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The Heat Shielding Benefits of The Rooftop Solar Panel Systems in The Hanoi Region

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ABSTRACT

The rooftop solar panel systems not only brings clean electricity, but also helps to reduce the amount of heat shining directly on the ceiling, causing heat to the air inside the house. This paper has performed simulation models by using a computational fluid dynamics (CFD) in combination with Monte-Carlo method to determine the ceiling and solar panel temperature values in different climatic conditions of the Hanoi city, Vietnam. The analysis results show that installing solar panels on the roof can reduce up to 12.0ºC for the inside air of the house, thereby saving electricity consumption from the use of air conditioners or ventilation fans during the hot season. In addition, this research also contributes to the temperature data of the panels in specific conditions in Hanoi, helping to ensure the safety and performance of the systems.

KEYWORDS

Rooftop Solar PV, CFD, Monte-Carlo.

INTRODUCTION

Solar energy is a clean and inexhaustible energy source of nature. In recent years, the Vietnamese government has issued many policies to support and promote the development of solar power plants across the country. Developing solar power will bring many environmental benefits, helping to limit the negative impacts of coal-fired power, in order to meet commitments on reducing greenhouse gas emissions that cause global warming. Besides large-scale solar power plants, the government is also very interested in developing rooftop solar power systems [1]. This helps families to be self-sufficient in electricity, and can also sell excess electricity if any. In addition to the benefits of electricity production, solar panels also have the effect of shielding, reducing the amount of heat shining directly into houses. Especially in the big cities, where the urban effect can cause severe heat problems, greatly affecting the health and work efficiency of people. To evaluate the heat shielding benefits of solar panels, we built a 3-D model of solar panels at an operating solar power plant in Ninhthuan province. After that, we conducted simulations and compared the results with the measured values. The obtained results show the similarity between the simulated model and reality. Since then, we has analyzed for a hypothetical 2-storey house model with and without the installation of solar panels in Hanoi city.

RESEARCH MODELS AND METHODS

Research models

The solar panel used in the model has 5 different layers including the top protective glass layer, two buffer layers of Ethylene Vinyl Acetate (EVA), the middle layer is Silicon PV cell (PV) and the last layer is Backsheet (PVF), details are given in Table 1 and Figure 1 below [2-4].

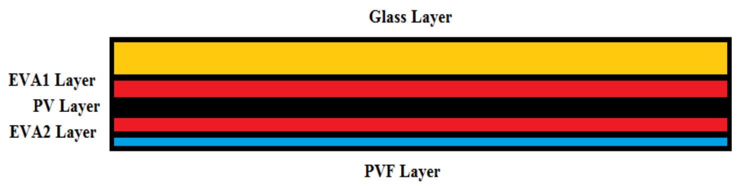

Figure 1. Structure layers of the solar panels.

At the solar power plant in Ninhthuan province, solar panels are used on pillars. The structure of one pillar includes 30 solar panels, each panel has a length of 1.96m, a width of 0.992mm, a total thickness of 0.04m. The pillar body is divided into two parts, the lower part is 0.26m high, the upper part is 0.9m high, along with two cross bars with lengths of 1.35m and 1.6m respectively as shown in Figure 2.

Table 1. Structure and physical properties of the layers of solar panels [2]

No.	**Layer**	**Thickness, mm**	**Density, kg/m^3**	**Heat Capacity, J/kgK**	**Heat Conductivity, W/mK**
1	Glass	3	3000	500	1.8
2	PV Cell	0.225	2330	677	148
3	EVA	0.5	960	2090	0.35
4	PVF	0.1	1200	1250	0.2

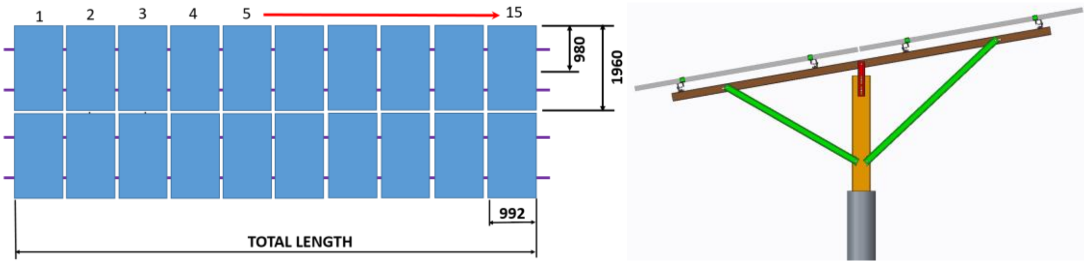

Figure 2. The structure of one pillar.

