Research on the Influence of Light-Controlled Lighting System and Light-Controlled Shading System on Building Energy Consumption Based on Light Environment

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Abstract. The light-controlled lighting system and the light-controlled shading system can adjust the architectural lighting and shading system according to the quality of the indoor light environment, and can reduce the building energy consumption. The energy consumption model of the light-controlled lighting system based on the illuminance of the indoor light control point and the light-controlled shading system based on the uncomfortable glare index for an office building in Wuhan was established respectively by the energy consumption simulation software eQuest. Three key types of glasses were considered to research the indoor light environment. The impacts of the light-controlled lighting system and the light-controlled shading system on building energy consumption were analyzed through simulations.

Keywords. Lighting system, shading system, light environment, energy saving.

1. Introduction
With the development of social economy, the indoor light environment of office buildings has been paid more attention. The international Healthy Building Standard WELL proposes the adoption of light-controlled lighting and light-controlled shading measures for the indoor light environment, to realize the building energy conservation strategy while improving the household experience on the comfort of indoor light environment [1].

The light-controlled lighting and light-controlled shading system can feed back the evaluation index of the indoor light environment based on the sensor, such as illuminance, uncomfortable glare index, etc. The lighting and shading system were adjusted to reduce the total energy consumption of the building for achieving the indoor light environment. The light-controlled lighting system can judge the satisfaction of indoor light environment through the illuminance information of the indoor monitoring point, and regulates artificial lighting to switch on and off, so that it can make full use of natural daylight to reduce artificial lighting running time, and reduce building energy consumption. The light-controlled shading system was adjusted to block the outdoor sun light and avoid indoor glare based on human behavior patterns. So the solar radiation into indoor space was reduced for energy saving.

Taking an office building in hot summer and cold winter areas of China as an example, the energy-saving potential and main influencing factors of light-controlled lighting system and light-controlled shading system were studied in this paper.
2. The Feasibility Analysis of Application of Light-Controlled Lighting System and Light-Controlled Shading System in an Office Building

2.1. Method

A prototype for simulation was established based on an office building in Wuhan. It was combined by 32 floors and the height for each floor was 4.2 m. The average area ratio of window of building was 0.73. The average heat transfer coefficient of the exterior walls and the roof was 0.76 and 0.5 W/(m²·K) respectively. The variable air volume air condition systems were adopted in this building. The building model by eQuest software was shown in figure 1.

![Figure 1. Schematic diagram of building model.](image)

The heat transfer coefficient and solar gain coefficient of glass are the main influencing factors of energy consumption in the office building with large area glass curtain wall. The visible light transmittance of glass is an important factor affecting the quality of indoor lighting. Therefore, this project selected three kinds of glass with different visible light transmittance commonly used in office buildings for research. The thermal performance parameters of glasses were shown in table 1.

| Glass type                | Visible light transmittance | Solar heat gain coefficient | Heat transfer coefficient (kW/m²) |
|---------------------------|-----------------------------|----------------------------|----------------------------------|
| Ordinary hollow glass     | 0.77                        | 0.68                       | 2.56                             |
| Coated hollow glass (silver gray) | 0.45                       | 0.43                       | 2.52                             |
| Green hollow glass        | 0.67                        | 0.48                       | 2.61                             |

The standardized regression coefficients of the variables shown in table 1 demonstrated that the impacts of the factors on the annual cooling loads of bedroom were different and in descending order of ACH, area ratio of window to wall, bedroom area and the orientation. The heat transfer performance of the three types of glasses was relatively close. The solar heat gain coefficient of glasses were different and in descending order of ordinary hollow glass, coated hollow glass, green
hollow glass, and the visible light transmittance of glasses in descending order of ordinary hollow glass, green hollow glass, coated hollow glass.

2.2. The Energy Consumption of Three Different Types of Glass Buildings
The energy consumption of three different types of glass buildings in table 1 was simulated by eQuest. The total building energy consumption and the main energy consumption composition were shown in figure 2.

