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Daylighting Performance Design for Art Studios of Old Factory Renovation Buildings in Subtropical Regions

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Abstract

In the subtropical zone of China, a large number of old factory buildings rich in industrial historical and cultural value have been transformed into art studios. In the existing research on building renovation, there are still problems such as insufficient lighting, low uniformity, and ignoring the effect of glare in the lighting environment of buildings after transformation. To fill this research gap, this paper provides a daylighting design strategy for these factory buildings in subtropical zones to ensure that the transformed art studios can offer an excellent indoor daylighting environment. Through the control variable method, the window-to-wall ratio, the form of external windows, and the visible light transmittance of glass are set with quantitative and variable values, and a design strategy that meets the requirements of international general daylighting standards is obtained step by step through the simulation. The daylight factor, uniformity, daylight autonomy, and dynamic glare probability are used in this research process to measure whether the daylighting strategy meets the daylighting requirements of the CIBSE Lighting Guide for art studios. The results show that the average indoor lighting coefficient can be increased from 1.29 to 6.18, and the minimum value of the lighting coefficient can be increased from 0.4 to 4.4 by enlarging the windowed wall ratio from 1:30 to 1:3, using the combination method of the horizontal window, skylight and skylight recommended by the analysis results, and selecting veneer glass with 88% transmittance. This allows for better uniform lighting inside the building and reduces glare. This conclusion can support the lighting performance design of industrial buildings in the future.

Keywords

Old Factory, Renovation Building, Art Studio, Daylight Performance

1. Introduction

1.1. History and Type of Old Factory Buildings

Generally, humans rely on and resonate with their history and culture, especially in more iconic realms such as architecture. Many old industrial parks were built and then reserved during the industrial revolution, since almost every city in every country has experienced a period of large-scale industrial production. After upgrading and transforming the industrial chain, most factories and industrial parks have lost their practical value. However, as outstanding work created in the industrial era, these buildings are a record of the development of urban industrial civilization and represent a characteristic of the period. This historical imprint and basis provide future generations with an excellent opportunity to witness the prior development of urban civilization and technology [1].

The old industrial buildings in China played a vital role in the development of industrial cities in the 20th century, reflecting the technological level and cultural orientation at that time. These buildings also bear the memories of urban builders and workers from a sociocultural perspective, as red brick walls and black iron frames arouse the memories and aspirations of that generation. Indeed, old industrial buildings have an indelible historical and cultural significance in the process of urban development [2].

In the 21st century, China has gradually attached importance to the transformation and reuse of old industrial buildings, including the conservation of resources and the protection of the historical context of the original buildings. Many excellent cases have emerged. For example, **Figure 1** shows a series of cultural and creative projects, such as the Beijing 798 Factory Art Zone, the Guangzhou Redtory, and the renovation of the TIT Creative Park [1]. Not only

(a)

(b)

Figure 1. Case studies of old factory renovation. (a) Beijing 798 Art Zone. (b) Guangzhou Redtory.

does this type of transformation contain a specific historical and cultural value, but many current buildings could also possess more practical functions after conversion. However, in the past, during the transformation process, more attention was given to the design of functional spaces, while the equally important research on lighting performance was usually ignored.

According to the building layouts, the types of old factory buildings can be categorized as follows: 1) single-storey factories with large factory areas, large column grids, and a complex section layout; 2) multiple-storey factories with simple structures, small column grids, vertical transportation, and horizontal windows; 3) mixed-storey factories combining the single-storey and multiple-storey features.

Construction times can be categorized into early-stage and modern [3]. Early-stage indicates a building built before WWII, they are few in number but have high preservation value. This type of building should be renovated with caution; the renovation strategy has limitations. Modern indicates factory buildings built after WWII, which are numerous and better suited for renovation than early-stage factories. It is evident that the modern factories are more suitable for robust renovation and have higher economic efficiency and flexibility.

According to the space, old factory buildings can be categorized into one of three types, as shown in **Figure 2** [3]: 1) Large-span factories have lofty inner spaces, and the supporting structures are typically giant steel frames without columns. These buildings were usually built for primary machine production and heavy industry. 2) Routine factory buildings are relatively lower than large-span ones but broader, and they were typically used for light industry. 3) Specific factory buildings have a special shape, typically reflecting some specific function or feature.

As the tall structures and spaces of large-span factories are more suitable for reconstruction into art studios, this study focuses on large-span factory types.

1.2. Current Daylighting Performance Problem in Renovation

There is a fundamental distinction between how to describe light scientifically from what humans see. According to Tregneza, daylight can be pictured by scientific parameters such as "luminous flux; as a luminance distribution; as radiant energy that varies in the spectrum, time and direction" [4]. While what we

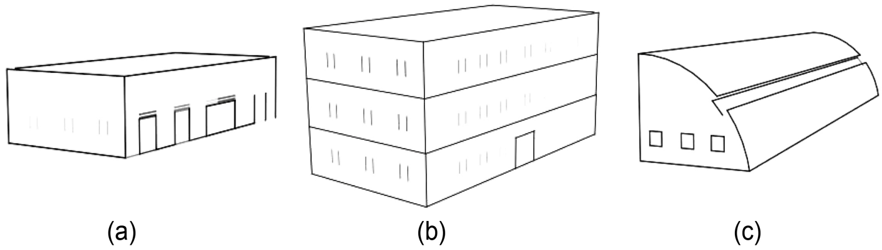


Figure 2. The types of factory buildings. (a) Large-span. (b) Routine. (c) Specificity.

can preserve is the "pattern of brightness", this is not a common sensation. For example, when we look outside, we see a view; when we enter a room, we see walls, ceiling and floor, and all the things inside the room [4] [5] [6]. The vision we have is not only what we see with our eyes but also what it means to us, affected by "our individual experiences and expectations," and "no two people will 'see' the things completely identical in one room" [4] [6]. Moreover, our perception of the environment depends not only on visualization but also on physical parameters such as acoustics and temperature, which are also related to the sociological condition [5] [6].

The daylighting performance of current renovation projects is uneven. Some can create a perfect daylighting condition, while others suffer from several daylighting design problems during transformation.

1.2.1. Lack of Daylight

Due to the unique structural and illuminance conditions of old industrial buildings, a daylighting strategy should be reconsidered when beginning a remodelling effort [7].

The original structure of old industrial buildings generally featured small and narrow windows. However, some owners or designers of old factory buildings chose to keep the initial window size for illuminance, which may not reach the daylighting requirement when given a new function. Even with some windows fixed on the south façade, daylight cannot penetrate a deep factory space. Therefore, during the renovation of old factory buildings, the size of the windows should be appropriately increased through a proper method.

1.2.2. Nonuniform Daylighting Performance

The position and orientation of windows can affect the uniformity of daylighting performance in renovation design. In the current art studio renovation projects occurring in old factory buildings, many select a single window type, such as a small horizontal window, without considering design, leading to nonuniform daylighting performance of the interior space and daylight failing to arrive at a suitable area in need of light [8].

Multiple window types can solve this problem by installing clerestories or skylights to supplement the insufficient light space and ensure that the illuminance performance is more uniform and stable.

1.2.3. Potential Glare Problem

During renovations, some designers have blindly enlarged the window size to maximize daylighting efficiency without carefully considering the potential glare problem of daylighting performance. However, art studios prefer diffuse sunlight rather than intensive and directional sunlight. In the 798 Art District, the extensive glazing area can provide enough daylight for the interior environment. However, a potential glare problem also emerged, especially on sunny days. In some cases, changing the visual transmittance of glazing and adding shading or a diffusion device can alleviate and even solve this problem [9].

1.3. Research Objectives

As the urban environment changed, the importance of industrial legacy buildings has gradually become prominent. Not only should the significance to the city be limited to pure protection, but can play a new role in order to meet the current needs after the original function is demolished. In this case, an art studio transformed by an old factory is one of the sustainable development ways, combining the historical architectural form with modern civilization.

This research on the lighting strategy for the renovation of the old factory building, combined with the scientific simulation and verification tools and based on the CIBSE standard. To provide a relatively complete set of art studios for the renovation of old factory buildings and even other buildings with different functions, ensuring those transformed buildings could meet the lighting requirements of the current users and have a good performance in terms of illumination, uniformity and glare control.

2. Methodology

2.1. Research Object

The research on reconstructing old factory buildings is based on regional characteristics, including climate and building zoning. Due to the vast land and diverse climate changes in China, the impact of different climatic characteristics should be taken into consideration. In general, the current old factory buildings in China are mainly located in developed cities in eastern China. East China is primarily a subtropical climate zone, so this paper specifically studies the subtropical climate zone where small manufacturers are concentrated. The building examined in this study is the Nanhai Machine Factory in Guangzhou, a typical small industrial workshop that will become an art studio after further transformation.

2.2. Research Criteria

Compared to other standards and assessments, **Table 1** shows that the CIBSE is more specific in many areas, which have different daylight requirements for different space functions such as the index of daylight factor, annual illuminance and daylight glare probability. Moreover, the CIBSE is the only standard with a specific daylight requirement for the art studio. Based on the existing global lighting-related standards, the CIBSE Lighting Guide of the United Kingdom is selected as the lighting design guide for the project, which requires a lighting coefficient, uniformity, brightness, glare value, and other requirements of various buildings. The guide requires that the average daylighting coefficient of the art studio should be greater than 5, the minimum daylighting coefficient should not be less than 2, the illumination should be 300 - 750 lx, and the uniformity

Table 1. Comparison of different standard for daylight requirement.

	BEAM Plus	BREEAM	CIBSE	LEED	Three Stars
Daylight Factor	80% area, 1% (1 credit) 95% area, 1% (2 credit)	Different latitude has a different standard	Different function has a different standard	75% occupied space, 2%	×
Vertical Daylight Factor	√	×	×	×	×
Uniformity		≥0.3, ≥0.7 (atria), or 80% area view sky, and d/w+d/HW < 2/(1-RB)	Task Illuminance: ≥0.7 illuminances of immediate surrounding area: ≥0.5	×	×
Annual Illuminance	≥75%, 100 lux (1 credit) ≥85%, 100 lux (2 credit)	≥80% area, 200 lux, 2650 hrs (avg.) 60 lux, 2650 hrs (min)	Different function has different standard	×	Refer to GB/t50033
View of sky	≥60%, (1 credit) ≥80%, (2 credit)	80% area	×	90%	×
Unified Glare Rating (UGR)	×	×	Different function has different standard	×	×
Window to Wall	×	Depends on distance from widow to work space	Depends on the depth of room from outside wall	×	0.3 ≤ x ≤ 0.4

should be greater than 0.7.

2.3. Parameters & Simulation Tool

2.3.1. Simulation Tool: DIVA-for-Rhino

DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros—NURBS modeler [10]. The plug-in was initially developed at the Graduate School of Design at Harvard University and is now distributed and developed by Solemma LLC. DIVA-for-Rhino allows users to conduct a series of environmental performance evaluations of individual buildings and urban landscapes, including radiation maps, photorealistic renderings, climate-based daylighting metrics, annual and individual time step glare analysis, LEED and CHPS daylighting compliance, and single thermal zone energy and load calculations.

2.3.2. Study Parameters

The project needs to judge the building lighting from multiple dimensions of illumination, so the following lighting parameters shown in Table 2 are adopted for the project: daylight factor [11] [12], illumination uniformity (U0) [12],

Table 2. Daylighting design parameters.

Daylight Factor	
Weather Data	Local climate EPW documents
Simulated plane height	750 mm
Distance of each nodes	600 mm
Daylight Autonomy	
Occupancies Schedule	8:00 am - 6:00 pm
Task Illuminance [15]	300 lx
Daylight Glare Probability	
Towards Direction	South
Occupancies Schedule	8:00 am - 6:00 pm

daylight autonomy [13], and daylight glare probability [14].

2.4. Control Variable Method

First, a building without walls and columns will be simulated to obtain the maximum daylight illuminance level and daylight factor level. Then, we set the quantitative indices one by one, list 2 - 3 options for each index, and pick the appropriate one. To select the index, we assess the result and whether it can reach the standard that follows. The quantitative indicator chosen for this study is the window to wall ratio (WWR). WWR is the fraction of the above grade wall area that is covered by fenestration, calculated as the ratio of the wall fenestration area to the gross above grade wall area. Window to wall ratio is one of the most important factors affecting the effect of ventilation, soundproofing and lighting in the room. According to the ASHRAE 90.1-2007 standard, a window to wall ratio (WWR) of 0.24 can result in the building interior being optimally lit and ventilated.

The index should be somewhat modified if the requirement cannot be satisfied.

Quantitative index A: window to wall ratio [16] [17]: 1) 1:5; 2) 1:4; 3) 1:3.

Quantitative index B: window type/position: horizontal window [14] [18]; skylight [12]; multiple.

Quantitative index C: glazing and visible transmittance [12]: single panel glazing with 88% visible transmittance; double panel low-e glazing with 65% visible transmittance [18].

