the '1000-roof ' programme has highlighted the difference between expected and real yield attributable to incorrect power ratings [2]. Little emphasis (in BIPV) has been given to this-film technologies until the issue of cost was recognized as a barrier to wider dissemination. The paper [3] indicated the potential of low-cost amorphous silicon and its favorable performance under high temperature and different spectral conditions. The latter's observation on the deficiencies of the STC rating and therefore their basis of computer simulation studies [4] the normal means of predicting annual energy yields- has now been acknowledged and promoted by The Fraunhofer Institute reflecting 'The 1000 roofs' Report conclusions [5].

The efficiency of solar cells is generally temperature dependent, usually with decreasing efficiency as the temperature increases because of the temperature dependence on mobility, diffusion length and lifetime of minority charge carriers and on the saturation current [6]. Stabilizing the temperature at a low level is highly desirable to achieve a stable efficiency of solar cells. For a PV-wall in BIPV system, this can be achieved by natural air ventilation. The theoretical and experimental analysis show that a temperature drop of 15°C for the roof surface can be achieved with a duct behind the PV modules. With a well designed ventilated air duct behind the PV modules the power output of the modules can be increased by 8.8% [7]. In [8], an indoor PV-wall test rig was built. With a well designed ventilated PV-wall structure, the PV cell temperature can be reduced by 15 °C and the PV-module power output can be increased by 8.3% compared with non-ventilation PV-wall structures. For integrated BP solar PV modules (BP270), an energy efficiency increase of 0.63% has been obtained, which is significant as the actual measured energy efficiency is only 10.69% when incident solar irradiant is 605.45 W/m^2.

However, the results in [7-8] were obtained mainly from the study in indoor test rig. In fact, the PV wall always locates in a transient climatic condition. The electric and thermal performance of a PV wall should be considered under the different environmental temperature, incident solar radiation and the transient wind speed. In the other hand, different types of PV module can obtain different results. The annual performance of the PV wall is very important for the designer. Hence, the study on the mechanism of heat transfer for the PV wall can help to find the optimum design of the PV-wall structure.

In this paper, a computer program has been compiled based on the energy balance and the heat transfer across a PV wall. It can be used to predict the annual thermal and electrical performance, i.e. the annual power output, the monthly heat gain, the transient variation of the PV temperature and the air gap temperature. Based on the computer program, the orientation of the PV panel, the depth and the height of the air duct on the electric and thermal performance are presented.

The Simulation Model

The simulation model of the PV-wall system is based on the energy balance and heat transfer through the PV wall. The detailed simulation model of a PV-wall with the natural ventilation can be consulted in [8]. However, It is much difficult for the annual study because the typical annual weather data is needed. The received solar radiation of a vertical PV wall with different orientations is most important for the annual analysis.

The heat transfer through a PV-wall

The energy balance of the PV panel

If the heat capacity of the PV modules is neglected, an energy balance can be written as

$$\begin{aligned} G &= E + Q_{pvo} + Q_{pvi} \\ &= E + h_{co}\ (T_p - T_e) + \xi_1 h_{ro}(T_p - T_e) + h_{ci}(T_p - T_a) + \xi_2 h_{ri}(T_p - T_{wo}) \end{aligned} \tag{1}$$

where, G is the total solar radiation absorbed by the PV panels, W/m^2; E is the electric power rate generated by the PV panels, W/m^2; Q_{pvo} is the heat transfer between the PV outside surface and the environment, W/m^2; Q_{pvi} is the heat transfer between the PV inside surface and the air element in the air-duct, the outside surface of the massive wall, W/m^2; h_{co} is the convection heat transfer coefficient on the outside surface of the PV panels, W/m^2·K; h_{ci} is the convection heat transfer coefficient on the inside surface of the PV panels, W/m^2·K; h_{ro} is the radiant heat transfer coefficient on the outside surface of the PV panels, W/m^2·K ; h_{ri} is the radiant heat transfer coefficient on the inside surface of the PV panels, W/m^2·K; T_p, T_e , T_a and T_{wo} are the temperatures of the PV panels, environmental air, the air in air duct and the outside surface of the massive wall respectively, K; ξ_1, ξ_2 are the emissivity factors.

PV module power output

The performance characteristics of EPV modules can be used here, which indicate the relationship between the solar radiation, the temperature of the PV panel and the electricity power output.

$$E = -8.6415 + 0.076128G_t + 1.02318\times 10^{-5} G_t^{\,2} + 0.20178T_P - 4.9886\times 10^{-3}\, T_p^{\,2} \qquad (2)$$

where G_t is the incident solar radiation intensity, W/m^2.

The absorbed solar radiation

The solar radiation absorbed by the PV-panels G is

$$G = \alpha\tau G_t \qquad (3)$$

where α is the absorptance of solar radiation of the PV panels; τ is the transmittance of the cover over the cells (usually glass sheet).

