

Window view clarity and glare with perforated shading systems: simulation versus user assessment

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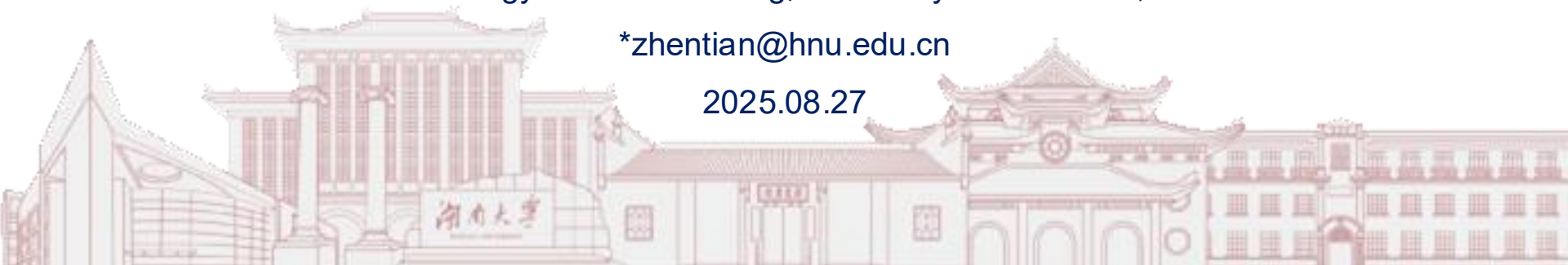
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Outline

01

Introduction

02

Methods

03

Results

04

Discussion

05

Conclusions

1

Introduction



Introduction



Glare in buildings



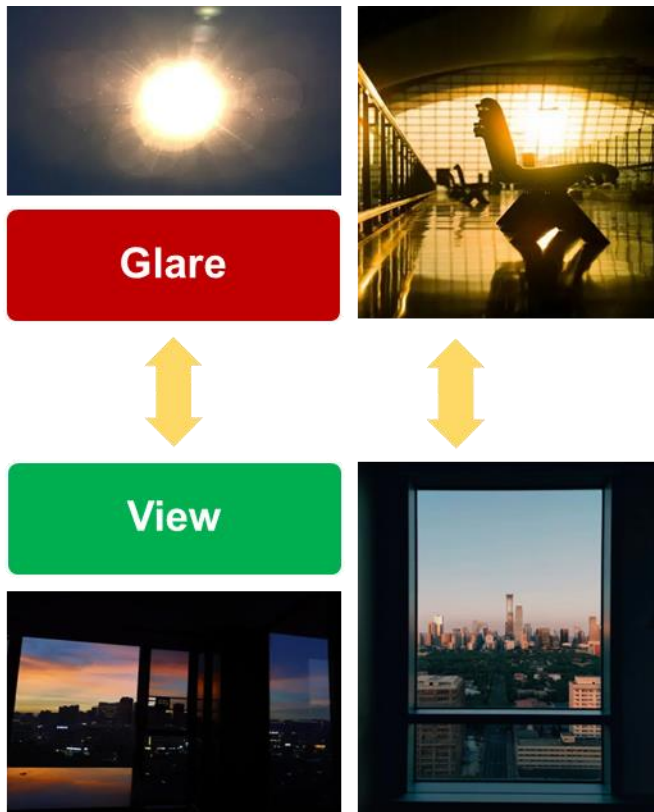
Close the curtains



Beautiful views

A common life problem:
We lose beautiful outdoor views to reduce glare in buildings.

Introduction



The relationship between View and Glare
in building indoor environment

Core question:

How to balance View and Glare in indoor environment?

Maybe we can use...



Fabric



Louver



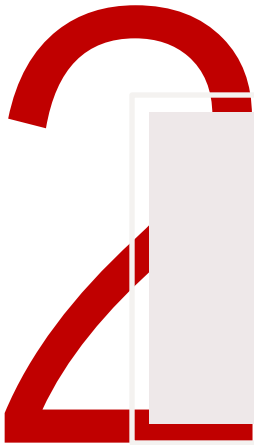
perforated panel



perforated panel

Aims:

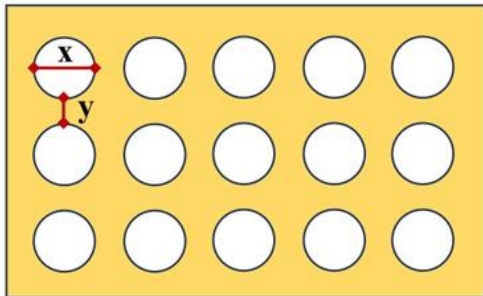
1. To evaluate and compare the view clarity of perforated panels based on **simulations and user feedback**, identifying key design factors such as color and perforation rate;
2. To develop a **quantitative method** for assessing the glare control performance of shading products;
3. To explore the relative importance of **view clarity and glare control** in overall visual experience and user preferences, in order to create a more balanced evaluation framework;
4. To discuss additional factors affecting view clarity, such as changes in **solar position**.

