EXPERIMENTAL AND SIMULATION STUDY ON BIFACIAL PHOTOVOLTAIC MODULES INTEGRATION WITH BUILDINGS

by

Haifei CHEN[a], Yunjie WANG[a], Huihan YANG[a], Yuanqing SHI[a], Bendong YU[b], and Jie YANG[a*]

[a]School of Petroleum Engineering, Changzhou University, Changzhou, Jiangsu, China
[b]College of Urban Construction, Nanjing Tech University, Nanjing, Jiangsu, China

Original scientific paper
https://doi.org/10.2298/TSCI220122088C

Compared with monofacial photovoltaic, bifacial photovoltaic modules can absorb the irradiance on both sides, thereby obtaining more electricity revenue, which can meet more demands. In order to further improve the electrical efficiency of bifacial photovoltaic, this paper proposes a bifacial photovoltaic module with adjustable inclination for simulation and experimental research, which can be well combined with architecture. Under the conditions of different inclination, orientations and heights, the output performance of the bifacial photovoltaic module is analyzed. Under the best inclination, the annual electrical energy of bifacial photovoltaic is about 9.4% higher than that of monofacial photovoltaic. When the spacing between the bifacial photovoltaic and the wall is 1-1.5 times the size of the photovoltaic, the electrical energy will increase the most. Considering the influence of wall color on bifacial photovoltaic performance, the photovoltaic electrical energy under the white wall can reach up to 35% higher than that with respect to the concrete color (dark grey).

Key words*: solar energy, photovoltaic module, wall color, adjustable inclination*

Introduction

Fossil energy is an indispensable fuel for the development in helping global economic growth [1, 2]. But at the same time, the burning of fossil fuels produces a lot of harmful gases and greenhouse gases represented by CO_2, which intensifies the greenhouse effect [3-5]. Therefore, many countries intend to reduce dependence on fossil fuels [6, 7], gradually introduce renewable energy into the energy structure and develop related new technologies [8, 9], seeking sustainable development. Among the different types of renewable energy, solar energy has attracted research based on electrical energy, heat utilization, waste treatment, *etc*. Because of its universality, harmlessness, and abundance [10-14], which radiated too many fields based on systematic and comprehensive research.

Among all the application fields of solar energy, photovoltaic electrical energy is the most common and fastest-growing application mode [15, 16]. Photovoltaic electrical energy is the use of solar cell made of semiconductor materials to generate photovoltaic effects,

*Corresponding author, e-mail: yj12345@cczu.edu.cn

which directly convert solar energy into electrical energy [17], and the research on photovoltaic electrical energy mainly focuses on the research of solar cell. The initial research mainly focused on the innovation of cell materials. For example, after silver nanoparticles are inserted into the dye-sensitized solar cell, the conversion efficiency of the cell has been significantly improved [18]. For perovskite cells, a new vacuum-deposited small molecule film is used as the HTL material, and experiments have shown that it has a very high hole drift mobility [19]. With the continuous advancement of research on small solar cells, the possibility of manufacturing large-area solar cells has been proposed, such as the use of polymer top electrodes to try to manufacture large-area solar cells of various sizes [20]. When the problem of a sharp drop in the electrical energy efficiency of solar cells with excessive temperature was discovered, cell cooling has become the focus of research in recent years. For example, the combination of nanotechnology and radiant cooling can greatly improve electrical energy efficiency and cell life [21].

In order to enable the continuously optimized solar cells to drive photovoltaic technology to be better used in people's daily lives, combining concentrating photovoltaic with building shutters, studying the solution of absorbing solar radiation to provide electricity and heat to the building at the same time to realize the integration of small photovoltaic devices and buildings [22]. In other ways, the internet of things technology is introduced to establish an online grid integrated auxiliary platform to further realize the combination of photovoltaic electrical energy and building [23]. For solar electrical energy components, a solar integrated wall designed on the basis of a circulating water system came into being, which show that the circulating water flow directly affects the electrical energy efficiency and the working state of the photovoltaic wall [24]. The rooftop photovoltaic experiment in Nigeria also verified the feasibility of combining the photovoltaic electrical energy system with the roof of the building [25]. For buildings in certain areas, some studies have tried to create an integrated photovoltaic-assisted heat pump system and integrate it with the building, which broadens the application of *zero energy building* [26].