The data of the annual solar radiation can be obtained from the local observatory. However, only the data of the solar radiation incident on a horizontal plane G_{th} are available in general cases, which includes the beam radiation G_{bh}, diffuse radiation G_{dh} and the reflected radiation G_{grh}.

$$G_{th} = G_{bh} + G_{dh} + G_{grh} \qquad (4)$$

For any tilted plane,

$$G_t = G_{bh}\cdot R_b + 0.5G_{dh}(1+\cos\beta) + 0.5\rho_g\cdot(G_{gb}+G_{gd})(1-\cos\beta) \qquad (5)$$

where, ρ_g is the ground reflectance; β is the tilt angle; R_b is the ratio between the beam radiation on the vertical plane and the beam radiation on the horizontal plane, it can be given as[9]

$$R_b = \frac{\cos\theta}{\cos\theta_z} \qquad (6)$$

where, θ is the angle of incidence; θ_τ is the zenith angle.

$$\cos\theta_z = \cos\phi\cos\vartheta\cos\omega + \sin\phi\sin\vartheta \qquad (7)$$

$$\begin{aligned}\cos\theta = {} & \sin\vartheta\sin\phi\cos\beta - \sin\vartheta\cos\phi\sin\beta\cos\gamma + \cos\vartheta\cos\phi\cos\beta\cos\omega \\ & + \cos\vartheta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\vartheta\sin\beta\sin\gamma\sin\omega\end{aligned} \qquad (8)$$

where, ω is hour angle; γ is solar azimuth; ϕ is angle of latitude. ϑ is solar declination angle, it can be give as:

$$\vartheta = 23.45 \sin 360 \frac{284+n}{365} \tag{9}$$

Natural convection

The air temperature T_a in the air duct varies along the vertical direction, X, can be determined from an energy balance on a differential unit of air in the air duct perpendicular to the flow. The energy balance yields:

$$DC_p \rho \frac{dT_a}{d\tau} = h_{ci}(T_p - T_a) - h_{w0}(T_a - T_{wo}) - \rho V_a D C_p \frac{dT_a}{dx} \tag{10}$$

where, ρ is the air density at position X, kg/m^3; C_p is the air heat capacity, J/kg·K; h_{w0} is the film coefficient on the outside surface of the massive wall, W/m^2·K; $D=\delta+D_{jf}$ is the depth of the air duct, m; δ is the depth of the PV module, m; D_{jf} is the gap depth under frames, m; T_{wo} is the temperature of the outside surface of the massive wall, K; V_a is the velocity of air flow in the air duct, m/s.

Heat transfer across the massive wall

It is assumed that the heat transfer is one-dimensional. The unsteady heat conduction equation is

$$\begin{aligned}
&\frac{\partial T}{\partial \tau} = \frac{\lambda_w}{\rho_w C_w}\frac{\partial^2 T}{\partial^2 Y} \\
&-\lambda_w\left(\frac{\partial T}{\partial Y}\right)_{y=0} = h_{w0}(T_{w0} - T_a) + \xi_3 h_{rwo}(T_{wo} - T_p) \\
&-\lambda_w\left(\frac{\partial T}{\partial Y}\right)_{y=D_w} = h_{cwi}(T_{wi} - T_n) + \sigma\sum_{j=1}^{5} F_{w-j}(T_{wi}^4 - T_j^4) \\
&T_{\tau=0} = T\big|_0(Y)
\end{aligned} \tag{11}$$

where, ρ_w is the density of the massive wall , kg/m^3 ; C_w is the specific heat of the massive wall , J/kg·$^\circ$C; λ_w is the thermal conductivity, W/m·K; h_{wi} is the convection heat transfer coefficient on the inside surface of the massive wall, W/m^2·K; T_n is the indoor temperature, K; T_{wi} is the temperature of the inside surface of the massive wall, K; D_w is the thickness of the massive wall, m; h_{rwo} is the radiant heat transfer coefficient between the outside wall surface and the PV back surface, it is the same as h_{ri}, W/m^2·K; $F_{w\text{-}j}$ is the geometrical surface coefficient of the massive wall inside surface with respect to the north, east, west walls, ceiling and floor of the room; T_j is the surface temperature of the wall surface j in the room, K; σ is the Stefan–Boltzman constant, 5.6×10^{-8} W/m^2·K^4; ξ_3 is the emissivity factor, it is the same as ξ_2.