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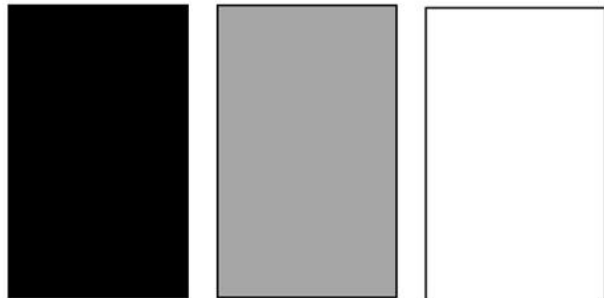
Methods



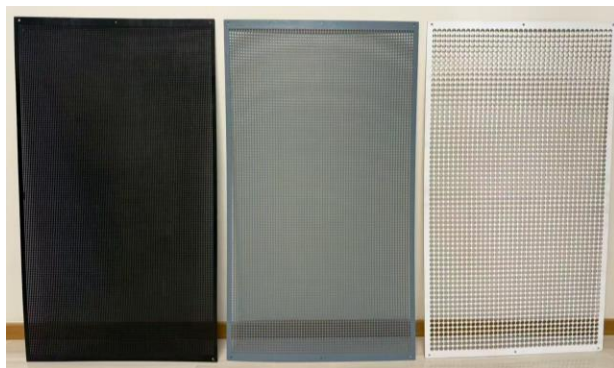
Methods: Design and Fabrication of Perforated Shading Panels



Design of perforated shading panels



Fabrication of perforated shading panels



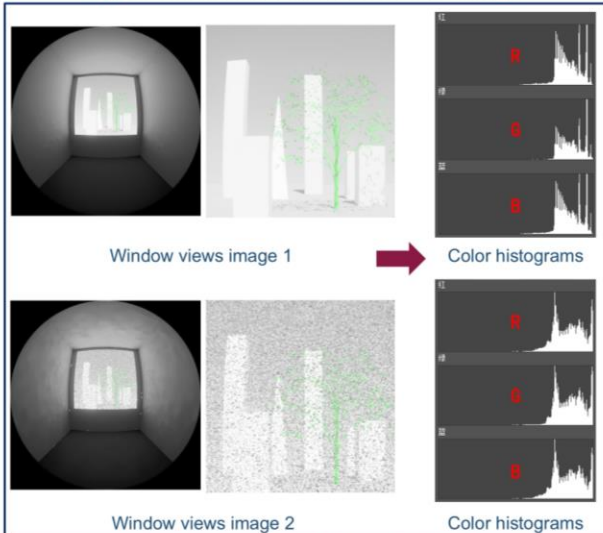
Hole Diameter (mm)	Spacing (mm)	Perforation Rate (%)	Surface Color
1.5	1.5	19.6 (20)	Black / Grey / White
3.0	1.5	34.9 (35)	Black / Grey / White
6.0	1.5	50.3 (50)	Black / Grey / White
12.0	1.5	62.1 (60)	Black / Grey / White

Methods: Design and Fabrication of Perforated Shading Panels

Why were these perforation rates selected?

In a previous simulation study¹ using Radiance, we identified that the optimal range of perforation rates of louver for balancing view quality, daylighting, and glare control falls **between 20% and 60%.**

Step 1: Extract color information from images



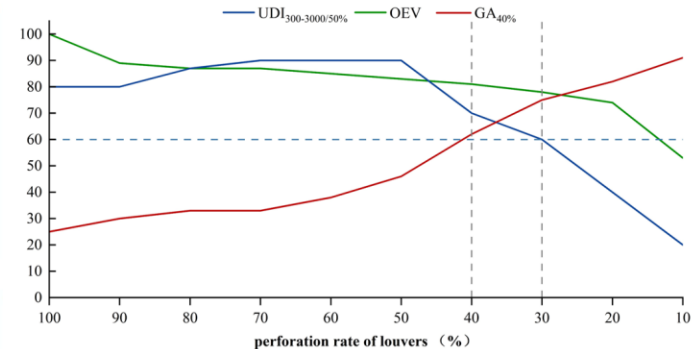
Step 2: Calculate the color similarity between image 2 and image 1

$$OEI = \frac{1}{3} \times \left(\frac{\sum_{i=0}^{255} D_i(R) + \sum_{i=0}^{255} D_i(G) + \sum_{i=0}^{255} D_i(B)}{256} \right)$$
$$D_i = \begin{cases} 1, & a_i = b_i \\ 1 - \frac{|a_i - b_i|}{\max(a_i, b_i)}, & a_i \neq b_i \end{cases}$$

Calculation formula

Step 3: Create a new quantitative metric

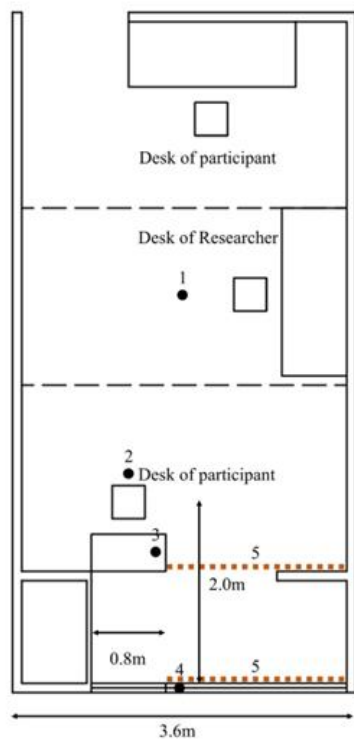
Outdoor Environment Visibility (OEI): By calculating the similarity between color images before and after the addition of louvers (higher similarity indicating better outdoor views), it is possible to quantify the differences in outdoor views resulting from changes in the CFSSs.