After decades of multi-angle research on solar cells, photovoltaic efficiency has been greatly improved, and the economic and environmental benefits generated have become more and more significant. Solar-related industries have developed vigorously, but gradually, the material and structure optimization of solar cells can no longer improve the photovoltaic efficiency appreciably in buildings. In order to use solar energy further effectively, based on the research of photovoltaic cells, bifacial photovoltaic electrical energy is proposed [27]. For some countries where bananas are the staple food, a brand-new bifacial solar collector is proposed to produce dried bananas [28], the drying speed of the collector is 1.5 times that of ordinary drying. For bifacial photovoltaic electrical energy, a local shadow detection method based on time series is proposed to solve the impact of partial shadows on the stability and electrical energy of photovoltaic electrical energy [29]. The use of solar energy for seawater desalination is already a relatively mature process, in order to further increase the output rate, based on the original vertical solar distiller, it is designed as a bifacial heat collection [30]. When the research direction is focused on bifacial solar cells, recently, the polysilicon layer created based on low pressure chemical vapor deposition and tube diffusion has successfully produced a new generation of bifacial polysilicon solar cells [31].

Bifacial photovoltaic is an emerging research field. Compared with monofacial photovoltaic, more solar energy can be used from the same area. There are many studies on the bifacial photovoltaic, but the existing bifacial photovoltaic modules have large specifications and cannot be combined with buildings, for example, when angle of incidence changes in pace with changing of seasons, the intensity of light reaches the back ones changes too, which arouses the heterogeneity of electricity production in different seasons and cannot make full use of external environmental conditions to obtain an increase in electricity revenue. Therefore, this article proposes an adjustable bifacial photovoltaic module which can resolve above problems. The electricity revenue of bifacial photovoltaic with different inclination angles, orientations and heights are analyzed. Furthermore, considering the effect of wall spacing and color on bifacial photovoltaic, an experimental platform was built for research, which has certain reference value in specific engineering applications.

Materials and methods

Monofacial photovoltaic modules can only receive solar light on the front to generate electricity, while part light can be reflected from the ground to the other side of the bifacial photovoltaic. Due to the special cell structure and transparent backing material of bifacial photovoltaic modules, which enable it to generate electricity from the front and the back to effectively use the received light to generate electricity, which include reflected light from the ground, scattered light in the atmosphere, reflected light from dust in the air, and reflected light from surrounding buildings. As shown in fig. 1, according to the trace of light, the bifacial photovoltaic module can obtain solar radiation from the front and back, so that the module can obtain more solar radiation. Compared with the monofacial photovoltaic module, it can obtain greater electrical energy.

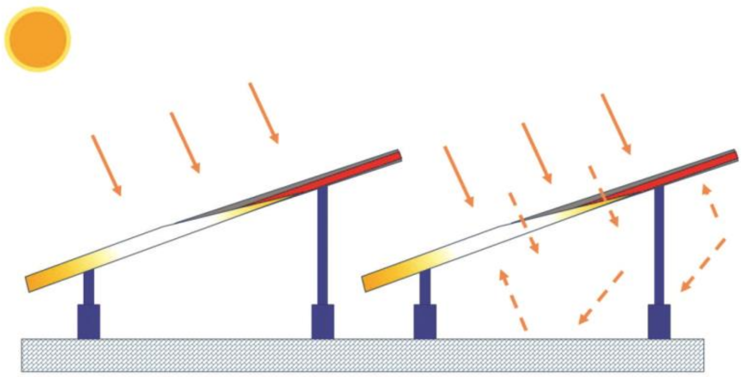
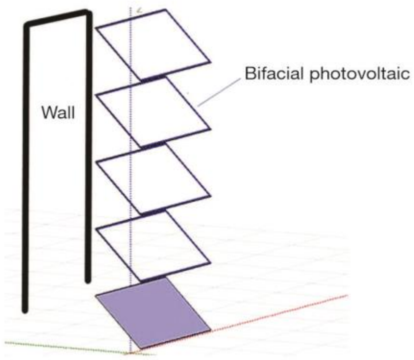


Figure 1. Comparison of irradiance between monofacial photovoltaic and bifacial modules

However, the existing bifacial photovoltaic have large specifications, the most symbolic limitation is that it is difficult to flexibly adjust the inclination angle according to changes in latitude and longitude to achieve energy increase. Therefore, a new bifacial photovoltaic module was proposed, which has a smaller specification, can be coupled with the building window, and can adjust the inclination according to the different latitude and longitude to obtain more electricity revenue. In order to study the performance of the bifacial photovoltaic module, as shown in fig. 2, this paper uses PVsyst 6 to establish a model of the front and back of the bifacial photovoltaic and build an experimental platform. Considering the influence of the reflector structure on the radiation of the photovoltaic backside, the electrical energy of the bifacial photovoltaic module is calculated.



