Future Cities and Environment
ISSN 2363-9075 Volume 12 (2026)

https://doi.org/10.70917/fce-2026-021
Article

Impact of Fixed External Shading Devices on Energy Consumption of Green Educational Building in Hot Summer and Warm Winter Climate Region

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Abstract: Through establishing a set of criteria systems, green building assessment provides specific and clear regulations for various aspects to guide the practice of green building. As an effective energy-saving measure, the external shading design can play a better role in reducing the transmittance of glass receiving solar radiation, as well as lowering the heat absorbed by the external enclosure structure, to achieve better indoor thermal environment comfort. Hence, the impact of fixed external shading facilities on their thermal and energy-saving performance has been highlighted in the existing research. However, there is a lack of comprehensive assessment methods for this passive energy-saving technique in either scientific research or practical evaluation standards, covering various aspects of energy conservation, economy, and environment. The intention of this study is to assess the impact of fixed external shading designs on energy consumption based on a green educational building project within hot summer and warm winter climate region in China. To fulfil this aim, a case study of a kindergarten building located in Shenzhen and a Chinese local building energy-saving simulation software BESI 2024 have been applied. The energy-saving rate of building envelope has been adopted as assessed criteria. Four types of fixed external shading design have been considered, e.g., horizontal shading, vertical shading, baffle-type shading, and integrated shading. Simulation results generated the best fixed external shading strategy among 21 proposed fixed external shading cases, which is 'Integrated shading I' with 6.03% of energy-saving rate of building envelope. This paper not only demonstrates details on how to apply BESI for building energy-saving simulation, but also provides data support for subsequent comprehensive assessment analysis on the best choice of fixed external shading design.

Keywords: fixed external shading; energy-saving; hot summer and warm winter; green building

1. Introduction

Green building has been internationally defined as a building that provided a healthy and comfortable activity space for humans, while making the most efficient use of resources and minimizing the impact on the environment (Li, 2008). Appropriately evaluating the energy consumption impact of different building components is critical for the energy efficiency structural design and building sustainable development. As an effective passive energy-saving measure, the external shading facilities can block direct solar radiation through windows, reducing heat transfer within the buildings and thus can help with thermal comfort adjustment as well as glare reduction (Kim *et al*., 2012; Khoroshiltseva, Slanzi and Poli, 2016). Consequently, lower the energy consumption of the cooling systems in summer, especially in the hot summer and warm winter climate region. Hence, in the early stages of building design, it is important for architects and designers to consider how to choose the appropriate shading design and their corresponding assessment methods.

Scholars around the world have carried out relevant research on the impact of external shading facilities, such as energy-saving effect (Liu, 2011; Wan, 2012), indoor thermal and humid environment (Yang, Liang and Wang, 2016; Wang, 2021), lighting effect (Wang, 2020; Jiang, 2021), visual effect (Zhang, 2016; Jiang, 2020), ventilation effect (Liu, 2011; Wang, 2013), etc. According to structural characteristics, the external shading design is divided into three categories, including fixed shading, movable shading, and green shading. Due to the low construction cost, the fixed external shading design is the shading measure that being firstly considered during the building design stage, and currently widely used in the Chinses major cities. Firstly, the primary research is about the energy-saving effects, finding the impact of fixed shading models on building energy consumption. For example, Liu (2010) carried out energy consumption simulation of fixed horizontal wing-shaped sunshades for a public building by DeST. The impact of different building orientations and various widths of sunshade on building energy efficiency has been analysed. Lu (2011) established an energy-saving building model by using BECS, to compare the power consumption of cooling system regarding different forms of reinforced concrete fixed external shading components and glass made fixed louver shading devices for a residential building in Guangzhou. Secondly, there are some studies on other building performance impact, such as lighting, ventilation, etc., investigating the impact of various shading designs on buildings. Liu (2011) used Ecotect, Phoenics, Daysim and DeST to explore the impact of the protrusion coefficient regarding the horizontal and vertical shading components on luminous flux, illumination ratio, ventilation volume, lighting energy consumption and air conditioning energy consumption for residential buildings in Guangzhou city. Wang (2013) conducted field measurement and simulation by using Ecotect and Phoenics. The effects of solar radiation, lighting, and ventilation regarding four types of fixed external shading devices have been analysed. Yang (2019) investigated the energy-saving and lighting effect of 24 fixed external shading designs, an office building in Nanchang area has been demonstrated by using the software of BESI 2018 and DALI 2018 based on the GBSWARE platform. Zhong (2021) constructed a building model based on an educational building in Chengdu, to investigate the energy-saving and lighting impact of the various fixed external shading strategies by using BESI 2020 and DALI 2020. Zhang (2022) established three types of classroom models based on the educational buildings in Zhuzhou. The energy-saving and lighting effects of various fixed external shading strategies for the three models have been analysed by using BESI 2020 and DALI 2020. Suman *et al*. (2025) compared three building models on mixed-mode ventilation, shading (horizontal overhangs) and appropriate materials with the base mechanical ventilation model of an office building. The differences in indoor air temperature, heating/cooling loads, energy use, thermal comfort and indoor CO_2 values amongst Hyderabad, Bogota, Johannesburg, Bangkok, and Chengdu have been investigated, to determine their corresponding best passive strategy for each city.

