WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2026.157478

ARCHIVES OF CIVIL ENGINEERING

Vol. LXXII ISSUE 1 2026

© 2026. Yan Wang, Ruoxi Chen, Xiaofei Zhu.

pp. 347 –357

This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (CC BY-NC-ND 4.0, https://creativecommons.org/licenses/by-nc-nd/4.0/), which permits use, distribution, and reproduction in any medium, provided that the Article is properly cited, the use is non-commercial, and no modifications or adaptations are made.

Research paper

Installation and configuration of photovoltaic systems in buildings under energy conservation and emission reduction

Yan Wang[1], Ruoxi Chen[2], Xiaofei Zhu[3]

Abstract: This paper provides a brief introduction to building integrated photovoltaic (BIPV). It utilized a particle swarm algorithm to optimize the arrangement scheme of the photovoltaic array on a concrete flat roof. Furthermore, the performance of the particle swarm algorithm was improved through a genetic algorithm (GA). Subsequently, an experimental analysis was conducted using an office building in a joint salinization factory in Henan Province. First, the effectiveness of the building energy model constructed using PKPM-Energy and Daysim software was validated. Then, a comparison was made between the GA, the particle swarm algorithm, and the improved particle swarm algorithm. The results indicated that the building energy consumption model constructed by the simulation software calculated the building's energy consumption effectively, which was used to guide the optimization algorithm. All three optimization algorithms successfully optimized the initial scheme. Moreover, the improved particle swarm algorithm exhibited the best optimization performance among the three algorithms.

Keywords: building, configuration optimization, energy conservation and emission reduction, photovoltaic array

[1]MSc., School of Architecture and Urban Planning, Henan University of Urban Construction, Pingdingshan, Henan 467036, China, e-mail: wyyanw@hotmail.com, ORCID: 0009-0009-4176-4414
[2]MSc., School of Architecture and Urban Planning, Henan University of Urban Construction, Pingdingshan, Henan 467036, China, e-mail: chenrxruox@outlook.com, ORCID: 0009-0003-4250-1153
[3]MSc., School of Architecture and Urban Planning, Henan University of Urban Construction, Pingdingshan, Henan 467036, China, e-mail: zxf_xiaof@outlook.com, ORCID: 0009-0001-8551-6465

1. Introduction

In the field of construction, on the one hand, construction processes generate a large amount of emissions, and on the other hand, buildings continue to consume energy and emit pollutants even after completion [1]. The photovoltaic system converts solar energy into electricity through the photovoltaic effect, which is based on the semiconductor material's photoelectric conversion characteristics. Due to the utilization of solar energy, photovoltaic systems have advantages such as cleanliness, renewability, low noise, and no pollution; therefore, they can be applied in the field of construction [2]. Building integrated photovoltaic (BIPV), a new form of construction, combines photovoltaic systems with buildings, resulting in a multifunctional structure that incorporates power generation, support, maintenance, and aesthetical enhancement [3]. The purpose of this article is to reduce the energy consumption of photovoltaic buildings by adjusting the layout scheme of photovoltaic arrays in these buildings. Several related studies have been conducted in this area. Piotrowska-Woroniak [4] performed performance simulations on photovoltaic systems with angle-changing solar panels used in buildings such as offices and kindergartens. The results demonstrated that photovoltaic systems effectively reduce CO_2 emissions. Conejos et al. [5] evaluated the performance and maintainability of BIPV. The study identified certain technical limitations in BIPV applications in tropical regions. Factors such as cost, aesthetics, and implementation challenges were identified as critical reasons for the limited adoption of BIPV in Singapore. He et al. [6] proposed a methodology for daylighting calculations in indoor environments equipped with BIPV curtain wall systems. Zhang et al. [7] studied whether the operation of photovoltaic arrays in solar energy parks would affect greenhouse gas emissions in natural ecosystems and found that solar photovoltaic has significant potential for reducing carbon emissions. Bouzidi et al. [8] introduced an approach using an artificial neural network to model a photovoltaic array with maximum power point tracking. They validated the efficacy of this method through experiments. Zheng et al. [9] used FLUENT software to analyze the wind load characteristics of photovoltaic arrays installed at different building heights. The analysis results showed that the higher the building height, the larger the vortex radius formed above the photovoltaic array. Etarhouni et al. [10] proposed a new magic square-enhanced configuration algorithm to overcome partial shading issues in photovoltaic arrays and verified its effectiveness through experiments. The aforementioned studies all analyzed photovoltaic buildings. Some examined the impact of solar panel angles on performance, some focused on maintainability aspects, and others investigated daylighting effects within photovoltaic buildings. This study also focuses on photovoltaic buildings, but it aims to reduce energy consumption by optimizing the layout of photovoltaic arrays using a particle swarm algorithm improved by a genetic algorithm (GA). This paper used a particle swarm algorithm to optimize the arrangement of photovoltaic arrays on concrete flat roofs. To enhance the performance of the particle swarm algorithm, a genetic algorithm (GA) was introduced. Subsequently, an experimental analysis was conducted on an office building at a joint salinization plant in Henan Province, China. The contribution of this article lies in combining the particle swarm algorithm and GA to optimize the layout of photovoltaic arrays in photovoltaic buildings, providing an effective reference for reducing energy consumption. However, a limitation of this study is that it only considers the case of inclined placement of photovoltaic panels when optimizing the layout of photovoltaic arrays. Therefore, future research should focus on developing optimization solutions for other placement scenarios.

