Results of Experimental Study of Photovoltaic Installation Based on Thin-Film Panels for Integration on Facade of the Building

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Abstract: This article presents the results of experimental studies of a photovoltaic installation (PVI) based on thin-film cadmium telluride panels. The aim of the work was an experimental study of the PVI for integration on the facade of the building. For the research, PVI was prepared by assembling photovoltaic panels (PVP) into window blocks. This installation consists of two parts. The design of the first part PV1 allows to change the angle of inclination relative to the horizon. The second part of PV2 has a strictly vertical orientation. The research was conducted in the geographical conditions of Tashkent in July-August and September-November 2025. The experimental results showed a significant dependence of the performance of photovoltaic installations on the angle of inclination to the horizon, on the seasons and weather conditions. For vertically installed PVP, the use of reflective devices that concentrate the sun's rays proved effective in the summer. According to preliminary studies, the use of reflectors has increased the flow of solar radiation to the surface of photovoltaic panels by an average of 25%, and electricity generation by 14%. In the summer, the optimal PVP tilt angle for the geographical area under study was 33°. The second stage of the research was the study of PVI's work in the autumn period of the year. The measurement results for this period showed that the PVP power at vertical orientation was 16% higher than the PVP power at an angle of 33°, and 13% less than the PVP power at an angle of 60° to the horizon. The conducted experimental studies make it possible to determine the geometric and energy parameters of PVI for optimal integration on the facade of the building.

1 INTRODUCTION

Urban development, new architectural buildings and houses are growing rapidly all over the world. If we analyze the trend of building construction, we can find that in the last decade, the construction of multi-storey buildings with a high degree of glazing creates favorable conditions for a significant increase in the area of application of photovoltaic systems integrated into the building.

Building Integrated Photovoltaics (BIPV) can replace parts of building materials such as tiles, facades, windows or skylights. At the same time, PV systems can simultaneously generate electricity and act as a functional part of building enclosing structures, for example, to protect against atmospheric influences, insulation or shading. BIPV technology allows to create energy efficient and environmentally friendly buildings [1], [2].

BIPV systems can be integrated into various building elements in the form of canopies, roofing and facade wall elements that receive solar radiation and simultaneously generate electricity. The development of photovoltaic technologies has allowed the development of photovoltaic panels with varying degrees of transparency. These are thin-film and double-layer silicon solar panels that transmit part of the light and retain transparency. Due to this, the BIPV system can be used in skylights and facades, while providing daylight transmission into the room. Thus, with the right engineering approach to solving the problem, due to their constructive advantages, window-facade type of BIPV panels not only generate electrical energy but also help reduce the energy consumption of the building for heating and cooling [3]-[7].

2 METHODS AND MATERIALS

The performance of photovoltaic panels (PVP) depends on a number of geometric parameters directly related to the geographical location of the area, the season of the year, the angle of inclination and orientation of the panels relative to the horizon. Maximum performance is provided by the perpendicular incidence of sunlight on the surface of the PVP. For example, in summer, when the sun is much higher relative to the horizon, the panels should be installed at a low slope, and in winter with a high slope to the horizon (Fig. 1) [8].

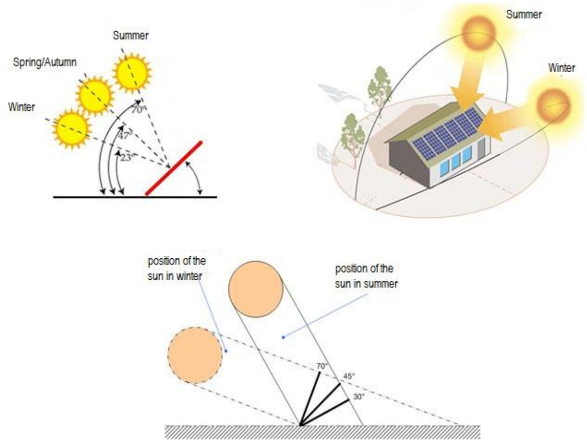
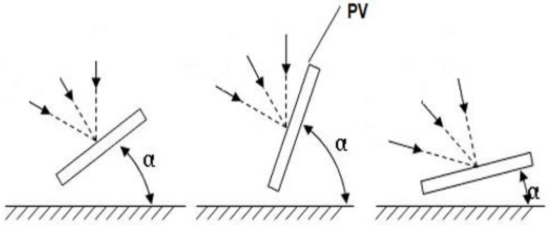


Figure 1: PV tilt angles and solar radiation drop pattern by season.