![Figure 2. The building energy consumption.](image)

It can be seen from the figure 2 that, under the three glass conditions, lighting energy consumption accounted for the largest proportion of total building energy consumption, followed by cooling energy consumption, and heating energy consumption was the smallest. Among the three working conditions, the total energy consumption and cooling energy consumption of ordinary hollow glass building were the largest, and the heating energy consumption was the smallest. The total energy consumption and cooling energy consumption of the coated hollow glass building were the smallest, and the heating energy consumption was the largest; the energy consumption of Green hollow glass building was in the middle. In summary, it can be seen that the solar heat gain coefficient of the glass was one of the main factors affecting the total building energy consumption.

2.3. The Analysis of Indoor Light Environment
Through the simulation of indoor light environment quality under the most unfavorable conditions by applying the lighting simulation analysis software Ecotect, the feasibility of adopting the light-controlled lighting system and the light-controlled shading system was studied. Indoor natural illuminance was used to evaluate the quality of indoor light environment. In a cloudy day, the natural daylight environment in the coated hollow glass room with low visible light transmission was the most unfavorable working condition, and the indoor natural light intensity was simulated by Ecotect. According to the standard for daylight design of buildings in China, the illuminance index in the office was not less than 300lux [2]. Therefore, the indoor natural illuminance more than 300lux was shown in figure 3.
Figure 3. Distribution of indoor natural illumination higher than 300lux.

The area within about 3 m from the external window was defined as the indoor outer zone. Figure 3 showed that under all cloudy conditions, the natural daylight at the working plane height 750mm of the outer zone was higher than 300lux, which meet the visual needs of the office, and the proportion of the area that meet natural lighting needs was about 40% of the total office area. The indoor outer zone has a better light environment, so it was feasible to implement light control in the outer zone of the building.

In summary, the lighting energy consumption and cooling energy consumption of this project both accounted for a large proportion of the building energy consumption, and the light environment quality of the indoor outer zone was good, so the application of light-controlled lighting system and light-controlled shading systems had energy-saving potential.

3. The Energy Consumption of the Light-controlled Lighting System

3.1. Method
Many researches [3-6] used eQUEST to calculate hourly sunlight characteristics, solar radiation heat gain, glare and building energy consumption. Therefore, this paper used eQuest software to analyze the building energy consumption of light-controlled lighting systems. The principle of eQuest software to realize light-controlled lighting was to set the ratio of light-controlled points and light-controlled lighting in the room, calculated the natural illuminance at the position of the light-controlled points, and controlled the lighting system to turn on according to the illuminance. The control methods of the light-controlled lighting system included on/off selection control and continuous control, among which continuous control the lighting can be complemented according to demand [7], and the energy-saving effect was more obvious.

The setting of the light control point position was related to the operating efficiency and the energy saving potential of natural lighting. In order to ensure that natural lighting can be fully utilized indoors without affecting artificial lighting in darker areas, it was set according to the results of the natural lighting simulations in the previous section. Under the most unfavourable conditions, about 40% of the office area within 3 m from the external window had good natural lighting. So in this paper, the proportion of light-controlled lighting was set to 40%, the others were non-light-controlled lighting, and artificial lighting was always on during working hours. The light control points were set at a
distance of 3 m from the external window, and the light control points were set in four different directions of the building. The illuminance threshold of the light control point was set to 300 lux. When the illuminance is greater than 300 lux, the natural lighting was fully utilized and the lighting system was turned off in the light-controlled lighting area. When the illuminance was lower than 300 lux, the lighting system was turned on in the light-controlled lighting area. The lighting control mode of the light control area was continuous control.

3.2. Results and Discussions

After simulation calculation, the calculation results of lighting, cooling, heating, and total energy consumption for the benchmark building without light-controlled lighting system and the design building with light-controlled lighting system were shown in figure 4.