2. Building integrated photovoltaic and its optimization based on an improved particle swarm algorithm

2.1. Building integrated photovoltaic

Photovoltaic systems are crucial in converting solar energy into electricity, providing sustainable power for a building's day-to-day operations [11]. Due to the fact that photovoltaics are clean, non-polluting, and renewable, they can reduce buildings' reliance on traditional energy sources while also avoiding additional carbon emissions. BIPV represents an innovative construction approach wherein a photovoltaic system is seamlessly integrated into the building structure. There are two main types of BIPV construction methods: installation type and integration type [12]. The installation type involves mounting the photovoltaic system equipment onto the building's surface, typically on the roof, using a simple support structure. This method has advantages such as ease of installation and lower cost. However, it requires a significant installation area and may increase the building's load due to the weight of the equipment [13].

On the other hand, the integration type involves incorporating PV system equipment as building components or materials during the construction process. This approach aligns more closely with the concept of BIPV. Its advantage lies in the fact that photovoltaic equipment can be used as building materials, without occupying too much building area or adding extra load to the building, while also contributing to the aesthetic appearance of the architecture [14]. However, there are challenges, such as higher technical costs for using photovoltaic devices as building materials, difficulties in integrating them into architectural design, and lower overall photovoltaic power generation efficiency due to the dispersion of PV devices used as building materials [15].

The installation-type construction method of BIPIV is widely adopted in buildings due to its easy installation and relatively low-cost advantages. However, it should be noted that this method may increase the building load. To address this concern, building designers must consider load margins during construction. Additionally, advancements in photovoltaic technology have led to lighter equipment, mitigating this drawback. The large area occupied by mounting points can be tackled in two ways. Firstly, a large open area can be selected in a building, such as the roof, to accommodate the photovoltaic system [16]. Secondly, a rational design of photovoltaic array arrangement can help optimize space utilization. The primary focus of this paper is to optimize the arrangement of photovoltaic arrays on building roofs to enhance the energy-saving and emission-reducing effects of the building.

2.2. Particle swarm algorithm

Due to the variety of building roof materials and the corresponding diverse installation methods for photovoltaic arrays, it is challenging to provide a comprehensive description for each case. Hence, this paper focuses on optimizing the layout scheme of photovoltaic arrays specifically for the commonly used concrete flat roofs. During the optimization process of photovoltaic array layout, the primary objective is to maximize the amount of sunlight radiation received by the arrays while minimizing the building's energy consumption. This can be regarded as a multi-objective optimization problem. Optimization algorithms can be employed to address such a challenge. In this study, the particle swarm algorithm is utilized to optimize the layout scheme of photovoltaic arrays. Additionally, a GA is introduced to enhance the optimization capability of the particle swarm algorithm [17].