The heat gain through the PV-wall which is concerned for comparing with that through the unique massive wall can be written as

$$Q_r = -\lambda_w \frac{\partial T}{\partial Y}\Big|_{y=D_w} \tag{12}$$

The annual performance

The annual electricity generation can be found from

$$\sum E_{epv} = \int_0^{365\times 24} E_{epv}\, dt \tag{13}$$

The annual solar radiation on the PV-wall is

$$\sum G_{tepv} = \int_0^{365\times 24} G_{tepv} dt \tag{14}$$

The annual energy efficiency of the PV panel can be found

$$\eta_{epv} = \sum E_{epv} / \sum G_{tepv} \tag{15}$$

The monthly heat gain through the PV-wall is calculated by

$$\sum Q_r = -\int_0^{N\times 24} \lambda_w (\frac{\partial T}{\partial Y})_{y=D_w} dt \tag{16}$$

where, N is the day number of the month.

The computer program and the case study

A computer program has been compiled to predict the annual electric and thermal performance of PV panels in Hong Kong. The data read component is configured to read the weather data of Hong Kong, the another parameters of PV-wall and the calculation control. The meteorological data from the Hong Kong Observatory for 1989 in Hong Kong, which is generally considered to be the typical weather year [10], was chosen for doing simulation.

Using the computer program, the following results can be found:

- the annual total solar radiation on any tilt or vertical PV-wall in different orientations;
- the daily, monthly and annual total electricity generation of a tilt or vertical PV-wall;
- the hourly(365×24) and monthly heat gain;
- the hourly air temperature distribution along the air-duct;
- the hourly temperature distribution on the PV panel;
- the hourly inlet and outlet air temperature of the air-gap;
- the hourly mean air velocity and air flow rate in the air duct;

- the hourly temperature distribution across the massive wall;
- the hourly power output and efficiency of the PV panel;
- (10) the hourly, monthly and annual efficiency of PV panels.

Based on the program, the electric and thermal performance of a PV-wall with different orientations, depths and heights can be analyzed. As a case study, a PV-wall in Hong Kong University is investigated. For our case study, the existing Chow Yei Ching Building within the campus of the University of Hong Kong has been chosen as the test site for long-term performance assessment and analysis of the PV-wall system. A south-west-facing PV panels(the solar azimuth=84.11^0) has been installed on the external north-west-facing wall(the solar azimuth=95^0) of a particular building. Two types of tandem-junction amorphous silicon thin-film PV-modules are used in the PV-wall. They are PST and EPV. The total area of the PV panels is about $93m^2$ (25m high by 3.7m wide).

Fig. 1 shows the diagram of the PV-wall. The PV-wall consists of two panels, i.e. PST panel and EPV panel, the steel structural frame, the void between the back of the panels and the massive wall surface. The steel structural frame is mounted on the building wall so that the PV array can be installed in the south-west orientation, and a void can be formed for the purpose of providing cooling to the PV panels by natural convection air currents.

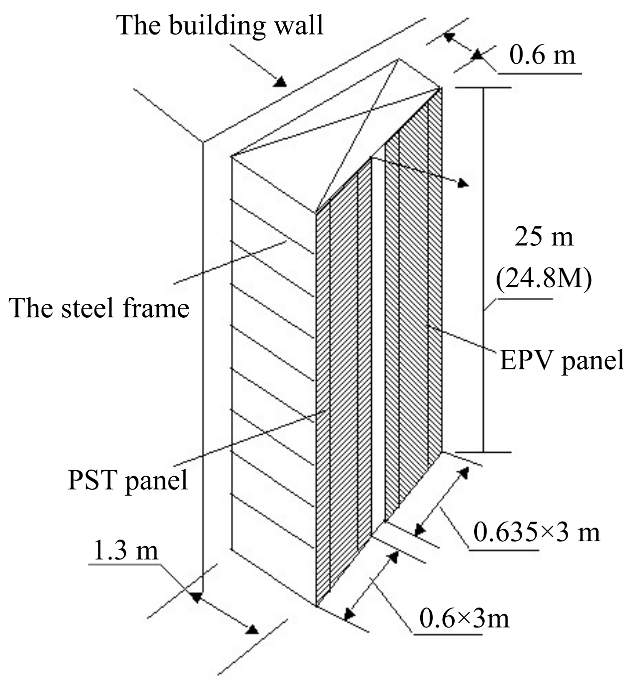

Fig. 1 The diagram of the PV-wall

Only considering the EPV PV panel in this paper, the following parameters relevant to Hong Kong, the PV panels orientation, the performance characteristic of EPV module, the massive wall and the frame structure are given as:

- Thickness of the concrete wall D_w =100 mm; the heat conductivity λ=2.16W/m^2.K; the special heat C_p=840 J/kg.K; the density ρ=2400 kg/m^3.
- The indoor air temperature t_n =22 ^{0}C.
- The width of the EPV PV-wall w=1.905m; The height of the EPV PV- wall L=24.8m; The average depth=0.775m; The area of the EPV PV panels is 47.25 m^2.
- The longitude and the latitude of Hong Kong are 114.172 ^{0} E and 22.304 ^{0}N.
- The tilt angle of the PV-panels is 90^0, and the solar azimuth angle of the PV panels is 84.11^0.