3. Case Study

3.1. General Information

The proposed subject of the daylighting strategy design project is an abandoned 1020 m^2 70-year-old factory in Guangzhou: the NanHai Machine Factory at No. 165 Dong Guan Zhuang Road. **Figure 3** and **Figure 4** show the building structure

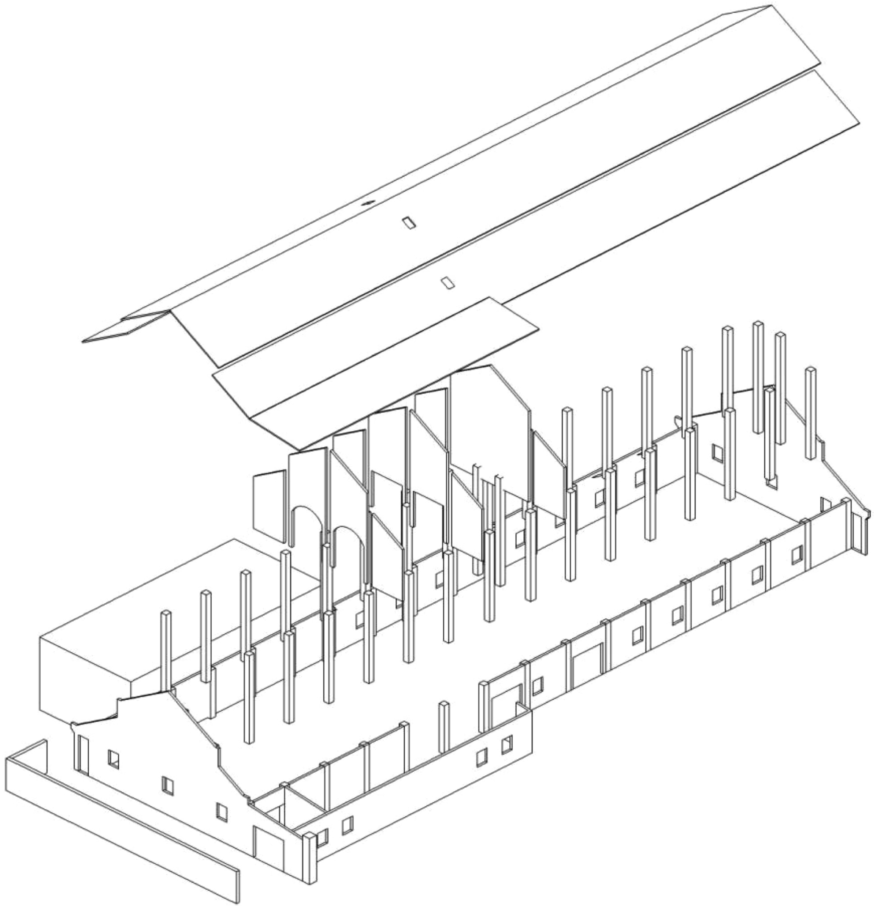


Figure 3. Building structure of the original factory.

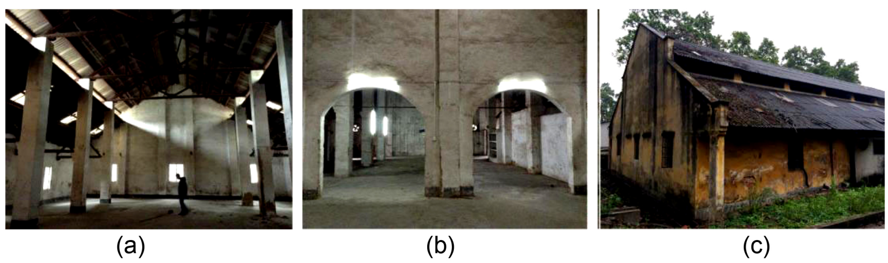


Figure 4. Scene picture of the original factory. (a) Picture of the original factory scene 1. (b) Picture of the original factory scene 2. (c) Picture of the original factory scene 3.

and scene of the original factory.

After the second planning by the government, the abandoned factory was rented out to the public. The new occupant of the old factory is an art professor at the university who intends to turn it into an art space for exhibiting, working and relaxing.

3.2. Data Collection

3.2.1. Site Information

Guangzhou is the capital and largest city of Guangdong Province in South China. Located on the Pearl River, approximately 120 km northwest of Hong Kong, Guangzhou is an important national transportation hub and trading port. One of the five National Central Cities, it holds subprovincial administrative status. Figure 5 shows that the site is situated in the Tianhe district near two universities, which have convenient transportation and a good scholarly atmosphere.

3.2.2. Climate Data

Located just south of the Tropic of Cancer, Guangzhou has a humid subtropical climate influenced by the East Asian monsoon. Summers are wet with high temperatures, high humidity, and a high heat index. As shown in Figure 6, we can see that the solar altitude angle changes from time to time, which will affect the shading design of the building to avoid overheating in summer and heat gain in winter.

The sky cover range in Guangzhou shows that most of the sky conditions in Guangzhou are overcast. In November, as the cold wind blows from the north, the sky will be clearer than in other months.

From the above illumination range diagram shown in Figure 7, we can see that the illumination is relatively high during September and December; according to the sky cover condition shown in Figure 8, the more the sky clears, the more illumination the building gains.

3.2.3. Building Information

After renovation design, the building has become a workshop with artistic functions and atmosphere, including an art studio, exhibitions, catering, offices and accommodations. Since the art studio is the most essential part of the building, Figure 9 shows that it is placed on the south side of the building, where it receives more daylight and a good view.

3.3. Previous Simulation and Analysis

A factory is a special place since it has strict requirements for artificial lighting

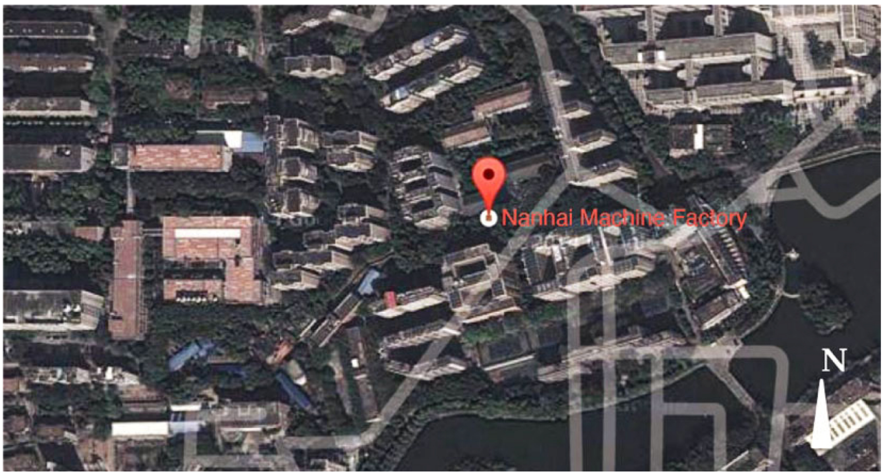
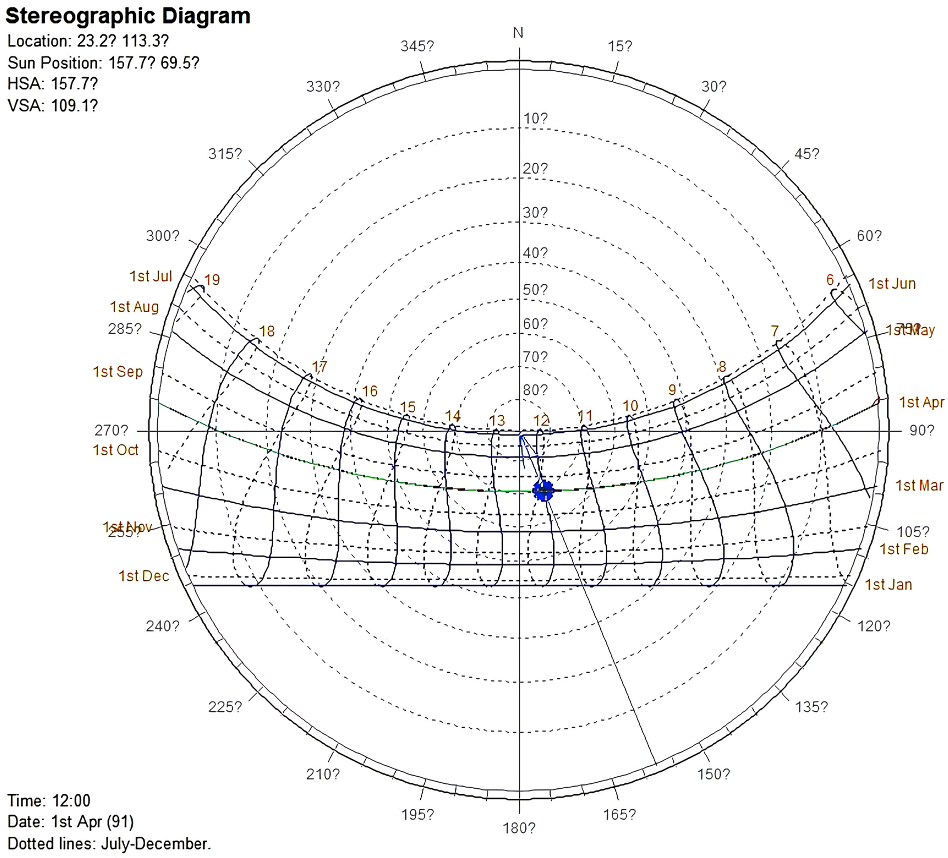
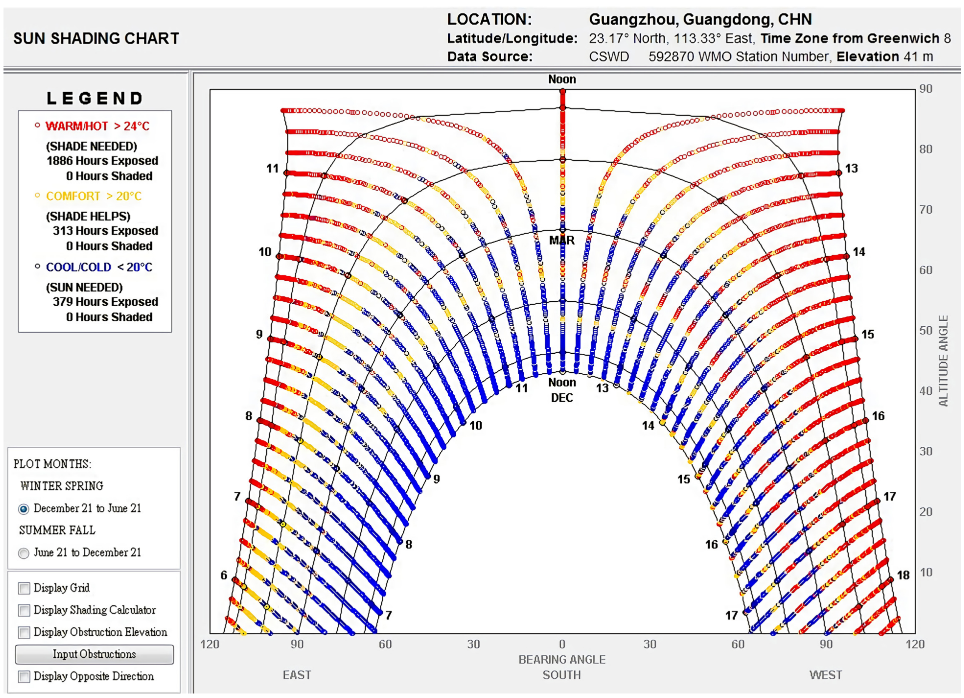


Figure 5. Location of the project case. Sun path diagram.



(a)



(b)

Figure 6. The diagrams of climate data of Guang Zhou. (a) Sun path diagram. (b) Sun shading diagram.

