ISBN: 978-981-18-5852-9
WCSE 2022 Spring Event: 2022 9th International Conference on Industrial Engineering and Applications
doi: 10.18178/wcse.2022.04.149

Visual Comfort Improvement of Public Workspace: A Product Design Guided by Lighting Simulation

Yige Fan [1], Shikang Wen [2], Jiatong Yue [3], Wen Yuan [4] and Jiao Xue [1 +]

[1] Shanghai Jiao Tong University, Shanghai, China

Abstract. A comfortable visual environment in public space can effectively enhance people's physical and mental experience when working indoors. In this study, rhino software was used to simulate the visual environment of the main library of Shanghai Jiao Tong University. DGP indicators were used for data analysis and evaluation before the product design process began. The effective shading size of the product is obtained through simulation. Under the guidance of this size, a product that can effectively improve visual comfort for public workspace is designed.

Keywords: workspace, visual comfort, visual environment improvement, product design

1. Introduction

Indoor visual comfort has great influence on the mental state and body feeling of indoor people [1]. A good indoor visual environment can effectively improve people's indoor visual comfort, so as to produce positive incentives for people's indoor study, work and other behaviors, and improve concentration and efficiency. At the same time, visual comfort can also make people happy and energetic.

The existing modern workspace takes the public building as an example, they usually choose fully transparent floor-to-ceiling windows to meet the lighting needs and the aesthetics of the building's facade. But at the same time, too much lighting will make the sunshine directly on the desktop, causing injury to eyes due to the uncomfortable glare, then affecting people's study and work efficiency[2].

Conventional methods, such as installing curtains or using blinds, solve the glare problem, but affect the aesthetics of the building facade and the environment in the public space.

Designers in the design discipline are trying to solve this contradiction between beauty and glare by designing portable products. Using software rhinoceros as a simulation platform, the researchers introduced DGP as an evaluation index. They simulate the data through this platform, and then guide the product design. However, the resulting product is limited by traditional design methods and can only reduce DGP on a few days of the year at specific times[3].

Our research motivation was to improve on this approach and design a new portable sunshade product. Compared with the existing design research, the effectiveness and functionality of the product produced by our research have been greatly improved through simulation. It can greatly reduce DGP to a more comfortable index range in multiple periods of each day, effectively solving the glare problem.

2. Guide Current Status Of Library Lighting Environment

Modern library plays an irreplaceable role in the convenience and efficiency of learning, office, and life for university teachers and students, and local citizens.

This library has four floors in total, and each floor has an E corridor connecting ABC's three workspaces. The area most affected by the glare problem is the fourth floor. Starting around 9 a.m., glare problems plagued the E corridor until around 4 p.m. In the ABC three workspaces, glare problems also began to appear in the mid-afternoon.

+ Corresponding author. Tel.: 86+156 1861 7216;
E-mail address: xuejiao@sjtu.edu.cn.

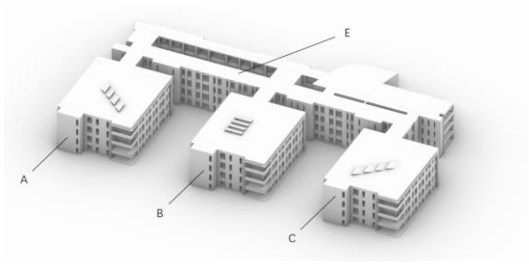

Fig. 1: Model of the main library of Shanghai Jiao Tong University.

Troubled by this problem, teachers and students began to take some proactive measures, such as carrying their own umbrellas to protect themselves during study. But there are several obvious problems with this practice. First, it is not convenient to carry an umbrella with you every day. Second, it takes a long time to fix the position of the parasol. Third, the opening of the parasol affects the feeling of the environment brought by the library and encroaches on other people's workspace.

3. Analysis Of Daylight Glare

3.1. Glare Evaluation Index ——Daylight Glare Probability

Daylight Glare Probability is an indicator to describe the probability of glare occurring, here in after referred to as DGP [4]. As a powerful glare metric，DGP can detect glare sources through the contrast of direct sunlight, as well as specular reflections.

In formula 1：

E_v is the vertical eye illuminance.