1 Guo, X., Zhao, Y., & Tian, Z. (2023). Impact of different perforation rates of perforated louvers on indoor visual comfort and outdoor views. Building Simulation Conference Proceedings, 18. <https://doi.org/10.26868/25222708.2023.1455>

¹ Smeulders, A. W. M., Worring, M., Santini, S., Gupta, A., & Jain, R. K. (2000). Content-based image retrieval at the end of the early years. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22(12), 1349–1380.

Methods: Experimental Setting



7.2m

Legend

1. Temperature sensor
2. Luminance camera
3. Illuminance sensor
4. Illuminance sensor
5. Black-out curtain

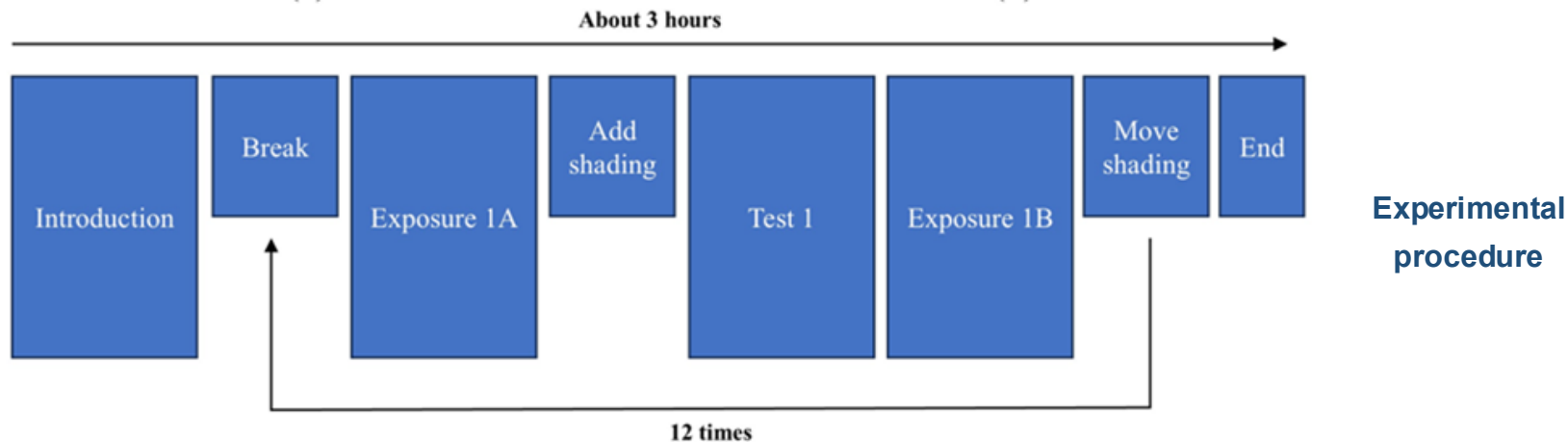


The office space in Changsha, China

Window view

Methods: Experimental procedure

To reduce the impact of changing daylight conditions, the experiment was carried out on clear, cloudless days between **10:00 and 15:00**. At the beginning, participants were given an explanation of the experiment, including **the meaning of glare and view clarity, how to fill out the questionnaire, and a look at all twelve perforated shading panels**. After a short break, they first observed the outdoor view without any shading to identify outdoor elements (e.g., buildings, roads) and evaluate glare. Then, a randomly selected shading panel was installed, and participants rated the clarity of the view through the panel. After that, they rated the glare again with the shading. After another short break, the process was repeated for the remaining eleven panels. The whole experiment took about three hours.

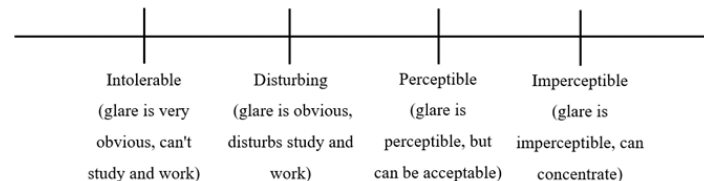


Methods: Experimental procedure

Questionnaire overview

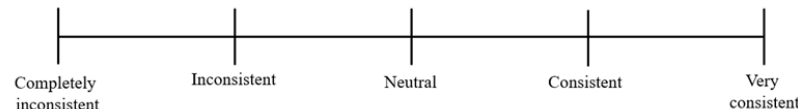
Section	Content	Evaluation method
Part 1	Participant Information Age, gender, visual condition (e.g., normal vision, glasses if needed)	Basic data collection
Part 2	Evaluation under Unshaded Condition ① Object identifiability ② Evaluating glare	① Object identifiability: number of visible categories ② Evaluating glare: subjective perception after viewing window (at least 1 minute)
Part 3	Evaluation under Shaded Condition ① Object identifiability ② View clarity ③ Evaluating glare	① Object identifiability: number of visible categories ② View clarity: detail clarity, color recognition, weather recognition, and satisfaction Likert scale (0–1, step=0.1) ③ Evaluating glare: subjective perception after viewing window (at least 1 minute)
Additional	Discomfort & Preference ① Visual discomfort after panel added ② Glare–clarity trade-off preference	① Open-ended for discomfort ② Continuous scale (e.g., from "No glare" to "Very clear view") with labeled anchor points

2. Please look up at the window for about one minute. Do you currently feel any glare from outside? Please mark your response with a ✓ on the line below.