In the particle swarm algorithm, each particle represents an optimization scheme, and the particle's coordinates in the search space are the specific optimization parameters of the optimization scheme. When the particles "move" in the search space to find the optimization, the iterative formula is the key to adjusting the position and speed of the particles, and its formula is:

$$\begin{cases} v_i(t+1) = \varpi v_i(t) + c_1 r_1 (P_i(t) - x_i(t)) + c_2 r_2 (G_g(t) - x_i(t)) \\ x_i(t+1) = x_i(t) + v_i(t+1) \end{cases} \tag{2.1}$$

where: $v_i(t+1)$ – the velocity of particle i after one iteration, $x_i(t+1)$ – the position of particle i after one iteration, $v_i(t)$ – the velocity of particle i before iteration, $x_i(t)$ – the position of particle i before iteration, ϖ – the inertia weight of particles, c_1 – learning factor [18], c_2 – learning factor, r_1 – a random numbers between 0 and 1, r_2 – a random number between 0 and 1, $P_i(t)$ – the historical optimal position of particle i, $G_g(t)$ – the current global optimal position.

The goodness of a particle is measured by the fitness value obtained by substituting its position into the fitness value function, and the position of the particle in the search space is continuously adjusted by the above formula, which ultimately makes the particles close to the optimal position.

2.3. Particle swarm algorithm improved with genetic algorithm

In the particle swarm algorithm, when the current optimal and historical optimal positions reach local optima, the entire particle swarm tends to converge towards the local optimum, acquiring only a local optimal solution. To overcome this limitation, this paper introduces genetic operations within the GA to enable particles to escape from local optimal positions. The specific steps of the improved method are as follows.

1. The relevant parameters about the building and the PV array are input. PKPM-Energy software and Daysim software are utilized to construct a building model capable of calculating the energy consumption of the building integrated with photovoltaic arrays. PKPM-Energy software is an energy analysis tool that calculates and analyzes building energy consumption based on the China Green Building Evaluation Standard. Daysim software is a widely-used RADIANCE-based daylighting analysis software employed for simulating daylight levels within and around buildings.
2. The initial population of particles randomly based on the parameters to be optimized within the photovoltaic array [19]. The parameters to be optimized are the width of the photovoltaic panels, the spacing between the photovoltaic panels, and the tilt angle between the photovoltaic panels and the roof surface. The randomly generated parameters must adhere to predetermined boundary conditions.

3. The population particles are decoded, and each represents a specific photovoltaic array arrangement scheme. The parameters the particles represent are substituted into the constructed rooftop photovoltaic building model. The building energy consumption is calculated as the fitness value of each particle using PKPM-Energy software and Daysim software.
4. Whether the optimization search is completed is determined. Optimization stops if the fitness values of the population particles stabilize or the maximum number of optimization is reached. The optimal particles within the population are outputted. Otherwise, proceed to the next step to continue optimization.
5. The particle swarm iteration formula is employed to iterate the population particles. To enhance the optimization performance of the particle swarm algorithm, the selection, crossover, and mutation operations from the GA are introduced [20] to prevent the particle swarm from being trapped in local optima. The selection operation involves preserving a portion of the optimal particles in the particle swarm without any changes. The remaining particles undergo crossover and mutation operations according to predefined probabilities. Crossover refers to the exchange of values on the same axes between two particles based on the selection probability. Mutation refers to random changes in values on the particle axes within a specified range based on the selection probability.
6. After completing one iteration, return to step (3) to continue the process.