The model selected for further analysis is a two-story house has 5m in the width, 15m in the length and 8m in the height. The material used for the ceiling is concrete with a thickness of 0.2m. The top of the house is installed with solar panels, the distance between the panels and the ceiling is 0.5m as shown in Figure 3. The models are built on the academic version of Ansys CFX software.

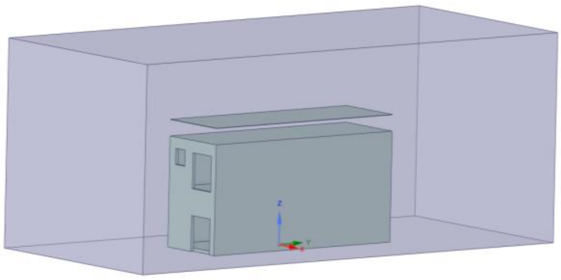

Figure 3. The model of the rooftop solar panels.

Research Methods

The method was used in this research is the CFD method, which is a modern numerical solution method and has been widely applied in many fields, including fundamental scientific researches and implementation of applications in the industry fields.

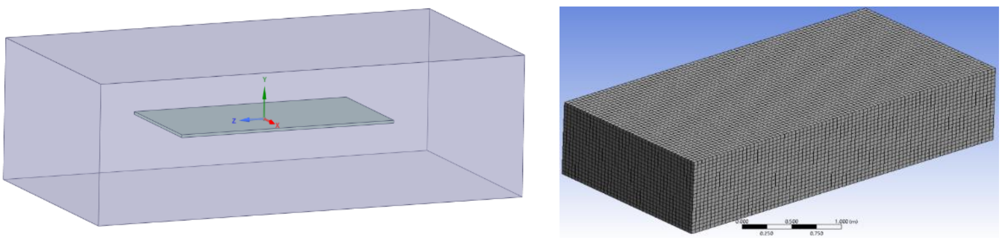

Figure 4. The meshing model of one solar panel in the power plant

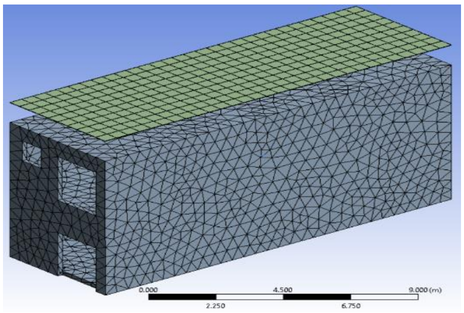

Figure 5. The meshing model of the rooftop solar panels

The CFD method is based on the Navier-Stocks equation system to calculate the dynamic processes and heat exchanges of fluids with other solid matters. The model has the participation of the thermal radiation source from the sun to the material surfaces of solar panels and the ceiling as illustrated in Figure 4 and Figure 5. The authors used the Monte-Carlo method to determine this radiative heat transfer process. The spectral radiative transfer equation used in Ansys CFX has the following form [1]:

$$\frac{dI_\nu\left(\vec{r},\vec{s}\right)}{ds} = -\left(K_{a\nu}+K_{s\nu}\right)\times I_\nu\left(\vec{r},\vec{s}\right)+I_b\left(\nu,T\right)+\frac{K_{s\nu}}{4\pi}\int_{4\pi} dI_\nu\left(\vec{r},\vec{s}\,'\right)\times\Phi\left(\vec{s}\times\vec{s}\,'\right)\times d\Omega'+S \qquad (1)$$

The fluid in the analytical model is an air under different environmental conditions, depending on the values of temperature, pressure and humidity.