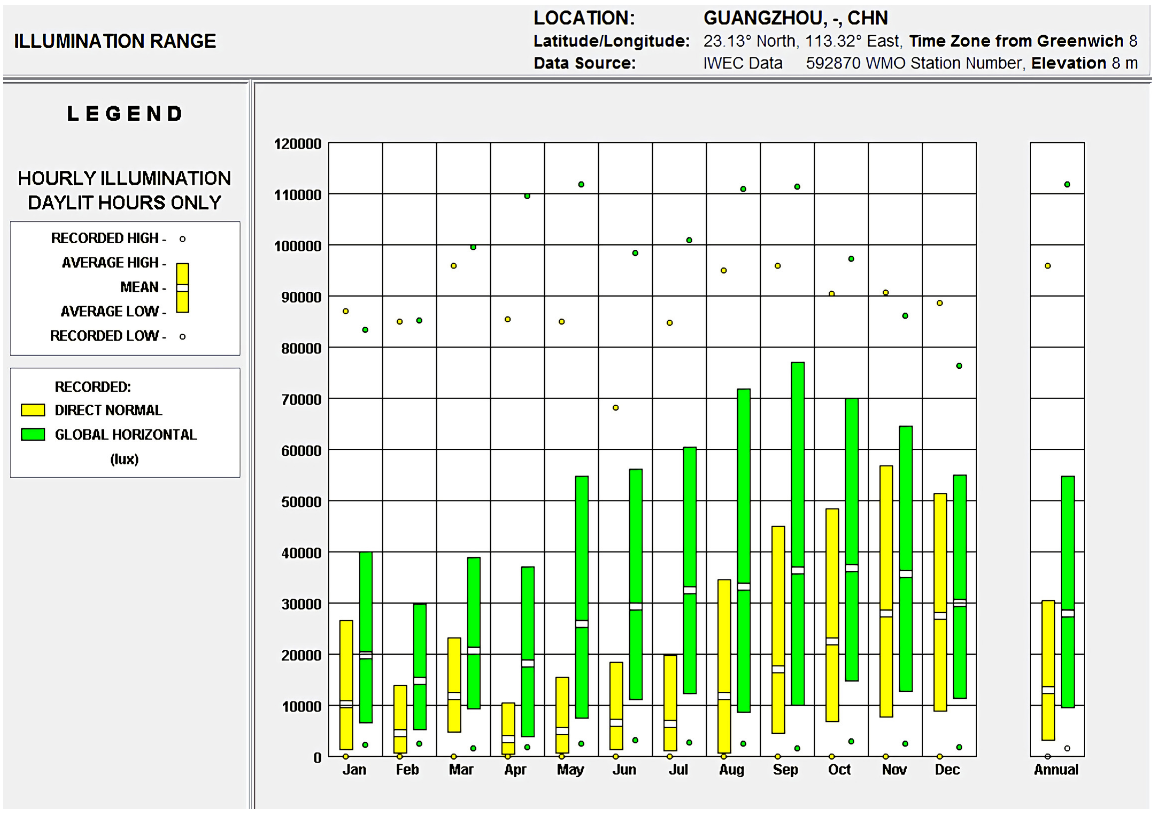


Figure 7. Illumination range of Guangzhou.

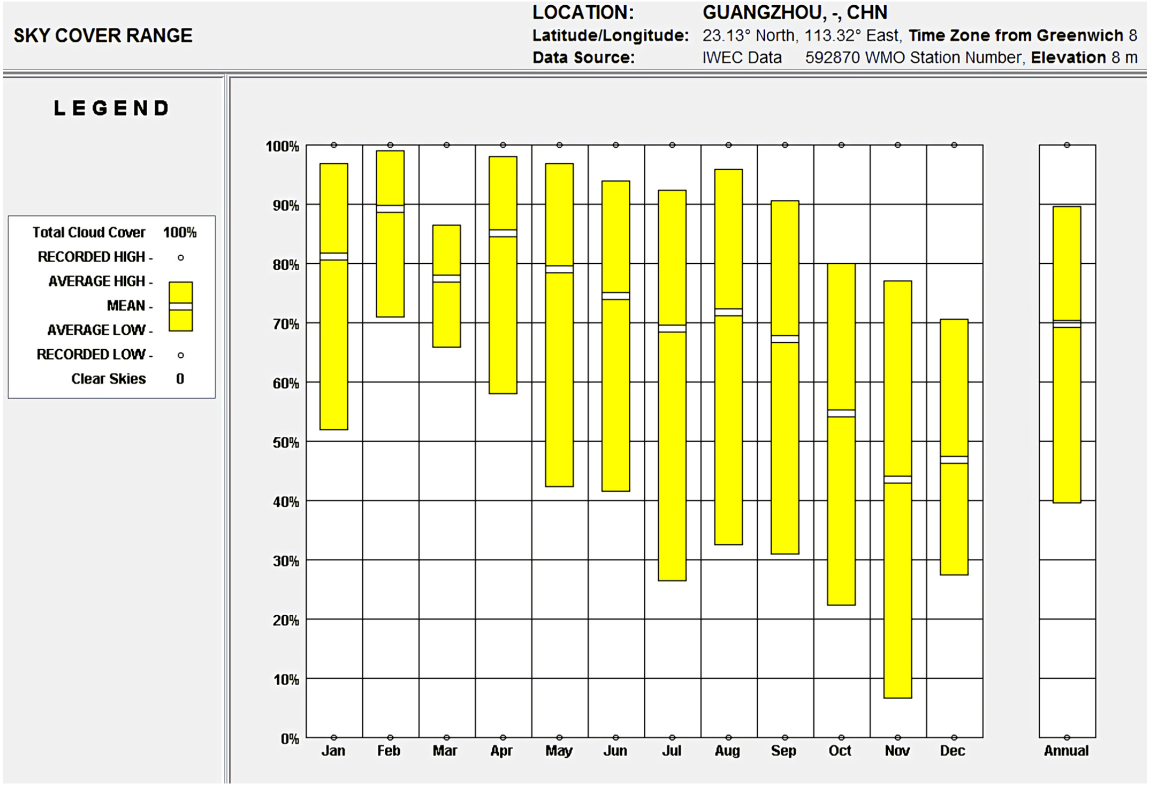


Figure 8. Sky cover range of Guangzhou.

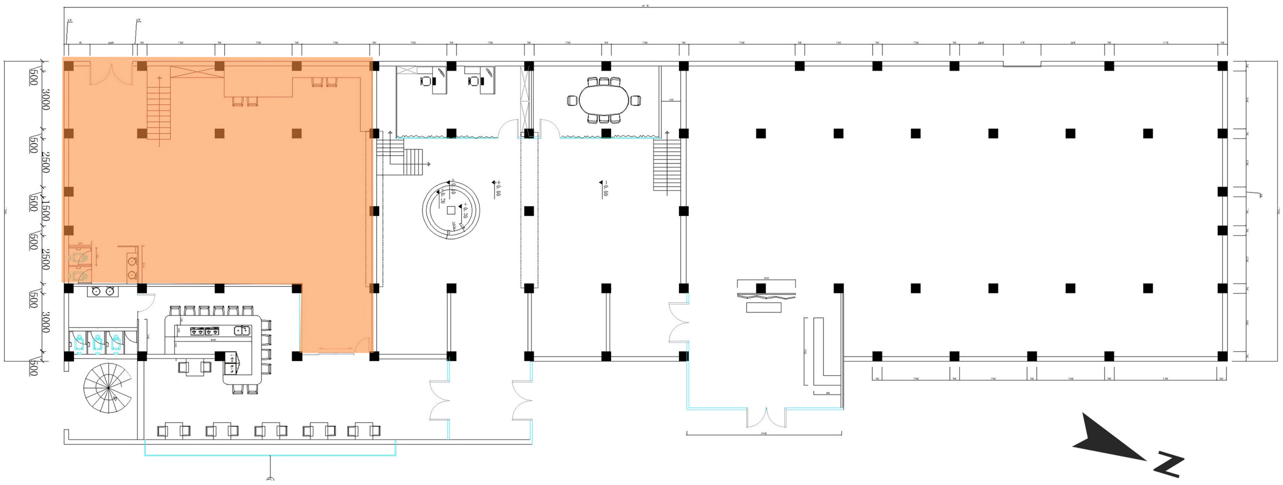


Figure 9. Key plan of 165 art factory and the location of art studio.

during its design process, with almost no consideration for natural daylight. This is because workers need a high-intensity lighting environment when they are engaged in specific work, and the intensity of required light is often beyond the reach of natural daylight. In the original construction, the windows are not a very large size, as shown in Figure 10, at 1100 × 1270 mm for each window on the east side and north and south façade; on the two sides of the roof, there is some interspace for daylight and ventilation. To summarize, the following problems exist.

3.3.1. Small Size Windows and Excessive Depth

The excessive depth makes it difficult for the building to allow light access, and the window size causes a low occupied time percentage of daylight autonomy (Figure 11). Only 48.08% of the occupied time reaches 300 lux.

3.3.2. Blocking of the Building on the West Facade

On the west facade, there is a two-storey building next to the factory with no gap at all, causing the west facade to not receive enough daylight hours horizontally.

3.3.3. Low Daylight Factor

Through the simulation of the daylight factor by DIVA, as shown in Figure 12, the mean daylight factor of the art studio is 1.29%, which falls short of the minimum daylight factor requirement of CIBSE for art studios.

3.4. Amelioration

3.4.1. Maximum Daylight Quantities

If all the walls and doors are open, Figure 13 shows the maximum amount of daylight that the building will receive. The mean daylight factor can reach 19.2% if all the walls and columns are gone.

3.4.2. Set the Window-to-Wall Ratio

The next step is to determine the window-to-wall ratio (WWR). From the

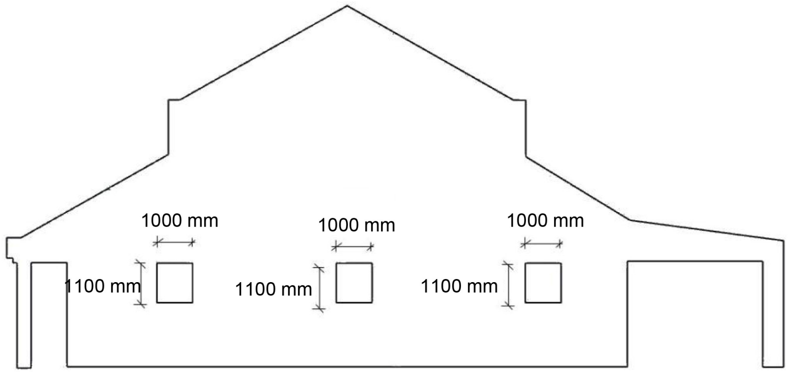


Figure 10. Original south facade and window size of the building.

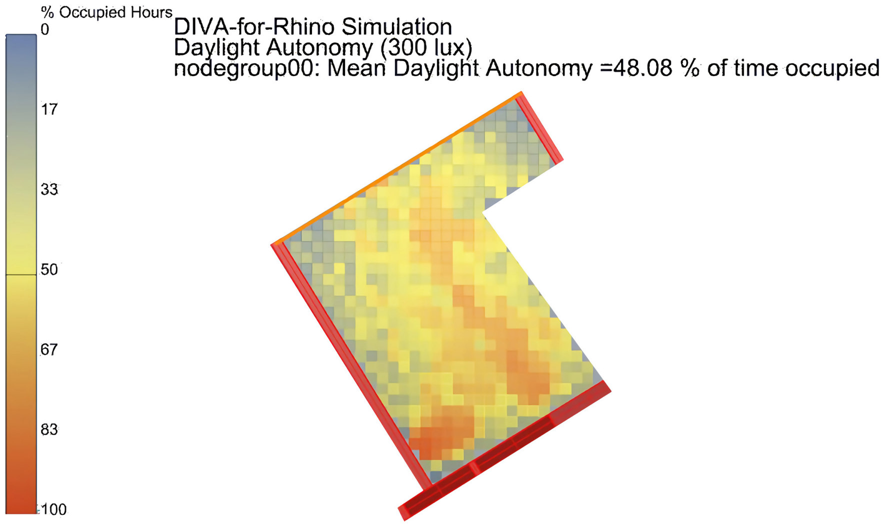


Figure 11. Daylight autonomy of original building.

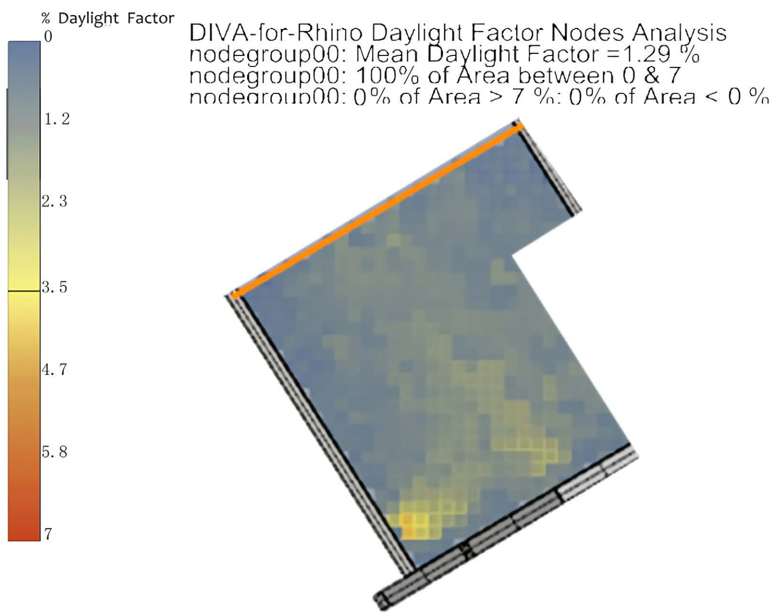


Figure 12. Daylight factor of the original factory building.