3. Case study analysis

3.1. Overview of the case study

The office building of a joint salinization plant in Henan Province was taken as a subject for case study, and the overall configuration of the office building is shown in Figure 1, which is a concrete flat roof. The field investigation found that the office building covers an area of 68×18 m, with a total of five floors and a total height of 17 m, and the area of the roof that can be used for installing photovoltaic arrays is 64.49×16.00 m. The thermal parameters of the office building envelope are shown in Table 1. In addition, the office building faces south. When installing photovoltaic arrays on the roof, as shown in Fig. 1, the photovoltaic modules were connected in rows as much as possible, and the interval between rows was the array pitch.

Fig. 1. Schematic diagram of the office building at the joint salinization plant site

www.czasopisma.pan.pl www.journals.pan.pl

Table 1. Thermal parameters of the enclosure

Envelope	**Construction**	**Construction content**	**Heat transfer coefficient** *W*/(m²·K)	**Specific heat capacity** *J*/(kg·K)
External wall	External	25 mm cement mortar	0.93	1,050
		70 mm polystyrene board	0.03	2,100
		15 mm cement mortar	0.93	1,050
		250 mm concrete block	1.34	920
		25 mm cement mortar	0.93	1,050
	Internal	Whitewashing with lime powder	–	–
Roof	External	20 mm cement mortar	0.93	1,050
		5 mm waterproof material	0.12	2,300
		20 mm leveling layer	0.93	1,050
		85 mm polystyrene board	0.03	2,100
		35 mm slope making layer	0.32	1,050
		150 mm reinforced concrete slab	1.74	920
		10 mm cement mortar	0.93	1,050
	Internal	Whitewashing with lime powder	–	–
External window	–	6 mm glass	1.09	837
Ground	–	20 mm marble slab	2.91	920

In the initial scheme of installing photovoltaic arrays on the roof of the office building, the installed capacity was 112.75 kWh, the type of photovoltaic modules was bifacial crystalline silicon, fixed at a tilt angle of 23° by supports. The orientation was the same as that of the building, the spacing of the array was 4 m, the height of the modules above the ground was 0.5 m, the photovoltaic conversion efficiency was 90.5%, the load-bearing capacity was 0.508 kN/m^2, and the maximum wind load was –0.639 kN/m^2.

3.2. Parameter setting

The relevant parameters of the three optimization algorithms are shown in Table 2. In addition, the boundary conditions of the population particles in the optimization process included: the width of photovoltaic panels ranged from 0.70 to 1.26 m; the spacing of photovoltaic panels ranged from 1.0 to 7.0 m; the tilt angle of photovoltaic panels ranged from 0° to 45°.

www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

Table 2. Relevant parameters of the optimization algorithms

	GA	**Particle swarm algorithm**	**Improved particle swarm algorithm**
Population size	100	100	100
Particle movement weight	–	0.8	0.8
Learning factor 1	–	0.2	0.2
Learning factor 2	–	0.2	0.2
Elite rate	0.4	–	0.4
Crossover rate	0.8	–	0.8
Mutation rate	0.02	–	0.02
Maximum number of iterations	50	50	50

3.3. Validation of the effectiveness of the building energy consumption model

The optimization of the rooftop photovoltaic array layout scheme relied on the utilization of optimization algorithms. The fitness function is crucial in this process as it guides the optimization direction. The fitness function's accuracy directly influences the optimization results' accuracy. The fitness function used in this paper calculated the building energy consumption through simulation using PKPM-Energy and Daysim software. Given that the simulation results were obtained using software, verifying the validity of these results is essential [21].

The case analyzed in this article is an office buildings, which mainly consume electricity for heating, cooling, lighting, and other daily operations. The electrical consumption of the building can be considered as its energy consumption, and measuring the building's electricity usage is relatively simpler. Hence, this study validated the accuracy of the calculation results obtained from two simulation software programs by comparing them with actual data.

