Simulation analysis of optimization design strategy of natural lighting in office buildings

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Abstract: As an important indicator of building quality, natural lighting is an important way to save energy and improve visual comfort in buildings. Reasonable use of natural lighting can effectively reduce building lighting energy consumption. Taking an office building project in Wuhan as an example, the article analyzes from three aspects: overall design, deepening design, and other factors, and proposes natural lighting optimization strategies such as building orientation and form layout, atrium daylighting, daylighting openings. Through software simulation analysis, the strategy is verified, and the project design plan is optimized. Thus the optimization design strategy of natural lighting in office buildings is summarized, which provides reference for future lighting and energy saving research.

1. Introduction
As one of the main building types in modern society, office buildings have a high demand for energy consumption. With the development of society, the problem of energy consumption has become increasingly prominent. Therefore, improving the indoor light environment of office buildings and reducing building energy consumption have become important issues of concern to the whole society. Based on the Building Lighting Design Standard (GB50033-2013), the natural lighting of the building is simulated and analysed, so as to carry out reasonable optimization design, and then summarize the optimization strategy of the office building indoor light environment, which is useful for building a resource-saving society.

2. Natural lighting evaluation basis
2.1. Building Lighting Design Standard (GB50033-2013) [1]
Wuhan City, where the project is located, belongs to category IV light climate zone, with a light climate coefficient of 1.1 and an outdoor natural light critical illuminance value of 4500lx [2]. According to the basic requirements of the standard value of daylighting coefficient of office buildings in the Building Lighting Design Standard GB50033-2013, the requirements for daylighting coefficient of this building can be calculated (Table 1). Combined with the optimization design requirements of the functional space, the average daylighting coefficient, window-to-land area ratio, and daylighting standard area are used as the evaluation basis. At the same time, the project is optimized by combining architectural modeling, facade, plane function and humanized design.

| Daylighting level location | Lowest daylighting coefficient (%) |
|---------------------------|------------------------------------|
| Side lighting             | Top lighting                       |

Table 1.Standard value of daylighting for office buildings
2.2. Green Building Evaluation Standard (GB/T 50378-2019)\(^3\)

Green buildings refer to buildings that maximize resources (energy, land, water, and materials), protect the environment and reduce pollution, and provide people with healthy, applicable and efficient use of space during the entire life cycle of the building. Green building evaluation standards provide a scientific basis for green buildings.

The evaluation rules of public buildings in terms of light environment are as follows:

1. Three points for the area whose daylighting coefficient meets the daylighting requirements of 60%.
2. Three points for the ratio of the area of the underground space with an average daylighting coefficient of not less than 0.5% to the area of the first floor of the basement reaches more than 10%.
3. At least 60% of the area of the main functional space in the indoor area has a lighting illuminance value not less than the hours required for lighting and an average of not less than 4h/d, 3 points.

3. Natural lighting optimization strategy

3.1. Overall design

3.1.1. Building orientation.

In the natural lighting design of office buildings, first of all, the orientation of the building should be determined on a macro level. Fully consider the climatic conditions, geographical conditions and surrounding environment of the site where the building is located, especially the light climatic conditions. The orientation of the building's daylighting opening has a great impact on the quality of the indoor light environment. For buildings in different climate zones, the best orientation of the window is also different. For example, in areas with a lot of sunny days, daylighting from the north can effectively avoid direct sunlight, and daylighting is relatively stable; In the north, the south-facing window has a large sun altitude angle, and the area of light entering the room is small, so the window should be facing south.

3.1.2. Layout of the building.

Common office building layout forms include "—" Type, "L" Type, "T" Type, and "回" Type, and their respective characteristics are shown in Figure 1.

| Type  | “—” type | “L” type | “T” type | “回” type |
|-------|----------|----------|----------|-----------|
| Graph | ![Line diagram](image) | ![L-shaped diagram](image) | ![T-shaped diagram](image) | ![Square diagram](image) |
| Pros  | The room on the south side has better lighting | The layout is more flexible, both connected and scattered | Similar to the "L" type, with richer changes | The surrounding rooms of the building have better lighting |
| Cons  | The room on the north side has poor lighting due to diffuse light from the sky | Glare is easy to occur near the window | Poor lighting in the corridors and rooms at the corners | There is no direct lighting on the inside of the corner, resulting in poor lighting |

Figure 1. Office building layout forms
When choosing the layout of the building form, it is recommended to combine multiple lighting methods for lighting optimization design. For example, when the building is deep, it is best to combine side windows and skylights for natural lighting.\cite{4} When the "井" type is difficult to meet the natural lighting needs of the internal space, it can be improved by combining the atrium, lighting wells and skylights.