The Effects of the Support Frame

The orientation of the PV-wall

The orientation of the PV-wall has a obvious effects on its electric performance because the different orientation receives different solar radiation. The PV panel should be mounted in the building wall where the most solar radiation is available, so that PV panel can generate the most electricity. However, it is restricted for many factors such as shading, aesthetic or the orientation of the existing building wall. As a designer, the solar radiation distribution in different orientations should be investigated firstly.

The Fig. 2 shows the total annual solar radiation in different orientations in Hong Kong, it is based on the meteorological data in 1989 which is generally considered to be the typical weather year from the Hong Kong Observatory and calculated based on the theory in [10]. It is observed that the building wall with the solar azimuth 65^{0}C can receive the most annual solar radiation in Hong Kong. The east facing wall(the solar azimuth=-90^0) has the minimum solar radiation. The maximum annual solar radiation do not exists in the south facing wall (the solar azimuth =0^{0}C) or in the west facing wall (the solar azimuth =90^{0}C).

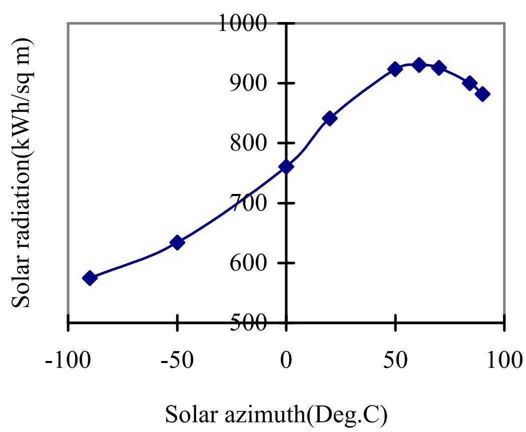

Fig. 2 The annual solar radiation with different solar azimuth

Table 1 shows the monthly solar radiation in different orientations which may be useful for the BIPV application in Hong Kong. It is observed that the different orientation has the different time when the maximum solar radiation exists.

Table 1 The monthly solar radiation distribution with different azimuth

Solar radiation kWh/m^2	Solar Azimuth								
	-90^0	-50^0	0^0	20^0	50^0	60.89^0	70^0	84.11^0	90^0
Jan.	29.09	36.95	62.19	69.54	70.90	68.69	65.75	59.97	56.93
Feb.	39.66	48.64	74.59	84.13	87.83	86.20	83.75	78.02	74.80
Mar.	48.00	53.02	66.27	75.85	83.97	84.70	84.41	81.80	79.96
April	36.44	36.55	36.73	40.91	46.80	48.18	48.94	49.34	49.22
May	47.73	46.63	43.48	48.57	59.54	62.50	64.42	66.29	66.65
June	56.07	53.37	48.33	52.63	69.19	74.01	77.35	81.03	82.00
July	65.74	61.85	53.35	60.43	80.38	86.03	89.85	93.90	94.87
Aug.	59.45	58.76	54.48	63.32	78.11	81.79	83.95	85.51	85.50
Sept.	56.74	59.52	63.02	70.68	79.50	81.05	81.48	80.25	79.07
Oct.	51.61	62.62	83.57	89.88	90.90	88.88	86.43	80.81	77.68
Nov.	47.43	64.34	91.86	95.93	90.19	85.96	81.32	73.53	69.55
Dec.	37.35	51.76	83.03	89.53	86.43	82.37	77.85	69.91	65.88
Total	574.89	634.01	760.91	841.41	923.75	930.36	925.49	900.35	882.11

In general, the PV-panel is mounted parallel to the building wall. In fact, the PV-panel can be non-parallel installed to the wall in order to receive more solar energy. This can be realized through changing the frame structure. In our case study, the objective for mounting the PV panels in the south-west orientation is to hope to generate more electricity according to the estimation under the local meteorological data. In comparison with the north-west-facing (The solar azimuth=95^0, i.e. parallel to the existing external north-west-facing wall), the EPV PV panel can receive more solar radiation by (900.35-867.498) × 47.25=1552.257 kWh for one year.

Fig. 3 illustrates the monthly electricity generation of EPV panel for solar azimuth=84.11^0 and solar azimuth=95^0. Only considering the EPV panel, the annual electricity generation increase can reach 2138.876-2010.658=128.218 kWh through changing frame, i.e. changing the orientation of the PV-panel.