The Monte-Carlo method will treat the radiation field as photons, each radiation will be treated as a photon and tracked from its emission at the source surface until the photon is absorbed or removed from the medium due to scattering. At each moment that the photon encounters physical interactions such as scattering or absorption, the radiation intensity value will be recalculated once. The software will store data for all the travel and interaction history of the photons and will eventually give the results of the radiation intensity in the environment. In order for the Monte-Carlo method to give good results, the number of photons generated at each loop needs to be high, so the Monte-Carlo method will require higher computer configuration and longer computation time in the comparison with other methods.

RESULTS AND DISCUSSION

The solar power plant in Ninhthuan

The time to conduct experimental measurements is April 12, 2020, meteorological parameters are given in Table 2 below:

Table 2. Meteorological parameters at the area of the solar power plant in Ninhthuan

Time, hour	Wind Velocity, m/s	Pressure, bar	Humidity, %	Solar Flux, W/m^2	Ambient Temperature, ºC
10	6.3	1.007	78	662	31.4
11	6.3	1.007	75	832	32.6
12	5.3	1.007	69	966	33.0
13	6.3	1.007	82	944	33.0
14	6.3	1.007	69	848	32.7

From Table 2, we can see that solar radiation has a high value from about 600 W/m^2 to approximately 1000 W/m^2, lasting for about 5 continuous hours, which gives high efficiency for converting into electricity generation and transmission system operation. The results of the model analysis are shown in Tables 3 and Figure 6.

Table 3. Temperature values obtained from experiments and simulations

Time, h	Exp, °C	Glass, °C	EVA1, °C	PV, °C	EVA2, °C	PVF, °C	ΔT, °C
10	54.4	50.4	50.4	50.4	50.4	50.4	4.0
11	56.2	55.8	56.0	55.9	56.0	56.0	0.4
12	56.4	62.1	62.3	62.1	62.3	62.3	5.7
13	56.6	59.1	59.2	59.3	59.2	59.2	2.5
14	53.9	56.5	56.5	56.4	56.5	56.5	2.6

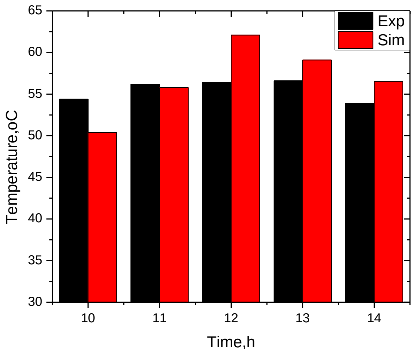

Figure 6. Temperature values on the surface of solar panels over time

From the above data table, we see the temperature of the different layers that make up the solar panel has approximately the same value, because the materials of these layers have a very small thickness, about mm. The temperature of the PV layer can be up to 62.1°C at 12:00 on April 12, 2020, the high temperature values will degrade the solar panel's efficiency in converting light into electricity. Besides, the simulated temperature is close to the experimental measurement, the highest deviation is 5.7°C, corresponding to 9.2%. From here we see that the model has a good fit with the actual values, the difference is in the acceptable range.

The model of rooftop solar panels

Hanoi city is a densely populated urban area and there are many high buildings. The buildings mostly use concrete material, which is a material with high heat retention properties, causing serious hot problems of today's big cities. To conduct the analysis, we have consulted the meteorological data of Hanoi at the latitude of 21.025 and the longitude of 105.875 at the data library site of SARAH Solar Radiation Data [3] of the The European Commission's Science and Knowledge Service.