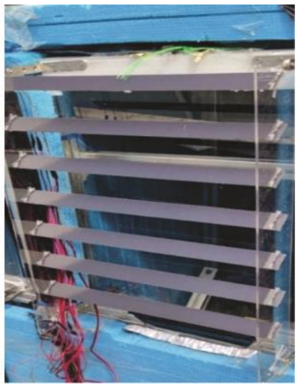


Figure 2. Schematic diagram of the simulation and experimental test platform for bifacial photovoltaic module

Simulation verification and discussion

Optimization of inclination and model verification

As the latitude and longitude are different, the height angle and azimuth angle of the solar energy will also be different, which can be calculated:

$$\beta = (a\ \varphi) + b \tag{1}$$

where $\alpha = 0.86 - 0.57\rho_g\exp(-E/h)$, $b = 4.5 + 62\rho_g\exp(-E/h)$, φ – the latitude of the installation site of the module, ρ_g – the reflectivity, E – the distance between the modules, and h – the installation height of the module.

In order to obtain the maximum energy output at any specific location, it is necessary to optimize the inclination angle of the bifacial photovoltaic. As shown in tab. 1, four typical cities are selected to calculate the optimal inclination angle of bifacial photovoltaic.

Table 1. Optimal inclination angles of bifacial photovoltaic in different areas

Area	Latitude and longitude	Optimal inclination for bifacial photovoltaic
Sanya	18°09′N,108°56′E	20°
Lhasa	29°36'N,91°06'E	31°
Changzhou	31°09′N,119°08′E	33°
Xilin Gol	43°02′N,115°13′E	45°

It can be seen from tab. 1 that the optimal inclination of bifacial photovoltaic varies in different regions. There is a tendency that the higher the latitude, the greater the optimal inclination angle. In addition, as shown in fig. 3, the inclination of bifacial photovoltaic which can be coupled with buildings in Changzhou area was verified by PVsyst 6 simultaneously. It can be seen from the figure that with the increase of the inclination, the bifacial photovoltaic gain percentage shows a trend of first increasing and then decreasing. The maximum electrical gain can be obtained when the inclination angle is 33°, which is 2° more than the optimal inclination in tab. 1 calculated by the formula. The result is included in the acceptable tolerance scope, which means that simulation results are basically consistent with the calculation results, and the accuracy of the model is verified.

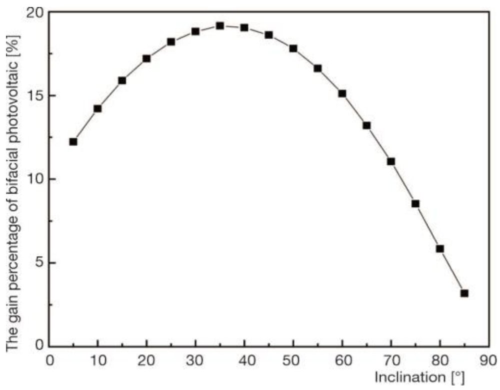


Figure 3. The change of the gain percentage of bifacial photovoltaic with the inclination