3.2. Deepening design

3.2.1. Atrium daylighting.
The atrium can provide good light and the possibility of incident on the farthest depth of the plane, which itself is equivalent to a collector and distributor of natural light. Especially for office buildings: on the one hand, the atrium can add natural light to the indoor space, improve the visual comfort of office staff, and reduce energy consumption. On the other hand, it is also a place to promote communication and activities between office staff.

Combining the atrium with skylight lighting can effectively improve the indoor light environment, thereby realizing the development requirements of green buildings.

3.2.2. Daylight opening.
Windows are the main daylight openings of office buildings, and most office buildings use side windows for daylighting. The size of the window has a great influence on the quality of natural lighting. By setting the height, size and shape of the window reasonably, the lighting in the room can be made more uniform.

For the height design of the daylighting opening, when the window is low, the incident light needs to be reflected to the deep part of the room through the light-colored floor; when the window position is high, the privacy of the room is better and the light can enter the deep part of the room. According to the data, people's visual plane is generally about 0.75m from the ground. Therefore, the reasonable height of the window sill is generally 0.9-1.1m.

For the area of the daylighting opening, when other conditions remain unchanged, the amount of indoor lighting will increase with the expansion of the daylighting opening area, and the average illuminance value will also increase. Generally, "window-to-land ratio" is used as a common indicator for estimating the indoor natural light level. The Code for Design of Office Buildings JGJ67-2006 stipulates that the window-to-ground ratio of the main rooms such as offices and conference rooms is 1/5.

For the shape of daylighting openings, generally speaking, rooms with large depths use vertical long windows, and areas with small depths and insufficient light use horizontal long windows.

3.3. Other factors
In addition to the above-mentioned natural lighting optimization design, the requirements for building energy conservation, aesthetics, and building environmental protection should also be considered. Choosing appropriate lighting materials, such as some new environment-friendly materials, can realize the recycling of light or electric energy while ensuring that the office lighting needs are met, thereby solving the problem of light pollution. In addition, the lighting structure and facilities should be adjusted in detail in combination with the building facade design to achieve the perfect unity of function and shape.

4. Strategy simulation verification

4.1. Project Overview
The project is located at the northwest corner of the intersection of a city’s main road and walking street in Wuhan, Hubei Province. There is a park on the north side of the base, and urban roads on the
east and south sides. The office building has a total of 5 floors, and the surrounding area is relatively empty, basically without the shelter of high-rise buildings.

4.2. Simulation optimization process

**Building layout**

As the base is short from north to south and long from east to west, in order to increase the south-direction daylighting, while conforming to the trend of the base, the building shape adopts the method of gradually retreating from the bottom to the north, and at the same time, each floor is staggered to increase south-direction daylighting. The plan is an inner corridor layout, adopting the "回"type plan layout with the central core tube running through. In response to the above analysis, a natural lighting simulation analysis was performed on the representative 3F of the project.

Through software simulation of lighting, it can be seen that the traditional "回"type layout has narrow and long corridor space and large room depth, resulting in insufficient natural light incident from the window at the end of the corridor, and the indoor natural lighting is not ideal. Therefore, the plane is deformed to increase the area of the daylight opening at the end of the corridor. When the simulation analysis was carried out again, the indoor lighting quality was improved, and the area meeting the lighting standard increased from 18.5% to 22.9%.