Figure 4 showed that the building's lighting energy consumption and total energy consumption were significantly reduced compared with the benchmark building after adopting the light-controlled lighting system. The energy consumption of buildings using ordinary hollow green glass combined with light-controlled lighting system was the lowest, followed by coated hollow glass, and ordinary hollow glass buildings had the largest energy consumption, but the difference in building energy consumption between the three types of glass was significantly reduced. The largest reduction in energy consumption was about 15.2%. Lighting was the main contributor to energy saving. The energy consumption of lighting was reduced by about 55%. The energy saving effect was very significant. The reduction in building energy consumption of coated hollow glass was the smallest, about 13.4%. As the heat disturbance load of the building's lighting had been significantly reduced, the cooling and heating energy consumption of the building had been reduced and increased to a certain extent, and the magnitude of the change was relatively small compared with the lighting.

![Figure 4. Comparison of energy consumption between benchmark building and design building](image)

Through analysis, it can be found that although the solar radiation heat gain coefficient of coated hollow glass was relatively small, its visible light transmission was relatively low, and the effective control time of the light-controlled lighting system was shorter, so the energy-saving potential of the light-controlled lighting system was small. Ordinary hollow glass had a large visible light
transmittance, and the effective control time of the light-controlled lighting control system was longer. The light-controlled lighting system was energy-saving. Due to its large solar radiation heat gain coefficient, the generated cooling energy consumption accounted for a large proportion. So the overall energy consumption of the building was still relatively large. Ordinary hollow green glass building had a large visible light transmittance, and their solar radiation heat gain coefficient was relatively small. The light-controlled lighting system had obvious energy-saving benefits, and its total building energy consumption was the smallest. In summary, for public buildings where lighting energy consumption accounted for a large proportion, the use of light-controlled lighting systems had greater potential for energy saving. When combined with the design of the light-controlled lighting system, the solar heat gain coefficient of glass had a relatively weak effect on building energy consumption. The visible light transmittance of glass was the main factor affecting building energy consumption. For public buildings in hot summer and cold winter areas, light Control lighting system, it was more suitable to use ordinary hollow green glass.

4. The Building Energy Consumption of Light-Controlled Shading System

4.1. Method
Due to the large-scale use of glass curtain walls in modern office buildings, glare had become one of the main problems in the indoor office environment. The DGI index was usually used internationally to evaluate the degree of uncomfortable glare caused by natural light sources in the room. The eQuest software with DOE as the core can calculate the uncomfortable glare index value of indoor light control points through the LOAD module of DOE. And according to whether the uncomfortable glare index was greater than the set value, the maximum uncomfortable glare index value of the light control point was set in the eQuest, and this paper used eQuest to study the energy consumption of the active outer shading system model. The visual comfort index of the office area was shown in table 2.

| Zone            | Glare perception | Discomfort glare index (DGI) |
|-----------------|------------------|-------------------------------|
| Discomfort zone | Unbearable       | >28                           |
|                 | Bearable         | 28                            |
|                 | Uncomfortable    | 26                            |
|                 | Slightly uncomfortable | 24                       |
| Comfort zone    | Acceptable       | 22                            |
|                 | Slightly acceptable | 20                        |
|                 | Detectable       | 18                            |
|                 | Slightly detectable | 16                        |

According to the above table, the critical discomfort glare index value of the comfort zone and the discomfort zone was 22, which was consistent with the discomfort glare index critical value of 22 in the DOE manual [7]. In order to ensure the visual comfort of the office area, in the simulation calculation, the uncomfortable glare index threshold of the light control point was 22. The movable external sunshade was in an opaque form, and the coverage of the movable external sunshade was set to 1, which can fully cover the external window. The artificial lighting system in the light-controlled sunshade system was turned on during office hours. When the uncomfortable glare index of the light control point was greater than 22, the movable external shading fully covered the outer window, blocking solar radiation from entering the room. When the uncomfortable glare index of the light control point was lower than 22, the movable external shading did not affect the solar radiation entering the room. Because the brightness near the outer window was larger, the glare here was the most uncomfortable, so the light control point was set in four different directions at a distance of 0.75m from the outer window working plane.
4.2. Results and Discussions

The calculation results of lighting, cooling, heating, and comprehensive energy consumption for the benchmark building without light-controlled shading system and the design building with light-controlled shading system were shown in figure 5.