L is the luminance of source.

ω is the solid angle of source.

P is the position index.

$$\mathrm{DGP} = 5.87 \times 10^{-5} E_v + 9.18 \times 10^{-2} \log\left(1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16 \qquad (1)$$

Table 1: DGP CLASSIFICATION

DGP level	DGP value
Intolerable	0.45≤DGP
Disturbing Glare	0.40≤DGP<0.45
Perceptible Glare	0.35≤DGP<0.40
Imperceptible Glare	DGP<0.35

The higher the DGP, the higher the probability of glare problem [4]. According to the scale of DGP (Table1), when the DGP is below 0.35, it’s in an imperceptible level.

3.2. Simulation Methods

In this study, we used DGP to evaluate the effectiveness of the product. We used Ladybug and Honeybee as the simulation platform, which is plug-in Grasshopper from Rhino. [6,7].

We use below steps to test DGP(Fig2)：

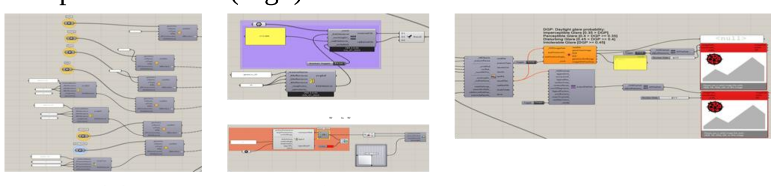

Fig. 2: The programming of DGP simulation.

Step1： Assign the material for different architectural components and define their parameters.

Step2： Installed a virtual library user in the building.

Step3： Input the weather data of Shanghai.

Step4： Running the simulation and get target DGP data.

3.3. Design Evolution

Our research defines DGP decline as the research goal and uses this as a basis to judge the effectiveness of the product.

We set December 30, 2020, as the target date for the simulation. From 13 to 17 o'clock on this day, we ran simulations every hour. The idea of our design evolution was to add sunshades to the architectural simulation to block the sun rays, and we used the program to simulate and calculate the DGP of different schemes and compare them with the results without sunshades.

Table 2: EXPERIMENTAL GROUP

	Height of the prototype （meter）	**Angle between the prototype and user （degree）**
A	0	0
B0	0.6	0
B1	0.8	0
B2	0.9	0
B3	1.0	0
B4	0.9	30
B5	1.0	30

Table 3: CONTROL GROUPS

	groups
Control group1	A、B0
Control group2	A、B0,B1,B2,B3
Control group3	A、B2、B4

We set the visual environment without sunshade as group A. Based on the rectangular sunshade with a width of 0.6m, we designed the strategy group B0. From the height of the sunshade and the included angle between the sunshade and the user, we carried out data iteration. Finally, we proposed five optimization design strategies from B1 to B5, compared four groups of DGP data to find suitable product design elements.

As shown in TABLEⅢ, we set up three control groups to conduct simulation comparison of different design strategies. In this way, we compare the actual product factors that affect the shading effect and determine the engineering size of the product design.

4. Optimal Product Design

4.1. Product Introduction

We finally developed a portable 180° mobile shading device. The mobile sunshade device is 40cm long and 5cm in diameter when folded up and 1m high when fully opened.

Fig. 3: Three states of product.

It has three states: a fully closed state, a half open state and a fully open state (Fig3).

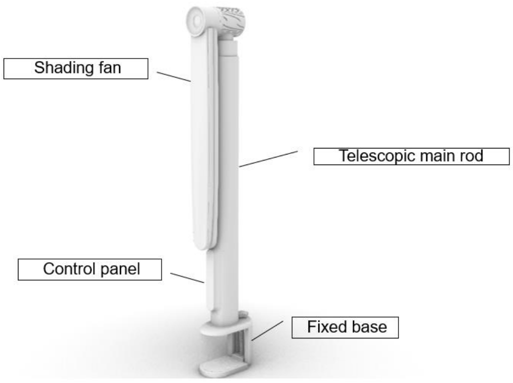

Fig. 4. Portable 180° mobile shading device.

The product is composed of four parts, from bottom to top: fixed base, control panel, telescopic main rod, shading fan (Fig.4).