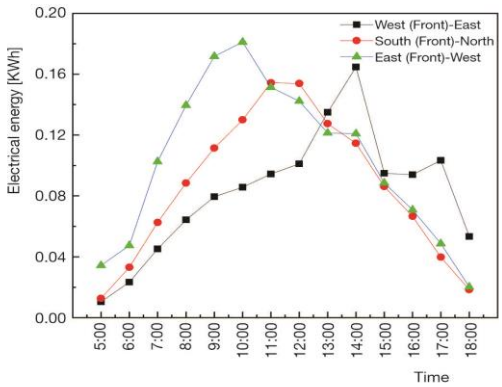


Figure 4. Electric energy of bifacial photovoltaic in different orientations

Analysis of the orientation of bifacial photovoltaic

Based on the bifacial factor of bifacial photovoltaic modules, the efficiency on each side is different. Therefore, the installation orientation of bifacial photovoltaic modules not only needs to consider the south direction, but also the east and west directions for vertical installation. As shown in fig. 4, the electrical energy of bifacial photovoltaic under different orientations was studied. It can be seen from the figure that the bifacial photovoltaic electrical energy under different orientations all increase first and then decrease, this is because of the influence of solar radiation, the radiation in the morning and afternoon is weak, and the radiation at noon is stronger, so the bifacial photovoltaic will first increase and then decrease. However, the trend has some slight differences. This is because of the influence of the Sun rising from the east to the west, so that the module under the orientation of east (front)-west can get more solar energy in the morning, and the module under the orientation of west (front)-east can get more solar energy in the afternoon, and the peak time is a little different. The bifacial photovoltaic under the orientation of north (front)-south can get the maximum power generation at noon, which is less than the peak value in the east (front)-west direction. It can be seen from tab. 2 that, under the cumulative situation of the whole year, the bifacial photovoltaic electrical energy in the south direction is the largest, and the electrical energy in the west direction is the smallest, which are represented by 344 kWh and 266 kWh, respectively.

Table 2. Electric energy of bifacial photovoltaic in different directions throughout the year

Orientations	West (Front)-East	North (Front)-south	East (Front)- West
Annual power generation [kWh]	266.39	364.17	344.62

Comparison between bifacial photovoltaic and monofacial photovoltaic

Figure 5 compares the annual electrical energy of monofacial photovoltaic module and bifacial photovoltaic module at different inclination through simulation. In this study, the inclination is from 0° to 90° and the orientation of photovoltaic is south (front)-north. The module area of monofacial photovoltaic and bifacial photovoltaic is 2 m^2, the nominal power generation is 365 wp, and the nominal voltage is 33 V. It can be seen from the figure that the annual electrical energy of monofacial photovoltaic and bifacial photovoltaic show a trend of first increasing and then decreasing with the inclination. Compared with monofacial photovoltaic, the annual electrical energy of bifacial photovoltaic is less affected by the inclination. It is obvious that the annual electrical energy of bifacial photovoltaic is higher than that of monofacial photovoltaic. Under the best inclination, the annual electrical energy of bifacial photovoltaic is about 9.4% higher than that of monofacial photovoltaic.

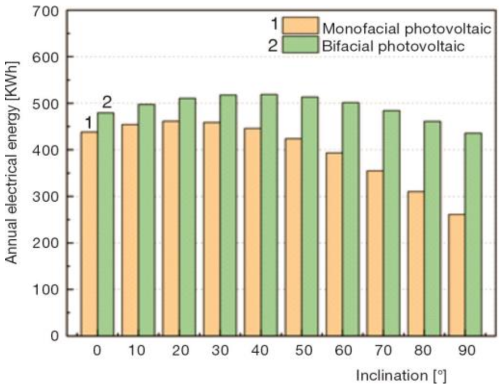


Figure 5. The annual electrical energy of monofacial photovoltaic module and bifacial photovoltaic module at different inclination

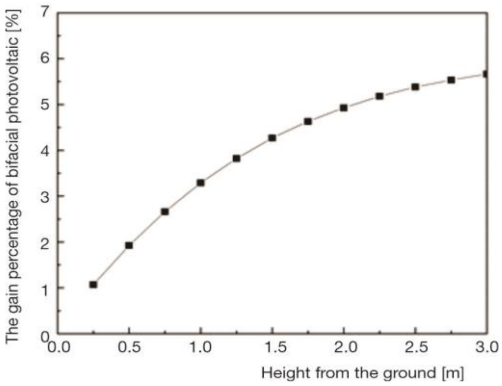


Figure 6. The effect of the height from the ground on the gain percentage of bifacial photovoltaic

Analysis of the height from the ground and ground reflectivity of bifacial photovoltaic

As shown in fig. 6, the ground reflectivity is maintained at 0.5, and the height from the ground is changed to study the gain percentage of the bifacial photovoltaic. The height from the ground refers to the distance between the center axis of the bifacial photovoltaic module and the ground. It can be seen from the figure that as the height from the ground increases, the gain percentage of the bifacial photovoltaic will increase. This is because the increase in height allows more light to be reflected to the photovoltaic on the back panel and absorbs more solar energy, which increases the proportion of revenue. If the height from the ground increases further and exceeds 2 m, the upward trend of the gain percentage will flatten out and eventually remain stable. This is mainly because the area of photovoltaic is limited and when the height exceeds a certain value, the reflected light will keep going in the external space of the photovoltaic and valid light no longer increases. Therefore, it is recommended that the height from the ground of the bifacial photovoltaic module be set to 2 m.