Evaluating glare

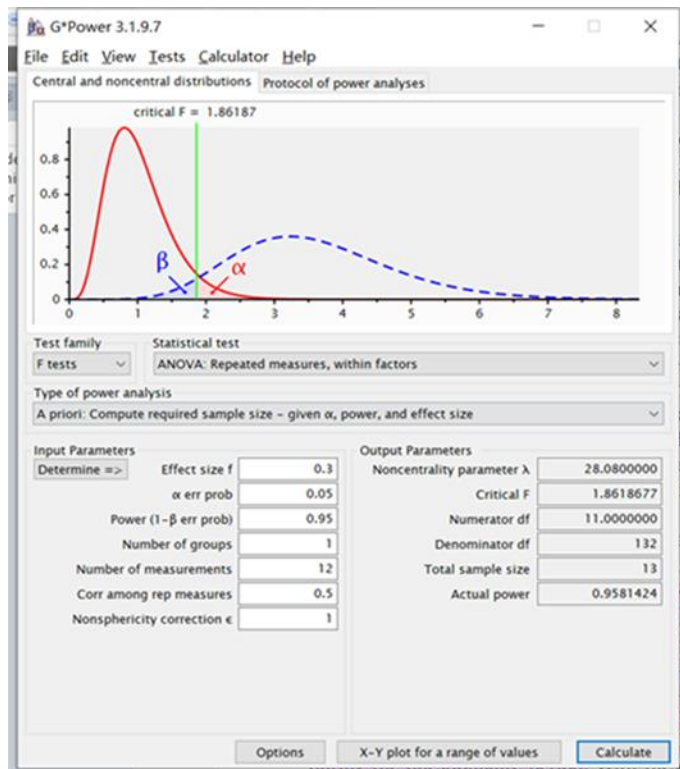
3. Compared to the view without the shading panel, how similar do you think the colors of the outdoor scene are now? Please mark your evaluation with a ✓ on the line below.



View clarity: Color

Sample questions from the questionnaire

Methods: Experimental procedure



G*Power sample size calculation

The G*Power analysis showed that at least 13 participants were needed.

Category	Details
Total Participants	27
Valid Data	25
Excluded	2 (due to weather changes)
Gender	Male: 10 Female: 15
Age Range	18–38
Average Age	24.92
Background	Architecture or related fields

Methods: Statistical analysis

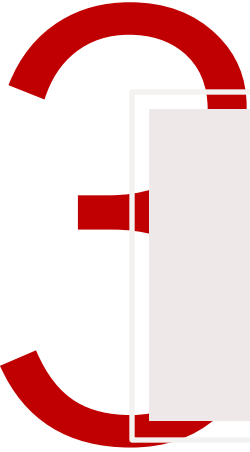
This study employed two statistical methods to analyze the experimental data.

Descriptive statistics

were used to summarize the scores for each shading configuration across all questionnaire items, including the **mean and median**. Violin plots were used to visualize the score distributions.

Wilcoxon signed-rank test

was used to examine **the statistical significance of differences** between shading configurations. Pairwise comparisons were conducted between different color groups and perforation rate groups. The significance level was set at $\alpha = 0.05$.

A red decorative graphic consisting of three curved segments arranged in a partial circle on the left side of the slide.

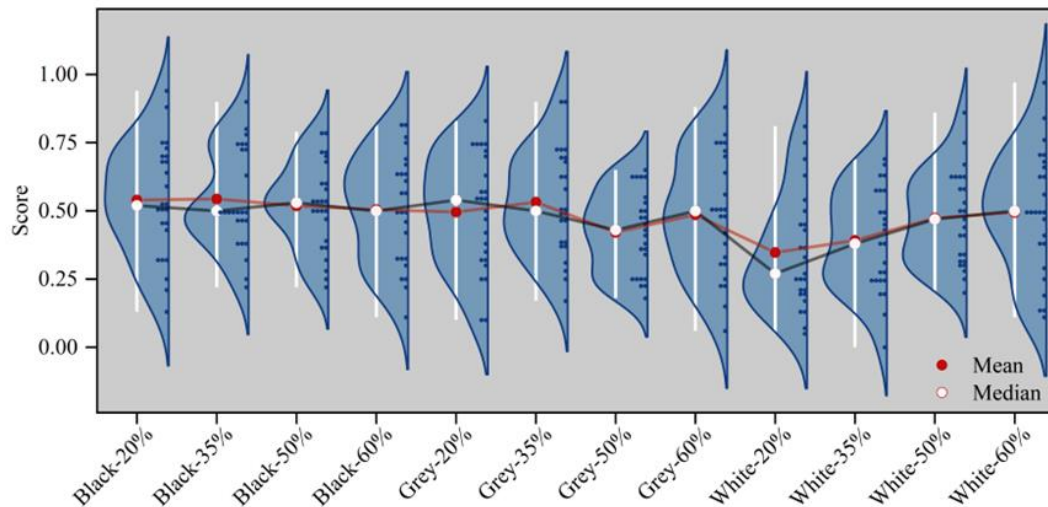
Results



Results: View clarity - Object detail distinguishability

Descriptive statistics - Different perforation rates had little impact on black and grey panels, while for white panels, a higher perforation rate led to higher detail scores.