To validate the accuracy of the simulation results, the initial scheme of photovoltaic arrays was utilized to facilitate the collection of actual data in the field. Field tests were conducted over periods of 1, 3, 5, and 7 days under cloudy or sunny conditions between February and April. The survey involved recording temperature settings, air change rates, indoor illuminance settings, lighting power density, occupant density, and building power consumption. Meteorological data was obtained from the Central Meteorological Observatory website (nmc.gov.cn/index.html). The collected data was then inputted into the building energy consumption model developed using PKPM-Energy and Daysim software for simulation and computation. Pearson's correlation analysis was subsequently performed to compare the simulated values with those obtained from the survey [22].

3.4. Experimental results

The validity of the building energy consumption calculated by the simulation software was verified to ensure the accuracy of the optimization algorithm. The correlation between the actual power consumption of the office building and the consumption calculated from simulation software was analyzed. The effectiveness of the values calculated by simulation software was validated according to the significance level of correlation. Table 3 demonstrates that the correlation coefficient was 0.969 between the measured power consumption of the building and the simulated consumption (Sig. = 0.001), indicating that the correlation between the measured and simulated power consumption was statistically significant. The improved particle swarm algorithm and two other optimization algorithms used for comparison utilized the simulated values obtained from PKPM-Energy software and Daysim software to optimize the arrangement of rooftop photovoltaic arrays.

Table 3. Correlation analysis between actual and simulated power consumption

Simulation duration	**One day**	**Three days**	**Five days**	**Seven days**	**Correlation coefficient**	**Sig.**
Actual power consumption/ kWh	2,652.34	7,957.36	13,260.58	18,564.98	0.969	0.001
Simulated power consumption/ kWh	2,647.57	7,945.87	13,249.54	18,557.69		

The annual building energy consumption was utilized as the fitness function. However, office buildings tend to have relatively high energy consumption levels. In order to facilitate a meaningful comparison, the value of annual building energy consumption was normalized during the optimization process. Fig. 2 illustrates the convergence curve of the three optimization algorithms during the optimization process. It can be observed that as the number of iterations increased, the fitness value decreased for all three optimization algorithms. Eventually, they converged to a stable state. The GA-optimized particle swarm algorithm achieved stability after approximately 16 iterations, and its stabilized fitness value was lower than that of the other two algorithms.

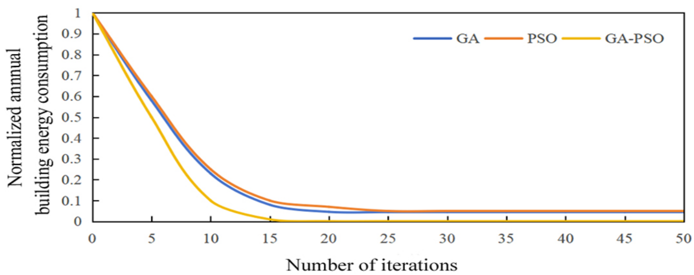

Fig. 2. Convergence curves of the three optimization algorithms in the optimization process

The photovoltaic array placement on concrete flat roofs was optimized using three different optimization algorithms, and the results are presented in Table 4. The optimization parameters of the photovoltaic array were obtained through the optimization algorithm and implemented in the simulation software to obtain the annual power consumption of the building. The annual solar radiation received per unit area of photovoltaic array was also obtained from the simulation software. Table 4 demonstrates that the different optimization algorithms yielded distinct photovoltaic array layout schemes, which differed from the initial scheme. Upon comparing the various schemes in the table, it is evident that the optimized schemes obtained through the three optimization algorithms outperformed the initial scheme in terms of annual solar radiation received per unit area and annual building energy consumption. Among the optimized solutions generated by the three optimization algorithms, the improved particle swarm algorithm performed the best, followed by the traditional algorithm and the GA.