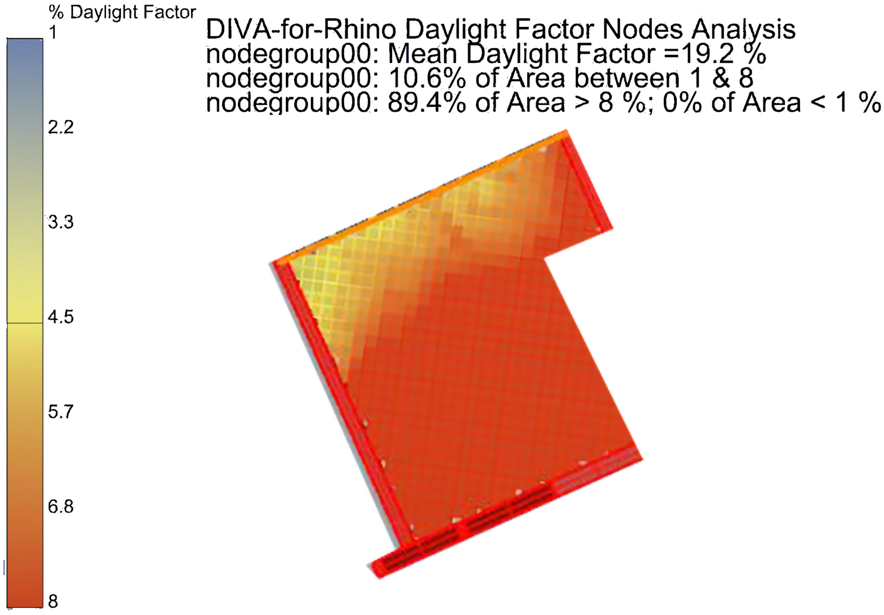


Figure 13. Maximum daylight factor that the art studio will receive.

references and case studies, there are three optional WWRs: 1. 1:5; 2. 1:4; 3. 1:3.

1) WWR = 1:5

From the simulation result a 1:5 WWR, we can see that the window near the art studio is 2000 × 8000 mm (**Figure 14**), and the mean daylight factor is 4.68, as shown in **Figure 15(a)**, which fails to reach the mean daylight factor criteria of CIBSE (mean daylight factor: 5). In **Figure 15(b)**, the daylight autonomy graph that sets 300 lux as the target illuminance, 84.43% of the time occupied, can reach the minimum illuminance requirement of CIBSE for the art studio. The daylight glare probability (DGP) in **Figure 16** is concentrated from 8:00 am to 10:00 am and focuses on the south direction. **Figure 16** shows that the DGP level can still be tolerated.

2) WWR = 1:4

From the simulation result of a 1:4 WWR, we can see that the window near the art studio is 3000 × 8000 mm (**Figure 17**). **Figure 18(a)** shows that the mean daylight factor is 5.95, and the minimum daylight factor is 2.1, which is higher than the 1:5 WWR and reaches the mean daylight factor criteria of CIBSE but still cannot meet the requirement of the minimum daylight factor (mean daylight factor: 5; minimum daylight factor: 2.5). The uniformity ratio of this option is 0.35, which cannot fulfil the requirement of CIBSE (Uniformity ≥ 0.7). In **Figure 18(b)**, the daylight autonomy graph that sets 300 lux as the target illuminance, 89.01% of the time occupied, can reach the minimum illuminance requirement of CIBSE for the art studio. The daylight glare probability is concentrated from 8:00 am to 10:00 am and focuses on the south direction. **Figure 19** shows that the DGP level is slightly higher than the previous option, but some shading devices can still reduce this kind of glare.

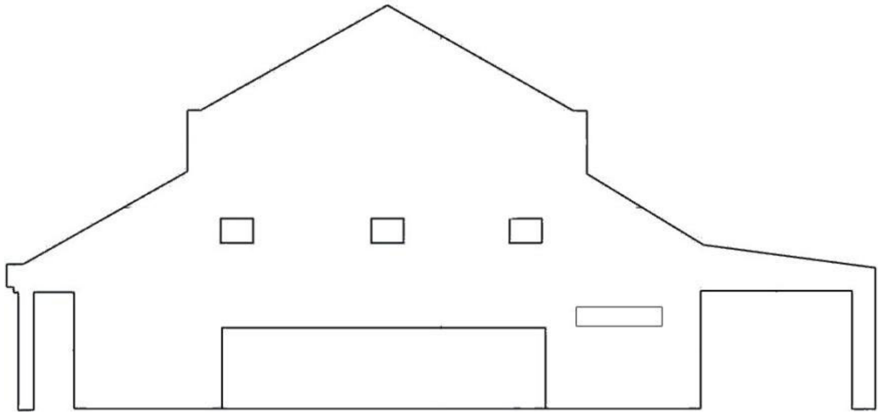
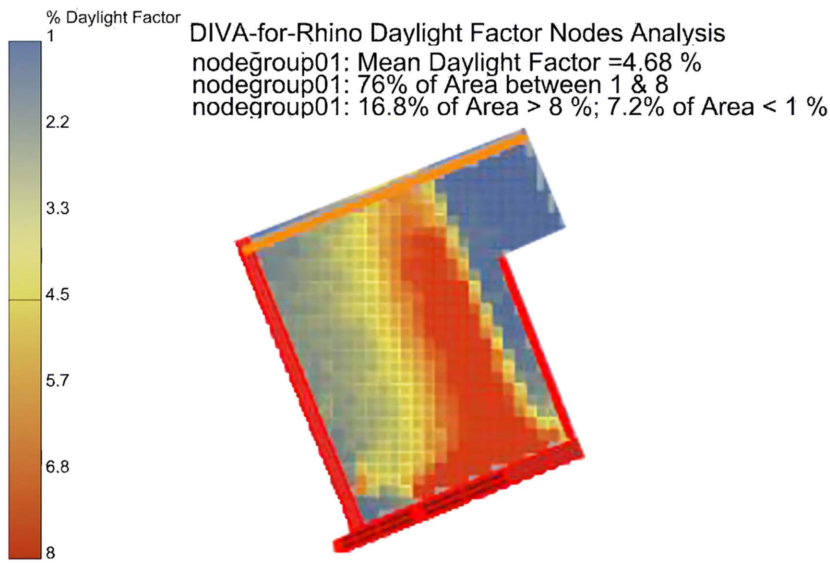
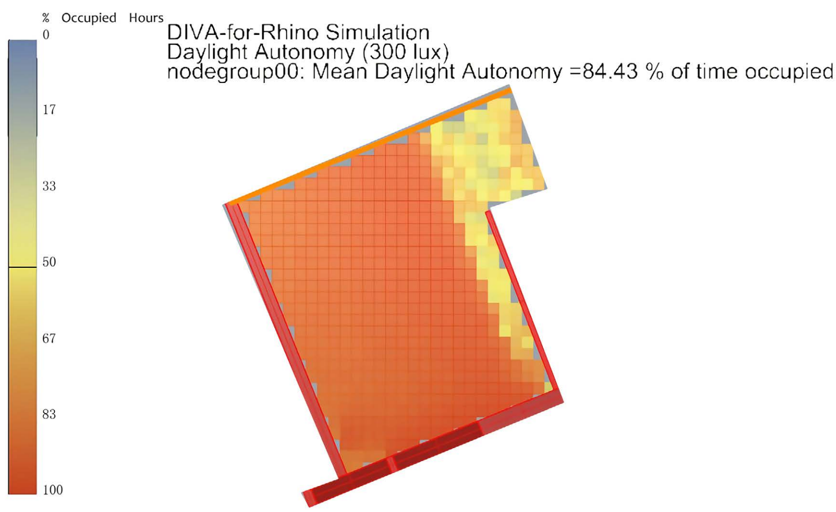


Figure 14. South facade wall for art studio with 1:5 WWR.



(a)



(b)

Figure 15. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of the art studio with 1:5 WWR.

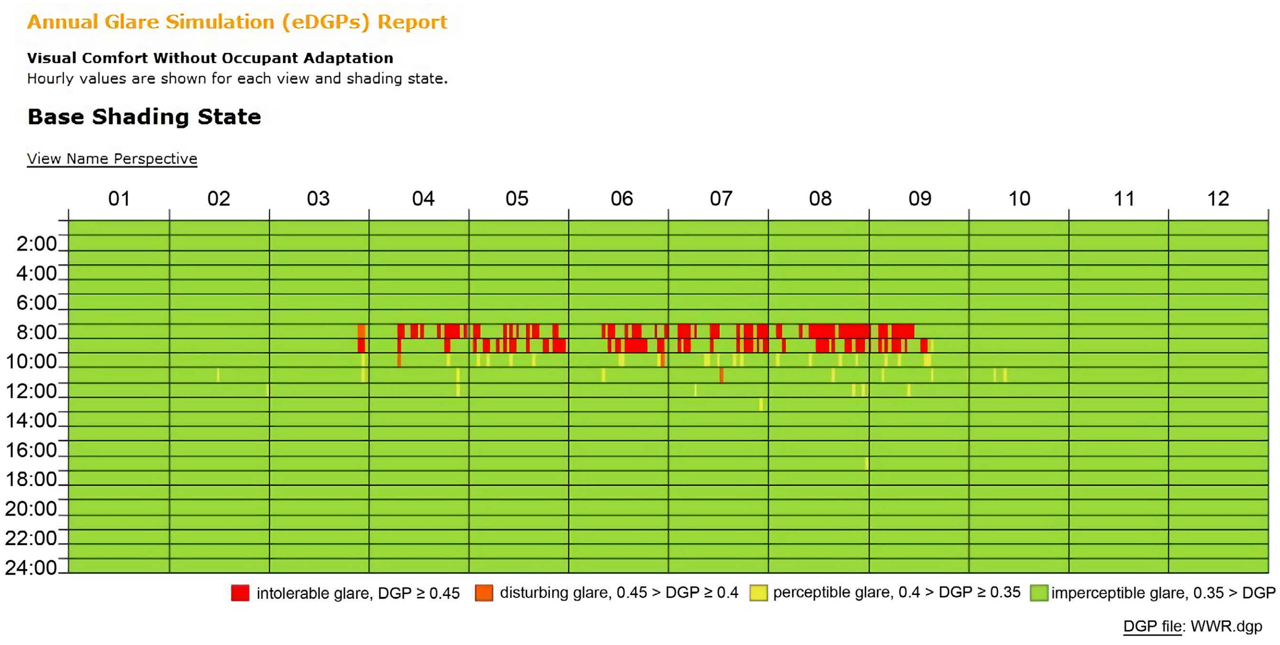


Figure 16. Annual daylight glares probability of art studio with 1:5 WWR.

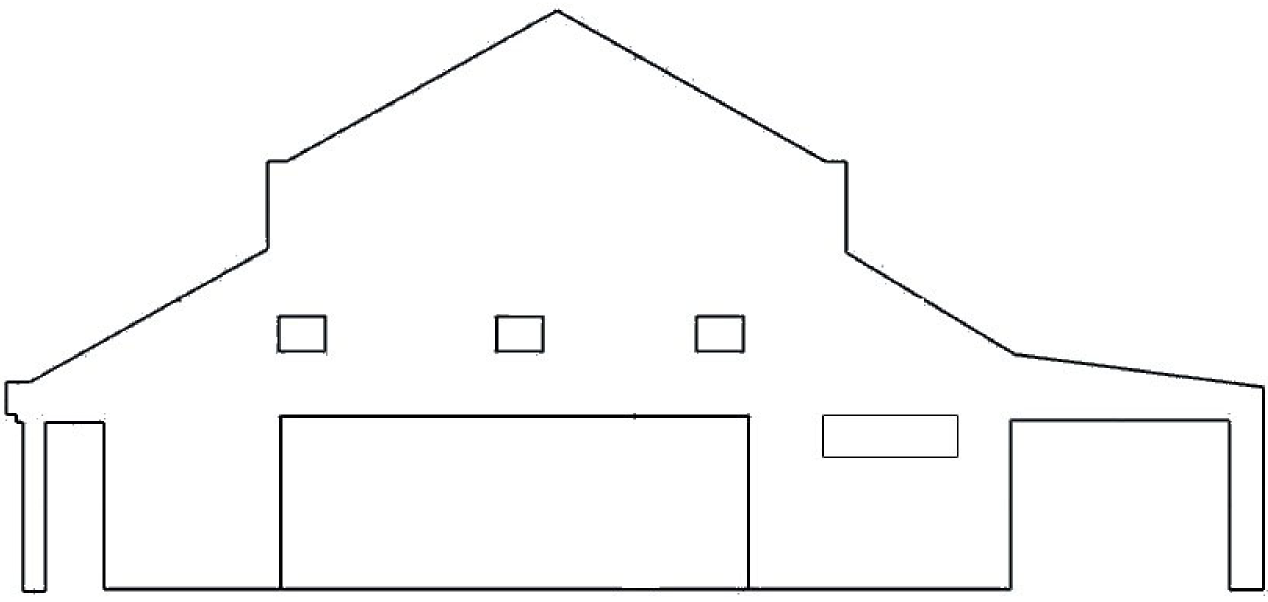


Figure 17. South facade wall for art studio with 1:4 WWR.