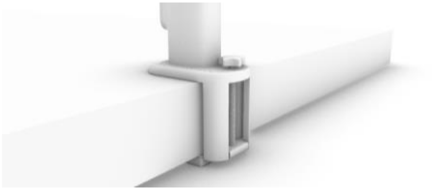

Fig. 5. Fixed with desk.

The fixed base mainly plays the role of fixing the position of the product, and its upper part is connected with the telescopic main rod. When using, the desktop is stuck in its depression. By adjusting the knob on the base, the distance between the upper and lower parts of the base is controlled, so as to clamp the desktop and realize the function of fixing the product on the desktop (Fig. 5).

Fig. 6. Control panel.

As the interactive interface between the user and the product, the control panel is the part for the user to actually operate the product (Fig6). It is attached to the surface of the telescopic main rod. The control panel has two functions: on the one hand, it can touch the screen to control the expansion and expansion of the product; on the other hand, it can display information, such as the use time.

Fig. 7. Telescopic main rod.

The lower part of the telescopic main rod is connected with the fixed base, and the upper part is connected with the sunshade fan through the movable component (Fig7). The telescopic main rod is composed of two levels of rods. The length of the contraction state is 40 cm, and when extended, the secondary rod extends upward, with a total length of 70 cm. The lower part of the rod is provided with a control motor. The rod is controlled by the control panel, and can be adjusted to extend the height in practical use, which can be telescoped within the range of 40-70 cm.

Fig. 8. Shading fan and movable component.

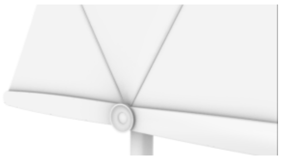

Fig. 9. Unfolded shading fan.

The shading fan is connected by a movable component and a telescopic main rod (Fig8). The shading fan has two forms of contraction and expansion. When retracted, the shading fan drops down and is close to the main rod. When unfolded, a sunshade surface with sunshade function is formed (Fig9). The movable component can rotate around the telescopic main rod, thus driving the sunshade fan to rotate. At the same time, the active component is equipped with a control motor, which is controlled by the control panel. In practice, it is controlled to rotate in the range of [-90°, 90°] through the control panel.

4.2. Interactive Display Of Product

The use and control of the product is realized by control panel. The control panel is divided into three areas from top to bottom: the upper part is the display area, the middle is the control area, and the lower part is the switch button.

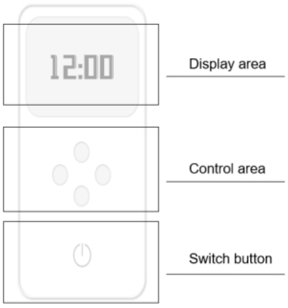

Fig. 10. Function division of control panel.

In practice, the user first fixes the product on the appropriate table position through the fixed base. Then long press the power button on the control panel to wake up the product.

Through the control area of the control panel (Fig10), press the up and down keys to control the expansion main rod part of the product to expand up or shrink down. Touch the switch button again for a short time, and the shading fan appears fully open. Control the left and right keys to realize the Angle rotation of the shading part.

The upper display area of the control panel will show the product's age and the weather conditions of the day.

5. Conclusion And Future Work

5.1. Experimental analysis

According to Fig.11, it can be seen that for the basic strategy B0, the sunshade basically did not play a role, and its DGP did not change significantly compared with group A.

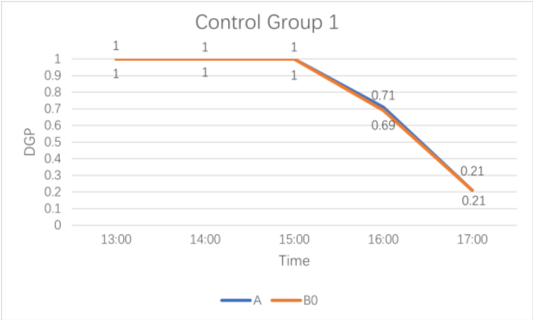

Fig. 11. Control group 1.