Based on the position of the sun according to the seasons, it is recommended to change the angle of inclination of the PVP relative to the horizon (Fig. 2).



(a) (b) (c)

Figure 2: The scheme of changing the angle of inclination of the PV according to the seasons: (a) spring-autumn; (b) winter; (c) summer, α - The angle of the PV to the horizon.

For PVP that are not equipped with a tracking device (tracker) for the movement of the sun, it is advisable to periodically change the angle of inclination.

In this case, the angle of inclination α is calculated using the following formula [9]-[11].

$$\alpha = \varphi - \delta. \qquad (1)$$

In formula (1), φ - is the geographical latitude of the area; δ - is the angle of declination of the sun for a given month, which is determined by the following Cooper formula.

$$\delta = 23{,}45\,\sin\left(360\,\frac{284+n}{365}\right). \qquad (2)$$

In formula (2), n is the ordinal number of the day starting from January 1 of the year.

In some seasons of the year, the use of vertical-oriented PVP will improve the efficiency of electricity generation by reducing the effects of dust, rain and snow. In some seasons of the year, the use of vertical-oriented PVP will improve the efficiency of electricity generation by reducing the effects of dust, rain and snow. Thin-film PV cadmium telluride is most suitable for vertical orientation and adaptation of PVP for windows and glass facades of buildings in terms of cost, efficiency and design parameters [12]-[15].

Taking into account the design features, 10 units of thin-film cadmium telluride PV Panels (PVP) were equipped for the manufacture of the experimental photovoltaic installation. The power of the PVP unit is 100 watts. The technical parameters of the cadmium telluride thin film photovoltaic panel are shown in Table 1.

Table 1: The technical parameters of the cadmium telluride thin film PVP.

Thin Film PV Modul Type: ASP-S2-100	
All technical data at STC: AM1,5, 1000W/m2, 25°C	
Maximum Power (+/-10%)	100 W
Open Circuit Voltage (Voc)	86.1 V
Short Circuit Current (Isc)	1.52 A
Voltage at Pmax (Vmp)	66.1 V
Current at Pmax (Imp)	1.52 A
Cell Technology	CdTe
Application Class	Class A

To study the geometric and energy parameters of a photovoltaic installation designed for integration on the facade of a building, we prepared and installed an experimental installation on the helio-polygon of the Department of Alternative Energy Sources (AIE) of TSTU. This PV installation (PVI) consists of an array of ten units of thin-film photovoltaic panels (PVP) of cadmium telluride installed in facade window profiles of the AKFA type (Fig. 3).

As discussed above, to ensure maximum PV performance, it is necessary to change the angle of the PV in different seasons of the year. For the geographical conditions of Tashkent, in the summer, the angle of inclination of the PV1 part of the experimental installation was set to 33°. In summer, when the declination of the sun is much higher than the horizon, the sun's rays will not fall perpendicular to the surface of the vertical part of the PV2 installation. To concentrate and increase the flow of solar radiation onto the surface of the vertical part of PV2, flat reflectors made of polished aluminum sheet were installed (Fig. 4).


(a)


(b)

Figure 3: Photo a) of the inclined PV1, b) of the vertical PV2 part of the PVI.

Figure 4: Photo of the vertical PV2 part of the PVI with flat reflectors made of aluminum sheet.

The experimental setup consists of two parts, PV1 and PV2, each with a power of 0.5 kW. In each part, five units of cadmium telluride PVP are fixed in separate window frames. The design of the PV1 part on the sides contains guides fixed to the posts of the main structure. The angle of inclination of the PV1 part is adjusted relative to the horizontal in the range of 0°-90°. The PV2 part of the PVI is installed vertically. The PVP arrays in each part of the installation have a serial electrical connection. The DC outputs of the parts are connected to a two-input inverter. The AC output from the inverter is connected to the local electrical network by a single-phase electric meter. This installation allows to monitoring of the electrical parameters of current, voltage and power.

One of the goals of the experimental work carried out was to compare the functioning of the two parts of the PVI in natural environmental conditions. This goal is achieved by conducting field measurements of external environmental factors, electrical and thermal characteristics of the installation.

