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The Daylighting Benefits of Semi-Enclosed Atrium: Based on the case study of Siyuan Centre

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Abstract: This report examined Siyuan Centre's light environment at Nottingham's Jubilee Campus. Analysing building orientation, glazing structure, environmental strategy, visual comfort, and passive energy-saving design met sustainable standards—daylight factor, spatial daylight autonomous, and functional daylight illumination. We explored how atrium daylight passively improves indoors.
On-site measurement, formula validation, and software simulation tested the atrium and two typical spaces. The test results showed that direct illumination caused glare in the atrium through the wide glazing, exceeding the comfort range. That affected nearby spaces, especially the two open-plan offices that use the atrium for indirect lighting. As an essential light source for them, the atrium provides an uneven and unstable light environment. This study proposed optimisation strategies for shading devices and section design to improve light distribution and reduce glare and simulated space performance after applying them.
Keywords: Daylighting, Atrium, Light Environment, Visual Comfort, Shading

1. Introduction

The research object is the semi enclosed atrium also known as the open sided atrium. The case studied is Siyuan Centre on the University of Nottingham's Jubilee Campus. A completed post-occupancy evaluation (POE) of this project mainly focused on energy and user satisfaction. In this study, the design for Visual comfort was the focus of research. Specifically investigated how the daylight from the atrium improve the indoor environmental conditions of adjacent spaces. The atrium and two typical spaces (Figure 1) were selected for detailed performance analysis. Targeted improvement strategies were proposed based on the analysis results, and the effect of the proposed strategy was compared with the existing performance.

Figure 1: The exterior (left), atrium (mid) and open plan office (right) of Siyuan Centre (G F Tomlinson)

In the atrium, the west side is facing outward, made of full glazing. It is speculated that the designer used this special form to provide a relatively indirect lighting method for two open floor offices. A group of long overhangs and vertical shading fins are on external side of the atrium (Figure 1), but in the measurements, it was found that the strategy have very limited improvement on the light environment. At the same time, too large glazing area is detrimental to energy efficiency.

Two spaces (B21 and C18) were initially used as open plan offices (Figure 1, Figure 2) connected to the atrium. Based on the questionnaire survey, some users had stated that they would be disturbed by noise from other floors and atriums while working here (QTC Projects 2014 p.13). The reason is probably that the atrium is also used as the main entrance and transportation space. the evaluator has suggested dividing some areas of the space into separate offices or creating more subdivision spaces (QTC Projects 2014 p.13). About open plan offices, a study pointed out it has an impact on privacy, while single person or shared office spaces have a positive impact on user happiness (Morrison & Smollan 2020). At present, the spaces have been changed (Figure 2). This change occurred after obtaining the BREEAM rating, which means that the performance of these spaces has not yet been evaluated, so it is necessary to test and analyse them again.

2. Research Strategy

This research used a combination of on-site measurement and computer simulation. Some Spaces worth studying were analysed. The advantages, potential and optimizing strategies of these Spaces were discussed. Finally, the predicted performance of the optimization was re-evaluated. The assess used BREEAM and IES recommended standards.

BREEAM stipulated that a good higher education building spaces should achieve an average daylighting factor (DF) of 2%. The uniformity is also required, that is, the uniformity ratio is at least 0.3 or the room satisfied the *room depth criterion* (BRE 2022 p.77)：

$$\frac{d}{W}+\frac{d}{hW}<\frac{2}{1-R_b}$$

Where

d-room's depth, w-room's width, h-window's height, R_b-average reflectance.

Climate based daylight modelling (CBDM) was used in assessment as well, that include:

Useful Daylight Illumination (UDI): Ratio of available illuminance in the range of 100 to 300 lux and ideal illuminance in the range of 300 to 3000 lux (IES 2021)

Spatial Daylight Autonomous (sDA):., the proportion of the space that is more than 300 lux in more than 50% of the occupied time: from 8:00 a.m. to 6:00 p.m (IES 2021)

Daylight autonomy (DA) corresponds to the percentage of time taken to meet the target illuminance at a certain point in space (Reinhart, 2001)

3. Existing Light Environment Investigation

Following the POE report, a number of patrons reported feeling uneasy due to the presence of glare. Nonetheless, some users are satisfied with these large window openings, believing that they maximize the use of natural light and improve the quality of these spaces (QTC Projects 2014 p.13).