Table 4. Meteorological parameters of Hanoi area [3]

Day	Time, h	Flux, W/m^2	T_ Air, °C	V, m/s	Day	Time, h	Flux, W/m^2	T_ Air, °C	V, m/s
31/05/ 2016	9:48	836	31.4	4.0	01/06/ 2016	9:48	813	33.4	3.4
	10:48	930	32.1	4.1		10:48	950	34.1	3.8
	11:48	1011	32.8	4.1		11:48	1027	34.8	4.1
	12:48	991	33.5	4.2		12:48	991	35.5	4.5
	13:48	907	33.4	4.2		13:48	902	35.2	4.4
	14:48	747	33.2	4.1		14:48	743	34.9	4.3
	TB	**903.7**	**32.7**	**4.1**		**TB**	**904.3**	**34.6**	**4.1**
02/06/ 2016	9:48	970	34.9	4.2	02/06/ 2016	13:48	744	36.4	4.1
	10:48	1031	35.6	4.5		14:48	542	36.4	3.7
	11:48	991	36.4	4.7		**TB**	**863.3**	**36.0**	**4.3**
	12:48	902	36.4	4.4					

The selected period is 3 consecutive days with high radiation intensity and high ambient temperature, which is May 31, June 1 and June 2, 2016. Detailed meteorological parameters are given in Table 4. Setting the meteorological parameters into the model, the obtained results are shown in Table 5 and Figure 7.

Table 5. Temperature distribution of the ceiling concrete layer

Time, day	Position	No -Panel	Panel	ΔT
31/05/2016	T_Top, °C	69.1	37.1	32.0
	T_Bot, °C	42.4	33.4	9.0
	T_Ave, °C	55.2	35.1	20.1
01/06/2016	T_Top, °C	71.5	38.0	33.5
	T_Bot, °C	44.2	36.2	8.0
	T_Ave, °C	57.4	37.0	20.4
02/06/2016	T_Top, °C	69.8	40.1	29.7
	T_Bot, °C	45.2	38.7	6.5
	T_Ave, °C	57.0	39.3	17.7

From the table of simulation results, we see that the temperature at the top of the ceiling in the absence of solar panels will have a higher temperature of up to 32°C on May 31, 33.5°C on June 1 and 29.7°C on June 2 compared to when the panels were installed. At the underside of the ceiling, which is directly exposed to the inside air of the house, the temperature differences are also 9.0°C, 8.0°C and 6.5°C respectively, as expressed in Figure 7. In case of the 2nd floor of the house has a air volume of V=5x15x3.5=262.5m^3, the air density is $\rho = 1.124$ kg/m^3, the specific heat is $c_p = 1076$ J/kgK. The heat transfer is determined when the temperature of mass m changes ΔT by a Formula 2 [5]:

$$Q = m \times c_p \times \Delta T \qquad (2)$$

From here, we have the different values of the heat transfer of 3 days are Q_{31}=2707.944kJ, Q_1=2407.061 kJ, Q_2=1955.737kJ respectively.

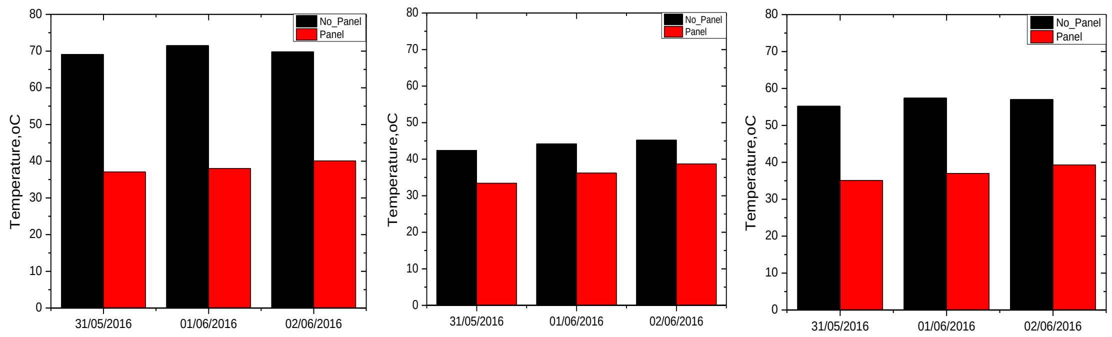

Figure 7. Temperature values of top *(right)*, bottom *(middle)* and average *(left)* of the concrete layer.

In order to assess more detail about the ability of heat transfer reduction of solar panels, our team continues to analyze the typical meteorological cases of Hanoi area. Specifically, we used wind speed is 3.0 m/s, air humidity is 70%, atmospheric pressure of 1.013 bar, and temperature values are 25°C, 30°C, 35°C, and 40°C respectively. The simulation results are given in Table 6.