The following measuring instruments were used to measure environmental parameters, in particular solar radiation flux density-G, ambient temperature-Ta, wind speed – v and PV parameters - short circuit current-Isc, no-load voltage-Uoc, installation power–P, Tpv - PV surface temperature (Fig. 5) [16], [17].


(a) (b) (c)

Figure 5: Photos of measuring instruments. a) FLIR thermal imager; b) AS856 anemometer; c) 1333R pyranometer.

3 RESULTS AND DISCUSSION

Experimental measurements of environmental parameters and electrophysical parameters of the PV1 and PV2 panel array of parts of the photovoltaic installation were carried out under field conditions in the geographical latitude and longitude of Tashkent. Experimental measurements were carried out in the period July-August 2025. Figure 6 shows graphs of changes in the solar radiation flux density at different angles of inclination of the PV.

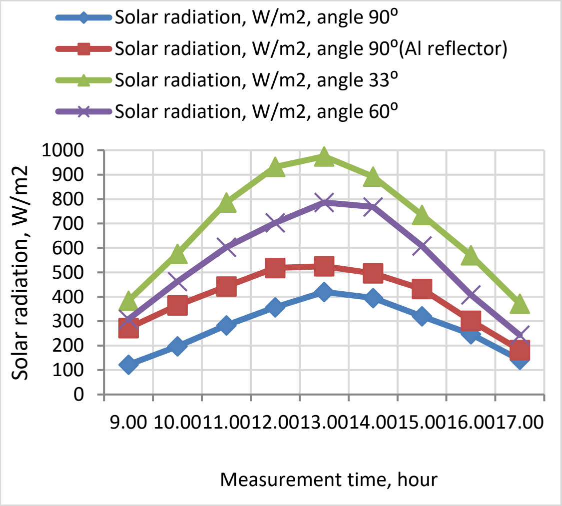


Figure 6: The graph of solar radiation.

As can be seen from Figure 6, during the summer period, the maximum values of solar radiation incident on the surface of PV1 are provided at an angle of inclination of 33 °. Due to the height of the sun above the horizon, the sun's rays fall at a lower angle from the perpendicular to the surface of the panels of the vertical PV2 part of the installation in the spring and summer, even when the sun is at its zenith. Therefore, the vertical surface receives lower values of solar radiation compared to the inclined part. To increase the flow of solar radiation to the surface of the vertically PV2 part of the installation, flat reflectors made of polished aluminum sheet are adapted (Fig. 4). This device made it possible to increase the flow of solar radiation on the panel surface by 25-56%.

Based on the results of measurements carried out over the summer period, present in Figure 7 graphs of changes in ambient temperature and wind speed. The air temperature did not change significantly during the measurements.

Figure 9 shows graphs of changes of power of the PV at different angle inclinations. Based on the results of experimental measurements for the period July-August and the constructed graphs, we present the values of environmental factors, heating temperature and PV power at different installation angles for the zenith time of a sunny day of the July (Table 2).

As noted above, in summer days, concentrating devices made of aluminum sheet were used to concentrate the sun's rays on the surface of a vertically installed PVP and increase the intensity of the absorbed solar radiation flow. As a result of this design, solar radiation is increased by 25-56%, and the power of the vertical PVP with reflectors has increased by an average of 14% compared to the power of the vertical PVP without reflectors.

The purpose of the second stage of the study was to determine the performance of installation in the autumn period when the declination of the sun becomes low.

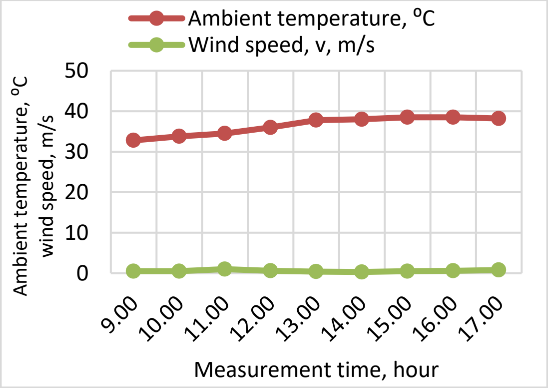


Figure 7: The graph of ambient temperature and wind speed.

Figure 8 shows graphs of changes in PV surface temperature during the day at different angles of PV inclination.