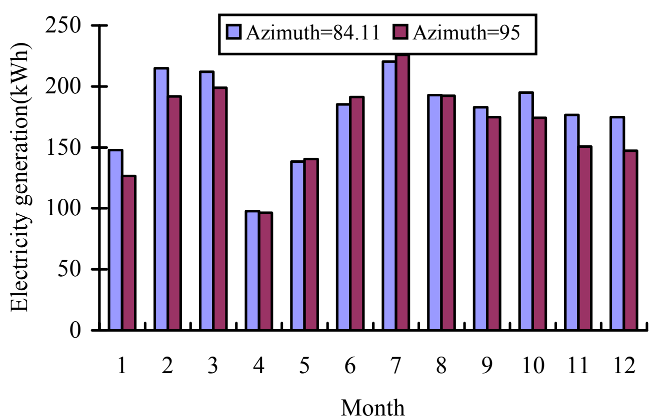

Fig. 3 The monthly electricity generation with different azimuth

The depth of the air gap

The PV panels absorb solar energy. Part of the absorbed solar energy is converted into electricity and part is transmitted into the air in the air-duct and the ambient air in the form of heat. The air circulates in the air-duct by natural convection to remove the heat converted from the absorbed solar energy, so that the PV module temperature can be decreased for increasing the electricity power output from the PV panels. The natural convection is close connected with the air-gap depth. The air-gap depth will influence the air flow friction, the air velocity and the air flow rate. In general, the smaller depth, the higher is the air friction and air-velocity, but the lower is the air flow rate. The high air velocity is beneficial to cool the PV panel, but the air flow rate is the major influence factor.

Figs. 4 to 5 illustrate the daily variation (August 30 is selected) of the air velocity and the airflow rate in the air duct.

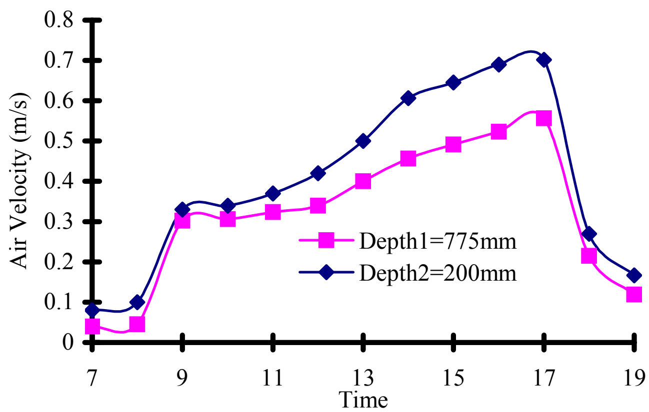

Fig. 4 The variation of air velocity with different depths

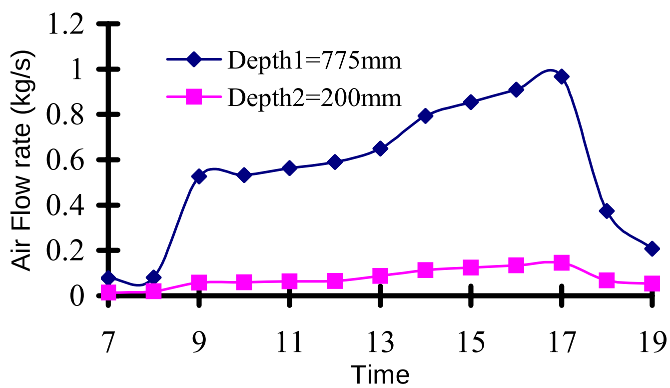

Fig. 5 The variation of air flow rate with different depths

Figs. 6 to 7 show the daily power output and heat gain. It is observed that the power output will be reduced and the heat gain will be increased for a narrow depth, although the air velocity in air duct will be increased. The narrow depth has a small air flow rate which is not sufficient to cool the PV panel. This is not beneficial for cooling the PV panel.