As shown in fig. 7, keep the height of the bifacial photovoltaic from the ground at 2 m, and study the influence of ground reflectivity on the gain percentage under different weather conditions. It can be seen straightforwardly that the gain percentage of bifacial photovoltaic increases in a proportional trend in conditions of both overcast day and sunny day. This is because increasing the reflectivity enables more energy to be reflected to the photovoltaic, thereby obtaining more energy. Compared with sunny days, under the same electrical efficiency, increasing the ground reflectivity on overcast days, the revenue of bifacial photovoltaic is higher than that under sunny days, which can reach up to 30%.

Experimental results and discussion

In order to test the performance of the bifacial photovoltaic coupled with the building, August 8, 2021 was selected for the test. The changes in solar irradiance and bifacial photovoltaic electrical energy are shown in fig. 8. The peak value of solar radiation is 330 W/m^2, which appears at 11 a. m. local time, the general trend of electrical energy is proportional to the change in irradiation, which is higher from 11 a. m. to 12:30 a. m. This phenomenon is attributed to the average maximum sunshine in the range of approximately 11:00 to 12:30.

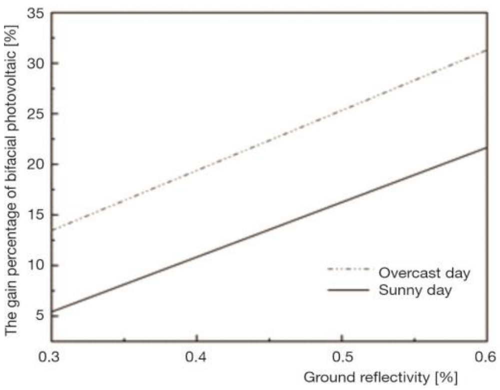


Figure 7. The effect of the ground reflectivity on the gain percentage of bifacial photovoltaic

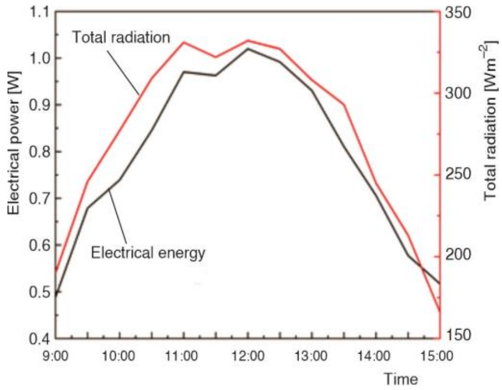


Figure 8. Variation in solar radiation and bifacial photovoltaic electrical energy

In order to study the effect of back reflection on the performance of bifacial photovoltaic, bifacial photovoltaic modules were fabricated as shown in fig. 9(a), and the experimental principle is shown in fig. 9(b). By controlling the distance between the photovoltaic module and the backplane, an optimal distance is first determined to maximize the bifacial gain.

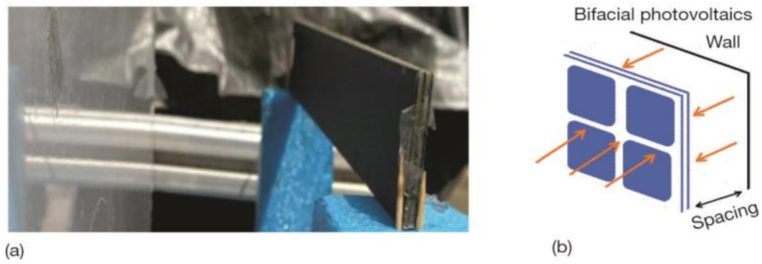


Figure 9. Experiment and schematic diagram of bifacial photovoltaic module

Figure 10 shows the variation of bifacial photovoltaic electrical energy with distance at different times. The spacing refers to the ratio of the distance between the bifacial photovoltaic module and the wall to the width of the bifacial photovoltaic module. It can be seen from the figure that as the spacing increases from 0.5 to 1.0, the electrical energy of bifacial photovoltaic at different times has increased simultaneously. This is because the spacing increases so that more energy is reflected to the back photovoltaic, thereby obtaining more electricity. If the spacing is further increased at the starting point of 1.0, the light reflected from the wall will diverge to other places, resulting in a reduction in the scattered radiation obtained by the backplane and a reduction in electrical energy, and this change faces the weakest impact at around 3:00 p. m. When the spacing between the bifacial photovoltaic and the wall is 1-1.5 times the size of the photovoltaic, the electrical energy will increase the most.