However, the above studies lacked economic and environmental consideration of fixed external shading strategies, and most of them were conducted based on the existing buildings, rather than the buildings at the design stage. This can be largely attributed to the difficulty in cost data collection regarding the external shading facilities, the hardness of determining the economic and environmental assessment methods and corresponding criteria, etc. It has been further inferred that there is a lack of awareness among researchers about the comprehensive assessment regarding the fixed external shading devices, with the overall consideration of energy-saving, economic and environmental influence on buildings.

The *Assessment Standard for Green Building (GB/T50378-2019)* has been promulgated by the Ministry of Housing and Urban-Rural Development (MOHURD) in 2019, as the latest specification and standard for green building evaluation in China. However, it is worth noting that ASGB-2019 has not yet formulated corresponding qualitative or quantitative assessment method and tools for the fixed external shading facilities, e.g., regulatory provision, scoring methods, weighting system, etc., and thus cannot directly reflect the energy-saving impact of the external shading equipment on buildings in the practical green building assessment report, let alone their economic and environmental performance.

The whole research project aims to provide a multi-criteria assessment framework for the fixed external shading devices. To fulfil the aim, the paper is intended to assess the impact of fixed external shading designs on energy consumption, and thus provide data support related to energy-saving performance for the subsequent multi-criteria assessment and analysis. This paper is structured into five sections: introduction, methods, results presenting simulation analysis, discussion, and the fifth section demonstrating the conclusions and further research work considering the application of comprehensive assessment methods for the external shading design.

2. Methods

2.1. Energy-saving Assessment

This paper proposes a method for the assessment of various fixed external shading designs on building energy consumption. A green educational building project in Shenzhen located in hot summer and warm climate region was adopted for case study. Developed by Beijing GBSWARE Co., Ltd., BESI is a professional Chinese local simulation software that provides energy consumption and energy-saving rate calculation for buildings. This software is built on the AutoCAD platform and based on 3D modelling. Through a series of thermal settings, BESI automatically generates a comparison building based on the designed building, calculates the annual cooling and heat consumption, as well as the heating, cooling, and lighting power consumption regarding the reference building and designed building, thus generates the energy-saving rate. Based on the DOE-2 (Department of Energy-2) core, it can seamlessly integrate with building energy-saving models, accurately and quickly obtaining dynamic ideal loads (GBSWARE, 2025). In practice, BESI can be used as a supporting software for energy efficiency certification and green building evaluation. Compared with the earlier versions, BESI 2024 has been upgraded, including temperature control period, refinement of fresh air schedule, expansion of system terminal equipment, and the upgrade of the automatic algorithm in the machine room, etc (GBSWARE, 2024a). Due to the improvement of calculation function, especially the support for the calculation of building energy-saving rate stipulated in the new standard, this paper applied BESI 2024 based on GBSWARE platform (GBSWARE, 2024b) to perform energy-saving simulation and analysis.

In this paper, 21 possible fixed external shading solutions were designed for the building project. The annual comprehensive heating and cooling energy consumption of each shading strategy was calculated, thus estimated the values of energy-saving rate of building envelope (Φ_{ENV}). This value was used as energy consumption assessed criteria in this study, to determine the optimum shading solution when considering their energy-saving effect. The energy-saving effect was assessed without considering the shading effect from the surrounding buildings, since it was to estimate the studied building's actual full potential for energy consumption.