Significance analysis - The main significant differences in detail perception scores were found between different colors.



Descriptive statistics of object detail distinguishability scores

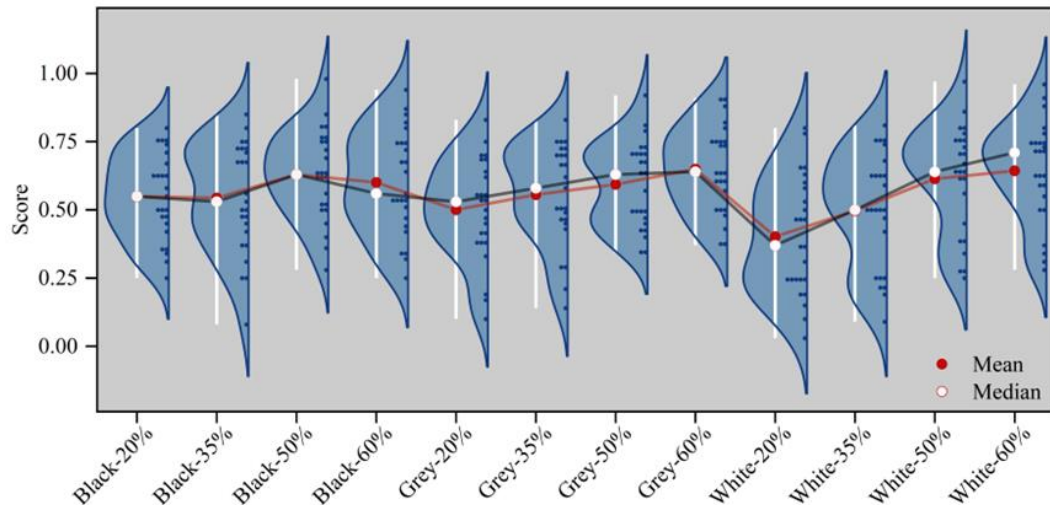
Pair	Z-Score	p-value
Black-Grey	-2.354	0.019
Black-White	-4.455	0.000
Grey-White	-2.602	0.009
20%-35%	-1.207	0.227
20%-50%	-0.539	0.590
20%-60%	-0.929	0.353
35%-50%	-0.533	0.594
35%-60%	-0.465	0.642
50%-60%	-1.167	0.243

Significance analysis of object detail distinguishability scores

Results: View clarity - Object color distinguishability

Descriptive statistics - Black and grey panels performed better than white ones. Additionally, higher perforation rates were associated with higher color scores.

Significance analysis - Except for the black-grey and 50%-60% perforation rate pairs, all other comparisons exhibited statistically significant differences.



Pair	Z-Score	p-value
Black-Grey	-1.169	0.242
Black-White	-2.490	0.013
Grey-White	-2.073	0.038
20%-35%	-2.497	0.013
20%-50%	-4.581	0.000
20%-60%	-4.911	0.000
35%-50%	-3.343	0.001
35%-60%	-3.902	0.000
50%-60%	-1.524	0.128

Descriptive statistics of object color distinguishability scores

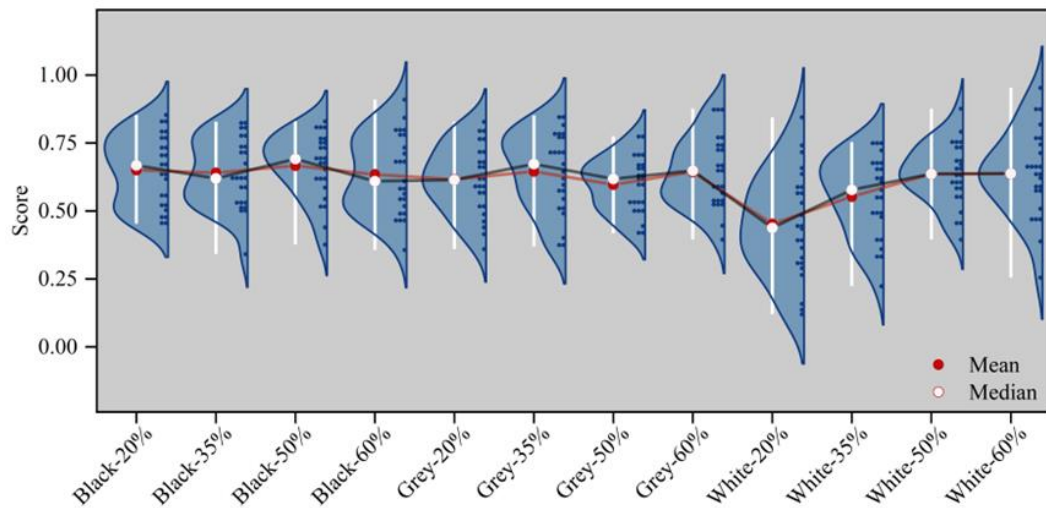
Significance analysis of object color distinguishability scores

Results: View clarity - Averaged scores

Average scores (based on the arithmetic mean of the six questions related to view clarity)

Descriptive statistics - Black and grey panels outperformed white ones. Among the white perforated panels, higher perforation rates corresponded to higher average scores.