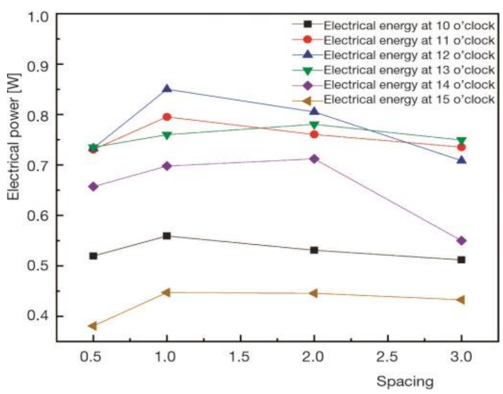


Figure 10. Electrical energy of bifacial photovoltaic change with distance at different times

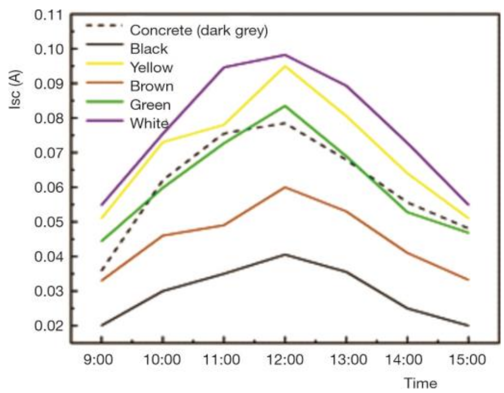


Figure 11. The effect of the background color of the wall on the short-circuit current

Due to the uncertainty of the background color of the installation wall, especially when bifacial photovoltaic are installed on the building, it is almost impossible to redesign the rear surface. In addition, the color of the wall background will affect the absorption and reflection of light, thereby changing its reflectivity, so it is necessary to explore the effect of the wall background color on the bifacial photovoltaic module. During the experiment, the background color of the wall was changed, and the short-circuit current was measured by Agilent for comparison. Figure 11 compares the short-circuit current by changing the background color of the wall. It can be seen from the figure that the wall color is different, and the short-circuit current of the bifacial photovoltaic will also change. This is because the color of the wall affects the absorption and reflection of light, so that the energy reflected by the wall to the back of the photovoltaic will be different. Due to the high reflectivity of white, the energy reflected from the white wall to the back of the photovoltaic will also be higher, so that the highest short-circuit current can be obtained compared with other color. When the wall color is black, most of the energy is absorbed, and the energy reflected from the wall will be reduced, so that the short-circuit current will be reduced.

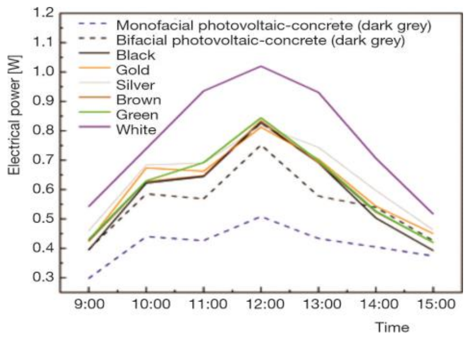


Figure 12. The effect of the background color of the wall on the electrical energy

Figure 12 shows the electrical energy of bifacial photovoltaic with different wall background colors. As can be seen from the figure, the electricity revenue of bifacial photovoltaic modules with different wall background colors is better than that of monofacial photovoltaic modules. Compared with other colors, the photovoltaic under the white wall can get much more energy. The photovoltaic electrical energy under the white wall is 35.64% higher than that with respect to the concrete color (dark grey).

Conclusion

In order to further improve the electrical efficiency of photovoltaic modules, this paper proposes an adjustable bifacial photovoltaic module. Through experiments and simulations, the performance of bifacial photovoltaic has been extensively analyzed as follows.