According to the *Standard for Green Performance Calculation of Civil Building (JGJ/T 499-2018)*, the proportion of building heating and cooling load reduction is determined by calculating the value of energy-saving rate of building envelope. The energy-saving rate of building envelope (Φ_{ENV}) refers to the percentage by which the annual heating and cooling energy consumption of designed building is reduced compared to the reference building, through improving the thermal performance of the building envelope. 3D models of a reference building and a design building are established at the same time in BESI 2024 system based on this specific calculation method. The calculation formula for the energy-saving rate of building envelope is shown in Equation (1) (MOHURD, 2018):

$$\Phi_{ENV} = \left(E_{bld,ref} - E_{bld,des}\right) / E_{bld,ref} x100\% \tag{1}$$

Where:

Φ_{ENV} = the energy-saving rate of the building envelope;

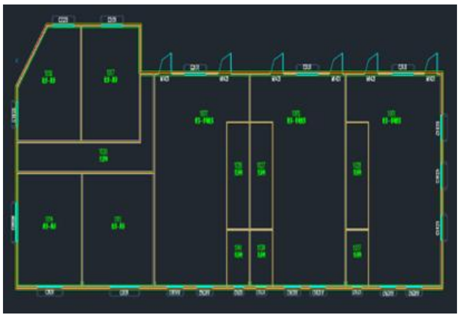
$E_{bld,ref}$ = the annual comprehensive heating and cooling energy consumption for reference building (kWh);

$E_{bld,des}$ = the annual comprehensive heating and cooling energy consumption for designed building (kWh).

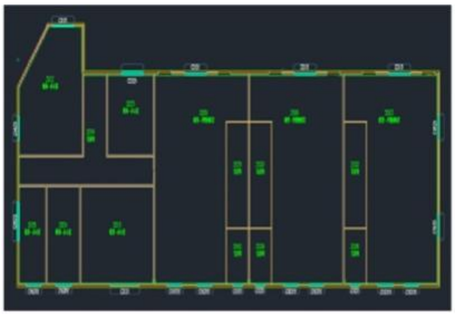
The above values can be collected through dynamic simulation by BESI 2024 (GBSWARE, 2024a).

2.2. Case Study

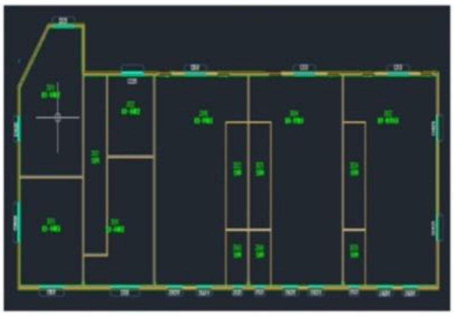
Thermal Design Code for Civil Building (GBT50176-2016) divides the climate regions of China into five main categories (MOHURD, 2016). The studied educational building project is located in the Pingshan District of Shenzhen, a city in the southern area (Area B) of the hot summer and warm winter region in China. The building type is Category A public building (DOHURD-GD, 2021). It is a hypothetical three-story kindergarten building framed in structural steel, which is in design and evaluation stage. This project has been certified as One-star green building in the green building pre-evaluation stage in Shenzhen. The building is located at 21°4' north by east, with a height of 11.70m from foundation to roof and a plan area of 2,138.25 m^2. The latitude is 23°30' North and the longitude is 113°83' East. The floor plan of the building is shown in Figure 1. According to the initial construction parameters of the 3D model (see Figure 2) in BESI 2024, the exterior wall solar radiation absorption coefficient of the building is 0.60, the roof solar radiation absorption coefficient is 0.70, and the shape coefficient is 0.27. The size parameters of the windows on each building façade and their window to wall ratio are listed in Table 1 and Table 2. The height of windows is 600mm. The U-value of the studied building is 0.2126 W/(m^{2}K) for roof, 0.3624 W/(m^{2}K) (Brick wall) and 0.6127 W/(m^{2}K) (Thermal bridge) for external wall, and 2.28 W/(m^{2}K) for window. The above U-values meet the requirements of the U-value limit regarding the building envelope listed in the standard of *Design Code for Energy Efficiency of Public Buildings SJG 44-2018* (SMBHC, 2018). As shown in Figure 2, the external shading type for the building is integrated shading. The protruding length of its horizontal shading board is 500mm and the vertical shading board is 200mm (see the base case of Integrated shading A listed in Table 3. Dimensions and energy-saving performance of 21 fixed external shading strategies for the studied educational building.). Simulation results from BESI showed that the energy-saving rate of building envelope regarding Integrated shading A was 5.27%. However, further discussion is needed to investigate which fixed external shading design can achieve the maximum energy-saving effect based on the studied building model.