Table 4. The initial scheme for rooftop photovoltaic arrays and the optimization schemes of three algorithms

	Initial scheme	**GA**	**Particle swarm algorithm**	**Improved particle swarm algorithm**
Width of photovoltaic panel/ m	1.00	1.06	1.10	1.12
Photovoltaic panel spacing/ m	4.0	3.8	3.4	2.9
The tilt angle of photovoltaic panels/ °	23	29	32	34
Annual solar radiation received per unit area kWh/m^2	193.9	210.3	211.4	239.2
Annual building energy consumption/ kWh	968104.16	921533.47	91147.32	889763.33

4. Conclusions

This paper briefly introduces BIPV and focuses on optimizing the arrangement of photovoltaic arrays on concrete flat roofs using the particle swarm algorithm. The performance of the particle swarm algorithm was enhanced through the integration of the GA. An experimental analysis was conducted on an office building at a joint salinization plant in Henan Province. The validity of the building energy consumption model constructed by PKPM-Energy software and Daysim software was initially verified. Subsequently, the GA, particle swarm algorithm, and improved particle swarm algorithms were compared. The building energy consumption model constructed by the simulation software exhibited a significant correlation with the actual building energy consumption, thus making it suitable for optimization algorithms. The improved particle swarm algorithm demonstrated the fastest convergence in the optimization process and achieved the lowest fitness value upon stabilization. All three optimization algorithms optimized the initial scheme. The improved particle swarm algorithm yielded the best result, followed by the traditional algorithm and GA.

References

[1] C. Liu, B. Luo, W. Wang, H.Y. Gao, Z.X. Wang, H.F. Ding, M.Q. Yu, and Y.Q. Peng, "Energy Management and Capacity Optimization of Photovoltaic, Energy Storage System, Flexible Building Power System Considering Combined Benefit", *Energy Engineering*, vol. 120, no. 2, pp. 541–559, 2023, doi: 10.32604/ee.2022.022610.

[2] A. Taer, T. Koyunbaba, and B.K. Kazanasmaz, "Thermal, daylight, and energy potential of building-integrated photovoltaic (BIPV) systems: A comprehensive review of effects and developments", *Solar Energy*, vol. 251, pp. 171–196, 2023, doi: 10.1016/j.solener.2022.12.039.

[3] J.M. Espeche, F. Noris, Z. Lennard, S. Challet, and M. Machado, "PVSITES: building-integrated photovoltaic technologies and systems for large-scale market deployment", *Proceedings*, vol. 1, no. 7, art. no. 690, 2017, doi: 10.3390/proceedings1070690.

[4] J. Piotrowska-Woroniak, "The photovoltaic installation application in the public utility building", *Ecological Chemistry & Engineering S*, vol. 24, no. 4, pp. 517–538, 2017, doi: 10.1515/eces-2017-0034.

[5] S. Conejos, M.Y.L. Chew, K. Tay, S. Tay, and S. Safiena, "Green maintainability assessment of building-integrated photovoltaic (BIPV) applications: lessons learnt", *International Journal of Building Pathology and Adaptation*, vol. 41, no. 2, pp. 320–346, 2023, doi: 10.1108/IJBPA-04-2019-0038.

[6] Y. He and M.A. Schnabel, "An approach for daylight calculation of a building integrated photovoltaic (BIPV) Facade", *Architectural Science Review*, vol. 61, no. 4, pp. 226–233, 2018, doi: 10.1080/00038628.2018.1470964.

[7] B. Zhang, R. Zhang, Y. Li, S. Wang, and F. Xing, "Ignoring the effects of photovoltaic array deployment on greenhouse gas emissions may lead to overestimation of the contribution of photovoltaic power generation to greenhouse gas reduction", *Environmental Science and Technology*, vol. 57, no. 10, pp. 4241–4252, 2023, doi: 10.1021/acs.est.3c00479.

[8] M. Bouzidi, H. Abdelkader, M. Smail, and V. Dumbrava, "Modeling of a photovoltaic array with maximum power point tracking using neural networks", *Applied Mechanics and Materials*, vol. 905, pp. 53-64, 2022, doi: 10.4028/p-ndl3bi.

[9] G. Zheng, J. Yao, Z. Tu, and X. Zhou, "Effect of building height on wind load characteristics of photovoltaic arrays", *Journal of Physics: Conference Series*, vol. 2399, art. no. 012003, 2022, doi: 10.1088/1742-6596/2399/1/012003.