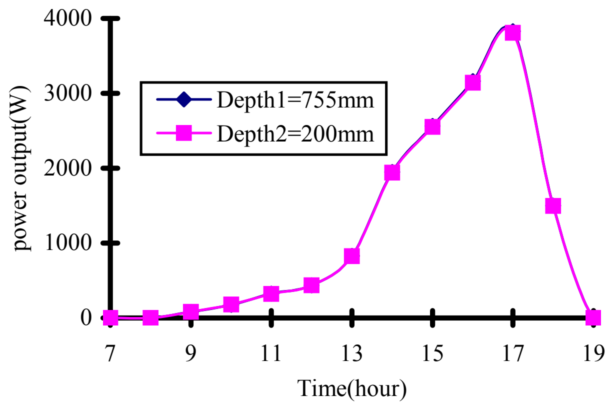

Fig. 6 The power output variation with depths

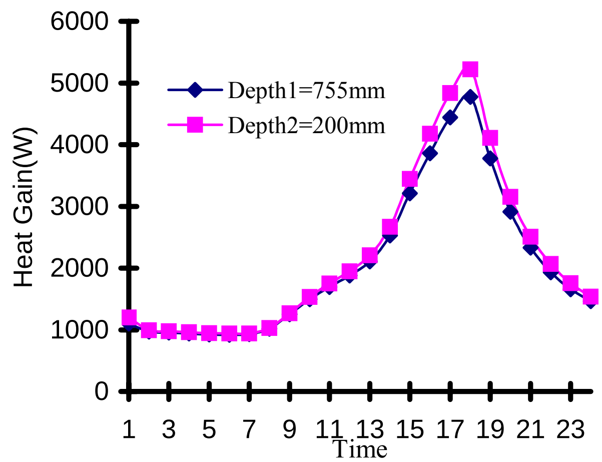

Fig. 7 The variation of heat gain with different depths

The computer program can also be used to investigate the influence of the air gap depth on the annual electric and thermal performance, i.e. the annual power output and the monthly heat gain. With different depths of the air gap as inputs to the simulation program, the different annual total power outputs and the monthly heat gain can be obtained in case of a constant height and width of PV arrays.

The Fig. 8 illustrates the variation of the annual electricity generation with the different depths. It shows that annual electricity generation will increased with the depth for a constant height and width of the PV-wall. For this case study, the difference of the annual electricity generation between two cases, i.e. depth=150mm and depth=775mm, can reach 2138.876-2116.653=22.223 kWh.

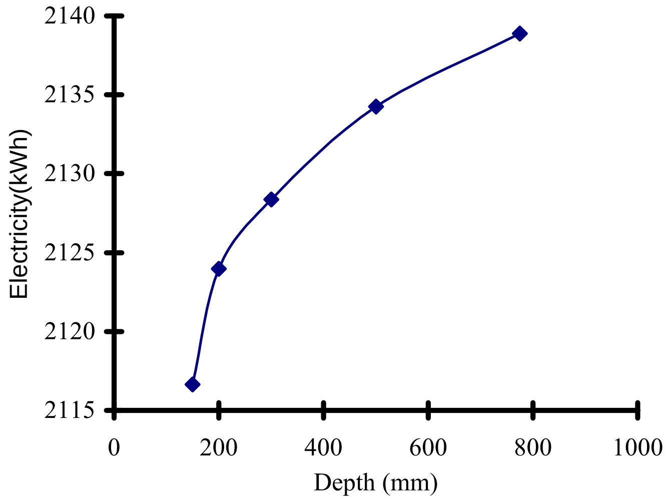

Fig. 8 The annual power generation with the depth

The Fig. 9 illustrates the variation of monthly heat gain with different depth. The influence of depth of the PV-wall on the monthly heat gain is very obviously. The monthly heat gain is increased with the reduction of the depth. Only considering August, the monthly heat gain in depth=0.15m is 1379.835-1282.883=96.952kWh is bigger in comparison with in depth=0.775m. It means, the cooling load component will increase 96.952kWh in August.

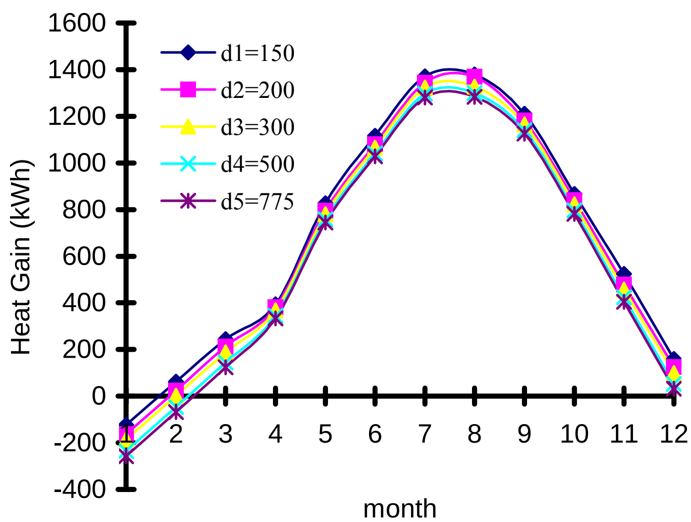

Fig. 9 The variation of monthly heat gain with different depth

The height of the PV panel

The height of the PV panel also affects the thermal and electric performance of the PV-wall. The mean air velocity in the air duct increases with the air duct height according to the model, but the outlet temperature at the top of the air-duct could be very high. As a result, the PV module temperature with a taller PV-wall will be higher compared with that of a shorter PV-wall structure. The objective of decreasing the PV module temperature cannot be achieved for an ever increasing air duct height. In the other hand, a higher PV-wall will increase the heat gain, so that the cooling load component will be increased obviously.

The Fig. 10 illustrates the daily temperature variation of PC panels and the outlet air temperature. Tpv1 and Tout1 represent the maximum temperature of PV panel and the outlet air temperature for Height=24.8m, respectively. Tpv2 and Tout2 mean the maximum temperature of PV panel and the outlet air temperature for Height=2m. In comparison with the case of Height=2m, the maximum temperature of PV panel and the outlet air temperature in case of Height=24.8m are obviously higher than that in case of Height=2m. Hence, the power output of unit area(m^2) of PV panel becomes lower and the heat gain of unit area(m^2) of PV-wall becomes bigger when the height is taller presented in Figs. 11 to 12.