(a) First floor



(b) Second floor



(c) Third floor

Figure 1. Floor plan of the studied educational building.

(a)

(b)

Figure 2. 3D model of the studied educational building.

Table 1. Size parameters of the windows on each façade of the studied educational building.

Orientation of façade	Number	Size	Quantity	Area of a single window	Total area of windows
East (140.75)	C1031	1.00*2.50	9	2.50	22.50
	C1631W	1.64*2.50	20	4.10	82.00
	C2631	2.60*2.50	2	6.50	13.00
	C3131	3.10*2.50	3	7.75	23.25
West (86.44)	C2325	2.31*2.50	3	5.78	17.34
	C3131	2.31*2.50	12	5.78	69.36
South (31.80)	C1625	1.64*2.50	3	4.10	12.30
	C2625	2.60*2.50	3	6.50	19.50
North (24.60)	C1625	1.64*2.50	6	4.10	24.60

Table 2. Window to wall ratio on each façade of the studied educational building.

Orientation of façade	Area of windows (m^2)	Area of wall (m^2)	window to wall ratio
South	31.80	161.45	0.20
North	24.60	214.11	0.11
East	140.75	542.20	0.26
West	86.70	566.29	0.15
Total	283.85	1484.05	0.19

2.3. Boundary Condition Setting

2.3.1. Building Climate Conditions

Energy consumption varies significantly between buildings located in different climatic regions. The weather data of Shenzhen is used as the simulation climate basis for the building model of a green educational building in the hot summer and warm winter region, China. The average temperature is between 25 °C and 29 °C in July, and greater than 10 °C in January. Due to the higher requirements for building shading and heat insulation, consideration is focused on cooling needs in summer when designing energy-saving buildings in this specific area, rather than heat preservation in winter (MOHURD, 2012; Lin, Liu and Wang, 2020). This subsequent simulation analysis is only conducted to calculate the value of the energy-saving rate of building envelope regarding various external shading designs under cooling conditions in summer.

2.3.2. Simulation Parameter Setting

In the energy consumption simulation model, the cooling period was set from 1st May to 31st October between 8:00 and 18:00 (excluding summer vacation period from 15th July to 25th August), through investigation of the summertime among relevant studies (Zhuo, 2015) and the opening time with a local kindergarten. The schedules for heating and cooling, personnel activities, lighting, and equipment operation were configured in accordance with the *Standard for green performance calculation of civil building (JGJ/T 499-2018)*. As consideration focused on the overall energy-saving effect of a certain shading design, only the dimension parameters of the proposed shading strategies were set in BESI.

2.4. Design Configurations of Fixed External Shading Devices

Four types of fixed external shading designs were considered, namely horizontal shading, vertical shading, baffle-type shading, and integrated shading (Zeng, 2018). Through relevant literature review (Ge and Ren, 2021; Liu, 2022) and further investigation with the local building structural engineer, the commonly used protrusion length on each building façade regarding the horizontal shading board ranged from 500mm to 1000mm, the vertical shading board ranged from 200mm to 600mm, and the length of the shading baffle ranged from 500mm to 800mm. The legend of fixed external shading designs is illustrated in Figure 3. The dimensions and 3D models of 21 fixed external shading strategies are illustrated in Table 3 and Figure 4.