3) WWR = 1:3

From the simulation result of a 1:3 WWR, we can see that the window near the art studio is 3500 × 10,000 mm (Figure 20). Figure 21(a) shows that the mean daylight factor is 6.66, and the minimum daylight factor is 2.6, which is higher than the 1:4 WWR and reaches the daylight factor criteria of CIBSE. However, the uniformity ratio of 0.4 still cannot reach the standard of 0.7. In Figure 21(b), the daylight autonomy graph that sets 300 lux as the target illuminance, 91.25% of the time occupied, can reach the minimum illuminance

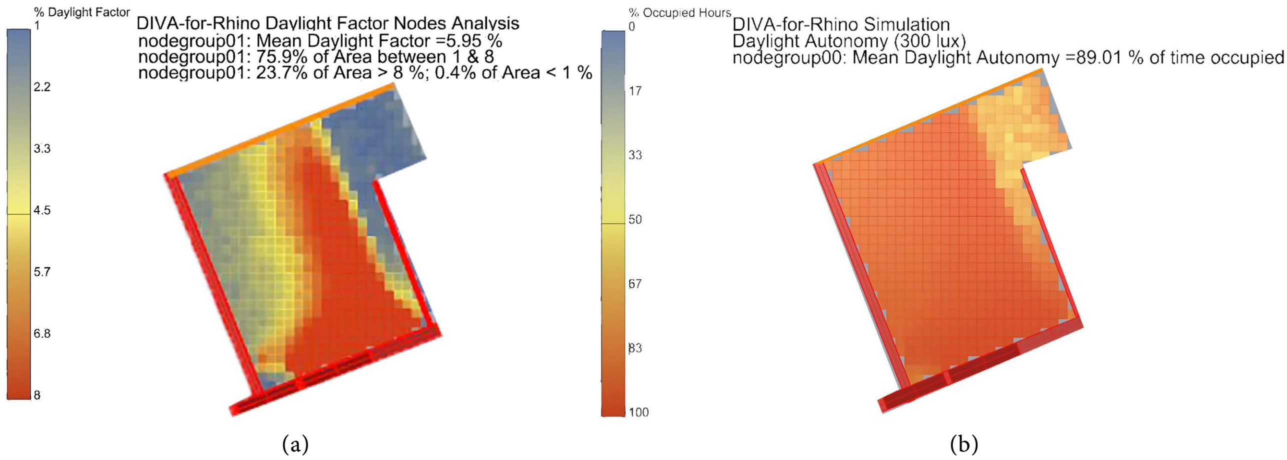


Figure 18. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of the art studio with 1:4 WWR.

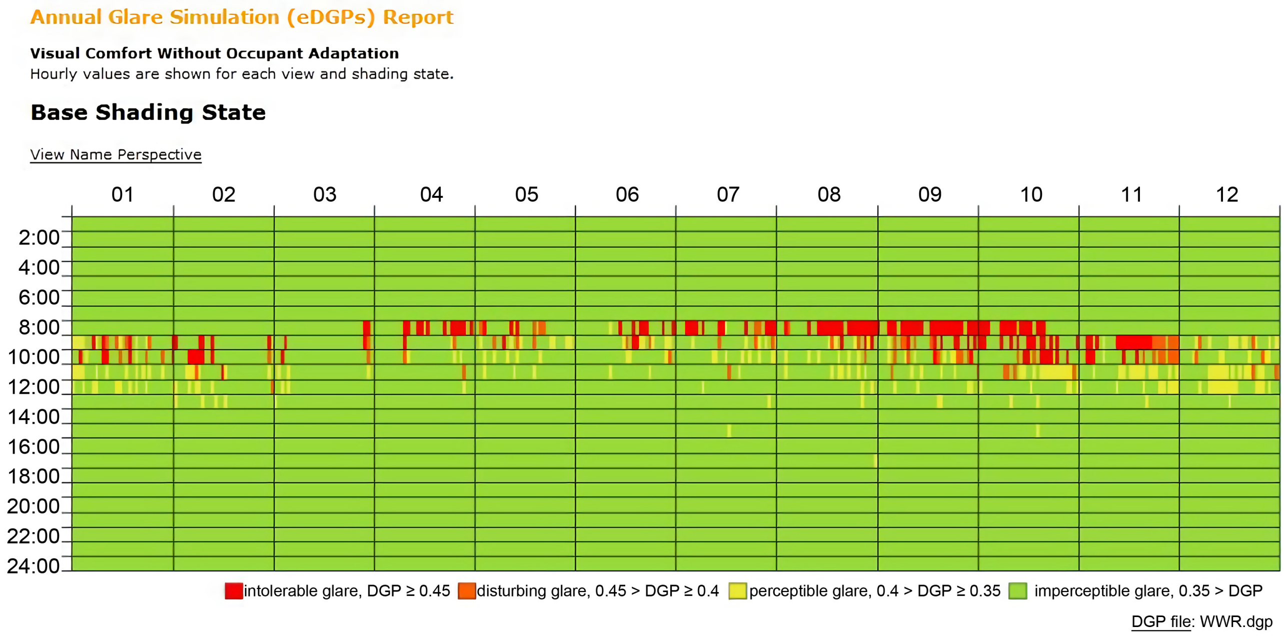


Figure 19. Annual daylight glare probability of art studio with 1:4 WWR.

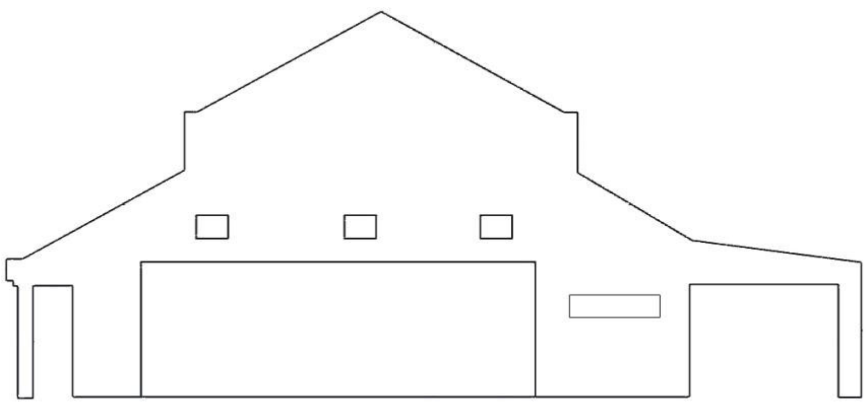


Figure 20. South facade wall for art studio with 1:3 WWR.

requirement of CIBSE for the art studio. The DGP is concentrated from 8:00 am to 16:00 am and focuses on the south direction. Figure 22 easily illustrates that the DGP level is much higher than the other two options, and the period time is much longer, which can be improved by choosing different window types in the next step, as well as the problem of uniformity.

After comparative analysis, Table 3 shows that the 1:3 WWR would be the best option for an adequate daylight factor and daylight autonomy, while the uniformity and glare problem needs to be fixed in the next step.

3.4.3. Window Type Chosen

From the previous option, although the WWR of 1:3 is a proper choice, it still cannot reach the requirement of the uniformity ratio standard of CIBSE, and the glare problem also needs to be solved. Therefore, the window's type and the position may be another aspect that deserves more consideration when solving this

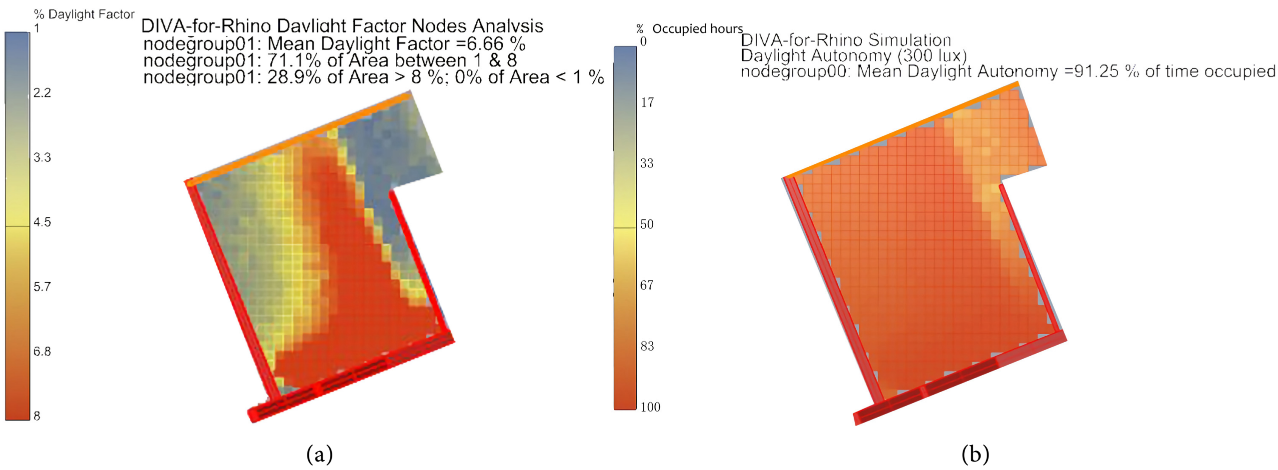


Figure 21. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of the art studio with 1:3 WWR.

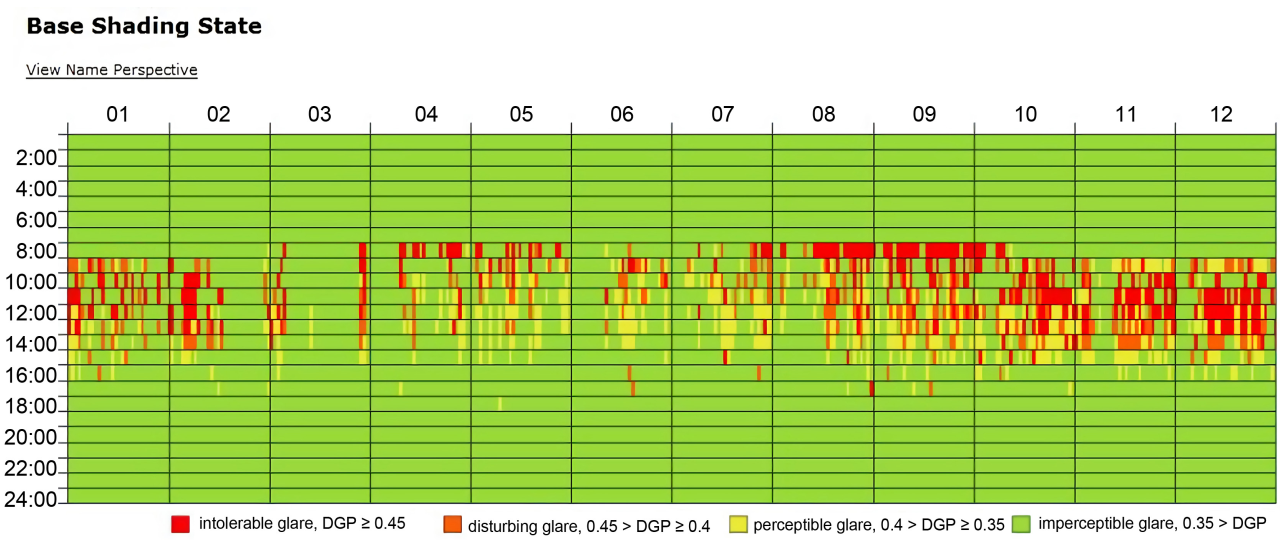


Figure 22. Annual daylight glares probability of art studio with 1:3 WWR.

problem.

In this step, three types of windows can be chosen: 1) Horizontal windows (including clerestories); 2) Skylights; 3) Multiple.

1) Horizontal Windows

According to the window-to-wall ratio, the primary window size should be 3500 × 8500 mm. Considering the uniformity of the daylight, this could be separated into a 3000 × 8500 mm horizontal window and a 500 × 8500 mm clerestory window, as shown in Figure 23. From the daylighting factor (Figure 24),

Table 3. Data comparison with different window to wall ratio.