In figure 5, because the active external shading system effectively blocks solar radiation, building cooling energy consumption had been significantly reduced, and at the same time, it had led to an increase in winter heating energy consumption. So after adopting the light-controlled sunshade system, the building cooling and total energy consumption were significantly reduced compared with the benchmark building, and the heating energy consumption was also significantly increased. The three types of glass design buildings had similar energy consumption for cooling and heating, and the gap between total energy consumption was also significantly reduced. Among them, the total energy consumption of coated hollow glass was the smallest, followed by ordinary hollow green glass, and ordinary hollow glass was the largest.

![Figure 5. Comparison of energy consumption between benchmark building and design building](image)

The total energy consumption of ordinary hollow glass light-controlled shading system buildings had the largest decrease, with an energy-saving ratio of about 9.4%, and its cooling energy consumption had been significantly reduced by 37.8%, and heating energy consumption had increased by a relatively large ratio. 64.7%. The cooling and heating energy consumption of the coated hollow glass building had a small change, the cooling energy consumption was reduced by 29%, and the heating energy consumption was increased by 26.4%.

To sum up, the solar radiation heat gain coefficient of coated hollow glass was relatively low, the visible light transmission was relatively low, and the relative brightness difference between indoor and outdoor was relatively small. Therefore, the time for glare generation and the effective time of the light-controlled sunshade system was less. The reduction in energy consumption for cooling and heating was relatively small. Under ordinary hollow glass conditions with relatively large visible light transmission, the glare time and the effective time of the light-controlled shading system were longer, and the energy consumption of the building changed more than the benchmark building. After adopting the light-controlled shading system, the energy consumption of glass buildings under the three working conditions had little difference. It can be seen that, combined with the light-controlled shading system, the solar radiation heat gain coefficient of glass had a weaker impact on building energy consumption, and the visible light transmittance of glass and the shading system had become one of the main factors affecting building energy consumption.
5. Conclusions

The impacts of the light-controlled lighting system and the light-controlled shading system on building energy consumption were analyzed through simulations in the present paper for an office building in Wuhan, and the main conclusions were as follows.

After the building adopts the light-controlled lighting system, the lighting energy consumption of glass with large visible light transmittance and small solar heat gain coefficient was significantly reduced, and the energy consumption of cooling and heating changed little, but the energy saving potential was large. Therefore, this project was more suitable for the use of ordinary hollow green glass with large visible light transmission and a small sun heat gain coefficient.

After the building adopts the light-controlled shading system, the energy consumption gap of the three different types of glass was reduced, and the solar heat gain coefficient of the glass had a weaker impact on the building energy consumption. The visible light transmittance of the glass and the external window shading were the main influencing factors of the building energy consumption. The light-controlled shading system effectively reduced the cooling energy consumption and also increased the heating energy consumption. Therefore, the light-controlled shading system was more suitable for seasonal use.

For buildings in hot summer and cold winter areas of China, where the proportion of lighting energy consumption was greater than the cooling energy consumption, light-controlled lighting systems had greater energy-saving potential than light-controlled shading systems.

In summary, the use of light-controlled lighting and light-controlled shading systems can significantly reduce energy consumption, and both had great energy-saving potential. The visible light transmittance of glass was one of the main factors affecting the energy-saving effects of light-controlled lighting and light-controlled shading systems. Therefore, when a light control system based on the indoor light environment was used, the visible light transmittance of the outer window glass should be fully integrated to optimize the design to achieve the maximum energy saving of the building.

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