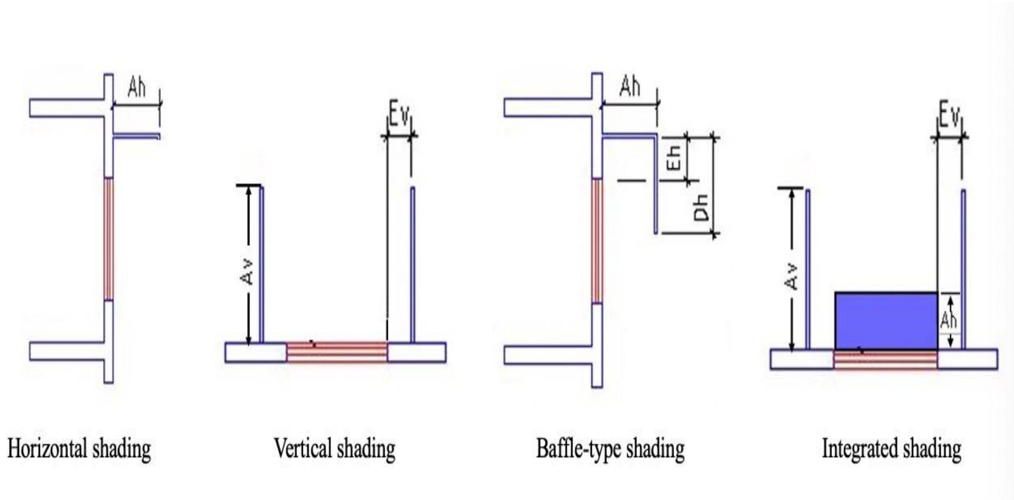


Figure 3. Legend of fixed external shading designs for the studied educational building.

Table 3. Dimensions and energy-saving performance of 21 fixed external shading strategies for the studied educational building.

No.	External shading strategies	Ah (mm)	Av (mm)	Dh (mm)	$E_{bld,des}$ (kWh)	Φ_{ENV}
1	Horizontal shading A	500	0	0	492,311	4.99%
2	Horizontal shading B	750	0	0	491,393	5.16%
3	Horizontal shading C	1000	0	0	490,663	5.30%
4	Vertical shading A	0	200	0	493,453	4.77%
5	Vertical shading B	0	400	0	492,175	5.01%
6	Vertical shading C	0	600	0	491,186	5.20%
7	Baffle-type shading A	500	0	500	489,664	5.50%
8	Baffle-type shading B		0	800	487,783	5.86%
9	Baffle-type shading C	750	0	500	488,800	5.66%
10	Baffle-type shading D		0	800	487,302	5.95%
11	Baffle-type shading E	1000	0	500	488,310	5.76%
12	Baffle-type shading F		0	800	487,051	6.00%
13	Integrated shading A	500	200	0	490,845	5.27%
14	Integrated shading B		400	0	489,648	5.50%
15	Integrated shading C		600	0	488,461	5.73%
16	Integrated shading D	750	200	0	489,892	5.45%
17	Integrated shading E		400	0	488,600	5.70%
18	Integrated shading F		600	0	487,556	5.90%
19	Integrated shading G	1000	200	0	488,984	5.63%
20	Integrated shading H		400	0	487,783	5.86%
21	Integrated shading I		600	0	486,909	6.03%

* where Ah is the protruding length of horizontal shading board. Eh is the distance between the horizontal shading board and the upper edge of the window (Eh=0). Av is the protruding length of vertical shading board. Ev is the distance between the vertical shading board and the edge of the window (Ev=0). Dh is the length of the vertical baffle.

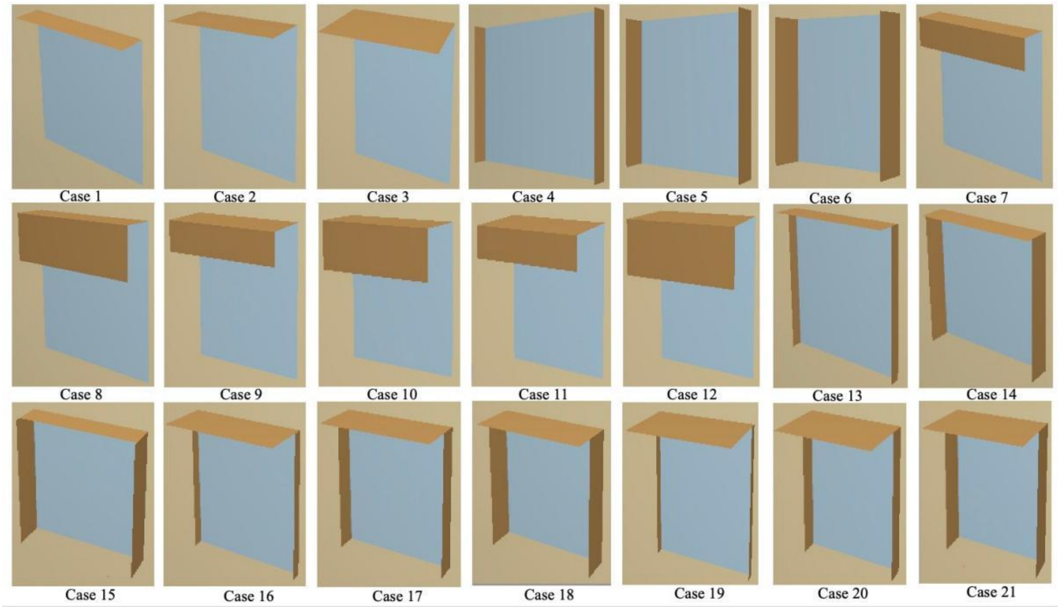


Figure 4. Screenshot of 3D model regarding fixed external shading cases for the studied educational building.