Significance analysis - Significant differences mainly existed between different colors and between the 20% perforation rate and the other perforation rates.



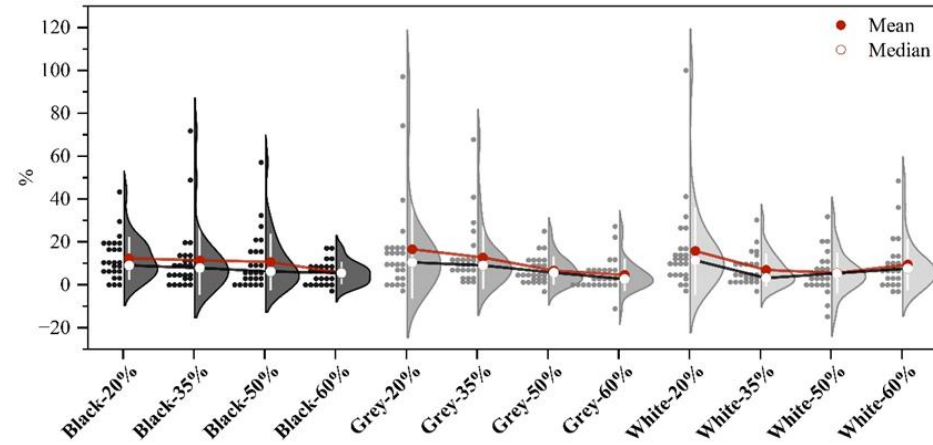
Descriptive statistics of averaged scores

Pair	Z-Score	p-value
Black-Grey	-2.229	0.026
Black-White	-4.753	0.000
Grey-White	-3.450	0.001
20%-35%	-2.454	0.014
20%-50%	-2.280	0.023
20%-60%	-2.283	0.022
35%-50%	-1.067	0.286
35%-60%	-1.242	0.214
50%-60%	-0.579	0.563

Significance analysis of averaged scores

Results: Glare (based on user perception)

To further quantify the glare control capacity of different perforated panels, this study recorded **the number of times perceptible glare occurred ($DGP \geq 0.35$) during evaluation trials without shading, denoted as N1**. It also recorded **the number of times perceptible glare was eliminated after applying the corresponding perforated shading panel ($DGP < 0.35$), denoted as N2**. **The ratio of N2 to N1 was then used to quantify the glare control capability of each shading panel, defined as the glare control index (GCI)**.

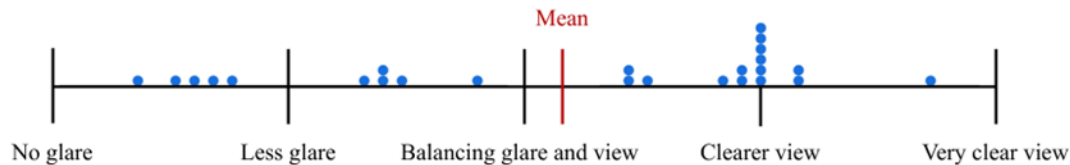


Distribution of glare reduction levels (%)
for different perforated shading panels

Color	Black				Grey				White			
Perforation rates	20	35	50	60	20	35	50	60	20	35	50	60
N1	10	17	13	16	14	13	14	11	15	11	11	14
N2	10	12	7	9	12	11	10	4	12	7	6	7
GCI	1.0	0.7	0.5	0.6	0.9	0.9	0.7	0.4	0.8	0.6	0.6	0.5

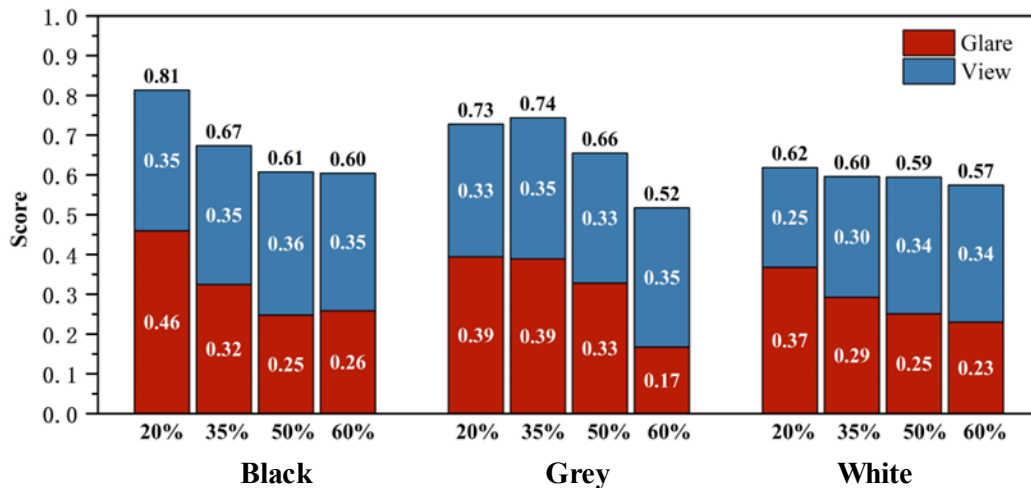
Glare control index of different perforated
shading panels