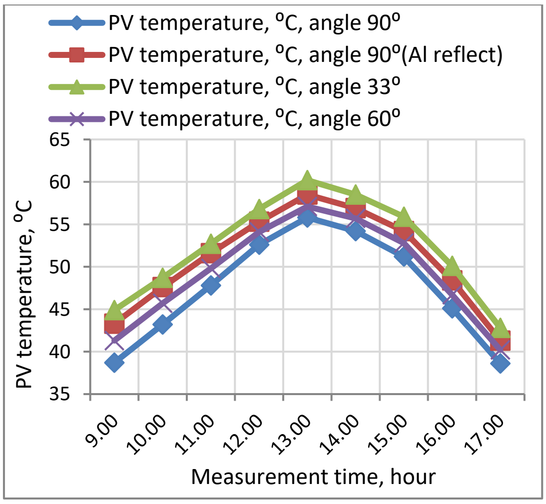


Figure 8: The graph of PV temperature.

After September 23, the day of the autumnal equinox, the declination of the sun begins to decrease until the winter solstice. From this period to November 2025, experimental measurements of the above parameters were carried out. The experimental results show a decrease in altitude, a decrease in the sun's inclination to the horizon, and an angle of 60 degrees became optimal for the inclined part. And for the vertical part of the PV, the values of solar radiation increased compared to the summer period and without the flat reflectors concentrating solar radiation. Figure 10 show graphs of changes in solar radiation flux density surface of PV array.

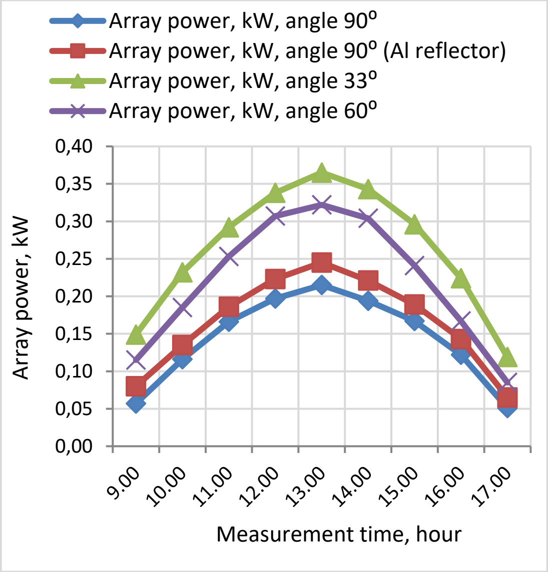


Figure 9: The graph of PV array power.

Table 2: Indicators of external factors and PV.

Indicators	Tilt angle of PV1 and PV2			
	33°	60°	90°	90° with Al reflectors
Solar radiation, W/m^2	975	786	420	525
Ta-ambient temperature, °C	37.8	37.8	37.8	37.8
Surface temperature of PV, °C	60.2	57.1	55.8	58.5
Actual Power, kW	0.365	0.322	0.215	0.245

As can be seen from the graphs of the solar radiation flux density in Figure 10, with the onset of the autumn period, the declination of the sun becomes below the horizon. Accordingly, the sun's rays will fall closer to perpendicular to the PV surface. Therefore, the values of solar radiation, respectively, turned out to be better at 60°, 90°than at 33°. Figure 11 show graphs of changes in ambient temperature and wind speed within daytime.

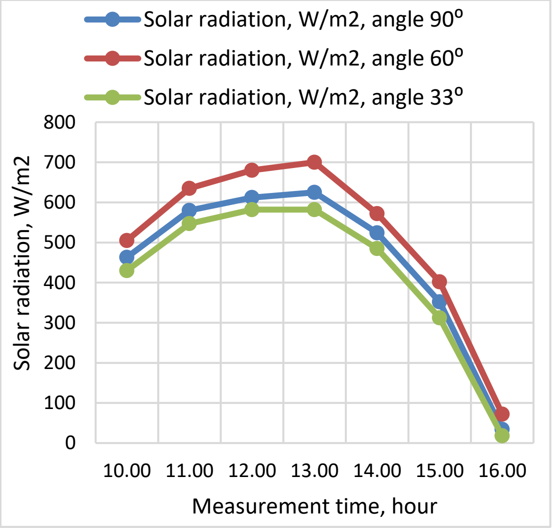


Figure 10: The graph of solar radiation.