	1:5	**1:4**	**1:3**
Wall Area	91 m^2	85 m^2	75 m^2
Main Window Size	2000 mm × 8000 mm	3000 mm × 8000 mm	3500 mm × 8500 mm
Window Area	22 m^2	28 m^2	38 m^2
Mean Daylight Factor (%)	4.68	5.95	6.66
Meet the criteria of CIBSE	NO	YES	YES
Minimum Daylight Factor (%)	0.8	2.1	2.6
Meet the criteria of CIBSE	NO	NO	YES
Uniformity Ratio	0.20	0.36	0.40
Meet the criteria of CIBSE	NO	NO	NO
Occupied time of 300 lux-Daylight Autonomy (%)	84.43	89.01	91.25
DGP	Low	Middle	High

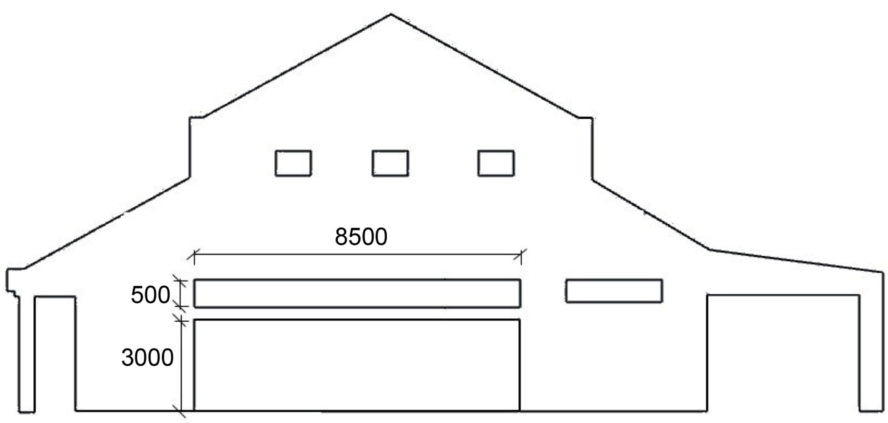


Figure 23. Window size of the horizontal window.

we can see that the mean daylight factor is nearly 6, which reaches the standard of CIBSE, but the daylight is concentrated near the window and makes a dark corner on the part that is far away from the light source; therefore, the uniformity of this option is just 0.3, which fulfils the requirement of CIBSE for art studios (0.7). Although the glare problem still remains (Figure 25), it has been slightly reduced due to the use of a clerestory.

2) Skylights

In this option, the window type is a skylight. Therefore, the horizontal window on the south façade will be blocked, and the only daylighting source will be the skylight.

The skylight is directed towards the sun, and the height of the building is just

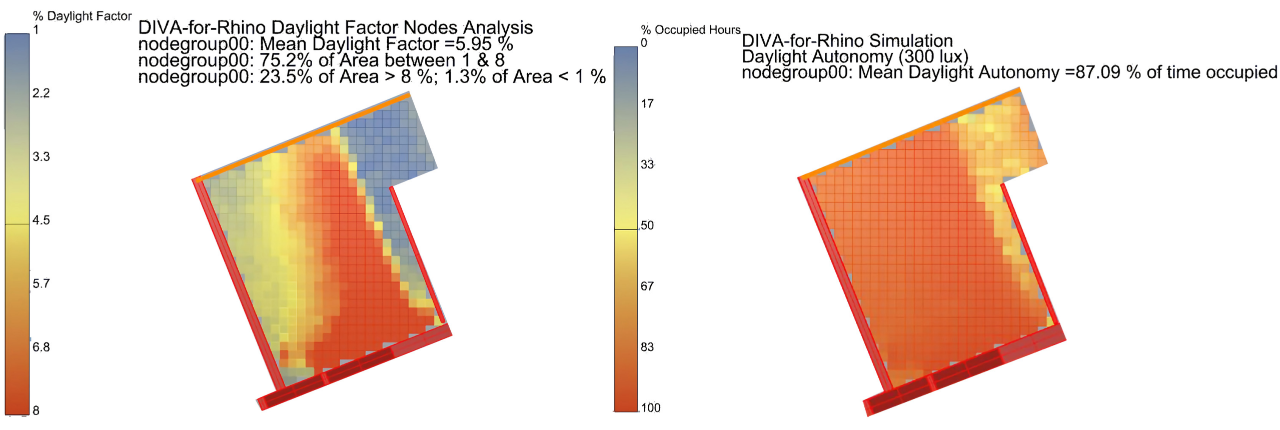


Figure 24. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of horizontal window.

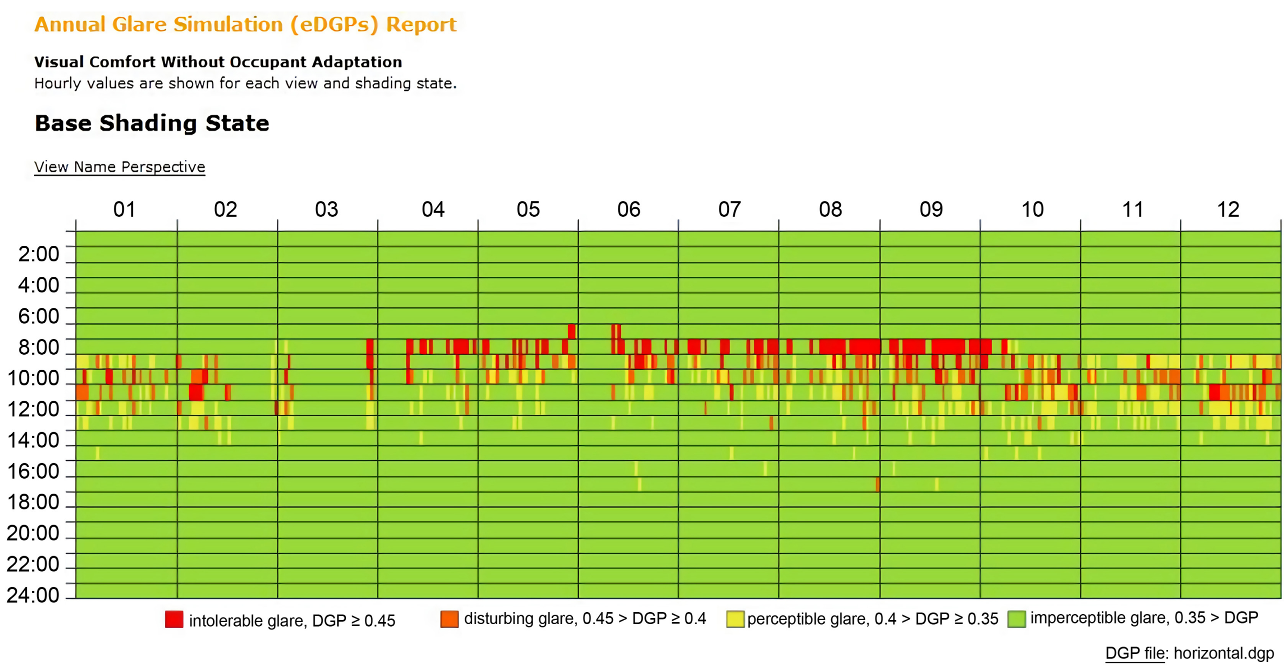


Figure 25. Daylight glare probability of horizontal window.

9000 mm, which does not have enough height to diffuse the daylight. Therefore, the size of the skylight will be 3200 × 15000 mm (Figure 26); at the same time, a 1800 × 13,000 mm translucent coating shown in Figure 26(b) will be fixed under the skylight to diffuse the daylight.

From the daylight factor data shown in Figure 27(a), the mean daylight factor is 5.43, and the uniformity ratio is 0.71, which fulfils the requirement of CIBSE. The daylight autonomy in Figure 27(b) is also relatively high, higher than the horizontal window.

Since there are no horizontal windows on the south façade, the perspective views of glare have changed towards the skylight, and from the DGP results in Figure 28 and Figure 29, we find that the intolerable glare starts from 8:00 am to 10:00 am and extends longer in summer.

However, while the simulation results are satisfactory, there is still a problem with the skylight, which means the lack of a natural view of the room that the occupants need.

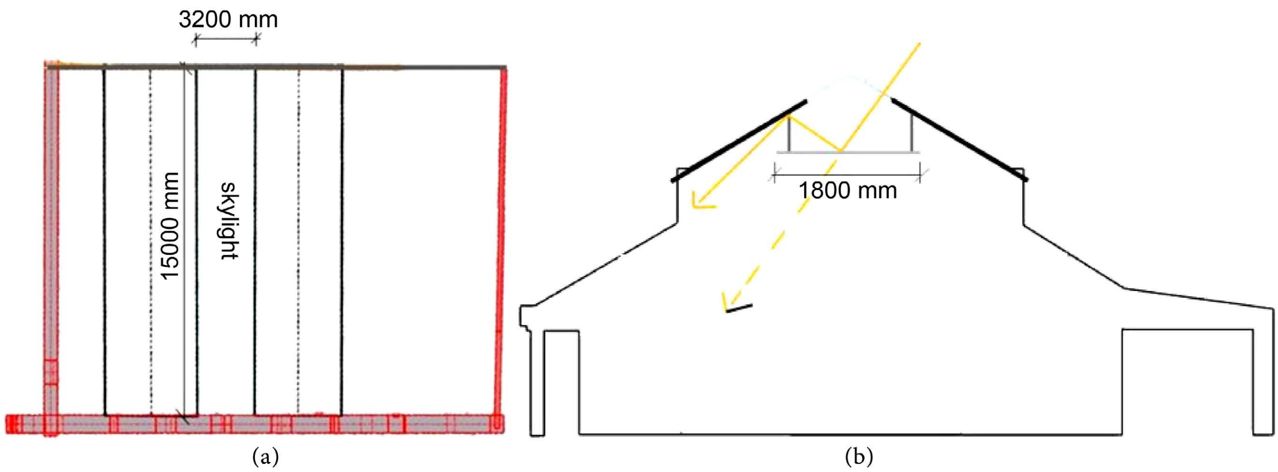


Figure 26. The simulation diagrams. (a) Size of skylightaylight factor. (b) Translucency coating for daylight diffusing.

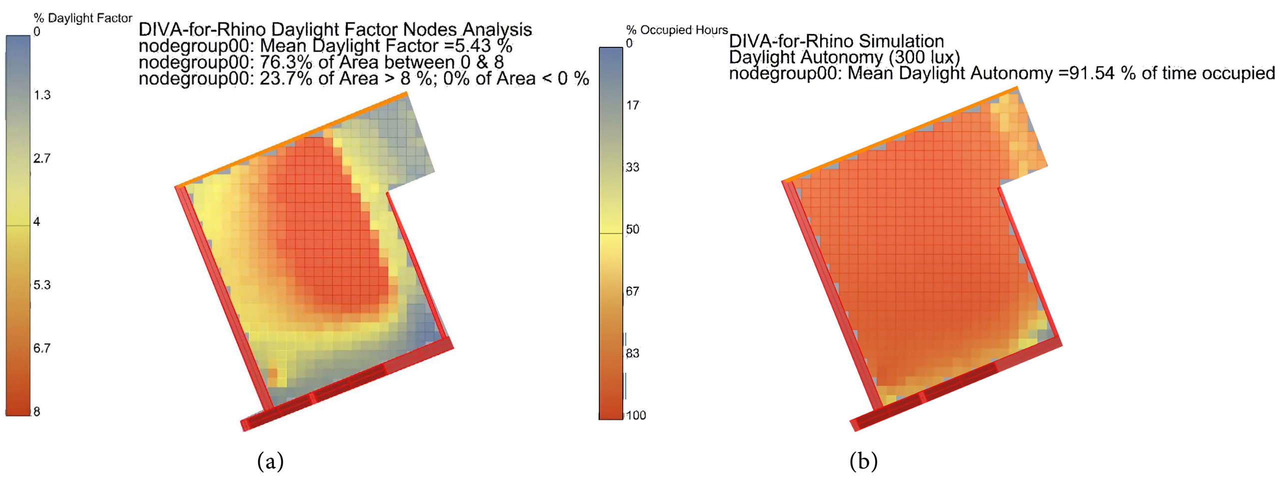


Figure 27. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of skylight window.

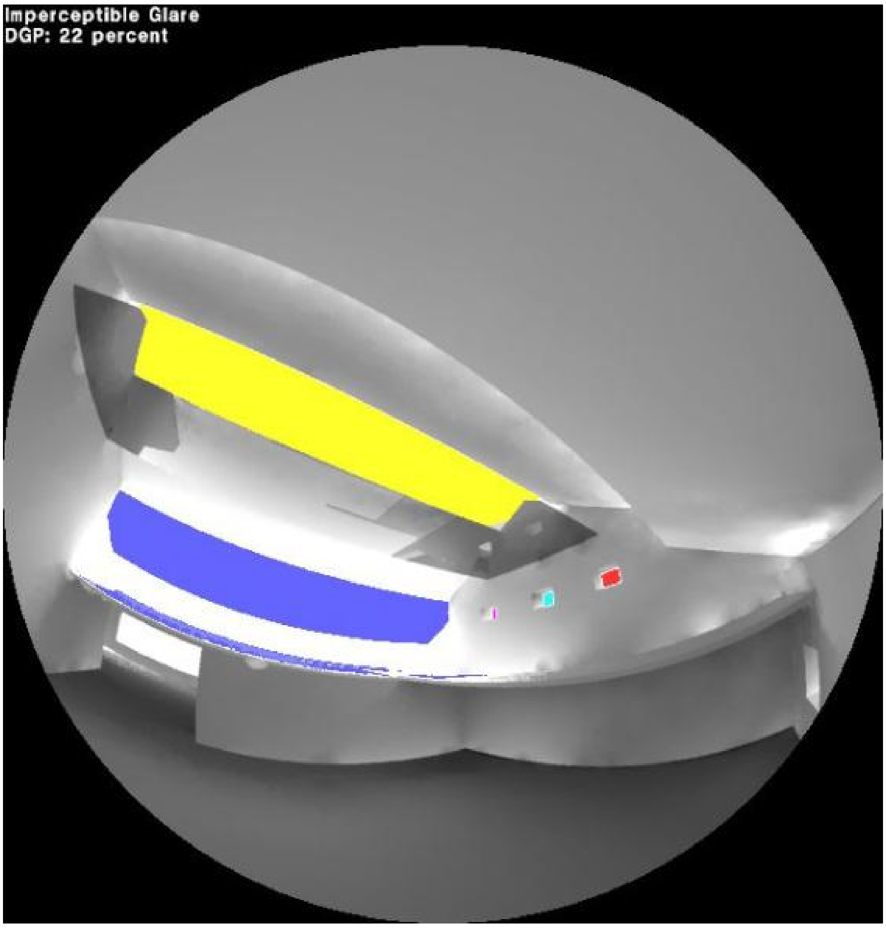


Figure 28. Daylight glare probability of skylight window.