- According simulations, the annual electrical energy of bifacial photovoltaic is less affected by the inclination compared with monofacial photovoltaic. The annual electrical energy of bifacial photovoltaic is higher than that of monofacial photovoltaic. Under the best inclination, the annual power generation of bifacial photovoltaic is about 9.4% higher than that of monofacial photovoltaic.
- The optimal inclination of bifacial photovoltaic are different in different regions. The higher the latitude, the greater the optimal inclination. Affected by the rising of the Sun from east to west, the modules in the east (front)-west direction can get more solar energy in the morning, and the modules in the west (front) direction can get more solar energy in the afternoon. In the cumulative situation of the whole year, bifacial photovoltaic electrical energy in the south direction is the largest, which can reach 364kWh throughout the year.
- As the height from ground increases, the gain percentage of bifacial photovoltaic will increase. It is recommended to set the height of the center axis of the bifacial photovoltaic module from the ground to 2 m. Increasing the reflectivity allows more energy to be reflected to the photovoltaic, thereby obtaining more energy. Increasing the reflectivity of the ground in overcast days, the gain percentage of bifacial photovoltaic can reach 30%.
- As the spacing from the wall increases, more energy is reflected to the back photovoltaic, thereby obtaining more power. When the distance between the bifacial photovoltaic and the wall is 1-1.5 times of the photovoltaic size, the bifacial photovoltaic power increases the most. Due to the uncertainty of the background color of the installation wall, this article studies 6 kinds of wall colors. Compared with other colors, the photovoltaic electrical energy under the white wall is 35.64% higher than that without the wall color.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Grant No. 51906020) and the Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX21_2813).

References

[1] Wang, W., *et al*., Evolution of Global Fossil Fuel Trade Dependencies, *Energy, 238* (2022), 1, 121924
[2] Mensah, I. A., *et al*., Analysis on the Nexus of Economic Growth, Fossil Fuel Energy Consumption, CO_2 Emissions and Oil Price in Africa based on a PMG Panel ARDL Ppproach, *Journal of Cleaner Production, 228* (2019), Aug., pp. 161-174
[3] Dingbang, C., *et al*., Does New Energy Consumption Conducive to Controlling Fossil Energy Consumption and Carbon Emissions?-Evidence from China, *Resources Policy, 74* (2021), 12, 102427
[4] Yan, J., The Impact of Climate Policy on Fossil Fuel Consumption: Evidence from the Regional Greenhouse Gas Initiative (RGGI), *Energy Economics, 100* (2021), 8, 105333
[5] Karmaker, A. K., *et al*., Exploration and Corrective Measures of Greenhouse Gas Emission from Fossil Fuel Power Stations for Bangladesh, *Journal of Cleaner Production, 244* (2020), 1, 118645
[6] Meng, M., *et al*., Decoupling, Decomposition and Forecasting Analysis of China's Fossil Energy Consumption from Industrial Output, *Journal of Cleaner Production, 177* (2018), Mar., pp. 752-759
[7] Luo, B., *et al*., An Evaluation of Influencing Factors and Public Attitudes for the Adoption of Biogas System in Rural Communities to Overcome Energy Crisis: A Case Study of Pakistan, *Sci Total Environ, 778* (2021), 7, 146208