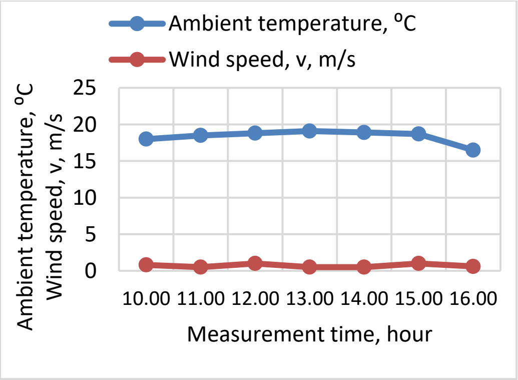


Figure 11: The graph of ambient temperature and wind speed.

Based on the results of experimental measurements for a sunny day in November, we present the values of environmental factors, heating temperature, and PV power at different installation angles for the zenith time of a sunny day of the November (Table 3).

Table 3: Indicators of external factors and PV.

Indicators	Tilt angle of PV1 and PV2		
	33°	60°	90°
Solar radiation, W/m^2	582	700	625
Ta-ambient temperature, °C	19.1	19.1	19.1
Surface temperature PV, °C	34.9	38.7	41.8
Actual Power, kW	0.234	0.312	0.271

As can be seen from the data shown in Table 3, the PV power at 90° without reflectors in November significantly approached the power value of the inclined part of the PV installation at an angle of 60°.

Figure 12 and 13 show graphs of changes PV surface temperature and power of PV within daytime in different angle inclination.

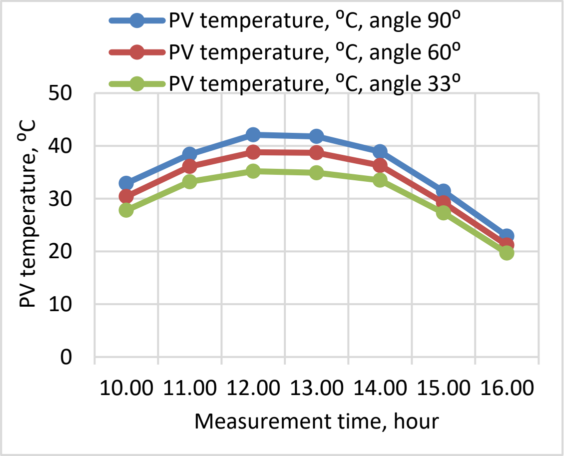


Figure 12: The graph of PV temperature.

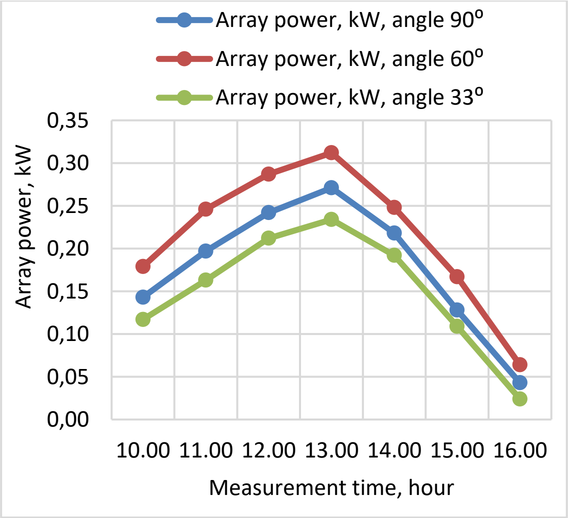


Figure 13: The graph of PV array power.

4 CONCLUSIONS

Experimental studies have shown a significant dependence of the performance of photovoltaic installations on the angle of inclination to the horizon, on the time of year, and weather conditions. For vertically installed PV in the spring and summer period, the use of reflective devices concentrating the sun's rays proved to be effective. According to preliminary studies, the use of reflectors made it possible to increase the flow of solar radiation on the PV surface by an average of 25% and power generation by 14%. In the spring and summer period, the optimal angle of inclination for PV was 33°.

The second initial stage of the study is the autumn-winter period of PV operation. This article presents partial measurement results in the autumn period. However, it has been determined that there is no need to use reflective devices for vertical PV during this period. The vertical PV produced a power 16% higher than the PV at a slope of 33°, 13% less than the PV power at a slope of 60°. In the future, experimental studies will be continued. The results obtained will serve to improve the experimental photovoltaic installation.

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