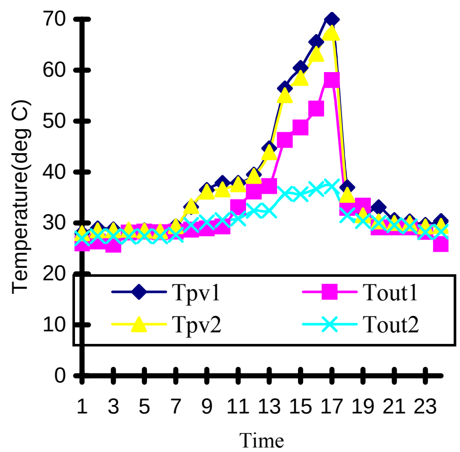

Fig. 10 The temperature variation with different heights

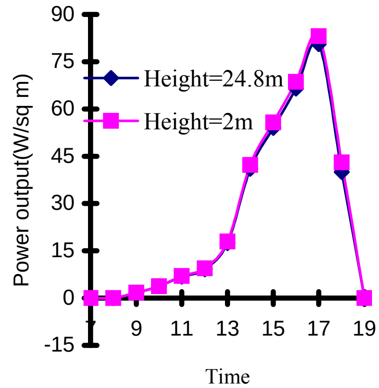

Fig. 11 The power output of unit area with different heights

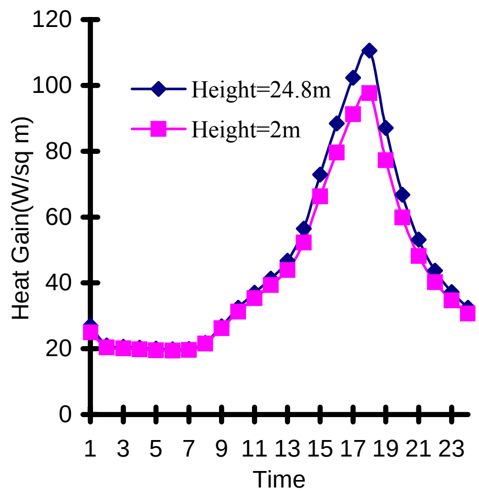

Fig. 12 The variation of heat gain of unit area with different heights

Also the above example is selected. The parameters are same as before, but the depth of the PV-wall is assumed as 0.2m. The Fig. 13 illustrates the annual electric performance variation of the PV module per unit area with different heights. It shows that the annual electricity generation of unit area (m^2) is reduced with the Height of the PV wall. Considering two cases, i.e. Height=2m and Height=24.8m, the difference of annual electricity generation is 46.43-44.96=1.47 kWh/m^2.

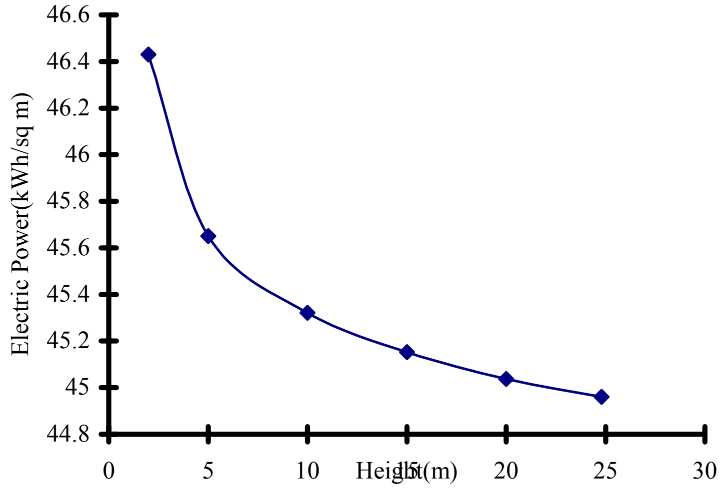

Fig.13 The variation of annual electricity generation with different heights

The Fig. 14 illustrates the thermal performance variation of the PV-wall with different heights. The monthly heat gain of unit PV-wall (m^2) is increased with the height. Only considering August, the monthly heat gain per unit area(m^2) in Height=24.8m is 28.989-26.715=2.274kWh higher than that in Height=2m.