[8] Khademi, M. H., Lotfi-Varnoosfaderani, M., Use of Biomass-Derived Glycerol as an Alternative to Fossil Fuels for Aniline Production: Energy Saving and Environmental Aspects, *Fuel, 310* (2022), 2, 122359
[9] Jastad, E. O., *et al*., The Role of Woody Biomass for Reduction of Fossil GHG Emissions in the Future North European Energy Sector, *Applied Energy, 274* (2020), 9, 115360
[10] Hu, G., *et al*., Potential Evaluation of Hybrid Nanofluids for Solar Thermal Energy Harvesting: A Review of Recent Advances, *Sustainable Energy Technologies and Assessments, 48* (2021), 12, 101651
[11] Pandey, A. K., *et al*., Utilization of Solar Energy for Wastewater Treatment: Challenges and Progressive Research Trends, *J Environ Manage, 297* (2021), 11, 113300
[12] Du, W., *et al*., Dynamic Energy Efficiency Characteristics Analysis of a Distributed Solar Photovoltaic Direct-Drive Solar Cold Storage, *Building and Environment, 206* (2021), 12, 108324
[13] Gong, B., *et al*., Phase Change Material Enhanced Sustained and Energy-Efficient Solar-Thermal Water Desalination, *Applied Energy, 301* (2021), 11, 117463
[14] Sarwar, J., *et al*., Comparative Analysis of a Novel Low Concentration Dual Photovoltaic/Phase Change Material System with a Non-Concentrator Photovoltaic System, *Thermal Science, 25* (2021), 2A, pp. 1161-1170
[15] Maka, A. O. M., *et al*., Solar Photovoltaic (PV) Applications in Libya: Challenges, Potential, Opportunities and Future Perspectives, *Cleaner Engineering and Technology, 5* (2021), 12, 100267
[16] Kumar Sahu, B., A Study on Global Solar PV Energy Developments and Policies with Special Focus on the Top Ten Solar PV Power Producing Countries, *Ren. and Sus. E. Rev., 43* (2015), Mar., pp. 621-634
[17] Babajide, A., Brito, M. C., Solar PV Systems to Eliminate or Reduce the Use of Diesel Generators at No Additional Cost: A Case Study of Lagos, *Nigeria, Renewable Energy, 172* (2021), July, pp. 209-218
[18] Saravanan, S., *et al*., Efficiency Improvement in Dye Sensitized Solar Cells by the Plasmonic Effect of Green Synthesized Silver Nanoparticles, *Jou. of Sci.: Ad. Materials and Devices, 2* (2017), 4, pp. 418-424
[19] Tsai, W.-L., *et al*., Very High Hole Drift Mobility in Neat and Doped Molecular Thin Films for Normal and Inverted Perovskite Solar Cells, *Nano Energy, 41* (2017), Nov., pp. 681-686
[20] Kang, M. H., *et al*., Fully Vacuum-Free Large-Area Organic Solar Cell Fabrication from Polymer Top Electrode, *Solid-State Electronics, 186* (2021), 12, 108192
[21] Tang, H., *et al*., Radiative Cooling of Solar Cells with Scalable and High-Performance Nanoporous Anodic Aluminum Oxide, *Solar Energy Materials and Solar Cells, 235* (2022), 1, 111498
[22] Liang, S., *et al*., Optical Design and Validation of a Solar Concentrating Photovoltaic-Thermal (CPV-T) Module for Building Louvers, *Energy, 239* (2022), 1, 122256
[23] Wu, X., *et al*., Integrated Design of Solar Photovoltaic Power Generation Technology and Building Construction Based on the Internet of Things, *Alexandria Eng. Journal, 61* (2021), 4, pp. 2775-2786
[24] Long, J., *et al*., Study on Solar Energy Utilization Characteristics of a Solar Building Integrated Wall, *Applied Thermal Engineering, 175* (2020), 7, 115289
[25] Ayodele, T. R., *et al*., Solar Energy Harvesting on Building's Rooftops: A Case of a Nigeria Cosmopolitan City, *Renewable Energy Focus, 38* (2021), Sept., pp 57-70
[26] Alessandro, M., *et al*., Photovoltaic-Thermal Solar-Assisted Heat Pump Systems for Building Applications: Integration and Design Methods, *Energy and Built Environment*, On-line first, https://doi.org/10.1016/j.enbenv.2021.07.002, 2021
[27] Fertig, F., *et al*., The BOSCO Solar Cell: Double-sided Collection and Bifacial Operation, *Energy Procedia, 55* (2014), Dec., pp. 416-424
[28] Pruengam, P., *et al*., Fabrication and Testing of Double-Sided Solar Collector Dryer for Drying Banana, *Case Studies in Thermal Engineering, 27* (2021), 10, 101335
[29] Liu, J., *et al*., Degradation Mechanisms and Partial Shading of Glass-Backsheet and Double-Glass Photovoltaic Modules in Three Climate Zones Determined by Remote Monitoring of Time-Series Current–Voltage and Power Datastreams, *Solar Energy, 224* (2021), Aug., pp. 1291-1301
[30] Sharon, H., Energy, Exergy and Enviro-Economic Assessment of Productivity Enhanced Passive Double Sided Vertical Convection Solar Distiller for Fresh Water Production, *Sustainable Energy Technologies and Assessments, 42* (2020), 10, 100846
[31] Yan, X., *et al*., Process Development and Integration of Double-Side Poly-Si Passivated Solar Cells with Printed Contacts via LPCVD and Ex-Situ Tube Diffusion, *Sol. E. Mat. and Sol. Cel., 230* (2021), 9, 111249

Paper submitted: January 22, 2022
Paper revised: April 14, 2022
Paper accepted: May 26, 2022