Results: Overall evaluation of view clarity and glare



User preference analysis showed a **weight of 0.54 for view clarity and 0.46 for glare control**, indicating a balanced preference. Based on these weights, shading panels with darker colors and lower perforation rates received higher overall scores.

User preferences for outdoor glare and view clarity in office



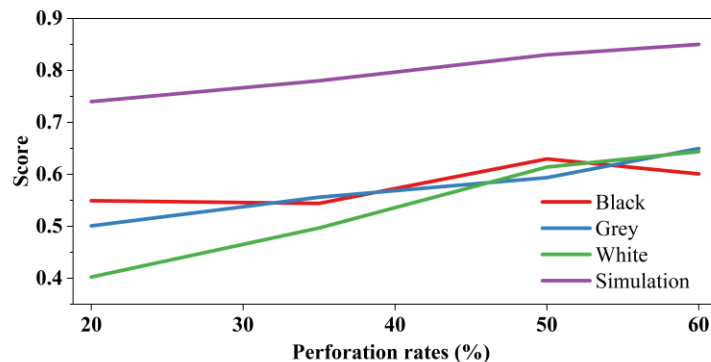
Overall scores of different perforated shading panels

A large, thick red graphic element resembling a stylized letter 'A' or a bracket, positioned to the left of the title box.

Discussion



Discussion: Simulation versus user assessment



Color evaluation vs. Simulation scores for different perforation rates

Color	R ² Value
Black	0.684
Grey	0.954
White	0.997

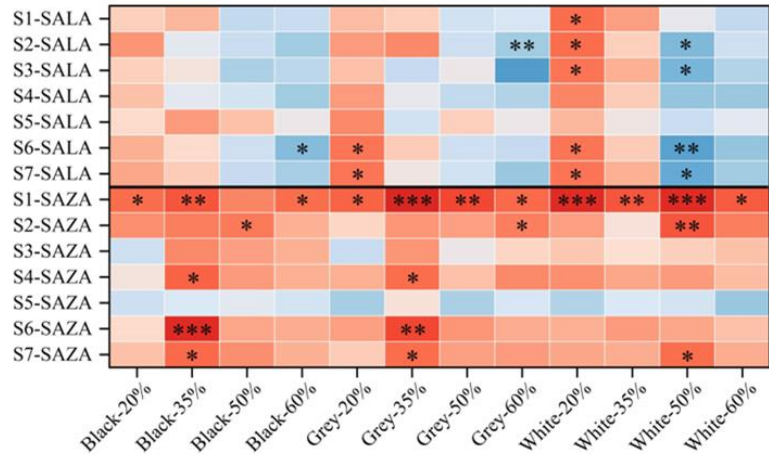
Linear fit (R²) between subjective color scores and simulated scores

Future Research Directions Based on Comparison Results:

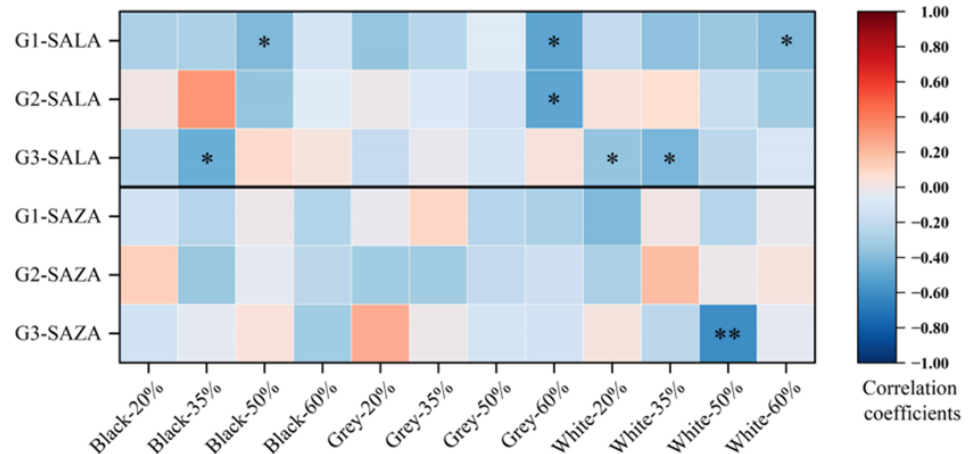
1. Can the **human eye's phototactic** (light-seeking) behavior be simulated?
2. Can the impact of **material surface color** on visual perception be reproduced through simulation?
3. How can simulation address the issue where, as **distance increases**, the human eye perceives things more clearly—yet simulated images may not reflect this effect?