[10] M. Etarhouni, M.B. Chong, and L. Zhang, "A novel square algorithm for maximising the output power from a partially shaded photovoltaic array system", *Optik*, vol. 257, art. no. 168870, 2022, doi: 10.1016/j.ijleo.2022.168870.

[11] K. Drabczyk, G. Kulesza-Matlak, P. Sobik, and O. Jeremiasz, "Photovoltaic modules with a modified ETFE foil for BIPV applications", *Opto-Electronics Review*, vol. 71, art. no. e147914, 2023, doi: 10.24425/opelre.2023.147914.

[12] N. Skandalos and D. Karamanis, "An optimization approach to photovoltaic building integration towards low energy buildings in different climate zones", *Applied Energy*, vol. 295, art. no. 117017, 2021, doi: 10.1016/j.apenergy.2021.117017.

[13] L.G. Teka, M. Zadshir, and H. Yin, "Mechanical analysis and design of large building integrated photovoltaic panels for a seamless roof", *Solar Energy*, vol. 251, pp. 1–12, 2023, doi: 10.1016/j.solener.2022.12.045.

[14] J. Wajs and J. Lukasik, "Assessment of the impact of jet impingement technique on the energy efficiency of air-cooled BIPV/T roof tile", *Archives of Thermodynamics*, vol. 45, no. 2, pp. 5–18, 2024, doi: 10.24425/ather.2024.150847.

[15] Y. Elaouzy and A.E. Fadar, "Investigation of building-integrated photovoltaic, photovoltaic thermal, ground source heat pump and green roof systems", *Energy Conversion and Management*, vol. 283, art. no. 116926, 2023, doi: 10.1016/j.enconman.2023.116926.

[16] L. Zhu, B. Wang, and Y. Sun, "Multi-objective optimization for energy consumption, daylighting and thermal comfort performance of rural tourism buildings in north China", *Building and Environment*, vol. 176, art. no. 106841, 2020, doi: 10.1016/j.buildenv.2020.106841.

[17] H. Aria and H. Akbari, "Optimisation of night-time ventilation parameters to reduce building's energy consumption by integrating DOE2 and MATLAB", *International Journal of Sustainable Energy*, vol. 34, no. 8, pp. 516–527, 2015, doi: 10.1080/14786451.2014.907802.

[18] M.B. Carutasiu, C. Ionescu, and H. Necula, "The influence of genetic algorithm parameters over the efficiency of the energy consumption estimation in a low-energy building", *Energy Procedia*, vol. 85, pp. 99–108, 2016, doi: 10.1016/j.egypro.2015.12.279.

[19] X. Wang, W. Cai, J. Lu, Y. Sun, and L. Zhao, "Model-based optimization strategy of chiller driven liquid desiccant dehumidifier with genetic algorithm", *Energy*, vol. 82, pp. 939–948, 2015, doi: 10.1016/j.energy.2015.01.103.

[20] M. Kaliappan, S. Augustine, and B. Paramasivan, "Enhancing energy efficiency and load balancing in mobile ad hoc network using dynamic genetic algorithms", *Journal of Network & Computer Applications*, vol. 73, pp. 35–43, 2016, doi: 10.1016/j.jnca.2016.07.003.

[21] Q. Deng, X. Gao, H. Zhou, and W. Hu, "System modeling and optimization of microgrid using genetic algorithm", *Energy & Energy Conservation*, vol. 1, pp. 540–544, 2015, doi: 10.1109/ICICIP.2011.6008303.

[22] S. Tsuchida, Y. Tsuno, D. Sato, T. Oozeki, and N. Yamada, "Optical simulation of the effect of partial shades cast by mounting structures on the output power of bifacial PV array", in *Proceedings of the Annual Meeting of the Japan Photovoltaic Society*. The Japan Photovoltaic Society, 2022, pp. 32, doi: 10.57295/jpvsproc.2.0_32.

Received: 2024-07-12, Revised: 2024-09-13