![Before](image1.png) ![After](image2.png)

**Figure 2. 3F floor plan**

**Table 2. Natural lighting simulation results**

|                  | Room area(㎡) | Daylight calculation area(㎡) | Standard area(㎡) | Proportion of standard area |
|------------------|---------------|-------------------------------|-------------------|----------------------------|
| Before           | 960.00        | 856.31                        | 158.42            | 18.5%                      |
| After            | 1019.74       | 916.05                        | 209.78            | 22.9%                      |

**Daylight opening**

Calculating the window-to-ground ratio of each room in 3F and comparing it with the Architectural Lighting Design Standards, it can be found that the east office does not meet the requirements of the national standard and the south and west offices have just reached the standard. In addition, the lighting conditions in the meeting room on the north side are better while the aisles and toilets are far from the standard values.
Through analysis, it can be seen that the outer wall of the east office is retracted inward, and the upper volume extends outward, which has a certain blocking effect on light. Secondly, the outer windows of the east office are smaller in size. Therefore, it is necessary to adjust the size of the exterior window, change the size of the office exterior window to 1.8m*2.1m; change the size of the corner window at the end of the aisle to 0.9*0.6 (front) and 0.9*2.1 (side), so that they all meet the standard window-to-ground ratio. Then, the exterior window glass type of the east office was changed to 6 high light transmission Low-E Glass + 12 air + 6 transparency, which greatly improved the light transmittance of the windows. When the simulation analysis was carried out again, it was found that the lighting quality of the east office and walkway was significantly improved, but the improvement of the bathroom was not obvious.

| Table3. Window-to-land ratio calculation result |
|-----------------------------------------------|
| Daylighting level | location | Window size | Window opening area/Room floor area | Building lighting design standards |
|-------------------|----------|-------------|-------------------------------------|----------------------------------|
|                   |          | 1.5*1.8;   | East: 0.16 | South: 0.25 | West: 0.21 | North: 0.4 | 1/5     |
| III Office        |          | 1.8*2.1    |           |           |           |           | 1/5     |
| III meeting room  |          | 0.6*0.9    |           |           |           |           | 1/10    |
| V Aisle           |          | 0.6*0.9    |           |           |           |           | 1/10    |
| V restroom        |          | 0.6*0.9    |           |           |           |           | 1/10    |

**Atrium daylighting**

Through the above optimization measures, the natural lighting problem of the peripheral rooms is better solved, but the lighting efficiency of the internal public space and the bathroom is still not high. Therefore, it is considered to set up a five-story atrium inside and combine it with skylights to supplement the top lighting. Taking into account the requirements of building energy saving, the skylight uses double-layer hollow Low-E glass, supplemented by the sunshade measures in the ceiling curtain, which can achieve a good light and heat transmission effect, thereby ensuring the comfort of the indoor light and heat environment [8].

Figure3. Plan after transformation

Figure4. Simulation model
After the above three optimizations, according to the simulation results, the proportion of the building's 3F daylighting factor compliance area increased from the initial 18.5% to the final 42.62%, and the increase was 1.3 times. As a consequence of that, the natural lighting optimization strategies mentioned in articles 3.1 and 3.2 have been verified.

5. Conclusion
Through the simulation and optimization analysis of a multi-storey office building project in Wuhan, the general strategy of natural lighting optimization methods and renovation methods of traditional office buildings is obtained as follows:

The first step is to carry out the overall design and determine the building layout by analyzing the site characteristics. After determining the orientation of the building, select the most appropriate building layout and volume, and make full use of the site advantages to maximize the use of natural light.

The second step is to deepen the design, that is, determine the lighting form. Firstly, based on the demand for natural light in different areas of the building, choose and combine the side lighting, skylight lighting and atrium lighting reasonably. Secondly, through simulation analysis and calculation, the position, size, shape and other details of the daylighting openings are optimized and adjusted to finally meet the daylighting standards and user needs.

The third step is to consider other important factors. Integrate architectural plan design and daylighting technology on the premise of green building energy saving design. Strengthening the application of new materials and technologies, especially the use of environmental protection materials, will help improve the energy-saving properties of buildings.

Finally, in the optimization design of natural lighting, it is necessary to integrate the field of view, facade effect, internal functional requirements, ergonomics and other factors to obtain the best optimized design result.

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