Discussion: Solar position

Solar altitude and azimuth angles were correlated with view clarity and glare ratings, with azimuth angle showing a clear influence on clarity. Future work will focus on developing a controlled method for quantitative evaluation.



Correlation analysis between solar altitude angle (SALA), solar azimuth angle (SAZA), and view clarity



Correlation analysis between solar altitude angle (SALA), solar azimuth angle (SAZA), and glare evaluation

Discussion: Visual discomfort

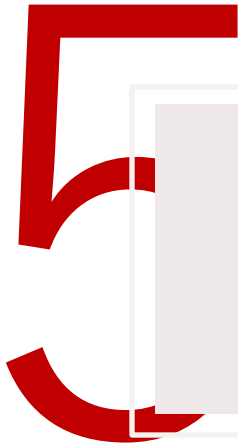
Many participants reported visual discomfort beyond glare, such as **dizziness or difficulty focusing, especially with panels that had larger holes and higher perforation rates**. The more open the panel, the more often discomfort occurred. **The cause and definition of this effect in daylighting design need further study.**

	Black				Grey				White			
Perforation Rate	20%	35%	50%	60%	20%	35%	50%	60%	20%	35%	50%	60%
Frequency	3	5	7	14	6	2	7	11	6	5	5	12
Percentage (%)	0.12	0.19	0.27	0.54	0.23	0.08	0.27	0.42	0.23	0.19	0.19	0.46
Percentage (%)	0.28				0.25				0.27			

Frequency of visual discomfort reported for shading panels with different perforation rates



Trouble focusing

A large, thick red graphic element on the left side of the slide, resembling a stylized '5' or a bracket.

Conclusions

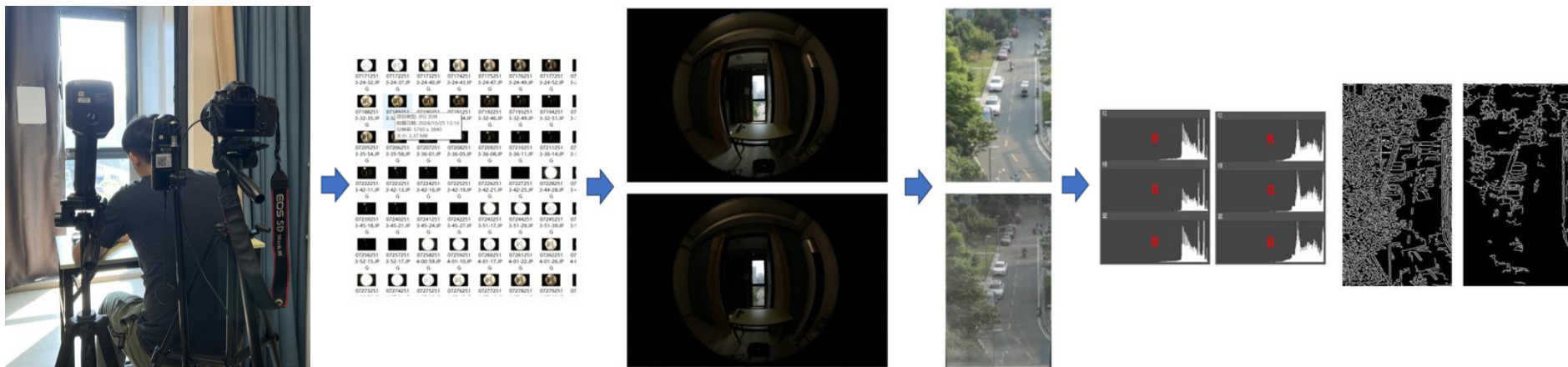


Conclusions

- 1. View Clarity:** The color and perforation rate of shading panels affect how clearly people see outside. Darker panels gave better view clarity. Higher perforation rates improved color and weather recognition but reduced overall clarity satisfaction, likely due to the hole patterns.
- 2. Glare Control:** A method was created to measure how well perforated shading systems reduce glare. Perforated shading systems with darker colors and smaller holes worked better at blocking glare.
- 3. User Preference:** Most users preferred a balance between clear views and glare control. Based on this, the overall scores were calculated. Perforated shading systems with darker colors and lower perforation rates got the best scores.
- 4. Other Factors:** The position of the sun affected view clarity and glare. Also, some users felt visual discomfort (like dizziness or eye strain) with panels that had large perforations. This may be due to the structure of the holes and needs more research.
- 5. Simulation versus user assessment:** Simulations show a good match with user feedback, and with appropriate methods, their effectiveness in reflecting human visual perception can be further improved.

Conclusions: ongoing work I

HDR cameras were used to capture window views during the experiment. Objective data—such as **color information** and **edge details**—are being extracted from these images.



Window View Transmission Quality Index, **WVTQ**
 $= A \times \text{Color Similarity Index (OEI)} + B \times \text{Edge Similarity Index} + C$

Conclusions: ongoing work II



A small testing platform was built using an adjustable LED lightbox. **Early tests showed it was over 80% similar to real-scene experiments.** In the next step, we will add glare and changing daylight to make it more realistic. **The final goal is to use this platform instead of full-size real-scene tests.**

Thank you! & Questions?

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