Table 6. The ceiling temperature values under the meteorological conditions

Solar Flux, W/m²	**T_Air, °C**	**Panel**			**No_Panel**			ΔT_Ave **°C**
		T_Top, °C	**T_Bot, °C**	**T_ave, °C**	**T_Top, °C**	**T_Bot, °C**	**T_Ave, °C**	
600	25	27.7	24.8	26.2	54.9	34.4	44.2	18.0
700		29.1	26.0	27.5	55.8	33.7	44.3	16.8
800		31.2	27.2	29.1	61.0	35.3	47.6	18.5
900		30.3	26.3	28.3	65.3	36.4	50.2	21.9
1000		30.9	27.8	29.3	69.8	39.1	53.8	24.5
600	30	34.9	32.8	33.4	57.8	38.3	47.7	14.3
700		33.0	30.8	32.0	62.5	39.5	50.5	18.5
800		33.8	29.8	31.7	67.4	40.7	53.5	21.8
900		36.7	31.8	34.1	70.9	42.0	55.8	21.7
1000		36.3	32.9	34.5	74.9	44.3	58.9	24.4
600	35	38.5	37.4	37.9	61.1	41.9	51.1	13.2
700		39.2	36.4	37.8	65.1	43.5	53.8	16.0
800		40.5	36.7	38.6	70.4	46.0	57.6	19.0
900		41.0	36.6	38.7	73.1	46.3	59.1	20.4
1000		38.5	35.8	37.1	78.7	47.8	62.6	25.5
600	40	42.9	42.9	42.9	64.9	46.3	55.2	12.3
700		44.6	40.4	42.4	71.3	49.0	59.7	17.3
800		44.1	40.5	42.2	74.5	49.4	61.4	19.2
900		45.8	43.1	44.4	77.9	51.1	63.9	19.5
1000		46.3	43.8	45.0	82.5	53.2	67.2	22.2

From Table 6 and Figure 8, we see that the temperature differences depend mainly on the value of solar radiation, when the radiation is 600W/m^2, the average deviation of the ceiling layer ranges from 12.3°C to 18°C. In the case of solar radiation with a value of 1000W/m^2, the average deviation is from 22.2°C to 25.5°C. When considering the below surface of the ceiling, the temperature differences are between 3.4°C and 12.0°C, the average difference is 8.7°C. The same calculation using Formula 2, the corresponding addition average heat transfer value is Q_{ave}=2762.022kJ. For the upper surface of the ceiling in the absence of solar panels, the air temperature is 40°C and the radiation is 1000W/m^2, the maximum temperature can be reached up to 82.5°C. In contrast, the temperature is only 46.3°C in case of solar panel installation as displayed in Figure 10.

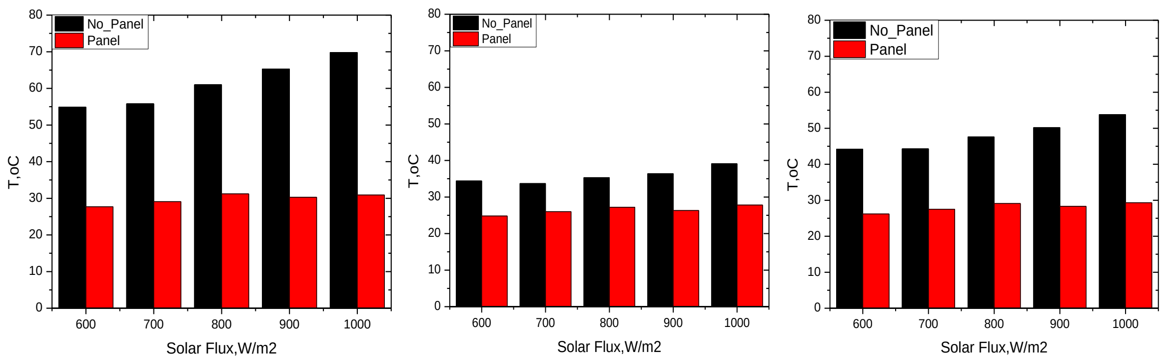

Figure 8. Temperature values of top *(right)*, bottom *(middle)* and average *(left)* of concrete layer when the air temperature is 25°C