3. Results

According to the Equation (1), the energy-saving rate of building envelope (Φ_{ENV}) regarding the 21 proposed fixed external shading strategies have be calculated (see Table 3). Calculation on the reference building case without any shading device showed that the total heating and cooling energy consumption in a year, $E_{bld,ref}$, is 518,148 kWh. As listed in Table 3, the energy-saving performance of each shading type is generated. As for horizontal and vertical shading design, the protruding size ranges from 500mm to 1000mm and from 200mm to 600mm respectively. As for baffle-type shading design, the protruding size of horizontal shading board ranges from 500mm to 1000mm, whilst the length of vertical baffle ranges from 500mm to 800mm. As for integrated shading design, the protruding size of horizontal shading board ranges from 500mm to 1000mm, whilst the protruding size of vertical shading board ranges from 200mm to 600mm.

Among the cases of horizontal and vertical shading design, as the protruding length increases, the building's annual comprehensive heating and cooling energy consumption ($E_{bld,des}$) shows a downward trend. When the horizontal protruding length of horizontal shading design reaches 1000mm (or vertical protruding length of vertical shading design reaches 600mm), $E_{bld,des}$ reduces to the minimum value. On the contrary, as the horizontal (vertical) protruding length increases, the energy-saving rate of building envelope (Φ_{ENV}) shows an upward trend. When the horizontal protruding length reaches 1000mm (or vertical protruding length reaches 600mm for vertical shading design), Φ_{ENV} increases to the maximum value. Hence, 1000mm and 600mm are the best choices among the horizontal and vertical shading strategies respectively, to ensure the lowest heating and cooling energy consumption and the highest energy-saving effect.

Among the cases of baffle-type and integrated shading design, when the horizontal protrusion size is constant, the value of building's annual comprehensive heating and cooling energy consumption ($E_{bld,des}$) decreases as the length of the vertical baffle (or vertical shading protrusion for integrated shading design) increases, while the value of the energy-saving rate of building envelope (Φ_{ENV}) increases. When the length of the vertical baffle (or vertical shading protrusion for integrated shading design) is constant, the value of annual heating and cooling energy consumption ($E_{bld,des}$) decreases as the horizontal protruding size increases, while the value of the energy-saving rate of building envelope (Φ_{ENV}) increases. Therefore, in the process of selecting the best protruding size of the baffle-type and integrated shading design, if only consider the values of building heating and cooling energy consumption or the energy-saving rate of building envelope, the maximum length of the horizontal shading board and the vertical baffle (or vertical shading board) should be both considered. The best baffle-type shading design is the case with horizontal protruding length of 1000mm and vertical baffle length of 800mm. The best integrated shading design is the case with a horizontal protruding length of 1000mm and a vertical protruding length of 600mm. This is to minimize the building's heating and cooling energy consumption or maximize the energy-saving effect.

It can be known from the analysis results listed in Table 3 that, among the 21 proposed fixed external shading designs, the Integrated shading I has the best energy-saving effect, of which protruding size of horizontal shading board is 1000mm and vertical shading board is 600mm. The annual heating and cooling energy consumption of this best shading strategy is 486,909kWh, and the value of the energy-saving rate of building envelope is 6.03%, 12.6% higher than the base external shading case named Integrated shading A.

4. Discussion

Further analysis of the above results reveals that there is an increase of 0.062% in the energy-saving rate of building envelope per 100mm increase in horizontal protrusion length regarding the horizontal shading design, and an increase of 0.108% in the energy-saving rate of building envelope per 100mm increase in vertical protrusion length regarding the vertical shading design. The reason why vertical shading provides a higher energy-saving rate increase per 100mm (0.108%) than horizontal shading (0.062%), possibly due to the building's orientation and window distribution (e.g., large east/west facades). Further analysis and discussion on the changes regarding the energy-saving rate of building envelope under different scenarios may be needed, such as selecting different protruding dimensions of shading devices on the façade of a single orientation, or only setting windows on the façade of a certain orientation with different shading protrusion, window sizes and quantity (e.g., set windows only on the east-facing façade or west-facing facade).