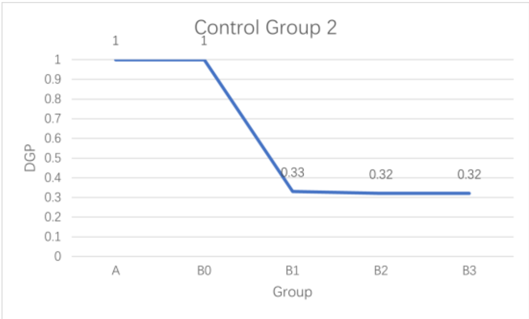

Fig. 12.Control group 2.

According to Fig.12, we did not change the included angle between the sunshade and the user, but gradually increased the height of the sunshade. As the height increased to 0.9m, the DGP decreased significantly from 1.00 to 0.32 at 13:00 o'clock. The DGP was less than 0.35 which was comfortable enough for the user. At the same time, we found that when the height was increased again, the influence of sunshade on DGP was no longer significant.

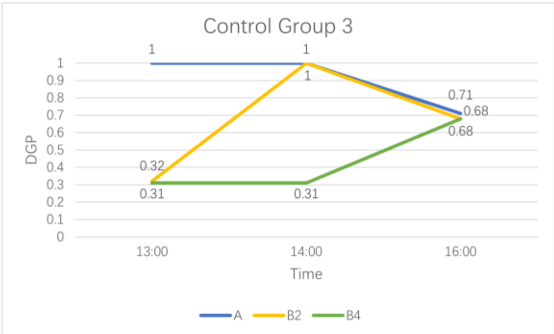

Fig. 13.Control group 3.

According to Fig.13, when the height of the sunshade was 0.9m and the angle between the sunshade and the user was rotated to 30°, DGP decreased significantly from 1.00 to 0.31 at 14:00, achieving the target DGP value.

Based on the above three control groups, we obtained rough constraints in the subsequent product design and implementation process. The part of our sunshade equipment below 0.6m was in invalid sunshade space. Only when the height of the equipment was appropriate, the sunshade task could be performed. At the same time, the angle between the appropriate sunshade equipment and the user also had a positive effect on reducing DGP.

Based on the above analysis， we framed the height of the product to 100cm, and limit its range of motion to 40-100cm in the vertical direction. And from a functional point of view, the product was designed a mechanical structure that can move freely to match the changing angle of the sun.

5.2. Analysis and comparison of results

We simulated the actual shading effect of the design. In the simulation software, we built a rod that its height could be adjusted between 0.4 to 0.7m, and a semicircle with a radius of 0.3m that can rotate 180°

with the rod as the axis on the upper part of the rod and we used this component to replace our design product.

By adjusting the height and rotation angle of this component, we simulated the DGP value from 13:00 to 17:00 o'clock on February 20 and December 30.

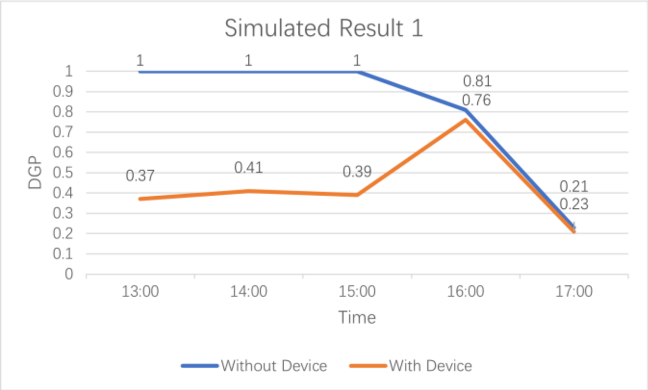

Fig. 14. Simulation on February 20.

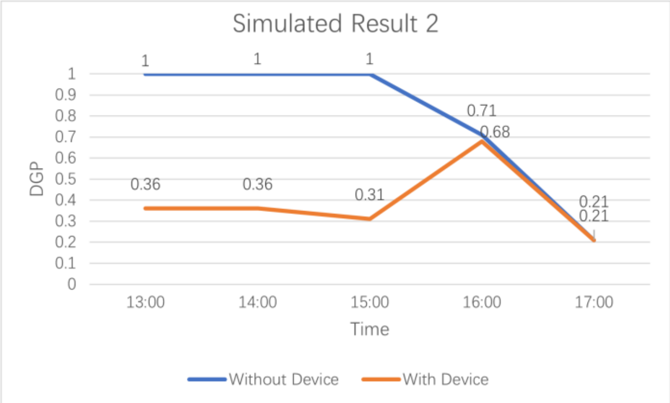

Fig. 15. Simulation on December 30.