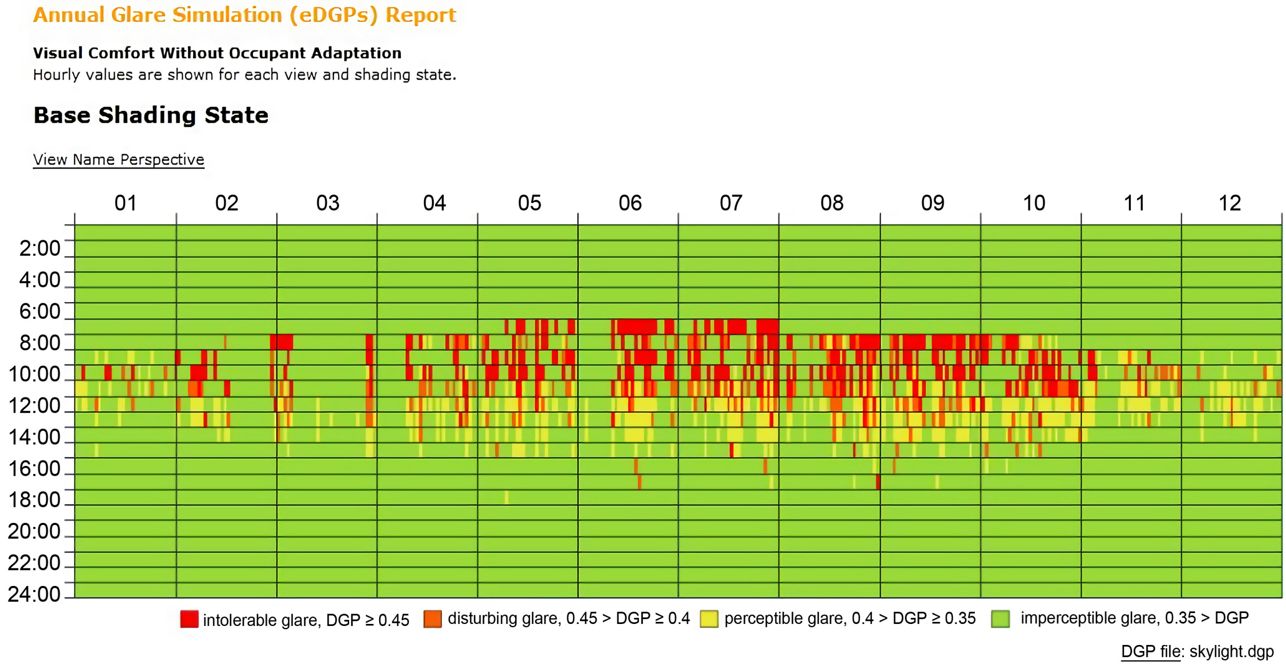


Figure 29. Daylight glare probability of skylight window.

3) Multiple

The combination of a horizontal window with a skylight may be the optimal option for daylighting performance, with an excellent natural view and uniformity and sufficient daylight. As the space has two sources of daylight, the horizontal window size should be modified to some extent to prevent excess daylight and maintain the window-to-wall ratio. As a result, the window size was reduced to 2500 × 8000 mm, including a 500 × 8000 mm clerestory (Figure 30).

Figure 31(a) shows that the mean daylight factor is 6.22, and the uniformity ratio is 0.72, which reaches the daylight standard of CIBSE for an art studio. The daylight autonomy in Figure 31(b) also has 100% area to reach the 300-lux minimum illuminance requirement. Compared to the previous options, this is the most uniform option. The daylight glare shown in Figure 32 still needs to be solved; although it is better than other options, the glazing type and visible transmittance data should be chosen in the next step.

After the simulation and comparison, Table 4 shows that the multiple window type is the optimal option among the three, which not only can fulfil the requirement of the standard but can also allow the occupants to have good vision,

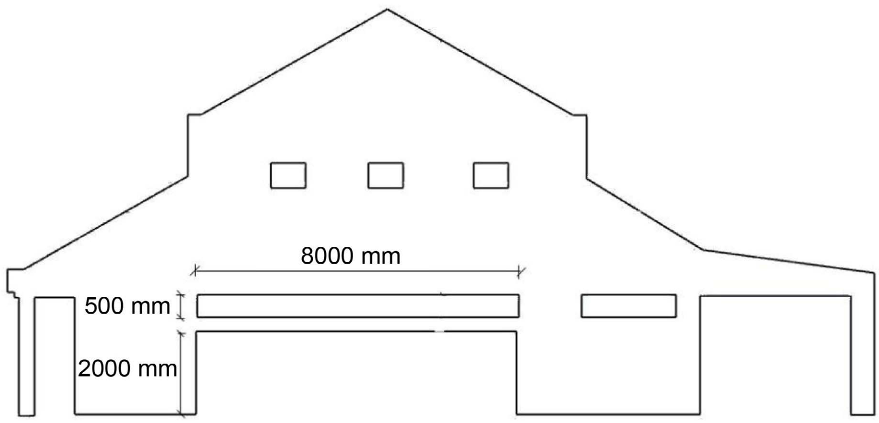
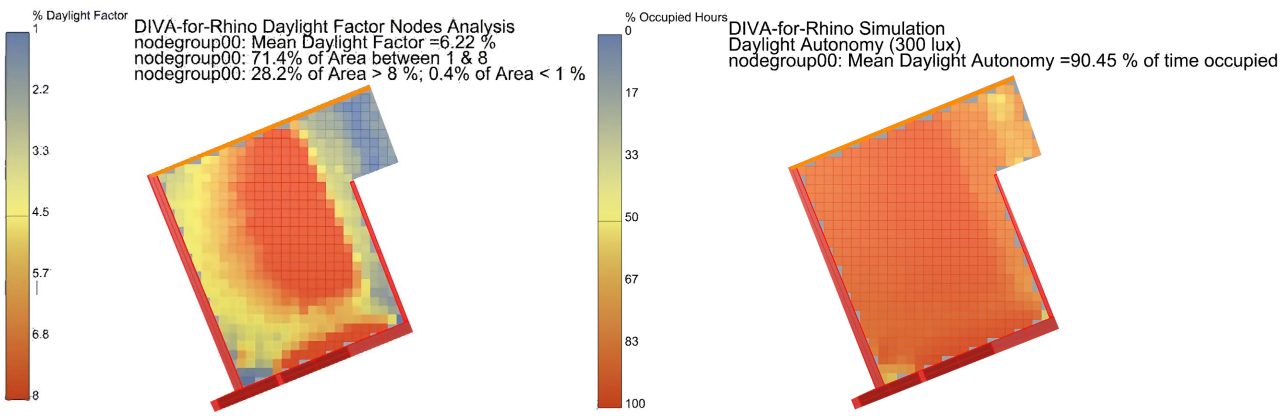


Figure 30. Horizontal window size.



(a) (b)

Figure 31. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of multiple window.

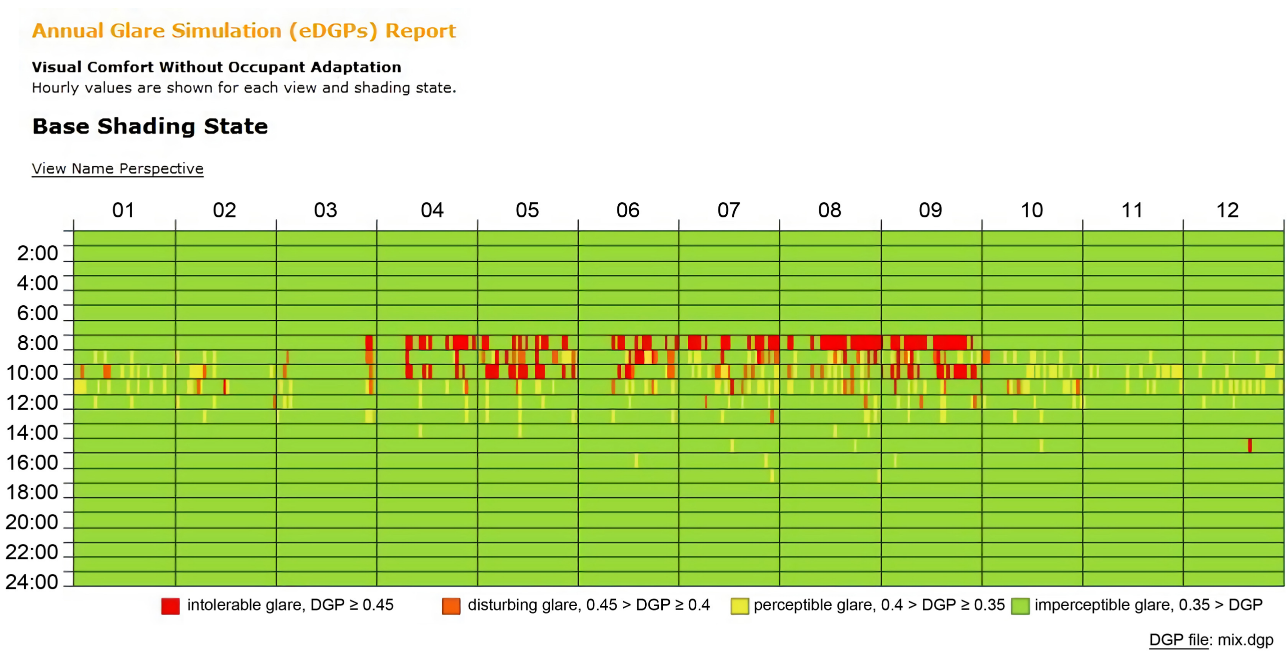


Figure 32. Daylight glares probability of multiple window.

Table 4. Data comparison with different window to wall ratio.

	Horizontal Window	Skylight	Multiple Window
Main Window Position	Horizontal, Clerestory	Skylight	Horizontal, Skylight, Clerestory
Mean Daylight Factor (%)	5.95	5.43	6.22
Meet the criteria of CIBSE	YES	YES	YES
Minimum Daylight Factor (%)	2.1	3.8	4.3
Meet the requirement of CIBSE	NO	YES	YES
Uniformity Ratio	0.36	0.71	0.72
Meet the requirement of CIBSE	YES	YES	YES
Occupied time of 300 lux-Daylight Autonomy (%)	87.09	91.54	90.45
DGP	High	Middle	Low
View of Outside	YES	NO	YES

which most artists and art workers truly need.

3.4.4. Glazing & Visible Transmittance

By ameliorating the window-to-wall ratio and window type, daylight issues are almost solved except for the glare problem. The glazing type and its visible light transmittance index can address this problem by reducing the visible light from the outside.

There are two options for glazing and visible transmittance: 1) single-panel glazing with 88% visible transmittance and 2) double-panel low-e glazing with

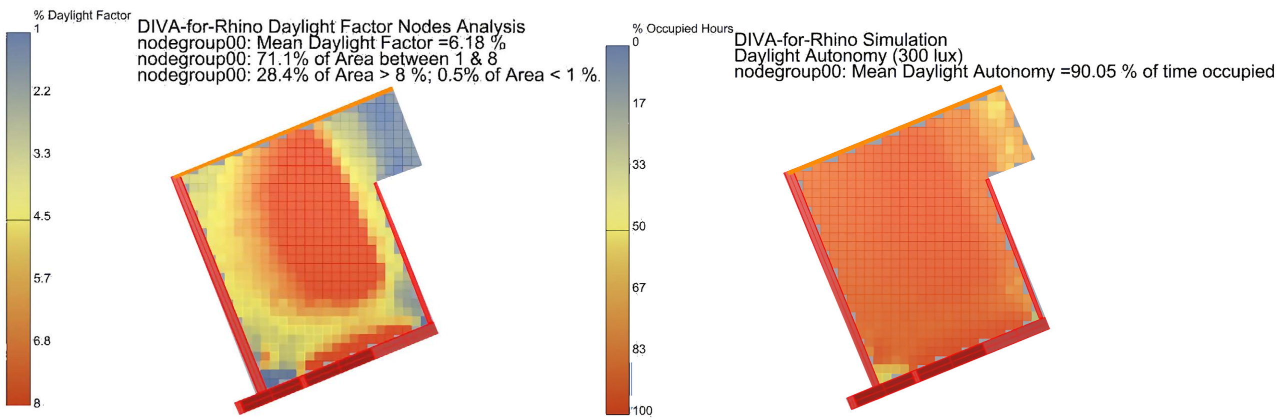
65% visible transmittance.