3.1 On-site Measurement results

To evaluate the light environment of the atrium, B21 and C18, on-site measurements were conducted at 3:00pm, 21 March 2023 (Vernal Equinox), partly cloudy outside. The measurement points were distributed along the section in each space (Figure 2).

Table 1 Daylight illuminance (Unit: lux) Measurement Results (3:00pm, 21 March 2023, Partly Cloudy)

	1	2	3	4	5	6	7	8
Level C	251	989	1479	1136	1926	2510	3600	11000
Level B	N/A	468	358	279	526	3410	4560	

Based on test results (Table 1), B21 did not have uneven distribution of lighting, with windows concentrated in one area, causing other areas to be darker. However, the illuminance went to 4560 near the atrium at 3pm in the afternoon. The C18 open floor office is bright, with few observation points having low illumination.

Figure 2: The Original Plan (Left) and the Current Plan of Level B (Mid) & C (Right)

3.2 Daylighting Performance Simulation

Table 2 Daylight Prediction (by IES VE)

Area	DF for Overcast Sky	sDA: 300 lux 50 % (8:00-18:00)	Annual UDI 100-3000 Lux for DA	UDI Annual Average Lux
B21	Range: 1% to 27% Average =1.7% DF>2% =45%	47%	<25 = 16% 25-50= 30% 50-75=34% >75= 20%	Min. =179.7 Max. =3748.8 Average=871
New Offices	Range: 0% to 13% Average =1.07% DF>2% =66%	100%	50-75=40% >75=60%	Min.=505.20 Max. =3982.10 Average=1517.88
C18	Range: 0% to 17% Average =4.52% DF>2% =92%	100%	>75=100 %	Min. =742 Max. =4716.9 Average =2489.9
Atrium	Range: 4% to 54% Average =11.78% DF>2% =100%	100%	<25 = 16% 25-50= 30% 50-75=34% >75= 20%	Min. =3455.2 Max. =8506.3 Average =6942

Regarding the daylight factor test (Table 2), the average value of the atrium was 11.78%>10%, with a maximum value of 54%. The average daily weight factors for b21 and c18 enclosed offices were 1.7% and 1.07%, respectively. About the uniformity, these spaces all satisfied the room depth criterion (BRE 2022 p.77).

In the testing of CBDM (climate-based daytime modelling), except for B21, where the sDA ratio was 47%<50%, all other spaces were 100%. In the UDI test, except for B21 and the atrium, which were 54%, all other spaces were above 80%. The annual average illumination was above 300lux, but the atrium is 6942 lux, beyond the useful range.

3.3 Discussion

According to the measurement and simulation, the daylight factor and UDI in some areas were outside the ideal range. The sDA was better because it was no upper limit. The daylighting is excessive in the atrium, but insufficient or uneven in B21 and the enclosed offices on the Level C, only C18 open office provided a good visual comfort.

It could be considered that the daylighting performance on Level B and Level C regressed after being transformed into independent offices. Because the transmission of light was blocked by the walls, resulting in uneven daylighting, that could have been distributed over a larger area. At the same time, the south facing windows locations were concentrated on these two floors, providing limited direct daylighting.

In the atrium, the illuminance sometimes went extremely high, affecting connected spaces. The atrium did not provide ideal daylighting for the adjacent open floor offices, probably due to its shading and semi enclosed spatial form, that allowed too much light to enter Level B and Level C.

A usable shading design usually conforms the formula found by Denis Lenardic (2018):

$$w = D \cdot tan(\Phi - \Psi)$$

Where

w, D - The geometric shape of the vertical shading, Φ - Sun azimuth, Ψ - Plane azimuth

In this project, the building's orientation is 253 degrees, and the depth and spacing of the sunshade fins are 300mm. The sun's azimuth angle at 3pm on the summer solstice in Nottingham is 114.95. Based on the calculation, these did not satisfy the formula. That is the shading fins could not block all the westward sunlight, causing the strong sunlight to enter the atrium, affecting the light environment of B21 and C18.