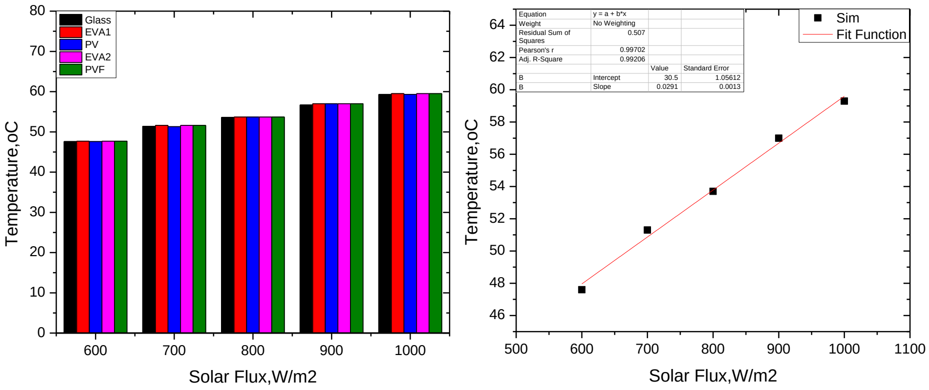

Figure 9. Panel temperature values when the air temperature is 25ºC

For the solar panels, the average temperature value of each layer under different meteorological conditions is summarized in Table 7. From the analysis results, we see that the average temperature of the material layers have approximately the same value, because the layers are very thin and have the high thermal conductivities.

Table 7. Temperature values of the layers in the panels

Solar Flux, W/m^2	**T_Air, ºC**	**T_Glass, ºC**	**T_EVA1, ºC**	**T_PV, ºC**	**T_EVA2, ºC**	**T_PVF, ºC**
600		47.6	47.7	47.6	47.7	47.7
700		51.4	51.6	51.3	51.6	51.6
800	25	53.6	53.7	53.7	53.7	53.7
900		56.7	57.0	57.0	57.0	57.0
1000		59.3	59.5	59.3	59.5	59.5
600		49.8	50.0	50.1	50.0	50.0
700		53.7	53.9	54.0	53.9	53.9
800	30	56.9	57.2	57.1	57.2	57.2
900		60.7	61.0	60.8	61.0	61.0
1000		65.7	66.0	65.8	66.0	66.0
600		54.3	54.5	54.5	54.5	54.5
700		59.0	59.1	58.9	59.1	59.1
800	35	63.6	63.8	63.9	63.8	63.8
900		64.0	64.3	64.3	64.3	64.3
1000		68.6	68.7	68.7	68.7	68.7
600		60.2	60.4	60.3	60.4	60.4
700		62.4	62.6	62.6	62.6	62.6
800	40	65.4	65.7	65.6	65.7	65.7
900		69.8	70.0	70.0	70.0	70.0
1000		72.6	72.9	72.8	72.9	72.9

The temperature value of the layers will vary depending on the specific ambient temperature and solar radiation. In order for the panels to achieve higher photovoltaic efficiency, the temperature of the PV layer must be low. However, Hanoi area has mainly high temperature conditions. During the summer and autumn months, the temperature is often above 35ºC and peaks can reach over 40ºC. The data from Table 7 show that the temperature of the PV layer can reach from 60.3ºC to 72.8ºC at the condition that the air temperature is 40ºC and the solar radiation is 1000W/m^2.