1) Single-panel Glazing with 88% Visible Transmittance

Single-panel glazing is the glass that is commonly used in buildings. The high visible transmittance allows daylight to access the space to the maximum extent. The daylight factor figure shown in Figure 33(a) shows that the daylight factor is 6.18, and the uniformity ratio is 7.2, reaching the standard of CIBSE for an art studio. Although the glare problem in Figure 34 still has a slight influence in the morning, as it is not a compulsory requirement for daylight performance, it can be solved by some shading devices.

2) Double-panel Low-e Glazing with 65% Visible Transmittance

Although the double-panel low-e glazing can protect the occupants from the



(a) (b)

Figure 33. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of single panel glazing with 88% VT.

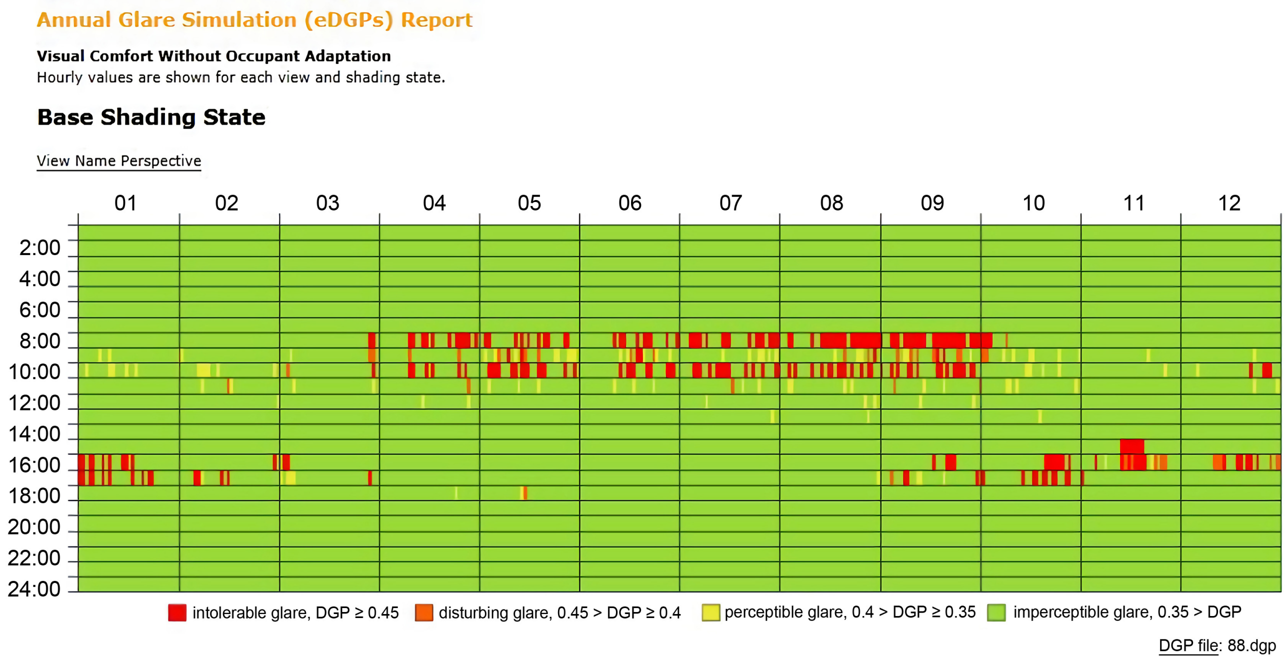


Figure 34. Daylight glare probability of single panel glazing with 88% VT.

glare problem (Figure 35), the material also reduces the daylight factor to 3.31 (Figure 36), which cannot fulfil the compulsory requirement of CIBSE for an art studio.

From the simulation analysis and the data comparison, Table 5 shows that although the low-e glazing can effectively reduce the glare, it also makes the daylight factor fail to reach the criteria of CIBSE. Therefore, single-panel glazing with 88% visible transmittance can be chosen for the art studio, and another shading device may improve the glare issues.

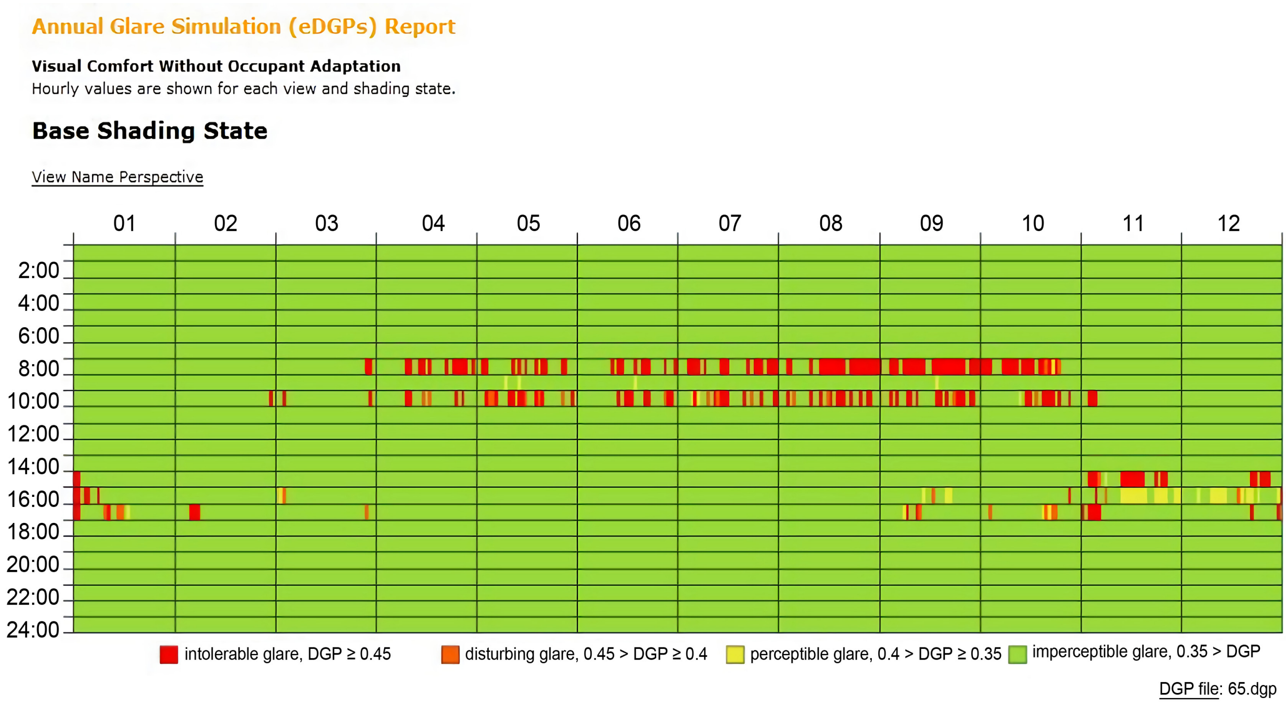


Figure 35. Daylight glare probability of double panel low-e glazing with 65% VT.

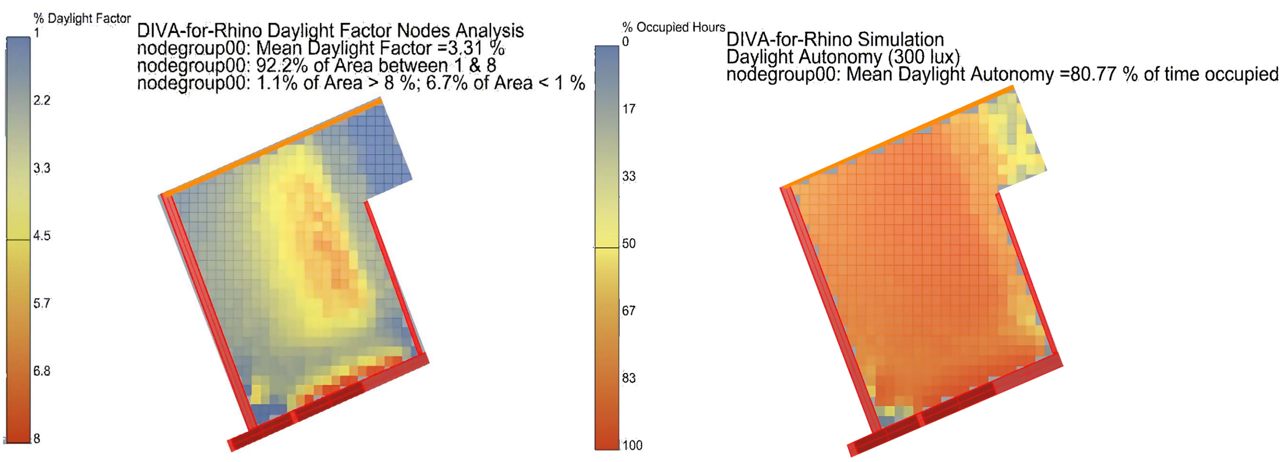


Figure 36. The simulation diagrams. (a) Daylight factor. (b) Daylight autonomy (300 lux) of double panel low-e glazing with 65% VT.

Table 5. Comparison data of different glazing.

	Single Panel Glazing	Double Panel Low-e Glazing
Visible Transmittance (%)	88	65
Mean Daylight Factor (%)	6.18	3.31
Meet the requirement of CIBSE	YES	NO
Minimum Daylight Factor (%)	4.4	1.0
Meet the requirement of CIBSE	YES	NO
Uniformity Ratio	0.71	0.33
Meet the requirement of CIBSE	YES	NO
Occupied time of 300 lux-Daylight Autonomy (%)	90.05	80.77
DGP	High	Low

Table 6. Comparison data of original building and renovation building.

	Original	Renovation
Main Window Size	Horizontal window: (1000 mm × 1100 mm) × 3	Horizontal Window: 2500 mm × 8000 mm Skylight: 3200 mm × 15000 mm
Window to Wall Ratio	1:30	1:3
Mean Daylight Factor	1.29	6.18
Meet the criteria of CIBSE	NO	YES
Minimum Daylight Factor (%)	0.4	4.4
Meet the criteria of CIBSE	NO	YES
Uniformity Ratio	0.46	0.71
Meet the requirement of CIBSE	NO	YES
Occupied time of 300 lux-Daylight Autonomy (%)	48.08	90.05
DGP	Low	Relatively Higher

3.5. Discussion

This study shows that the daylighting performance of old factory buildings is not as good as expected, and they cannot be directly used as art studios without renovation of the window design and façade design. Through case studies, designers of similar projects have offered several feasible recommendations and suggestions.

However, this study primarily focused on the daylighting performance part of the art studio, with recommendations based on previous studies and strategies. Using the control variable method, designers can make choices according to different needs of daylighting performance.

The thermal and visual comfort aspects of an art studio renovated from an old factory should be continued in further research, and on-site measurements are required to test the proposed designs. In addition, overall building performance studies and integrated building designs are also needed to support local governments in further promoting energy-efficient and environmentally friendly buildings.

4. Conclusions

Through the quantitative analysis shown in **Table 6**, by controlling variables such as window to wall ratio, window types and positions, glass types, and light transmittance, the simulation test was conducted according to CIBSE standards using the software DIVA-for-Rhino, which ultimately led to the identification of the optimal window and facade design options. Specifically, the window to wall ratio would enlarge from 1:30 to 1:3, and the window type would be more diverse, including horizontal windows and skylights. Although there will be some intolerable glare in the early morning from 8:00 am to 10:00 am after renovation, the other daylight performances are satisfactory, which can meet the requirements for an art studio. It solves the original drawbacks of the old factory such as lack of light and glare generation.

In China, the transformation of old factories into art parks has gradually become an important method of urban micro-renovation and is an effective way to combine the city's historical industrial culture with modern art. As the function of the building changes, the needs of the new users also change, so good lighting will be the key to this renovation task. This study proposes a solution for improving the lighting problem of old factories, giving them new energy, bridging the past and the future, becoming a new carrier for the flourishing of the art field, and promoting the innovation and practical development of old factory culture in China.

Author Contributions

Conceptualization: Pei Pei; methodology: Pei Pei and Shuang Jiang; software: Pei Pei and Shuang Jiang; validation: Pei Pei and Yiwei Men; formal analysis: Pei Pei and Shuang Jiang; investigation: Pei Pei and Shuang Jiang; resources: Pei Pei, Yiwei Men; data curation: Pei Pei; writing original draft preparation: Pei Pei, Yiwei Men; writing review and editing: Yiwei Men; visualization: Pei Pei and Shuang Jiang; supervision: Yiwei Men. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data in this paper are given in the tables and figures within the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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