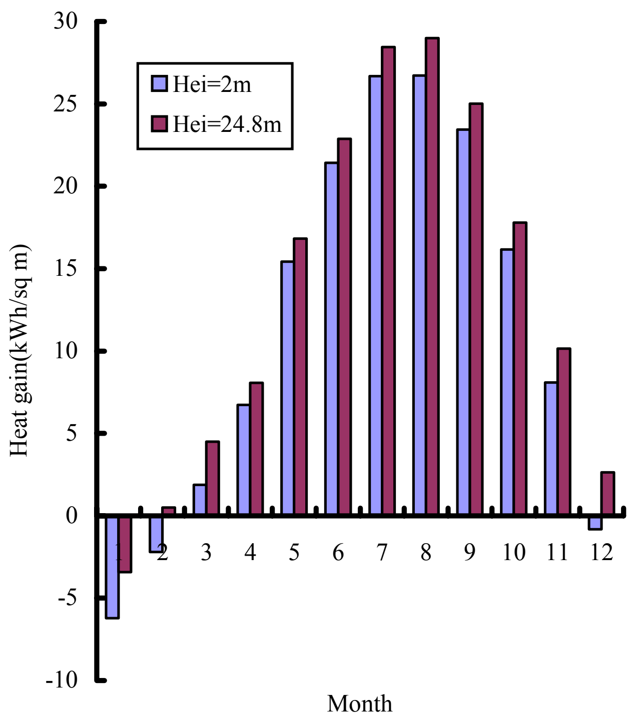

Fig. 14 The variation of heat gain with different heights

Conclusion

With the above study, the influence of the frame structure on the electric and thermal performance of a PV-wall is obviously. Results show that determining the orientation of the PV panel is very important. The PV panel can be non-parallel to the building wall installed to that orientation where the received solar radiation is bigger. In the case study, it is observed that EPV panel can obtain more annual electricity generation by 128.218 kWh through well-designed frame, i.e. changing the orientation of PV panel(solar azimuth 84.11^0) non-parallel to the massive wall(solar azimuth $95^{0)}$. However, the orientation selection of the PV-wall is restricted for many factors such as shading, aesthetic or the orientation of the existing building wall.

The depth of air duct should not be designed too narrow. If the air-depth is too narrow, the air flow friction will be very large, the air flow rate is small, so that the PV modules cannot be cooled sufficiently. The electric power output will be reduced and the heat gain will be increased. For this case study, the difference of the annual electricity generation and the monthly heat gain (August) between two cases, i.e. depth=150mm and depth=775mm, can reach 22.223kWh and 96.952kWh, respectively. In contrary, the construction cost of the air duct will be expensive if the depth is designed too deep. The best value of the air duct depth should be found to minimize the air duct, but not to reduce the cooling effect on the PV modules. With electric, thermal and economic analysis the rational depth of the air gap can be found.

The height of the PV panel should not be designed very high. The taller air-duct, the higher PV module temperature is, i.e. the lower PV power output and the bigger heat gain. Considering another two cases, i.e. Height=2m and Height=24.8m, the difference of annual electricity generation and the monthly heat gain (August) are 1.47 kWh/m^2 and 2.274kWh/m^2. This is caused by higher air-temperature and higher friction for the air flow in the air-duct, so that the height of an air duct for a PV–wall structure should be chosen as low as possible depending the PV module dimensions.

References

[1] T. Schoen and H. Schmidt, “Building integrated PV activities within the IEA framework: Going from Task 16 to Task,” Progress in photovoltaic, research and applications, Vol. 4, 1996, pp. 237-245.
[2] Fraunhofer Institute for Solar Energy, 1000 roofs program, 1995.
[3] H. Youichi and T. Tatsuo, “Evaluation of photovoltaic modules considering spectral solar radiation,” Electrical engineering in Japan, Vol. 114, No. 8, 1994, pp. 93-105.
[4] R. Ruther and J. Livingstone, “Seasonal variations, in amorphous silicon solar module output and thin-film characteristics,” Solar energy conference, Australia, Solar energy materials and solar cells, Vol. 36, pp. 29-43, 1993.
[5] K. Bucher, Gleiss and D. Batzner, “Photovoltaic modules in buildings: Performance and safety,” World renewable energy conference, Florence, Vol. 1, 1998, pp. 545-551.
[6] A. L. Fahrenbruch and R. H. Bube, “The Fundamentals of solar cells,” Academic press, New York, 1983.
[7] B. J. Brinkworth, B. M. Cross, R. H. Marshall and H. X. Yang, “Thermal regulation of photovoltaic cladding,” Solar energy, Vol. 61, No. 3, 1997, pp. 169-178.
[8] H. X. Yang, R. H. Marshall and B. J. Brinkworth, “Validated simulation for thermal regulation of photovoltaic wall structures,” In Proc., 25th photovoltaic specialist conference, USA, 1996.
[9] J. A. Duffie and W. A. Beckman, “Solar energy thermal process,” J. Wiley, USA, 1980.

[10] S. C. M. Hui, and J. C. Lam, "Test reference year for comparative energy study," Hong Kong engineer, Vol. 20, No. 2, 1992, pp. 13-16.