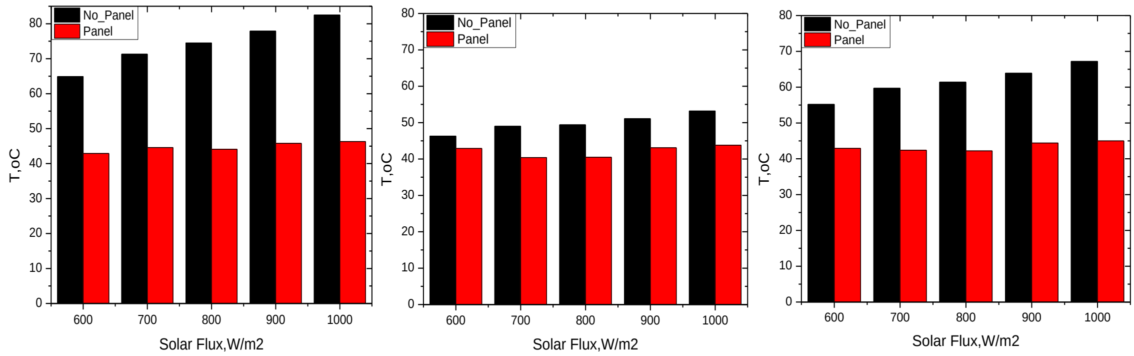

Figure 10. Temperature values of top *(right)*, bottom *(middle)* and average *(left)* of concrete layer when the air temperature is 40°C.

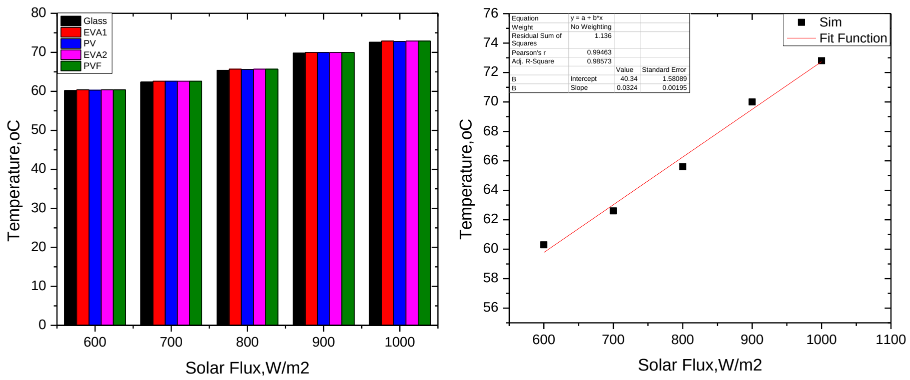

Figure 11. The values of panel temperature when the air temperature is 40°C.

In order to find the change rule of PV layer under the different conditions of air temperature and solar radiation, we based on the simulation results in the Table 7 and conducted a theoretical function fitting as shown in Figure 9 and Figure 11, the found function has the form as below:

$$T_{PV} = a \times Flux + b \tag{3}$$

The parameters a and b in Formula 3 are given in Table 8 below.

Table 8. Parameters of temperature change function of the PV layer

T_Air, °C	**a, m^2/W**	**Δa, m^2/W**	**b, °C**	**Δb, °C**
25	0.0291	0.0013	30.50	1.05
30	0.0382	0.0018	27.00	1.48
35	0.0338	0.0042	35.02	3.44
40	0.0324	0.0019	40.34	1.58

From the Function 3, we can determine the temperature values of the PV layer under different air temperature conditions, from which the user can calculate the efficiency of solar panels based on the supplier's data. This can help users install a solar panel system that is the best suited to the climatic conditions in Hanoi.

DISCUSSION

The area of Hanoi city is a densely populated area, many high buildings are built mainly of concrete materials. The average temperature of the city in the hot season remains from 30°C to 40°C, the average wind speed in the city ranges from 1m/s to 4m/s. The amount of solar radiation in the summer and autumn months has a high value, ranging from 600W/m^2 to 1000W/m^2. Therefore, the air in the city is always hot and the urban effect manifests itself more and more seriously. To reduce the indoor air temperature, we should use the roof covering the top of the house. From the analysis, it is shown that the use of solar panels will bring two benefits at the same time, which is to bring home electricity and significantly reduce the heat energy accumulated in the house.

However, installing rooftop solar panels in the Hanoi area will result in a reduced efficiency of photovoltaic energy conversion compared to the optimal operating conditions recommended by the supplier, because the PV layers will have to receive high temperature value.

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