As can be seen from the Fig.14,Fig.15, We conducted two comparisons on the two target dates respectively to compare DGP values without and with shading devices. On February 20, when our product was set up in the simulation environment, the measured DGP was controlled below 0.41 between 13:00 and 15:00, and had a downward trend between 16:00 and 17:00, with a value of 0.21-0.76. On December 30, when our product was set up in the simulation environment, the measured DGP was controlled below 0.36 between 13:00 and 15:00, and had a downward trend between 16:00 and 17:00, with a value between 0.21-0.68.

In the existing design study, which used a square slab as its base form, the DGP value dropped below 0.35 at 6 p.m. on February 20 and 5 p.m. on December 30[4]. Our umbrella shaped product has achieved a breakthrough in both effectiveness and functionality

5.3. Innovations and future work

Our research has the following two innovations.

Firstly, we introduced a glare evaluation index, DGP, which makes our design strategy more reliable than the traditional design process. The design of the product is no longer determined by the designer, but guided by data from the very beginning, which ensures the shading effect of the final product.

Secondly, our research resulted in a portable sunshade product that can rotate 180°. The design of the product meets our research objective: to improve visual comfort by reducing DGP to solve glare problems.

In our final simulation test, our product was able to reduce the DGP from 1 to less than 0.41 between 13:00 and 15:00 of the two target dates selected. The validity of the designed product is verified, and the rationality of the optimized design strategy is verified.

The limitations of our research are as follows: First, from the perspective of design strategy, although this design process is guided by simulation results, it is not closely combined with theories related to visual environment. Second, from the perspective of product design, our product design still has a lot of room for improvement in user experience. Third, according to the target results, our product has not yet achieved the optimal improvement in visual comfort, and has not achieved a significant decrease in DGP for the whole time of one day.

In the future research work, we will be committed to providing a more intelligent product design generation method, optimizing the target-oriented algorithm and proposing the scientific path of product design. At the same time, our ultimate goal is still to explore how to reduce DGP. In addition, we will further improve the product from the perspective of design, considering the product attributes of the design results, so that it has more industrial aesthetics and more functions. Our products should be more intelligent and sustainable, so as to improve users' experience and enhance their psychological happiness.

6. References

[1] M. B. C. Aries, J. A. Veitch, and G. R. Newsham, "Windows, view, and office characteristics predict physical and psychological discomfort," *Journal of Environmental Psychology,* vol. 30, no. 4, pp. 533-541, 2010.

[2] P. Leather, M. Pyrgas, D. Beale, and C. Lawrence, "Windows in the Workplace: Sunlight, View, and Occupational Stress," *Environment and Behavior,* vol. 30, no. 6, pp. 739-762, 1998/11/01 1998.

[3] J. Xue, Y. Wang, and M. Wang, "Smart Design of Portable Indoor Shading Device for Visual Comfort—A Case Study of a College Library," *Applied Sciences,* vol. 11, no. 22, 2021.

[4] J. Wienold and J. Christoffersen, "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras," *Energy and Buildings,* vol. 38, no. 7, pp. 743-757, 2006.

[5] J. Y. Suk, M. Schiler, and K. Kensek, "Investigation of existing discomfort glare indices using human subject study data," *Building and Environment,* vol. 113, pp. 121-130, 2017/02/15/ 2017.

[6] N. Nasrollahzadeh, "Comprehensive building envelope optimization: Improving energy, daylight, and thermal comfort performance of the dwelling unit," *Journal of Building Engineering,* vol. 44, p. 103418, 2021/12/01/ 2021.

[7] L. Giovannini, F. Favoino, V. R. M. Lo Verso, A. Pellegrino, and V. Serra, "A Simplified Approach for the Annual and Spatial Evaluation of the Comfort Classes of Daylight Glare Using Vertical Illuminances," *Buildings,* vol. 8, no. 12, 2018.