Further, through blocking solar radiation heat and light through physical facilities, the best shading design of this study can reduce indoor heat acquisition, lower the indoor temperature in summer, reduce the usage duration and energy consumption of cooling system, thus achieve a 6.03% energy-saving effect of the entire building. Apart from different external shading designs, other energy-saving measures for the enclosure structures, such as using different wall insulation materials (e.g., rock wool, glass wool, polystyrene plastic, polyurethane foam plastic, polyethylene plastic, and composite wall materials, etc), adopting different window designs (e.g., increasing the number of window glass layers, applying transparent polyester films, installing door and window sealing strips, using low-E glass, etc.), using different roof shading and heat insulation technologies or curtain wall technologies, etc., can also help to reduce the overall U-value of the exterior wall and achieve energy-saving effect. However, they are beyond the scope of this research.

Apart from energy conservation, lighting is also a critical factor that needs to be considered when designing educational buildings. The design of a comfortable indoor lighting environment not only enhances visual comfort and helps improve learning outcomes of students, but also reduces the usage time of lighting equipment, thereby lowering the building energy consumption. Appropriate external shading design not only contributes to energy conservation but also has an impact on indoor lighting and glare. How to select a suitable external shading design that is both energy-efficient and has good lighting effects requires future in-depth research on the comprehensive energy consumption of lighting and heating, with consideration of appropriate evaluation indexes and methods.

5. Conclusion

This paper presents a case study to examine 21 fixed external shading strategies planned for a three-storey educational building framed in structural steel, which is a One-star certified green kindergarten project in hot summer and warm winter climate region, China. Simulations were carried out by using BESI 2024 to assess the energy-saving effect of the proposed shading strategies which classified into four shading types (e.g., horizontal shading, vertical shading, baffle-type shading, and integrated shading). Based on the assessment results, the assessed criteria named energy-saving rate of building envelop (Φ_{ENV}) regarding each shading strategy is generated. This is based on the changes of the dimensions with respect to the shading alternatives. Simulation results reveal that the best shading strategy with the best energy-saving impact on buildings is Integrated shading I, of which protruding size of horizontal shading board is 1000mm and vertical shading board is 600mm. The annual heating and cooling energy consumption of this best shading case is 486,909 kWh, and its energy-saving rate of building envelope is 6.03%, 12.6% higher than the base external shading case of Integrated shading A.

The energy-saving rate of building envelope is mainly related to the design of the external shading, the protruding length of the shading boards and the length of the shading baffle. Various energy-saving effects will be generated by different types of external shading designs. In the same type of fixed external shading devices, the energy-saving rate of building envelope is directly proportional to the protruding length of the sunshade and the length of the baffle. Further analytical results indicate that there will be an increase of 0.062% in the energy-saving rate of building envelope for every 100mm increase in horizontal protrusion length regarding the horizontal external shading design, whilst an increase of 0.108% in the energy-saving rate of the building envelope for every 100mm increase in vertical protrusion length with respect to the vertical external shading design.

The limitation of this study lies in: 1) Language limitation of the operating interface of Chinese simulation software which limits its global promotion. 2) Simple building case that considers fewer influencing factors during simulation process. 3) Lacking consideration of the protrusion length optimization regarding the shading board suitable to different building orientations. 4) Limitation of climate region without considering heating consumption. 5) Lacking sensitivity analysis or discussion of uncertainty as there may be potential error in the simulation results. 6) Lacking consideration of indoor visual comfort and ventilation effects of external shading facilities when choosing the optimal shading design. Future work will not only overcome those limitations but also be devoted to applying different economic and environmental analysis techniques in combination with energy dynamic simulations and shading material consideration, as well as to proposing multi-criteria assessment approach for the selected external shading strategies. Furthermore, future analysis could be devoted to refining the assessed criteria included and extending the study to other sustainable construction components.

Funding

This research received no external funding.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Author Contributions

Danxia Qiu, wrote the main manuscript text and prepared all figures. Liben Jiang and Andrew Fsadni supervised the project and reviewed the manuscript. Qingnian Wang reviewed the grammar. Yu Qin provided technical support. All authors approved the manuscript.

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