4. Optimizing Strategies

4.1 Strategy 1: Optimization of Shading Devices

The effect of the existing shading design is not ideal. A reasonable external shading device can control the natural lighting in the room, reduce daylighting, and improve visual comfort. In addition, it can also control the solar thermal gain, improve the energy efficiency of the atrium, and reduce the use of primary energy (Luca F, Sep ú lveda A & Varjas T 2022).

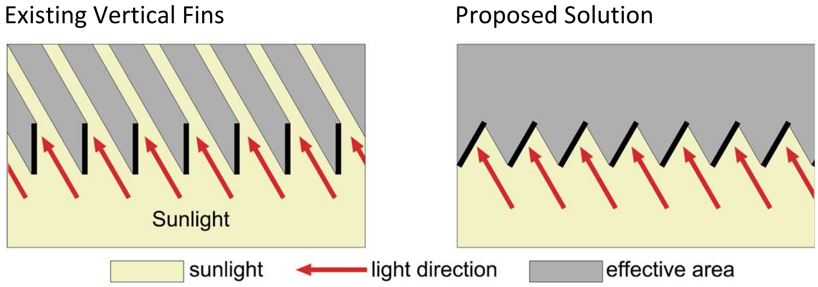

Figure 3: The Shading effects of the west vertical fins at 3pm on the summer solstice

In this optimizing, the vertical fins were changed into slanted vertical fins with a rotation angle of 30 degree, to achieve an effective shading area (Figure 3). After preliminary graphical analysis, the fins rotated by 30 ° can completely block out the sunlight at 3 pm on the summer solstice and provide a margin, which means it can provide better light buffering in the afternoon.

4.2 Strategy 2: Optimization of Spatial Form

The existing atrium design has a limited benefit on the light environment. In strategy 2, the form of the atrium was modified, divided into two parts that were staggered and interlocked (Figure 4). A part of C18 open floor office was placed above the entrance atrium, and the area below the roof light was set as glazing floor, serving as the ceiling lighting of the level B. This optimization can transfer excess light to the Level B with insufficient light to optimize the distribution of lighting and improve the uniformity of lighting.

The atrium was rearranged, several staggered platforms were formed, the incident light can provide a certain degree of buffering. Secondly, a part of the C18 open floor office was moved above the atrium, closer to the full height glazing, allowing the scenery to better blend into the office space through the glass. By dividing C21 into two parts, the number of users could be reduced in each space, which would be positive for users' psychology (Morrison & Smollan 2020).

The issue of noise interference with office work could be alleviated, because the office space located above the noisy area (the entrance), a large portion of the noise propagation path would be absorbed by the building structure with soundproofing materials, noise levels in open plan office can be reduced (Cekan P. et al. 2019).

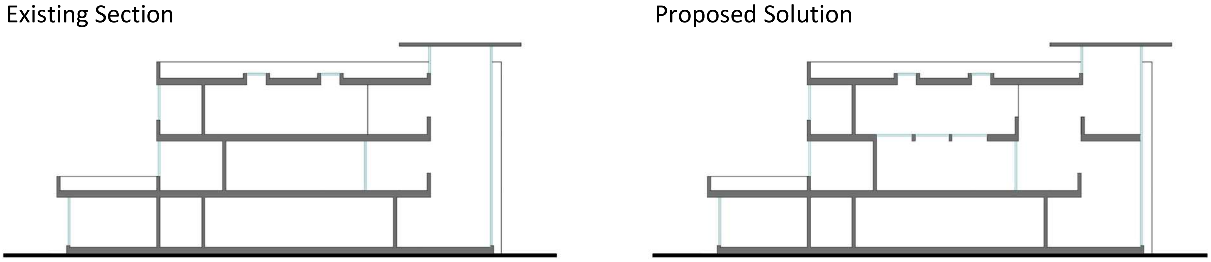

Figure 4: The building section and the proposed solution

4.3 Daylighting Performance Predictions

To test the effects of optimizing strategies, the changes were applied to digital model for testing, set up as two cases. The data were compared with the existing performance. Case 1 was the performance of the building after applying strategy 1. Case 2 was the performance after applying both Strategy 1 and Strategy 2.

In case 1, daylighting was controlled, and the percentage of UDI and annual average lux in the atrium reached a good level. However, due to the reducing of shading on overall daylighting, various test results of B21 and C18 enclosed offices decreased. The daylighting of C18 open office relies less on the atrium so it was not much affected (Table 3).

In case 2, the improved space redistributed daylight, achieving a daily light factor of 2% to 10% for each space, an sDA of over 50%, and an annual average lux of over 300. The percentage of UDI was still below 80%. (Table 4). It could be considered that the light environment was greatly improved compared to existing data and case 1, and the combined spaces reduce dependence on westward direct light and increase indirect lighting.

Table 3 Case 1 Daylight Prediction (by IES VE)

Area	DF for Overcast Sky	sDA: 300 lux 50 % (8:00-18:00)	Annual UDI 100-3000 Lux for DA	UDI Annual Average Lux
B21	Range: 0.1% to 6.2% Average =1.17% DF>2% =30.4%	26%	<25 = 39% 25-50= 32% 50-75=22% >75= 6%	Min. =96.5 Max. =1762.9 Average=418
New Offices	Range: 0.1% to 8.8% Average =1.86% DF>2% =60%	94%	25-50= 2% 50-75=73% >75= 24%	Min.=275.6 Max. =2099 Average=826.89
C18	Range: 0.4% to 9% Average =4.54% DF>2% =85%	85%	25-50= 9% 50-75=20% >75=70 %	Min. =210 Max. =3799 Average =1750
Atrium	Range: 0.5% to 16% Average =4.73% DF>2% =95%	100%	50-75=25% >75=74 %	Min. =332.3 Max. =3205.4 Average =1088.36

Table 4 Case 2 Daylight Prediction (by IES VE)

Area	DF for Overcast Sky	sDA: 300 lux 50 % (8:00-18:00)	Annual UDI 100-3000 Lux for DA	UDI Annual Average Lux
B21	Range: 0.5% to 6.2% Average =2.22% DF>2% =56%	53%	<25 = 20% 25-50= 32% 50-75=42% >75=4 %	Min. =136.6 Max. =1750 Average=425
New Offices	Range: 0.1% to 8.8% Average =2.2% DF>2% =75%	100%	50-75=75% >75= 31 %	Min.=306 Max. =2426 Average=926
C18	Range: 0.70% to 9% Average =6.03% DF>2% =95%	81%	25-50= 7% 50-75=30% >75=63%	Min. =156 Max. =3471 Average =1501
Atrium	Range: 1% to 15.4% Average =4.6% DF>2% =90%	100%	50-75=24% >75=75%	Min. =367 Max. =3281 Average =1113

5. Conclusion

The westward atrium is easily affected by the westward sunshine. The low solar elevation angle, strong light and difficulty in shading are the main reasons for overlighting.

A more effective shading device can reduce daylighting and provide softer lighting. The slanted vertical fins as a sunshade device could block more westward sunlight compared to conventional vertical fins, providing an effect of controlling illuminance. However, its impact on thermal performance has not been assessed, so it is uncertain if this optimization improved thermal comfort and energy efficiency (Luca F, Sepúlveda A & Varjas T 2022).

The spatial form also had an impact the lighting environment. The lower and wider atrium section has better effects compared to the higher and narrower section. Because in the lower atrium, the structure of the building, such as the roof, and the floor slabs of other floors, play a similar role in shading, blocking a portion of the sunlight on the west side, thereby improving the lighting environment. Multiple atriums arranged in a staggered manner have better lighting and spatial experience than a single atrium, and the combination of enclosed and semi enclosed atriums performs better than a semi enclosed atrium.

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